STRUCTURAL CHARACTERISATION OF CONCRETE AND SANDCRETE HOLLOW BLOCK PRODUCED FROM SELECTED CEMENT BRANDS IN NIGERIA

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DECLARATION

I declare that the work in this Thesis entitled “Structural Characterisation of Concrete and Sandcrete Hollow Block Produced from Selected Cement Brands in Nigeria” has been carried out by me in the Department of Civil Engineering of Ahmadu Bello University, Zaria, Nigeria. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

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Abubakar Salihu Ovajimoh **Date**

CERTIFICATION

This thesis entitled STRUCTURAL CHARACTERISATION OF CONCRETE AND SANDCRETE HOLLOW BLOCK PRODUCED FROM SELECTED CEMENT BRANDS IN NIGERIA by Abubakar Salihu OVAJIMOH meets the regulations governing the award of the degree of Doctor of Philosophy in Civil Engineering of Ahmadu Bello University, and is approved for its contribution to Knowledge and literary presentation.

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Abstract

The current wave of collapse of building structures all over the world including Nigeria necessitates the need to carryout research on the properties of the construction materials. Concrete and sandcrete hollow blocks are major construction materials used in the building industry. The objective of this study is to determine the properties of sandcrete hollow blocks (SHB) and concretes produced from seven selected brands of ordinary Portland cement labeled A to G. The cement brands were purchased from local markets in Nigeria. The water, sand, gravel and the cement brands were characterized and results compared with the British standards (BS EN 1008:2002 for water, BS EN 12620 for sand and gravel, and BS EN 197-1: 2011for cement) in order to determine their suitability for production of concrete and SHB. A total of 2774 SHB and 105 concrete cubes produced from the above materials were investigated. Tests were conducted on the SHB to determine: the optimum water to cement ratio, dry and wet strengths and density development and water absorption. The strength and density development tests were also carried out on the concrete cubes. Results were compared with British Standards. The average tricalcium silicate contents by mass were 33, 46.97, 30.41, 68.99, 51.77, 34.25 and 6.34% respectively for cement brands A to G. Those of dicalcium silicate contents were 38.39%, 16.43%, 37.46%, 5.66%, 24.17%, 28.84%, and 49.78%. The average 28-day dry compressive strengths of the SHB produced from cement brands A to G were 4.24, 5.83, 4.62, 3.75, 5.38, 3.45 and 4.21 N/mm^2 respectively. SHB cured for 28 days in the dry state and then immersed in water, were found to suffer a sharp drop in compressive strength after one day soaking before rising in strength again. This was observed for SHB produced from the seven cement brands, A to G and mix ratio range of 1:6 to 1:12. The characteristic strengths of the concretes produced from cement brands A to G were 29.5, 31.81, 31.80, 29.74, 28.78, 29.24 and 27.90 N/mm^2 respectively. The local cement brands A, D, F and G did not meet the standard specifications of tricalcium silicate content of 46% to 67% and dicalcium silicate content of 8% to 31% (EN 197 -1: 2000). The optimum water to cement ratio of SHB was 0.45. The compressive strengths of the SHB produced from cement brands A to G were higher than the minimum standard strength of $2.9N/mm^2$ (BS EN 771:2006). It was inferred from the study that wall constructed of SHB experiences a sharp drop in strength after one day inundation by flood. Concretes produced from the local cement brands A, D, F and G had strengths lower than the minimum standard strength of $30N/mm^2$ (BS EN 206: 2000) due to non-compliance of the cements silicate compounds to the standard. Concretes produced from imported cement brands B and C met the standard. It was suggested that SHB should be subjected to additional standard test after one day immersion in water based on the above established phenomenon.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Cement is a major and binding component of concrete and sandcrete hollow blocks which are widely used for building and other structures in Nigeria. The major problem is that the measured compressive strengths of the two construction materials are lower than the minimum strengths (Adewole *et al*., 2015; Bamigboye *et al*., 2015) specified in the standards (BS EN 206: 2000 for concrete and BS EN 771-3: 2006 for sandcrete hollow block) in recent time in Nigeria and other developing countries.

1.1.1 Cement

Cement is the most expensive component of concrete and sandcrete block. The high cost of cement in Nigeria is attributed to (Pan African Plc, 2010) the failure of its supply to meet the demand which forced its price to go up, lack of stable power supply, its hoarding to encourage importation, monopoly of its supply by few people, high cost of its importation and huge capital required to set its production factory.

The other problem is that in 2014, the stakeholders of the construction and building industry traded blame with the local manufacturers of cement on the frequent collapse of buildings in Nigeria (The Guardian Newspaper, 2014). The stakeholders alleged that the wide spread use of a weaker grade 32.5 cement was a major cause of building collapse. They claimed that the bags of cement sold in the markets did not carry the label. The cement manufacturers on the other hand, insisted that cement grade had nothing to do with building collapse. They claimed that the professionals or consultants handling the jobs did not follow specifications as well as poor quality application of cement, poor construction methods, inadequate supervision and corruption were the reasons responsible for the building failures (The Guardian Newspaper, 2014). This trading of blame between the stakeholders of building industry and cement manufacturers gave rise to the question: "Can the grade of cement affect the structural integrity of a building?"

The questionnaires administered by Standard Organisation of Nigeria revealed that most stakeholders and professionals in the building/ construction industries, academics and researchers did not know the grade of cement they buy from the market (Adewale, 2015). Also, the local cement industries producing the grade 32.5 cement were given approval by SON after ensuring the compliance of their product with the standard (NIS 444 - 1: 2003). It was revealed that cement grade 32.5 has been phased out in many countries and its importation has been banned even before 2003 (NIS 444-1: 2003).

The standard, BS EN 197-1: 2011 classified cement into three classes or grades: 32.5, 42.5 and 52.5. This means that the minimum 28-day mortar strengths of the cement grades are $32.5N/mm^2$, $42.5N/mm^2$ and $52.5N/mm^2$ respectively. The standard also specified that cement class 32.5 can have mortar strength between $42.5N/mm^2$ and $52.5N/mm^2$ while class 42.5 can have mortar strength between $42.5N/mm^2$ and $62.5N/mm^2$. This is what the manufacturers of cement in Nigeria capitalize on and believe that the class of cement does not make any difference in its quality.

The local cement industries producing grade 32.5 before 2014 were Larfarge West African Cement Company, Ashaka Cement Plc, Cement Company of Northern Nigeria (CCNN) and UniCem (2015). The imported cement dealers import class 42.5 cement.

Burham cement, Atlas cement, Ibeto cement, Eagle cement and others are imported CEM I cement brands which are class 42.5N, ordinary Portland cement. It was also observed that while the 50kg bags of class 32.5 cement were readily available, the 50kg bags of class 42.5 cement were not readily available in the market except in jumbo form and are usually supplied to the big industries (Adewole et al., 20014). Current market survey however, indicates that class 42.5 is now available in 50 kg bags and with the label as specified in the revised NIS 444-1: 2014.

Another problem of the cement brands produced locally and supplied to the markets is the introduction of Portland limestone cement types which are sold in two types: CEM II /A-L and CEM II / B-L instead of Portland cement (CEM I) which was originally being used in Nigeria (Adewole, 2014; uniCem, 2015). CEM II / A-L type is a cement produced by replacing 6 – 20% of the clinkers in Portland cement with limestone while CEM II / B-L is produced by replacing 21 – 35% of the clinkers in Portland cement with limestone (BS EN 197-1: 2011).

Based on the above problems of cement brands produced and sold in the Nigerian markets and the inability of the standard mortar tests at 2 days and 28 days to distinguish between the class 32.5 cement and the class 42.5 cement as well as the introduction of Portland limestone in the Nigerian markets it became imperative that the only reliable option is to test and characterise the products of the cement brands sold in the Nigerian markets and determine the fineness of the brands of cement. The products are mainly concrete and sandcrete hollow block which are widely used in Nigerian building and construction industry.

Adewole et al. (2014), Adewole et al. (2015) and Bamigboye et al. (2015) had extensively worked on Portland Limestone cement and its concrete grades. They had not worked on the ordinary Portland cement brands sold in the Nigerian markets and their products such as concrete and sandcrete hollow blocks to be in position to compare their strengths with those of Portland Limestone cements currently flooding most of the Nigerian markets. There is therefore the need to characterize the concrete and sandcrete hollow block produced from ordinary Portland cement present in Nigerian Markets.

1.1.2 Concrete

Concrete is one of the major products of cement that is widely used for constructing buildings and other structures. The major problem is that the tested concretes (Adewole et al., 2015; Bamigboye, 2015; Yahaya 2009 and others) produced from cement brands sold in the Nigerian markets did not measure up to the strength requirement of the grades 20/25 and 25/30 (BS EN 206: 2000). This was attributed to the Portland limestone cement types recently introduced to the Nigerian markets (Adewole et al., 2015). According to BS EN 206: 2000, Portland limestone cement can only produce the standard minimum strength of concrete if the replacement level of clinker in the ordinary Portland cement does not exceed 15%. But the Nigerian cement manufacturers are producing classes 32.5R and 42.5R Portland limestone (CEM II /B-L 32.R and CEM II / B-L 42.5R) where the level of replacement is between 21% and 35% and recommend them for structural works (uniCem, 2015).

Studies carried out by Bamigboye et al. (2015) also revealed that the 28-day compressive strength test results for concretes produced from three of the four tested brands of cement in Nigeria failed to meet the required minimum standard for mix ratios 1:2:4 and 1:3:6. Studies carried out by Yahaya (2009) revealed that concretes produced from two imported cement brands and two local cement brands did not meet the minimum standard specifications. It was observed that the mix ratio used was 0.7. The improper water cement ratio and lack of adherence to the standard specifications of the chemical compound might have contributed to the poor results of the concrete strengths in addition to the above reason which was not considered in the previous studies. There is therefore, the need to characterise the concrete and sandcrete hollow blocks produced from selected cement brands sold in Nigerian markets considering the gaps highlighted above.

1.1.3 Sandcrete hollow block (SHB)

The major problem facing the production of sandcrete hollow block is that the tested compressive strength of sandcrete hollow blocks produced by most commercial block making industries did not meet the required standard. Studies carried out on the assessment of the quality of the blocks produced by commercial block-making industries revealed that majority of their blocks had 28- day dry strengths in the range of 0.50 to 1.5 N/mm^2 in Nigeria (Ejeh and Abubakar, 2008; Ewa and Ukpata, 2013; Onwuka *et al.*, 2013).

Several reasons were advanced for the commercial production of substandard sandcrete hollow blocks. The major reasons were poor cement to sand mix ratio, inadequate curing and poor workmanship. The contribution made to the problem by improper use of water to cement ratio which are presently based on trial and error method was not considered by previous works. Odeyemi *et al*. (2015) carried out a research on sandcrete hollow blocks produced from Dangote and Elephant cement brands with a mix ratio of 1:6. Manual and vibrating machine were used to produce the blocks.

The results obtained for the 28-day dry compressive strength of SHB produced manually from Dangote and Elephant cement brands were 1.70N/mm^2 and1.73N/mm^2 respectively. The SHB produced from the vibrating machine had strengths of 1.78N/mm^2 and 1.82N/mm^2 for Dangote and Elephant brands of cement respectively. These values failed to meet the BS EN 771-3: 2006 and NIS 87: 2004 standard specifications of 2.9N/mm^2 and 2.5N/mm^2 respectively. They did not consider using optimum water to cement ratio but used trial and error instead as the two standards made no provision for it.

Ejeh and Abubakar (2008) and others had carried out studies on the assessment of commercial sandcrete hollow blocks produced by block making industries. The test results indicated that most of these commercial blocks were substandard because the average 28-day strength was 0.50N/mm^2. They further reported that a drop in compressive strength was observed when the sandcrete hollow block was cured for 28 days and then immersed in water.

They did not consider treating standard blocks in the same way as the substandard commercial blocks. Also the effect of mix ratio, curing and cement brand on the drop had not been studied. Standard sandcrete hollow blocks need to be produced and subjected to the same condition as in the above studies on substandard blocks varying the mix ratio, cement brand and curing periods.

1.2 Statement of the problems and Justifications

1.2.1 Statement of the problem

Concrete and sandcrete hollow block are two major materials used in Nigeria and other countries. The major problem is that the tested strength of concrete (Adewole *et al*., 2015 and Bamigboye *et al*., 2015) and sandcrete hollow block (Odeyemi *et al*., 2015; Ewa and Ukpata, 2013 and Onwuka *et al.*, 2013) produced from cement brands in Nigeria do not always meet the required standards for the two materials (BS EN 206: 2000 for concrete and BS EN 771-3: 2006 for sandcrete hollow block). These observations are more common with sandcrete hollow blocks produced by commercial block making industries (Ewa and Ukpata, 2013 and Onwuka *et al.,* 2013) and concretes produced by concrete practitioners. Some of the major reasons advanced for the low strength of the two materials (Samson et al. 2002) were poor mix ratio, inadequate curing and poor workmanship. The effect of water to cement ratio (which is currently largely based on trial and error method) on sandcrete production (Onwuka *et al*., 2013; Samson *et al*., 2002) was not considered in the previous studies as a contributing factor to the observed low strengths. While the standards for concrete made provision for water cement ratio, the standards for sandcrete hollow blocks did not provide for water to cement ratio. Also the specifications for the cement used for sandcrete and concrete productions are normally based on physical and mechanical properties such as setting times and 28-day strengths. Chemical analyses of cement were seldom carried out.

Another problem is that previous studies (Odeyemi, 2015; OLanitori, 2006 and Samson et al., 2002) had based the assessment and suitability of the sandcrete hollow block on its 28-day dry and wet strengths. But, sandcrete hollow block wall inundated in flood water may not reach 28-days before it fails. Therefore, the assessment of wet block based on the 28-days did not represent the actual situation. Ejeh and Abubakar (2008), Ejeh and Ayinmode (2000) and others carried out studies on commercial sandcrete hollow blocks which were all substandard. The observed drops in compressive strength of the soaked blocks were not significant because the blocks were substandard. The previous studies did not cover standard blocks. Also the effects of mix ratio, cement brand and curing on the drops were not studied. All these observed parameters are important in structural characterisation of concrete and sandcrete hollow block. These observed gaps in the previous studies form the basis of this thesis.

1.2.2 Justifications

1. The cement brands produced locally and those imported before 2003 were purely ordinary Portland cement (CEM I) class 42.5N. In 2003, the Standard Organisation of Nigeria (SON) introduced the cement standard specification NIS 444-1: 2003 which allowed the local production of Portland Limestone cement of types CEM II /A-L 42.5 N, CEM II /B -L 42.5R and CEM II/B –L 32.5R which have minimum 28-day mortar cube strengths of 42.5, 42.5 and 32.5N/mm^2 respectvely. The imported cement brands have been largely

Portland cement (CEM I). There have been complaints by the stakeholders of the building and construction industry about the low quality of the cement sold in Nigerian markets particularly the Portland Limestone cements as well as the low strengths of concretes and sandcrete hollow blocks produced from them. There is therefore, the need to characterise the cement brands sold in Nigerian markets and the two products, concrete and sandcrete hollow block.

Nigeria has been experiencing flood which usually affect walls of buildings and fences constructed with sandcrete hollow block. Such walls are sometimes inundated with flood water for few days and may lead to large cracks or their collapse. The same applies to walls of buildings along coastal areas. The present method of simulating this incidence with 28-day wet compressive strength of sandcrete hollow block may not be sufficient as some walls may not survive the flood inundation for up to 28 days before failure. There is the need to characterise sandcrete hollow block immersed in water to determine the period at which the compressive strength of such flood inundated wall is a minimum. The result of such research may lead to a new approach in method of design of load bearing walls.

Majority of sandcrete hollow blocks produced by the block making industries are substandard and this has led to huge losses in the process of placement and transportation of the product. Structural characterization of sandcrete block may lead to production of standard blocks which will reduce the losses.

1.3 Aim and Objectives

1.3.1 Aim

The aim of the study is to characterise concrete and sandcrete hollow blocks produced from selected cement brands in Nigeria. This is pursued through the objectives below.

1.3.2 Objectives

The objectives of the studies are to:

(i) Characterise the water, sand and gravel used for production of sandcrete hollow blocks and concretes.

(ii) Determine the physical, mechanical and chemical characteristics of selected seven cement brands labeled A to G purchased from local markets in Nigeria.

(iii) Determine the optimum water to cement ratio to be used in production of sandcrete hollow block by testing the strengths of sandcrete hollow blocks produced under varied water to cement ratio.

(iv) Determine the strength and density development profile of sandcrete hollow blocks produced from cement brands A to G and cured in the dry state by spraying with water for 28 days.

(v) Determine the economical cement to sand mix ratio and curing period to be used to produce sandcrete hollow block of compressive strength that satisfy the minimum strength of 2.9N/mm^2 (BS EN 771-3:2006) and an average compressive strength of 3.5N/mm^2.

(vi) Determine the strength and density development profile of sandcrete hollow blocks produced from cement brands A to G; cured in the dry state by spraying with water for 28 days and then immersed in water for another 28 days,

(vii) Determine the water absorption of the sandcrete hollow blocks produced from cement brands A to G.

(viii) Determine the strength and density development of concretes produced from cement brands A to G and its characteristic strength.

1.4 Scope and Limitations

1.4.1 Scope

This research work is centered on the modes of production of hollow sandcrete blocks of standard sizes 450mm x 225mm x 225mm (9") and concrete cubes of size 150mm and grade 25/30 commonly used in the construction industries. The study is focused on the principal properties of the blocks and concrete such as compressive strength, density and water absorption and the curing method employed. Blocks and concretes were made from seven ordinary Portland cement brands of class 42.5, which means that the strength of the Portland cement at 28 days is 42.5N/mm^2.

1.4.2 Limitations

The ages of the cement brands were unknown to the researcher as the bags did not carry any date of manufacture.

1.5 Study Area

Seven brands of ordinary Portland cement labeled A, B, C, D, E, F and G were used to carry out the study. The cement brands studied were selected and purchased from Bauchi, Port Harcourt, Abuja, Lokoja, Onitsha, Lagos and Kaduna markets in Nigeria as presented in Table 1.0

Table1: Selected Cement Brands Used for Study and the Purchased Markets Sources in Nigeria

Serial Number	Brand of cement	Market	Geopolitical Zone in Nigeria
1.	A	Bauchi	North-East
2.	B	Port HarCourt	South-South
3.	C	Abuja	Federal Capital Territory
4	D	Lokoja	North-Central
5.	E	Onitsha	South-East
6.	F	Lagos	South-West
7	G	Kaduna	North-West

1.6 Expected Research Outcome

The expected outcomes of the research are that the:

i. compressive strengths of the mortar cubes produced from each of the seven cement brands A, B, C, D, E, F and G at 2 days curing age exceed $10N/mm^2$ while the 28-day compressive strengths should exceed $42.5N/mm^2$,

ii. percentage of the tricalcium silicate compound in each of the seven cement brands should be in the range of 42% to 67% while that of the dicalcium silicate should be in the range of 8% to 31%,

iii. optimum water to cement ratio should produce the highest strength at all the mix ratio studied,

iv. average 28-day dry strengths of the blocks produced from the seven brands of cement at mix ratio range of 1:6 to 1:8 should meet the standard BS EN 771-3:2006,

v. standard blocks which meet the BS EN 771-3:2006 standard requirements should not show any noticeable drop in strength when soaked in water like the substandard block did in the previous studies with commercial,

vi. water absorption of the blocks produced from each of the seven ordinary Portland cement brands at mix ratio of 1:6 should not exceed 6%,

vii. characteristic strength of the concrete cubes produced from each of the seven cement brands studied exceeds $30N/mm^2$.

CHAPTER TWO

LITERATURE REVIEW

2.0 Preamble

This chapter deals with review of related studies. The review of some of the studies previously carried out on assessments of quality of water, aggregates, cement brands, sandcrete hollow block, and concrete in Nigeria and other countries are presented.

2.1 Water

Water from public utilities or well water fit for drinking is recommended for making sandcrete hollow blocks. If other sources of water are used, they should be stored in plastic or galvanized tanks (NIS 87: 2004). According to U.S. Army Corps Engineers (1963) water with pH in the range of 6.0 to 8.0 are suitable for concrete works. In addition such water must not contain organic matter. Water containing salts of sodium, potassium as well as other salts of natural origin in excess is regarded as unsuitable for concrete or sandcerete blocks. However, recent study (Osuji and Nwankwo, 2015) had shown that the effect of sea water on concrete is negligible.

The U.S. Army Corps Engineers (1979) specified that when the quality of water is questionable, the 7-day and 28-day mortar cubes test results should be a minimum of 90% of the mortar cube results of the same periods using distilled water. The specification for quality of mixing water is provided in ASTM C 1602-2006 and BS EN 1008:2002 codes.

2.2 Aggregate

2.2.1 Assessment on quality of sand and its substitutes

Olugbenga *et al.* (2000) carried out a research work on the study of compressive strength characteristics of laterite and sandcrete hollow blocks in Ile-Ife in Osun State of Nigeria. The objective of their study was to determine the possibility of partial replacement of sand with laterite in the production of sandcrete hollow block so as to cut down the cost. This was because laterite is more abundant and cheaper than the sand which is now widely used. The 6" sandcrete hollow block of standard dimensions 450mm x150mm x225mm prepared with mix ratios 1:6 and 1:8 were used. The levels of replacement of sand with laterite were 0, 10%, 20%, 30%, 40%, 50% and 60% respectively. Results showed that sandcrete hollow blocks with 10% level of replacement with laterite gave the highest compressive strength and that compaction became more difficult as the percentage of laterite increased. The compressive strengths of the sandcrete hollow blocks decreased with level of replacement of laterite and therefore it is not a better material than sand.

Boeck *et al*. (2000) conducted a study on the effect of gradual replacement of sand with stone dust in sandcrete block making. They used river sand which fell almost in zone 1 grading limit. The objective of the study was to determine the percentage level of replacement of sand with stone dust in sandcrete production. The stone dust was said to have the advantage of providing the finer particles smaller than 300 μm when added to the sand thereby ensuring good workability of sandcrete hollow block and reduce the occurrence of segregation. The mix ratio used was 1:5 while the level of replacement were 0, 20%, 40%, 60%, 80% and 100%. The results showed that the density increased with the addition of stone dust up to 40% of the fine aggregate after which it decreased. The compressive strength of the 450mm x 225mm x 225mm sandcrete blocks however, showed gradual decrease with the addition of stone dust. This was attributed to the increased surface area due to the addition of fines. They observed that for high density and good workability, the mix with 2 parts of sand to 1 part of stone dust gave good results.

Also the combined grading curve of sand and stone dust fell fully within the limits of zone 1 for fine aggregates. It can be deduced from this study that the stone dust has not been able to produce higher strength than the sand. Also stone dust is not readily available. Thus the stone dust has not been able to demonstrate any superiority and advantage over sand to justify its use.

Omoregie and Alutu, (2006), carried out a study on the influence of fine aggregate combination on particle size distribution, grading parameters and compressive strength of sandcrete blocks. They observed that low priced sand of lower quality were widely patronised in Nigeria despite its high content of silt and clay. Tests on coefficient of uniformity, C_u, curvature coefficient C_c and the fineness modulus F_m were determined from laboratory on fine sand deposits in parts of South – South, Nigeria (Benin City). The compressive strengths and other properties of the sandcrete hollow blocks produced were determined.

Results showed that the grading of the combined sand, the strength and durability characteristics of the sandcrete were greatly improved by the combination. The cost of the block was highly reduced. The high priced sand produced sandcrete block of compressive strength 6.05N/mm^2 and 5.59N/mm^2 for river sand from Okhuahia River and Ovia River respectively. The low priced sand produced sandcrete hollow blocks with strengths 2.57 and 2.47N/mm^2 for Ikpoba erosion sand and Okhoro erosion sand respectively. The combined sand in the ratios of 2: 1 (high priced sand: low priced sand) and 1:2 (high priced sand: low priced sand) produced sandcrete blocks of 28-day dry compressive strengths of 4.92 and 4.71N/mm^2 respectively. Also the grading zones of the high priced sand and low priced sand were 3 and 4 respectively. Those of the combinations in the above proportions were in zone 2. The water cement ratio used was based on trial and error method.

Agbede and Joel (2004) conducted a research on the suitability of Quarry dust as partial replacement for sand in hollow sandcrete block production. The source of the sand used for the study was River Benue at Makurdi while the quarry stone dust was sourced from Quarry at Ahua of Mkar near Gboko, Nigeria. The study revealed that the mean compressive strength of the hollow sandcrete blocks was 1.26N/mm^2 for blocks moulded from river sand from River Benue at Makurdi while the highest mean compressive strength of 1.97N/mm^2 was recorded at 28 days for blocks made from quarry dust only. The values obtained from a mixture of river sand and stone dust varied between 1.40N/mm^2 to 1.72N/mm^2 for mix ratios 1:1 to 1:4. In this study, the cement to sand mix ratio used was not stated. Also the highest compressive strength of 1.97 N/mm^2 recorded did not meet the mimimum standard. They were just merely comparing this result with that of commercial blocks which were substandard.

Chindaprasirt *et al.* (2009) conducted a study on influence of fineness of rice husk ash and additives on the properties of light-weight aggregate. The objective of their study was to produce light weight aggregate (LWA) from rice husk ash (RHA). The rice husk ash was obtained from biomass power plant in Thailand with specific gravity in the range 2.0 to 2.3. The chemical composition of the RHA was as shown in Table 2.1

Table 2.1: Percentage Chemical Composition of Rice Husk Ash.

SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O	LOI
87.46	2.53	0.78	0.40	1.58	4.73	2.52

Source: (Chindapasirt *et al.*, 2009)

The results showed that ground RHA – LWA gave better performance in terms of expansion, solubility, and disintegration than the as-received RHA-LWA. The density of the light weight aggregate of 0.20 – 0.40 g/cm^3 was achieved.

The major drawback was the disintegration of the LWA in boiling water. Thus RHA is not a good substitute for sand.

Joshua *et al.* (2014) conducted a study on replacement of sand with laterite in sandcrete blocks at Ota. According to Joshua and Lawal (2011), lateritic soil is a potential substitute for blocks produced from sand and cement. It is cheaper and abundantly available and could bring down the cost of housing drastically.

Accoridng to Lasisi and Ogunjimi (1984), a soil could be classified as lateritic based on its silica resquioxide ratio (SRR) defined as:

$$(SRR) = \frac{S_iO_2}{Fe_2O_3+Al_2O_3} \quad (2.1)$$

SRR < 1.33 are indicative of laterite

SRR between 1.33 and 2.0 are laterites

SRR > 2.00 are non – laterites

Sandcrete blocks were made with percentage increase in laterite in step of 10% up to 60%. A mix ratio of 1:6 by volume was used. The cement used was Dangote, which was also produced locally. Test results showed that the lateritic soil in Ota was mostly sandy clay of high plasticity and may replace sand in sandcrete block by up to 20%. However, Joshua et al. (2014) observed that there was a linear decrease in the strength of the block with increasing sand replacement with lateritic soil. Thus, from this study it could be concluded that although, laterite satisfy the criteria of abundance as the sand does, the former has not been able to produce blocks of high strength as the latter does. The chemical characteristics of the cement used were not determined.

2.2.2 Studies on coarse aggregate in Nigeria

Aginam et el. (2013) investigated the effects of coarse aggregate types on the compressive strength of concrete. The coarse aggregate types studied were crushed granite washed gravel and unwashed gravels. Concrete cubes of sizes 150mm were prepared with the the three types of aggregates and tested at 7, 14, 21 and 28 curing days.The mix ratio used was 1:3:6 and the maximum size of aggregate was 20mm.Test results indicated that the concrete produced from crushed granite had the highest strength and had compressive strengths of 22.1, 23.5, 23.9 and 25.1N/mm^2 at 7, 14, 21 and 28 days curing ages respectively. The results of the washed gravel were 16.0, 16.7, 17.3 and 19.2N/mm^2 at curing ages of 7, 14, 21 and 28 days respectively. The results for the unwashed gravel were 15.5, 16.6, 16.6 and16.9N/mm^2 at curing ages of 7, 14, 21 and 28 days respectively. Thus the washed gravel had higher strength than the unwashed (Bloem and Graynor, 1963).

The water to cement ratio used was not reported this might have been prepared by trial and error method. If the appropriate water to cement ratio was used, the concrete strengths would have been higher than the reported results.

2.3 Cement

2.3.1 Raw materials of Portland cement

The raw materials used for Portland cement manufacture consist of (Neville, 2012):

(i) Calcareous material as the primary source such as limestone or chalk

(ii) Alumina and silica found in clay or shale

(iii) Marl, a mixture of calcareous and argillaceous materials.

2.3.2 Process of manufacture of cement

The process of manufacture of Portland cement essentially consists of (Neville, 2012):

(i) Grinding of the raw materials

(ii) Mixing them intimately in certain proportions,

(iii) Burning in a large rotory kiln at a temperature of about 1450 ^{0}C,

(iv) The materials sinter and partially fuses into balls known as clinkers,

(v) The clinkers are cooled and ground to a fine powder,

(vi) Gypsum is then added.

(vii) The product is the commercial Portland cement.

2.3.3 Types of Portland Cements

According to Mindess and Darwin (2003) Portland cements may be grouped into five main classes: (i) General purpose (ii) moderate heat of hydration and moderate sulphate resistant (iii) high early strength (iv) low heat of hydration (v) high sulphate resistant.

The ASTM has designated the five classes of Portland as the Types i-v. According to Thomas and Jennings (2008) the cement types differ chemically in their C_3A contents while the physical differences are in their fineness. They also stated that the effective performance of a Portland cement type is judged by its early rate of hydration.

BS EN 197- 1: 2011 classified cement into five types: Portland cement (CEM I), Portland-Composite Cements (CEM II /Composite), Blastfurnace cement (CEM III), Pozzolanic cement (CEM IV) and Composite cement (CEM V) depending on the percentage of clinker and other materials contents. CEM I cement contains at least 95% clinker and not more than 5% gypsum. Most Nigerian cements currently produced locally in abundance are either Portland limestone (CEM II/ A-L) or Portland limestone (CEM II /B-L) cement while the imported one are ordinary Portland (SEM I).

2.3.4 Common brands of Portland available in Nigerian markets.

Majority of the cement companies in Nigeria have diversified by introducing Portland Limestone cement as their new products. The current survey of the markets revealed that the new products which are in 50 kg bags are even more available and patronised than the old products of Portland cements initially being produced by the local cement industries. The briefs on some common brands of cement sold in the Nigerian markets are presented below.

(i) Ashaka Cement

According to Ashaka Cement Company profile (2014), the setting up of the company became necessary when the feasibility study conducted indicated that there was a large deposit of limestone in Ashaka, a village about 100km from Gombe in the defunct North-Eastern State. The cement produced is called Ashaka cement.

Initially the company was owned by (www.wikinvest.com/.../Ashaka_cement):

(a) Federal Government of Nigeria 50%

(b) Defunct North Eastern State 25%

(c) The Blue Circle (Portland Cement England) 25%

(Technical Partner)

General Olusegun Obasanjo was the Head of State of the Federal Republic of Nigeria when he commissioned the project after which production commenced in August 1979.

The cement quality control complies with the following standards: BS 12, Standard Organisation of Nigeria (SON), NIS 444, 445, 446, 447 and 448, 2003. Presently the parent company of Ashaka cement has shifted from Blue Circle to Lafarge South Africa. Also in January, 2016, Ashaka Cement Company Plc introduced a new product called Supaset which is Portland limestone cement of type CEM II / A-L 42.5R.

(ii) Atlas Cement.

Atlas Cement Company is based at Onne Port in PortHarcourt, Nigeria. It imports a cement brand called Atlas cement. The plant has installed capacity of 500,000 metric tones per annum. It bagged 485,000 metric tones in 2008 (Atlas Cement Company profile, 2012). The company is principally owned by the Lafarge group and thus handles all the cement import allotted to the group (www.atlasobscura.com).

(iii) Burham Cement

Burham is a name of an imported ordinary Portland cement (OPC) manufactured to British standard BS 12:1996 with compressive strength of $42.5N/mm^2$ compliant, packaged in super poly propylene sack that is leak proof and water resistant. The cement is imported by Global Cement Company. Burham cement has the following striking attributes (Global Cement Company, 2014):

1. It sets fast
2. Its consistence and soundness are good
3. Its percentage of insoluble residue and sulphate contents are low

Its percentage of loss on ignition (LOI) is low

Burham cement is available in 50kg, jumbo sacks (2 metric tones) and Bulk, (30 metric tones) (www.globalcement.com). The cement is Portland cement of type CEM I 42.5N.

(iv) Dangote cement

Dangote cement is owned by Dangote Industries Limited (DIL), a leading Nigerian manufacturing and trading company. It is manufactured in Obajana in kogi state of Nigeria, about 220kms South West of Abuja, the Nigerian capital. The cement factory has a combined production capacity of 4.4million metric tones per annum and includes a 135MW capacity gas power plant, a 94Km gas pipe line. The quarry project is located on 527 hectares land belonging to Oyo-iwa communities in kogi state of Nigeria. The mine is located about 8km off the Zariagi Kabba Road, at a junction adjacent to the Obajana cement plant. The quarry is within 9km distance from the Obajana cement plant. Apart from limestone, it is estimated that appropriately 29 million tones of additive materials are also available.

Preliminary investigation indicate the ocurences of 450 million metric tones of limestone and 112.5 million tones of additive materials in 6 other exclusive prospective leases held by Dangote industries Ltd (20km^2 each). This gives a tentative total of 569 million tones of limestone and 119 million tones of additives materials in the area. The present available limestone reserves of both inferred and measured category is expected to last at the proposed 16,500 metric tones, for more than 90 years. The cement plant is scheduled to last for only 50 years. This makes the project a sustainable one. The basic raw materials for the production of cement are limestone, clay/marl, laterite and gypsum. All of these raw materials are located about 7.5km away from the cement plants. Gypsum is sourced through vendors in the North Eastern region of Nigeria. The project implementation started in 2003 and was commissioned in 2005. The cost of the project is US $798 million and is financed with sponsor's equity of US $319 million and US $479 million in the form of long term debt from local and international lenders (www.dangotecement.com).

Currently Dangote Cement Company serves as the parent company to Benue Cement Company and Ibeshe Cement Company. In 2014, Dangote Cement Company introduced new products called Dangote cement 3X and Dangote cement X which are Portland limestone cement of type CEM II / A-L 42.5R and CEM II / B-L 32.5R respectively. The new cement produc were said to comply with NIS 444-1: 2014.

(v) Eagle cement

According to the company profile, the cement is produced by Eastern Bulk Cement Company Limited (EBC) and was incorporated in March, 1977. It began its production in November, 1981. It has been in operation for over 27 years as a pioneer of cement bagging company in the Niger Delta region of Nigeria. The company is located at Rumu Olumieni near Porttharcourt in Rivers state of Nigeria. With an installed production capacity of 1.00 million metric tones, EBC has a current production output of 960,000 metric tonnes of Eagle cement per annum. This is supplied in packages of 50kg bags, jumbo bags of 1.5 metric tones and bulk loading through the use of bulk carriers of 30 metric tones (www.eaglecement.com/). It produces ordinary Portland cement of class 42.5N.

(vi) Elephant Cement

Lafarge Cement WAPCO Nigeria PLc, formally West African Portland Cement PLc (WAPCO), was established in 1960 with its first factory in Ewekoro, in Ogun state. The second factory in Sagamu, also in Ogun State, was established in 1978. The cement brand produced by the company is called Elephant Cement. It operates mainly in the South West geopolitical area of Nigeria. The company started its production with an initial capacity of 200,000 tonnes per annum, but this later grew with demand to about 1.5 million tones per annum. A modern, state-of-the art plant was commissioned in Ewekoro in August 2003 to replace the obsolete and aged plant. This has led to increase in the companys capacity by over 1 million tones per year. Elephant Cement falls under the category of Ordinary Portland Cement (OPC). It is available in 50kg bags and bulk 30-tonne tankers (www.lafargewapco.com or company profile). The company now produces Portland Limestone cement of type CEM II / A-L 42.5N.

(vii) Sokoto cement

Cement Company of Northern Nigeria PLC (CCNN) was founded by the Premier of the then Northern region, Alhaji Sir Ahmadu Bello, Sardauna of Sokoto. It was incorporated in 1962 and commenced production in 1967 with an initial installed capacity of 100,000 tonnes per annum, using the wet process of production, at the Kalambaina plant. Cement Company of Northern Nigeria PLC produces and markets Sokoto ordinary Portland cement in strict compliances with the Nigerian standard quality assurance. The plant is located on a pure limestone belt of over 200 million tones, capable of sustaining the plants operation for at least 100 years (www.sokotocement.com). The current parent company is Lafarge and it produces Portland limestone cement of type CEM /A- L 42.5N.

(ix) UniCem Cement.

The cement is produced jointly by United Nigeria Cement Company under the three parent companies: Holcim, Lafarge South Africa and Flour Mill. The company in trying to diversify its products introduced Portland Limestone cement in 2012. Portland Limestone of Type CEM II / A-L 42.5N.Its area of operation is predominantly in South East.

(x) Ibeto Cement

This is an imported cement of class CEM I by Ibeto Cement Company. Currently the parent company is Lafarge.

(xi) BUA cement

The cement is produced by Edo Cement Company. The company had an install capacity of 0.35 million tonnes per year in 2009. BUA produces Portland limestone of type CEM II/A-L 42.5N.

(xi) Some of the other cement brands found in the Nigerian markets are Pure-Chem cement, Diamant cement and Magen-Roi cement.

2.3.5 Current studies on some cement brands in Nigerian markets

Omoniyi and Okunola (2015) carried out a study on the physical and chemical characterisation of Ashaka, Burham, Dangote and Sokoto cement brands sold in the Nigerian Market. The results indicated that the three brands of cement which were locally produced (Ashaka, Dangote and Sokoto brands of cement) had C_3S contents of 42.5, 99.04, and 56.32% respectively. The imported cement (Burham cement) had C_3S content of 64.13%. The corresponding C_2S contents were 24.40, 5.96, 26.45 and 11.99% for Ashaka, Burham, Dangote and Sokoto cement brands respectively. It was however, observed that the results of the C_3S and C_2S contents for the Dangote was not correct as the sum of its two silicate compounds amount to 125.49%. This was not realistic as the sum of the two silicates exceeded 100%. The implication is that the C_3S contents of the rest cement brands were in the range of 42.65 to 64.13% while their C_2S contents were in the range 5.96 to 24.40%. The initial and final setting time of the four cement samples were in the ranges of 178 to 198 and 236 to 285minutes respectively. The soundness and mortar strengths of the cement brands were in ranges 1 to 3.43mm and 33.5 to 50.43N/mm^2 respectively. It was not indicated in the study whether the cements were Portland cement (CEM I) or Portland limestone cement (CEM II/A –L 42.5N or CEM II/B-L 42.5R).

Oyelade (2011) studied the possibility of partial replacement of cement with coconut husk ash (CHA) and produced SHB of dimension 450x150x225mm at different percentages of cement replacement. Results as presented in Tables 2.2 and 2.3 showed that the compressive strength of the SHB decreased as the level of replacement increased. A nominal 5% level of replacement was found to give satisfactory result for non-load block.

Table 2.2: Characterisation of OPC and Cocoanut Husk Ash (CHA)

Oxide	Cement (%)	CHA (%)
Total organic content (TOC)	1.7	8.88
Calcium oxide (CaO)	62.32	0.25
Silicate (SiO_2)	18.72	0.005
Aluminate (N_2O_3)	6.2	5.10
Femite (Fe_2O_3)	0.94	2.48
Magnesium oxide (MgO)	1.62	0.09
Sulphur oxide (SO_3)	1.1	0.12

Sodium oxide (Na_2O)	0.34	0.02

Source : (Oyelade, 2011)

Table 2.3: Strengths and Densities of Sandcrete Hollow Blocks at levels of Replacement of OPC with Coconut Husk Ash

Percentage replacement	Density	28-day stress SHB strength (N/mm^2)
0	1860.70	2.48
5	1830.70	2.16
10	1766.3	1.40
15	1886	1.14
20	1853.0	0.51
25	1835.30	0.29
30	1821.50	0.06

Source: (Oyelade, 2011)

Thus the block maximum density is at 15% level of replacement while compressive strength decreased as the percentage level of replacement increased.

Oyekan and Kamiyo (2011) carried out a study on partial replacement of cement with rice husk ash (RHA) in sandcrete blocks. The cement used for the study was Elephant ordinary Portland cement produced by West African Portland Cement Company (WAPCO). They characterised the cement and RHA. The results of the chemical oxide percentage compositions of the two materials are presented in Table 2.4.

Table 2.4: Chemical Analysis of RHA and Cement

	Moisture	SiO_2	Ash	Fe_2O_3	CaO	MgO	Na_2O	K_2O	PbO	Sio_2	BaO	Al_2O_3

RHA (%)	0.27	-	11.28	-	0.06	-	1.18	0.10	-	16.0	0.24	0.03
Cement (%)	-	1.48	-	4.75	64.73	2.01	0.19	0.42	-	21.0	-	5.22

Source: **(**Oyekan and Kamiyo, 2011)

Analysis of the cement compounds indicates the following percentage contents by mass: C_3S = 57.90%, C_2S = 16.85%, C_3A = 5.80%, C_4AF = 14.44%. The CaO/SiO_2 =3.82

Okigbo (2013) carried out a study on the physical and mechanical properties of five brands of cements used in Nigeria. The cement brands studied were Burham, Dangote, Ashaka, Benue and Pure Chem. Results showed that the fineness were 403, 425, 263, 396 and 195m^2/kg for Burham, Dangote, Ashaka, Benue and Pure chem. The 28 - day strengths of concretes produced at mix ratio of 1:2:4 from the Burham, Dangote, Ashaka, Benue and Pure chem were 31.82, 36.52, 25.55, 31.05 and 19.11respectively. Results showed that Dangote cement had the highest compressive strength and also having the highest fineness.

However, the chemical analysis of the cement brands was not carried out. Also the w/c ratio used for the concretes was not stated. From his study Pure Chem cement did not meet the standard (BS EN 197-1: 2011). Also the standard specification for concrete (BS EN 206: 2000) of mix ratio is 1:2.5:3.5 (BS EN 206: 2000) at water to cement ratio of 0.60. These gaps observed in the study will be addressed in this study.

2.3.6 Studies on blending materials in ordinary Portland cement.

Lasisi (1977) carried out a study on the use of rice husk ash in sandcrete block production. The objective of the study was to determine the effects of RHA on the strength of sandcrete blocks and also to find the optimum percentage of the RHA that could be added without any deterioration in strength. Results indicated that up to 40% of RHA could be added as a partial replacement for cement without significant change in the compressive strength at 60 days.

Compressive strength of various mix proportions were compared with British Standard minimum compressive strength for blocks for various walls. It was found that sandcrete of 1:5 mortar mixed with 40% RHA by weight could be used in both load and non-load bearing walls. The study did not consider the compressive strength of the block when immersed in water.

Cook et al. (1977) reported that rice husk ash obtained from the controlled burning of rice husk has pozzolanic properties.

Al-Khalaf and Yousif (1984) carried out a study on the use of rice husk ash in concrete. Test result revealed that:

i. The most convenient and economical temperature required for conversion of rice husk into ash was 500 ^{o}C.
ii. Water requirement decreased as the fineness of RHA increased.
iii. The higher the percentage of RHA contents the lower the compressive strength.

Rahman (1987) recommended the use of rice husk ash in sandcrete blocks for masonry units, because the construction industry in developing countries has suffered a depression due to several factors among which are the increasing cost of material e.g cement and shortage of building materials.

Michael (1994) carried out research work on rice husk as a stabilizing agent in clay bricks. In his work clay bricks were produced with 0%, 2%, 3%, 4%, 5% and 10% rice husk. Some of the bricks were burnt in an electric furnace to a temperature of 1005 ^{o}C for 3-4 hours. Compressive strength and absorption tests were carried out. It was concluded that the addition of husk reduces the compressive strength of the bricks and the husk clay bricks became higher as the percentage of husk clay increases.

Singh *et al* (1995) conducted a study on the hydration of Portland blended cements. They reported that in order to save resources and energy, it was then a common practice to use Portland blended cements made from Portland cement and agricultural/industrial wastes. He further stated that with the increased demand on specific performance characteristics in concrete such as improved strength, low heat, sulphate resistance, improved impermeability and certain other applications, these waste materials had imparted superior qualities to Portland cements. The study was centred on hydration characteristics of Portland blended cements made from bag house dust, granulated blast furnace slag and rice husk ash. The cement used for the study was obtained from VSK plant, Bhutan in India while the granulated blast furnace slag was taken from M/S Indian and Steel Company Limited, Burnpur. The rice husk was obtained from a local mill at Gorakhpwr and burnt in an open. The chemical analysis of the cement and the blending materials are as shown in Table 2.5.

Table 2.5: Chemical Composition of Blending Materials (% mass).

Material	LOI	SiO_2	Al_2O_3	Fe_2O_3	Cao	MgO	$Others$
Portland Cement Clinker	1.0	20.5	6.5	4.5	63.5	3.5	Alkaline traces
Bag house dust	18.2	12.3	2.8	2.2	56.2	0.8	-
Granulated blast Furnace Slay	0.3	35.0	21.3	1.1	33.1	8.0	0.8%
Rice husk Ash fired in open heap	10	81.0	2.6	1.9	1.8	1.2	Alkaline traces
Rice husk ash heated at 700°C for 2 hours	0.5	89.0	2.8	2.1	2.2	1.3	Alkaline traces

Source: (Singh *et al.*, 1995)

From the results, they drew the following conclusions. i) The non-evaporable water contents are always lower in the presence of the waste materials as compared to the Portland cement. ii) Bag house dust reduces the rate of heat evolution without affecting the hydration characteristics, iii) Granulated blast furnace slag in the presence of Bag house dust retards the hydration of silicate phase and delays the conversion of ettringite to monosulphate, iv) Rice husk ash on the other hand accelerates the hydration and increase the rate of heat evolution, v) RHA – 700 in combination with Bag house dust gave maximum strength at 7 day and 28 days of hydration.

Mehta (1996) reported that RHA is suitable as raw material for making hydraulic cement.

Dashan and Kamang (1999) carried out extensive work on some characteristics of acha husk ash (AHA) and ordinary Portland cement concrete. Test results indicated that the compressive strength for all the mixes containing AHA increased with age up to the 14-day hydration but decreased to the 28-day hydration period as against the conventional concrete which increased steadily up to 28 day hydrations period.

Cisse and Laquerbe (2000) characterised the properties of sandcrete blocks produced from filler with that produced from RHA blended cement. The objective of the study was to evaluate the properties of sandcrete produced from ground and unground RHA which is an agricultural waste material. The use of RHA in sandcrete block was to create employment opportunities, reduce wastes and preserve the environment as well as reduce cost of sandcrete production. The sandcrete block used was a solid prism of dimensions 4cm x 4cm x 16cm. Both unground and ground RHA were used and open air curing and curing in water were employed.

Results indicated that the average 28-day dry compressive strength of the blocks made with unground RHA was 4.98 MPa while that of ground RHA was 10.37MPa. The strength results at 28 days in the wet state in water were 9.56 MPa and 18.59 MPa for unground and ground RHA blocks respectively. Strengths at 28 days for ground RHA blocks double that of unground RHA irrespective of the curing method and age. Also strength obtained for RHA blocks are much higher than that of limestone or chart blocks due to the pozzolanic nature of RHA.

Anwar *et al.* (2000) conducted a study on using rice husk ash as a cement replacement material in concrete. The objective of the research was to study the main characteristics of RHA, properties of fresh concrete and development of fundamental properties of hardened concrete containing RHA. Results revealed that water – cement ratio increased with increase of the RHA content. The initial and final setting times of the percentages RHA with grinding times of 10 (RHA_{10}) paste increased with increased percentage RHA_{10} replacement while the initial setting time of the percentages RHA with grinding time of 60 (RHA_{60}) the percentages RHA with grinding times of 10 paste decreased when the percentage replacement increased. RHA_{10} and RHA_{60} denote the percentages RHA with grinding times of 10 and 60 minutes respectively. They concluded that the properties of RHA vary depending on the burning and grinding methods. The initial and final setting times are affected by addition of RHA. The chemical composition of RHA satisfies ASTM C618: 78 requirement for chemical composition. Compressive strength of concrete decreased with increase in RHA content up to 28 days. After 28 days, RHA concrete showed the same or higher strength than an OPC mix.

RHA has its special properties and good influence in concrete properties especially those controlling the durability such as low chloride permeability and low diffusion in concrete. Therefore RHA concrete may require less depth of cover to protect the reinforcing steel than those concretes using OPC alone. The findings of this study is in agreement with that of Cook *et al.* (1977) who reported increases in setting times of RHA pastes over those of plain concrete.

The results of the initial and final setting times of OPC with RHA as conducted at the facilities of Osaka Cement Company in Japan are shown in Table 2.6.

Table 2.6: Initial and Final setting times of OPC with RHA

Cement: OPC: RHA	W/(OPC +RHA) Ratio	RHA Type	Setting Time Initial	(Hour – Minutes) Final
100:0	0.280	RHA_{10}	2 – 25	3 – 22
90:10	0.364	RHA_{10}	2 – 31	3 – 49
80:20	0.444	RHA_{10}	3 – 03	4 – 28
70:30	0.525	RHA_{10}	3 – 02	5 – 17
60:40	0.608	RHA_{10}	3 – 10	5 – 40
100:0	0.280	RHA_{60}	2 – 25	3 – 22
90:10	0.308	RHA_{60}	2 – 09	3 – 18
80:20	0.353	RHA_{60}	1 – 55	3 – 39
70:30	0.399	RHA_{60}	1 – 29	4 – 17
60:40	0.448	RHA_{60}	1 – 24	4 - 20

Source: (Anwar *et al.,* 2000)

Nehdi *et al.* (2003) conducted a study on the performance of rice husk ash produced using a new technology as a mineral admixture in concrete. The study investigated the use of a new technique for the controlled combustion of Egyptian rice husk to mitigate the environmental concerns associated with its uncontrolled burning and provided a supplementary cementing material for the local construction industry. The reactor used provided efficient combustion of rice husk in a short residency time through the suspension of processed particles by jets of process air stream that is forced through stationary angled blades at high velocity.

The parameters of the RHA investigated include oxide analysis, x-ray diffraction, carbon content, grindability, water demand, pozzolanic activity index, surface area and particle size distribution. In addition, concrete mixtures incorporating various proportions of silica fume (SF) and Egyptian RHA (EG-RHA) produced at different combustion temperatures were made and compared. Results indicated that the compressive strengths achieved by concrete mixtures incorporating the new RHA exceeded those of concrete containing similar proportion of SF. Resistance to surface scaling of RHA concrete was less than that of concrete containing similar proportion of SF. Also chloride penetrability was substantially decreased by RHA though it was slightly higher than that of SF concrete.

Jauberthie *et al.* (2003) studied the properties of light weight mortar using rice husk mixture. This study was said to be of benefit due to the pozzolanic reaction of rice husk ash as well as the organic fibre reinforcement. A rice husk mortar specimen measuring 40 x 40 x 160 mm^3 was studied for one year storage at 50% relative humidity and 95% relative humidity. Results showed that at high humidity (95%); the mortar gained strength by virtue of the well developed pozzolanic reaction. However, it became more brittle due to the loss of fibre reinforcement effect. The converse of this situation was found with specimens stored at 50% relative humidity. Thus the study showed the importance of storage conditions on the behavior of light weight rice husk mortar.

Bui *et al.* (2005) conducted a study of the particle size effect on the strength of rice husk ash blended with gap-graded Portland cement concrete. He opined that the use of RHA in concretes provides a lot of advantages such as improved strength and durability, reduced materials costs due to cement savings and environmental benefits related to the disposal of waste materials and to reduce carbon emissions. The reactivity of RHA was attributed to its high content of amorphous silica and to its very large surface area governed by the porous structure of the particles.

The results showed that partial replacement of Portland cement by RHA led to an increased water demand which can be compensated for by use of superplasticizer. In addition, partial replacement of Portland cement with up to 20% RHA by mass yielded increased early-age compressive strength values only in the case of the gap-graded binder mixtures. The computer simulation approaches particularly with gap-graded led to a decrease in porosity and particularly in spacing. This eventually led to more significant physical contribution to strength.

Oyetola and Abdullahi (2006) carried out a study on the effect of replacing OPC with rice husk ash (RHA) and compared the 28-day dry compressive strengths of the blocks produced from the blended and unblended OPC. Results indicated that a 20% optimal percentage replacement level of OPC with RHA gave satisfactory result. The compressive strength of the sandcrete hollow blocks from blended cement decreased with increase in percentage replacement level of RHA. However, the test was not extended to wet development strength and density of the blocks produced with blended cement by immersing the blocks in water for some days.

Rodriguez (2006) studied the development of strength of concrete with rice husk ash (RHA). The study was aimed at investigating the influence of residual RHA from the rice paddy milling industry in Uruguary and RHA produced by controlled incineration from the United States on the strength development at different ages. The physical and chemical compositions of the cement and the two RHA as analysed by Rodiquez (2006) are presented in Tables 2.6 and 2.7.

Table 2.7: Physical properties of cement and RHA

	Sp. gram	Fineness		Setting times		Compressive Strengths			
		Spec Surface	N_2 absorption	Initial	Final	1-day	3-day	7-day	28-day
Cement	3.14	309	-	145 min	275 min	10.1	22.8	33.1	45.1
RHA UY	2.06	-	28800	-	-	-	-	-	-
RHA (USA)	2.16	-	24300	-	-	-	-	-	-

Source: (Rodiquez, 2006)

Table 2.8: Chemical Analysis of Cement and RHA

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	M_nO	Na_2O	K_2O	SO_3	LOI
Cement	21.98	4.65	2.27	61.55	4.27	-	0.11	1.04	2.19	2.30
RHA UY	87.2	0.15	0.16	0.55	0.35	-	1.12	3.60	0.32	6.55
RHA USA	88	-	0.1	0.8	0.2	0.2	0.7	2.2	-	8.1

Source**: (**Rodiquez, 2006)

Compounds of Cement used.

Tricalcium silicate C_3S = 44.0%

Dicalcium silicate C_2S = 29.90%

Tricalcium aluminate C_3A = 8.5%

Tetracalcium aluminate C_4AF= 6.9%

ACTIVITY INDEX

Cement = 100%

RHA UY = 92.93

RHA USA = 92.40

Laskar and Talukdar (2008) carried out a research work on rheological behavior of high performance concrete with mineral admixture and their blending. The objective of the study was to investigate the rheological behavior of high performance concrete (HPC) incorporating rice husk ash, condensed silica fume (CSF) and (PFA) pulverized fuel ash. The chemical compositions of the cement and the additives as analyzed by them are shown in Table 2.9:

Table 2.9: Composition of Cement and Other Additives

Particulars	Cement	Fly ash	Silica Fume	RHA
Specific gravity	3.10	2.10	2.24	2.45
Sio_2	20.7%	57%	87.8%	91.6%
Al_2O_3	6.2%	27.1%	1.0%	0.37%
Fe_2O_3	3.1%	5.4%	4.4%	0.55%
C_aO	64.9%	6.1%	0.4%	0.8%
M_gO	0.82%	2.0%	0.24%	0.2%

K_2O	0.53%	0.6%	0.5%	2.2%
so_2	2.7%	1.4%	-	2.9%
LOI	0.9%	0.8%	2.9%	3.4%

Source: (Laskar and Talukdar, 2008)

Results indicated that yield stress was found to decrease due to increase in RHA replacement level. Plastic viscosity was found to increase very steeply and the percentage increase in plastic viscosity was highest in RHA among all the additives.

When CSF replaces cement, optimum values of replacement levels exist for minimum values of yield stress and maximum plastic viscosity. There was decrease in yield stress and plastic viscosity when PFA replaced cement. In the ternary blends with equal masses,

Garces *et al.* (2008) carried out a study on mechanical and physical properties of cement blended with sewage sludge ash (SSA). The objective of the study was to evaluate the suitability of SSA for blending with various commercially available cements. Physical and chemical properties of mortars made from various cements with various percentages replaced by SSA (10-30%) were studied using the mortar from unblended cements as the control. Results revealed that the blended cements prepared by 10% substitution of cement for SSA meets the requirements of the European Standard BS EN 197-1: 2000 in terms of workability. Mortars fabricated with 10% SSA replacement met the mechanical requirements of the European Standard in terms of early age compressive strength and nominal compressive strength. The chemical composition of the sewage sludge ash as analysed by Garces *et al.* (2008) is as shown in Table 2.10:

Table 2.10: Chemical Composition of SSA

LOI	Moisture	CaO	SiO_2	SO_3	P_2O_5	Fe_2O_3	Al_2O_3	MgO	K_2O	TiO_2	Na_2O
5.1	0.5	30.6	19.2	11.1	12.3	10.0	8.9	2.7	1.4	1.0	0.8

Source : (Garces *et al*., 2008)

Ganesan et al. (2008) carried out a study to determine the optimum level of percentage replacement of OPC with Reburnt rice husk residue (RHA) in order to satisfy the strength and durability properties of concrete. Mortar and concrete cubes were produced at different levels of replacement and subjected to permeability, water absorption, sorptivity and chloride diffusion tests for both blended and unblended cements. The chemical oxide compositions of the RHA and OPC determined as presented in Table 2.11.

Table 2.11: Chemical composition of OPC and RHA in India

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	LOI
OPC	20.25	5.04	3.16	63.61	4.56	0.08	0.51	3.12
RHA(India)	87.32	0.22	0.28	0.48	0.28	1.02	3.14	2.10

Source : (Ganesan *et al.*, 2008)

Results indicated that 30% replacement of OPC with RHA gave reasonable improvement in the permeability of the concrete and had no adverse effect on the strength of concrete.For the blended cement the water absorption, chloride diffusion and chloride permeation of the concrete were reduced by 35, 28 and 75% respectively.

2. 4 Sandcrete Hollow Block

2.4.1 Definitions of block

“A block is a masonry unit which when used in its normal aspect exceeds the length or width or height specified for bricks” (BS EN 771-3: 2006). Sandcrete is usually used as hollow rectangular blocks in the standard forms of 450mm x 225mm x 225mm, 450mm x 150mm x 225mm and 450mm x 100mm x 225mm in Nigeria. A brick is a masonry unit not exceeding 337.5mm in length, 225mm in thickness or 112.5mm in height (BS 2028, 1985).

Blocks are classified as solid, cellular hollow and insulating. A solid block is one which contains no formed holes or cavities other than those inherent in the material (BS 6073-1).

“Cellular block is a block which has one or more formed holes or cavities which do not wholly pass through the block. A hollow block is one which has one or more formed holes and cavities which pass through the block. Insulating blocks are usually cellular blocks faced with polystyrene or having cavities filled with UF foam or Polystyrene to improve their thermal qualities.” (BS EN 771-3: 2006)

BS 2028: 1985 defines a hollow block as “a block having one or more large holes or cavities which pass through the block and the solid material is between 50% and 75% of the total volume of the block calculated from the overall dimensions”.

2.4.2 Methods of manufacturing sandcrete blocks

Three main methods are used in the manufacture of sandcrete blocks (Baiden and Asante, 2004). These are: hand ramming compaction method, Manual tamping machine method and motorized vibration method.

(i) Hand ramming compaction method.

This method is used mainly by the small scale block industries. The sand and the cement are measured unto a platform on the ground and mixed with shovel three times. Water is then added and the resulting mix turned two more times with shovel before being fed into the mould (Onwuka et al., 2013). According to Baiden and Asante (2004) the machine is made up of a steel box which is constructed to specified dimensions (plate 1). The two projections in the steel plates creat the two hloes in the sandcrete hollow block when the box is filled with the mixture (Baiden and Asante, 2004). Compaction is done with the aid of a wooden bat, in a shape of a chisel. The compacted unit is removed and placed in a wooden pallet and allowed dry and cured (Baiden and Asante, 2004).

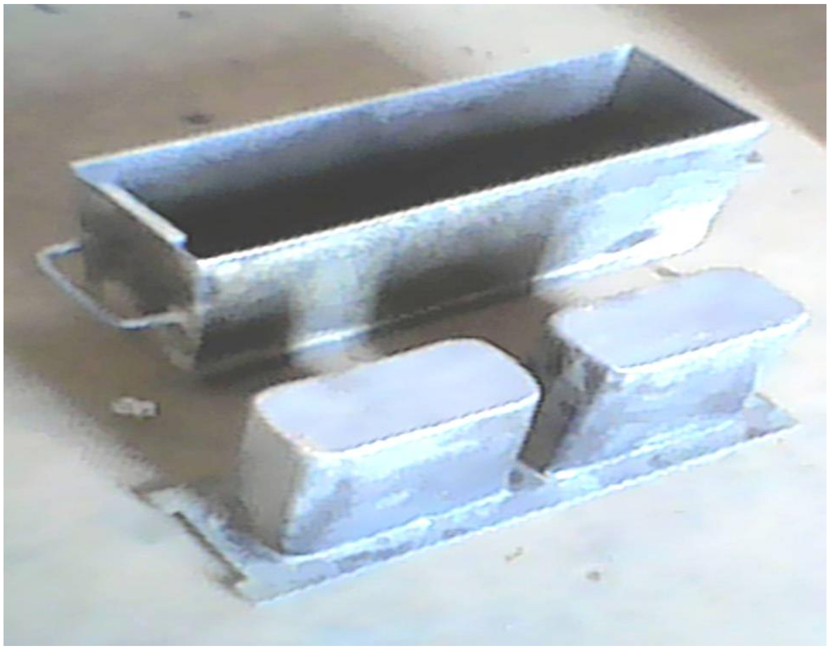

Plate I: Hand Rammed Hollow Block Mould.

(ii) Manual tampering machine

The machine is made up of a mould which is held by the base plate and connected to a system of lever and supported on four legs (Baiden and Asante, 2004). Compaction is achieved with the aid of a second plate on the top which serves the dual role of covering the mould as well as a means of compaction of the sand, cement and water mixture fed into the mould. This second plate is weighted with steel to achieve the required level of compaction by impact for four or more times (Baiden and Asante, 2004). The compacted unit is removed by means of a lever system incorporated. The four legs are usually braced to achieve stability of the machine (Baiden and Asante, 2004).

Figure II: Manual Tamping Machine

(iii) Motorized vibration machine method

The machine is constructed for easier operation. It can be used by people who are not skilled. It runs on both electric motor as well as diesel engine and is very suitable for rural areas. Its operation depends on three levers and pressure which is constant (Baiden and Asante, 2004). The diesel type makes use of fan belt which is fixed on the motor and roller. This turns the roller. Vibration is achieved when a metallic mass hits the bottom of the wooden pallet (Baiden and Asante, 2004) with the aid of the second lever. The “presser” is normally brought down on the cement- sand and water mixture. The compacted unit is removed by means of the longest lever.

2.4.3 Curing

According to BS 8110 (1997) curing is "the process of preventing the loss of moisture from the concrete whilst maintaining a satisfactory temperature regime." This definition adds that the curing should prevent the development of high temperature gradients within concrete. According to Marsh (2003) other definitions exist that make reference to hydration, durability and cost. Thus the objective of curing is to keep the concrete or sandcrete block saturated, or as near saturated as possible for sufficient time for the original water-filled space to become filled to the desired extent by cement hydration products (Marsh, 2003). Curing is carried out in any of the following forms (Marsh, 2003):

i. Formwork retention,
ii. suspension of covering above the surface before the concrete sets (horizontal surface),
iii. spraying with water,
iv. pounding with water,
v. covering with wet sand, earth, sawdust, straw,
vi. waterproof reinforced paper or plastic sheeting,
vii. tenting or other shelter against drying winds,
viii. sunshields
ix. covering with an insulating layer or heated enclosure.

Curing condition is one of the factors that affect the strength development of sandcrete blocks. Blocks cured under different conditions have been found to have different strength (Eze-Uzomaka, 1977). Water sprinkling on blocks as well as shade curing has been commonly used by local block industries. Blocks cured with water sprinkling method had been found to yield higher strength than those cured with other methods. The effect of water sprinkling is to augment the water in the mix which is required for hydration and therefore the water sprinkling is more effective at low water/cement ratios. Beyond the optimum water/cement ratio, curing with water is detrimental to strength development of the sandcrete block. This may create void as a result of water withdrawal from the block and does not permit proper bonding (Lasisi and Ogunjimi, 1984).

2.4.4 Standard test requirements for sandcrete hollow block

Most codes and standards normally take compressive strength of hollow block as the ultimate axial load divided by its cross sectional area of the block including holes. Thus, actual ultimate strength in the material of the tested hollow block is then much higher than the nominal compressive strength and depends on the ratio of net cross sectional area to the gross one (BS 2028:1985, BS 6073: 1981 as ammended in 2004, BS EN 771-3: 2006 and NIS 87: 2004).

The NIS 87: 2004 specified that the average compressive strength of load bearing sandcrete blocks should not be less than 3.45N/mm^2 with lowest individual strength of 2.5N/mm^2. BS 2028: 1985 specified that the average compressive strength of load bearing blocks should be a minimum of 3.5 N/mm^2 while BS 6073: 1981, as ammended in 2004, specified a minimum of 2.8N/mm^2. The number of blocks to be tested is from 3 to 12 in number, with immersion period range of one to 28 days.

BS 2028: 1985 limits the ratio of net volume of the materials in the block to the gross volume of the block to 50 percent. Thus, the width of the cavities measured at right angle to the face of the block as laid in the wall shall not exceed two- third of the total thickness of the block. On the other hand, NIS 74: 1976 states that holes passing through the block or burnt clay unit should be at least 25 percent of the block volume. BS 5628 – 1:1992 classified the compressive strength of hollow blocks as 2.8, 3.5, 5.0, 7.0, 10, 15, 20 and 35N/mm^2. The current code BS EN 771-3: 2006 replaced BS 6073: 1981. The actual ultimate stress in the tested hollow block is from 133 percent to 200 percent of the nominal compressive strength. The listed codes either specify contact layer for test as either mortar, plywood, celotex or do not recommend any material for contact layer.

2.4.5 Assessments of quality of commercially produced sandcrete blocks

Okpalla and Ihaza (1987) conducted a study on 306 number, 9’’ sandcrete hollow blocks produced by some industries in the northern part of Nigeria. Although the authors did not present the average 28-day dry compressive strengths results, it was concluded that the machine compacted 9” sandcrete hollow blocks were of very low qualities, lower than the then Federal Ministry of Works (FMW) minimum 28-day compressive strength of 1.7 N/mm^2 in Nigeria.

Similar study carried out (Okpalla and Ihaza, 1987) on 9” hollow sandcrete blocks compacted with vibrating machine and randomly selected from 30 block industries from Benin City in South- South zone, Nigeria revealed the following results:

(i) 21% of the tested blocks samples had strength up to or more than 2.1 N/mm^2

(ii) 52% had strength greater than 1.7 N/mm^2 which was then the Federal Ministry of Works (FMW, 1979) minimum 28-day compressive strength in Nigeria.

(iii) 27% failed to meet the above FMW (1979), minimum specification. Similar studies were carried out by Abieyuwa (1998) in other towns in Ekpoma and its vicinity in the same South- South zone, Nigeria. Results revealed that 95% of the tested sandcrete hollow block samples failed to meet the minimum strength of 2.5N/mm^2. They did not consider the contribution of the water to cement ratio to the poor strength of blocks. The wet strengths of the SHB were not studied by the above researchers.

Okolie and Akagu (1994) carried out a study on the compressive strength assessment of 450mm x 225mm x 225mm sandcrete hollow blocks produced with vibrating machines in 25 block industries located in Enugu, Eastern Nigeria. Result revealed that none of the 28-day dry compressive strengths of the blocks met the then Federal Ministry of Works (1979) minimum strength specification of 1.7 N/mm^2. This may be due to the poor mix ratio, inadequate curing and improper water to cement ratio used in producing the blocks.

Clark (2000) and Olaniyi (2000) conducted similar studies on 9" hollow sandcrete blocks produced by 20 block industries located at Ughelli and Warri respectively in South- South zone, Nigeria. Results revealed that none of the machine compacted 9" hollow blocks met the then FMW (1979) minimum compressive strength specification of 1.7N/mm^2. Only 13% of the blocks tested at Effuru at the age of 28days met the minimum specification. The water cement ratio used was inappropriate as this was based on trial and error method.

Adedeji and Ejeh, (1998) carried out a study on strength characteristic of dry-jointed sandcrete assemblies under vertical loads. The objective of their study was to develop a vigorous behavioural model useful for predicting the compressive strength of axially and eccentrically loaded masonry prisms and their failure modes. They used 450mm x 225mm x 225mm hollow blocks for full size and hollow 225mm x 225mm x 225mm blocks for half size. The two sets of blocks were made to comply with the available standards and data and also checked for absorption, moisture content, density, weight, dimension and compressive strength. It was observed that with increase in eccentricity, the ultimate compressive stress of the prism was recorded at the extreme fibre. It was also discovered that the average axial compressive strength for the ISB-Prism was higher than that of the conventional sandcrete block. Most prisms were subjected to the same condition of production, curing and testing. The test was not conducted under wet condition by immersing the blocks in water. The equation developed by Robert and Ahmed (1983) which was used for dry-jointed sandcrete block may not be applicable under soaked condition.

Boeck *et al*, (2000) carried out a survey of the sandcrete hollow blocks produced by the block making industries in the federal capital territories. The survey covered Abuja and the towns surrounding it such as Nyanya, Gwaga, Deidei, Zuba and Gwagwalada. The study indicated that most factories used coarse sand while few used a combination of mixture of river sand and crushed stone dust. Most block making industries produced 9" SHB of standard dimension 4.50mm x 225 x 225mm and at mix ratio range of 1:13 to 1:17. The block moulding machines were generally Rosacommetta which is the vibrating type and produces a single block per cycle of operation. Results of their studies indicated that the 28-day dry strength of the blocks ranged between 0.47 to 1.68N/mm^2 while in the wet state the strengths were in the range of 0.32 to 1.07N/mm^2. These values were found to be lower than 2.9N/mm^2, the minimum standard strength specified by BS EN 771- 1:2006.

Although they suggested that the compressive strength of the blocks could be increased by producing SHB at varied water to cement ratios and the optimum water to cement ratio obtained, they were not able to carry out this in their studies. Also the cement brands used by the industries were not mentioned in the paper. The chemical analysis of the cement brand was not carried out in their study. This study intends to consider these gaps identified in their work.

Ejeh and Ayinmode (2000) carried out survey studies on 9" hollow sandcrete blocks, compacted with vibrating machine, from five selected block industries in Kwara state, Nigeria. The result showed that both the dry and wet compressive strengths were far below the standard BS 2028: 1985 requirement. The average 28 day dry and 28-day wet compressive strengths were $0.38N/mm^2$ and $0.8N/mm^2$ respectively for the five industries studied. The minimum soaked strength was only stated for the substandard commercial blocks and no attempt was made to produce and test standard blocks as a control.

Samson *et al* (2002), carried out quality assessment of commercial sandcrete hollow blocks produced by block–making industries in Bauchi and Gombe. Results indicated that the average 28- day strength of SHB produced with vibrating machine was $0.49N/mm^2$. The initial setting time of Ashaka cement used was 40.3 minute while the final setting time was 356mintues.

The soundness of the cement was 2.0mm while its 3 –day strength was $13.15N/mm^2$. The average silt content of the sand used from the five industries studied were 9.89%, 8.38%, 5.40%, 5.70% and 8.21%. Thus majority of the industries used sand with silt content exceeding 6%, the specified minimum standard by BS 2028:1985. They concluded that poor mix ratio, inadequate curing and poor workmanship were the factors responsible for the low strengths of the blocks.

They also reported that the water to cement ratio used was based on trial and error method. However, the study did not consider the chemical analysis of the Ashaka cement used and the impropriate water to cement ratio used by the block- making industries which was reported to be based on trial and error method.

These two factors might have contributed significantly to the low strengths of the blocks. Even the blocks used for the control test by the researchers did not meet the BS 2028:1985 and BS BN 771-3:2006 minimum standards of 2.8N/mm^2 and 2.9N/mm^2 respectively. This study intends to take into consideration these factors.

Baiden and Asante (2004) conducted a study on the effect of orientation and compaction methods of producing sandcrete blocks on their strength properties. They considered hand ramming compaction moulds, manual tamping compaction frame and motorized vibration machine as the three modes of producing SHB. The horizontal flat and vertical straight orientations were also considered for each method. The test results of the six different combinations of mode of block compaction and orientations are summarised in Table 2.12

Table 2.12: 28-Day Dry Compressive Strengths of Sandcrete Blocks produced from different modes of Compaction and Orientation Combinations.

Mode of Compaction	Orientation	Average Compressive strength of blocks (N/mm^2)
Hand ramming	Horizontal	2.13
Hand ramming	Vertical	2.48
Manual tamping	Horizontal	1.85
Manual tamping	Vertical	1.35
Motorised vibration	Horizontal	2.28
Motorised vibration	Vertical	2.78

Source: (Baiden and Asante, 2004)

The materials such as water, sand were characterized. Other properties of SB determined were water absorption and bulk density.

They concluded that:

i. The sand should be properly scrutinised by means of test results before it is purchased.

ii. Hand ramming method with vertical orientation was recommended where electricity is not available

iii. The motorized vibration method with vertical orientation was recommended as the best method for moulding sandcrete block as its compressive strength met the local mini standard 2.7N/mm^2 for Ghana.

However, the research did not consider the importance of using optimum water cement ratio. Production was based on trial and error method. This might have accounted for the low strength of SHB using the different methods and orientations. Also the chemical analysis of the cement used was not carried out. Only the physical properties of cement were reported. This study intends to address these lapses observed.

Olanitori, (2005) assessed the compressive strength of sandcrete hollow blocks produced in Akure in Ondo State of Nigeria. Based on the interview with the staff of the eight industries it was revealed that they used six 50kg bags of cement per tapper load of sand to produce the 9” blocks (225mm) and five 50kg cement to produce the 6” blocks. Thus an approximate mix ratio of 1:10 and 1:12 were used to produce 9” and 6” blocks respectively. Results showed that the characteristics strength of the sand 6” SHB produced by the block making industries were 1.17N/mm^2 and 1.21N/mm^2 respectively at mix ratio of 1:8.

The results of the control blocks at mix ratio of 1:6 were 1.33N/mm^2 and 1.35N/mm^2 for 9” and 6” SHB respectively. Thus even the control blocks did not meet the BS EN 771-3:2006 minimum standard strength of 2.9N/mm^2. The lack of knowledge on concreting by those engaged in the eight industries for production of SHB was said to be responsible. However, the fact that none of the control blocks met the standard indicates that the problem is caused not only by the lack of experience. The water cement ratio used by the block-making industries also contributed to the low strength of the blocks. The chemical qualities of the cement brands used for the blocks also contributed and were not considered. These gaps observed in their studies were considered in this study.

Abdullahi (2005) conducted a research on the compressive strength of commercial sandcrete hollow blocks produced in Bosso and Shiroro area in Minna, Niger State of Nigeria. Results of his study indicated that the average compressive strength of the blocks produced by the five block industries considered were in the range of 0.11-0.75N/mm^2. These values were found to be below the specified maximum value 2.9N/mm^2 prescribed by BS EN 771.2006 standard. He blamed the poor strengths results of the SHB on the poor quality control measures of the block-making industries. Inadequate curing and early sale of the blocks before attaining the age of 28 days were the reasons advanced for the low strengths of the SHB. The improper w/c ratio of the SHB as well as the chemical the properties of the cement brands used by the five industries were not considered in his study. These gaps will be addressed in this study.

Afolayan et al (2008) carried out a study on the characterisation of the compressive strength of sandcrete hollow blocks produced in Ondo State, Nigeria. The two standard sizes of SHB used were 450 x 225 x 225mm (9") and 450 x 150 x 225mm (6"). The total numbers of blocks studied were 75 for 9" and 75 for 6" SHB.

Results revealed that the 9" block had an average compressive strength of 0.45N/mm^2 while that of 6" was 0.55N/mm^2. The coefficient of variation of the 9" SHB was 0.71 while that of the 6" SHB was 0.54. They concluded that the compressive strengths of the blocks did not measure up to standard and that the quality control of the commercial industries in the state was poor. However they did not consider the effect of water cement ratios used by the commercial block making industries as well as the chemical qualities of the cements used. The blocks were not also soaked for one day to determine the strength. This study intends to consider the problems identified.

Ejeh and Abubakar (2008) carried out a study on the assessment of the quality of SHB produced by commercial block industries in Zamfara State, Nigeria. The survey of the block industries revealed that the mix ratio used range from 1:10 to 1.14. The curing was done for only three days. Test results showed that the 28-day dry compressive strengths of the blocks ranged from 0.33 to 0.66N/mm^2 while the average compressive strengths of the blocks ranged from 0.42 to

$0.66 N/mm^2$. A drop in strength of each soaked sandcrete hollow block was observed after one day immersion in water before the strength rose again.

The low compressive strengths of the SHB were attributed to poor mix ratio, lack of optimization, poor compaction and inadequate curing. The authors did not consider the contribution of improper mix ratio used by the block industries and did not report the chemical properties of the Ashaka cement used to produce the SHB. Also no attempt was made to produce sandcrete hollow blocks which satisfy the standard (BS EN 771-3: 2006) to serve as control and determine the strength development profile of standard blocks immersed in water. Also the effect of cement brands, mix ratio and curing on the drop in compressive strength of the commercial blocks were not studied. These observed gaps form the basis of undertaking this research.

Oyekan and Kamiyo conducted tests on 225x225x450 and 225x180x450 sandcrete hollow blocks produced with mix ratios of 1:6 and 1:8, using plain cement and cement blended with RHA at varying levels of replacement. Results showed that for 225x150x450 SHB, the compressive strength increased to an appreciable level above that of SHB produced from plain cement up to 5% level of replacement after which it decreased with increase in RHA. A maximum compressive strength of $2.4 N/mm^2$ at 5% level of replacement was recorded. These values were low because the w/c ratio used was based on trial and error method.

Wenapere, and Ephraim, (2009), studied the physico-mechanical behavior of sandcrete block masonry units. According to Wenapere (2009), the current views on the strength deformations and failure mechanisms of concrete masonry under static and dynamic loads were presented in the recent studies by Abrams (1996, 1997), Andam (2002 a, b), Page (1981), Paulson *et al*. (1990) and Stroven (2002), among others. The effect of mix proportion and compactive effort on the economy and strength of sandcrete masonry have been investigated by only few studies among which were Wenapere (2003), Andam (2002a, b), Boeck *et al.* (2000) and Uzomaka (1977) and others.

The problems of frame – in – fill interaction were said to have been tackled in the research carried out by Ephraim et al. (1990), Liauw *et al*. (1983) and Madan *et al*. (1997) among others.

Wenapere and Ephraim (2009) studied the mechanical characteristics of 1:4 model sandcrete hollow blocks and their prototype hollow sandcrete blocks in the laboratory. The size of the model block was 112.5 x 37.5 x 56.25 (mm) and that of the prototype was 450 x 150 x 225 (mm). and the mix ratios of sandcrete hollow blocks were 1:4, 1:6, 1:8 and 1:10. The objective of their study was to determine the structural characteristics of a ¼ model sandcrete hollow block and its prototype sandcrete hollow block in the laboratory.

The result obtained was to provide a basis of studying blockwall behaviour subjected to different structural loading conditions in the laboratory. The results of the 28-day compressive strengths of the prototype blocks at mix ratios of 1:4, 1:6, 1:8 and 1:10 were 7.60, 8.85, 4.47 and 3.80 N/mm^2 respectively. The corresponding values for the model blocks were 7.46, 6.50, 4.3 and 3.65N/mm^2. Thus there was a high correlation between the model test results and those of its prototype. The tests under the wet condition were not carried out by immersing the model and its Prototype blocks in water. Also, the cement brand used for the study was not characterized.

Mahmoud *et al* (2010) carried out a study on the strength characteristics of sandcrete blocks in Yola metropolis. The blocks of standard sizes 450 x 150mm x 225 and 450 x 225x225, were used for the research. The main sources of sand are from the Benue river, Girei, Nguore and Fufore areas. The average compressive strength of the blocks based on net area ranged from 0.41 to 1.31N/mm^2 for the 9" blocks while that of the 6" blocks ranged from 0.18 to 1.38N/mm^2. However the standard specified the use of gross area for the computation of the strengths of blocks. Therefore the actual average computed strengths based on gross area were less. The average 28-day dry compressive strength of the blocks produced in Yola ranged from 0.26 to 0.84N/mm^2 for 9" hollow blocks with an average of 0.54N/mm^2. The average 28-day dry compressive strength of the 6" block produced in Yola ranges from 0.10 to 0.92N/mm^2 with a mean of 0.61N/mm^2. Thus none of the block industries studied in Yola produced standard blocks. No attempt was made to consider the effect of water to cement ratio to the low value of the blocks strengths by the researchers. The wet compressive strengths and density development test of the sandcrete hollow blocks was not conducted

Adebakin *et al*, (2012) carried out a research on the use of sawdust in producing low cost and light weight sandcrete hollow blocks. The objectives of their study were to reduce cost of building as well as reduce the weight of dead loads in building especially high rise buildings. SHB were produced using varied water/cement ratios of 0.50, 0.54, 0.55, 0.56, 0.57 while the level of replacement of sand with sawdust were corresponding 0%, 10%, 20%, 30% and 40% respectively. Result showed that the use of 10% sawdust produced the dry acceptable strength results when mixed with sand, cement and water at mix ratio of 1:8 and w/c ratio of 0.54. The 28 -day dry SHB strengths from their study was less than 3N/mm^2. The optimum water to cement ratio was not used and the cement was not analyzed to determine the chemical composition. These lapses need to be addressed.

Raheem *et al.* (2012) carried out a study on comparative analysis of SHB and lateritic interlocking blocks used for walls. The objective of the study was to compare the strengths, densities and costs of the two construction materials. Dangote cement and mix ratio of 1:9 were used in producing the blocks while mix ratio of 1:19 was used for the lateritic blocks. The results indicated that the range of 28 -day dry compressive strengths of the 225mm (9") blocks was 1.59N/mm^2 to 4.25N/mm^2 while that of 150mm (6") SHB ranged from 1.48N/mm^2 to 2.25N/mm^2, as curing increased from 7 days to 28 days. For lateritic interlocking blocks the strength varied from 1.10N/mm^2 at 7 days to 5.03N/mm^2 at 28 days. The relative costs per square metre of the 9" block, 6" block and the lateritic interlocking block were N2,808, N2,340 and N2,120 respectively. The researchers did not subject the three types of blocks to wet development strength and density tests. The weakness or limitation of lateritic blocks will have manifested and the minimum soaking strengths of the blocks would have been determined.

Onwuka *et al*. (2013) had carried out a survey and assessment of the blocks produced from 10 block-making industries. The objective of the assessment was to determine the mode of production of blocks, mix ratio used, the nature and quality of sand, the structural properties of the blocks and compare result with standard. Results indicated that three to seven (3 to 7) wheel-barrows of water determined by trial and error were used by the industries. Mixing of cement, sand and water by hand was employed by the small industries and the production of SHB was usually by hand mould. The big industries employ use mixers and vibrating machines for the production of SHB.

Results indicated that the average compressive strength of the blocks was 0.96 N/mm^2 while the standard deviation of 0.207N/mm^2. The value did meet the minimum standard of 2.9 N/mm^2 (BS EN 771-3: 2006). The low strengths of the SHB were caused by poor mix ratio, inadequate water to cement ratio which was based on trial and error. The cement brands used by the ten industries were not characterized to determine their suitability for sandcrete blocks. This study intends to address these gaps observed us their study.

Ewa and Ukpata (2013) carried out the assessment of the compressive strength of commercial sandcrete blocks produced in Calabar, Akwa Ibom State, Nigeria. The ordinary Portland cement brand used was UNICEM by the ten industries studied. Results revealed that the 28 day dry compressive strengths of the commercial sandcrete hollow blocks produced by 10 block making industries located in the Calabar metropolis were in range between 0.23N/mm^2 and 0.58N/mm^2 with a mean value of 0.35N/mm^2. The results did not meet the minimum standard compressive strengths of 1.75N/mm^2 and 2.0N/mm^2 specified by Nigerian Building code (2006) and NIS 87: 2004 respectively for non-load bearing blocks. The water to cement ratios used to mould the blocks were based on trial and error method and it varied from one industry to another and not indicated. The oxide analysis was carried out 0n the cement. The SHB were not soaked in water to determine their characteristic properties.

Odeyemi *et al.,* (2015) carried out a research on the SHB produced from Dangote and Elephant cement brands using manual and machine modes of compaction and compared the results. The mix ratio used was 1:6 while the water to cement ratio was 0.5. The results revealed that the 28-day dry compressive strengths of the 6” SHB produced manually from Dangote and Elephant brands of ordinary Portland cement were 2.83 and 2.89N/mm^2 respectively. That of the 28-day dry compressive strengths of machine compacted blocks from Dangote and Elephant brands of ordinary Portland cement were 2.96 and 3.03N/mm^2 respectively. The authors claimed that strengths of the SHB from both cements satisfied the local code (NIS 87: 2004) which specified a minimum strength of

1.80N/mm^2 and 2.0N/mm^2 for hand and machine compacted 6” blocks respectively.

However, close scrutiny of the paper indicated that the authors used net area rather than the gross area specified by the standards (NIS 87: 2004 and BS EN 771-3: 2006). The actual compressive strengths using gross area were much lower than the reported results. The manual results for SHB produced from Dangote and Elephant brands of ordinary Portland cement were actually 1.78 and 1.70N/mm^2 respectively. The machine results for the SHB produced from Dangote and Elephant brands of ordinary Portland cement were actually 1.78 and 1.82N/mm^2 respectively. Thus, the strengths results of the SHB produced from Dangote and Elephant cement brands did not satisfy the standards (NIS 87: 2004 and BS EN 771-3: 2006). Although a mix–ratio of 1:6 and a w/c of 0.5 were used, the results did not meet the standards because the optimum water to cement ratio was not used. The researchers used w/c = 0.5 by trial and error method and the chemical analysis of cement brands used were not conducted. This study intends to address these gaps observed in their study.

Umasabor and Alutu (2015) studied the effect of grades of the cement grades 42.5 and 32.5 on some properties of sandcrete block. Cement used for the project was Dangote grades 42.5 and 32.5. Three types of aggregates were used to produce sandcrete cubes of sizes 150mm: Ovbiogie sharp sand, Okhuahe sharp sand and Iguosa river erosion sand. The mix ratios used were 1:6, 1:8 and 1:10.

216 sandcrete cubes were produced and tested for compression at ages 1, 3, 7, 28 days.

Test results for cement grade 32.5 blocks show that the seven day compressive strengths at mix ratio of 1:6 were 3.48, 3.31 and 3.4N/mm^2 for Ovbiogie, Iguosa and Okhuahe sands. For mix ratio of 1:8, the results were 3.03, 2.34 and 2.43N/mm^2 respectively. The test results for the grade 42.5 cement blocks at mix ratio of 1:6 were 6.52, 6.03 and 6.22N/mm^2 for ovbiogie, Iguosa and Okuahe sands respectively. For mix ratio of 1:8, the 7-day strengths of the sandcrete blocks were5.48, 3.69 and 2.89N/mm^2 for Ovbiogie, Iguosa and Okhuahe sands respectively.

They concluded that the cement grade does not translate to sandcrete block strength. Their conclusion is wrong. While the results of grade 42.5 cement blocks all met the NIS 87: 2004 those of cement grade 32.5 did not all meet the average strength criteria of 3.45N/mm^2. The water to cement ratio used was based on trial and error method.

2.4.6 Two- factor analysis of variance (ANOVA)

Analysis of variance (ANOVA), a statistical method is used when the sets of response variables to be compared or tested under a hypothesis are more than two because the t-test cannot analyse them (Panneerselvam, 2012; Clewer and Scarisbrick, 2001). When the factors that influence the response variables to be tested are two, then the two-factor analysis of variance is employed. For example if the hypothesis is to test whether the mean compressive strengths of sandcrete blocks are significantly different or not when the mix ratio is varied from 1:4 to 1:12 and using seven brands of cement, then the sets of mean compressive strengths are considered as the response variables (Chatterjee and Hadi, 2006). The mix ratio of the cement-sand and the cement brands used to make the blocks are considered as the factors (Kutner *et al.*, 2005).

The model of the randomized complete block design is as follows (Panneerselvam, 2012):

$$Y_{ij} = \mu + B_i + T_j + e_{ij} \tag{2.6}$$

where:

μ is the overall mean

Y_{ij} is the observation with respect to the j^{th} treatment of the factor cement brand and i^{th} block (mix ratio)

B_i is the effect of the i^{th} block (cement brand)

T_j is the effect of the j^{th} treatment factor (mix ratio)

e_{ij} is the random error associated with the ith block (cement brand) and j^{th} treatment factor (mix ratio)

The hypothesis with respect to treatment (mix ratio) is:

Null hypothesis, H_0: $T_1 = T_2 = T_3 = \ldots = T_{12}$

That is, the mix ratio has no significant effect on the strength of the sandcrete block.

The hypothesis with respect to block factor (cement brand) is:

Null hypothesis, H_0: $B_1 = B_2 = B_3 = \ldots = B_7$

That is, the cement brand has no significant effect on the strength of the sandcrete block.

Total Sum of the Squares (SS_{total}) = Sum of the Squares of blocks ($SS_{mix\ ratio}$) + Sum of the Squares of treatment ($SS_{cement\ brand}$) + Sum of the Squares of errors (SS_{error}). That is,

$$SS_{total} = SS_{mix\ ratio} + SS_{cement\ brand} + SS_{error} \quad (2.7)$$

The generalized shortcut formulae to compute the sum of squares of different components of the model are given as (Panneerselvam, 2012):

$$SS_{total} = \sum_{i=1}\sum_{j=1} Y_{ij}^2 - T^2/N \quad (2.8)$$

$$SS_{mix\ ratio} = \sum_{j=1}^{t} Y_i / t - T^2/N \quad (2.9)$$

$$SS_{cement\ brand} = \sum_{i=1} Y_j / b - T^2/N \quad (2.10)$$

$$SS_{error} = SS_{total} - SS_{mix\ ratio} - SS_{cement\ brand}$$

2.5 Concrete

.James *et al* (2011) conducted an investigation on a total of 72 concrete cubes prepared with a mix ratio of 1:2:4 in a laboratory and used the ponding, sprinkling, wet covering plastic sheet, totally un cured types (open air) and cubes left uncured for two days before curing ponding -29.5 N/mm^2, wet covering -28.5N/mm^2, sprinkling -27.5N/mm^2, plastic sheeting -26.9N/mm^2 uncured for 2 days, 26.5N/mm^2, totally uncured 24.6N/mm^2. Results showed that the ponding method of curing produced concrete cubes with the highest strength and densities.

Usman *et al.* (2012) studied the possibility of substituting saw dust and palm kernel shell as alternative replacement of fine and coarse aggregates in concrete. Concrete cubes of sizes 150mmx150mmx150mm were casted and cured using mix ratios of 1:2:4 and 1:3:6. The compressive strength development and water absorptions of the concrete cubes were determined.

Control cubes using sand and gravels were also produced. Results showed that the specific gravities of sawdust, palm kernel shell, sand and gravels were 0.77, 1.62, 2.57 and 2.67 respectively.

The 28 day compressive strengths of concretes produced from various materials are presented in Table 2.13

Table 2.13: Compressive Strengths and Water Absorptions of Concretes Produced with Various Combinations of Cement, Sand, Palm Kernel Shell and Saw Dust.

Type of concrete	Mix ratio		
	1:2:4	1:3:6	Water absorption
Cement, sand, granite	22	21.11	14.1%
Cement, sawdust, granite	5.78	5.02	13.1%
Cement, sand, palm kernel	5.87	4.00	12.0%
Cement, saw dust, palm kernel shell	0.00	0.6	

Source: (Usman et al., 2012)

The compressive strengths of the concrete by replacing sand and gravel with saw dust and palm kernel shell produced light weight concrete of very low compressive strength and high water absorption. The influence of water cement ratio and the cement chemical quality was not considered in the study.

Raheem *et al.* (2013) carried out a study on partial replacement of OPC with groundnut shell ash (GSA) using mix ratio of 1:2:4 and 1:2:2:2:6. The percentage replacement with GSA was 0, 5%, 10, 15%, 20%. Concrete cubes of sizes 150mmx150mmx150mm were tested. A total of 32 cylindrical concrete specimen and 32 cubes were used.

The compressive strengths and splitting tensile strengths of the cubes and cylinders decreased as the percentage of GSA increased. An optimal content of 10% which produced concrete cubes with compressive strength of 21.34N/mm^2 and splitting tensile strength of 2.11N/mm^2 for mix ratio of 1: 2: 4 was considered reasonable. The optimum water to cement ratio used for producing the concrete cubes and cylinders has not been specified. The addition of GSM to the concretes had reduced their compressive strengths drastically. The GSM and the cement used were not characterized. This study intends to address the gaps observed in their study.

Adewale *et al. (2014)* investigated the strengths of concretes produced from the Nigerian Portland-limestone cement obtained from the depots in Ibadan. According to the authors cement sold in the Nigerian markets is not ordinary Portland cement but mainly Portland-limestone cement designated as CEM II/A-L and CEM II/B-L in the current Nigerian Industrial Standards for cements NIS 444-1:2003. The authors asserted that OPC are no longer sold in 50 kg bags but are reserved for special request by the big firms. According to the authors most professionals such as engineers, architects, academic, researchers, bricklayers, masons and others are unaware of the different grades of cements 32.5 and 42.5 presently available in the markets. The results of their studies are presented in the Table 2.14

Table 2.14: Compressive Strengths of Concretes Produced from Cement Classes 42.5 and 32.5

Mix Ratio	Strengths Cement grade 42.5	Cement grade 32.5	Percentage difference
1:2:4	29.8	24.5	17.78%
$1{:}1^{1}/_{2}{:}\ 3$	30.1	27.0	10.30%
1:1:2	30.6	29.6	3.27%

Source: (Adewale *et al., 2014)*

Thus the concrete produced from Portland-limestone of grade 42.5 had higher strengths than Portland limestone of grade 32.5. They recommended that SON need to enlighten the Nigerians on the current grades of cement present in Nigeria. This study had not considered the water to cement ratio used for the chemical composition of the cement compound which adversely affect the strength of concretes produced. Most of the previous researchers did not indicate the grade of cement used, but only the brands are mentioned.

Yahaya *et al* (2014) carried on the compressive strength of concretes produced form four brands of OPC brands: Eagle, cement, Dangote cement, Unicem and Dangote cement. The water cement ratios used was 0;5 while the concrete mix used was 1:2:4. The results of the 28 day compressive strengths were: 48.74, 46.34, 44.35 and 44.96 N/mm^2 for Eagle, Ibeto, Unicem and Dangote cement brands respectively. According to them, the target was 30N/mm^2

The results of these investigations are not reliable. The chemical analyses of the cement were not carried out.

Adewole *et al.* (2015) conducted a study to determine the appropriate mix ratios for concrete grades 20/25, 25/30 and 28/35 using Nigerian cement brands of classes 32.5 and 42.5. He noted that most of the roadside craftsmen/artesians involved in building and other concrete works cannot differentiate between the cement grades 32.5 and 42.5. Even most of the professionals and academia are also ignorant of the presence of these two grades of cement in Nigeria. Thus, these artesians use the same popular mix ratio of 1:2:4 commonly used to prepare concretes of grade 20/25, even with cement grade 32.5. The result is that the compressive strengths of the concrete are usually lower than 25N/mm^2. A richer mix of 1:1.5:3 concrete may have to be used to produce concrete of grade 20/25 of Portland limestone. He also revealed that cement grade 32.5 is unsuitable for use in concrete grade 25/30. Thus research conducted revealed the following results presented in Table 2.15.

Table 2.15: Compressive Strength of Concretes Produced from Portland Limestone Classes 42.5 and 32.5 Cements

Mix Ratio	Average strength (N/mm^2)

	Cement grade 42.5	Cement grade 32.5
1:2:4	29.8±2.6	24.5±54
$1{:}1^{1}/_{2}{:}3$	30.1±3.2	27.0±5.8
1:1:2	30.6±5.2	29.6±3.2

Source: (Adewale *et al., (2015)*

They concluded that the Nigerian Portland limestone cements are not suitable for producing concrete of grades 20/35 and 25/30. He recommended that Nigerian Limestone cement production of class 42.5 should be used for concrete grades 20/25 and 25/30. The effect of the chemical compound compositions on the strength of concrete had not been considered. The water cement ratio used was not specified whether it is according to standards.

Bamigboye *et al*. (2015) assessed the strengths of concretes produced form different brands of Portland cements. The cement brands used over Dangote (3x) cement, Purechem, cement, unicem cement, Elephant (superset) cement and Ibeto cement which were supplied in 50kg taps. The aggregate size was 20mm and fine aggregate was river sand. Five concrete cubes of size 150mm x 150mm x 150mm were used for each brand. The mix ratios used were 1:2:4 and 1:3:6, the results of the tests are presented in Table 2. 16.

Table 2.16: Compressive Strength of Concrete Cubes Produced from Brands Of Cement.

Cement brand	Mix ratios	
	1:2:4	1:3:6
Dangote (3x)		

Purechem	24.58	11.63
Unichem	22.16	15.86
Elephant (superset)	27.93	16.71
Ibeto	38.80	22.07

Source: (Bamigboye *et al*., 2015)

They concluded that only the Ibeto and Elephant (superset) cement brands met the minimum specified strength of 25N/mm^2 (BS 8110, 1997). The water to cement ratio and the cement characterization was not considered.

Osuji and Nwankwo (2015) conducted a research on the effect of marine water on compressive strength of concrete. The Escravos area of Nigerian Delta was used as case study. They examined two cases of fresh water and marine water which were used for curing and casting the concrete. The result of their study is summarized in the Table 2.17:

Table 2.17: Summary of Concrete Cube Crushing Strength

Cube Identification	Concrete Cube Crushing Strength (28 day)
FF	25.01
SS	28.79
FS	26.16
SF	27.37

Source: (Osuji and Nwankwo, 2015)

They concluded that the effect of sea water on the concrete strengths is negligible. The concrete mix ratio utilized and the water to cement ratio used were not considered.

CHAPTER THREE

MATERIALS, METHODS AND RESULTS

3.1 Preamble

In Nigeria and most particularly in Kaduna State, most sandcrete blocks produced are of two types. They are the 6" and 9" hollow blocks. Their standard sizes are 450 x 150 x 225 millimetres and 450 x 225 x 225 millimetres respectively. They are produced by using hand mould or vibrating machine. Both hand moulded and machine vibrated blocks were produced with control mix and quality materials. Thus the 6" and 9" hollow blocks were produced and tested.

3.2 Materials

The materials used for the production of the sandcrete hollow blocks were water, sand and cement only. The concrete was produced using water, sand, gravel and cement. The water used was public water supply from tap while the sand was obtained from River Kaduna at Rafin Guza in Kaduna. The gravel was purchased from the market in Kaduna. Seven brands of ordinary Portland cement labeled A, B, C, D, E, F and G were used. The markets in Nigeria where the cements were purchased have been presented in chapter one, page 12, Table 1.0.

3.3 Methods

Experimental tests were carried out to characterize the materials according to standards. Thus all materials were tested to see if they were up to standard. Sandcrete blocks and concretes were produced using the above materials and tested experimentally. The results of the tests were analysed, compared with standards and reasonable conclusions were drawn. The tests performed on the materials, produced sandcrete blocks and concrete are presented below.

3.3.1 Water quality

According to BS EN 1008: 2002, as a general rule, water of chemical composition acceptable for drinking, when treated for distribution through the public supply is suitable for making concrete. However, the potable water sample was still subjected to the following tests; pH value, conductivity, turbidity, total hardness, chloride, sulphate, total solids, suspended solids and dissolved solids in laboratory in the Civil Engineering Department, Kaduna

Polytechnic. The results of the water analysis test carried out are presented in Table 3.1.

Table 3.1: Chemical Analysis of Tap Water

S/No	Parameter	Unit	Result
1	pH	no	7.25
2	Conductivity	µs/cm	900
3	Turbidity	Nephelometric	0.95
4	Total Hardness	mg/l	344.00
5	Chloride	mg/l	99.40
6	Sulphate	mg/l	105.54
7	Total Solids	mg/l	200.00
8	Suspended Solids	mg/l	0.00
9	Dissolved Solids	mg/l	200.00

3.3.2 Sand

Samples of the sand were subjected to various tests in Civil Engineering Department Materials Laboratory in Kaduna Polytechnic following the procedure specified in BS 812- 2:1995; BS 812-109: 1990 and BS EN 933-1: 1997, The parameters of the sand samples determined were specific gravity, bulk density, moisture content, void ratio and porosity. Others were dry density, clay, silt contents, organic content and sieve analysis.

The results of the tests performed on sand samples from River Kaduna at Rafin Guza are shown in Tables 3.2 and 3.3:

Table 3.2: Physical properties of River Kaduna Sand at Rafin Guza

S/N	Parameter of sand	Unit	Result
1.	Specific gravity	-	2.66

2.	Moisture content	%	10.24
3.	Void ratio	%	27
4.	Porosity	%	21.41
5.	Bulk density	kg/m^3	1935
6.	Dry density	kg/m^3	1755
7.	Clay content	%	1.83
8.	Silt content	%	1.86
9.	Organic content	%	0.35

Details of the results are shown in Appendices A-1 – A-7.Each value is an average of three samples.

Table 3.3: **Sieve Analysis of Sand Sample in accordance to BS EN 12620: (2013)**

Sieve No.	Cummulative Percentage Passing
7	92.82
10	85.98
14	75.30
18	58.90
25	41.02

36	21.83
52	17.83
60	9.63
100	3.03
150	1.65
200	0.01
Pan	-

Details of the results are shown in Appendix A-8

3.3.3 Cement tests

Seven brands of ordinary Portland cements were randomly selected from the markets and all the necessary tests performed on them in accordance to codes and standards. The tests were carried out in Civil Engineering Department, Kaduna Polytechnic, Nigeria. The seven brands of ordinary Portland cement selected were labeled A, B, C, D, E, F and G. The following tests were performed on the cement brand samples:

(i) Standard consistence, initial and final setting time tests

The standard consistence, initial setting time and final setting time tests were carried out on the cement brands samples in accordance to BS EN 196-Part 3: 2008 and BS EN 197-1: 2011 giving methodology and specification. The results of the tests are presented in Table 3.4.

Table 3.4: Standard Consistency, Initial and Final Setting Times

Cement brands	Standard consistence (%)	Initial setting time (minutes)	Final setting time

			(minutes)
A	30	142	310
B	33	134	324
C	32	139	321
D	30	134	346
E	26	141	322
F	28	147	323
G	29	145	381

Details of the results are shown in Appendices A-9 – A-15.Each value is an average of three samples.

(ii) Soundness of cement test

The soundness of the cement samples was determined following the method described in BS 12: 1996, BS EN 196-Part 3: 2008 and as specified in BS EN 197-1: 2011. The results of the test are presented in Table 3.5.

Table 3.5: Soundness of cement Test Results

Cement Brand	Average soundness
A	1.67
B	2.00
C	2.33
D	0.50
E	2.00

F	1.33
G	2.00

Details of the results are shown in Appendices A-16 – A-22. Each value is an average of three samples.

(iii) Cement specific gravity test

The specific gravity test was carried out on the cement samples using pycnometer in accordance to ASTM C 150 - 2012. The results of the test are presented in Table 3.6.

Table 3.6: Cement Specific Gravity Test Results

Cement brand	Specific gravity
A	3.14
B	3.14
C	3.14
D	3.14
E	3.15
F	3.14
G	3.15

Details of the results are shown in Appendices A-24 – A-30.Each value is an average of three samples.

(iv) Cement fineness

This test was carried out by two methods on the cement samples in accordance to BS EN 196-6: 2010. The first method was by sieve analysis while the second is by specific surface area method (Blaine air permeability method). The results of the test are presented in the second column of Table 3.7. The test results on fineness of the cement samples using specific area method (Blaine air permeability method) are shown in the third column of Table 3.7.

Table 3.7: Cement Fineness (Sieve and Specific Surface Area Methods)

Cement brand	Cement Fineness	
	Sieve method (%)	**Specific Surface Area method (m^2/kg)**
A	4.6	368
B	8.7	390
C	7.0	372
D	2.0	342
E	8.8	380
F	7.0	346
G	2.6	349

Details of the results are shown in Appendices A-31 – A-37.Each value is an average of three samples.

(v) Cement mortar cube test results

The cube mould used was standard size of 70.7mm. The cement to sand mix ratio used was 1:3 while the water to cement ratio used was 0.40. The cement mortar cube test was carried out on seven brands of cement in accordance to BS EN 196-1:2005. The results of the test are presented in Table 3.8.

sTable 3.8: Cement Mortar Cubes Strength (w/c =0.40)

Cement Brand	2-day strength	28-day strength
A	17.23	47.75
B	25.64	55.30
C	18.73	49.33
D	16.32	47.07
E	18.79	49.86
F	16.36	45.05

G	14.07	47.09

Details of the results are shown in Appendices A-38 – A-44.Each value is an average of three samples.

(vi) Concrete cube strength test

The concrete cube strength test was carried out in accordance to BS EN 12390-2 and BS EN 12390-3: 2009 as specified in BS EN 206-1: 2000. The cube mould used was of size 150mm. The concrete mix ratio by mass was 1: 2.5: 3.5 and the water to cement ratio was 0.60. The results of the test are presented in Table 3.9.

Table 3.9: Concrete Cube Strength Test (w/c =0.60)

Age (Days)	3	7	14	21	28
Cement Brand	Compressive Strength (N/mm^2)				
A	12.48	16.91	21.31	25.81	29.66
B	14.49	17.37	22.98	28.10	32.29
C	14.35	16.98	22.89	28.20	32.14
D	12.44	17.02	21.42	25.49	29.81
E	12.42	16.69	21.30	25.42	29.40
F	12.35	16.73	20.97	25.45	29.34
G	12.02	16.02	20.97	25.10	28.07

Details of the results are shown in Appendices A-45 – A-51.Each value is an average of three sample.

(vii) Percentage oxide composition of Portland cement test

The oxide composition by mass of each cement brand sample was determined in the Chemical Engineering Department Laboratory of the Kaduna Polytechnic in Nigeria. The percentage of each of the oxides: Calcium oxide (CaO), Silica (SiO_2), Aluminium Oxide (Al_2O_3), Iron oxide (Fe_2O_3), Magnesium oxide (MgO), Sulphate (SO_3), Free calcium Oxide (CaO_f), Insoluble Residue (IR), Loss on Ignition (LOS) and others by mass of the total cement oxide was determined in accordance to BS EN 196-2: 2000 (recently amended in 2013) as specified in BS EN 197-1: 2011. The percentage oxide composition test results are presented in Table 3.10.

Table 3.10: Percentage Oxide Composition of Portland Cement Brand Samples.

Cement Brand	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	SO_3 (%)	MgO (%)	CaO_f (%)	IR (%)	LOI (%)	Others (%)	Total (%)
A	61.00	22.00	6.00	2.00	1.72	0.73	1.70	2.20	1.60	1.05	100
B	54.50	18.00	4.46	3.45	1.14	0.54	1.75	4.50	3.20	8.46	100
C	58.00	21.00	6.00	2.00	1.03	0.73	1.85	4.01	3.12	2.26	100
D	62.00	20.00	4.00	2.50	0.34	2.17	1.90	3.02	1.48	2.59	100
E	59.00	21.95	2.00	2.20	1.76	0.70	1.50	2.73	2.41	5.75	100
F	58.00	19.00	8.00	2.00	0.30	2.30	0.30	3.00	1.50	5.60	100
G	59.00	28.45	1.41	2.20	1.76	0.59	1.73	2.00	1.60	1.26	100

(viii) Computation of lime saturation factor of cement brand samples

According to BS12:1996, the lime saturation factor (LSF) of a cement is given by the equation:

$$LSF = \frac{CaO - 0.7(SO_3)}{2.8(SiO_2) + 1.2(Al_2O_3) + 0.65(Fe_2O_3)} \quad (3.1)$$

where the terms in brackets denote the percentage by mass of the oxides.

The Lime saturation factor for each cement brand was calculated using the values for CaO, SO_3, SiO_2, Al_2O_3 and Fe_2O_3 obtained in the percentage oxide composition test on page 84. . The computed lime saturation factor for each of the seven brands of the cement studied is presented in Table 3.11.

Table 3.11: **Lime Saturation factor of ordinary Portland cement brands**

Cement brand	Lime saturation factor
A	0.85

B	0.93
C	0.85
D	0.98
E	0.88
F	0.90
G	0.69

(ix) Computation of percentage of chemical compounds in Portland cement

The four chemical compounds present in the cement are Tricalcium Silicate ($3CaO.SiO_2$), Dicalcium Silicate ($2CaO.SiO_2$), Tricalcium Aluminate ($3CaO.Al_2O_3$) and Tetra Alumino Ferrite ($4CaO.Al_2O_3.Fe_2O_3$) which are abbreviated as C_3S, C_2S, C_3A and C_4AF respectively.

The percentages by mass of the chemical compounds in the ordinary Portland cements were computed from the results obtained in percentage of the oxides using the following Boque equations (Taylor, 1997):

Tricalcium Silicate ($3CaO.SiO_2$): $(C_3S) = 4.07(CaO) – 7.60(SiO_2) – 6.72(Al_2O_3) – 1.4(Fe_2O_3) – 2.85(SO_3)$ (3.2)

Dicalcium Silicate ($2CaO.SiO_2$): $(C_2S) = 2.87(SiO_2) – 0.75(3CaO.SiO_2)$ (3.3)

Tricalcium Aluminate ($3CaO.Al_2O_3$): $(C_3A) = 2.65(Al_2O_3) – 1.69(Fe_2O_3)$

(3.4)

Tetra calcium Alumino Ferrite ($4CaO.Al_2O_3.Fe_2O_3$):

$(C_4AF) = 3.04 (Fe_2O_3)$ (3.5)

where the terms in brackets in the equations denote the percentage by mass of the substances. The results of the computations for the cementitious compounds abbreviated as C_3S, C_2S, C_3A, and C_4AF, are shown in Table 3.12.

Table 3.12: Computed Percentages of Chemical Compounds in Portland Cement Brands

Cement brand	Tricalcium Silicat (C_3S) (%)	Dicalcium Silicate (C_2S) (%)	Tricalcium Aluminate (C_3A) (%)	Tetra Calcium Alumino Ferrite (C_4AF) (%)
A	33.00	38.39	12.52	6.08
B	46.97	16.43	5.99	10.49
C	30.41	37.46	12.52	6.08
D	68.99	5.66	6.38	7.60
E	51.77	24.17	1.58	6.69
F	34.25	28.84	17.82	6.08
G	6.34	49.78	0.02	6.69

Details of the computations are shown in Appendices A-59 – A-65.

3.3.4 Sandcrete hollow block tests

This deals with the various tests performed on sandcrete hollow blocks. This involves the production of sandcrete hollow blocks, their mix ratios, water-cement ratio, dry and wet development strengths, dry and wet densities development and water absorptions using a particular block production industry site called Richifa Block Industry in Kaduna. This production was done by oneself to ascertain whether the sandcrete hollow blocks strengths will reach the standards.

The blocks were produced using **Richifa Block Industry Machine**. The Richifa Block Industry is situated along the Western Bye-Pass Road in Kaduna. This is one of the best block industries within the Kaduna town. SThe machine used for compaction of the blocks is the Rosa Cumesa brand and is four horse-power.

The machine can produce both 9” and 6” sandcrete hollow blocks at the same time. The ingredients used were water, sand and cement which were tested above. The sandcrete hollow blocks produced were of standard sizes 450mm × 225mm × 225mm (9"). The number and distribution of blocks produced for the tests are as shown in the Table 3.13.

Table 3.13: Research Experimental Program

Sandcrete hollow block size produced (mm)	450 x 225 x 225	A, B, C, D, E, F and G	
Mix ratio	1:4 to 1:12		
Source of water	Tap water		
Source of sand	River Kaduna at Rafin Guza		
Type of sand	Coarse river sand		
Source of Purchased OPC cement	Nigerian markets	A, B, C, D, E, F and G	
Block industry used and location	Richifa Block Industry in Kaduna		
Type of equipment used for block production	Vibrating machine		
Number of blocks produced and tested after 28 days curing for optimum water to cement ratio determination	162 with allowance for excess and wastage of 12	A and C	Total = 348
Number of blocks produced and tested after 1, 3, 7, 14, 21 and 28 days curing for dry strength and density development at above mix ratio range	169 with allowance of 5 as excess and wastes	A, B, C, D, E, F and G	Total = 1218
Number of blocks produced and tested after 1, 3, 7, 14, 21 and 28 days curing for dry strength and density development at above mix ratio range	169 with allowance of 5 as excess and wastes	A, B, C, D, E, F and G	Total = 1218
No of blocks for water absorption	12	A, B, C, D, E, F and G	Total including excess= 88

Thus a total number of 2870 sandcrete hollow 9” blocks were produced and 2774 of the blocks were tested. Majority of the blocks wasted was during the process of transportation from the block industry to the laboratory after one day curing.

(i) Water to cement ratio

To obtain the water to cement ratio (w/c) suitable for production of hollow sandcrete blocks, two cement brand samples A and C were used. The cement brand A is locally produced while the brand C is an imported cement and are representative samples of the two sets of cement studied.

The Federal Ministry of Works specifications (1979) for sandcrete hollow blocks was a mix ratio of 1:4 while the Nigerian Industrial Standards (NIS 87: 2004) specifies a mix ratio of 1:6. The international standard specified a mix ratio range of 1:6 – 1:8 while in Nigeria most block industries use mix ratios in the range of 1:8 – 1:12 (Olanitori, 2005). Based on the above reasons the mix ratio range of 1:4 to 1:12 was used for this study. Batching was by volume because most block industries in Nigeria use it.

According to Iloghalu (1985) the water to cement ratio of sandcrete blocks should be within the range of 0.40 to 0.70 and therefore the water to cement ratio of 0.35 to 0.60 was used for this study. Blocks produced with water to cement ratios of 0.35, 0.40, 0.45, 0.50 and 0.60 were cured and tested for 28-day compressive strengths in Civil Engineering Department, Material Laboratory, Kaduna Polytechnic in Kaduna. The results of the 28-day dry compressive strengths test of the blocks made from cement brands A and C using water to cement ratios 0.35 to 0.60 are presented in Tables 3.14 and 3.15.

Table 3.14: Determination of Optimum Water/Cement Ratio for Cement Brand A- Blocks at 28 Days Curing Age

w /c Mix ratio	0.35	0.40	0.45	0.50	0.60
		Compressive strength (N/mm^2)			
1:4	3.80	4.70	4.93	4.77	4.51
1:5	3.65	4.49	4.59	4.53	4.37
1:6	3.42	4.10	4.24	4.13	4.04
1:7	3.15	3.95	4.05	4.03	3.92
1:8	2.74	3.83	3.89	3.80	3.56
1:9	1.91	2.68	3.38	2.80	2.38
1:10	1.66	2.05	2.97	2.70	2.26
1:11	1.43	1.60	2.33	2.08	2.03
1:12	1.31	1.54	1.69	1.60	1.57

Table 3.15: Determination of Optimum Water/Cement Ratio for Cement brand C- Blocks at 28 days Curing Age

w /c Mix ratio	0.35	0.40	0.45	0.50	0.60
		Compressive strength (N/mm^2)			
1:4	4.04	4.65	5.23	4.87	4.75
1:5	3.92	4.46	4.83	4.69	4.65
1:6	3.68	4.10	4.62	4.40	4.28
1:7	3.50	3.98	4.37	4.17	4.10
1:8	3.21	3.95	4.05	4.01	3.56
1:9	2.98	3.09	3.21	2.92	2.38
1:10	2.55	2.64	2.75	2.61	2.26
1:11	1.96	1.96	2.25	2.06	2.03
1:12	1.43	1.60	1.69	1.57	1.57

(ii) Dry development strength test of 9” Sandcrete hollow Blocks moulded

The dry development strength test was carried out by testing three block samples per age per Portland cement brand for mix ratios 1:4 to 1:12. The blocks produced with w/c ratio of 0.45 (the optimum value obtained from (i) above) were tested with the universal crushing machine hydraulically operated in accordance to BS EN 772-1: 2000. The tests were carried out at curing ages of 1, 3, 7, 14, 21 and 28 days after weighing the blocks.

The results of the test are presented in Tables 3.16 to 3.22 for 9” blocks made from cement brands A, B, C, D, E, F and G respectively.

Table 3.16: Dry Compressive Strength Development for Cement Brand A- 9” Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio	Compressive Strength (N/mm^2)					
1:4	0.44	1.26	3.04	4.19	4.40	4.93
1:5	0.36	1.01	2.83	3.89	4.05	4.59
1:6	0.31	0.87	2.66	3.40	3.75	4.24
1:7	0.30	0.87	2.11	2.71	3.15	4.05
1:8	0.29	0.84	1.81	2.15	2.70	3.89
1:9	0.26	0.75	1.72	2.00	2.11	3.38
1:10	0.22.	0.64	1.53	1.84	1.99	2.97
1:11	0.22	0.61	0.97	1.47	1.59	2.33
1:12	0.17	0.47	0.87	1.29	1.46	1.69

Details of the results are shown in Appendices A-66 – A-71.Each value is an average of three samples.

Table 3.17: Dry Compressive Strength Development for Cement Brand B- 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio			Compressive Strength (N/mm^2)			
1:4	0.49	1.43	7.36	7.50	8.06	8.56
1:5	0.37	0.96	5.30	5.81	6.62	7.2
1:6	0.29	0.84	5.06	5.16	5.59	5.83
1:7	0.27	0.79	3.11	4.20	4.76	5.20
1:8	0.26	0.77	2.55	3.30	3.85	4.34
1:9	0.25	0.73	1.65	2.24	2.84	3.33
1:10	0.24	0.70	1.27	1.40	1.83	2.21
1:11	0.23	0.68	1.00	1.18	1.37	1.52
1:12	0.21	0.63	0.83	0.99	1.19	1.33

Details of the results are shown in Appendices A-72 – A-77.Each value is an average of three samples.

Table 3.18: Dry Compressive Strength Development for Cement Brand C- 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio			Compressive Strength (N/mm^2)			
1:4	0.88	2.52	3.29	4.77	5.02	5.32
1:5	0.48	1.33	2.82	4.28	4.61	4.83
1:6	0.39	1.15	2.57	4.16	4.43	4.62
1:7	0.31	0.84	2.05	2.99	3.42	4.37
1:8	0.27	0.79	1.93	2.60	3.01	4.05
1:9	0.25	0.73	1.68	2.14	2.59	3.21
1:10	0.23	0.61	1.35	1.94	2.20	2.75
1:11	0.19	0.53	1.07	1.62	1.86	2.25
1:12	0.15	0.41	0.95	1.52	1.63	1.67

Details of the results are shown in Appendices A-78 – A-83.Each value is an average of three samples.

Table 3.19: Dry Compressive Strength Development for Cement Brand D- 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio	Compressive Strength (N/mm^2)					
1:4	0.45	1.22	3.24	4.05	4.27	4.40
1:5	0.35	1.00	3.03	3.44	3.67	4.00
1:6	0.32	0.94	2.56	3.11	3.40	3.75
1:7	0.25	0.68	2.06	2.70	3.18	3.66
1:8	0.22	0.63	1.88	2.27	2.55	3.43
1:9	0.18	0.52	1.50	2.11	2.43	3.04
1:10	0.16	0.48	1.27	1.98	2.13	2.71
1:11	0.15	0.42	1.02	1.49	1.62	2.30
1:12	0.13	0.39	0.95	1.34	1.44	1.44

Details of the results are shown in Appendices A-84 – A-89. Each value is an average of three samples.

Table 3.20: Dry Compressive Strength Development for Cement Brand E- 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio	Compressive Strength (N/mm^2)					
1:4	0.46	1.26	5.41	5.86	6.21	6.46
1:5	0.30	0.84	5.10	5.42	5.79	6.10
1:6	0.27	0.79	4.61	5.06	5.24	5.38
1:7	0.25	0.68	3.98	4.40	4.80	5.04
1:8	0.22	0.63	3.65	3.90	4.18	4.37
1:9	0.19	0.52	2.24	2.61	2.85	3.10
1:10	0.15	0.42	1.99	2.08	2.44	2.77
1:11	0.13	0.32	1.33	1.37	1.69	1.98
1:12	0.12	0.26	0.95	1.09	1.43	1.70

Details of the results are shown in Appendices A-90 – A-95. Each value is an average of three samples.

Table 3.21: Dry Compressive Strength Development for Cement Brand F- 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio	Compressive Strength (N/mm^2)					
1:4	0.45	1.25	2.86	3.22	3.71	4.15
1:5	0.41	1.13	2.57	3.03	3.44	3.74
1:6	0.33	0.90	2.10	2.98	3.23	3.45
1:7	0.31	0.83	1.91	2.88	3.12	3.35
1:8	0.27	0.77	1.76	2.53	2.80	3.03
1:9	0.19	0.49	1.11	2.22	2.58	2.81
1:10	0.15	0.36	0.82	2.01	2.13	2.21
1:11	0.12	0.34	0.79	1.69	1.89	2.07
1:12	0.10	0.19	0.40	1.48	1.60	1.70

Details of the results are shown in Appendices A-96 – A-101. Each value is an average of three samples.

Table 3.22: Dry Compressive Strength Development for Cement Brand G- 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio	Compressive Strength (N/mm^2)					
1:4	0.33	0.90	1.89	1.93	3.38	4.74
1:5	0.27	0.72	1.53	1.74	3.21	4.61
1:6	0.22	0.64	1.47	1.62	2.98	4.21
1:7	0.19	0.54	1.21	1.45	2.81	4.10
1:8	0.18	0.50	1.15	1.36	1.96	3.49
1:9	0.16	0.46	1.05	1.30	1.80	2.30
1:10	0.15	0.43	1.00	1.18	1.71	2.17
1:11	0.14	0.38	0.86	0.98	1.43	1.81
1:12	0.12	0.36	0.84	0.96	1.29	1.55

Details of the results are shown in Appendices A-102 – A 107. Each value is an average of three samples.

(iii) Wet development strength test of sandcrete hollow 9” blocks moulded

For this test, the 9” sandcrete hollow blocks made from cement brands A, B, C, D, E, F and G were cured under dry state by spraying twice daily (morning and evening) up to the age of 28 days. The blocks were then immersed in water as shown in Plate I and tested for 1, 3, 7, 14, 21 and 28 days soaked compressive strengths in the wet state using the universal compression testing machine in accordance to BS EN 772-1:2000.

Plate III: Sandcrete hollow blocks soaked in Water

The results of the wet strength development test are presented in Tables 3.23 to 3.29

For 9”sandcrete hollow blocks made from cement brands A, B, C, D, E, F and G respectively which were soaked in water after the usual curing in the dry state for 28 days.

Table 3.23: Wet Compressive Strength Development for Cement Brand A- 9" Sandcrete Hollow Blocks Immersed in Water.

Age (days)	1	3	7	14	21	28
Mix Ratio			Compressive Strength (N/mm^2)			
1:4	1.26	1.52	1.94	2.60	3.00	3.15
1:5	1.05	1.39	1.57	1.90	2.20	2.50
1:6	0.91	1.19	1.26	1.50	1.60	1.70
1:7	0.70	0.93	1.12	1.30	1.45	1.50
1:8	0.59	0.77	0.88	1.08	1.20	1.25
1:9	0.58	0.68	0.73	0.82	0.95	1.02
1:10	0.56	0.63	0.66	0.70	0.74	0.90
1:11	0.42	0.47	0.49	0.55	0.59	0.71
1:12	0.37	0.39	0.41	0.46	0.51	0.61

Details of the results are shown in Appendices A-108 – A-113. Each value is an average of three samples.

Table 3.24: Wet Compressive Strength Development for Cement Brand B- 9" Sandcrete Hollow Blocks Immersed in Water.

Age (days)	1	3	7	14	21	28
Mix Ratio			Compressive Strength (N/mm^2)			
1:4	1.75	1.82	1.89	2.17	2.48	2.80
1:5	1.15	1.40	1.55	1.67	1.80	1.94
1:6	0.98	1.29	1.47	1.57	1.69	1.77
1:7	0.93	1.20	1.28	1.37	1.48	1.53
1:8	0.92	1.16	1.28	1.31	1.36	1.44
1:9	0.90	1.13	1.26	1.29	1.31	1.42
1:10	0.84	0.97	1.11	1.14	1.17	1.22
1:11	0.79	0.89	0.92	0.94	0.96	1.01
1:12	0.73	0.82	0.91	0.94	0.95	0.97

Details of the results are shown in Appendices A-114 – A-119. Each value is an average of three samples.

Table 3.25: Wet Compressive Strength Development for Cement Brand C- 9" Sandcrete Hollow Block Immersed in Water.

Age (days)	1	3	7	14	21	28
Mix Ratio	Compressive Strength (N/mm^2)					
1:4	2.41	2.87	3.00	4.14	4.20	4.40
1:5	1.55	1.68	2.01	2.10	2.22	2.50
1:6	1.19	1.43	1.85	1.90	1.97	2.10
1:7	1.05	1.10	1.19	1.29	1.51	1.93
1:8	0.94	0.97	1.02	1.25	1.35	1.66
1:9	0.73	0.82	0.86	0.95	1.08	1.25
1:10	0.65	0.66	0.75	0.79	0.88	1.02
1:11	0.63	0.64	0.70	0.73	0.76	0.80
1:12	0.54	0.56	0.58	0.62	0.67	0.72

Details of the results are shown in Appendices A-120 – A-125. Each value is an average of three samples.

Table 3.26: Wet Compressive Strength Development for Cement Brand D- 9" Sandcrete Hollow Blocks Immersed in Water.

Age (days)	1	3	7	14	21	28
Mix Ratio	Compressive Strength (N/mm^2)					
1:4	1.82	2.04	2.17	2.25	2.36	2.49
1:5	1.60	1.85	1.91	2.07	2.23	2.40
1:6	1.01	1.09	1.40	1.59	1.79	2.02
1:7	0.89	1.01	1.03	1.31	1.62	1.88
1:8	0.77	0.82	0.96	1.23	1.33	1.48
1:9	0.73	0.77	0.82	1.04	1.27	1.45
1:10	0.70	0.73	0.79	0.96	1.15	1.31
1:11	0.63	0.63	0.75	0.87	0.98	1.10
1:12	0.49	0.52	0.54	0.59	0.66	0.72

Details of the results are shown in Appendices A-126 – A-131. Each value is an average of three samples.

Table 3.27: Wet Compressive Strength Development for Cement Brand E- 9" Sandcrete Hollow Blocks Immersed in Water.

Age (days)	1	3	7	14	21	28
Mix Ratio	Compressive Strength (N/mm^2)					
1:4	1.12	1.16	1.29	1.40	1.53	1.66
1:5	0.94	1.01	1.05	1.09	1.15	1.50
1:6	0.84	0.87	0.87	1.07	1.08	1.19
1:7	0.73	0.79	0.86	0.88	0.96	1.14
1:8	0.66	0.73	0.84	0.85	1.08	1.10
1:9	0.63	0.66	0.68	0.75	0.84	0.96
1:10	0.56	0.63	0.65	0.68	0.70	0.73
1:11	0.53	0.55	0.61	0.65	0.69	0.72
1:12	0.47	0.48	0.50	0.54	0.59	0.63

Details of the results are shown in Appendices A-132 – A-137. Each value is an average of three samples.

Table 3.28: Wet Compressive Strength Development for Cement Brand F- 9" Sandcrete Hollow Blocks Immersed in Water.

Age (days)	1	3	7	14	21	28
Mix Ratio	Compressive Strength (N/mm^2)					
1:4	1.25	1.51	1.83	1.95	2.05	2.30
1:5	1.19	1.40	1.54	1.70	1.84	2.20
1:6	0.97	1.23	1.31	1.42	1.68	1.80
1:7	0.72	0.89	1.01	1.36	1.41	1.50
1:8	0.69	0.71	0.85	1.25	1.28	1.31
1:9	0.44	0.50	0.68	0.91	1.15	1.24
1:10	0.42	0.48	0.64	0.76	1.12	1.07
1:11	0.36	0.40	0.55	0.63	1.01	1.05
1:12	0.32	0.34	0.38	0.53	0.56	0.77

Details of the results are shown in Appendices A-138 – A-143. Each value is an average of three samples.

Table 3.29: Wet Compressive Strength Development for Cement Brand G - 9" Sandcrete Hollow Blocks Immersed in Water.

Age (days)	1	3	7	14	21	28
Mix Ratio	Compressive Strength (N/mm^2)					
1:4	1.33	1.51	1.71	2.07	2.43	2.81
1:5	1.24	1.47	1.58	1.87	2.14	2.42
1:6	0.90	1.23	1.32	1.61	1.91	2.14
1:7	0.82	0.93	1.15	1.35	1.60	1.86
1:8	0.73	0.83	0.95	1.16	1.50	1.70
1:9	0.63	0.68	0.77	0.82	0.92	0.98
1:10	0.60	0.62	0.67	0.71	0.79	0.89
1:11	0.57	0.59	0.63	0.68	0.72	0.84
1:12	0.55	0.56	0.59	0.63	0.66	0.75

Details of the results are shown in Appendices A-144 – A-149. Each value is an average of three samples.

(iv) Bulk densities of blocks

The Bulk density tests were performed in accordance to BS EN 772- 13: 2000.

Both the dry density and the wet density tests were performed. All the blocks were cured in the usual normal curing for 28 days as earlier explained. The test results for the dry density development for blocks made from cement brands A, B, C, D, E, F and G are presented in Tables 3.30 to 3.36 while Tables 3.36 to 3.42 are for the wet.

Table 3.30: Dry Density Development for Cement brand A - 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio		Dry density (kg/m^3)				
1:4	1610	1691	1813	1884	1870	1826
1:5	1580	1643	1788	1859	1793	1816
1:6	1540	1630	1793	1840	1775	1798
1:7	1525	1617	1773	1825	1762	1778
1:8	1515	1611	1768	1820	1759	1765
1:9	1512	1643	1763	1752	1754	1765
1:10	1510	1651	1735	1742	1714	1760
1:11	1505	1590	1679	1740	1709	1755
1:12	1503	1590	1679	1694	1738	1747

Details of the results are shown in Appendices A-150 – A-155. Each value is an average of three samples.

Table 3.31: Dry Density Development for Cement brand B - 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio		Dry density (kg/m^3)				
1:4	1750	1910	2306	2395	2445	2484
1:5	1730	1829	2217	2378	2370	2353
1:6	1690	1800	2148	2360	2325	2271
1:7	1670	1790	2110	2305	2280	2226
1:8	1630	1780	2051	2352	2330	2170
1:9	1610	1760	2026	2302	2240	2135
1:10	1608	11755	1983	2203	2180	2089
1:11	1590	1740	1944	2186	2140	2071
1:12	1580	1730	1907	2079	2060	2000

Details of the results are shown in Appendices A-156 – A-161. Each value is an average of three samples.

Table 3.32: Dry Density Development for Cement brand C- 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio			Dry density	(kg/m^3)		
1:4	1630	1685	1772	1861	1871	1874
1:5	1625	1670	1747	1813	1849	1823
1:6	1590	1665	1742	1788	1886	1823
1:7	1580	1660	1772	1785	1841	1821
1:8	1570	1611	1747	1798	1826	1821
1:9	1550	1617	1709	1823	1851	1820
1:10	1548	1617	1747	1760	1831	1820
1:11	1545	1617	1747	1760	1848	1820
1:12	1540	1617	1747	1727	1826	1820

Details of the results are shown in Appendices A-162 – A-167. Each value is an average of three samples.

Table 3.33: Dry Density Development for Cement brand D- 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio			Dry density	(kg/m^3)		
1:4	1630	1736	1823	1800	1844	1960
1:5	1610	1789	1765	1844	1825	1778
1:6	1570	1723	1747	1778	1765	1765
1:7	1540	1603	1695	1770	1758	1740
1:8	1530	1590	1752	1765	1752	1730
1:9	1525	1590	1690	1776	1747	1650
1:10	1520	1570	1665	1752	1737	1640
1:11	1500	1550	1650	1747	1722	1620
1:12	1480	1545	1630	1737	1709	1610

Details of the results are shown in Appendices A-168 – A-173. Each value is an average of three samples.

Table 3.34: Dry Density Development for Cement brand E- 9" Hollow Sandcrete Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio			Dry density (kg/m^3)			
1:4	1450	1585	2159	2159	2235	2239
1:5	1430	1617	2159	2199	2220	2253
1:6	1420	1590	2133	2159	2195	2184
1:7	1400	1566	1975	2021	2040	2048
1:8	1390	1511	1986	1949	2010	2020
1:9	1388	1585	1949	1988	1990	2014
1:10	1385	1579	1738	1843	1980	1895
1:11	1383	1577	1633	1764	1775	1786
1:12	1380	1550	1593	1725	1747	1749

Details of the results are shown in Appendices A-174 – A-179. Each value is an average of three samples.

Table 3.35: Dry Density Development for Cement brand F- 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio			Dry density (kg/m^3)			
1:4	1650	1660	1720	1810	1875	1924
1:5	1610	1650	1709	1874	1860	1798
1:6	1590	1620	1696	1762	1752	1699
1:7	1530	1572	1640	1772	1665	1641
1:8	1480	1510	1552	1582	1600	1608
1:9	1420	1470	1544	1618	1590	1580
1:10	1418	1450	1494	1593	1580	1550
1:11	1350	1370	1425	1519	1515	1480
1:12	1330	1360	1418	1493	1490	1460

Details of the results are shown in Appendices A-180 – A-185. Each value is an average of three samples.

Table 3.36: Dry Density Development for Cement brand G- 9" Sandcrete Hollow Blocks

Age (days)	1	3	7	14	21	28
Mix Ratio		Dry density (kg/m^3)				
1:4	1380	1500	1707	1727	1780	1800
1:5	1378	1460	1735	1722	1760	1778
1:6	1370	1450	1633	1714	1750	1773
1:7	1350	1420	1626	1709	1720	1730
1:8	1340	1410	1612	1704	1715	1722
1:9	1330	1400	1608	1702	1710	1702
1:10	1290	1380	1702	1699	1705	1692
1:11	1275	1350	1702	1700	1675	1687
1:12	1260	1330	1593	1686	1672S	1656

Details of the results are shown in Appendices A-186 – A-191.Each value is an average of three samples.

Table 3.37: Wet Density Development for Cement brand A- 9" Sandcrete Hollow Blocks Immersed in water

Age (days)	1	3	7	14	21	28
Mix Ratio		Dry density (kg/m^3)				
1:4	1749	1855	1829	1882	1855	1815
1:5	1802	1829	1868	1829	1840	1800
1:6	1749	1855	1829	1749	1825	1790
1:7	1749	1802	1802	1829	1815	1775
1:8	1749	1829	1829	1833	1809	1770
1:9	1776	1829	1829	1831	1806	1765
1:10	1802	1802	1829	1830	1804	1740
1:11	1723	1802	1829	183 0	1802	1725
1:12	1723	1749	1829	1830	1790	1710

Details of the results are shown in Appendices A-192 – A-197. Each value is an average of three samples.

Table 3.38: Wet Density Development for Cement brand B- 9" Sandcrete Hollow Blocks Immersed in water

Age (days)	1	3	7	14	21	28
Mix Ratio		Dry density (kg/m^3)				
1:4	1749	1829	1838	1842	1828	1800
1:5	1670	1829	1860	1868	1862	1840
1:6	1670	1802	1829	1868	1862	1840
1:7	1670	1735	1786	1802	1796	1780
1:8	1696	1730	1768	1789	1780	1760
1:9	1670	1730	1768	1789	1780	1760
1:10	1670	1720	1758	1784	1775	1750
1:11	1670	1718	1752	1780	1770	1747
1:12	1670	1718	1750	1778	1768	1745

Details of the results are shown in Appendices A-198 – A-203. Each value is an average of three samples.

Table 3.39: Wet Density Development for Cement brand C- 9" Sandcrete Hollow Blocks Immersed in water

Age (days)	1	3	7	14	21	28
Mix ratio		Dry density (kg/m^3)				
1:4	1749	1881	1932	1948	1925	1887
1:5	1749	1855	1885	1895	1885	1857
1:6	1749	1816	1877	1908	1878	1848
1:7	1715	1816	1829	1929	1878	1846
1:8	1723	1749	1776	1790	1776	1760
1:9	1723	1749	1776	1790	1776	1760
1:10	1684	1749	1770	1789	1772	1758
1:11	1684	1749	1765	1776	1770	1750
1:12	1736	1749	1760	1770	1768	1750

Details of the results are shown in Appendices A-204 – A-209. Each value is an average of three samples.

Table 3.40: Wet Density Development for Cement brand D- 9" Sandcrete Hollow Blocks Immersed in water

Age (days)	1	3	7	14	21	28
Mix Ratio		Dry density (kg/m^3)				
1:4	1683	1951	1961	1961	1930	1910
1:5	1680	1913	1913	1956	1915	1890
1:6	1670	1874	1920	1950	1907	1883
1:7	1657	1829	1902	1880	1871	1865
1:8	1670	1829	1860	1869	1858	1850
1:9	1656	1816	1820	1829	1825	1822
1:10	1643	1810	1815	1829	1820	1805
1:11	1630	1749	1782	1816	1810	1802
1:12	1563	1740	1762	1802	1795	1790

Details of the results are shown in Appendices A-210 – A-215. Each value is an average of three samples.

Table 3.41: Wet Density Development for Cement brand E- 9" Sandcrete Hollow Blocks Immersed in water

Age (days)	1	3	7	14	21	28
Mix Ratio		Dry density (kg/m^3)				
1:4	1722	1829	1840	1855	1832	1805
1:5	1749	1802	1821	1835	1820	1800
1:6	1696	1749	1752	1832	1815	1792
1:7	1696	1696	1736	1786	1780	1740
1:8	1657	1696	1723	1773	1760	1730
1:9	1670	1670	1696	1769	1752	1748
1:10	1670	1696	1702	1753	1740	1733
1:11	1670	1670	1749	1750	1730	1728
1:12	1666	1662	1670	1722	1720	1720

Details of the results are shown in Appendices A-216 – A-221.Each value is an average of three samples.

Table 3.42: Wet Density Development for Cement brand F- 9" Sandcrete Hollow Blocks Immersed in water

Age (days)	1	3	7	14	21	28
Mix Ratio			Dry density (kg/m^3)			
1:4	1596	1650	1744	1840	1794	1784
1:5	1560	1630	1724	1830	1794	1764
1:6	1570	1644	1736	1811	1782	1738
1:7	1560	1600	1724	1794	1764	1725
1:8	1520	1650	1708	1780	1748	1717
1:9	1504	1636	1700	1764	1717	1700
1:10	1490	1620	1682	1750	1712	1697
1:11	1460	1620	1680	1730	1708	1690
1:12	1490	1615	1678	1715	1703	1687

Details of the results are shown in Appendices A-222 – A-227. Each value is an average of three samples.

Table 3.43: Wet Density Development for Cement brand G- 9" Sandcrete Hollow Blocks Immersed in water

Age (days)	1	3	7	14	21	28
Mix Ratio			Dry density (kg/m^3)			
1:4	1606	1711	1788	1860	1840	1833
1:5	1601	1725	1784	1860	1836	1820
1:6	1590	1720	1767	1850	1824	1810
1:7	1569	1715	1744	1833	1820	1808
1:8	1543	1711	1743	1811	1800	1790
1:9	1530	1704	1740	1794	1784	1780
1:10	1512	1598	1718	1790	1780	1766
1:11	1512	1580	1710	1790	1777	1750
1:12	1511	1580	1707	1788	1761	1750

Details of the results are shown in Appendices A-228 – A-233. Each value is an average of three samples.

(v) Water absorption test for sandcrete hollow blocks

The water absorption test was conducted on the block samples following the procedure prescribed in NIS 87: 2004 Appendix B. Similarly, the ASTM C140: 2001 method of test was also employed. The results of the test are presented in Table 3.44.

Table 3.44: Water Absorption Test for Blocks

Cement brand	Average absorption of blocks (%) NIS 87: 2004	Average absorption kg/m^3 ASTM C140:2001
A	5.61	92.17
B	5.00	79.0
C	7.32	118.5
D	4.69	79.0
E	4.92	79.0
F	4.80	79.0
G	5.00	79.0

Details of the results are shown in Appendices A-234. Each value is an average of three samples.

(vi) The generalized ANOVA table for randomized complete block design (RCBD) is presented in Table 3.45 , where t is the treatment which in this case is the mix ratio and b is the block which is cement brand.

Table 3.45: Generalized ANOVA Table for Randomized Complete Block Design (RCBD)

Sources of variation	**Degrees of Freedom (df)**	**Sum of Squares (SS)**	**Mean Sum of Squares (MSS)**	**F-Ratio or Variance Ratio**
Between Treatments(mix ratio)	t -1	SS.treatment ($SS_{mix\ ratio}$)	SS.treat./(t-1) (MSSt)	MSSt/MSSerror
Between Blocks (cement brand)	b -1	SS.block ($SS_{cement\ brand}$)	SS.block/(b-1) (MSSb)	MSS.b/MSSerror
Error or Residual	(t – 1)(b – 1)	SS_{error}	SS_{error}/(t -1)(b-1) (MSSerror)	
Total	N – 1	SS_{total}		

Source: (Panneerselvam, 2012)

where t is the number of treatments and b is the number of blocks.

3.3.5 Coarse aggregate tests

(a) Physical characterization of coarse aggregates

The gravel used was of nominal size of 20mm. The tests performed on the coarse aggregates were specific gravity, Los Angeles abrasion, aggregate crushing value, aggregate impact value, elongation index, flakeness index and sieve analysis.

(i) Specific gravity of coarse aggregate test

The specific gravity test for the coarse aggregate was performed in accordance to BS EN 12620: 2013

(ii) Los Angeles abrasion test for coarse aggregate

The Los Angeles abrasion test was carried out on the coarse aggregate in accordance to (ASTM C 535: 1996, BS 812-113: 1990 as specified in BS EN 12620: 2013.

(iii) Aggregate crushing value (ACV) test

The aggregate crushing value test was performed in accordance to BS 812-110: 1990 as specified in BS EN 12620: 2013

(iv) Aggregate impact value test on coarse aggregates

The aggregate impact vale test was performed in accordance to BS 812-112: 2000 as specified in BS EN 12620: 2013

(v) Flakiness index and elongation index tests on coarse aggregates.

The flakiness index and Elongation index tests on coarse aggregate were carried out in accordance to BS EN 933-3: 1997 as specified in BS EN 12620: 2013.

The results of the tests are presented in Tables 3.46

Table 3.46: Physical Characterization of Coarse Aggregate - Test Results

S/No.	Property	Unit	Result
1.	Specific gravity	-	2.62
2.	Los Angeles abrasion	%	30.34
3.	Aggregate crushing value	%	27.90
4.	Aggregate impact value	%	17.39
5.	Elongation index	%	30.19
6.	Flakiness	%	9.27

Details of the results are shown in Appendices A-236 – A-241. Each value is an average of three samples.

(vi) Sieve analysis test on coarse aggregates

The sieve analysis test was performed on the coarse aggregate in accordance to BS EN 933-1: 1997 as specified in BS EN 12620: 2013.

The result of the sieve analysis carried out is presented in Table 3.47 for coarse aggregate of norminal size of 20mm.

Table 3.47: Sieve Analysis of Coarse Aggregate (20mm nominal size)

Sieve Size (mm)	Percentage Passing
50	-
38.1	100
19.05	91.77
9.52	1.67
4.76	0.18
Pan	0.03

Details of the results are shown in Appendices A-242. Each value is an average of three samples.

(b) Chemical characterization of coarse aggregates

The coarse aggregates were tested for soundness, chloride and sulphate contents.

(i) Soundness of aggregates test

The soundness test on coarse aggregates was carried out in accordance to BS EN 1744-1: 2009 as specified in BS EN 12620: 2013.

(ii) Chloride of coarse aggregate test

The percentage chloride content in the coarse aggregates soluble in water was determined in accordance to BS EN 1744-1: 2009 as specified in BS EN 12620: 2013.

(iii) Sulphate content of coarse aggregate test

The sulphate content of the coarse aggregate was determined in accordance to BS EN 1744-1: 2009 as specified in BS EN 12620: 2013.

The results of the chemical properties of the coarse aggregates studied are presented in Table 3.48.

Table 3.48: Chemical Characterization of Coarse Aggregate

S/N	Property	Unit	Result
1.	Soundness	%	98.8
2.	Chloride content	%	0.25
3.	Sulphate	%	0.08

3.3.6 Concrete tests

(i) Strength, slump and compacting factor tests of concrete

The concrete tests conducted were slump test, compaction factor test and concrete cube compressive strength test The tests were conducted in accordance to BS EN 12350:2009 and BS EN 12390-2 and 3:2009.

The slump test results of the fresh concretes produced from the seven cement brands are presented in Table 3.49.

Table 3.49: Slump and Compaction Factor Test Results

Cement Brand	Concrete Slump (mm)	Concrete Compaction Factor
A	26	0.92
B	24	0.93
C	27	0.92
D	25	0.91
E	25	0.92
F	23	0.87
G	24	0.89

(ii) Density of concrete

The densities of concretes produced from the seven brands were determined in accordance to BS EN 12390-7: 2009 as specified in BS EN 206-1: 2000. The density developments of the concrete cubes are presented in Table 3.50.

Table 3.50: Density Development of the Concrete Cubes

Cement		Curing Age			
Brand	3	7	14	21	28
		Density (kg/m^3)			
A	2377	2396	2419	2410	2450
B	2384	2404	2418	2414	2413
C	2352	2426	2415	2430	2402
D	2425	2364	2403	2400	2415
E	2326	2402	2413	2417	2424
F	2402	2402	2413	2417	2424

G	2326	2378	2395	2401	2402

Details of the results are shown in Appendices A-243 – A-249. Each value is an average of three samples.

CHAPTER FOUR

ANALYSIS AND DISCUSSION OF RESULTS

4.0 Preamble

The test results presented in chapter three were analysed and discussed to arrive at a reasonable conclusion. These are presented below.

4.1 Chemical Analysis of the Water

The test results conducted on the public water supply (portable water) used for block moulding in the block industry are shown on chapter three, page 75, Table 3.1.

According to BS EN 1008: 2009, as a general rule, water of chemical composition acceptable for drinking is adequate for making sandcrete hollow blocks or concrete. The chloride content of the water was found to be 99.40 mg/l. The standard chloride content allowed for concrete is a maximum of 1000mg/l. Thus the chloride content was found to be within the allowable limit.

The sulphate content of the water was 105.54mg/l while the maximum allowable value is 1000mg/l for concrete work. Thus the sulphate content was only 10.5% of the maximum allowable and this is satisfactory for block.

The pH value of the water allowed for concrete or block work should be between 6 and 8. The pH value obtained for the tested water sample was 7.25. The pH value of the water was found to be within the allowable limit.

The total solids were 200mg/l while there was no suspended solid present in the water. The total hardness was 344mg/l and turbidity was 0.95 Ntu. These values are within the tolerable limits of drinking water and thus block making.

Based on the above findings, the public water supply (from water board) was found to be very suitable for block making and was therefore used.

4.2 Sand

The test results of sand sample from River Kaduna at Rafin Guza were presented in chapter three, page 76, Table 3.2. The physical tests on sand such as specific gravity, moisture content, void ratio, porosity, bulk density, dry density, clay content, silt content and]organic content were presented . The average results compared to the standards are presented in Table 4.1:

Table 4.1: Comparison of Parameters of Sand from River Kaduna at Rafin Guza with Standard

S/No	Parameter	Unit	Average Result	Standard
1	Specific gravity	-	2.66	2.66 – 2.69
2	Void ratio	%	27	-
3	Moisture content	%	10.24	-
4	Porosity	%	21.41	-
5	Bulk density	kg/m^3	1935	-

6	Dry density	kg/m^3	1755	-
7	Clay content	%	1.83	6 max.
8	Silt content	%	1.83	6 max.
9	Organic content	%	0.35	-

The specific gravity of the sand was found to be 2.66. The normal range of specific gravity for sand is 2.66 – 2.69 (Neville, 2012). The value of the specific gravity of the sand is good for the purpose of sandcrete hollow block making in terms of strength development. Thus the sand sample passed the test on specific gravity.

The moisture content, void ratio and porosity of the sand were determined to be 10.24%, 27% and 21.41% respectively.

The bulk density of the sand was found to be $1935kg/m^3$ while the dry density was $1755kg/m^3$. The bulk density is within the normal range of $1800kg/m^3$ and $2000kg/m^3$. The normal range of dry density is $1700kg/m^3$ to $1800kg/m^3$.The sand sample passed the density tests. The silt and clay contents were 1.86% and 1.83% respectively. The maximum allowed content is 6%. The organic content in the sand was as low as 0.35%. The sand sample passed the silt and clay content tests. Based on the above parameters, the sand from River Kaduna at Rafin Guza was found to be very suitable for producing sandcrete hollow blocks and was therefore used.

The sieve analysis of the sand sample from River Kaduna at Rafin Guza is presented in Table 3.3 page 77, of chapter three. The grading curves are shown in Figure 4.1.

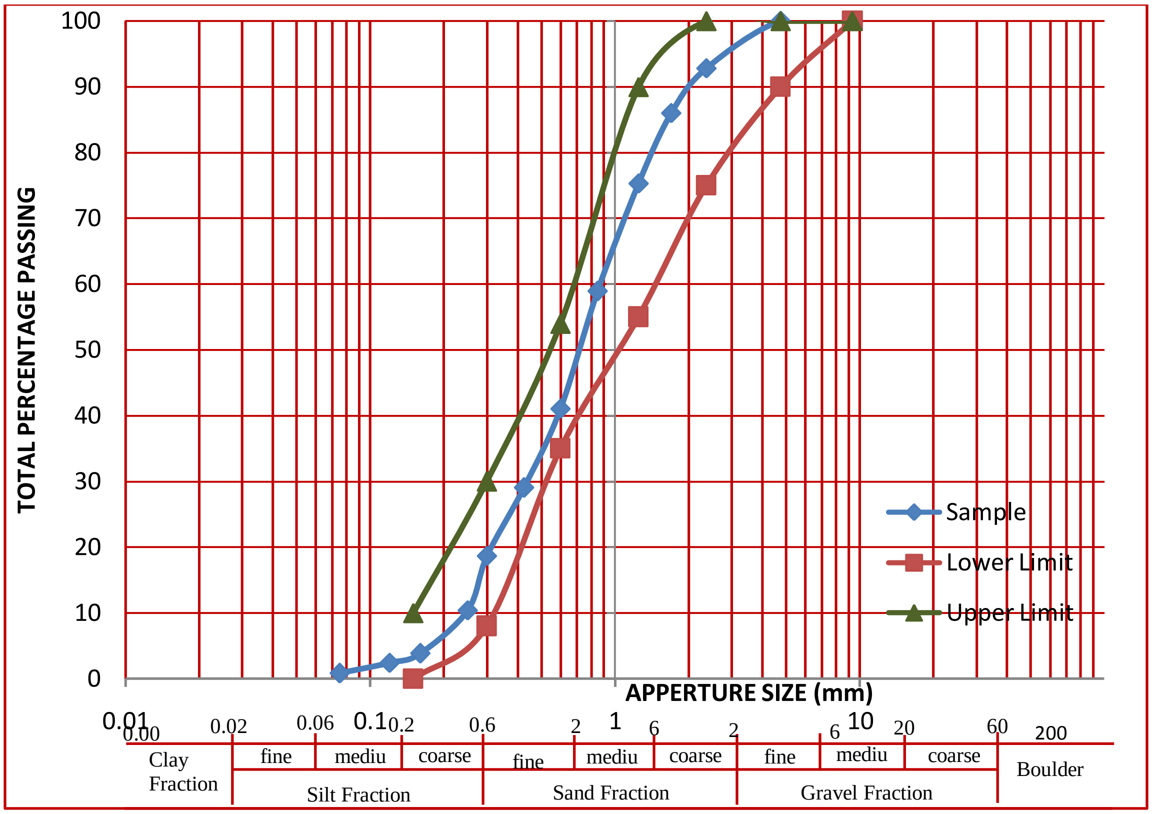

Figure 4.1: Fine Aggregate Grading of Sand Sample from River Kaduna at Rafin Guza

From the grading curve it was found that the sand sample from River Kaduna at Rafin Guza fell within zone Two (2). This corresponds to coarse sand which is very suitable for moulding blocks.

4.3 Cement

The test results carried out on the seven brands of cement are presented in chapter three pages 78 to 84, Tables 3.4 to 3.12.

4.3.1 Comparison of physical and mechanical properties of the cement brands

Tests results on physical and mechanical characterizations of the seven brands of cement used for the research are presented in Table 4.2. The average results are compared to the standards.

Table 4.2: Comparison of Physical and Mechanical Properties of the Cement Brands

Cement Brand	Stand. Consist. (%)	Initial Setting Time (min.)	Final Setting Time (min.)	Sound-ness. (mm)	Specific Gravity	Fineness (sieve) Method (%)	Fineness Specific Surface Area method (m^2/kg)	Mortar Cube Strength (N/mm^2)		Concrete ube Strength (N/mm^2)	
								2-day	28-day	3-day	28-day
A	30	142	310	1.67	3.14	4.6	368	17.23	45.75	12.48	29.66
B	33	134	324	2.00	3.14	8.7	390	25.64	55.30	14.49	32.29
C	32	139	321	2.33	3.14	7.0	372	18.73	49.33	14.35	32.14
D	30	134	346	0.50	3.14	2.0	342	16.32	45.07	12.44	29.81
E	26	141	322	2.00	3.15	8.8	380	18.79	49.86	12.42	29.40
F	28	147	323	1.33	3.14	7.0	346	16.36	43.05	12.35	29.34
G	29	145	381	2.00	3.15	2.6	349	14.07	44.09	12.02	28.07
Standard	26-33	45 ≥	≤ 600	≤ 10	3.14-3.15	≤ 10	300-400	10 ≥	42.5 ≥	13 ≥	30 ≥

Standard consistency, initial and final setting times

The results of the tests are presented in chapter three page 78, Table 3.4. The standard consistenc of the seven cement brands studied are shown in Figure 4.2. The normal standard consistence is between 26 and 33 percent. All the cement brands studied can be said to have normal standard consistence.

(a) Standard consistency results

The results of the standard consistencies of the seven cement brands studied are shown in Figure 4.2. The normal standard consistency is between 26 and 33 percent (BS EN 197-1: 2011). All the cement brands studied can be said to have normal standard consistency.

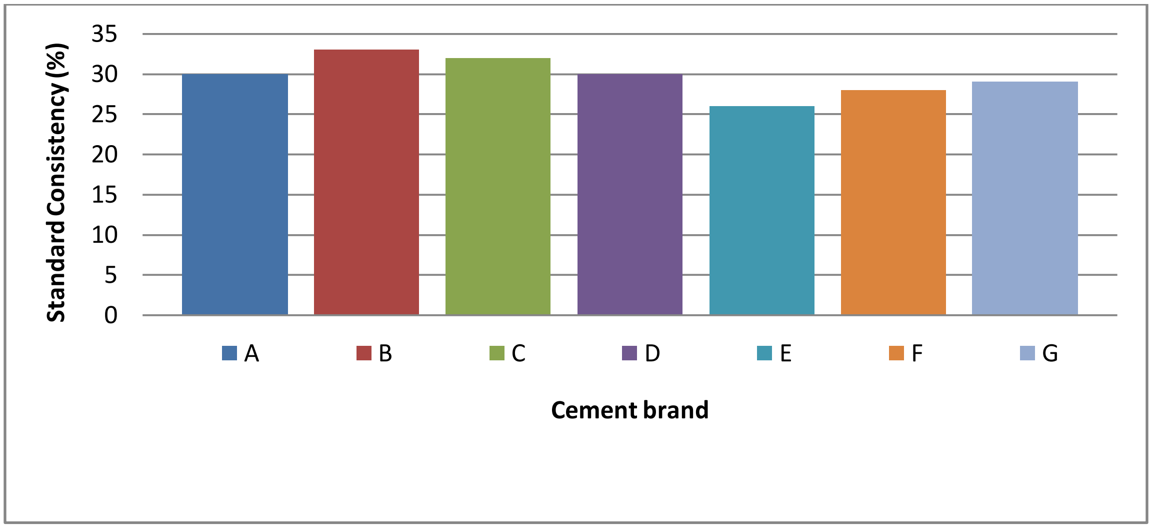

Figure 4.2: Standard Consistence of Ordinary Portland Cement Brand Samples

(b) Initial setting time tests

The results of the initial setting time tests carried out on the seven brands of cement samples in chapter three, page 78 have been presented in Table 3.4. The results are shown in Figure 4.3. The standard (BS 12: 1991) specifies a minimum of 45 minutes for initial setting time of grade 42.5 ordinary Portland cement. Cement brands B and D had the shortest initial setting times. This is attributed to their higher values of tricalcium silicate contents than the rest brands. In addition their tricalcium aluminate values were within the standard range. The tricalcium silicate and the tricalcium aluminate are mainly responsible for the early hydration of cement.

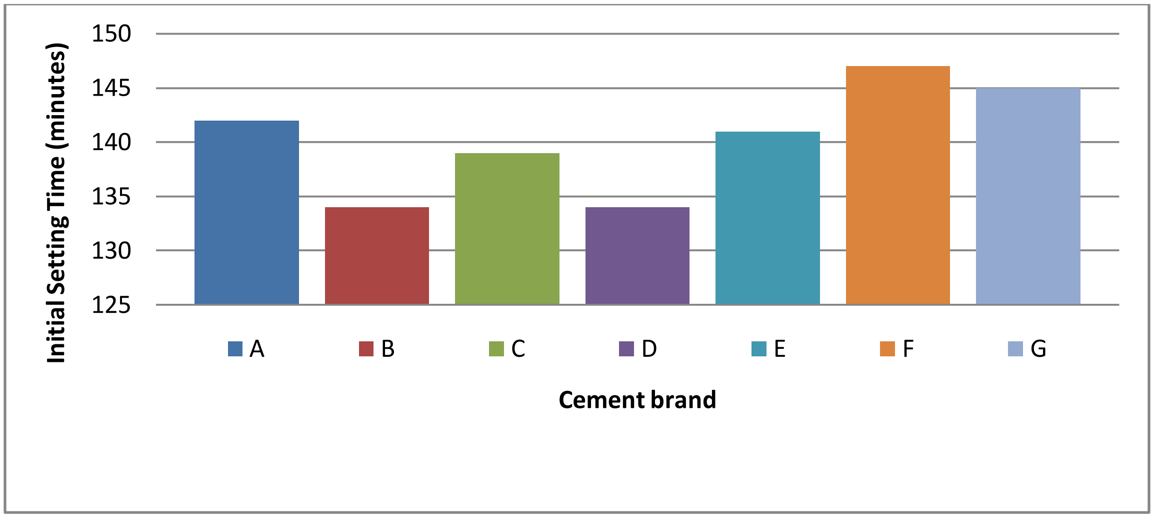

Figure 4.3: Initial Setting Time of Cement Brands Samples

(c) Final setting time tests results

The average final setting times of the seven cement brands studied are presented in Figure 4.4. BS 12: 1996 specified a maximum value of 10 hours (600 minutes) for its final setting time. The cement brands A, B, C, D, E, F and G tested passed the final setting time test.

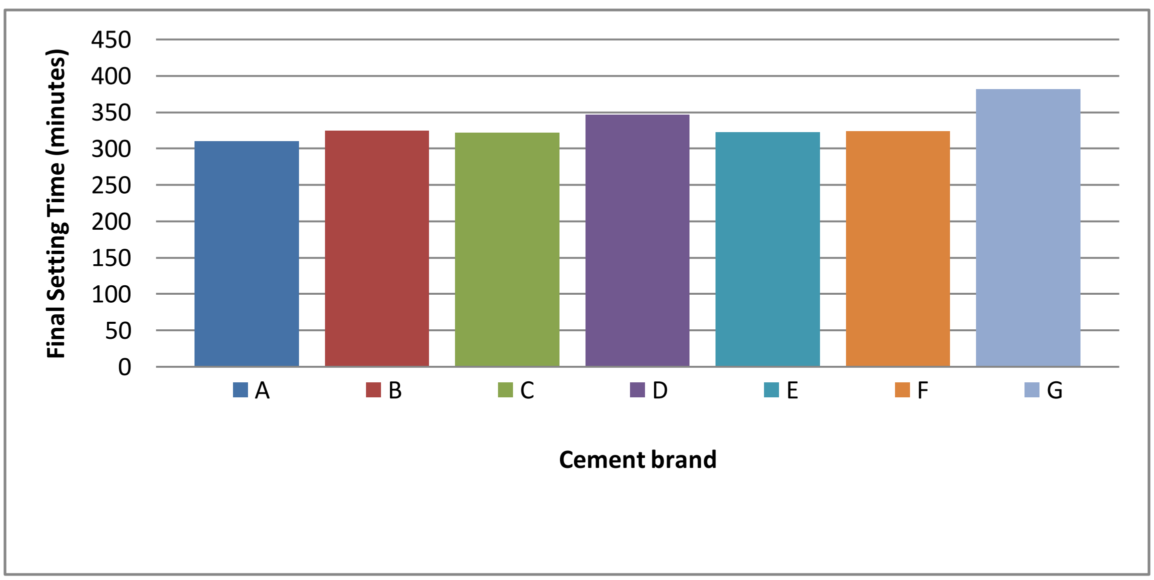

Figure 4.4: Final Setting Time of Ordinary Portland Cement Brand Sample

The cement brand G had the longest final setting time (381 minutes). The relatively longer initial and final setting times of cement brand sample G compared to the rest was attributed to its very low tricalcium silicate (C_3S) content and high content of silicon oxide. The excessive silica of cement G gave rise to its high content of dicalcium silicate. The C_3S which is responsible for early hydration in cement is very low while the C_2S had a slow intricate rate of hydration which led to the longer setting time. The low value of the aluminium oxide content of cement brand G also contributed to its longer setting times compared to other brands.

(d) Soundness of cement test results

The average soundness results of the tests performed on the seven brands of cement were presented in chapter three, page 79, Table 3.5.

The maximum expansion specified in the standard is 10mm (BS EN 197-1: 2011 and BS 12: 1996) for ordinary Portland cement. This shows that the unsoundness caused by free lime present in each of the seven cement brand samples studied was minimal (Neville, 2012). The cement brands A, B, C, D, E, F and G passed the soundness test.

(e) Cement specific gravity test results

The specific gravity test was performed on the seven brands of cement in chapter three, page 79. The test results are presented in Table 3.6. The standard specification for ordinary Portland cement specific gravity is 3.14 to 3.15 (ASTM C 150-12). The cement brands A, B, C, D, E, F and G passed the specific gravity test.

(f) Cement fineness (sieve and specific surface area methods) test results

The fineness tests were carried out for the seven brands of cement in chapter three, page 80, Table 3.7. The results of the fineness of the cement brands by sieve and specific surface area methods are presented in Figures 4.5 and 4.6 respectively. The maximum allowable percentage retained on sieve 90 is 10 % (BS EN 196-6: 2010) while in the specific surface area method the fineness should be in the range of 300-400 m^2/kg for ordinary Portland cement. The seven cement brands passed the fineness tests.

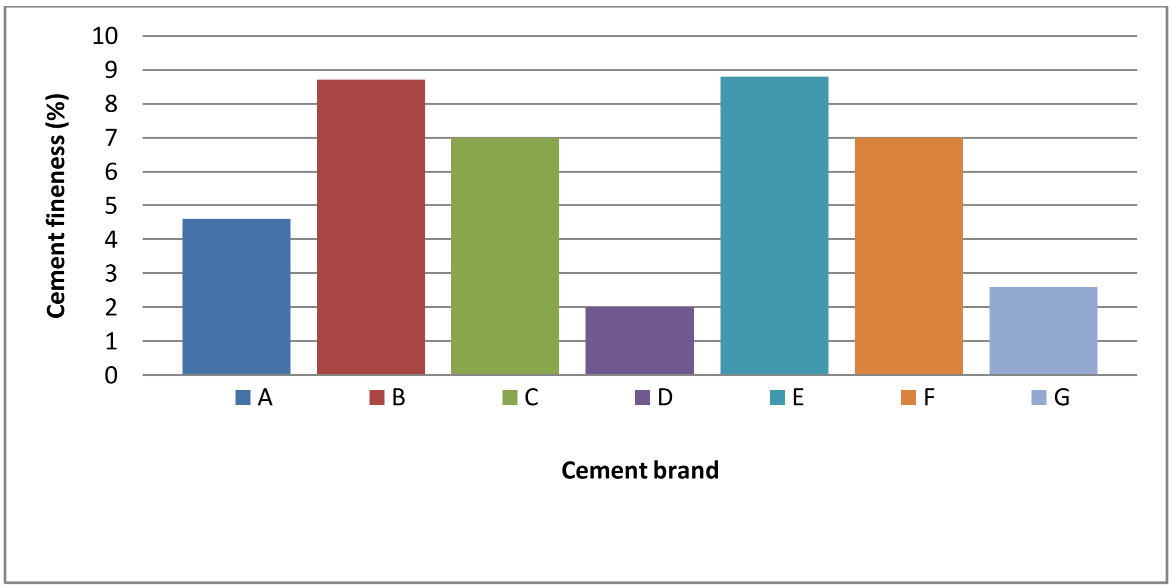

Figure 4.5: Cement brand samples Fineness (Sieve Method)

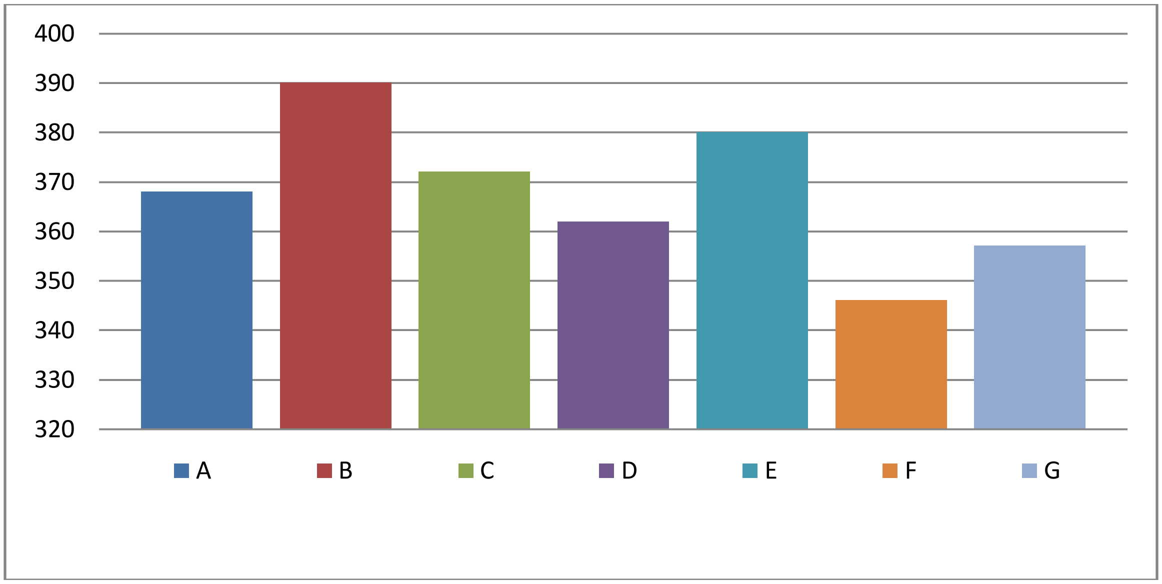

Figure 4.6: Cement Brand Samples Fineness (Specific Surface Area Method)

(g) Cement mortar cube test results

The mortar cube strength test for the seven brands of ordinary Portland cement was presented in chapter three, page 81 Table 3.8. The standard specification (BS 12: 1996) for compressive strength of ordinary Portland cement (CEM I and CEM II 42.5 N) is a minimum of 10 N/mm^2 at 2 days and 42.5 N/mm^2 at 28 days curing ages. BS EN 197-1: 2011 specified a minimum of 10N/mm^2 and 42.5 N/mm^2 for 2 days and 28 days curing ages respectively for the same grade of cement. Figure 4.7 shows the 2-day and 28-day mortar cube compressive strengths results for the seven cement brands samples A, B, C, D, E, F and G. The seven cement brands samples studied passed the mortar cube strength test.

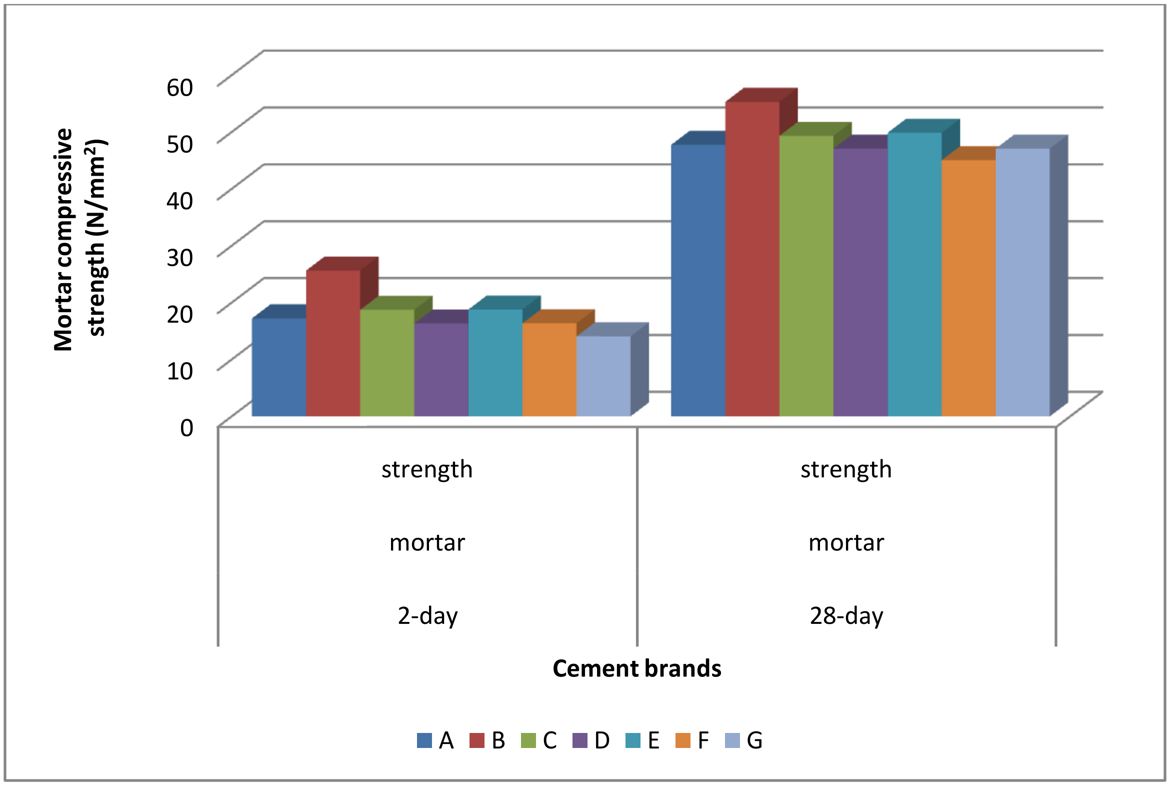

Figure 4.7: Mortar Cube Strength Test of OPC Brands Samples

(h) Concrete cube strength test

The concrete cube strength test performed for the seven cement brands was presented in chapter three, page 81. Table 3.9 The current code BS EN 206-1: 2000, compressive strength test at 3 days and 28 days. BS EN: 206 -1: 2000 specified a minimum compressive strength of 13 N/mm^2 and 30 N/mm^2 with -5% tolerance. Cement brands A, B, C, D, E and F passed the test as shown in Figure 4.8.

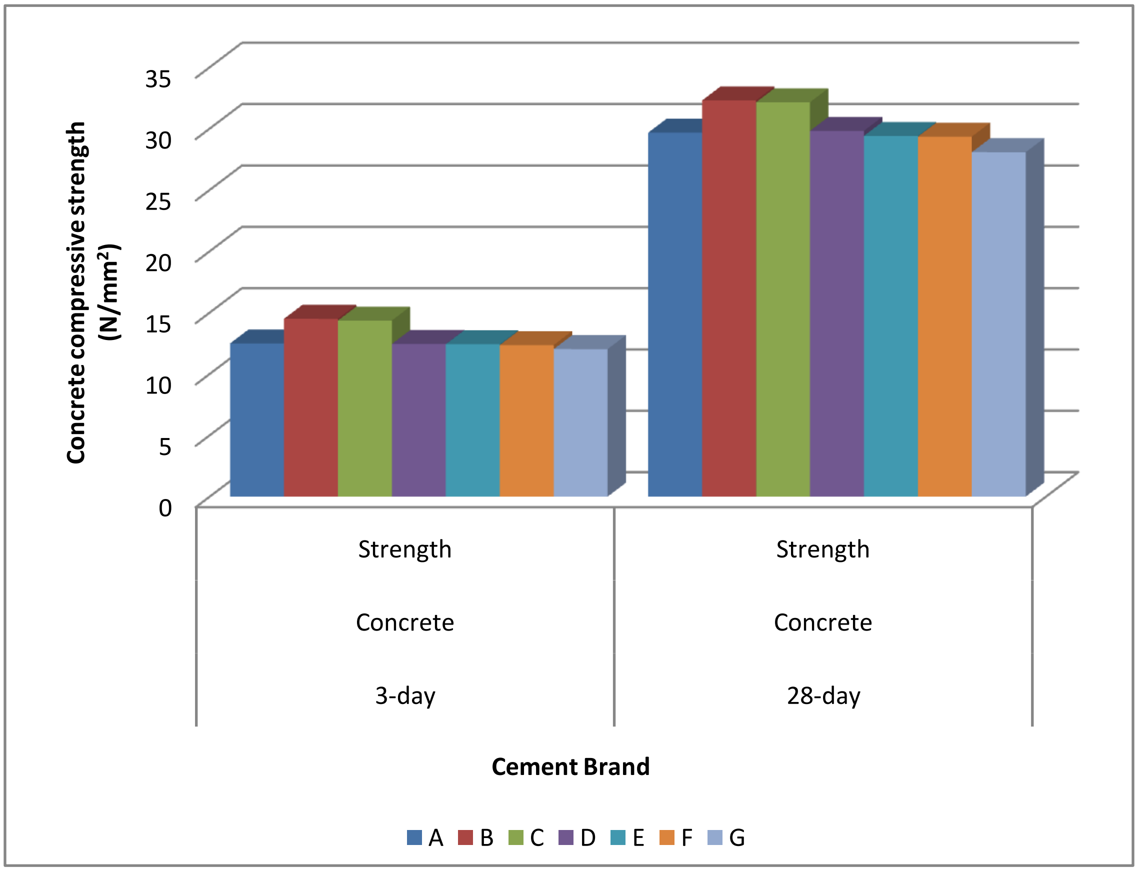

Figure 4.8: Concrete Cube 3-day and 28-day Strengths for Cement Brands

Cement brand G did not pass the 3-day concrete cube strength test. Its 28-day strength of 28.07N/mm^2 was not within the acceptable limit. This is attributed to its very low C_3S and high C_2S or SiO_2 contents. The C_3S which is responsible for early strength was very low (6.34%) resulting in low hydration rate while C_2S which is responsible for later strength development was high (49.78%) in cement brand G. The concrete compressive cubes strengths were observed to be considerably lower than the corresponding mortar cube strengths at 28 days curing. This may be attributed to the larger volume and size of voids in the interfacial transition zone in concrete than in the mortar. The interfacial transition zone in concrete is weaker than in mortar (Mehta and Monteiro, 2006). The interfacial zone in concrete contains micro-cracks which do not require high energy to extend on application of load.

4.3.2 Chemical oxide characterization of the seven cement brands compared to standard

The test of the percentage oxide composition of the seven brands of ordinary Portland cement studied was presented in chapter three, page 82**.** Table 3.10 The comparison of each of the oxide to the standard is shown in Table 4.3.

Table 4.3: Chemical Oxide Characterization of the Seven Cement Brands Compared to Standard

Cement brand	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	Mgo (%)	CaO(f) (%)	SO_3 (%)	IR (%)	LOI (%)
A	61	22	6.0	2.0	0.73	1.70	1.72	2.20	1.60
B	54.5	18.0	4.46	3.45	0.54	1.75	1.14	4.50	3.20
C	58	21	6	2	0.73	1.85	1.03	4.01	3.12
D	62	20	4.0	2.5	2.17	1.90	0.34	3.02	1.48
E	59	22	2	2.2	0.7	1.50	1.8	2.73	2.41
F	58	19	8	2	2.3	0.30	0.3	3.00	1.50
G	59	28	1.4	2.2	0.6	1.73	1.8	2.00	1.60
Standard	61-69	18-24	2.5-8	1.5-7	0.5-4	≤ 3	≤ 3.5	≤ 5	≤ 5

The analysis of each of the oxide results is presented as follows:

(a) Calcium oxide: Cement brands A and D passed the test of calcium oxide being within the range (61-69%) as specified in BS 12: 1991 while the rest did not. Cement brand D had the highest value of 62% while B had the least value of 54.5% as shown in Figure 4.9.

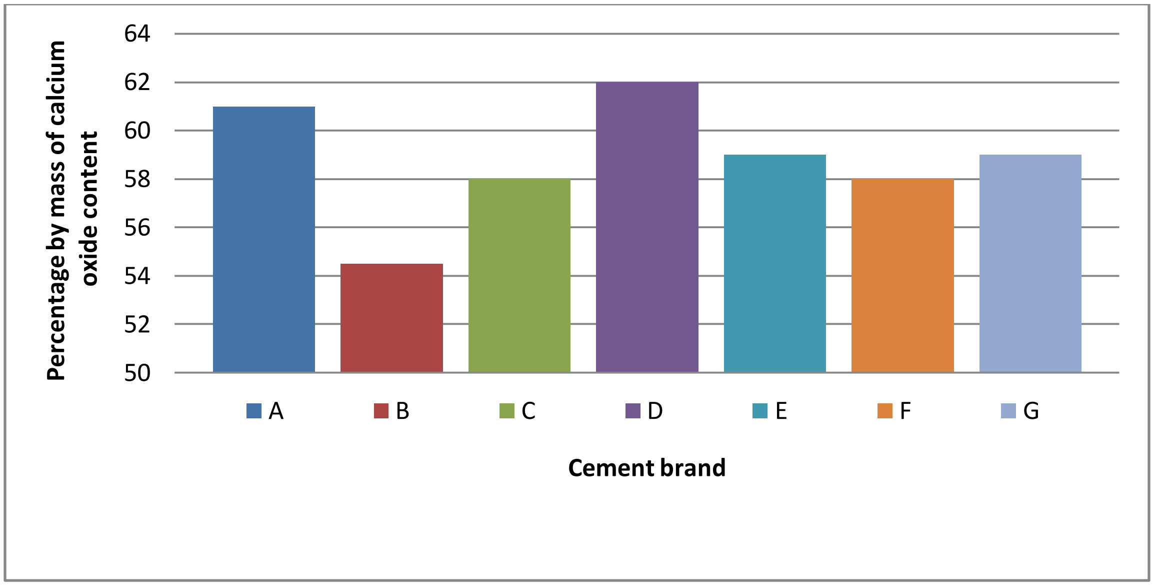

Figure 4.9: Percentage Calcium Oxide Contents of Cement Brands

(b) Silica: The standard specified a range of 18-24%. The cement brands A, B, C, D, E and F passed the silicon oxide specification while cement brand G did not. Cement G had the highest silica content of 28.45% while B had the least value of 18% as shown in Figure 4.10. The cement brands passed the test except G which is above the maximum allowable value of 24%. The longer setting times of cement brand G is attributed to its higher silica content compared to the rest brands.

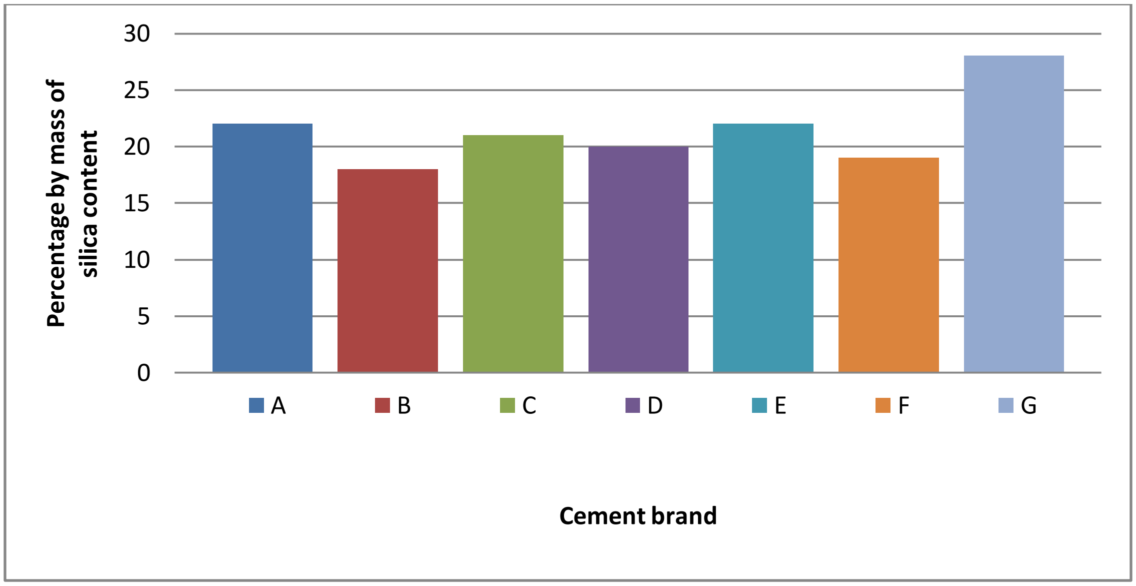

Figure 4.10: Percentage Silicon Oxide Contents of Cement Brands

(c) Aluminium oxide

The aluminium oxide contents in the seven brands samples studied are presented in chapter three page 82, Table 3.10. Aluminium oxides of the cement brand samples A, B, C, D and F passed the test as their contents lie within the standard range of 2.5-8% while those of E and G cement samples did not. The highest aluminium oxide was from cement brand F while G had the least content of 1.41% as shown in Figure 4.11. The aluminium oxide contents were not excessive to cause very high quick setting or flash set. The low value of the aluminium oxide content of cement brand G also contributed to its longer setting times compared to other brands.

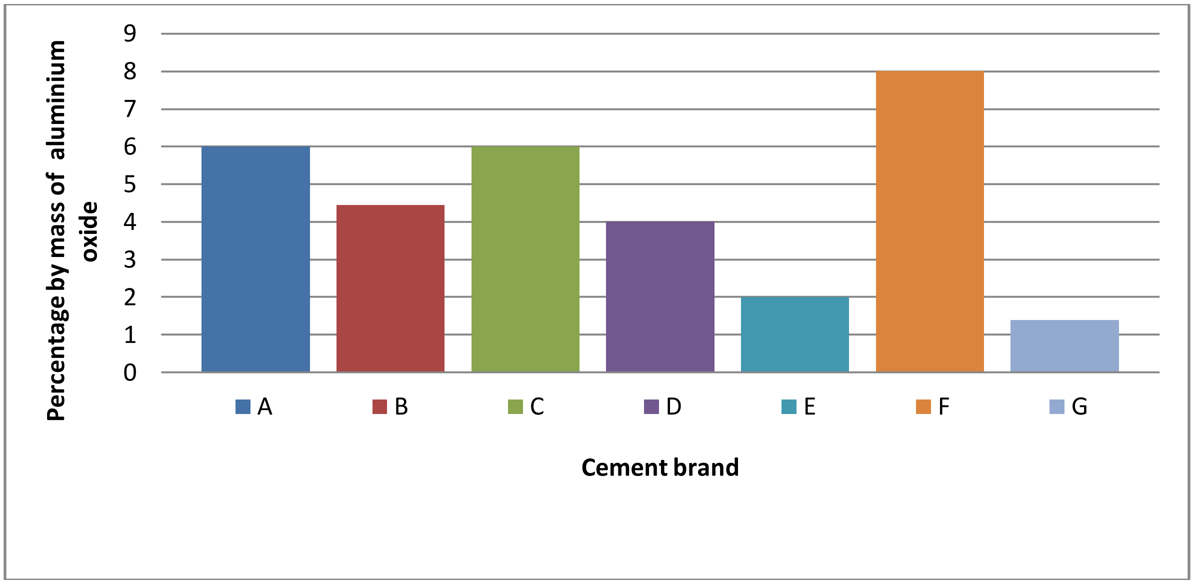

Figure 4.11: Percentage Aluminium Oxide Contents of Cement Brands

(d) Iron oxide

The percentages of the iron oxide contents in the cement brands tested are presented in page 82, Table 3.10. The cement brand samples A, B, C, D, E, F and G passed the tests of Iron oxide having satisfied the standard range of 1.5-7%. The highest iron oxide content of 3.45% was obtained from cement brand B while the brands A, C and F each had the least content of 2% as shown in Figure 4.12.

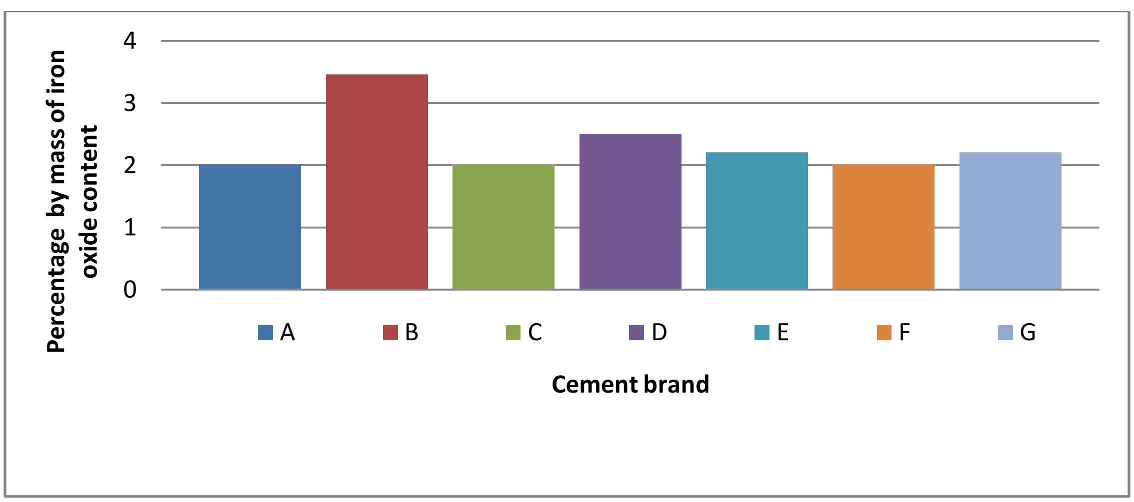

Figure 4.12: Percentage Iron Oxide Contents in Cement Brands

(e) Magnesium oxide

The Magnesium oxide contents of the seven cement brands studied were within the range of 0.5 to 4% specified in the standards. The cement brand F had the highest MgO content of 2.3% while B had the least content of 0.54% as shown in Figure 4.13. The cement brands met the standard. Thus the MgO contents were not excessive to cause delayed setting and expansion which could lead to cracking.

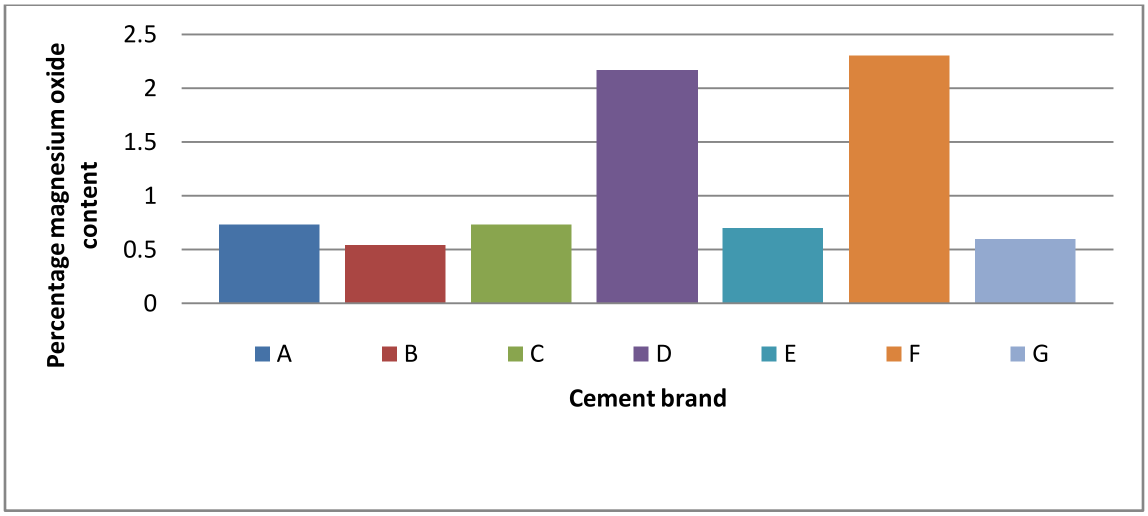

Figure 4.13: Percentage Magnesium Oxide Contents in Cement Brands

(f) Free calcium oxide

The percentage distributions of the free calcium oxide in the seven cement brands samples tested are shown in page 82, Table 3.10. The free calcium oxide contents of the cement brands were less than 2%. Cement brand D had the highest content of 1.90% while F had the least content of 0.3% as shown in Figure 4.14. The seven cement brands passed the test.

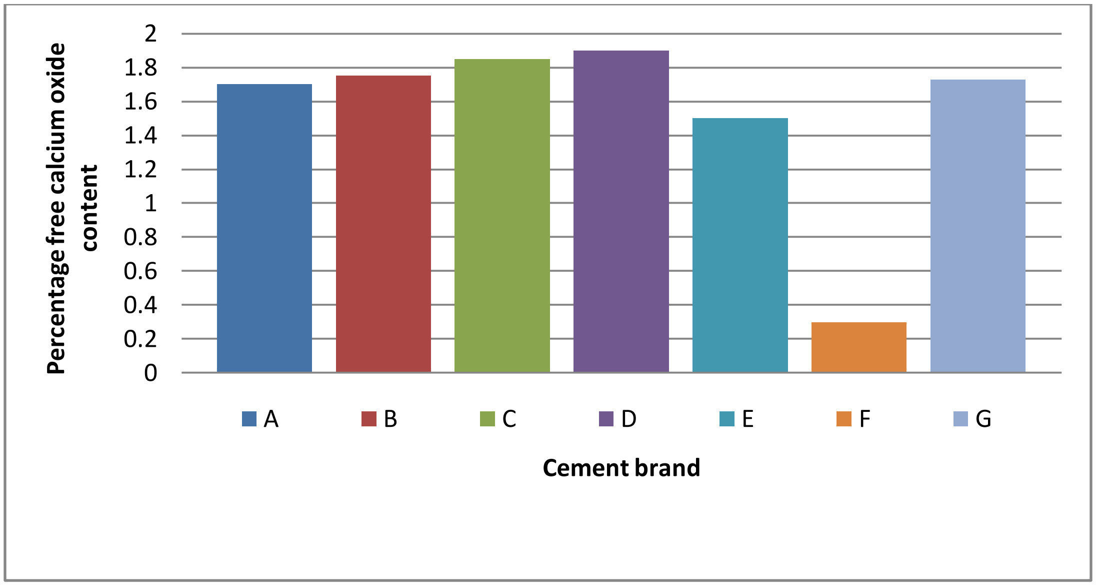

Figure 4.14: Percentage Free Calcium Oxide Contents in Cement Brands

(g) Sulphate

BS EN 197-1: 2000 specified a maximum SO_3 content of 3.5% content for CEM I and CEM II cements. Cement brands E and G had the highest SO_3 content of 1.76% while F had the least content of 0.30%. The seven cement brands passed the test as shown in Figure 4.15. Sulphate is added to regulate the initial setting and hardening reactions that take place during hydration (DeHayes and Tennis, 2006).

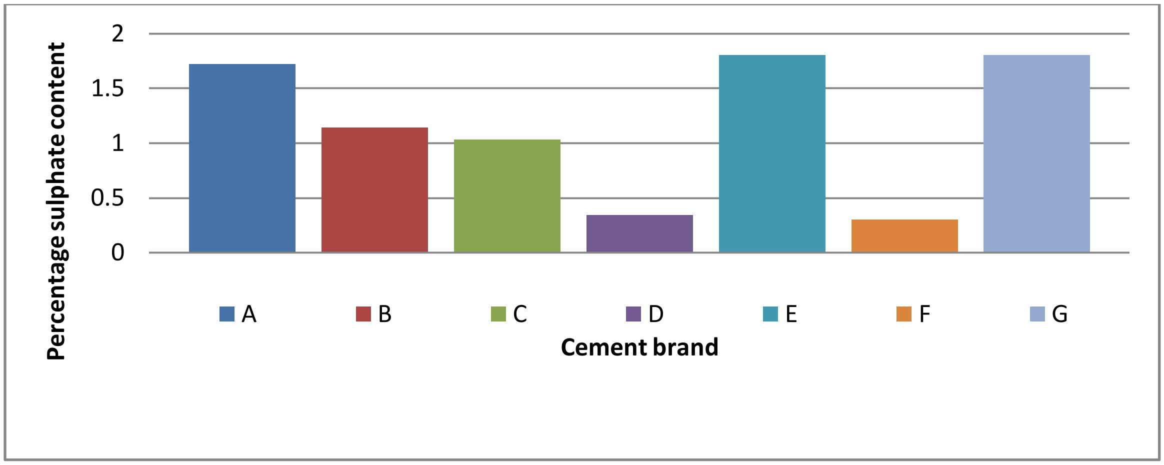

Figure 4.15: Percentage Sulphate Contents in Cement Brands

(h) Insoluble residue

BS EN 197-1: 2000 specified a maximum value of 5% content for insoluble residue (IR). Cement brand B had the highest insoluble residue of 4.50% while the least content of 2.0% was recorded in G as shown in Figure 4.16. The seven cement brands studied passed the test. The levels of adulteration of the cement brands studied were within tolerable limit.

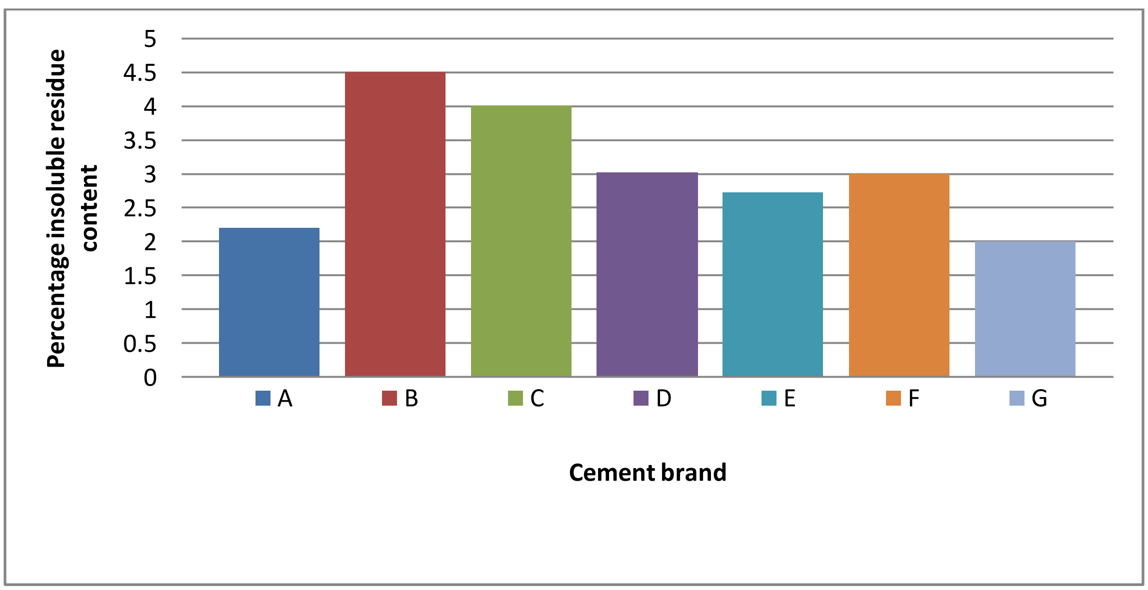

Figure 4.16: Percentage Insoluble Residue Contents in Cement Brands

(i) Loss on ignition (LOI)

The local cement brands A, D, F and G were fresher than the imported cement brands B, C and E. This is attributed to the fact that the imported brands were more exposed to the atmosphere and absorb more moisture than the local BS EN 197-1: 2000 specified a maximum of 5% content for Loss on Ignition (LOI). The cement brand B had the highest loss on ignition of 3.2% while D had the least value of 1.48% as shown in Figure 4.17.

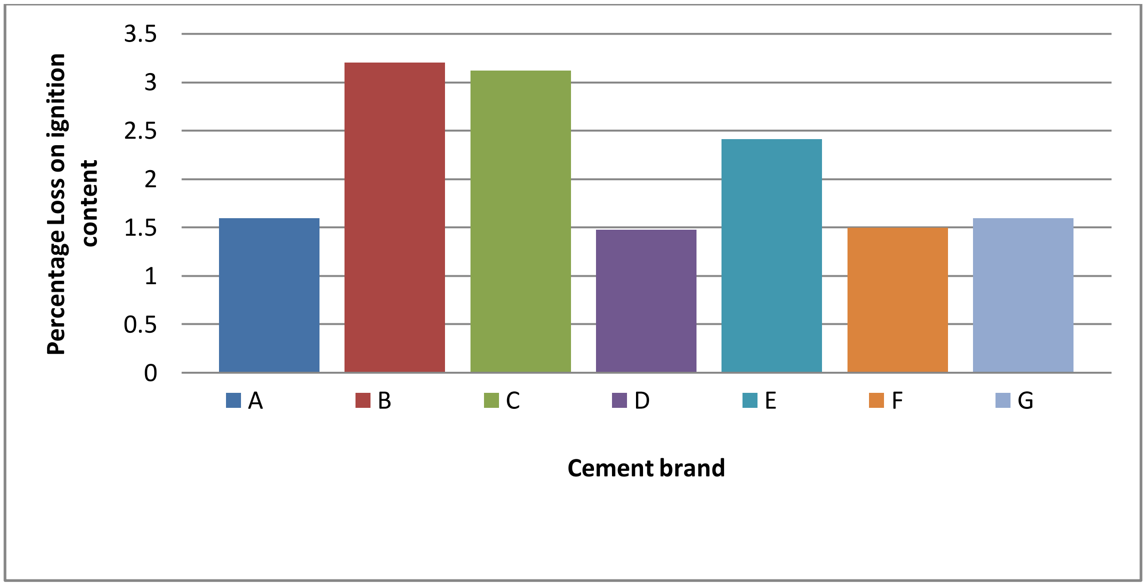

Figure 4.17: Percentage Loss on Ignition Contents in Cement Brands

4.3.3 Computation of lime saturation factor (LSF) of cement samples

The lime saturation factor of the seven brands of cement A, B, C, D, E, F and G were computed using equation 3.1 and results presented in chapter three, page 83, Table 3.11. The brands of ordinary Portland cement A, B, C, D, E, F and G met the minimum and maximum criteria that LSF should be 0.66 and 1.02 respectively as shown in Figure 4.18.

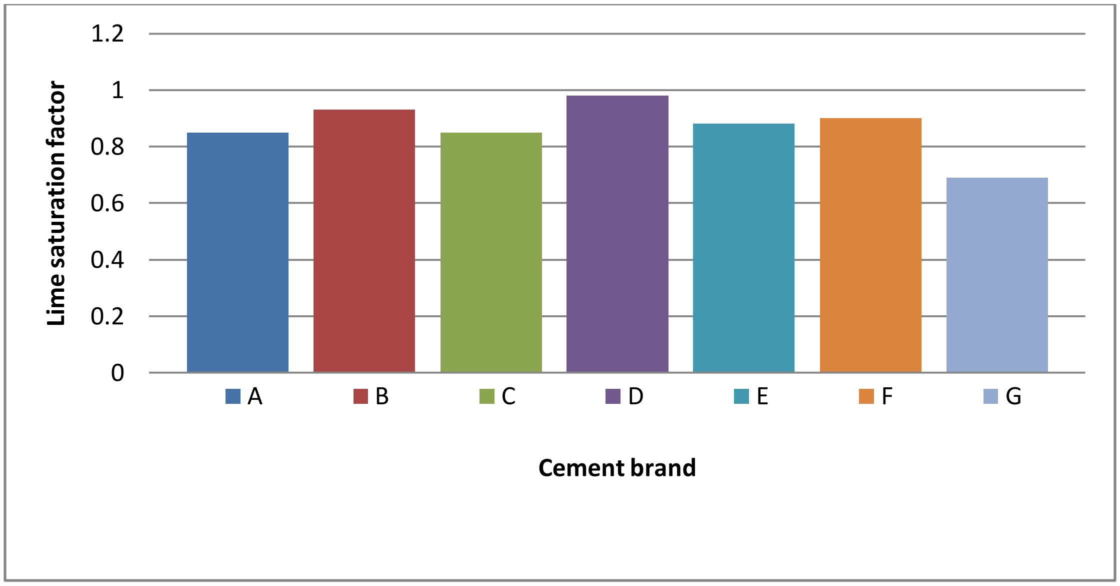

Figure 4.18: Lime Saturation Factors of Tested Seven Ordinary Portland Cement Brands

4.3.4 Chemical compound characterization of the seven cement brands compared to standard

The percentage composition of chemical compounds in the cement brands studied were computed using Boque equations 3.3 to 3.5 in chapter three, pages 83 to 84 and the results of the oxide compositions presented in page 86, Table 3.12. The results of the computations for the cementitious compounds abbreviated as C_3S, C_2S, C_3A, and C_4AF, are shown in Table 3.12.

The chemical compounds in the ordinary Portland cement brands compared to standard are presented in Table 4.4.

Table 4.4: Chemical Compound Characterization of the seven Cement Brands compared to Standard

Cement brand	C_3S (%)	C_2S (%)	C_3A (%)	C_4AF (%)
A	33.00	38.39	12.52	6.08
B	46.97	16.43	5.99	10.49
C	30.41	37.46	12.52	6.08
D	68.99	5.66	6.38	7.60
E	51.77	24.17	1.58	6.69
F	34.25	28.84	17.82	6.08
G	6.34	49.78	0.02	6.69
Standard	42 - 67	8 - 31	5 -14	6 -12

(a) Tricalcium silicate (C_3S) results in cement brands

The percentage tricalcium silicate content in each of the seven cement brands was determined from Boque equations (Taylor, 1997) and the results are presented in chapter three, page 84, Table 3.12. The highest value of tricalcium silicate (3 $CaO.SiO_2$ or C_3S) recorded in the test was 68.99% for cement brand D while the least value was 6.34% for Cement brand G as shown in Figure 4.19.

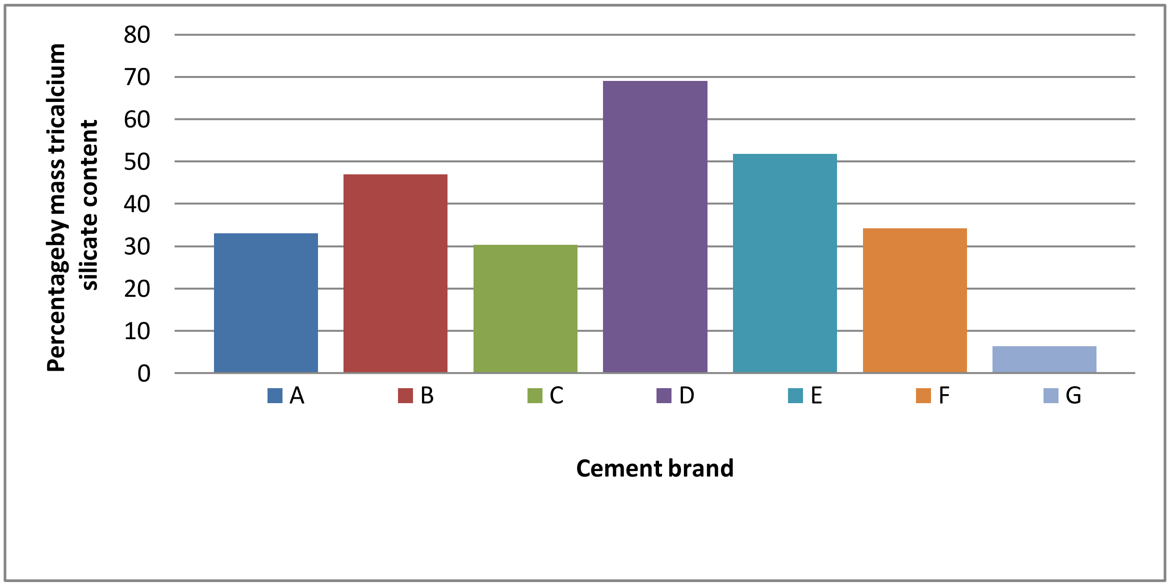

Figure 4.19: Percentage by Mass Tricalcium Silicate in Cement Brands

The normal tricalcium silicate content by mass, for ordinary Portland cement ranges from 42% to 67% (EN 197-1: 2000). Thus cement brands B and E met the normal specifications for C_3S while brands A, C, D, F and G failed to meet the normal specification. The very low value of C_3S in cement brand G may be attributed to its low lime saturation factor which made the burning in the kiln difficult during the cement production (Neville, 2012).

(b) Dicalcium silicate (C_2S) results in cement brands

The percentage by mass of C_2S present in each of cement brands A, B, C, D, E, F and G as determined from Boque equations (Taylor, 1997) is shown in chapter three, page 84, Table 3.12. Cement brand G recorded the highest value of 49.78% for dicalcium silicate (C_2S) among the brands of cement studied while the least value is 5.66% for cement D as shown in Figure 4.20.

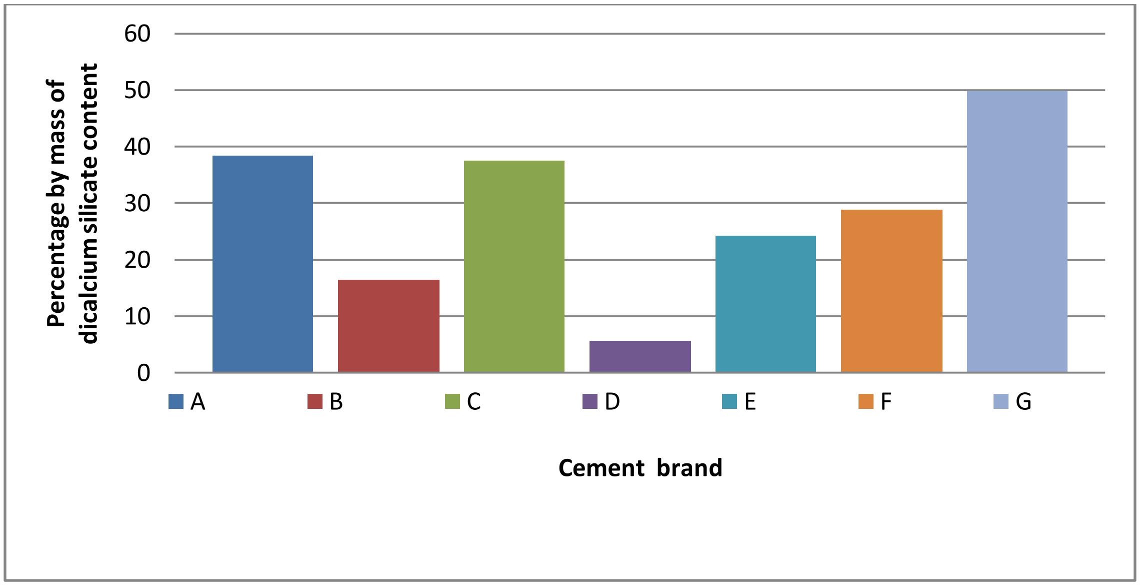

Figure 4.20: Percentage by Mass of Dicalcium Silicate in Cement Brands.

The normal range of C_2S content in cement is 8% to 31% (EN 197-1: 2000). Thus cement brands B, E and F met this specification. The cement brands A, C, D, and G did not meet this specification.

(c) Tricalcium aluminate results in cement brands

The percentage by mass of the C_3A content in each of the cement brand samples A, B, C, D, E, F, G is presented in chapter three, page 84, Table 3.12. The highest value recorded in the brand samples of cement tested was 17.82% for cement brand F while the least value was 0.02% for Cement brand G as shown in Figure 4.21.

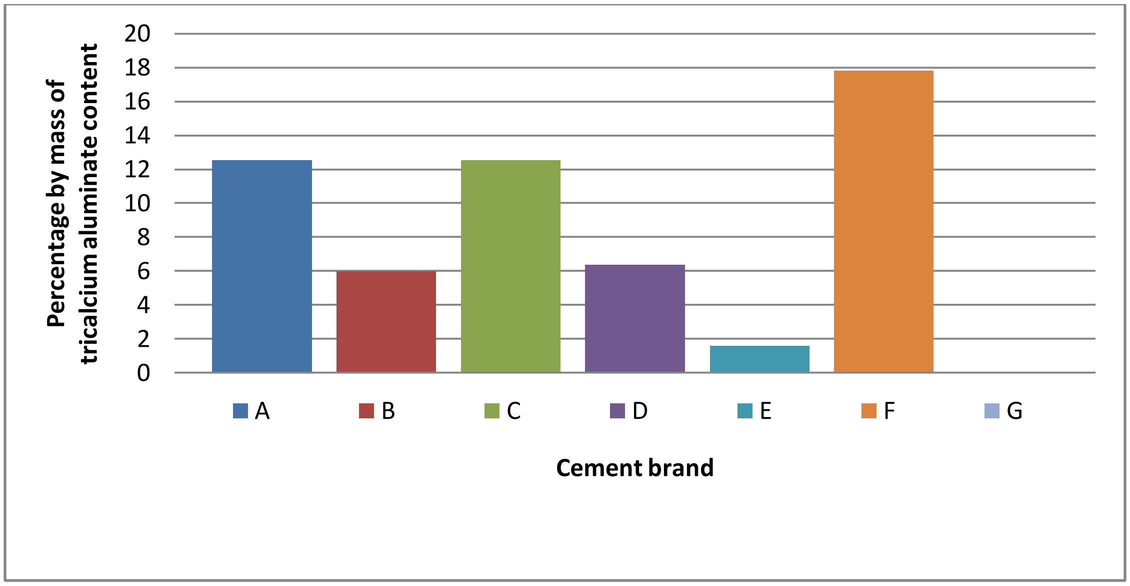

Figure 4.21: Percentage by Mass of Tricalcium Aluminate in Cement Brands

The normal range for C_3A component is 5% to 14% for ordinary Portland cement (EN 197-1: 1992). The cement brands A, B, C and D passed the test of C_3A content while brands E, F and G failed to meet the specification.

(d) Tetra calcium alumino ferrite (C_4AF) results in cement brands

The C_4AF contents in the cement brands A, B, C, D, E, F and G are presented in chapter three, page 84, Table 3.12. For Tetra Calcium alumino ferrite ($4CaO.Al_2O_3Fe_2O_3$) or C_4AF content, cement brand B recorded the highest value of 10.49% while the least value was 6.08% for brands A, C and F as shown in Figure 4.22.

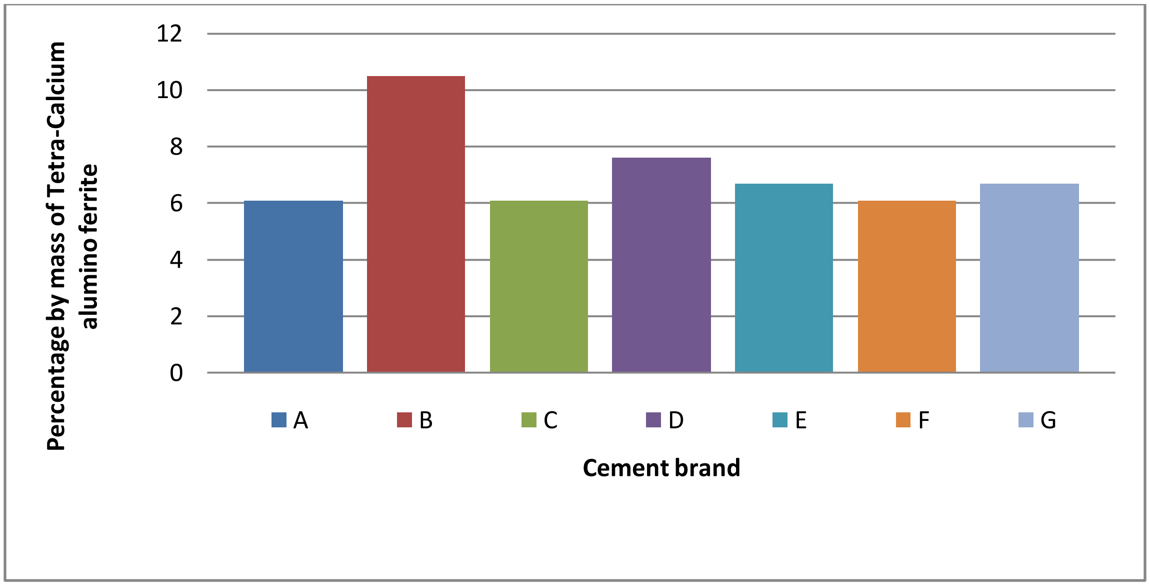

Figure 4.22: Percentage by Mass of Tetracalcium Alumino Ferrite in Cement Brands

The normal range for C_4AF component is 6% to 12 (EN 197-1: 2000) for ordinary Portland cement. Thus all the seven cement brands studied met the normal standard specification for C_4AF.

(e) Comparison of results with BS EN 197-1: 2000 requirement for Portland cement

According to BS EN 197-1: 2000, for Portland cement, (i) The combined percentage composition of C_3S and C_2S should be at least two-thirds of the total mass of the compounds and average of 70%, (ii) The ratio by mass CaO/SiO_2 shall not exceed 2. (iii) The MgO content shall not exceed 5%.

Only cement brands A, D and E met the average specification of 70% while B, C, F and G did not as shown in Figure 4.23.

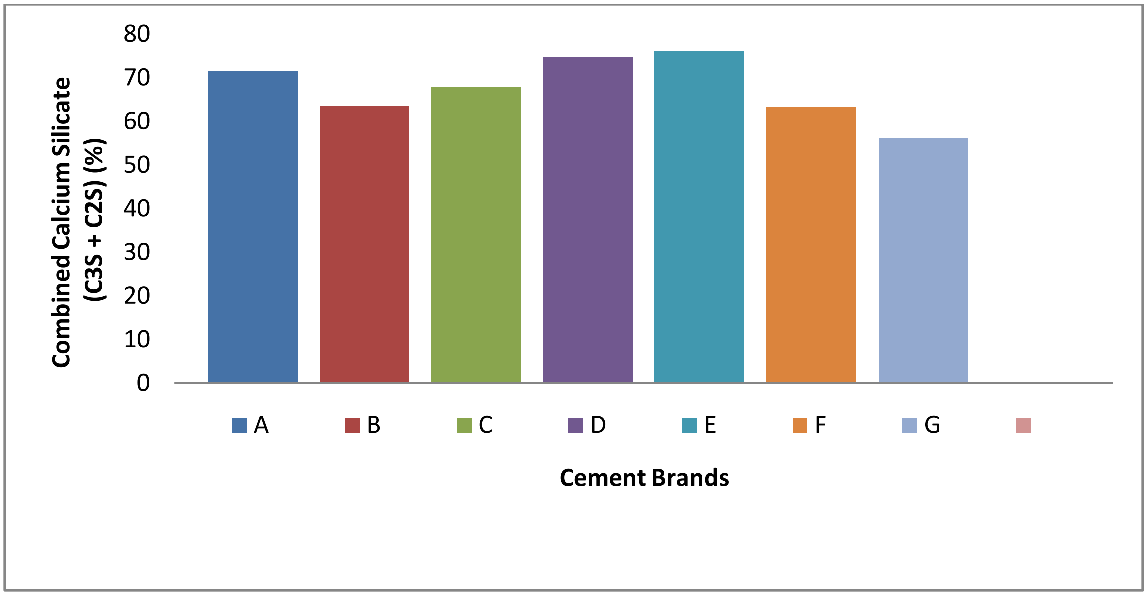

Figure 4.23: Combined Percentage of Tricalcium Silicate and Dicalcium Silicate in Cement Brands

The lime – silica ratio of each of the seven cement brands studied is shown in Figure 4.24.

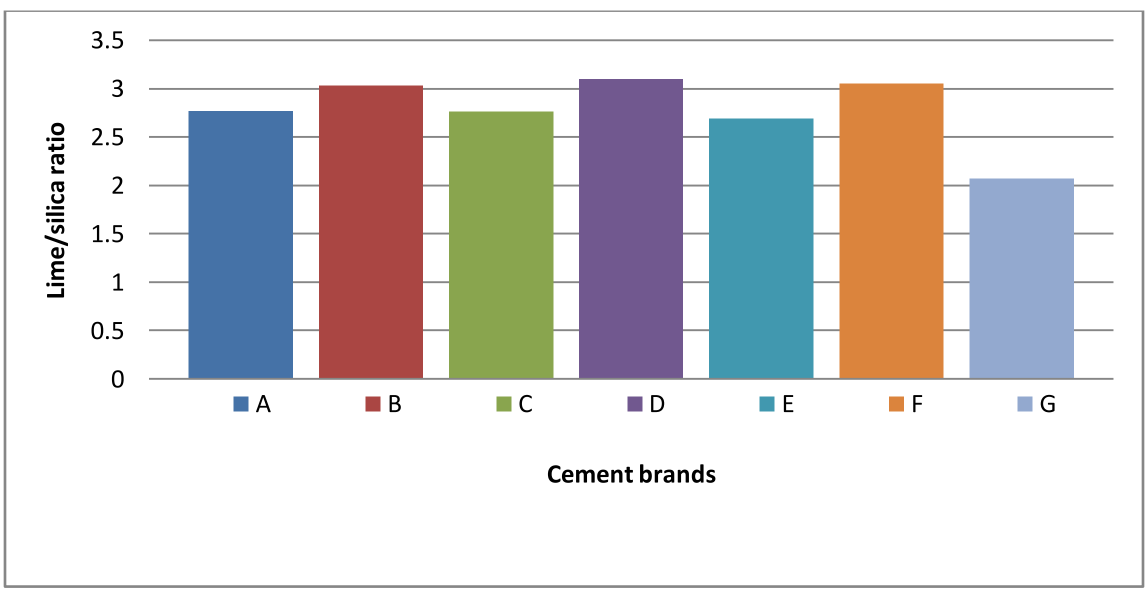

Figure 4.24: Lime / Silica Ratio in Cement Brands

The combined calcium silicate compounds for cement brand G was 56.12% which was drastically too low due to its very low C_3S content attributed to its low lime saturation factor. Only cement brands A, D and E met the average specification of 70% while B, C, F and G did not.

4.4 Sandcrete Hollow Block Tests

The tests results on blocks were presented in chapter three, pages 87 to 104. The tests results such as determination of optimum water/cement (w/c) ratio, dry development strength, wet development strength, dry bulk density, wet density and water absorption tests are presented.

4.4.1 Optimum water to cement ratio

The test results for the determination of optimum water to cement ratio were presented in chapter three, page 87, Tables 3.14 and 3.15. The water/cement ratio (w/c) test was performed using cement brands A (a locally produced cement brand) and C (an imported cement brand) blocks at cement- sand mix ratios (MR) of 1:4 to 1:12. The dry compressive strengths of the blocks tested after 28 days were found to increase as the water to cement ratio increased from 0.35 to 0.45 after which the compressive strengths of the blocks decreased from mix ratio of 0.45 to 0.60 as shown in Figures 4.23 and 4.24.

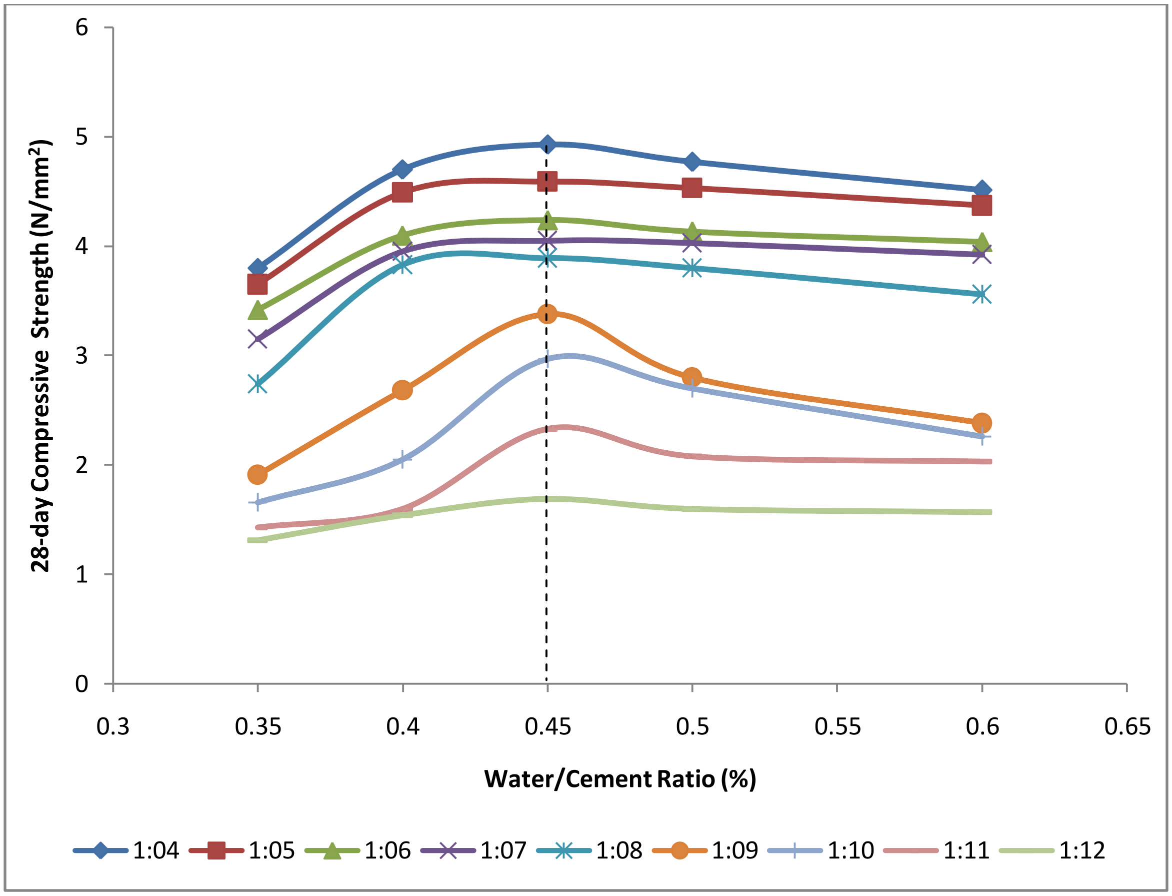

Figure 4.25: Dry compressive Strength Versus Water to Cement Ratio for Cement Brand A-Hollow Blocks at 28 Days.

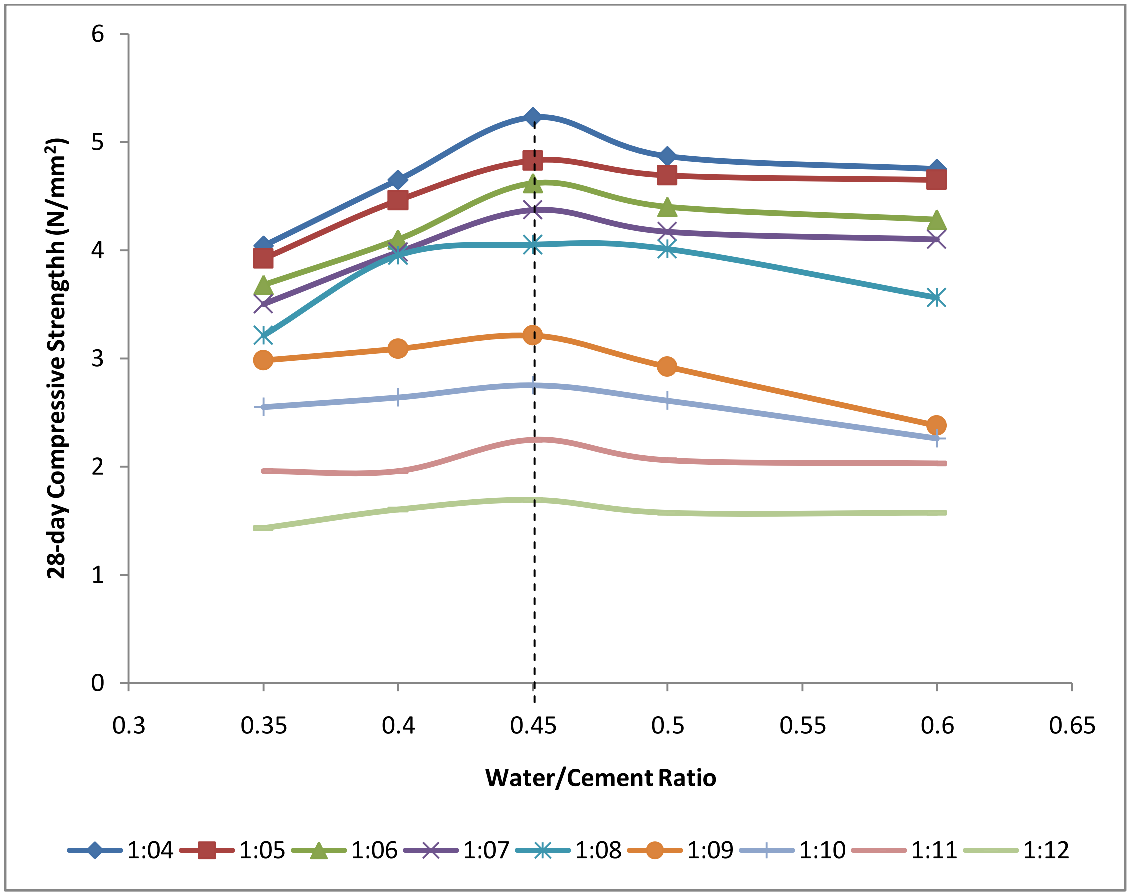

Figure 4.26: Dry Compressive Strength Versus Water to Cement Ratio for Cement Brand C – Hollow Blocks at 28 days.

This is attributed to the fact that, between w/c ratio of 0.35 and 0.45, there was insufficient water to fill the gel-pores completely and the capillary pores were empty. As the hydration progressed, the effective relative humidity became low and the hydration become very slow or even stopped, even though free space remained (Taylor, 1997). That is, self desiccation took place. As the w/c ratio increased the hydrated products increased while the unhydrated cement reduced, hence the strength of the block increased.

At the w/c ratio of 0.45 the water needed for the chemical reaction to form the Calcium- Silicate-Hydrates (C-S-H) and other products of hydration and completely fill the gel- pores was sufficient. Therefore, complete hydration was experienced and hence the strengths of the blocks were at maximum.

When the w/c ratio was increased from 0.45 to 0.6, more water was present in the mixture. In fresh cement paste, sandcrete or concrete with high content of water, cement particles may be completely dispersed or deflocculated due to the large organic molecules adsorbed on their surfaces displacing water films and reducing aggregate forces between cement particles (Helmuth, 1987). According to Helmuth (1987) supplementary cementitious materials that contain small percentages of ultrafine particles may also aid in dispersing cement particles by adsorption of the ultrafine particles on the surface of the larger particles.

With higher amounts of water in the mixture comes greater dispersion (CEMEX USA, 2013). Therefore, less bridging of the C-S-H crystals took place. The resulting sandcrete blocks were lower in strength. Hence, the strength decreased from w/c of 0.45 to 0.6. These are in line with Powers-Brown (1949) theory and CEMEX USA (2013).

However, the Powers Brownyard theory stated that the optimum w/c ratio was 0.38 for concrete inside an enclosure which is continuously supplied with water. In the case of CEMEX USA (2013) the optimum w/c ratio of 0.45 for concrete cured continuously with water. Wenapere and Ephraim (2009) observed that the optimum w/c for the 450mm x150mm x 225mm hollow sandcrete block and its 1:4 model was 0.50 although the paper did not indicate how the blocks were cured. In this study, it was observed that for 450mm x 225mm x225mm hollow sandcrete blocks produced with cement to sand mix ratios of 1:4 to 1:12 using vibrating machine and cured only twice (morning and evening) the optimum w/c ratio was 0.45. The optimum water to cement ratio at which the strengths of blocks were maximum was 0.45.

4.4.2 Dry and wet development strength tests for sandcrete hollow 9" blocks made with machine

The dry and wet tested results are shown in chapter three, pages 88 to 91, Tables 3.16 to 3.22 and pages 93 to 96, Tables 3.23 to 3.29. The dry development strengths of the blocks are shown in the first segment (first 28-days) of Figures 4.27 to 4.33.

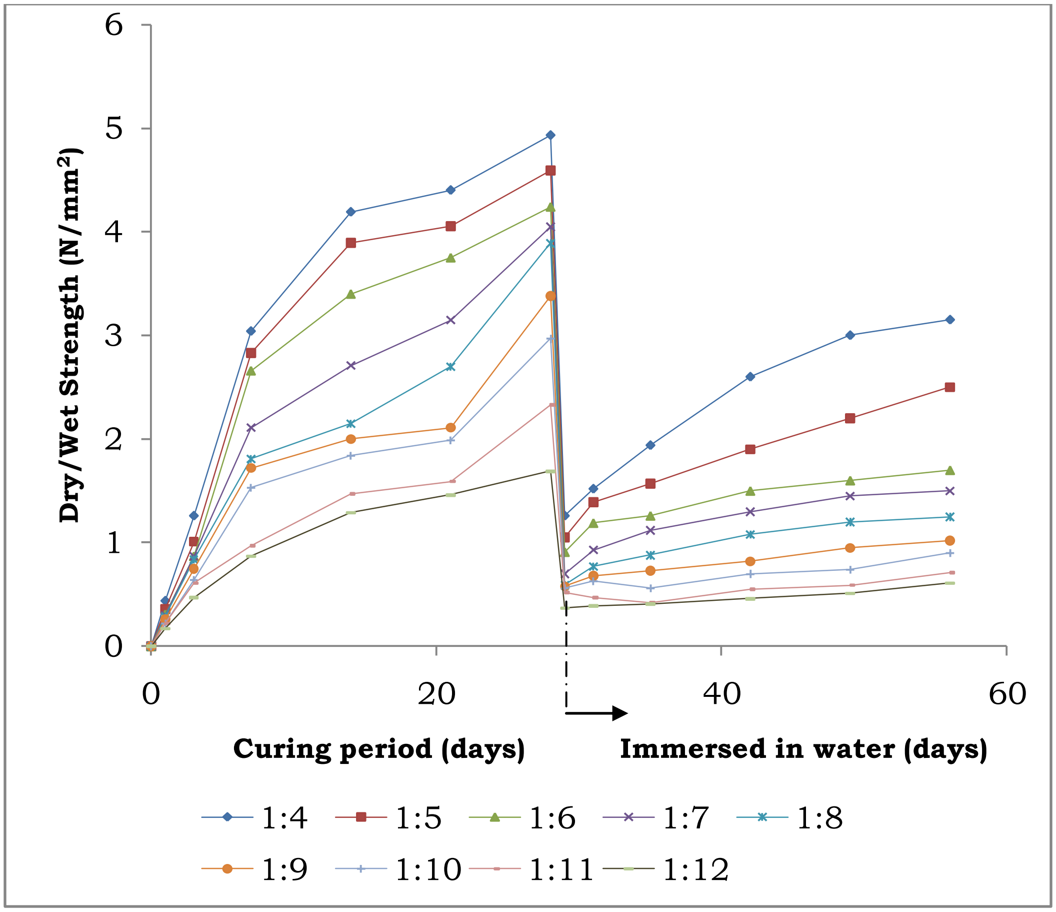

Figure 4.27: Combined Dry and Wet Compressive Strength Development for Cement Brand A - Hollow Blocks.

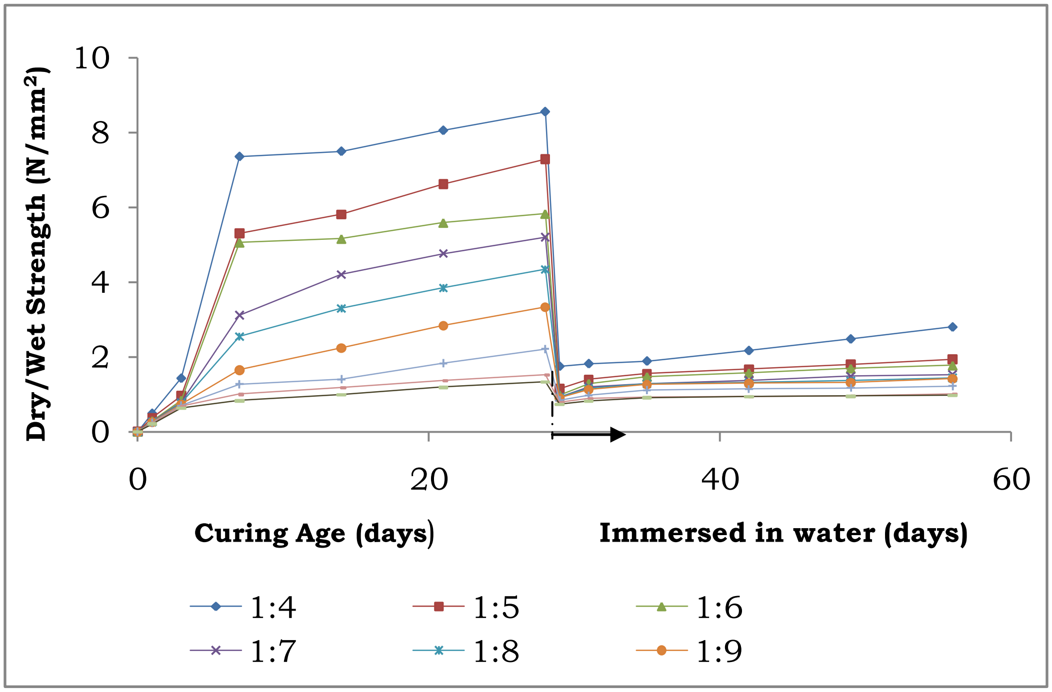

Figure 4.28: Combined Dry and Wet Compressive Strength Development for Cement Brand B - Hollow Blocks.

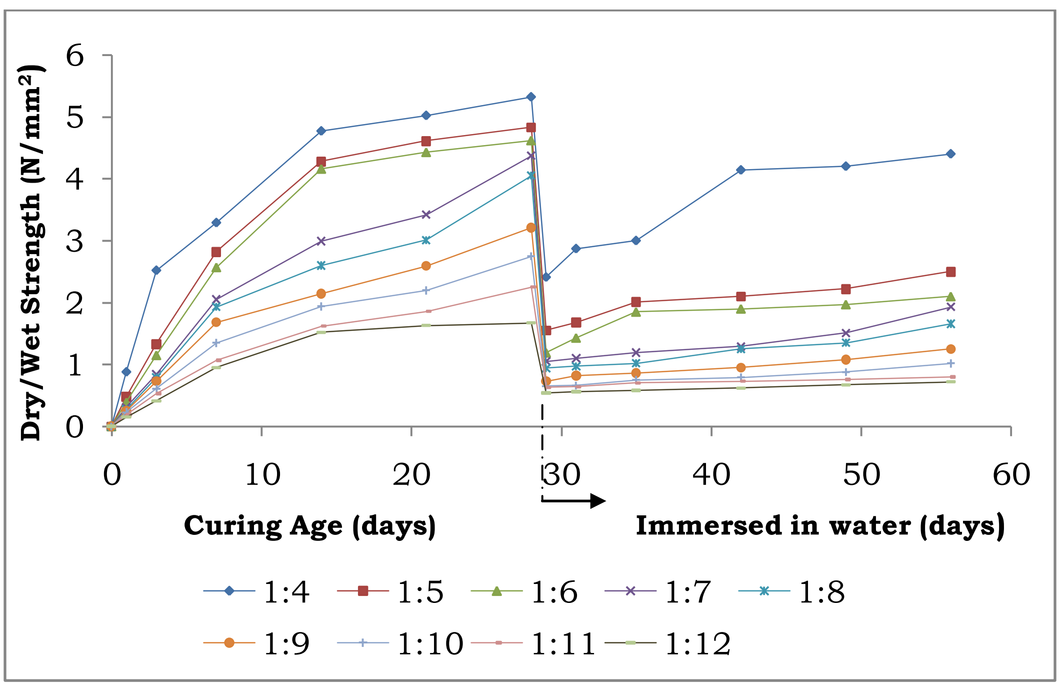

Figure 4.29: Combined Dry and Wet Compressive Strength Development for Cement Brand C - Hollow Blocks.

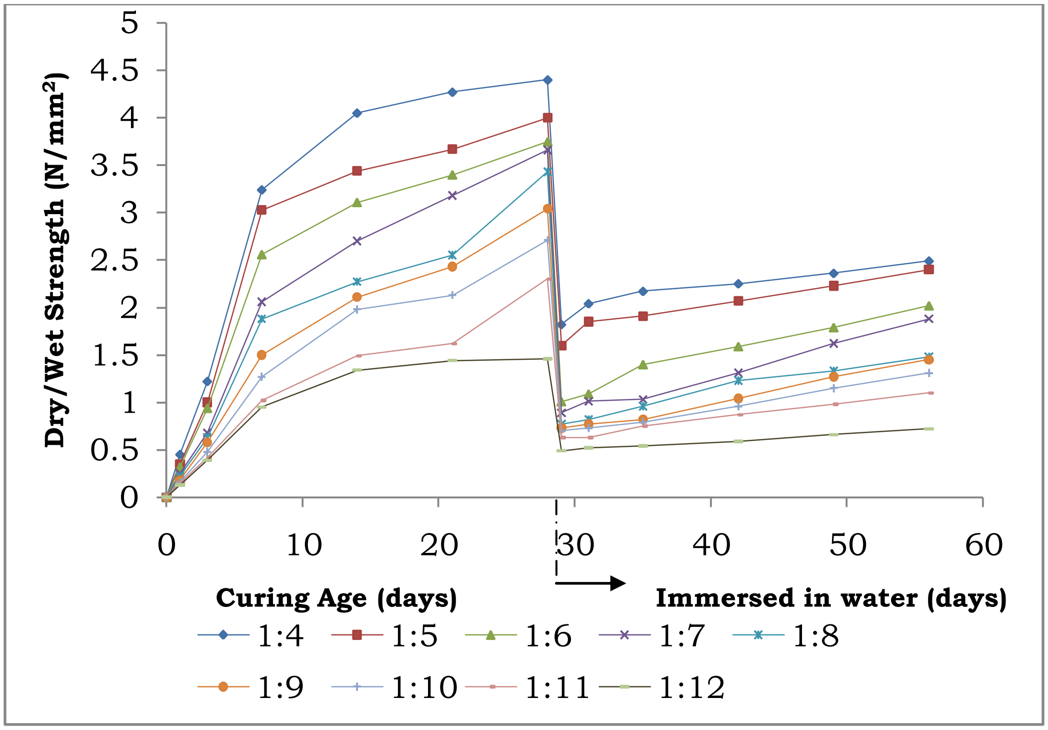

Figure 4.30: Combined Dry and Wet Compressive Strength Development for Cement Brand D - Hollow Blocks.

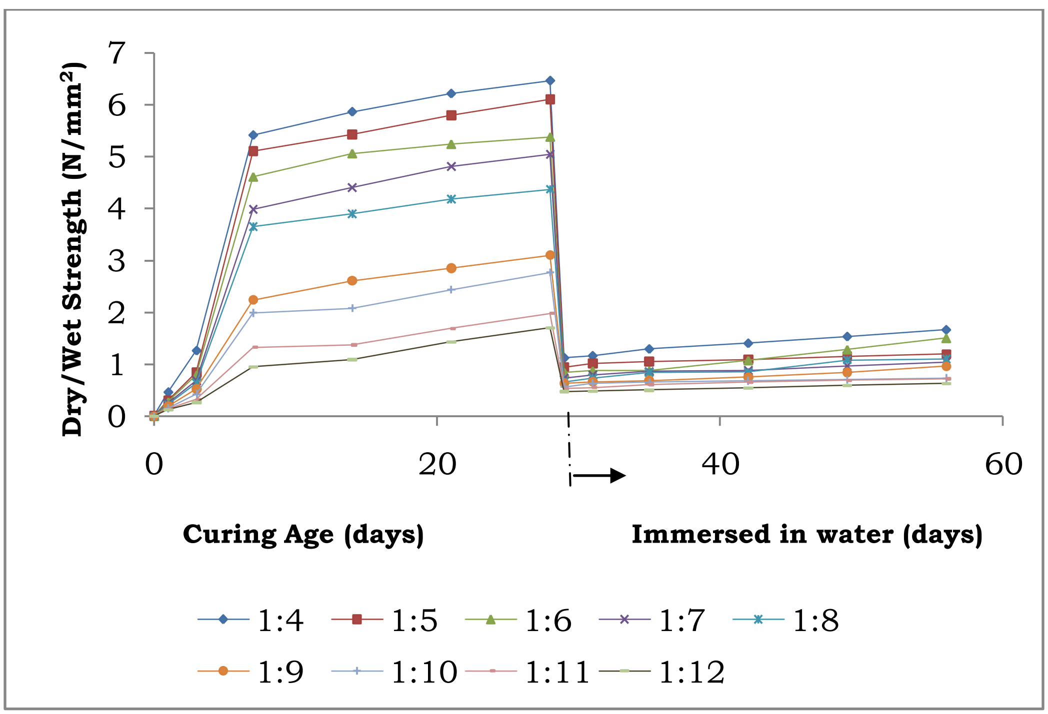

Figure 4.31: Combined Dry and Wet Compressive Strength Development for Cement Brand E - Hollow Blocks.

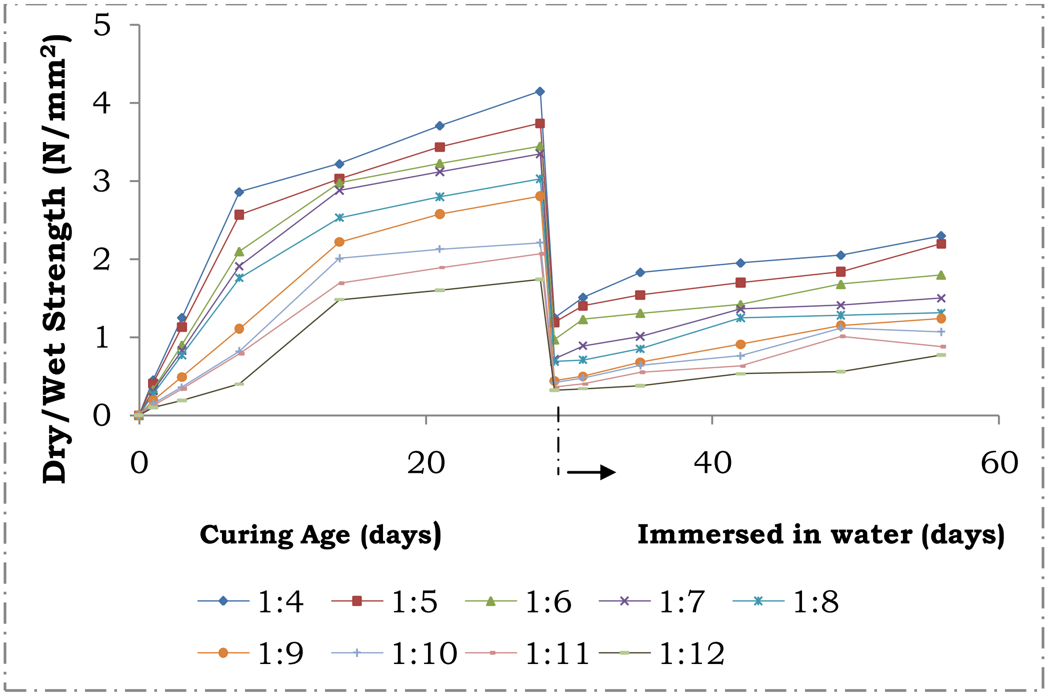

Figure 4.32: Combined Dry and Wet Compressive Strength Development for Cement Brand F - Hollow Blocks.

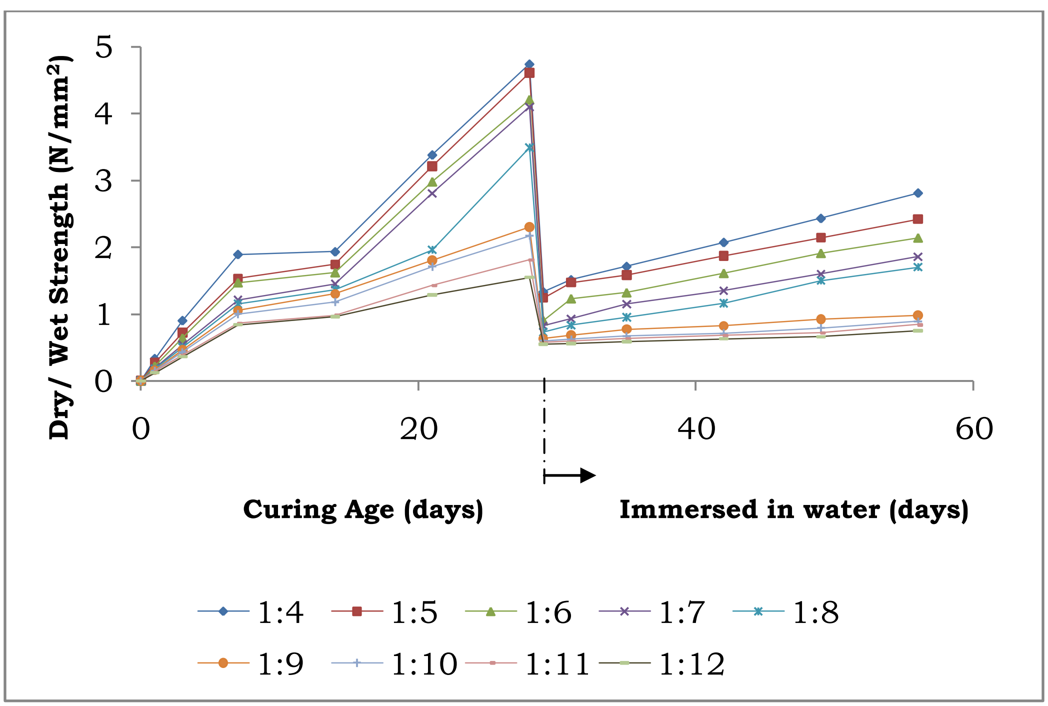

Figure 4.33: Combined Dry and Wet Compressive Strength Development for Cement Brand G - Hollow Blocks.

There was gradual parabolic increase in strength of the sandcrete hollow blocks for each mix ratio from curing ages of 0 up to 28 days. Cement brand B blocks had the highest dry compressive strength between mix ratios 1:6 to 1:8. This is attributed to the cement's adequate compliance with the standard in terms of cement compounds. Its C_3S, C_2S, C_3A and C_4AF values complied with the standards.

The sandcrete hollow blocks were initially cured in the dry state for 28 days before they were soaked in water. The wet development strengths of the soaked blocks are presented in the second segment (29^{th} to 56^{th} days) of Figures 4.27 to 4.33. There was a sudden sharp drop in the strength between 28^{th} day and 29^{th} day with the minimum strength occurring at the end of the 29^{th} day. This was followed by a steady slow increase in strength from the 29^{th} day to the 56^{th} day.

The sandcrete has been identified to be made up of three zones consisting of the cement paste, the aggregate particles and the interfacial transition zone (Mehta and Monteiro, 2006). The interfacial transition zone (ITZ) has been identified as the weakest part of sandcrete block as it is easily prone to crack formation on application of load (Thomas and Jennings, 2008). The nature of the bond between the cement paste and the fine aggregate has been identified to be made up of two component sources. (i) the chemical interaction between the highly alkaline pore solutions and the reactive silica in the aggregates, (ii) the mechanical interlocking between the cement hydration products (C-S-H, calcium hydroxide, ettringite) and the aggregate particles. (Neville, 2012 , Thomas and Jennings, 2008). The interlocking component has been identified as the significantly stronger component holding the composite sandcrete material together. (Thomas and Jennings, 2008; Mehta and Monteiro, 2006). When the sandcrete blocks were soaked in water the paste became saturated.

The entry of water molecules between the gel particles sets up a disjoining pressure in the C-S-H (Taylor, 1997). This tends to weaken or reduced the interlocking forces between the hydration products (C-S-H and others) and the aggregate particles and thereby fovoured the initiation of or spread of cracks which lowered the strength.

At the age of 28 days about 10 % to 15% of the initial cement was not hydrated in the dry state (Shetty, 2010). The presence of water on immersion of the sandcrete hollow blocks gave rise to hydration of the cement thereby increasing the cohesive forces of the gel particles. This was responsible for the slow and steady rise in strength of the blocks again. The minimum compressive strength was thus experienced after one day soaking period.

From the Figures 4.27 to 4.33, the minimum soaking period of one day was observed for the blocks made with cement ratios 1:4 to 1:12 and for blocks made from all the seven brands of ordinary Portland cement. The minimum soaking period of block was found to be independent of mix ratio and brand of cement. The minimum soaking strength of the block however, depended on mix ratio. The average minimum strength of the blocks at mix ratio of 1:6 was $1N/mm^2$. The significance of this is that walls made of sandcrete hollow blocks have their compressive strength reduced sharply after one day soaking when flooded.

4.4.3 Comparison of tested blocks results with standards

The 28 day dry compressive strengths of the machine vibrated sandcrete hollow blocks made from the cement brands A, B, C, D, E, F and G studied were compared to the local and international standards.

4.4.4 Comparison of tested blocks results with Nigerian Industrial Standard, NIS 87:2004

The comparison of the tested 28-day dry compressive strengths of the blocks with the Nigerian Industrial Standard, NIS 87:2004 at mix ratio of 1:6 is presented in Table 4.5 where: P-average is the average compressive strength of the blocks samples at mix ratio of 1:6 and P-minimum is the minimum individual compressive strength of the blocks at mix ratio of 1:6. .

Table 4.5: Comparison of 28- Day Strength of 9" Machine Vibrated Blocks to NIS 87:2004 at Mix Ratio of 1:6

Cement brand	P –average (N/mm^2)	p-minimum (N/mm^2)	Remarks
A	4.24	4.21	Satisfactory
B	5.83	5.80	Satisfactory
C	4.62	4.58	Satisfactory
D	3.75	3.72	Satisfactory
E	5.38	5.37	Satisfactory
F	3.45	3.44	Satisfactory
G	4.21	4.20	Satisfactory

The blocks were found to have all satisfied the NIS 87: 2004 minimum individual compressive strength of 2.5N/mm^2 and an average compressive strength of 3.45N/mm^2.

4.4.5 Comparison of block compressive strength with BS2028:1985 Standard

The test results of the 28-day blocks compressive strengths for mix ratio 1:6 to 1:8 were compared with the above standard. The BS 2028: 1985 specified an average compressive strength of 3.5N/mm^2 and a minimum individual strength of 2.8 N/mm^2. Results showed that the blocks made from cement brands A, B, C, E and G passed the test. For cement brand D- blocks, mix ratios 1:6-1:7 passed the test while for cement brand F blocks the mix ratios 1:4 to 1:5 passed the test.

4.4.6 Comparison of blocks compressive strength with BS EN 771-3: 2006.

Blocks at the age of 28-days and of mix ratio range 1:6 to 1:8 were compared with the standard. The BS EN 771-3: 2006 specified a minimum strength of 2.90N/mm^2. Results showed that the blocks from the cement brands A, B, C, D, E, F and G satisfied this code (BS EN 771-3:2006).

4.4.7 Comparison of results of Olanitori (2005) study with this study

In chapter two, page 56, Olanitori (2005) observed that some of the industries he studied used a mix ratio of 1:8 in the production of sandcrete hollow blocks. He could only obtain average of 28-day dry compressive strength of 1.33 N/mm^2 for 9" sandcrete hollow blocks. Table 4.6 shows that the average 28-day dry compressive strength of the 9" sandcrete hollow blocks made with vibrating machine at mix ratio of 1:8 is 3.8 N/mm^2. This is 286% of the industries average value.

Table 4.6: Average 28-day Dry Compressive Strengths of 9" Sandcrete Hollow Blocks Produced in this Study.

	A	B	C	D	E	F	G	Average	STD
Mix Ratio		Compressive strength (N/mm^2)							
1:4	4.93	8.56	5.32	4.40	6.46	4.15	4.74	5.51	(NIS 87:
1:5	4.59	7.29	4.83	4.00	6.10	3.74	4.61	5.02	2004)
1:6	4.24	5.83	4.62	3.75	5.38	3.45	4.21	4.50	3.45
1:7	4.05	5.20	4.37	3.66	5.04	3.35	4.10	4.25	
1:8	3.89	4.34	4.05	3.43	4.37	3.03	3.49	3.80	BS EN
1:9	3.38	3.33	3.21	3.04	3.10	2.81	2.30	3.02	771-3:
1:10	2.97	2.21	2.75	2.71	2.77	2.21	2.17	2.54	2006
1:11	2.33	1.52	2.25	2.30	1.98	2.07	1.81	2.04	2.8min.
1:12	1.69	1.33	1.67	1.44	1.70	1.70	1.55	1.58	

The implication of the above is that the problem of production of blocks of low strength by the commercial block industries is beyond the use of poor cement to sand mix ratio and inadequate curing. The main factors which influence the strength of a hollow sandcrete block are mix ratio, compactive force, duration of curing and water to cement ratio. The commercial block industries usually pay more attention to the first two factors which are capital intensive while the last two which are cheap are often ignored. In the case of the duration of curing, the block industries are often in hurry to dispose their products and produce more so as to make more profit and also to create more spaces for the new incoming products. Therefore, the blocks are not properly cured. The last factor, the water to cement ratio is not often given adequate consideration. The optimum water to cement ratio has to be used in order to obtain maximum block strengths and in this study it is 0.45.

4.4.8 Wet compressive strengths of the blocks were lower than their dry strengths

It was also observed that the compressive strengths of the sandcrete hollow blocks soaked in water were much lower than those of the same cement brand and mix ratio in the dry state. The lower strength of the soaked blocks is attributed to the disjoining pressure within the soaked cement paste (Mehta and Monteiro, 2006; Taylor, 1997).

4.4.9 Minimum soaking strength of sandcrete hollow blocks made from cement brands

The strengths of the soaked blocks made from cement brands A, B, C, D, E, F and G for mix ratios 1:4 to 1:12 corresponding to the 29th day (one day soaking period) in Figures 4.27 to 4.33 are presented in Table 4.7. These strengths of the soaked blocks are referred to as mjnjmum soaking strengths.

Table 4.7: Minimum Strengths for Cement Brand Blocks Soaked in Water for One Day

Cement brand	A	B	C	D	E	F	G
Mix Ratio	Critical Compressive Strength (N/mm^2)						
1:4	1.26	1.75	2.41	1.82	1.12	2.30	1.99

1:5	1.05	1.15	1.55	1.60	0.94	1.33	1.20
1:6	0.91	0.98	1.19	1.01	0.84	1.06	0.90
1:7	0.70	0.93	1.05	0.89	0.73	0.92	0.89
1:8	0.59	0.92	0.94	0.77	0.66	0.80	0.88
1:9	0.58	0.90	0.73	0.73	0.63	0.71	0.83
1:10	0.56	0.84	0.65	0.70	0.62	0.61	0.56
1:11	0.42	0.79	0.63	0.63	0.53	0.56	0.53
1:12	0.37	0.73	0.54	0.49	0.47	0.43	0.42

4.4.10 Comparison of minimum soaked strengths results with block industry results

The minimum soaking period of one day was obtained by Ejeh and Abubakar (2008) for commercial blocks produced by five block industries in Zamfara State, Nigeria. The cement brand used was Ashaka cement. The minimum soaking strengths obtained for the blocks from the five block industries were 0.35, 0.20, 0.28, 0.14 and 0.22 N/mm^2. These values are much lower than the minimum soaking strengths obtained from this study (Table 4.36) indicating that the mix ratios used by the block industries were leaner than 1:12. The poor curing might have contributed to the low values of the minimum soaking strengths of the blocks from the industries in Zamfara State.

The implications of the results from the two studies (this study and the industry study by Ejeh and Abubakar) are that the minimum soaking period of sandcrete hollow block soaked in water is the same for poorly cured and well cured conditions. It is the same for all the mix ratios studied. Its minimum soaking strength depends on curing and mix ratio of the cement to sand used to produce the block. Also the same minimum period of one day was obtained when seven cement brands were used in this study. This indicates that the minimum soaking period of the block is independent of the ordinary Portland cement brand used.

4.4.11 Analysis of variance for mix ratio and cement brand on minimum strengths of blocks

The hypotheses used were:

1. H_0: there is no significant difference between the minimum soaking strength of the blocks for mix ratio range 1:4 to 1:12 at 1% level of significance.

2. H_0: there is no significance difference between the mean minimum soaking strength of the blocks for the cement brands A, B, C, D, E, F and G at 1% level of significance.

3. H_0: there is no significance difference between the mean minimum soaking strength of the blocks for the cement brands A, B, C, D, E, F and G and mix ratios 1: 4 to 1:12 at 1% level of significance.

The Tables 4.8 and 4.9 show the one-way analysis of variance for the mix ratio and cement brands respectively on the minimum soaking strengths of the sandcrete hollow blocks presented in Table 4.7.

Table 4.8: ANOVA for Mix Ratios

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.367	8	1.171	25.944	.000
Within Groups	2.437	54	.045		
Total	11.805	62			

Table 4.9: ANOVA for Cement Brand

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.047	6	.175	.909	.495
Within Groups	10.757	56	.192		
Total	11.805	62			

Table 4.10 shows the two-way analysis of variance (ANOVA) for the subject effects (mix ratio and cement brand) of the minimum soaked strengths of sandcrete hollow blocks presented in Table 4.7.

Table 4.10: Two way ANOVA Tests of Between-Mix Ratio and Cement Brand Effects

Source	Sum of Squares	df	Mean Square	F	Sig.
Cement Brand	1.047	6	.175	6.029	.000
Mix Ratio	9.367	8	1.171	40.442	.000
Error	1.390	48	.029		

Total	63.069	62				

R Squared = .882 (Adjusted R Squared = .848)

Results indicated that there was significant difference between the mean minimum soaking strengths of the blocks for different mix ratios and so the null hypothesis was rejected. For the different cement brands, there was no significant difference between the mean minimum soaking strengths of the blocks. Therefore, the null hypothesis was accepted. Therefore, it was concluded that the minimum soaking strength depends on the mix ratio of the blocks. For the subject effects (mix ratio and cement brand) there was significant difference between the mean minimum soaking strengths of the blocks. Therefore, the null hypothesis was rejected. Therefore, it was concluded that the minimum soaking strength depends on the subject effects.

There were observed differences between the minimum soaking strengths of the blocks made from the cement brands A, B, C, D, E, F and G at the same ratio in Table 4.8, yet the result of the analysis of variance carried out indicated that the differences were not significant.

The differences may be attributed to the deficiencies observed in the oxides and chemical compound compositions of some of the cement brands, experimental errors and differences in the ages of the cement brands which were unknown to the researcher. It can be concluded from analysis of variance that the minimum soaking strength of the sandcrete hollow block was independent of the brand of cement used.

4.4.12 Dry density development of 9” sandcrete hollow blocks

The results of the dry density development for the 9” sandcrete hollow blocks at mix ratios of 1:4 to 1:12, presented in chapter three, pages 97 to 100, Tables 3.30 to 3.36 were plotted. The bulk densities of the sandcrete hollow blocks increased up to maximum values at 14 days curing age after which they reduced slightly as shown in Figures 4.34 to 4.40.

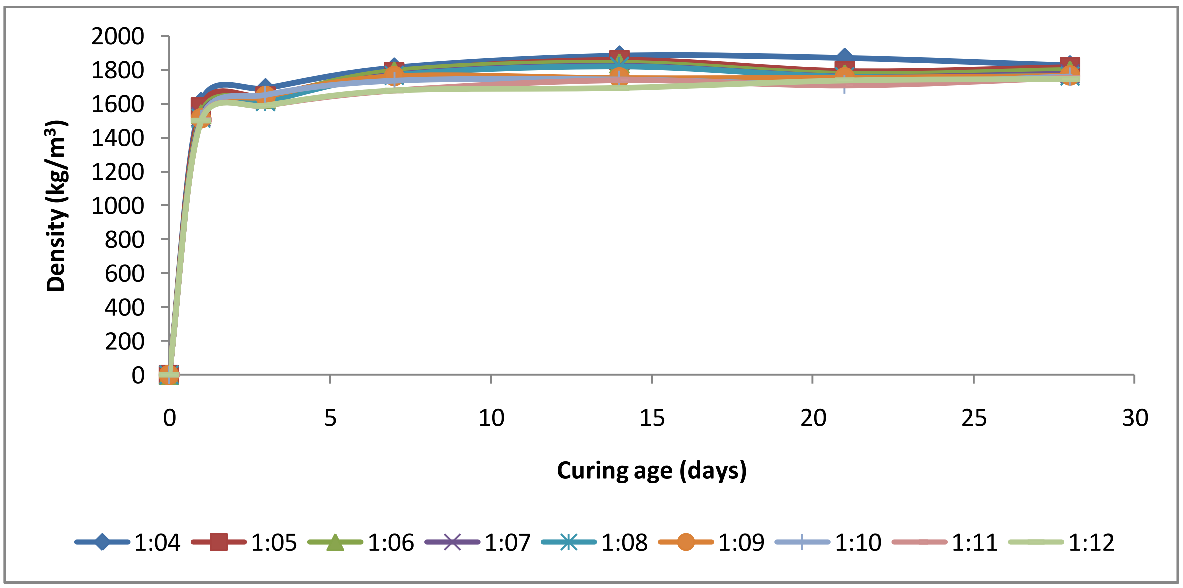

Figure 4.34: Dry Density Development for Cement Brand A- 9'' Sandcrete Hollow Blocks

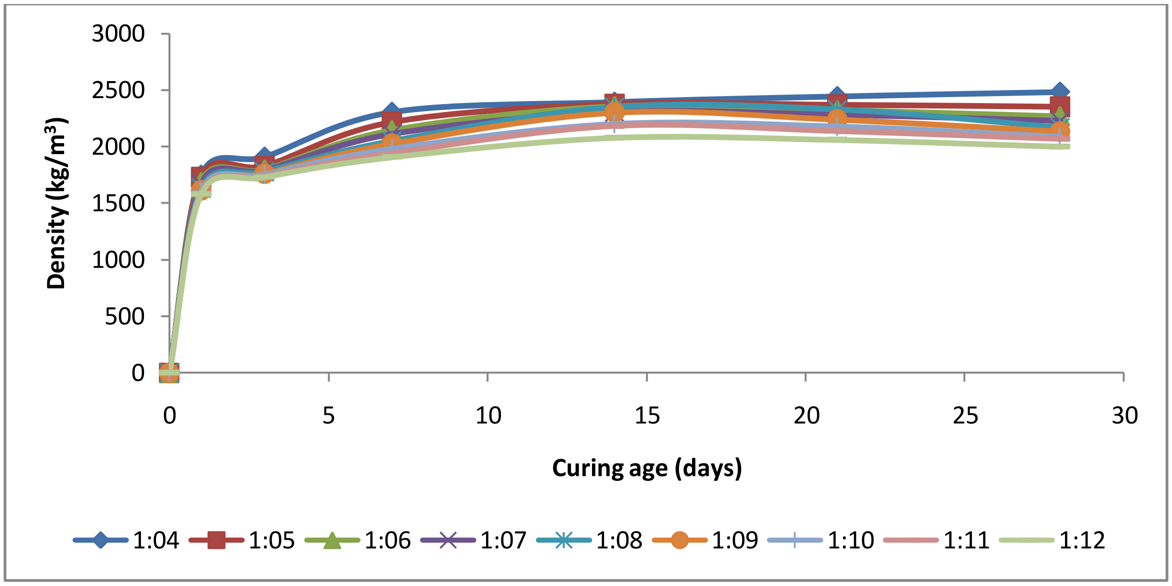

Figure 4.35: Density Development for Cement Brand B - 9'' Sandcrete Hollow Blocks

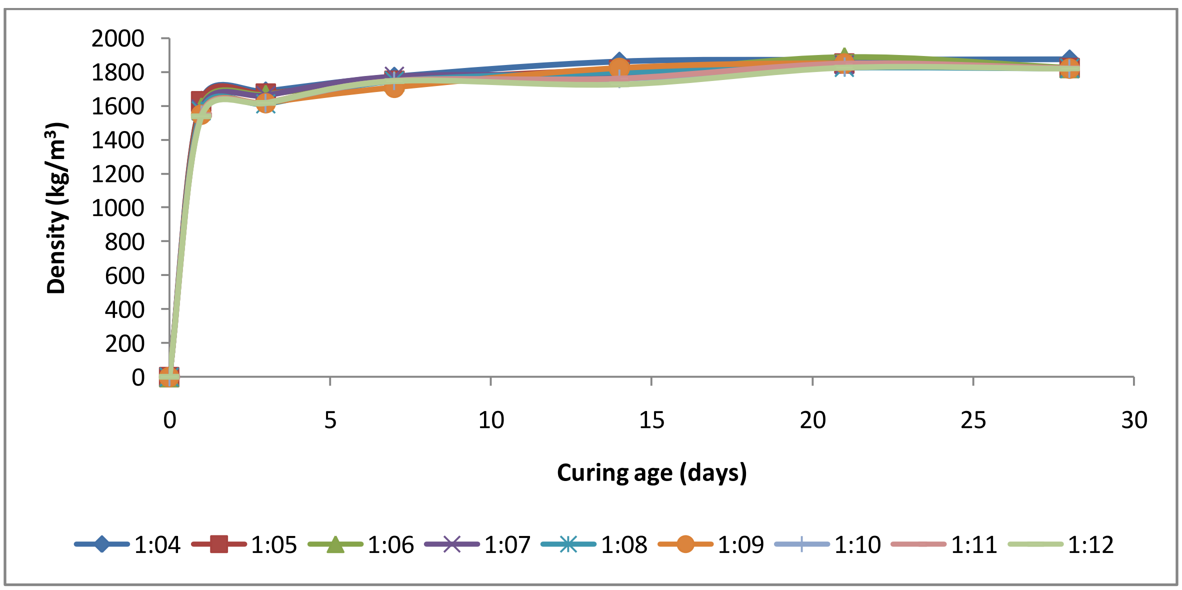

Figure 4.36: Dry Density Development for Cement Brand C - 9'' Sandcrete Hollow Blocks

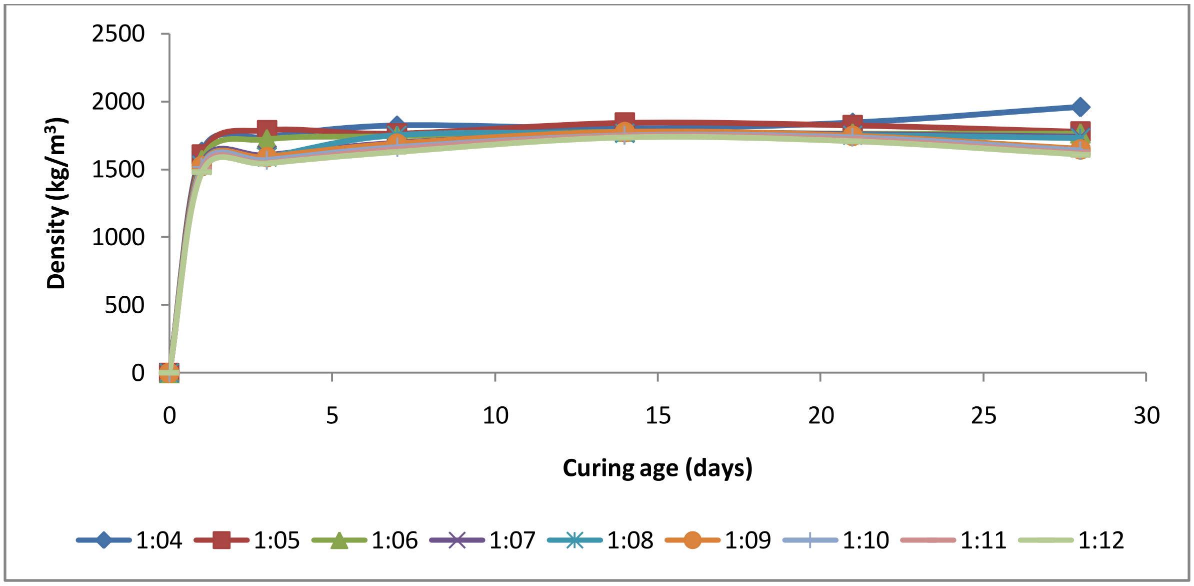

Figure 4.37: Dry Density Development for Cement Brand D - 9'' Sandcrete Hollow Blocks

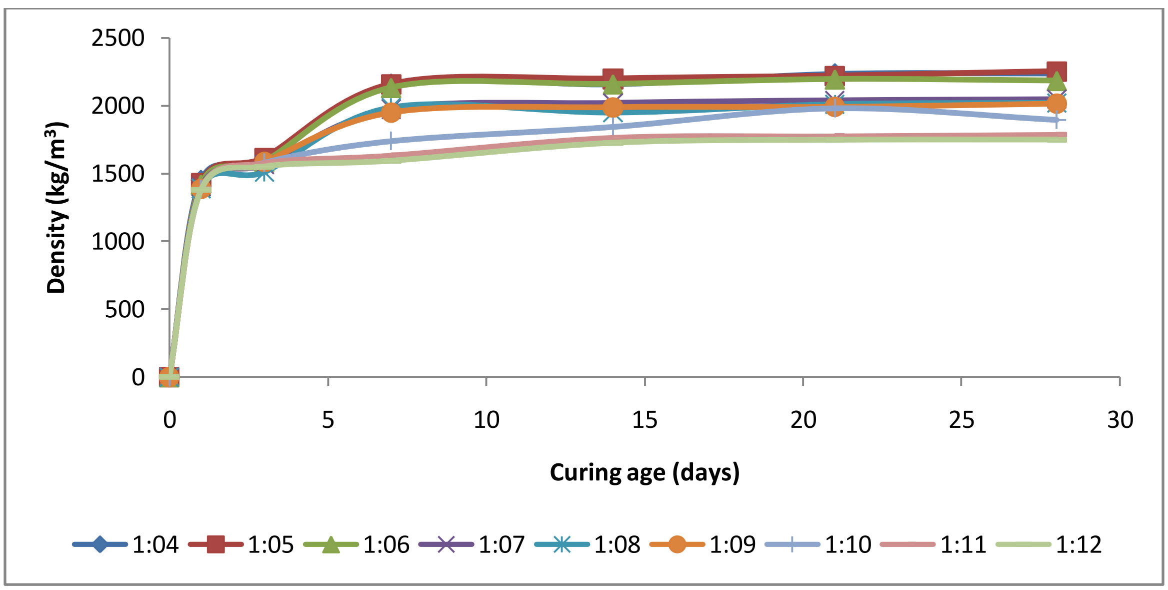

Figure 4.38: Dry Density Development for Cement Brand E -9'' Sandcrete Hollow Blocks

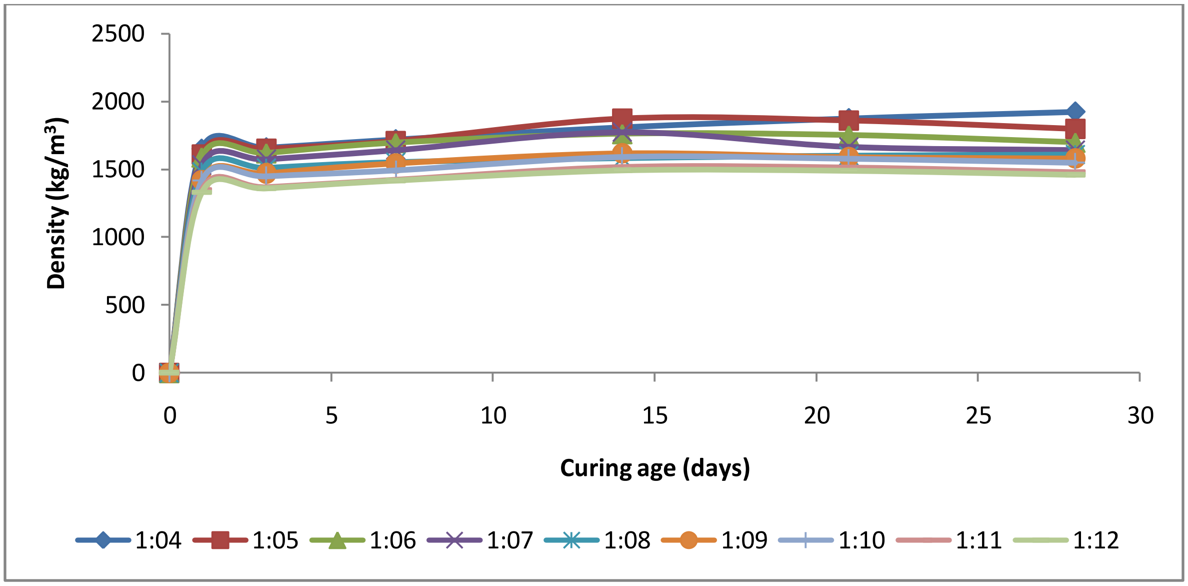

Figure 4.39: Dry Density Development for Cement Brand F - 9'' Sandcrete Hollow Blocks

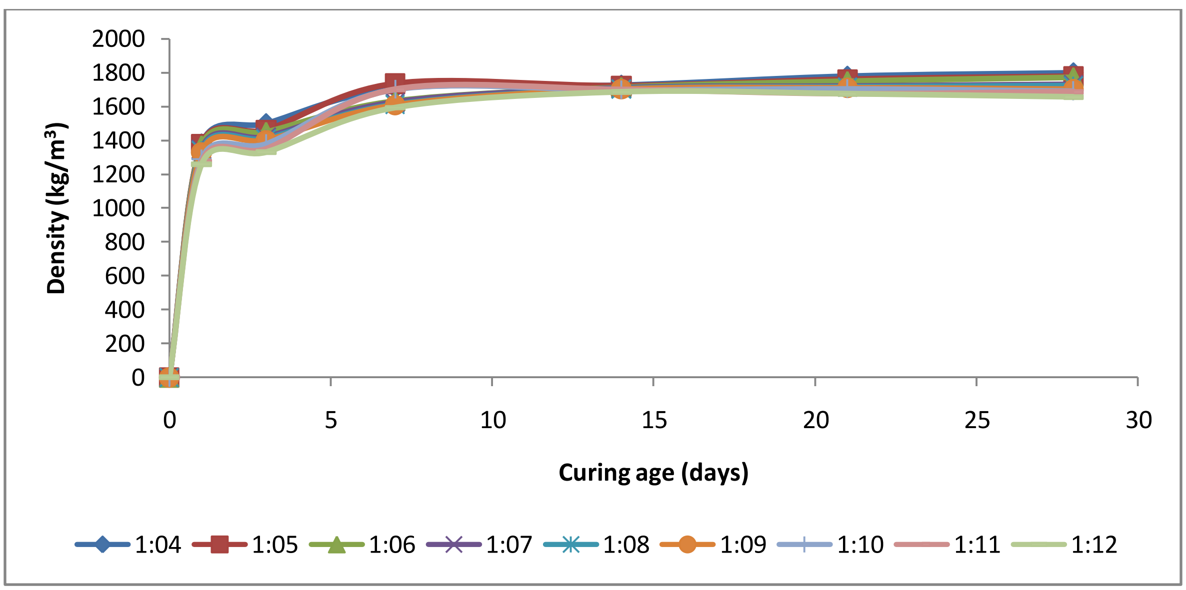

Figure 4.40: Dry Density Development for Cement Brand G - 9'' Sancrete Hollow Blocks

This trend was observed in the sandcrete hollow blocks made from cement brands A, B, D, and E. The blocks satisfied the NIS 87:2004 and BS 2028: 1985 standard minimum density of 1500 kg/m^3.

4.4.13 Wet density development of 9” hollow blocks made with vibrating machine

The results of the wet density development of the blocks were presented in chapter three, pages 100 to 103, Tables 3.37 to 3.43. The wet density development test was conducted by curing the blocks in the dry state by spraying with water for 28 days and then immersed in water for another 28 days. Therefore, the 28-day dry density was the initial density instead of zero. The wet density development of the 9” hollow blocks made from the cement brands A, B, C, D, E, F and G compacted with vibrating machine are presented in Figures 4.39 to 4.45. The 28-day dry densities at different mix ratios were used as the initial wet densities. The figures indicate that the critical soaking period occurred after one day, thus confirming those obtained from compressive strengths development.

The wet density development test was conducted by curing the blocks in the dry state by spraying with water for 28 days and then immersed in water for another 28 days. Therefore, the 28-day dry density was the initial density instead of zero. The wet density development of the 9” hollow blocks made from the cement brands A, B, C, D, E, F and G compacted with vibrating machine are presented in Figures 4.41 to 4.47.

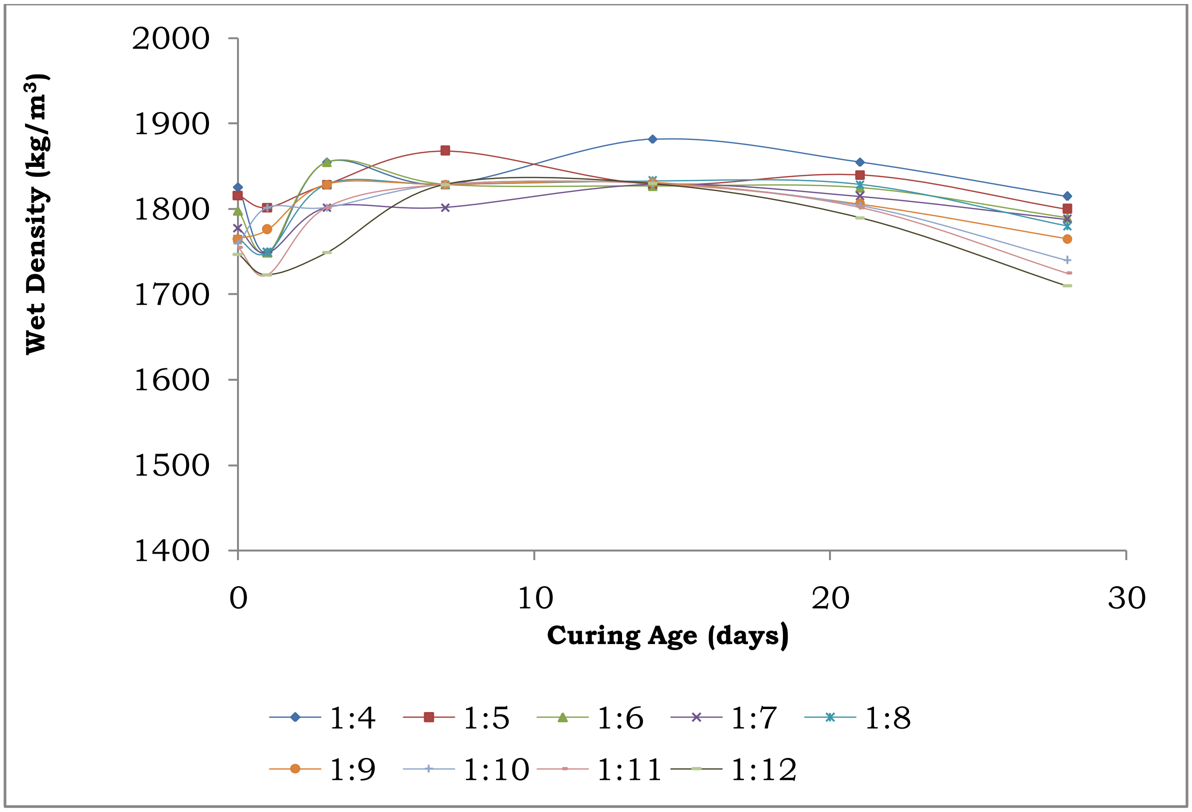

Figure 4.41: Wet Density Development for Cement Brand A -9'' Sandcrete Hollow Blocks

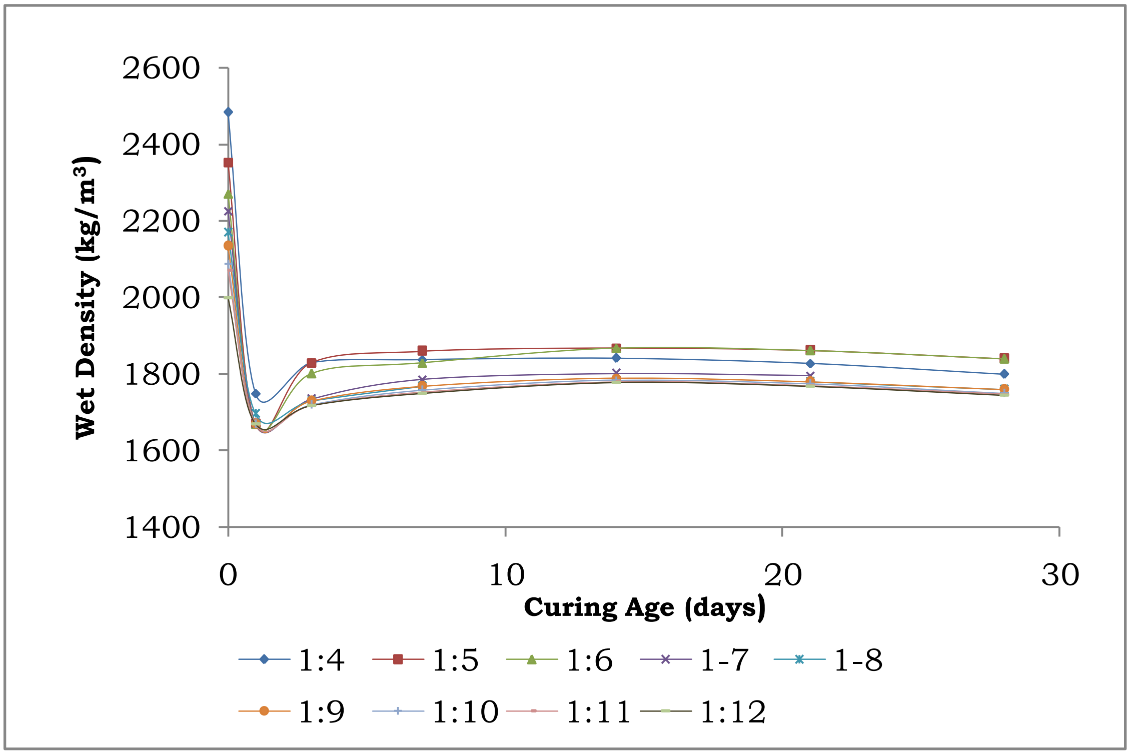

Figure 4.42: Wet Density Development for Cement Brand B- 9'' Sandcrete Hollow Blocks

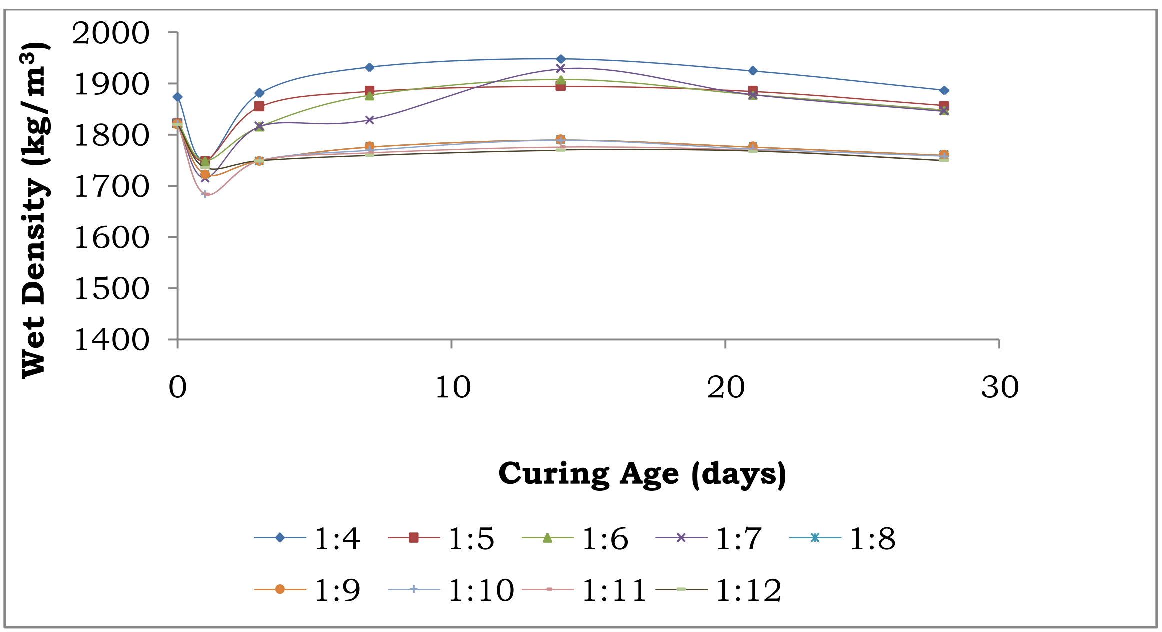

Figure 4.43: Wet Density Development for Cement Brand C- 9'' Sandcrete Hollow Blocks

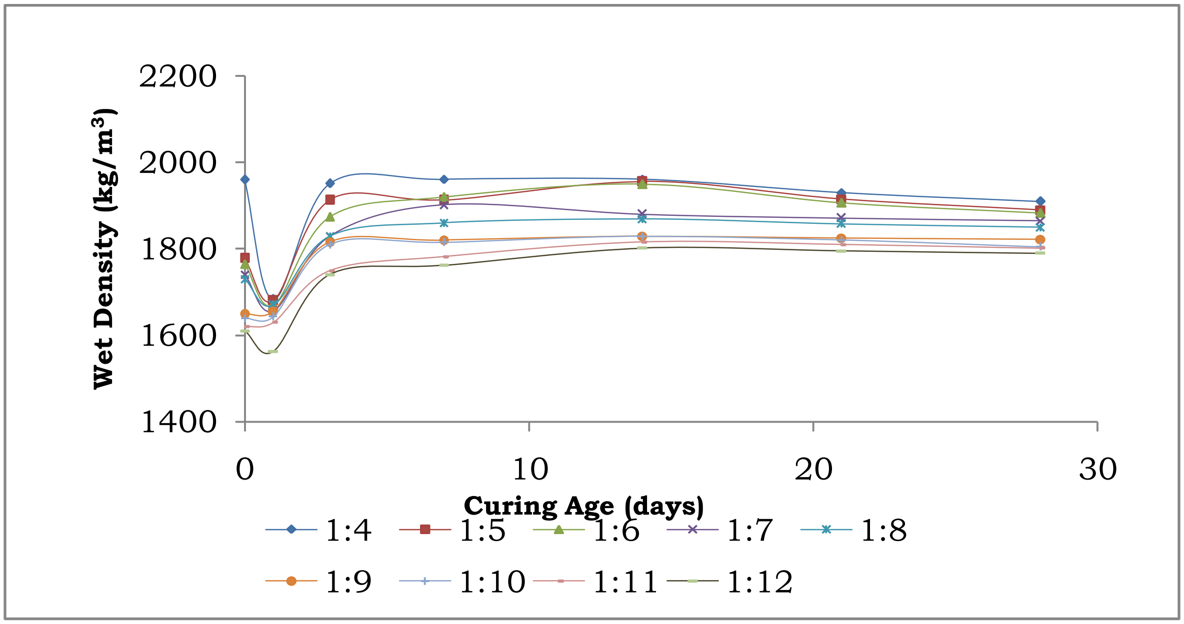

Figure 4.44: Wet Density Development for Cement Brand D-9'' Sandcrete Hollow Blocks

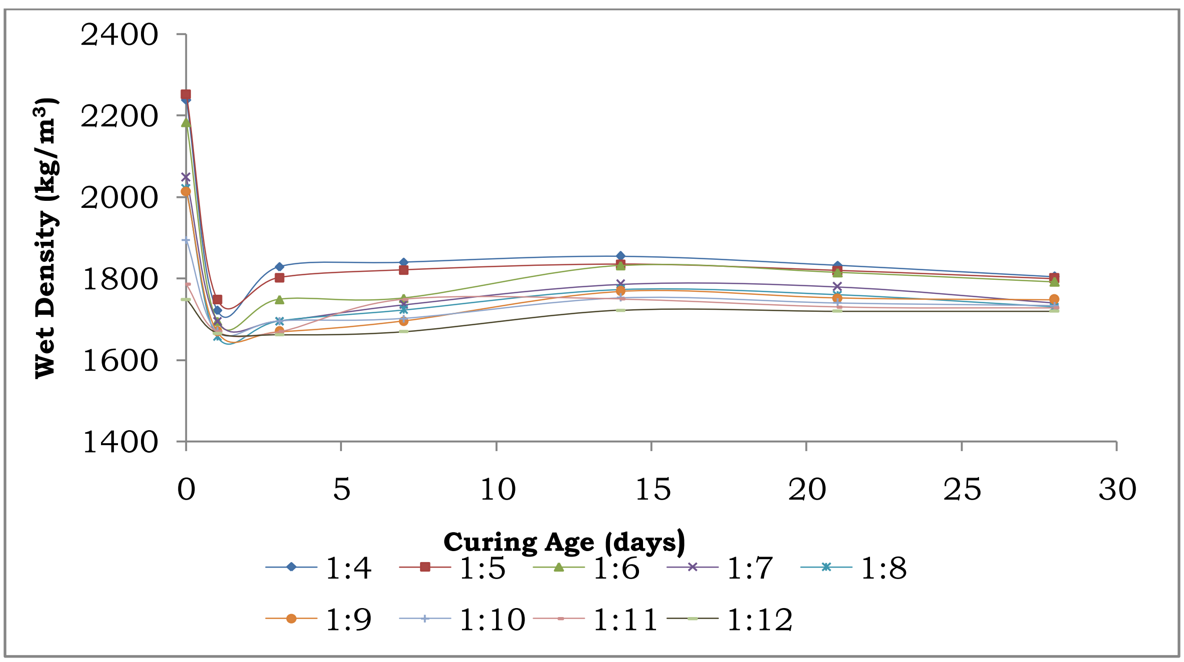

Figure 4.45: Wet Density Development for Cement Brand E- 9'' Sandcrete Hollow Blocks

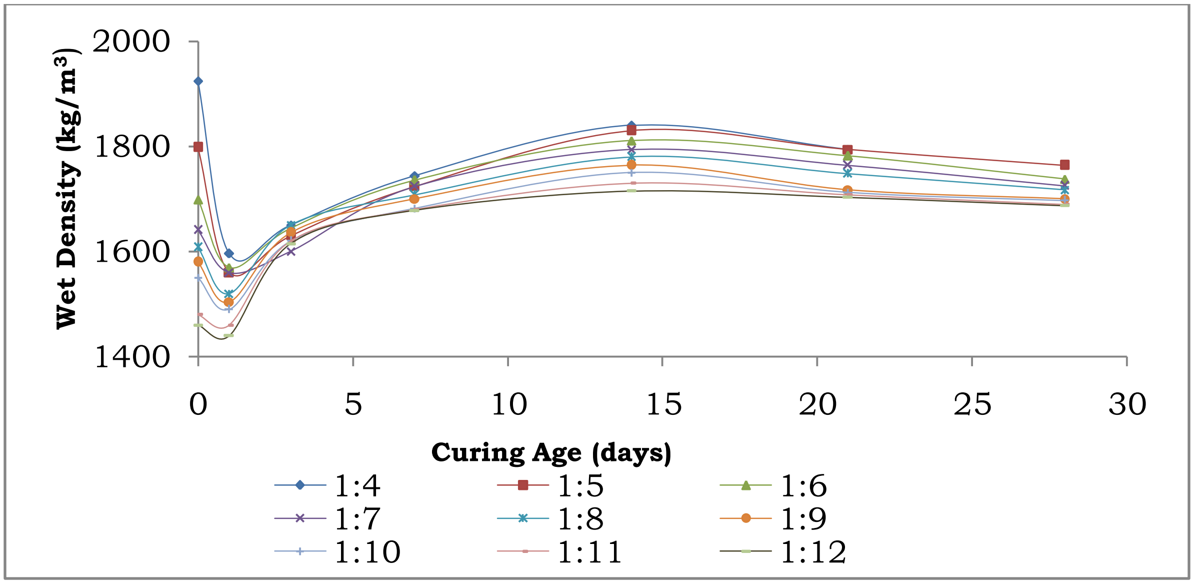

Figure 4.46: Wet Density Development for Cement Brand F- 9'' Sandcrete Hollow Blocks

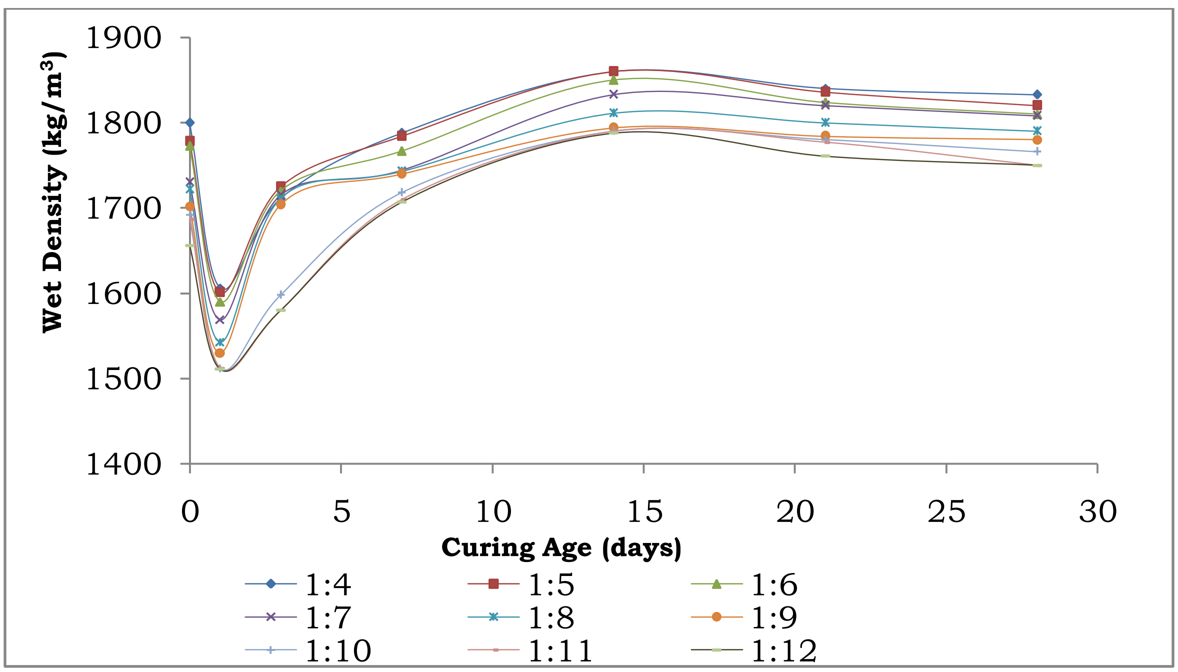

Figure 4.47: Wet Density Development for Cement Brand G- 9'' Sandcrete Hollow Blocks

The minimum soaking density was experienced after one day soaking period for all mix ratios and blocks from the seven brands.

4.4.14 Water absorption of blocks

The water absorptions test of the blocks was presented in chapter three, page 104, Table 3.44. Results indicated that the average water absorptions of the blocks produced from the seven brands of ordinary Portland cement were in the range 4.69 to 7.32%. According to NIS 87: 2004, the average water absorption should be less than 12%. For ASTM C140: 2001 the average water absorption should be less than 240kg/m^3. The values obtained were in the range of 79 to 118.5kg/m^3. Thus, the 9" hollow sandcrete blocks produced by compacting with vibrating machine passed the water absorption test.

4.4.15 Estimation of cost of producing sandcrete hollow block

The cost implication of producing standard sandcrete hollow blocks is an important factor in ensuring compliance by the block industries. This will determine the affordability and level of patronage of the product from the industries by the users. The cost estimates of a block produced at mix ratios of 1:6, 1:8, 1:10 and 1:12 were determined as presented in Table 4.11.

According to the standard, the mix ratio specified for making a sandcrete hollow block is 1:6. That is, one part of cement to six parts of sand either by weight or volume. The mix ratio of 1:6 to 1:8 is recommended by this study.

Table 4.11: Estimation of the Cost of Producing a Sandcrete Hollow Block

Mix Ratio	No. of blocks produced per 50kg cement bag	No. of bags of cement per tipper load	Total No. of blocks produced per tipper load of sand (₦)	Cost of sand per tipper load (₦)	Cost of cement per tipper load (₦)	Cost of water per tipper load (₦)	Total cost of materials per tipper load (₦)	Cost of materials per block (₦)	Cost of Labour per block (₦)	Total cost of producing a block (₦)
1:6	15	10	150	12000	17000	225	29225	194	20	205
1:8	20	7.5	150	12000	12750	168.75	24919	166	20	186
1:10	25	6	150	12000	10200	135	22335	149	20	169
1:12	30	5	150	12000	8500	113	20613	137	20	157

The cost of producing a standard sandcrete hollow block was estimated to be N205 while its average compressive strength from this study is 4.50N/mm^2 at mix ratio of 1:6. By using mix ratios of 1:8, 1:10 and 1:12, the cost of producing a sandcrete hollow block is reduced as the cement content (the most expensive component) is reduced. The corresponding average compressive strengths of the block at the three mix ratios are reduced. Table 4.12 shows the computations of the reduction in cost of production of a sandcrete hollow block and reduction of its average compressive strengths at mix ratios of 1:8, 1:10 and 1:12.

Table 4.12: Computation of Percentage Reduction in Cost of Production and Strength of Sandcrete Hollow Block

Mix ratio	Cost of production of a block	compressive strength of block	Reduction in cost of block	Reduction in compressive strength of block	Percentage reduction in cost of production of block	Percentage reduction in compressive strength of block
1:6	205	4.50	0	0	0	0
1:8	186	3.80	19	0.7	9.3	15.6
1:10	169	2.54	36	1.96	17.56	43.6
1:12	157	1.58	48	2.92	23.4	64.0

The Figure 4.48 shows the plot of percentage reduction in strength of the sandcrete hollow block versus reduction in its cost of production from the standard at mix ratio of 1:6. A linear relationship between the percentage reduction in cost of production of block (x) and the percentage reduction in its strength (y) given by:

$$y = 2.55x$$

was established. The coefficient of determination was 0.96. This means that for every 1% reduction in cost of producting one block by reducing its mix ratio from the standard value of 1:6, there is a corresponding reduction in its compressive strength of 2.55%, provided that all other factors are adequate and constant.

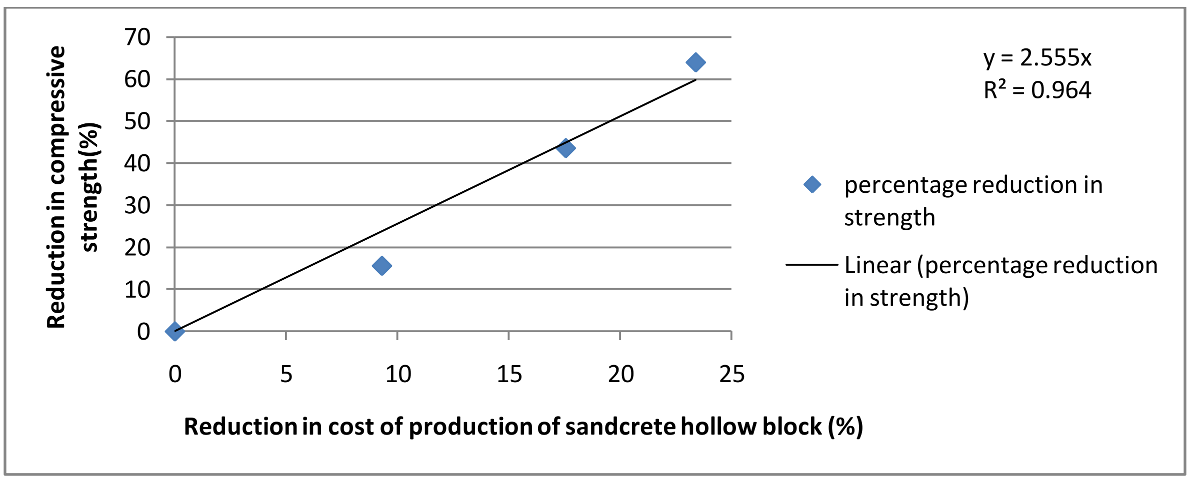

Figure 4.48: Percentage Reduction in Compressive strength of sandcrete Hollow Block versus Percentage Reduction in its Cost of Production

The current Prices of cement brands A, B, C, D, E, F and G and the corresponding cost of producing a sandcrete block at mix ratios 1:6, 1:8, 1:10 and 1:12 are presented in Table 4.13.

Table 4.13: Unit Cost of a Sandcrete Hollow Block Produced from Cement Brands

Cement Brand	Prices per 50kg bag of Cement (₦)	Mix Ratio 1:6	1:8	1:10	1:12
		Cost of producing a block (₦)			
A	1900	208	185	165	155
B	2000	225	190	170	155
C	2000	225	190	170	155
D	1700	208	175	160	150
E	2000	225	190	170	155
F	1900	208	185	165	155
G	2000	225	190	170	155

The cost of production of a sandcrete hollow block from imported cement is slightly higher than the block produced from local cement brands. The block produced from cement brand D was the cheapest though its compressive strength is comparatively low. Cement brand A- block strikes a balance between strength and cost of production.

4.5 Coarse Aggregate

4.5.1 Physical characterization of coarse aggregate - test results

The tests for coarse aggregate were carried out in chapter three, page 107, Table 3.46.

The results of the aggregate physical properties are shown in Figure 4. 49

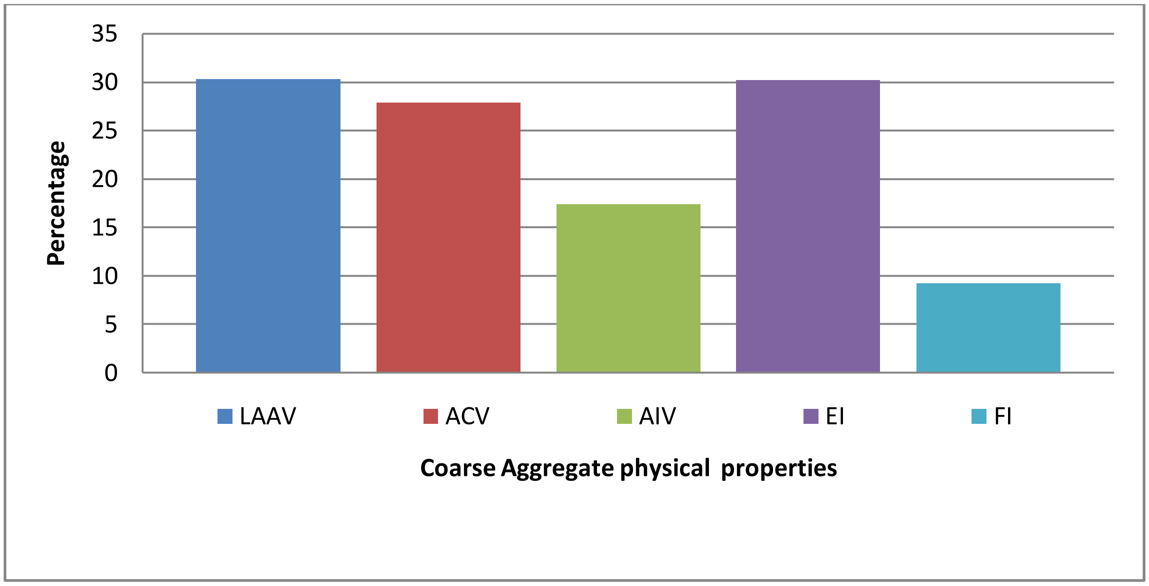

Figure 4.49: Physical Properties of Tested Coarse Aggregate.

(a) Specific gravity of the coarse aggregate test result

The coarse aggregate used for the test was from granite rock. The specific gravity of granite rock ranges from 2.6 to 3.0 with an average value of 2.69 (Neville, 2012). The average specific gravity of the granite used was 2.62. Although, the result fell within the range, it is considered to be low.

(b) Los Angeles abrasion value (LAAV) of coarse aggregate test result

The LAAV is one of the measures of the resistance to fragmentation and wear of the coarse aggregates in concrete. The LAAV of the tested aggregate was 30.34%. The maximum allowable Los Angeles abrasion value is 30% (BS EN 12620:2013) for natural aggregates. The LAAV of the tested aggregate was slightly higher but it was within acceptable range.

(c) Aggregate crushing value (ACV) of coarse aggregate test result

The aggregate crushing value is also one of the measures of the resistance to fragmentation of aggregates in concrete. The maximum value specified in BS EN 12620: 2013 is 30%. The test value of 27.90% was therefore considered adequate. Thus, the tested aggregate passed the ACV test.

(d) Aggregate impact value of coarse aggregate (AIV) test result.

This test is the third measure of resistance to fragmentation of coarse aggregates. The maximum allowed by BS EN 12620: 2013 is 30%. The AIV of the tested coarse aggregate was 17.39%. Thus, the tested coarse aggregate satisfied the standard.

(e) Elongation index of coarse aggregate test result

The elongation index is one of the geometrical requirements of coarse aggregate particles. The maximum value of the elongation index specified by the BS EN 12620:2013 for natural coarse aggregate used for concrete is 35%. The result showed that the elongation index of the tested coarse aggregate was 30.19%. The coarse aggregate passed the elongation index test.

(f) Flakiness index of coarse aggregate test result

The flakiness index is another geometrical requirement of coarse aggregate particles. The BS EN 12620:2013 specifies the maximum flakiness index of natural coarse aggregate for concrete as 30%. The tested coarse aggregate met the standard requirement.

(g) Sieve analysis of coarse aggregate test result

The sieve analysis was carried out in chapter three, page 108, Table 3.47 for coarse aggregate of norminal size of 20mm. The grading curve falls within the lower and upper limits stipulated by BS EN 12620: 2006 for natural coarse aggregate of nominal size of 20mm as shown in Figure 4.50. Thus, the results of the resistance to fragmentation, geometrical requirements and grading curve of the natural coarse aggregate tested show that it is suitable for concrete work.

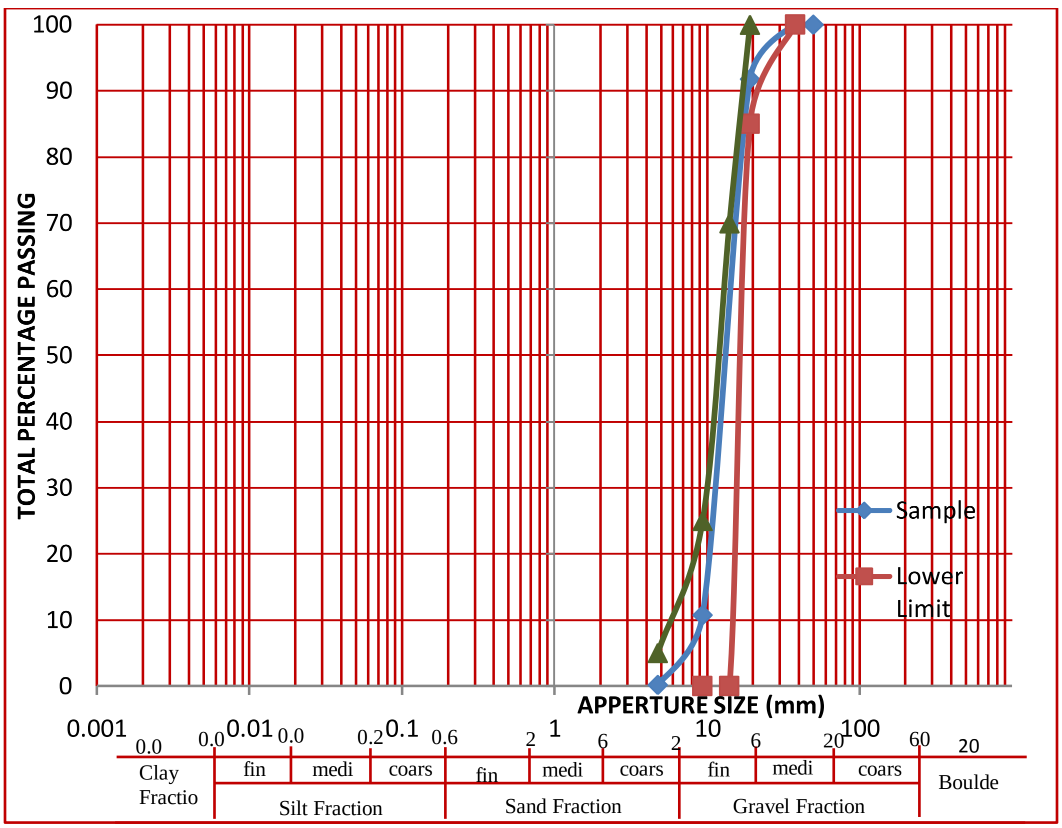

Figure 4.50: Grading Curve of Tested Natural Coarse Aggregate

4.5.2 Chemical characterisation of the coarse aggregate

The chemical characterization tests such as soundness, chloride content and sulphate contents were carried in chapter three, page 109, Table 3.48.

(a) Soundness of coarse aggregate

This test is one of the measures of the durability of the coarse aggregates. The soundness of the coarse aggregate test is the percentage of the aggregate broken up as a result of its five cycles of immersion in a saturated magnesium sulphate solution alternating with oven drying (Neville, 2012). The standard requirement (BS EN 12620: 2013) is that it should not be less than 94% (6% loss in mass). The test result obtained was 98.8% or (1.2% loss in mass). Thus, the coarse aggregate was sound.

(b) Chloride content in coarse aggregate

The standard (BS EN 12620: 2013) specifies a maximum chloride content of 0.05%. Test result indicated that the chloride content of the coarse aggregate was 0.25%. Thus, the coarse aggregate did not pass the chloride test. The chloride may pose a danger of corroding the steel reinforcement and the chloride salt may also absorb moisture from the air and cause effervescence, unsightly white deposits on the surface of the concrete (Neville, 2012).

(c) Sulphate content in course aggregate

The maximum sulphate content specified in BS EN 12620: 2013 is 0.08%. The test result reveals that the sulphate content was 0.08%. The coarse aggregate passed the sulphate content test.

4.6 Concrete Tests

The concrete test include fresh concrete tests and hardened concrete tests on concretes produced from the seven brands of cement A, B, C, D, E, F and G. The fresh concrete tests conducted in chapter three, page 117 were consistence test using slump test and compaction factor test. The hardened concrete test conducted was concrete cube strength test.

4.6.1 Slump and compaction factor test results

The slump test on the fresh concretes produced from the seven cement brands were presented in chapter three, page 110, Table 3.49. The slump test results were less than 50mm and were satisfactory. The compaction factors were adequate.

4.6.2 Concrete cube strength of cement brands.

The results of the cube strengths of the cement brands A, B, C, D, E, F and G were presented in chapter three, page 81, Table 3.9. The compressive strength developments of the concrete cubes from the seven cement brands are shown in Figure 4.51.

The Figure 4.49 shows that the concretes produced from cement brands B and C had their 28-day compressive strength exceeding the minimum international standard (BS EN 206- 1:2000) strength of 30 N/mm^2. The concretes produced from cement brands A, D, E and F had their 28-day compressive strength 29.66, 29.81, 29.40 and 29.34 N/mm^2 respectively which are above the 95% acceptable limit of 28.5N/mm^2. The concrete produced from cement brand G had 28-day compressive strength of 28.07 N/mm^2 which is below the acceptable limit and hence did not meet the standard.

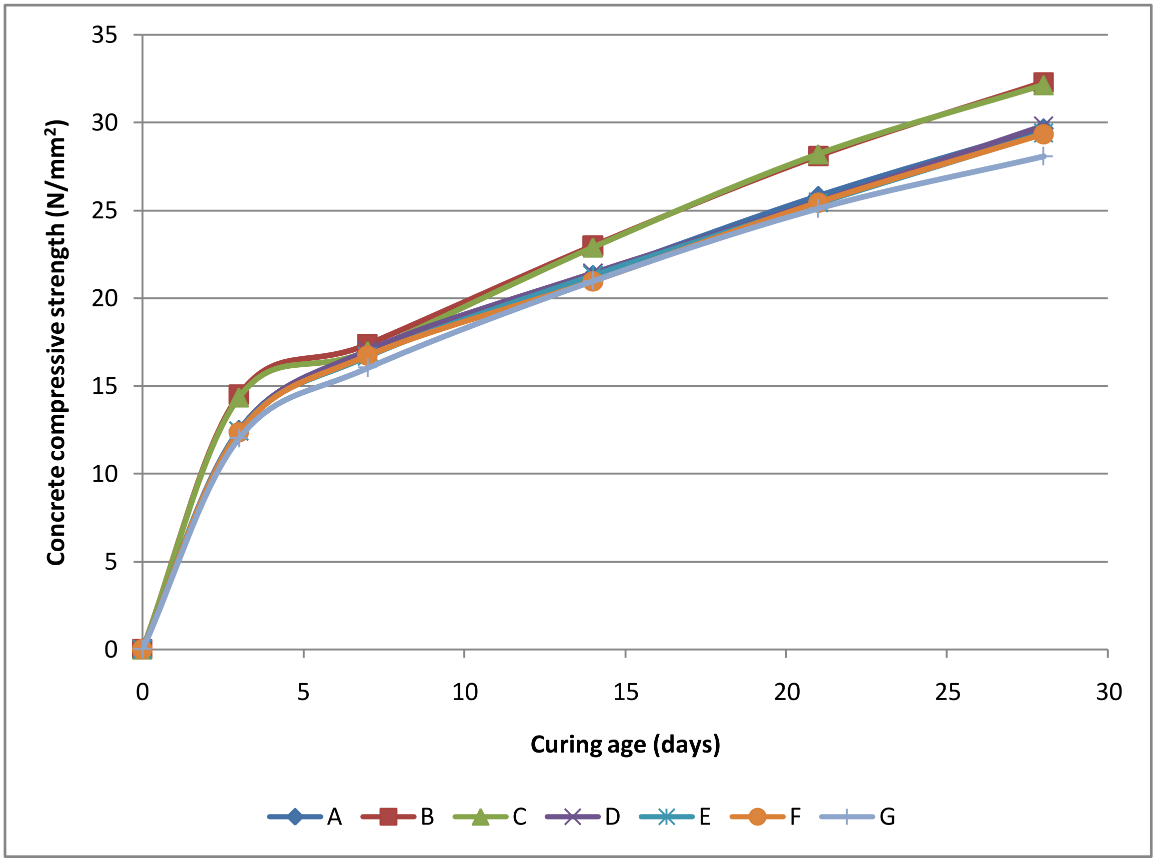

Figure 4.51: Compressive Strength Development of Concrete Cubes of Cement Brands

4.6.3 Comparison of compressive strength of concrete cubes with standard

Only concrete cubes from cement brands B and C had compressive strength higher than the 30N/mm^2 minimum strength specified by BS EN 206 part 1: 2000 at 28-day curing age for concrete cube of class C 25/30. C 25/30 means 28-day concrete cylinder strength of 25N/mm^2 and a corresponding concrete cube strength of 30 N/mm^2. The 28-day strength of the concrete produced from cement brands A, D, E and F are slightly lower than 30 N/mm^2 but are within acceptable limit (28.5N/mm^2). Therefore, blocks from cement brands A, B, C, D, E, and F satisfy the BS EN 206-1:2000 at 28 days curing age. The concrete cubes produced from cement G did not met the BS EN 206-1: 2000 specification. This is attributed to the very low C_3S, the negligible content of C_3A and extremely high C_2S content of cement G. All these factors contributed to the slow rate of hydration and hence the low strength of concrete cubes produced from cement brand G.

4.6.4 Performance of the seven cement brands in concrete and sandcrete block production

The cement brand B –concrete cubes were observed to have the highest strengths compared to the cubes of the rest six cement brands. This may be attributed to the fact that it was the only cement brand that met the standard compositions by mass of the cement compounds C_3S, C_2S, C_3A and C_4AF. Thus its performance in both sandcrete hollow block and concrete was the best. The concrete produced from cement brand C had the second highest compressive strengths. The sandcrete blocks produced from cement brand C had the third highest compressive strengths.

Concrete cubes produced from cement brand D gave the third highest concrete strength. This may be attributed to the high content of C_3S in the cement while its C_2S content was low. The performance of cement D in sandcrete hollow block was low.

The concrete produced from cement brand A maintained the same fourth position as in sandcrete hollow blocks in terms of strength. Thus cement brand A is suitable for both concrete and sandcrete production.

The concrete produced from cement brand E had the fifth strength out of the seven cement brand concretes tested. This may be attributed to its very low C_3A content. The performance of the cement in sandcrete was however high.

The performance of concrete made from cement brand F was low in both concrete and sandcrete hollow block. The performance of cement G was the least in concrete, however its performance in sandcrete block was high. The performances of the seven cement brands in concrete and sandcrete hollow blocks are summarized in Table 4.14.

Table 4.14: Ranking of Cement Brands in the Order of Performance in Concrete and Sandcrete Hollow Block Strengths

S/N	Cement brand	Rank in Concrete Cube strength	Rank in Sandcrete Hollow Strength	Sum of ranks	Overall Rank
	A	4	4	8	4
	B	1	1	2	1
	C	2	3	5	2
	D	3	6	9	5
	E	5	2	7	3
	F	6	7	13	7
	G	7	5	12	6

Thus, the performances of the seven cement brands studied in descending order of strength in both concrete cube and sandcrete hollow block tests were:

B > C > E > A > D > G > F

The implication of this analysis is that the imported cement brands (B, C and E) produced concretes and sandcrete hollow blocks of greater compressive strengths than the locally produced cement brands (A, D, G and F). This is attributed to the fact that none of the local cement brands met both standard specifications of the two calcium silicates (C_3S and C_2S) compound compositions. The relative performances of the seven cement brands in terms of strengths are depicted in Figure 4.52.

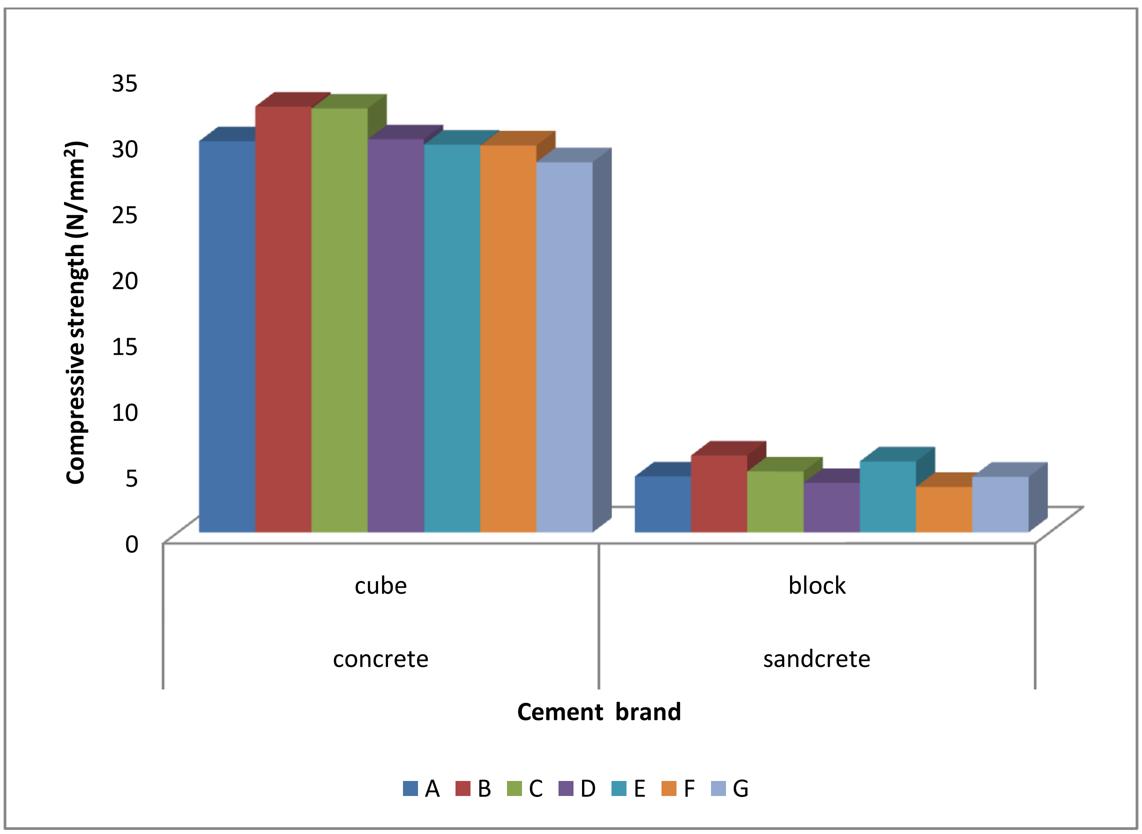

Figure 4.52: Strength Performance of Cement Brands in Concrete and Sandcrete Hollow Block

4.6.5 Density development of concrete

The density test results were presented in chapter three, page 110, Table 3.50. The density developments of the concrete cubes produced from cement brands A, B, C, D, E, F and G are presented in Figures 4.53 to 4.59.

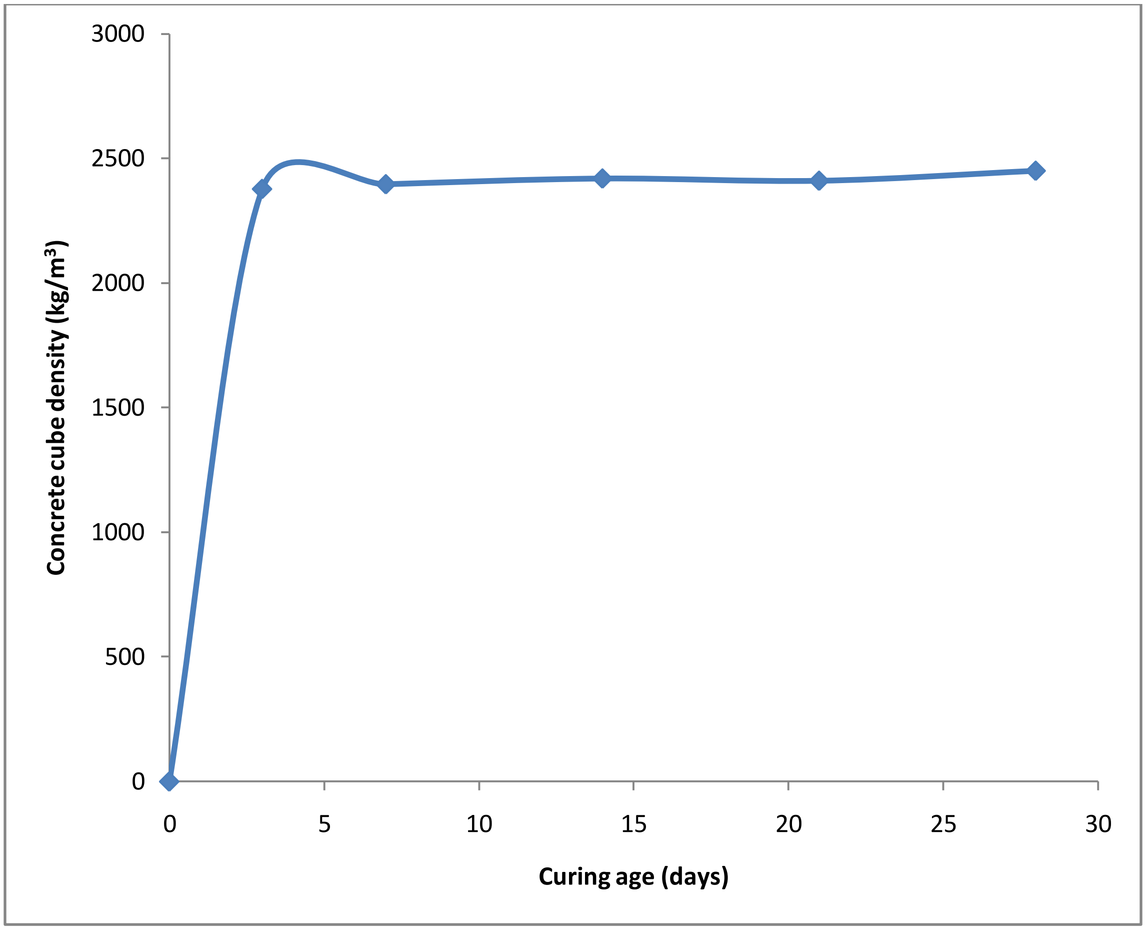

Figure 4.53: Density Development of Concrete Cubes Produced from Cement Brand A

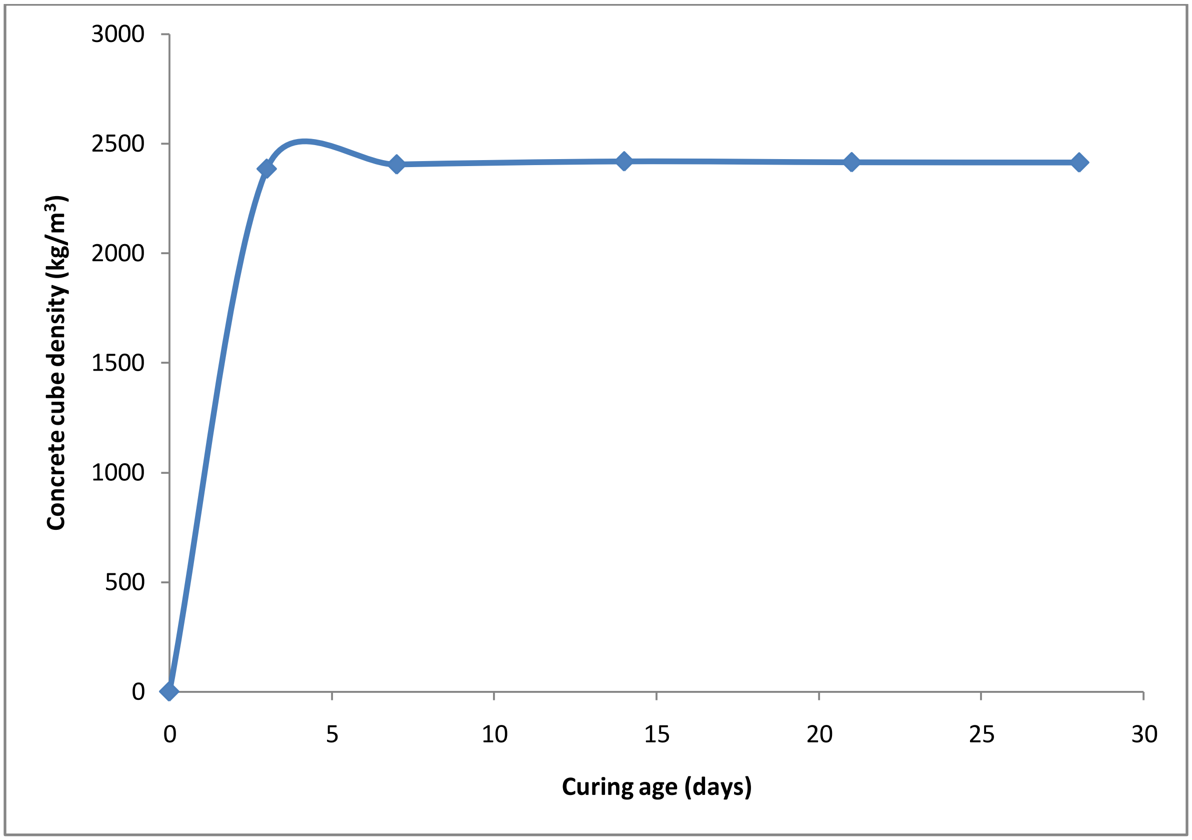

Figure 4.54: Density Development of Concrete Cubes Produced from Cement Brand B

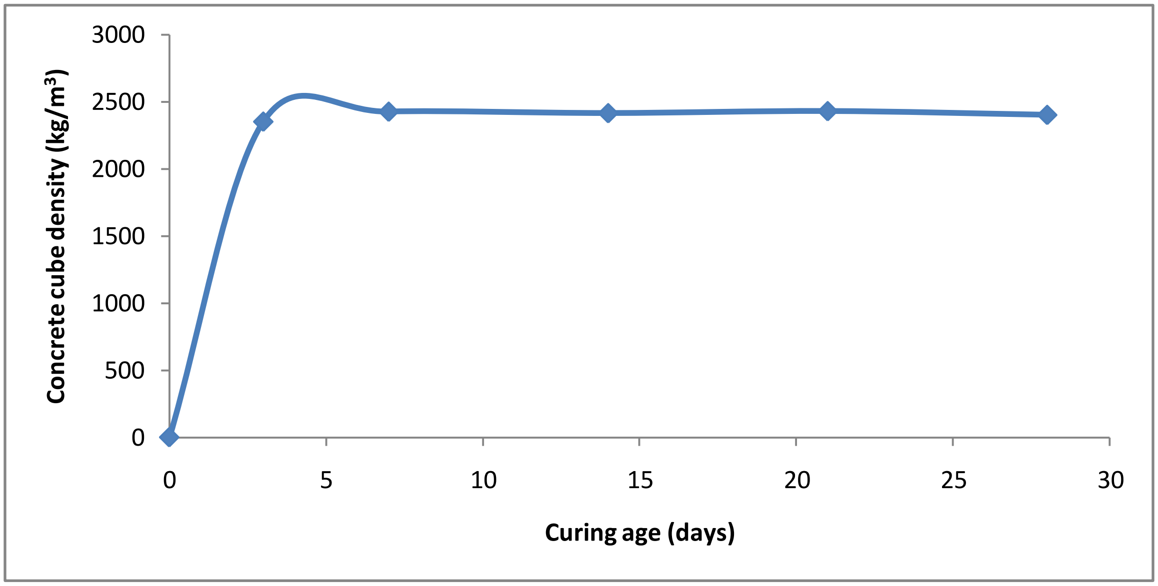

Figure 4.55: Density Development of Concrete Cubes Produced from Cement Brand C

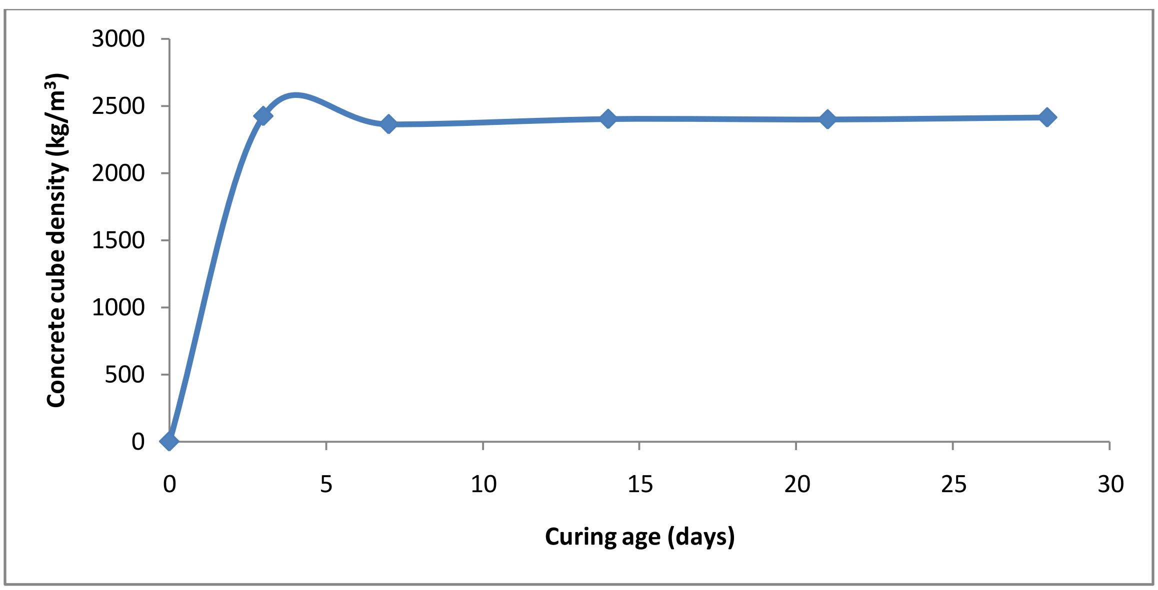

Figure 4.56: Density Development of Concrete Cubes Produced from Cement Brand D

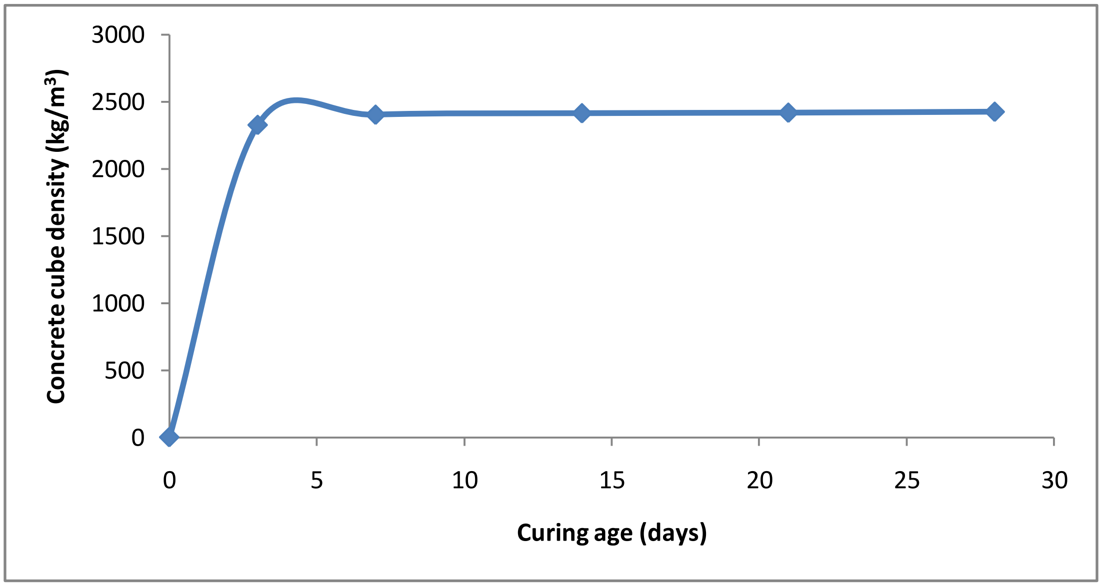

Figure 4.57: Density Development of Concrete Cubes Produced from Cement Brand E

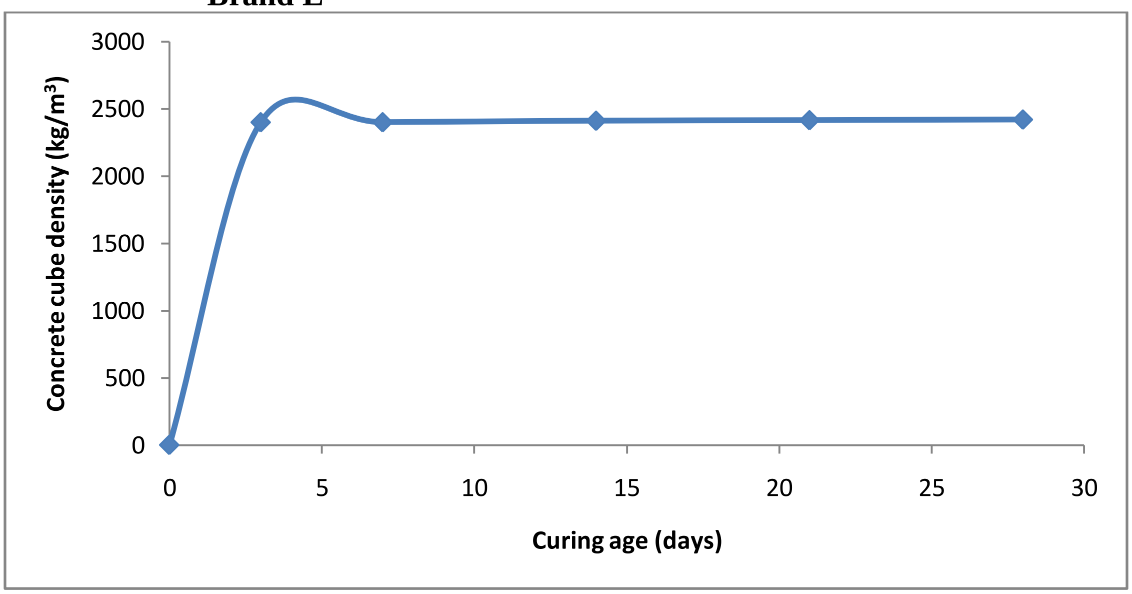

Figure 4.58: Density Development of Concrete Cubes Produced from Cement Brand F

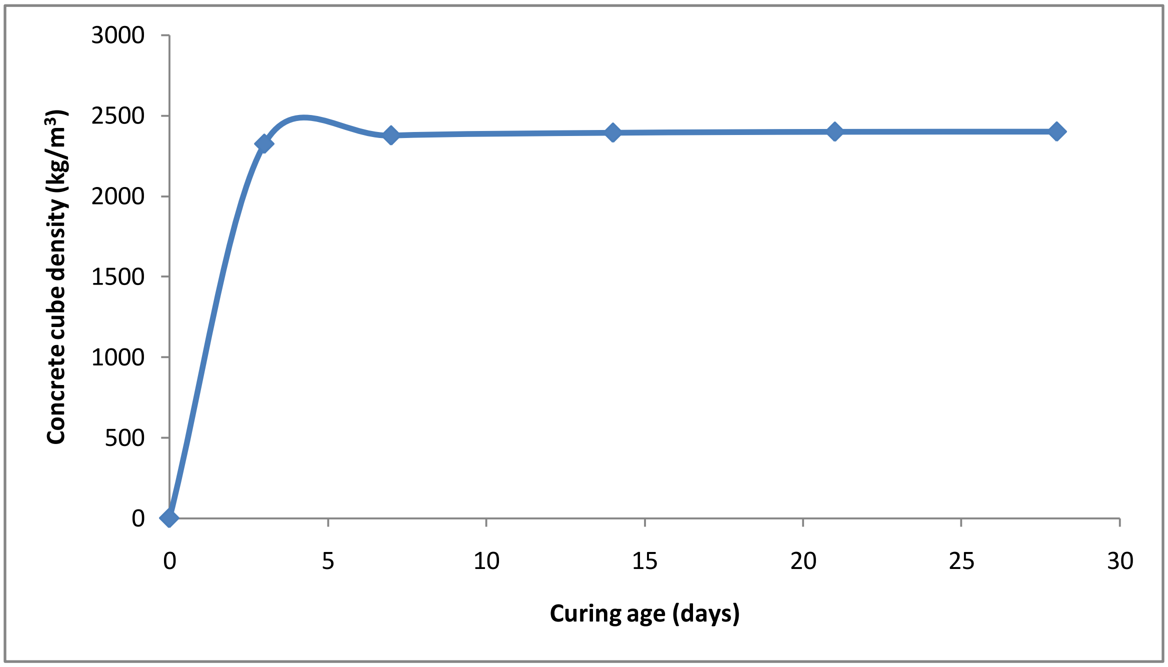

Figure 4.59: Density Development of Concrete Cubes Produced from Cement Brand G

The concrete density development curves of the seven brands of cements are similar and the average density of the concrete cubes was 2400kg/m^3. According to BS EN 206-1:2000, the density of normal weight concrete is in the range of 2000kg/m^3 to 2600kg/m^3. Thus, the densities of the concretes produced from the seven cement brands A, B, C, D, E, F and G met the requirement of the standard.

4.7 Discussions on Cement and their Products

4.7.1 Cement brand A

The cement brand A is one of the locally produced cements in Nigeria. Its initial and final setting times were 142 and 310 minutes respectively. The results did not agree with the findings of Omoniyi and Okunola (2015) whose ranges of initial and final setting times were 178 to 198minutes and 236 to 285 minutes respectively.

The C_3S and C_2S contents were determined to be 33% and 38.39% respectively. These values did not meet the EN 197-1:2000 standard specifications of 42 – 67% and 8 – 31% respectively for C_3S and C_2S. The results were did not agree with findings of Omoniyi and Okunola (2015) who obtained ranges 42.65 to 64.13% and 5.96 to 24.40% for C_3S and C_2S respectively for the four brands of Nigerian cement tested.

The soundness of the cement was 1.67mm and it met the BS EN 197 – 1:2011. The mortar cube strengths of the cement were 17.23 and 47.75N/mm^2 for 2-day and 28-day curing periods respectively. These are greater than the standard minimum values of 10N/mm^2 and 42.5N/mm^2 specified in BS EN 197 – 1:2011. The 28- day mortar cube strength was within the range of 33.5 to 50.52N/mm^2 obtained by Omoniyi and Okunola (2015).

The 28-day strengths of the sandcrete hollow blocks produced from cement brand A was 4.24N/mm^2 while the minimum soaked strength was 0.91N/mm^2 after one-day immersion in water. The 28-day strengths exceeded the 2.9N/mm^2 and 2.5N/mm^2 specified in BS EN 771 – 3:2006 and NIS 87: 2004 respectively. This strength is much higher than that of commercial blocks previously studied, Ejeh and Abubakar, (2008);

Ewa and Ukpata (2013), Mahmood et al., (2010) and others). The average density and water absorption of the block were 1798kg/m^3 and 5.61% respectively. These met the standards. The characteristics strength of concrete cubes produced from cement brand A was 29.5N/mm^2. The average strength of concrete obtained by Adewole et al., (2015) was 30.1N/mm^2 with a standard deviation of 3.2N/mm^2. The characteristic strength of concrete obtained by Adewole using a mix ratio of 1:1.5:3 mix ratio was 24.85N/mm^2.

Thus, the compressive strength of the concrete produced from ordinary Portland cement brand A with a mix ratio of 1:2.5: 3.5 gave a higher characteristic strength of 29.5N/mm^2. Adewole et al., (2015) used Portland limestone. Thus the Portland limestone with a richer mix gave only 0.84% of the strength of the ordinary Portland cement brand A. Thus it is more economical to use ordinary Portland cement CEM I 42.5N than CEM II/A – L 42.5N. This cement had the best performance in terms of strengths for the concrete and sandcrete hollow block among the four local cement brands tested.

4.7.2 Cement brand B

Cement brand B is an imported cement and is widely used in Nigeria. The initial and final setting times were 134 and 310 minutes respectively. The results satisfied the BS EN 197 – 1:2011 requirements. The results were not in line with the findings of Omoniyi and Okunola (2015). The cement compound compositions were 46.97%, 16.43%, 5.99% and 10.49% for C_3S, C_2S, C_3A and C_4AF compounds respectively. These results met the requirements of EN 197 – 1:2000. However, the C_3S and C_2S

contents of the cement brand B were in agreement with the findings of Omoniyi and Okunola (2015).

The mortar cube strengths for 2-day and 28-day curing ages were 25.64 and 55.34N/mm^2 respectively. These values met the requirements of BS EN 197 – 1:2011. The 28-day strength was above the range of 33.5 to 50.52N/mm2 obtained by Omoniyi and Okunola (2015).

The sandcrete hollow block produced from the cement brand B had 28-day dry strength and 1-day soaked strength of 5.83N/mm^2 and 0.98N/mm^2. These values were higher than that of the commercial blocks (Ewa and Ukpata, 2013). The water absorption of the block was 5% which is less than 6% permitted in BS EN 771 – 3: 2006. The implication is that block wall of this cement brand will have its strength reduced to 16.8% when inundated with flood water for a period of 24 hours or one day. The average density of the block was 2271kg/m^3 and its water absorption was 5%.

The concrete 3-day and 28-day characteristic strengths at water to cement ratio of 0.60 and mix ratio of 1:2.5:3.5 were 14.49N/mm^2 and 31.80N/mm^2 respectively. The results were above the minimum strength of 13N/mm^2 and 30N/mm^2 specified for concrete grade 25/30 respectively. When these results were compared with Adewole et al., (2015), the latter was just 75.1% of the former. This cement brand gave the highest strength for both sandcrete and concrete out of the seven brands of cement studied.

4.7.3 Cement brand C

This is an imported cement that is also widely used in Nigeria. The initial and final setting times of the cement were 139 and 321 minutes respectively. The C_3S, C_2S, C_3A

and C_4AF contents were 30.41, 37.46%, 12.52% and 6.08% respectively. The C_3S and C_2S content were not in line with the findings of Omoniyi and Okunola (2015).

The 2-day and 28-day mortar cube strength of the cement were 18.73 and 49.33N/mm^2 indicating that cement had high early strength. The results met the standard specifications of BS EN 197 – 1:2011 which specifies minimum strengths of 10N/mm^2 and 42.5N/mm^2 respectively. The 28-day mortar strength was within the range obtained by Omoniyi and Okunola (2015). Its lime saturation factor was determined to be 0.85 which satisfied the standard specifications of the range 0.66 – 1.02.

The 28-day dry compressive strength and the 1-day minimum soaking strength of the sandcrete hollow blocks produced from cement brand C were 4.62N/mm^2 and 1.19N/mm^2 respectively. This implies that a wall made with sandcrete hollow block produced from cement brand C will only have 25.8% of its strength when inundated by flood water for a day. The results were higher than the findings of Ejeh and Abubakar, 2008 whose average strengths were 0.5N/mm^2 and 0.24N/mm^2 for commercial blocks for 28 days dry strength and minimum soaking strength respectively. This implies that the strength of the wall made with the substandard commercial blocks only dropped to 48% of its initial strength when inundated by flood water for one day.

This implies that the drop in strength was more pronounced in standard sandcrete hollow blocks than the substandard sandcrete hollow blocks. The average density of the blocks made from cement brand C was 1823kg/m^3 while its water absorption was

7.32%. The water absorption did not meet the minimum standard requirement (BS EN 771 – 3:2006) of 6% for sandcrete block.

The average 3-day and 28-day characteristic strengths of the concrete cubes produced from cement brand C were 14.35N/mm^2 and 31.8N/mm^2 respectively. The results were well above the minimum standard characteristic strength of 30N/mm^2 (BS EN 206: 2000) for concrete grade 25/30. The characteristic strength of the concrete produced from cement brand C with mix ratio of 1:2.5 :3.5 and w/c ratio of 0.60 was much higher than that obtained by Adewole et al., 2015 and Bamigboye et al., (2015) from a mix ratio of 1: 1 ½ : 3 and 1:2:4 respectively.

This indicates that concrete produced from Portland limestone cement with a richer mix of 1:1.5 : 3 had only 78.1% of the concrete produced from ordinary Portland cement CEM I with a lower mix ratio of 1:2.5:3.5 at w/c of 0.60. The implication is that the Portland limestone cements (CEM II/A – L 42.5N, and CEM II/B - L 42.5R) which recently flooded most Nigerian markets at the expense of the Portland cement (CEM I) had a lower strength than ordinary Portland cement. The standard organization of Nigeria should compel the local cement manufacturers to produce more of Portland cement than the Portland limestone presently produced and also to ensure that the percentage of limestone in the cement does not exceed the 15% stipulated by BS-EN. 197–1:2011. This cement is very suitabe for both concrete and sandcrete blocks as the strengths met the standards.

4.7.4 Cement brand D

The cement brand D is a locally produced cement and widely used in Nigeria. The initial and final setting times of the cement brand were 134 and 346 minutes respectively. These all met the BS EN 197 – 1: 2011 standards. The test results of the C_3S, C_2S, C_3A and C_4AF contents of the cement brand D were found to be 68.99%, 5.66%, 6.38% and 7.60% respectively. The C_3S and C_2S contents were outside the range specified by EN 197 – 1: 2000. The SC_3S and C_2S contents of this cement were not in agreement with the findings of and Omoniyi and Okunola (2015). The soundness of the cement was 0.50mm, which is much less than 10mm (maximum specified by BS EN 797 – 1:2011). The fineness of the cement was 2.0% (sieve method) and $342m^2/kg$ (Blaine method). These all met the standard requirements.

The 2-day and 28-day mortar cube strengths of cement brand D were $16.32N/mm^2$ and $47.07N/mm^2$ respectively. These values were well above the minimum strengths of $10N/mm^2$ and $42.5N/mm^2$ specified by BS EN 197 – 1:2011. The average 28-day dry strengths and one-day minimum soaked strength of the standcrete hollow block produced from this cement were $3.75N/mm^2$ and $1.01N/mm^2$ respectively. This implies that wall made from this block will have its strength reduced to 26.9% of its strength after being inundated by flood water for one day. These values obtained for the 28-day and 1-day soaking strength of the blocks produced from this brand were much higher than the findings of Ejeh and Abubakar, (2008) for substandard commercial blocks earlier studied. The drop for substandard blocks drop was only 48%. This means the drop is more pronounced in standard blocks studied than the substandard blocks previously studied. The average density of the blocks was $1765kg/m^3$ while the average water absorption of the block was 4.69%. The water absorption met the maximum standard of 6% specified in BS EN 197 – 1:2011.

The 3-day strength and 28-day characteristic strength of the concrete cubes produced from cement brand D were 12.44N/mm^2 and 29.74N/mm^2 respectively. This cement had the highest concrete cube strength out of the four locally produced cement brands studied. This was attributed to the high content of C_3S of 68.99%. The characteristic strength of the concrete cube produced from cement brand D was much higher than that of Adewole et al., (2015) for concrete produced from Portland Limestone cement. The concrete characteristic cube strength of 24.85N/mm^2 was obtained by Adewole et al., (2015) for Portland Limestone cement. This represents 83.6% of the concrete strength obtained in this study for concrete produced from Portland cement brand D. The average density of the block was 2415kg/m^3 and the water absorption was 4.69%.

4.7.5 Cement brand E

The cement brand E is imported cement and is found in Nigerian markets. The initial and final setting times of the cement were 141 and 322 minutes respectively. These met the standard specifications of BS EN 197 – 1:2011 but were not in agreement with findings of Omoniyi and Okunola (2015). The C_3S, C_2S, C_3A and C_4AF contents of the cement brand were found to be 51.77%, 24.17%, 1.58% and 6.69%. The C_3A content of this cement did not meet the standard specifications of (5 – 14%). However the C_3S and C_2S met the EN-197 – 1:2000. The values of the C_3S and C_2S were in agreement with the findings of Omoniyi and Okunola (2015). The measured soundness was 2.0mm which met the standard. The fineness of cement determined by Sieve and Blaine methods were 8.8% and 380m^2/kg respectively. The specific gravity was 3.15.

The 2-day and 28-day mortar cube strengths were 18.79N/mm^2 and 49.86N/mm^2. These values met the BS EN 197 – 1:2011. The 28-day strength was in agreement with the findings of Omoniyi and Okunola (2015). The 28-day dry compressive strength and 1-day minimum soaked compressive strength of the sandcrete hollow blocks were 5.38N/mm^2 and 0.84N/mm^2 respectively. This means wall constructed with SHB produced from this brand will experience a drop in strength to about 15.6% of its strength when inundated with flood water.

The values obtained for the standard blocks in this study were higher than that from Ejeh and Abubakar (2009), where the drop was to 0.48%. This means the drop is more pronounced in standard blocks than in substandard blocks.

The average density of the SHB produced from this cement brand was 1798kg/m^3 while its water absorption was 4.92%. These met the requirements of BS EN 771 – 1:2006.

The average 3-day strength and 28-day characteristic strength of the concrete cubes produced from cement brand E were 12.42N/mm^2 and 28.78N/mm^2 respectively.

These values were higher than the results obtained by Adewole, et al. (2015) and Bamgboye et al. (2015) for concretes produced from Portland Limestones cement. The characteristic strength obtained by Adewole et al, 2015 for concrete cubes produced from Portland Limestone cement at mix ratio of 1:1½:3 was 24.5N/mm^2. This was 86.34% of the strength obtained from concrete produced from ordinary Portland cement (CEM I) brand E.

The average density of the concrete cube produced from cement brand E was 2424kg/m^3 and its water absorption was 4.92%.

4.7.6 Cement brand F

This cement is locally produced in Nigeria and is common in Nigerian markets. The initial and final setting times of the cement were 147 minutes and 323 minutes respectively. The C_3S, C_2S. C_3A and C_4AF contents of the cement brands were determined to be 34.25%, 28.84%, 17.82% and 6.08% respectively. The C_3S and C_3A contents did not meet the EN 197 – 1:2000 standard specifications. The C_3S and C_2S obtained were not in agreement with the findings of Omoniyi and Okunola (2015). The soundness of the cement was 1.33mm while the fineness determined using Sieve and Blaine methods were 7.0% and 346m^2/kg respectively. These met the standard requirements of cement.

The mortar cube strength at 2-day and 28-day curing strengths using mix ratio of 1:3 and w/c = 0.40, were 16.36N/mm^2 and 45.05N/mm^2. These values met the standard minimum values of 10N/mm^2 and 42.5N/mm^2 specified in BS EN 197 – 1:2011. The 28-day strength of the mortar agreed with the findings of Omoniyi and Okunola (2015).

At mix ratio of 1:6 and water to cement ratio of 0.45, the 28-day dry compressive strength and 1-day soaked minimum compressive strength of sandcrete hollow blocks produced from cement brand F were 3.45N/mm^2 and 0.97N/mm^2 respectively. This means that wall made of SHB produced from cement brand F will experience a drop in strength to about 28.1% of its strength when inundated with flood water. The results of dry compressive strength and soaked strength obtained from this study were much higher than the results obtained from commercial substandard blocks studied by Ejeh and Abubakar (2011) Onwuka et al. (2013).

The average density of the sandcrete blocks produced from this brand of cement was 1738kg/m^3 at mix ratio of 1:6 while the water absorption of the blocks was 5.0%. This value met the standard specifications of BS 771 – 3:2006.

The mix ratio used for the concrete was 1:2.5:3.5 at water cement ratio of 0.60 as required by the standard. The average 3-day compressive strength and the 28-day characteristic strength of the concrete cubes produced from cement brand F were 12.35N/mm^2 and 29.24N/mm^2 respectively. The characteristic strength is within the acceptable range of 27 – 30N/mm^2. The characteristic strength of 29.24N/mm^2 was much higher than the characteristic strengths obtained by Adewole et al. (2015) and Bamigboye et al., (2015). The characteristic strength of 24.85N/mm^2 was obtained by Adewole et al. (2015), for concrete cubes produced with mix ratio of 1:1.5:3 from the Portland Limestone cement studied. This value represents only 85% of the characteristic strength of the concrete cubes produced from ordinary Portland Cement (CEM I). The current market is flooded with new products of Portland Limestone products such as CEM II/A–L:42.5N and CEM II/B–L:42.5R. The CEM II/B-L:42.5R has Limestone content in the range of 21 – 35%. For structural work BS EN 206:2000 specified a maximum limestone content of 15%. Thus the new products are costly than the ordinary Portland cement as one needs to use richer mixes for the former to achieve the same concrete strength with the latter. This cement had the worst performance in terms of sandcrete hollow production, as its average 28-day strength of 3.45N/mm^2 did not measure up to 3.5N/mm^2 specified as the average compressive of blocks.

4.7.7 Cement brand G

The cement brand G is a locally produced cement and is available in Nigerian markets. The tested result of the initial and final setting times of the cement brand were 145 and 381 minutes respectively. This cement recorded the highest final setting time. This was attributed to the high content of C_2S (49.78%) and low content of C_3S (6.34%). The soundness of the cement was 2.0mm which is much lower than 10mm, the maximum allowable value specified in BS EN 197–1:2011.

The test results of the C_3S, C_2S, C_3A and C_4AF contents for the cement brand were 6.34%, 49.78%, 0.02% and 6.69%. The cement did not meet the specifications of EN 197–1:2000 in terms of C_3S, C_2S and C_3A. The C_3S and C_2S results did not agree with the findings of Omoniyi and Okunola (2015). The specific gravity of the cement was 3.15 and the fineness determined by sieve and Blaine's methods were 2.6% and 349m^2/kg. The 2-day and 28-day mortar cube strengths were determined to be 14.07N/mm^2 and 47.09N/mm^2 respectively. These values met the standard specifications (BS EN 197–1:2011) of 10N/mm^2 and 42.5N/mm^2 minimum. The 28-day mortar test results agreed with the findings of Omoniyi and Okunola (2015).

The sandcrete hollow blocks produced with water to cement ratio (w/c) of 0.45 and mix ratio of 1:6 had 28-day dry compressive strength and 1-day soaked compressive strengths of 4.21N/mm^2 and 0.9N/mm^2 respectively. This means the wall made of sandcrete blocks produced from cement G will have its strength reduced to 21.4% of its 28-day strength after being inundated with flood water for one day.

The results obtained from this study for the 28-day dry strength and the minimum soaking strengths of the blocks were higher than in previous studies by Ejeh and Abubakar, (2008) – which was conducted on substandard commercial sandcrete hollow blocks. The drop is more pronounced in the standard blocks than the substandard blocks previous studied. The density and water absorptions of the blocks were found to be 1773kg/m^3 and 5.0% respectively. The water absorptions met the maximum standard value of 6% specified by BS EN 771–3:2006.

The concrete cubes of this cement brand G were prepared with mix ratio 1:2.5:3.5 at water to cement ratio of 0.60. The 3-day strength and the 28-day characteristic strengths of the concrete cubes produced from cement brand G were 12.02N/mm^2 and 27.90N/mm^2. The 3-day strength did not meet the standard value of 13N/mm^2 while the 28-day characteristic strength of 27.90N/mm^2 is within the acceptable range of 27–30N/mm^2 for concrete grade 25/30. The characteristic strengths of similar studies conducted by Adewole et al., (2015) and Bamigboye et al., (2015) were lower than this. The characteristic strength of the concrete cubes produced from Portland Limestone cement at a richer mix ratio of 1:1½:3 was only 24.85N/mm^2. This means the strength of concrete produced from Portland Limestone cement was 89% of the cement of concrete produced from ordinary Portland cement brand G.

4.8 Structural characterization of cement, SHB and concretes in Nigeria

The ranges and means of structural characterisations of concrete and sandcrete hollow blocks from selected seven cement brands in Nigerian market are presented in table 4.15.

Table 4.15: Structural Characterisation of Cement, SHB and Concrete in Nigeria

Item	Property	Range	Average
Cement	Initial setting time	134 – 147mins	140
	Final setting	310 – 381mins	332
	sp.gr	3.14 – 3.15	3.14
	C3S	6.34 – 68.99%	38.81%
	C2S	5.66 – 38.39%	28.67%
	C3A	1.58 – 17.82	8.11%
	C4AF	6.08 – 10.49	7.10%
	Mortar cube 2-day Strength 28-day	14.07 – 25.64 45.05 – 55.33	$18.2N/mm^2$ $48.8N/mm^2$
SHB	28-day dry strength	$5.45 – 5.83N/mm^2$	$4.50N/mm^2$
	One-day minimum soaked strength	$0.84 – 1.19N/mm^2$	$0.98N/mm^2$
	Density		$1902kg/m^3$
	Water absorption	4.69 – 7.32%	5.33%
Concrete	3 day strength	12.02 – 14.49%	$12.93N/mm^2$
	28 day strength	27.90 – 31.81	$29.83N/mm^2$

	Density		2402 – 2450	$2402kg/m^3$
	Fineness	Sieve	2.0 – 8.8%	5.81%
		Blaine	342 – 390	$363.9m^2/kg$
	Lime Saturation factor Soundness		0.69 – 0.98 0.5 – 2.33	0.88 1.69mm

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Findings

1. The public water supply had pH, Chloride and sulphate contents of 7.25, 99.4mg/l and105.54mg/l respectively. The sand from River Kaduna at Rafin Guza had silt and clay, organic contents of 3.49% and0.35% respectively and its grading curve fell in zone 2. The gravel had an aggregate crushing value, soundness and sulphate contents of 27.90%, 1.2% and 0.08% respectively.

2. The Cement brand A (a locally produced cement) had initial and final setting times of 142 and 310 minutes respectively. Its mortar cube strengths at 2-days and 28-days were 17.23 and 47.75N/mm^2 respectively. Its C_3S, C_2S, C_3A and C_4AF contents were 33, 38.39, 12.52 and 6.08% respectively.

   The Cement brand B had initial and final setting times of 134 and 324 minutes respectively. Its mortar cube strengths at 2-days and 28-days were 25.64 and 55.30N/mm^2 respectively. Its C_3S, C_2S, C_3A and C_4AF contents were 46.97, 16.43, 5.99 and 10.49% respectively.

   The Cement brand C had initial and final setting times of 139 and 321 minutes respectively. Its mortar cube strengths at 2-days and 28-days were 18.73 and 49.33N/mm^2 respectively. Its C_3S, C_2S, C_3A and C_4AF contents were 30.41, 37.46, 12.52 and 6.08% respectively.

   The Cement brand D had initial and final setting times of 134 and 346 minutes respectively. Its mortar cube strengths at 2-days and 28-days were 16.32 and 47.07N/mm^2 respectively. Its C_3S, C_2S, C_3A and C_4AF contents were 68.99, 5.66, 6.38 and 7.60% respectively.

The Cement brand E had initial and final setting times of 141 and 322 minutes respectively. Its mortar cube strengths at 2-days and 28-days were 18.79 and 49.86N/mm^2 respectively. Its C_3S, C_2S, C_3A and C_4AF contents were 51.77, 24.17, 1.58 and 6.69% respectively.

The Cement brand E had initial and final setting times of 147 and 323 minutes respectively. Its mortar cube strengths at 2-days and 28-days were 16.36 and 45.05N/mm^2 respectively. Its C_3S, C_2S, C_3A and C_4AF contents were 34.25, 28.84, 17.82 and 6.08% respectively.

The Cement brand E had initial and final setting times of 145 and 381 minutes respectively. Its mortar cube strengths at 2-days and 28-days were 14.07 and 47.09N/mm^2 respectively. Its C_3S, C_2S, C_3A and C_4AF contents were 6.34, 49.78, 0.02 and 6.69% respectively.

3. The optimum water to cement ratio to be used in production of sandcrete hollow block is 0.45 as it recorded the maximum strength at the mix ratios 1:4 to 1:12 studied.

4. The strength of the sandcrete hollow blocks increased parabolically with curing age up to 28 days for brands A to G. The 28-day dry strengths of the SHB were 4.24, 5.83, 4.62, 3.75, 5.38, 3.45 and 4.21N/mm^2 for A to G respectively. The density of the blocks increased with curing age up to maximum at 14 days after which it decreased with age up to 28 days.

5. To balance the economy and satisfy the minimum standard (BS EN 771-1: 2006) strength of 2.9N/mm^2, the cement to sand mix ratio should be in the range 1:6 to 1:8 at a minimum curing age of seven days.

6. Strength development of SHB cured in the dry state by spraying with water for 28-days and then soaked in water revealed that there was a sharp drop in the compressive strength after one day soaking period after which the strengths rose with period of soaking. The sharp drop in strength was attributed to the disjoining pressure of the water which weakened sharply the interlocking bonds between the cement hydration products crystals and the sand particles. This was observed for blocks produced from the seven cement brands and mix ratio range of 1:4 to 1:12.The minimum soaked strengths of the blocks produced from cement brands A, B, C, D, E, F and G were 0.91, 0.98, 1.19, 1.01, 0.84, 1.06 and 0.90N/mm^2 respectively at mix ratio 1:6.

7. The average water absorption of the SHB were 5.61, 5.00, 7.32, 4.69, 4.92, 4.80 and 5.00% for sandcrete hollow blocks produced from cement brands A, B, C, D, E, F and G respectively which are lower than 6% Except that of C-blocks.

8. The characteristic strengths of the concretes produced from cement brands A, B, C, D, E, F and G were 29.5, 31.81, 31.80, 29.74, 28.78, 29.24 and 27.90N/mm^2 respectively. The characteristic strength of concretes produced from cement brands B and C were above 30N/mm^2 specified in BS EN 206:2000 while those from the local cement brands A, D, F and G were within the acceptable limit of 27N/mm^2. The average 28-day densities of the concretes produced from cement brands A to G were 2450, 2413, 2402, 2415, 2424, 2424 and 2402kg/m^3 respectively.

5.2 Conclusions

Based on the above findings, the following conclusions were drawn:

1. The tap water, the sand from River Kaduna at Rafin Guza and gravel were suitable materials for concrete and sandcrete hollow block production.
2. The locally produced cement brands A, D, F, and G did not meet the EN 197-1: 2000 standard specifications for both tricalcium and dicalcium silicates while the imported cement brands B and E met the standard.
3. The optimum water to cement ratio to be used in production of sandcrete hollow block is 0.45.
4. Sandcrete hollow blocks were produced from cement brands A to G and their 28-day dry compressive strengths met the British standard (BS EN 771-3: 2006).
5. Economical standard blocks could be produced at mix ratio range of 1:6 to 1:8 and curing age of seven days.
6. Sandcrete hollow blocks cured for 28 days in the dry state and then immersed in water suffered a sharp drop in strength after one day immersion. This suggested that sandcrete hollow block wall inundated with flood water suffers the same sharp drop in strength after one day inundation no matter the initial strength.
7. The averge water absorption of the sandcrete hollow blocks produced from cement brands A to G was 5.33% and this is less than 6%.
8. The average compressive strengths of the concrete produced from the cement brands A, D, F and G (locally produced cement brands) were lower than $30N/mm^2$ but within acceptable range of 27 – $30N/mm^2$ while those of imported cement brands B and E were above $30N/mm^2$. Lack of adherence to

standard specifications of the two silicate compounds was responsible for the low concrete strengths of the local cement brands.

5.3 Recommendations

1. As flood is rampant in many parts of Nigeria, a new design approach should be developed for load bearing sandcrete block walls taking into consideration the problem of sharp drop in strength when inundated by flood water.
2. Assessment of wet strength of sandcrete hollow block should be based on one day immersion instead of the current 28-day strength.
3. Further studies are required in developing mathematic models for the estimation of the minimum soaked strengths of the sandcrete hollow block.
4. Other construction materials such as brick, concrete, should be studied under similar conditions to sandcrete hollow block.
5. The local cement industries of cement brands A, D, F and G should improve on the quality control of the two silicate compounds.

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APPENDICES

A – 1: Specific Gravity of Sand from River Kaduna at Rafin Guza

Sample No.	Mass of Sample (B) (g)	Mass of Pyconometer + Water (P) (g)	Mass Of Pyconometer + Water + Sample Ps (g)	Specific Gravity	Average Sp. Gravity
1	500	1649	1961	2.66	
2	500	1649	1960	2.65	2.66
3	500	1649	1961	2.66	

A – 2: Moisture Content of Sand from River Kaduna at Rafin Guza

Sample No.	Mass of Container (gm)	Mass of Container + wet sample (gm)	Mass of container + dry sample (gm)	Dry weight (gm)	Loss in weight (gm)	Moisture content
1	120	1500	1370	1250	130	10.40
2	125	1325	1105	1105	110	9.95
3	124	1454	1329	1205	125	10.37

A – 3: Computation of Void Ratio of Sand from River Kaduna at Rafin Guza

The void ratio, e of the sand was determined from the relation: $e = G_S M_C$

Where e is the void ratio, G_S is the specific gravity of the sand and M_C is the moisture content.

From Appendix A – 57 and A – 58

G_S = 2.66, M_C = 0.1024

e = 2.66 x 0.1024 = 0.2724

e = 27.24%

A – 4: Computation of Porosity of Sand from River Kaduna at Rafin Guza

The porosity, n of the sand sample was determined from the relation:

$$n = \frac{e}{1+e} \times 100\%$$

$$n = \frac{0.2724 \times 100}{1+0.2724} = 21.41\%$$

A – 5: Bulk Density of Sand from River Kaduna at Rafin Guza

The bulk density r_b of the sand was computed from the relation:

Void ratio = $1 - \left(\frac{loose\ \ bulk\ \ density}{1000\ \times Specific\ \ Gravity}\right)$

$$= 1 - \frac{r_b}{1000Gs}$$

From appendices A – 59 and A – 57, the void ratio, e and specific gravity of the sand are:

e = 0.2724, Gs = 2.66

$$0.2724 = 1 - \frac{r_b}{1000 \times 2.66}$$

$$r_b = 1935 kg/m^3$$

A – 6: Dry Density of Sand from River Kaduna at Rafin Guza

The dry density was completed from the relation:

$$r_b = \frac{r_b}{1+w} = \frac{1935}{1+0.1024} = 1755 kg/m^3$$

A – 7: Determination of Clay and Silt Content of Sand from River Kaduna at Rafin Guza by (Field Settling Test Method)

Sample No.	Sample height (mm)	Height of Clay (mm)	Height of Silt (mm)	Height of Sand (mm)	Clay Content %	Silt Content %
1	500	9	9	482	1.86	1.86
2	500	8.5	9	482.5	1.76	1.86
3	500	9	9	482	1.83	1.86
		Average			1.83	1.86

A – 8: Sieve Analysis of Sand Sample from Rafin Guza

BS SIEVE No	WEIGHT RETAINED (g)	CUMMULATIVE WEIGHT RETAINED (g)	PERCENTAGE WEIGHT RETAINED (%)	TOTAL PASSING (%)
7	35.92	35.92	7.18	92.82
10	34.20	70.12	14.02	85.98
14	53.40	123.52	24.70	75.30
18	82.00	205.52	41.10	58.90
25	89.40	294.92	58.98	41.02
36	60.00	354.92	70.98	29.02
52	52.00	406.92	81.38	18.62
72	41.00	447.92	89.58	10.42
100	33.00	480.92	96.18	3.82
150	6.90	487.82	97.56	2.44
200	8.20	496.02	99.20	0.80
PAN				

A– 9: Standard Consistence, Initial and Final setting Times for Portland Cement Brand A

Sample	Mass Cement (g)	Volume of water (ml)	w/c	Depth of pen mm	Standard Consistence (%)	Initial setting Time (ur)	Final setting Timer (hr)
AC_1	400	120	0.30	6	30	142	5.15
AC_2	400	120	0.30	6	30	141	5.16
AC_3	400	120	0.30	6	30	142	5.17
Average				6	30	142	5.16

A– 10: Standard Consistence, Initial and Final Setting Times for Portland Cement Brand B

Sample	Mass of cement (g)	Volume of water (ml)	w/c	Depth of pen (mm)	Standard Consistence (%)	Initial setting Time (hr)	Final setting Time (hr)
AtC_1	400	133	0.33	6	33	132	5.50
AtC_2	400	133	0.33	6	33	137	5.30
AtC_3	400	133	0.33	6	33	133	5.40
Average				6	33	134	5.40

A– 11: Standard Consistence, Initial and Final Setting Times for Portland Cement Brand C

Sample	Mass cement (g)	Volume of water (ml)	w/c	Depth of pent	Standard Consistence (%)	Initial setting Time (hr)	Final setting Time (hr)
B_uC_1	400	130	0.33	7	33	143	5.45
B_uC_2	400	129	0.32	6	32	133	5.32
B_uC_3	400	129	0.32	6	32	142	5.30
Average					32	139	5.35

A– 12: Standard Consistence, Initial and Final Setting Times for Portland Cement Brand D

Sample	Mass cement (g)	Volume of water (ml)	w/c	Depth of pent (mm)	Standard Consistence (%)	Initial setting Time (hr)	Final setting Time (hr)
$D_a C_1$	400	120	0.30	6	30	134	5.77
$D_a C_2$	400	120	0.30	6	30	134	5.77
$D_a C_3$	400	120	0.30	6	30	134	5.77
Average					30	134	5.77

A–13: Standard Consistence, Initial and Final Setting Times for Portland Cement Brand E

Sample	Mass cement (g)	Volume of water (ml)	w/c	Depth of pen (mm)	Standard Consistence (%)	Initial setting Time (hr)	Final setting Time (hr)
$E_a C_1$	400	105	26	6	26	143	5.36
$E_a C_2$	400	105	26	6	26	139	5.35
$E_a C_3$	400	105	26	6	26	141	5.36
Average					26	141	5.36

A– 14: Standard Consistence, Initial and Final Setting Times for Portland Cement Brand F

Sample	Mass cement (g)	Volume of water (ml)	w/c	Depth of pent (mm)	Standard Consistence (%)	Initial setting Time (hr)	Final setting Time (hr)
$E_l C_1$	400	115	0.28	6	28	147	5.40
$E_l C_2$	400	115	0.28	6	28	148	5.39
$E_l C_3$	400	115	0.28	6	28	146	5.36
Average						147	5.38

A– 15: Standard Consistence, Initial and Final Setting Times for Portland Cement Brand G

Sample	Mass cement (g)	Volume of water (ml)	w/c	Depth of pen (mm)	Standard consistence (%)	Initial setting Time (hr)	Final setting Time (hr)
SOC_1	400	118	29.0	6	29	144	6.40
SOC_2	400	118	29.0	6	29	145	6.35
SOC_3	400	118	29.0	6	29	147	6.30
Average					29	145	6.35

A– **16: Soundness for Portland Cement Brand A**

Sample	Initial distance d_i (mm)	Final distance d_2 (mm)	$d_2 - d_i$ (mm)
AC_7	10	12.0	2.00
AC_8	10	11.0	1.00
AC_9	10	12.0	2.00
Average			1.67

A– 17: Soundness for Portland Cement Brand B

Sample	Initial distance d_1 (mm)	Final distance d_2 (mm)	$d_2 - d_1$ (mm)
AtC_1	10	12	2
AtC_2	10	12	2
AtC_3	10	12	2
Average			2

A– 18: Soundness for Portland Cement Brand C

Sample	Initial distance d_1 (mm)	Final distance d_2 (mm)	$d_2 - d_1$ (mm)
BuC_1	10	12	2
BuC_2	10	12	2
BuC_3	10	13	3

Average			2.33

A– 19: Soundness for Portland Cement Brand D

Sample	Initial distance d_1 (mm)	Final distance d_2 (mm)	$d_2 - d_1$(mm)
$D_a C_1$	10.00	10.50	0.50
$D_a C_2$	10.00	10.50	0.50
$D_a C_3$	10.00	10.50	0.50
Average			0.50

A– 20: Soundness for Portland Cement Brand E

Sample	Initial distance d_1 (mm) being boiling	Final distance d_2 (mm) after boiling	$d_2 - d_1$ (mm)
$E_a C_1$	10	12	2
$E_a C_2$	10	12	2
$E_a C_3$			
	10	12	2
Average			2

A– 21: Soundness for Portland Cement Brand F

Sample	Initial distance d_1 (mm)	Final distance d_2 (mm)	$d_2 - d_1$(mm)
ElC_1	10.00	11	1
ElC_2	10.00	12	2
ElC_3	10.00	10.50	0.50
Average			1.33

A– 22: Soundness for Portland Cement Brand G

Sample	Initial distance d_1 (mm)	Final distance d_2 (mm)	$d_2 - d_1$ (mm)
SOC_1	10	12	2.00

SOC_2	10	12	2.00
SOC_3	10	12	2.00
Average			2.00

A-23 Specific Gravity of Cement

The specific gravity of cement was determined using pyconometer and following the procedure in BS 812, Part 2, 1975 and is determined from the relation:

$$G_S = \frac{B}{P + B - P_S}$$

A – 24: Specific Gravity for Portland Cement Brand A Test

Sample No.	Mass of Sample (B) (g)	Mass of Pyconometer + Water (P) (g)	Mass Of Pyconometer + Water + Sample Ps (g)	Specific Gravity	Average Sp. Gravity
1	500	1649	1990	3.14	
2	500	1649	1989	3.13	3.14
3	500	1649	1990	3.14	

A – 25: Specific Gravity for Portland Cement Brand B Test

Sample No.	Mass of Sample (B) (g)	Mass of Pyconometer + Water (P) (g)	Mass Of Pyconometer + Water + Sample Ps (g)	Specific Gravity	Average Sp. Gravity
1	500	1649	1992	3.18	
2	500	1649	1987	3.09	3.14
3	500	1649	1990	3.14	

A – 26: Specific Gravity for Portland Cement Brand C Test

Sample No.	Mass of Sample (B) (g)	Mass of Pyconometer + Water (P) (g)	Mass Of Pyconometer + Water + Sample Ps (g)	Specific Gravity	Average Sp. Gravity
1	500	1649	1990	3.14	
2	500	1649	1990	3.14	3.14
3	500	1649	1990	3.14	

A – 27: Specific Gravity for Portland Cement Brand D Test

Sample No.	Mass of Sample (B) (g)	Mass of Pyconometer + Water (P) (g)	Mass Of Pyconometer + Water + Sample Ps (g)	Specific Gravity	Average Sp. Gravity
1	500	1649	1990	3.14	
2	500	1649	1989	3.13	3.14
3	500	1649	1990	3.14	

A – 28: Specific Gravity for Portland Cement Brand E Test

Sample No.	Mass of Sample (B) (g)	Mass of Pyconometer + Water (P) (g)	Mass Of Pyconometer + Water + Sample Ps (g)	Specific Gravity	Average Sp. Gr
1	500	1649	1689	3.13	3.15
2	500	1649	1691	3.16	

3	500	1649	1691	3.16	

A – 29: Specific Gravity for Portland Cement Brand F Test

Sample No.	Mass of Sample (B) (g)	Mass of Pyconometer + Water (P) (g)	Mass Of Pyconometer + Water + Sample Ps (g)	Specific Gravity	Average Sp. Gravity
1	500	1649	1689	3.13	
2	500	1649	1690	3.14	3.14
3	500	1649	1690	3.14	

A – 30: Specific Gravity for Portland Cement Brand G Test

Sample No.	Mass of Sample (B) (g)	Mass of Pyconometer + Water (P) (g)	Mass Of Pyconometer + Water + Sample Ps (g)	Specific Gravity	Average Sp. Gravity
1	500	1649	1991	3.16	
2	500	1649	1990	3.14	3.15
3	500	1649	1991	3.16	

A – 31: Fineness for Portland Cement Brand A

Sieve Size (μm)	Weight retained (g)	Percentage Retained (%)	Percentage Finer (%	Fineness
250	13.0	1.30	1.30	
180	15.0	1.50	2.80	
125	27.0	2.70	5.50	4.6
90	46.0	4.60	10.1	
50	112.0	11.20	21.3	
36	787.0	78.78	100.0	

Cumulative			141	4.6

A – 32: Fineness for Portland Cement Brand B

Sieve Size (μm)	Weight retained (g)	Percentage Retained (%)	Percentage Finer (%	Fineness
250	5.0	0.5	0.5	
180	1.4	1.4	1.9	
125	2.2	2.2	4.1	8.7
90	8.7	8.7	12.8	
50	10.5	10.5	23.3	
36	76.7	76.7	100.0	
Cumulative			142.6	8.7

A – 33: Fineness for Portland Cement Brand C

Sieve Size (μm)	Weight retained (g)	Percentage Retained (%)	Percentage Finer (%	Fineness
250	12.0	1.2	1.2	
180	45.0	4.5	5.7	
125	90.0	9.0	14.7	7.0
90	70.0	7.0	21.7	
50	170.0	17.0	38.7	
36	613.0	61.3	100.0	
Cumulative			182	7.0

A – 34: Fineness for Portland Cement Brand D

Sieve Size (μm)	Weight retained (g)	Percentage Retained (%)	Percentage Finer (%	Fineness
250	10.0	1.0	1.0	
180	13.0	1.3	2.3	
125	15.0	1.5	3.8	2.0
90	20.0	2.0	5.8	
50	30.0	3.0	8.8	
36	912.0	91.2	100.0	

Cumulative			121.7	1.22

A – 35: Fineness for Portland Cement Brand E

Sieve Size (μm)	Weight retained (g)	Percentage Retained (%)	Percentage Finer (%	Fineness
250	15.0	1.5	1.5	
180	14.0	1.4	2.9	
125	42.0	4.2	7.1	8.8
90	88.0	8.8	15.9	
50	100.0	10.0	25.9	
36	751.0	75.1	100.0	
Cumulative			153.30	8.8

A – 36: Fineness for Portland Cement Brand F

Sieve Size (μm)	Weight retained (g)	Percentage Retained (%)	Percentage Finer (%	Fineness
250	10.0	1.0	1.0	
180	47.0	4.7	5.7	
125	93.0	9.3	15.0	7.0
90	70.0	7.0	22.0	
50	170.0	17.0	39.0	
36	610.0	61.0	100.0	
Cumulative			182.7	7.0

A – 37: Fineness for Portland Cement Brand G

Sieve Size (μm)	Weight retained (g)	Percentage Retained (%)	Percentage Finer (%	Fineness
250	26.0	2.6	2.6	
180	15.0	1.5	4.10	2.6
125	32.0	3.2	7.30	
90	26.0	2.6	9.90	

50	60.0	6.0	15.90	
36	841.0	84.1	100.0	
Cumulative			139.80	2.6

A– 38: Mortar Cube Strength for Portland Cement Brand A (w/c = 0.40)

Sample Number	Size of cube	Testing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2)	
							Test	Average
1	70	2	Water	0.81	1:3	84.3	17.20	17.23
2	70	2	Water	0.81	1:3	84.3	17.20	
3	70	2	Water	0.81	1:3	84.7	17.29	
4	70	28	Water	0.88	1:3	225.4	46.00	45.75
5	70	28	Water	0.89	1:3	226.4	46.20	
6	70	28	Water	0.90	1:3	220.8	45.05	

A– 39: Mortar Cube Strength for Portland Cement Brand B (w/c = 0.40)

Sample Number	Size of cube	Testing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2)	
							Test	Average
1	70	2	Water	0.82	1:3	125.4	25.60	
2	70	2	Water	0.83	1:3	125.9	25.70	
3	70	2	Water	0.82	1:3	128.9	26.32	25.64
4	70	28	Water	0.89	1:3	268.5	54.80	
5	70	28	Water	0.90	1:3	270.0	55.10	55.30
6	70	28	Water	0.90	1:3	274.4	56.00	

A– 40: Mortar Cube Strength for Portland Cement Brand C (w/c = 0.40)

Sample Number	Size of cube	Testing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2)	
							Test	Average

1	70	2	Water	0.80	1:3	91.1	18.60	
2	70	2	Water	0.80	1:3	92.1	18.80	
3	70	2	Water	0.80	1:3	92.0	18.79	18.73
4	70	28	Water	0.81	1:3	245.0	50.00	
5	70	28	Water	0.80	1:3	242.5	49.50	49.33
6	70	28	Water	0.80	1:3	237.6	48.49	

A– 41: Mortar Cube Strength for Portland Cement Brand D (w/c = 0.40)

Sample Number	Size of cube	Testing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load KN	Crushing Strength N/mm^2	
							Test	Average
1	70	2	Water	0.82	1:3	80.4	16.40	16.32
2	70	2	Water	0.80	1:3	80.5	16.42	
3	70	2	Water	0.81	1:3	79.0	16.14	
4	70	28	Water	0.82	1:3	221.0	45.10	45.07
5	70	28	Water	0.83	1:3	222.5	45.40	
6	70	28	Water	0.83	1:3	219.0	44.71	

A– 42: Mortar Cube Strength for Portland Cement Brand E (w/c = 0.40)

Sample Number	Size of cube	Testing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2)	
							Test	Average
1	70	2	Water	0.81	1:3	90.7	18.50	18.79
2	70	2	Water	0.81	1:3	92.1	18.80	
3	70	2	Water	0.81	1:3	93.3	19.04	
4	70	28	Water	0.81	1:3	244	49.80	49.86
5	70	28	Water	0.81	1:3	245	50.00	
6	70	28	Water	0.82	1:3	243.9	49.78	

A– 43: Mortar Cube Strength for Portland Cement Brand F (w/c = 0.40)

Sample Number	Size of cube	Testing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2)	
							Test	Average
1	70	2	Water	0.81	1:3	80.4	16.40	16.36
2	70	2	Water	0.81	1:3	79.9	16.30	
3	70	2	Water	0.81	1:3	80.3	16.38	
4	70	28	Water	0.81	1:3	210.7	43.00	43.05
5	70	28	Water	0.81	1:3	209.7	42.80	
6	70	28	Water	0.82	1:3	212.4	43.35	

A– 44: Mortar Cube Strength for Portland Cement Brand G (w/c = 0.40)

Sample Number	Size of cube	Testing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2)	
							Test	Average
1	70	2	Water	0.80	1:3	69.7	14.20	
2	70	2	Water	0.80	1:3	69.1	14.10	14.07
3	70	2	Water	0.80	1:3	68.2	13.91	
4	70	28	Water	0.85	1:3	216.6	44.20	
5	70	28	Water	0.85	1:3	216.3	44.15	44.09
6	70	28	Water	0.86	1:3	215.2	43.92	

A– 45: Compressive Strength of Concrete Cubes from Portland Cement Brand A (w/c = 0.60)

Sample	Cube size (mm)	Curing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2)	
							Test cube	Average
AC 1	150	3	Water	8.05	1:2.5:3.5	281	12.48	12.48
AC 2	150	3	Water	8.00		280	12.44	
AC 3	150	3	Water	8.02		282	12.53	
AC 4	150	7	Water	8.10	1:2.5:3.5	380	16.88	16.91
AC 5	150	7	Water	8.09		382	16.97	
AC 6	150	7	Water	8.07		380	16.88	

AC 7	150	14	Water	8.16	1:2.5:3.5	480	21.33	21.31
AC 8	150	14	Water	8.15		476	21.15	
AC 9	150	14	Water	8.18		483	21.46	
AC 10	150	21	Water	8.13	1:2.5:3.5	580	25.77	25.81
AC 11	150	21	Water	8.13		582	25.36	
AC 12	150	21	Water	8.14		581	25.82	
AC 13	150	28	Water	8.21	1:2.5:3.5	665	29.55	29.66
AC 14	150	28	Water	8.30		670	29.77	
AC 15	150	28	Water	8.30		668	29.68	

A– 46: Compressive Strength of Concrete Cube from Portland Cement Brand B

(w/c = 0.60)

Sample	Cube size (mm)	Curing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2)	Average
AtC_1	150	3	Water	8.03	1:2.5:3.5	327	14.53	14.49
AtC_2	150	3	Water	8.04		322	14.31	
AtC_3	150	3	Water	8.07		329	14.62	
AtC_4	150	7	Water	8.12	1:2.5:3.5	391	17.38	17.37
AtC_5	150	7	Water	8.10		390	17.33	
AtC_6	150	7	Water	8.12		392	17.42	

AtC_7	150	14	Water	8.14	1:2.5:3.5	517	22.98	22.98
AtC_8	150	14	Water	8.15		516	22.93	
AtC_9	150	14	Water	8.19		518	23.02	
AtC_{10}	150	21	Water	8.17	1:2.5:3.5	634	28.18	28.10
AtC_{11}	150	21	Water	8.11		630	28.00	
AtC_{12}	150	21	Water	8.16		633	28.13	
AtC_{13}	150	28	Water	8.17	1:2.5:3.5	740	32.89	32.29
AtC_{14}	150	28	Water	8.16		730	32.44	
AtC_{15}	150	28	Water	8.10		710	31.55	

A– 47: Compressive Strength of Concrete Cubes from Portland Cement Brand C

(w/c = 0.60)

Sample Number	Size of cube	Testing Age (days)	Curing condition	Weight of Cube (kg)	Mix Proportion	Crushing Load (kN)	Crushing Strength (N/mm^2) Test	Average
1	150	3	Water	7.90	1:2.5:3.5	324	14.40	14.35
2	150	3	Water	8.01		326	14.48	
3	150	3	Water	7.90		319	14.17	
4	150	7	Water	8.19	1:2.5:3.5	380	16.88	16.98
5	150	7	Water	8.18		383	17.02	
6	150	7	Water	8.19		384	17.06	

7	150	14	Water	8.15	1:2.5:3.5	515	22.88	22.89
8	150	14	Water	8.16		512	22.75	
9	15	14	Water	8.14		519	23.06	
10	150	21	Water	8.21	1:2.5:3.5	630	28.00	28.20
11	150	21	Water	8.19		640	28.44	
12	150	21	Water	8.20		634	28.17	
13	150	28	Water	8.10	1:2.5:3.5	720	32.00	32.14
14	150	28	Water	8.12		720	32.00	
15	150	28	Water	8.10		730	32.44	

A– 48: Compressive Strength of Concrete Cubes from Portland Cement Brand D (w/c = 0.60)

Sample	Cube size (mm)	Curing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2)	
							Test	Average

$D_a C_1$	150	3	Water	8.19	1:2.5:3.5	276	12.27	12.44
$D_a C_2$	150	3	Water	8.18		280	12.44	
$D_a C_3$	150	3	Water	8.18		284	12.62	
$D_a C_4$	150	7	Water	8.00	1:2.5:3.5	380	16.89	17.02
$D_a C_5$	150	7	Water	8.00		380	16.89	
$D_a C_6$	150	7	Water	7.94		384	17.29	
$D_a C_7$	150	14	Water	8.11	1:2.5:3.5	481	21.38	21.42
$D_a C_8$	150	14	Water	8.11		480	21.33	
$D_a C_9$	150	14	Water	8.11		485	21.56	
$D_a C_{10}$	150	21	Water	8.08	1:2.5:3.5	569	25.29	25.49
$D_a C_{11}$	150	21	Water	8.12		572	25.42	
$D_a C_{12}$	150	21	Water	8.10		580	25.77	
$D_a C_{13}$	150	28	Water	8.15	1:2.5:3.5	670	29.78	29.81
$D_a C_{14}$	150	28	Water	8.15		670	29.78	
$D_a C_{15}$	150	28	Water	8.18		672	29.87	

A– 49: Compressive Strength of Concrete Cube from Portland Cement Brand E (w/c = 0.40)

Sample	Cube size (mm)	Curing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2)	
							Test	Average

$E_a C_1$	150	3	Water	7.90	1:2.5:3.5	280	12.44	12.42
$E_a C_2$	150	3	Water	7.80		281	12.48	
$E_a C_3$	150	3	Water	7.85		278	12.35	
$E_a C_4$	150	7	Water	8.10	1:2.5:3.5	376	16.71	16.69
$E_a C_5$	150	7	Water	8.12		374	16.62	
$E_a C_6$	150	7	Water	8.10		377	16.75	
$E_a C_7$	150	14	Water	8.14	1:2.5:3.5	480	21.33	21.30
$E_a C_8$	150	14	Water	8.15		480	21.33	
$E_a C_9$	150	14	Water	8.15		478	21.24	
$E_a C_{10}$	150	21	Water	8.15	1:2.5:3.5	570	25.33	25.42
$E_a C_{11}$	150	21	Water	8.16		574	25.51	
$E_a C_{12}$	150	21	Water	8.16		572	25.42	
$E_a C_{13}$	150	28	Water	8.17	1:2.5:3.5	670	29.77	29.40
$E_a C_{14}$	150	28	Water	8.18		650	28.88	
$E_a C_{15}$	150	28	Water	8.19		665	29.55	

A– 50: Compressive Strength of Concrete Cube from Portland Cement Brand F (w/c = 0.60)

Sample	Cube size (mm)	Curing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2) Test	Average
$E_l C_1$	150	3	Water	8.10	1:2.5:3.5	277	12.31	12.35
$E_l C_2$	150	3	Water	8.12		278	12.35	
$E_l C_3$	150	3	Water	8.10		279	2.40	
$E_l C_4$	150	7	Water	8.10	1:2.5:3.5	376	16.71	16.73
$E_l C_5$	150	7	Water	8.12		380	16.88	
$E_l C_6$	150	7	Water	8.10		374	16.62	
$E_l C_7$	150	14	Water	8.14	1:2.5:3.5	470	20.88	20.97
$E_l C_8$	150	14	Water	8.15		476	21.15	
$E_l C_9$	150	14	Water	8.15		470	20.88	
$E_l C_{10}$	150	21	Water	8.15	1:2.5:3.5	572	25.42	25.45
$E_l C_{11}$	150	21	Water	8.16		572	25.42	
$E_l C_{12}$	150	21	Water	8.16		574	25.51	
$E_l C_{13}$	150	28	Water	8.17	1:2.5:3.5	659	29.28	29.34
$E_l C_{14}$	150	28	Water	8.18		560	29.33	
$E_l C_{15}$	150	28	Water	8.19		662	29.42	

A– 51: Compressive Strength of Concrete Cube from Portland Cement Brand G

(w/c = 0.60)

Sample	Cube size (mm)	Curing Age (days)	Curing condition	Weight of Cube (kg)	Mix Ratio	Crushing Load (kN)	Crushing Strength (N/mm^2) Test	Average
SOC_1	150	3	Water	7.85	1:2.5:3.5	272	12.08	12.02
SOC_2	150	3	Water	7.90		270	12.00	
SOC_3	150	3	Water	7.80		270	12.00	
SOC_4	150	7	Water	8.02	1:2.5:3.5	360	16.00	16.02
SOC_5	150	7	Water	8.02		360	16.00	
SOC_6	150	7	Water	8.04		362	16.08	
SOC_7	150	14	Water	8.08	1:2.5:3.5	470	20.88	20.97
SOC_8	150	14	Water	8.07		470	20.88	
SOC_9	150	14	Water	8.10		476	21.15	
SOC_{10}	150	21	Water	8.10	1:2.5:3.5	560	24.88	25.10
SOC_{11}	150	21	Water	8.11		565	25.11	
SOC_{12}	150	21	Water	8.11		570	25.33	
SOC_{13}	150	28	Water	8.11	1:2.5:3.5	635	28.22	28.07
SOC_{14}	150	28	Water	8.11		630	28.00	
SOC_{15}	150	28	Water	8.11		630	28.00	

Computation of Lime Saturation Factor for ordinary Portland Cement

A – 52: Computation of Lime Saturation Factor for Cement Brand A

$$LSF = \frac{CaO - 0.7(SO_3)}{2.8(SiO_2) + 1.2(Al_2O_3) + 0.65(Fe_2O_3)}$$

$$LSF = \frac{61 - 0.7 \times 1.72}{2.8 \times 22 + 1.2 \times 6 + 0.65 \times 2} = 0.85$$

A – 53: Computation of Lime Saturation Factor for Cement Brand B

$$\text{LSF} = \frac{54.50 - 0.7(1.14)}{2.8 \times 18 + 1.2 \times 4.46 + 0.65 \times 3.45} = 0.926 = 0.93$$

A – 54: Computation of Lime Saturation Factor for Cement Brand C

$$\text{LSF} = \frac{58 - 0.7(1.03)}{2.8 \times 21 + 1.2 \times 6 + 0.65 \times 2} = 0.85$$

A – 55: Computation of Lime Saturation Factor for Cement Brand D

$$\text{LSF} = \frac{62 - 0.7(0.34)}{2.8 \times 20 + 1.2 \times 4 + 0.65 \times 2.50} = 0.98$$

A – 56: Computation of Lime Saturation Factor for Cement Brand E

$$\text{LSF} = \frac{59 - 0.7(1.76)}{2.8 \times 21.95 + 1.2 \times 2 + 0.65 \times 2.20} = 88$$

A – 57: Computation of Lime Saturation Factor for Cement Brand F

$$\text{LSF} = \frac{58 - 0.7(0.38)}{2.8 \times 19 + 1.2 \times 8 + 0.65 \times 2} = 0.90$$

A – 58: Computation of Lime Saturation Factor for Cement Brand G

$$\text{LSF} = \frac{59 - 0.7(1.3768)}{2.8 \times 28.45 + 1.2 \times 1.41 + 0.65 \times 2.20} = 0.69$$

Computation of Percentage Composition of the Chemical Compound in Ordinary Portland Cement

The percentages of the chemical compounds in the ordinary Portland cements were computed from the results obtained in percentage of the oxides using the following Bogue Formulae presented in chapter three, pages 89 to 90, equations 2 to 5.

A – 59: Computation of Chemical Compounds in Cement Brand A

C_3S = 4.07 x 61 – 7.60 x 22.0 – 6.72 x 6.0 – 1.4 x 2 – 2.85 x 1.72 = 33.0

C_2S = 2.87 x 22 – 0.75(33.0) = 38.39

C_3A = 2.65 x 6 – 1.69 x 2 = 12.52

C_4AF = 3.04 x 2 = 6.08

A – 60: Computation of Chemical Compounds in Cement Brand B

C_3S = 4.07 x 54.50 – 7.60 x 18 – 6.72 x 4.46 – 1.4 x 3.45 – 2.85 x 1.14 = 46.97

C_2S = 2.87 x 18 – 0.75 x 46.97 = 16.43

C_3A = 2.65 x 4.46 – 1.69 x 3.45 = 5.99

C_4AF = 3.04 x 3.45 = 10.49

A – 61: Computation of Chemical Compounds in Cement Brand C

C_3S = 4.07 x 58 – 7.60 x 21 – 6.72 x 6 – 1.4 x 2 – 2.85 x 1.03 = 30.41

C_2S = 2.87 x 21 – 0.75 x 30.41 = 37.46

C_3A = 2.65 x 6 – 1.69 x 2 = 12.52

C_4AF = 3.04 x 2 = 6.08

A – 62: Computation of Chemical Compounds in Cement Brand D

C_3S = 4.07 x 62 – 7.60 x 20 – 6.72 x 4 – 1.4 x 2.5 – 2.85 x 0.34 = 68.99

C_2S = 2.87 x 20 – 0.75 x 68.99 = 5.66

C_3A = 2.65 x 4 – 1.69 x 2.50 = 6.38

C_4AF = 3.04 x 2.5 = 7.60

A – 63: Computation of Chemical Compounds in Cement Brand E

C_3S = 4.07 x 59 – 7.60 x 21.95 – 6.72 x 2 – 1.4 x 2.20 – 2.85 x 1.76 = 51.77

C_2S = 2.87 x 21.95 – 0.75 x 51.77 = 24.17

C_3A = 2.65 x 2 – 1.69 x 2.20 = 1.58

C_4AF = 3.04 x 2.20 = 6.69

A – 64: Computation of Chemical Compounds in Cement Brand F

C_3S = 4.07 x 58 – 7.60 x 19 – 6.72 x 8 – 1.4 x 2 – 2.85 x 0.30 = 34.25

C_2S = 2.87 x 19 – 0.75 x 34.25 = 28.84

C_3A = 2.65 x 8 – 1.69 x 2 = 17.82

C_4AF = 3.04 x 2 = 6.08

A – 65: Computation of Chemical Compounds in Cement Brand G

C_3S = 4.07 x 59 – 7.60 x 28.45 – 6.72 x 1.41 – 1.4 x 2.20 – 2.85 x 1.76 = 6.34

C_2S = 2.87 x 19 – 0.75 x 6.34 = 49.78

C_3A = 2.65 x 1.41 – 1.69 x 2.2 = 0.02

C_4AF = 3.04 x 2.2 = 6.69

A – 66: Dry Compressive Strength of Hollow 9” Sandcrete Blocks Moulded With Machine from Portland Cement Brand A at 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	42.5	0.42	0.44
1:4	46.6	0.46	
1:4	45.6	0.45	
1:5	34.4	0.34	0.36
1:5	38.8	0.38	
1:5	36.5	0.36	
1:6	29.4	0.29	0.31
1:6	32.4	0.32	
1:6	32.4	0.32	
1:7	29.4	0.29	0.30
1:7	31.0	0.31	
1:7	31.4	0.31	
1:8	28	0.28	0.29
1:8	29.3	0.29	
1:8	29	0.29	
1:9	25	0.25	0.26
1:9	26.3	0.26	
1:9	27	0.27	
1:10	21.3	0.21	0.22
1:10	22	0.22	
1:10	22.3	0.22	
1:11	20	0.20	0.20
1:11	21	0.21	
1:11	20.2	0.20	
1:12	16	0.16	0.17
1:12	18	0.18	
1:12	18.2	0.18	

A – 67: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded With Machine from Portland Cement Brand A at 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	127	1.26	1.26
1:4	138	1.37	
1:4	127	1.26	
1:5	106	1.05	1.01
1:5	95	0.94	
1:5	106	1.05	
1:6	74	0.73	0.87
1:6	95	0.94	
1:6	95	0.94	
1:7	95	0.94	0.87
1:7	85	0.84	
1:7	85	0.84	
1:8	85	0.84	0.84
1:8	85	0.84	
1:8	85	0.84	
1:9	74	0.73	0.75
1:9	74	0.73	
1:9	79	0.78	
1:10	74	0.73	0.64
1:10	58	0.57	
1:10	63.3	0.63	
1:11	63.3	0.63	0.61
1:11	58	0.57	
1:11	63.3	0.63	
1:12	47	0.47	0.47
1:12	47	0.47	
1:12	47	0.47	

A –68: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded With Machine from Portland Cement Brand A at 7 days Curing Age (w/c = 0.45)

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	300	2.97	3.04
1:4	312.5	3.09	
1:4	308	3.05	
1:5	280.6	2.78	2.83
1:5	288	2.85	
1:5	288	2.85	
1:6	267	2.64	2.66
1:6	268	2.65	
1:6	270	2.67	
1:7	214.3	2.12	2.11
1:7	212	2.10	
1:7	212	2.10	
1:8	181	1.79	1.81
1:8	181	1.79	
1:8	186.5	1.85	
1:9	174	1.72	1.72
1:9	173	1.71	
1:9	174.6	1.73	
1:10	154	1.52	1.53
1:10	154	1.52	
1:10	155	1.53	
1:11	98	0.97	0.97
1:11	100.6	1.00	
1:11	94	0.93	
1:12	89	0.88	0.87
1:12	87.6	0.87	
1:12	87.6	0.87	

A – 69: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand A at 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	423	4.19	4.19
1:4	425	4.21	
1:4	422	4.18	
1:5	409	4.05	3.89
1:5	393	3.89	
1:5	376	3.72	
1:6	339	3.36	3.40
1:6	352	3.49	
1:6	339	3.36	
1:7	275	2.72	2.71
1:7	275	2.72	
1:7	271	2.68	
1:8	219	2.17	2.15
1:8	219	2.17	
1:8	214	2.12	
1:9	202	2.00	2.00
1:9	202	2.00	
1:9	201	1.99	
1:10	181	1.79	1.84
1:10	189	1.87	
1:10	189	1.87	
1:11	148.6	1.47	1.47
1:11	148.6	1.47	
1:11	149	1.48	
1:12	132	1.31	1.29
1:12	129	1.28	

1:12	129	1.28

A – 70: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand A at 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	441	4.37	4.40
1:4	441	4.37	
1:4	450	4.46	
1:5	408	4.04	4.05
1:5	411	4.07	
1:5	408	4.04	
1:6	379	3.75	3.75
1:6	382	3.78	
1:6	376	3.72	
1:7	326	3.23	3.15
1:7	314	3.11	
1:7	314	3.11	
1:8	275	2.72	2.70
1:8	272	2.69	
1:8	272	2.69	
1:9	212	2.10	2.11
1:9	213	2.11	
1:9	213	2.11	
1:10	201	1.99	1.99
1:10	201	1.99	
1:10	201	1.99	
1:11	162	1.60	1.59
1:11	160	1.58	
1:11	160	1.58	
1:12	148	1.47	1.46
1:12	148	1.47	
1:12	145	1.44	

A – 71: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Ashaka Portland Cement Brand A at 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	496	4.91	4.93
1:4	494	4.89	
1:4	503	4.98	
1:5	462	4.57	4.59
1:5	465	4.60	
1:5	463	4.58	
1:6	427	4.23	4.24
1:6	432	4.28	
1:6	425	4.21	
1:7	408	4.04	4.05
1:7	411	4.07	
1:7	407.9	4.04	
1:8	391	3.87	3.89
1:8	392	3.88	
1:8	397	3.93	
1:9	340	3.37	3.38
1:9	340	3.37	
1:9	343	3.40	
1:10	297	2.94	2.97
1:10	301	2.98	
1:10	302	2.99	
1:11	243	2.41	2.33
1:11	231	2.29	
1:11	231	2.29	
1:12	172	1.70	1.69
1:12	172	1.70	
1:12	168.7	1.67	

A – 72: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand B at 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	48.6	0.48	0.49
1:4	50.6	0.50	
1:4	50.6	0.50	
1:5	32.4	0.32	0.37
1:5	40.5	0.40	
1:5	39.5	0.39	
1:6	30.4	0.30	0.29
1:6	28.4	0.28	
1:6	30.4	0.30	
1:7	30	0.28	0.27
1:7	26	0.26	
1:7	30	0.28	
1:8	27	0.27	0.26
1:8	26.3	0.26	
1:8	26	0.26	
1:9	25	0.25	0.25
1:9	24.3	0.24	
1:9	25	0.25	
1:10	25	0.25	0.24
1:10	24	0.24	
1:10	23.3	0.23	
1:11	24	0.24	0.23
1:11	23	0.23	
1:11	23	0.23	
1:12	21	0.21	0.21
1:12	22	0.22	
1:12	21.3	0.21	

A – 73: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand B at 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	148.2	1.47	1.43
1:4	158.8	1.57	
1:4	127	1.26	
1:5	95.3	0.94	0.96
1:5	90	0.89	
1:5	106	1.05	
1:6	84.7	0.84	0.84
1:6	84.7	0.84	
1:6	84.7	0.84	
1:7	79.4	0.79	0.79
1:7	84.7	0.84	
1:7	74	0.73	
1:8	74	0.73	0.77
1:8	74	0.73	
1:8	84.7	0.84	
1:9	74	0.73	0.73
1:9	74	0.73	
1:9	74	0.73	
1:10	74	0.73	0.70
1:10	63.5	0.63	
1:10	74	0.73	
1:11	74	0.73	0.68
1:11	63.5	0.63	
1:11	68.8	0.68	
1:12	68.8	0.68	0.63
1:12	58.2	0.58	
1:12	63.5	0.63	

A – 74: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand B at 7days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	740.6	7.33	7.36
1:4	740	7.33	
1:4	749	7.42	
1:5	527	5.22	5.30
1:5	550.5	5.45	
1:5	527	5.22	
1:6	515	5.10	5.06
1:6	514	5.09	
1:6	503	4.98	
1:7	314	3.11	3.11
1:7	314	3.11	
1:7	314	3.11	
1:8	260	2.57	2.55
1:8	254.5	2.52	
1:8	257.5	2.55	
1:9	166	1.64	1.65
1:9	167.5	1.66	
1:9	166.4	1.65	
1:10	130	1.29	1.27
1:10	127	1.26	
1:10	127	1.26	
1:11	102	1.01	1.00
1:11	102	1.01	
1:11	99	0.98	
1:12	85	0.84	0.83
1:12	86	0.85	
1:12	82	0.81	

A – 75: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand B at 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	758	7.50	7.50
1:4	752	7.45	
1:4	761	7.53	
1:5	581	5.75	5.81
1:5	599	5.93	
1:5	581	5.75	
1:6	522	5.17	5.16
1:6	521	5.16	
1:6	521	5.16	
1:7	426	4.22	4.20
1:7	425	4.21	
1:7	422	4.18	
1:8	332	3.29	3.30
1:8	332	3.29	
1:8	337	3.34	
1:9	226	2.24	2.24
1:9	226	2.24	
1:9	225	2.23	
1:10	144	1.43	1.40
1:10	142	1.41	
1:10	139	1.38	
1:11	125	1.24	1.18
1:11	117	1.16	
1:11	116.6	1.15	
1:12	99	0.98	0.99
1:12	99	0.98	
1:12	101	1.00	

A – 76: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand B at 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	820	8.10	8.06
1:4	818	8.08	
1:4	810	8.00	
1:5	673	6.65	6.62
1:5	668	6.60	
1:5	669	6.61	
1:6	567	5.60	5.59
1:6	567	5.60	
1:6	563	5.56	
1:7	487	4.81	4.76
1:7	476	4.70	
1:7	482	4.76	
1:8	395	3.90	3.85
1:8	375	3.70	
1:8	400	3.95	
1:9	294	2.90	2.84
1:9	283.5	2.80	
1:9	286.5	2.83	
1:10	192	1.90	1.83
1:10	175	1.73	
1:10	188	1.86	
1:11	139	1.37	1.37
1:11	142	1.40	
1:11	135	1.33	
1:12	121.5	1.20	1.19
1:12	118	1.17	
1:12	121.5	1.20	

A – 77: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand B at 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	868	8.59	8.56
1:4	868	8.59	
1:4	858	8.50	
1:5	740	7.33	7.29
1:5	734	7.27	
1:5	734	7.27	
1:6	586	5.80	5.83
1:6	593	5.87	
1:6	586	5.80	
1:7	524	5.19	5.20
1:7	526	5.21	
1:7	524	5.19	
1:8	453	4.49	4.34
1:8	438	4.34	
1:8	423	4.19	
1:9	336	3.33	3.33
1:9	336	3.33	
1:9	336	3.33	
1:10	222	2.20	2.21
1:10	225	2.23	
1:10	222	2.20	
1:11	157	1.55	1.52
1:11	148	1.47	
1:11	157	1.55	
1:12	133	1.32	1.33
1:12	133	1.32	
1:12	137	1.36	

A – 78: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand C at 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	91	0.90	0.88
1:4	85	0.84	
1:4	91	0.90	
1:5	51	0.50	0.48
1:5	45	0.44	
1:5	51	0.50	
1:6	38.5	0.38	0.39
1:6	40.5	0.40	
1:6	40	0.40	
1:7	28.4	0.28	0.31
1:7	32	0.32	
1:7	32	0.32	
1:8	26	0.26	0.27
1:8	28	0.28	
1:8	28	0.28	
1:9	24	0.24	0.25
1:9	26	0.26	
1:9	26	0.26	
1:10	20	0.20	0.23
1:10	24	0.24	
1:10	24.3	0.24	
1:11	18	0.18	0.19
1:11	20	0.20	
1:11	20.3	0.20	
1:12	14	0.14	0.15
1:12	16	0.16	
1:12	16	0.16	

A – 79: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand C at 3 Days Curing Age

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	275.2	2.72	2.52
1:4	254	2.51	
1:4	233	2.31	
1:5	148.2	1.47	1.33
1:5	127	1.26	
1:5	127	1.26	
1:6	116.5	1.15	1.15
1:6	116.5	1.15	
1:6	116.5	1.15	
1:7	84.7	0.84	0.84
1:7	84.7	0.84	
1:7	84.7	0.84	
1:8	79.4	0.79	0.79
1:8	79.4	0.79	
1:8	79.4	0.79	
1:9	74	0.73	0.73
1:9	74	0.73	
1:9	74	0.73	
1:10	63.5	0.63	0.61
1:10	63.5	0.63	
1:10	58.2	0.58	
1:11	53	0.52	0.53
1:11	53	0.52	
1:11	55	0.54	
1:12	42.3	0.42	0.41
1:12	37	0.37	
1:12	44.5	0.44	

A – 80: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement C Brand at 7 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	333	3.30	3.29
1:4	333	3.30	
1:4	331.5	3.28	
1:5	275	2.72	2.82
1:5	287	2.84	
1:5	291	2.88	
1:6	263	2.60	2.57
1:6	262	2.59	
1:6	255	2.52	
1:7	210	2.08	2.05
1:7	209.5	2.07	
1:7	201	1.99	
1:8	189	1.87	1.93
1:8	198	1.96	
1:8	198	1.96	
1:9	172	1.70	1.68
1:9	169	1.67	
1:09	169	1.67	
1:10	155	1.53	1.35
1:10	98	0.97	
1:10	156	1.54	
1:11	109.5	1.08	1.07
1:11	107	1.06	
1:11	107.7	1.07	
1:12	96.5	0.96	0.95
1:12	95.9	0.95	
1:12	95.3	0.94	

A – 81: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand C at 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	477	4.72	4.77
1:4	485	4.80	
1:4	483	4.78	
1:5	429	4.25	4.28
1:5	429	4.25	
1:5	439	4.35	
1:6	429	4.25	4.16
1:6	417	4.13	
1:6	415	4.11	
1:7	300	2.97	2.99
1:7	303	3.00	
1:7	302	2.99	
1:8	268	2.65	2.60
1:8	258	2.55	
1:8	262	2.59	
1:9	226	2.24	2.14
1:9	207	2.05	
1:9	215	2.13	
1:10	195	1.93	1.94
1:10	195	1.93	
1:10	199	1.97	
1:11	163	1.61	1.62
1:11	166	1.64	
1:11	163	1.61	
1:12	155	1.53	1.52
1:12	155	1.53	
1:12	151	1.50	

A – 82: Dry Compressive Strength of Hollow 9” Sandcrete Blocks Moulded with Machine from Portland Cement Brand C at 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	506	5.01	5.02
1:4	509	5.04	
1:4	505	5.00	
1:5	463	4.58	4.61
1:5	465	4.60	
1:5	468	4.63	
1:6	446	4.42	4.43
1:6	446	4.42	
1:6	451	4.47	
1:7	346	3.43	3.42
1:7	343	3.40	
1:7	346	3.43	
1:8	302	2.99	3.01
1:8	305	3.02	
1:8	305	3.02	
1:9	260	2.57	2.59
1:9	260	2.57	
1:9	266	2.63	
1:10	219	2.17	2.20
1:10	229	2.27	
1:10	219	2.17	
1:11	189	1.87	1.86
1:11	189	1.87	
1:11	186	1.84	
1:12	167	1.65	1.63
1:12	167	1.65	
1:12	160	1.58	

A – 83: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand C at 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	539	5.34	5.32
1:4	537	5.32	
1:4	536	5.31	
1:5	487	4.82	4.83
1:5	488	4.83	
1:5	487	4.82	
1:6	463	4.58	4.62
1:6	468	4.63	
1:6	468	4.63	
1:7	440	4.36	4.37
1:7	441	4.37	
1:7	441	4.37	
1:8	410	4.06	4.05
1:8	411	4.07	
1:8	407	4.03	
1:9	326	3.23	3.21
1:9	323	3.20	
1:9	323	3.20	
1:10	278	2.75	2.75
1:10	276	2.73	
1:10	278	2.75	
1:11	222	2.20	2.25
1:11	231	2.29	
1:11	228	2.26	
1:12	170	1.68	1.67
1:12	170	1.68	
1:12	166	1.64	

A – 84: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded With Machine from Portland Cement Brand D at 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	47	0.46	0.45
1:4	42.5	0.42	
1:4	46.6	0.46	
1:5	33	0.33	0.35
1:5	35	0.35	
1:5	37.4	0.37	
1:6	31	0.31	0.32
1:6	33	0.33	
1:6	33.4	0.33	
1:7	23	0.23	0.25
1:7	25	0.25	
1:7	26	0.26	
1:8	23	0.23	0.22
1:8	21	0.21	
1:8	23	0.23	
1:9	17.2	0.17	0.18
1:9	18	0.18	
1:9	18	0.18	
1:10	17	0.17	0.16
1:10	16	0.16	
1:10	16	0.16	
1:11	15	0.15	0.15
1:11	14	0.14	
1:11	15	0.15	
1:12	13	0.13	0.13
1:12	13	0.13	
1:12	13	0.13	

A – 85: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand D at 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	106	1.05	1.22
1:4	127	1.26	
1:4	138	1.37	
1:5	101	1.00	1.00
1:5	101	1.00	
1:5	101	1.00	
1:6	95	0.94	0.94
1:6	95	0.94	
1:6	95	0.94	
1:7	63.5	0.63	0.68
1:7	68.8	0.68	
1:7	74	0.73	
1:8	63.5	0.63	0.63
1:8	63.5	0.63	
1:8	63.5	0.63	
1:9	53	0.52	0.52
1:9	53	0.52	
1:9	53	0.52	
1:10	48	0.48	0.48
1:10	48	0.48	
1:10	48	0.48	
1:11	48	0.48	0.42
1:11	42.3	0.42	
1:11	37	0.37	
1:12	32	0.32	0.39
1:12	42.3	0.42	
1:12	42.3	0.42	

A – 86: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand D at 7 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	334.5	3.31	3.24
1:4	311	3.08	
1:4	335.7	3.32	
1:5	303	3.00	3.03
1:5	310	3.07	
1:5	305	3.02	
1:6	261.7	2.59	2.56
1:6	262.8	2.60	
1:6	250	2.48	
1:7	208.4	2.06	2.06
1:7	210	2.08	
1:7	207.2	2.05	
1:8	189.5	1.88	1.88
1:8	189.5	1.88	
1:8	189.5	1.88	
1:9	151	1.50	1.50
1:9	151	1.50	
1:9	154	1.52	
1:10	130.2	1.29	1.27
1:10	127	1.26	
1:10	127	1.26	
1:11	104	1.03	1.02
1:11	104	1.03	
1:11	102	1.01	
1:12	94.7	0.94	0.95
1:12	97	0.96	
1:12	97	0.96	

A – 87: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand D at 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	416	4.12	4.05
1:4	406	4.02	
1:4	406	4.02	
1:5	345	3.42	3.44
1:5	348	3.45	
1:5	349	3.46	
1:6	316	3.13	3.11
1:6	316	3.13	
1:6	311	3.08	
1:7	272	2.69	2.70
1:7	278	2.75	
1:7	269	2.66	
1:8	228	2.26	2.27
1:8	228	2.26	
1:8	231	2.29	
1:9	213	2.11	2.11
1:9	214	2.12	
1:9	213	2.11	
1:10	200	1.98	1.98
1:10	200	1.98	
1:10	201	1.99	
1:11	151.6	1.50	1.49
1:11	153	1.51	
1:11	148	1.47	
1:12	133	1.32	1.34
1:12	136	1.35	
1:12	136	1.35	

A – 88: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand D at 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	432	4.28	4.27
1:4	432	4.28	
1:4	429	4.25	
1:5	370	3.66	3.67
1:5	370	3.66	
1:5	374	3.70	
1:6	340	3.37	3.40
1:6	344	3.41	
1:6	347	3.44	
1:7	321	3.18	3.18
1:7	321	3.18	
1:7	320	3.17	
1:8	260	2.57	2.55
1:8	252	2.50	
1:8	260	2.57	
1:9	243	2.41	2.43
1:9	246	2.44	
1:S9	246	2.44	
1:10	216	2.14	2.13
1:10	213	2.11	
1:10	216	2.14	
1:11	163	1.61	1.62
1:11	163	1.61	
1:11	166	1.64	
1:12	144	1.43	1.44
1:12	143	1.42	
1:12	148	1.47	

A – 89: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand D at 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	441	4.37	4.40
1:4	441	4.37	
1:4	450	4.46	
1:5	408	4.04	4.00
1:5	400	3.96	
1:5	404	4.00	
1:6	376	3.72	3.75
1:6	376	3.72	
1:6	385	3.81	
1:7	370	3.66	3.66
1:7	370	3.66	
1:7	371	3.67	
1:8	349	3.46	3.43
1:8	340	3.37	
1:8	349	3.46	
1:9	305	3.02	3.04
1:9	309	3.06	
1:9	308	3.05	
1:10	272	2.69	2.71
1:10	272	2.69	
1:10	277	2.74	
1:11	238	2.36	2.30
1:11	231	2.29	
1:11	228	2.26	
1:12	151	1.50	1.44
1:12	142	1.41	
1:12	142	1.41	

A – 90: Dry Compressive Strength of Hollow 9” Sandcrete Blocks Moulded with Machine from Portland Cement Brand E at 1 Day Curing Age

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	42.5	0.42	0.46
1:4	48.6	0.48	
1:4	49	0.48	
1:5	28.4	0.28	0.30
1:5	32	0.32	
1:5	30.4	0.30	
1:6	26	0.26	0.27
1:6	28	0.28	
1:6	28.3	0.28	
1:7	23	0.23	0.25
1:7	26	0.26	
1:7	26	0.26	
1:8	21	0.21	0.22
1:8	23	0.23	
1:8	23.3	0.23	
1:9	17	0.17	0.19
1:9	20	0.20	
1:9	20.3	0.20	
1:10	14	0.14	0.15
1:10	16	0.16	
1:10	16.2	0.16	
1:11	11	0.11	0.13
1:11	14	0.14	
1:11	14.2	0.14	
1:12	11	0.11	0.12
1:12	12	0.12	
1:12	12.1	0.12	

A – 91: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand E at 3 Days Curing Age

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	127	1.26	1.26
1:4	127	1.26	
1:4	127	1.26	
1:5	84.7	0.84	0.84
1:5	84.7	0.84	
1:5	84.7	0.84	
1:6	84.7	0.84	0.79
1:6	79.4	0.79	
1:6	74	0.73	
1:7	68.8	0.68	0.68
1:7	63.5	0.63	
1:7	74	0.73	
1:8	63.5	0.63	0.63
1:8	63.5	0.63	
1:8	63.5	0.63	
1:9	53	0.52	0.52
1:9	53	0.52	
1:9	53	0.52	
1:10	42.3	0.42	0.42
1:10	47.6	0.47	
1:10	37	0.37	
1:11	32	0.32	0.32
1:11	32	0.32	
1:11	32	0.32	
1:12	26.5	0.26	0.26
1:12	26.5	0.26	
1:12	26.5	0.26	

A – 92: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand E at 7days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	556	5.50	5.41
1:4	545	5.40	
1:4	539	5.34	
1:5	515	5.10	5.10
1:5	516	5.11	
1:5	515	5.10	
1:6	468	4.63	4.61
1:6	464	4.59	
1:6	465	4.60	
1:7	403	3.99	3.98
1:7	400	3.96	
1:7	403	3.99	
1:8	379	3.75	3.65
1:8	364	3.60	
1:8	364	3.60	
1:9	231	2.29	2.24
1:9	227	2.25	
1:9	222	2.20	
1:10	201	1.99	1.99
1:10	200.7	1.99	
1:10	201	1.99	
1:11	130	1.29	1.33
1:11	133	1.32	
1:11	139	1.38	
1:12	94	0.93	0.95
1:12	94.7	0.94	
1:12	98.3	0.97	

A – 93: Dry Compressive Strength of Hollow 9” Sandcrete Blocks Moulded With Machine from Portland Cement Brand E at 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	580	5.74	5.86
1:4	598	5.92	
1:4	598	5.92	
1:5	551	5.46	5.42
1:5	546	5.41	
1:5	546	5.41	
1:6	522	5.17	5.06
1:6	527	5.22	
1:6	485	4.80	
1:7	446	4.42	4.40
1:7	445	4.41	
1:7	443	4.39	
1:8	394	3.90	3.90
1:8	403	3.99	
1:8	385	3.81	
1:9	269	2.66	2.61
1:9	260	2.57	
1:9	263	2.60	
1:10	207	2.05	2.08
1:10	209	2.07	
1:10	213	2.11	
1:11	130	1.29	1.37
1:11	142	1.41	
1:11	144	1.43	
1:12	110	1.09	1.09
1:12	110	1.09	
1:12	111	1.10	

A – 94: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand E at 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	638	6.30	6.21
1:4	628	6.20	
1:4	621	6.13	
1:5	587	5.80	5.79
1:5	572	5.65	
1:5	599	5.92	
1:6	531.6	5.25	5.24
1:6	537	5.30	
1:6	523	5.17	
1:7	496	4.90	4.80
1:7	476	4.70	
1:7	487	4.81	
1:8	425	4.20	4.18
1:8	427	4.22	
1:8	418	4.13	
1:9	294	2.90	2.85
1:9	283.5	2.80	
1:9	289	2.85	
1:10	253	2.50	2.44
1:10	253	2.50	
1:10	235	2.32	
1:11	172	1.70	1.69
1:11	172	1.70	
1:11	170	1.68	
1:12	146	1.44	1.43
1:12	146	1.44	
1:12	144	1.42	

A – 95: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand E at 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	655	6.49	6.46
1:4	669	6.62	
1:4	634	6.28	
1:5	617	6.11	6.10
1:5	617	6.11	
1:5	615	6.09	
1:6	546	5.41	5.38
1:6	542	5.37	
1:6	542	5.37	
1:7	509	5.04	5.04
1:7	515	5.10	
1:7	504	4.99	
1:8	440	4.36	4.37
1:8	440	4.36	
1:8	444	4.40	
1:9	314	3.11	3.10
1:9	314	3.11	
1:9	312	3.09	
1:10	285	2.82	2.77
1:10	277	2.74	
1:10	278	2.75	
1:11	201	1.99	1.98
1:11	198	1.96	
1:11	201	1.99	
1:12	171	1.69	1.70
1:12	170	1.68	
1:12	173	1.71	

A – 96: Dry Compressive Strength of Hollow 9” Sandcrete Blocks Moulded with Machine from Portland Cement Brand F at 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	42.5	0.42	0.45
1:4	47	0.46	
1:4	47	0.46	
1:5	38.5	0.38	0.41
1:5	42.5	0.42	
1:5	42.5	0.42	
1:6	30	0.30	0.33
1:6	34.4	0.34	
1:6	34	0.34	
1:7	28.3	0.28	0.31
1:7	32.4	0.32	
1:7	32	0.32	
1:8	26	0.26	0.27
1:8	28	0.28	
1:8	28	0.28	
1:9	16.3	0.16	0.19
1:9	20.3	0.20	
1:9	20	0.20	
1:10	12	0.12	0.15
1:10	16.2	0.16	
1:10	16	0.11	
1:11	11	0.11	0.12
1:11	12	0.12	
1:11	12	0.12	
1:12	10	0.10	0.10
1:12	11	0.11	
1:12	10	0.10	

A – 97: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand F at 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	131.6	1.30	1.25
1:4	134	1.32	
1:4	114	1.13	
1:5	111	1.10	1.13
1:5	111	1.10	
1:5	120	1.19	
1:6	97	0.96	0.90
1:6	92	0.91	
1:6	85	0.84	
1:7	81	0.80	0.83
1:7	81	0.80	
1:7	91	0.90	
1:8	76	0.75	0.77
1:8	75	0.74	
1:8	83	0.82	
1:9	52.7	0.52	0.49
1:9	51	0.50	
1:9	44.5	0.44	
1:10	35.4	0.35	0.36
1:10	37	0.37	
1:10	36	0.36	
1:11	33	0.33	0.34
1:11	35	0.35	
1:11	34	0.34	
1:12	20	0.20	0.19
1:12	20	0.20	
1:12	18	0.18	

A – 98: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand F at 7 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	287	2.84	2.86
1:4	290	2.87	
1:4	290	2.87	
1:5	259	2.56	2.57
1:5	259	2.56	
1:5	260.5	2.58	
1:6	212	2.10	2.10
1:6	212	2.10	
1:6	212	2.10	
1:7	192.4	1.90	1.91
1:7	192.4	1.90	
1:7	193.6	1.92	
1:8	177	1.75	1.76
1:8	178	1.76	
1:8	177.6	1.76	
1:9	113	1.12	1.11
1:9	112	1.11	
1:9	112.5	1.11	
1:10	82.3	0.81	0.82
1:10	83	0.82	
1:10	82.3	0.81	
1:11	126	1.25	0.79
1:11	59.2	0.59	
1:11	53.3	0.53	
1:12	44.4	0.44	0.40
1:12	39	0.39	
1:12	39	0.39	

A – 99: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded With Machine from Portland Cement Brand F at 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	320	3.17	3.22
1:4	321	3.18	
1:4	335	3.32	
1:5	308	3.05	3.03
1:5	308	3.05	
1:5	302	2.99	
1:6	300	2.97	2.98
1:6	301	2.98	
1:6	302	2.99	
1:7	290	2.87	2.88
1:7	292	2.89	
1:7	290	2.87	
1:8	253	2.50	2.53
1:8	253	2.50	
1:8	260	2.57	
1:9	226	2.24	2.22
1:9	225	2.23	
1:9	222	2.20	
1:10	203.6	2.02	2.01
1:10	202	2.00	
1:10	203.6	2.02	
1:11	174	1.72	1.69
1:11	169	1.67	
1:11	170	1.68	
1:12	149	1.48	1.48
1:12	149	1.48	
1:12	149	1.48	

A – 100: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand F at 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	385	3.80	3.71
1:4	375	3.70	
1:4	369	3.64	
1:5	355	3.51	3.44
1:5	344	3.40	
1:5	352	3.48	
1:6	324	3.20	3.23
1:6	324	3.20	
1:6	334	3.30	
1:7	315	3.11	3.12
1:7	314	3.10	
1:7	319	3.15	
1:8	283.5	2.80	2.80
1:8	283.5	2.80	
1:8	282	2.79	
1:9	263	2.60	2.58
1:9	263	2.60	
1:9	256	2.53	
1:10	218	2.15	2.13
1:10	221	2.18	
1:10	208.5	2.06	
1:11	192	1.90	1.89
1:11	192	1.90	
1:11	190	1.88	
1:12	167	1.65	1.60
1:12	157	1.55	
1:12	162	1.60	

A – 101: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand F at 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	418	4.14	4.15
1:4	420	4.16	
1:4	420	4.16	
1:5	376	3.72	3.74
1:5	376	3.72	
1:5	380	3.76	
1:6	347	3.44	3.45
1:6	349	3.46	
1:6	349	3.46	
1:7	338	3.35	3.35
1:7	338	3.35	
1:7	340	3.37	
1:8	308	3.05	3.03
1:8	305	3.02	
1:8	305	3.02	
1:9	278	2.75	2.81
1:9	284	2.81	
1:9	290	2.87	
1:10	226	2.24	2.21
1:10	226	2.24	
1:10	219	2.17	
1:11	213	2.11	2.07
1:11	207	2.05	
1:11	207	2.05	
1:12	174	1.72	1.70
1:12	172	1.70	
1:12	169	1.67	

A – 102: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand G at 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	30.4	0.30	0.33
1:4	35.4	0.35	
1:4	35.4	0.35	
1:5	24.3	0.24	0.27
1:5	28.4	0.28	
1:5	28.4	0.28	
1:6	21.3	0.21	0.22
1:6	23.3	0.23	
1:6	23.3	0.23	
1:7	18.2	0.18	0.19
1:7	20	0.20	
1:7	20	0.20	
1:8	17	0.17	0.18
1:8	19	0.19	
1:8	18.2	0.18	
1:9	15	0.15	0.16
1:9	16	0.16	
1:9	16.2	0.16	
1:10	14	0.14	0.15
1:10	15	0.15	
1:10	15	0.15	
1:11	13	0.13	0.14
1:11	14.2	0.14	
1:11	14	0.14	
1:12	12	0.12	0.12
1:12	12	0.12	
1:12	13	0.13	

A – 103: Dry Compressive Strength of Hollow 9” Sandcrete Blocks Moulded with Machine from Portland Cement Brand G at 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	101	1.00	0.90
1:4	81	0.80	
1:4	92	0.91	
1:5	71	0.70	0.72
1:5	71	0.70	
1:5	78	0.77	
1:6	66	0.65	0.64
1:6	64	0.63	
1:6	65	0.64	
1:7	50.6	0.50	0.54
1:7	55.7	0.55	
1:7	58	0.57	
1:8	50.6	0.50	0.50
1:8	53	0.52	
1:8	49.5	0.49	
1:9	51	0.50	0.46
1:9	46	0.45	
1:9	44.6	0.44	
1:10	45	0.44	0.43
1:10	44.5	0.44	
1:10	42.5	0.42	
1:11	40.5	0.40	0.38
1:11	40.5	0.40	
1:11	34	0.34	
1:12	34	0.34	0.36
1:12	36	0.36	
1:12	37	0.37	

A – 104: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand G at 7days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	191	1.89	1.89
1:4	193	1.91	
1:4	188	1.86	
1:5	155	1.53	1.53
1:5	156	1.54	
1:5	155	1.53	
1:6	147.9	1.46	1.47
1:6	148	1.47	
1:6	148	1.47	
1:7	122	1.21	1.21
1:7	122	1.21	
1:7	122	1.21	
1:8	116	1.15	1.15
1:8	116	1.15	
1:8	115.9	1.15	
1:9	107	1.06	1.05
1:9	109	1.08	
1:9	102	1.01	
1:10	103	1.02	1.00
1:10	101	1.00	
1:10	98	0.97	
1:11	87	0.86	0.86
1:11	87	0.86	
1:11	87	0.86	
1:12	89	0.88	0.84
1:12	86	0.85	
1:12	80.5	0.80	

A – 105: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand G at 14 days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	199	1.97	1.93
1:4	196	1.94	
1:4	191	1.89	
1:5	175	1.73	1.74
1:5	175	1.73	
1:5	177	1.75	
1:6	164	1.62	1.62
1:6	162	1.60	
1:6	166	1.64	
1:7	148	1.47	1.45
1:7	146	1.45	
1:7	145	1.44	
1:8	138	1.37	1.36
1:8	140	1.39	
1:8	134	1.33	
1:9	131	1.30	1.30
1:9	132	1.31	
1:9	131	1.30	
1:10	122	1.21	1.18
1:10	118.5	1.17	
1:10	118.5	1.17	
1:11	100.6	1.00	0.98
1:11	97	0.96	
1:11	100.6	1.00	
1:12	97	0.96	0.96
1:12	97	0.96	
1:12	96	0.95	

A – 106: Dry Compressive Strength of Hollow 9” Sandcrete Blocks Moulded with Machine from Portland Cement Brand G at 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	344	3.40	3.38
1:4	354	3.50	
1:4	328	3.24	
1:5	313	3.10	3.21
1:5	324	3.20	
1:5	337	3.33	
1:6	304	3.00	2.98
1:6	304	3.00	
1:6	299	2.95	
1:7	294	2.90	2.81
1:7	273	2.70	
1:7	287	2.83	
1:8	203.5	2.01	1.96
1:8	204.5	2.02	
1:8	191	1.89	
1:9	182	1.80	1.80
1:9	182	1.80	
1:9	183	1.81	
1:10	183	1.80	1.71
1:10	162	1.60	
1:10	176	1.74	
1:11	146	1.44	1.43
1:11	147	1.45	
1:11	142	1.40	
1:12	131.6	1.30	1.29
1:12	132	1.30	
1:12	130	1.28	

A – 107: Dry Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand G at 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Dry Compressive Strength (N/mm^2)	Average Dry Compressive Strength (N/mm^2)
1:4	480	4.75	4.74
1:4	478	4.73	
1:4	478	4.73	
1:5	467	4.62	4.61
1:5	463.5	4.59	
1:5	465	4.60	
1:6	424	4.20	4.21
1:6	424	4.20	
1:6	427	4.23	
1:7	412.6	4.09	4.10
1:7	415	4.11	
1:7	416	4.12	
1:8	360	3.56	3.49
1:8	359	3.55	
1:8	339	3.36	
1:9	233	2.31	2.30
1:9	233	2.31	
1:9	232	2.30	
1:10	212	2.10	2.17
1:10	223	2.21	
1:10	221	2.19	
1:11	185	1.83	1.81
1:11	180	1.78	
1:11	184	1.82	
1:12	159	1.57	1.55
1:12	156	1.54	
1:12	154.5	1.53	

A – 108: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand A Immersed in Water for 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	138	1.37	1.26
1:4	127	1.26	
1:4	117	1.16	
1:5	106	1.05	1.05
1:5	117	1.16	
1:5	95.3	0.94	
1:6	101	1.00	0.91
1:6	90	0.89	
1:6	85	0.84	
1:7	74	0.73	0.70
1:7	63.3	0.63	
1:7	74	0.73	
1:8	52.7	0.52	0.59
1:8	74	0.73	
1:8	52.7	0.52	
1:9	63.3	0.63	0.58
1:9	58	0.57	
1:9	53	0.52	
1:10	53	0.52	0.56
1:10	58	0.57	
1:10	58	0.57	
1:11	53	0.52	0.52
1:11	53	0.52	
1:11	53	0.52	
1:12	43	0.43	0.37
1:12	37.3	0.37	
1:12	32	0.32	

A – 109: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand A Immersed in Water for 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	180	1.78	1.52
1:4	140	1.39	
1:4	140	1.39	
1:5	140	1.39	1.39
1:5	140	1.39	
1:5	140	1.39	
1:6	117	1.16	1.19
1:6	127	1.26	
1:6	117	1.16	
1:7	95.3	0.94	0.93
1:7	101	1.00	
1:7	85	0.84	
1:8	79.3	0.79	0.77
1:8	74	0.73	
1:8	79.3	0.79	
1:9	68.7	0.68	0.68
1:9	68.7	0.68	
1:9	68.7	0.68	
1:10	63.3	0.63	0.63
1:10	63.3	0.63	
1:10	63.3	0.63	
1:11	48	0.48	0.47
1:11	53	0.52	
1:11	42.6	0.42	
1:12	42.6	0.42	0.39
1:12	37.3	0.37	
1:12	37.3	0.37	

A – 110: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand A Immersed in Water for 7 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	196	1.94	1.94
1:4	196	1.94	
1:4	196	1.94	
1:5	159	1.57	1.57
1:5	159	1.57	
1:5	160	1.58	
1:6	127	1.26	1.26
1:6	127	1.26	
1:6	127	1.26	
1:7	117	1.16	1.12
1:7	106	1.05	
1:7	117	1.16	
1:8	86	0.85	0.88
1:8	95	0.94	
1:8	86	0.85	
1:9	74	0.73	0.73
1:9	74	0.73	
1:9	74	0.73	
1:10	68.3	0.68	0.66
1:10	63.3	0.63	
1:10	68.3	0.68	
1:11	49.6	0.49	0.42
1:11	49.6	0.49	
1:11	49.6	0.49	
1:12	41.5	0.41	0.41
1:12	42.5	0.42	
1:12	41.5	0.41	

A – 111: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand A Immersed in Water for 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	180	1.78	2.60
1:4	140	1.38	
1:4	150	1.48	
1:5	130	128	1.90
1:5	130	1.28	
1:5	130	1.28	
1:6	90	0.88	1.50
1:6	130	1.28	
1:6	110	1.09	
1:7	110	1.09	1.30
1:7	110	1.09	
1:7	110	1.09	
1:8	80	0.79	1.08
1:8	85	0.84	
1:8	85	0.84	
1:9	100	0.99	0.82
1:9	100	0.99	
1:9	100	0.99	
1:10	71	0.70	0.70
1:10	70	0.69	
1:10	71	0.70	
1:11	50.6	0.50	0.55
1:11	60.8	0.60	
1:11	56.7	0.56	
1:12	47.6	0.47	0.46
1:12	45.6	0.45	
1:12	45.6	0.45	

A – 112: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand A Immersed in Water for 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	334	3.30	3.00
1:4	294	2.90	
1:4	283.5	2.80	
1:5	229	2.26	2.20
1:5	222	2.19	
1:5	218	2.15	
1:6	162	1.60	1.60
1:6	162	1.60	
1:6	161	1.59	
1:7	152	1.50	1.45
1:7	142	1.40	
1:7	147	1.45	
1:8	120.5	1.19	1.20
1:8	121.5	1.20	
1:8	121.5	1.20	
1:9	97.2	0.96	0.95
1:9	95	0.94	
1:9	96	0.95	
1:10	81	0.80	0.74
1:10	71	0.70	
1:10	74	0.73	
1:11	60	0.59	0.59
1:11	61	0.60	
1:11	60	0.59	
1:12	50.6	0.50	0.51
1:12	51.6	0.51	
1:12	51.	0.51	

A – 113: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand A Immersed in Water for 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	303	3.00	3.15
1:4	346	3.42	
1:4	307	3.03	
1:5	263	2.60	2.50
1:5	243	2.40	
1:5	254	2.51	
1:6	184	1.82	1.70
1:6	170	1.68	
1:6	162	1.60	
1:7	156	1.54	1.50
1:7	156	1.54	
1:7	145	1.43	
1:8	132	1.30	1.25
1:8	124.5	1.23	
1:8	123.5	1.22	
1:9	102	1.01	1.02
1:9	105	1.04	
1:9	102	0.92	
1:10	93	0.81	0.90
1:10	82	0.97	
1:10	98	0.70	
1:11	71	0.78	0.71
1:11	79	0.64	
1:11	65	0.62	
1:12	63	0.58	0.61
1:12	59	0.64	
1:12	65	1.05	

A – 114: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand B Immersed in Water for 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	159	1.57	1.75
1:4	191	1.89	
1:4	180	1.78	
1:5	95	0.94	1.15
1:5	95	0.94	
1:5	159	1.57	
1:6	117	1.16	0.98
1:6	79	0.78	
1:6	101	1.00	
1:7	106	1.05	0.93
1:7	90	0.89	
1:7	85	0.84	
1:8	97	0.96	0.92
1:8	97	0.96	
1:8	85	0.84	
1:9	97	0.96	0.90
1:9	85	0.84	
1:9	91	0.90	
1:10	85	0.84	0.84
1:10	85	0.84	
1:10	85	0.84	
1:11	79.3	0.79	0.79
1:11	79.3	0.79	
1:11	79.3	0.79	
1:12	74	0.73	0.73
1:12	74	0.73	
1:12	74	0.73	

A – 115: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand B Immersed in Water for 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:04	169	1.67	1.82
1:04	191	1.89	
1:04	191	1.89	
1:05	138	1.37	1.40
1:05	138	1.37	
1:05	148	1.47	
1:06	127	1.26	1.29
1:06	138	1.37	
1:06	127	1.26	
1:07	127	1.20	1.20
1:07	138	1.18	
1:07	127	1.22	
1:08	117	1.16	1.16
1:08	117	1.16	
1:08	117	1.16	
1:09	111	1.10	1.13
1:09	117	1.16	
1:09	114	1.13	
1:10	97	0.96	0.97
1:10	96	0.95	
1:10	111	1.00	
1:11	90	0.89	0.89
1:11	93	0.92	
1:11	87	0.86	
1:12	84	0.83	0.82
1:12	84	0.83	
1:12	81	0.80	

A – 116: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand B Immersed in Water for 7 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	191	1.89	1.89
1:4	191	1.89	
1:4	191	1.89	
1:5	159	1.57	1.55
1:5	159	1.57	
1:5	153	1.51	
1:6	148	1.47	1.47
1:6	148	1.47	
1:6	148	1.47	
1:7	127	1.26	1.28
1:7	133	1.32	
1:7	127	1.26	
1:8	143	1.42	1.28
1:8	127	1.26	
1:8	117	1.16	
1:9	127	1.26	1.26
1:9	127	1.26	
1:9	126	1.25	
1:10	101	1.00	1.11
1:10	127	1.26	
1:10	107	1.06	
1:11	95	0.94	0.92
1:11	95	0.94	
1:11	95	0.94	
1:12	92	0.91	0.91
1:12	92	0.91	
1:12	92	0.91	

A – 117: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand B Immersed in Water for 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	275	2.72	2.17
1:4	180	1.78	
1:4	201	1.99	
1:5	174	1.72	1.67
1:5	164	1.62	
1:5	169	1.67	
1:6	159	1.57	1.57
1:6	158	1.56	
1:6	159	1.57	
1:7	134	1.33	1.37
1:7	140	1.39	
1:7	140	1.39	
1:8	120	1.19	1.31
1:8	138	1.37	
1:8	138	1.37	
1:9	129	1.28	1.29
1:9	131	1.30	
1:9	131	1.30	
1:10	101	1.00	1.14
1:10	117	1.16	
1:10	127	1.26	
1:11	94	0.93	0.94
1:11	96	0.95	
1:11	96	0.95	
1:12	93	0.92	0.94
1:12	95	0.94	
1:12	97	0.96	

A – 118: Wet Compressive Strength of Hollow 9” Sandcrete Blocks Moulded with Machine from Portland Cement Brand B Immersed in Water for 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	253	2.50	2.48
1:4	254	2.51	
1:4	246	2.43	
1:5	182	1.80	1.80
1:5	184	1.82	
1:5	180	1.78	
1:6	172	1.70	1.69
1:6	172	1.70	
1:6	169	1.67	
1:7	153	1.51	1.48
1:7	154	1.52	
1:7	144	1.42	
1:8	137	1.35	1.36
1:8	136	1.34	
1:8	141	1.39	
1:9	135	1.33	1.31
1:9	133	1.31	
1:9	131	1.29	
1:10	120	1.19	1.17
1:10	120	1.19	
1:10	114	1.13	
1:11	102	1.01	0.96
1:11	98	0.97	
1:11	91	0.90	
1:12	96	0.95	0.95
1:12	95	0.94	
1:12	96	0.95	

A – 119: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand B Immersed in Water for 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	286	2.82	2.80
1:4	284	2.80	
1:4	281	2.78	
1:5	204	2.02	1.94
1:5	190	1.88	
1:5	194	1.92	
1:6	175	1.73	1.77
1:6	182	1.80	
1:6	180	1.78	
1:7	157	1.55	1.53
1:7	154	1.52	
1:7	154	1.52	
1:8	147	1.45	1.44
1:8	147	1.45	
1:8	144	1.42	
1:9	144	1.42	1.42
1:9	145	1.43	
1:9	142	1.41	
1:10	123.5	1.22	1.22
1:10	121.5	1.20	
1:10	126	1.24	
1:11	104	1.03	1.01
1:11	101	1.00	
1:11	101	1.00	
1:12	100	0.99	0.97
1:12	97	0.96	
1:12	97	0.96	

A – 120: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand C Immersed in Water for 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	254	2.51	2.41
1:4	233	2.31	
1:4	243	2.41	
1:5	159	1.58	1.55
1:5	157	1.56	
1:5	152	1.51	
1:6	127	1.26	1.19
1:6	127	1.26	
1:6	106	1.05	
1:7	103	1.02	1.05
1:7	109	1.08	
1:7	106	1.05	
1:8	106	1.05	0.94
1:8	95	0.94	
1:8	85	0.84	
1:9	74	0.73	0.73
1:9	74	0.73	
1:9	74	0.73	
1:10	63.3	0.63	0.65
1:10	69	0.68	
1:10	63.3	0.63	
1:11	63.3	0.63	0.63
1:11	63.3	0.63	
1:11	63.3	0.63	
1:12	53	0.52	0.54
1:12	53	0.52	
1:12	58	0.57	

A – 121: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand C Immersed in Water for 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	265	2.62	2.87
1:4	265	2.62	
1:4	339	3.36	
1:5	180	1.78	1.68
1:5	169	1.67	
1:5	159	1.57	
1:6	148	1.47	1.43
1:6	138	1.37	
1:6	148	1.47	
1:7	112	1.11	1.10
1:7	110	1.09	
1:7	110	1.09	
1:8	117	1.03	0.97
1:8	105	1.04	
1:8	81	0.80	
1:9	81	0.80	0.82
1:9	81	0.80	
1:9	79	0.86	
1:10	74	0.63	0.66
1:10	69	0.66	
1:10	85	0.69	
1:11	58	0.57	0.64
1:11	63.3	0.63	
1:11	74	0.73	
1:12	53	0.52	0.56
1:12	63.3	0.63	
1:12	53	0.52	

A – 122: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand C Immersed in Water for 7 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	300	2.98	3.00
1:4	301	2.99	
1:4	305	3.03	
1:5	205	2.03	2.01
1:5	205	2.03	
1:5	200	1.98	
1:6	189	1.87	1.85
1:6	194	1.92	
1:6	178	1.76	
1:7	120	1.19	1.19
1:7	121	1.20	
1:7	120	1.19	
1:8	98	0.97	1.02
1:8	113	1.12	
1:8	98	0.97	
1:9	89	0.88	0.86
1:9	89	0.88	
1:9	83	0.82	
1:10	78	0.77	0.75
1:10	73	0.73	
1:10	76	0.75	
1:11	72	0.72	0.70
1:11	72	0.72	
1:11	65	0.64	
1:12	57	0.57	0.58
1:12	59	0.59	
1:12	57	0.57	

A – 123: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand C Immersed in Water for 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	413	4.09	4.14
1:4	406	4.02	
1:4	434	4.30	
1:5	212	2.10	2.10
1:5	212	2.10	
1:5	212	2.10	
1:6	192	1.90	1.90
1:6	202	2.00	
1:6	182	1.80	
1:7	127	1.26	1.29
1:7	127	1.26	
1:7	138	1.37	
1:8	126	1.25	1.25
1:8	129	1.28	
1:8	123	1.22	
1:9	104	1.03	0.95
1:9	103	1.02	
1:9	81	0.80	
1:10	85	0.84	0.79
1:10	79	0.78	
1:10	74	0.73	
1:11	74	0.73	0.73
1:11	75	0.74	
1:11	74	0.73	
1:12	63.3	0.63	0.62
1:12	63	0.62	
1:12	63	0.62	

A – 124: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand C Immersed in Water for 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	435	4.30	4.20
1:4	425	4.20	
1:4	415	4.10	
1:5	223	2.20	2.22
1:5	235	2.32	
1:5	217	2.14	
1:6	203.5	2.01	1.97
1:6	206.5	2.04	
1:6	188	1.86	
1:7	154	1.52	1.51
1:7	153	1.51	
1:7	152	1.50	
1:8	142	1.40	1.35
1:8	132	1.30	
1:8	137	1.35	
1:9	111	1.10	1.08
1:9	107	1.06	
1:9	109	1.08	
1:10	91	0.90	0.88
1:10	83	0.82	
1:10	93	0.92	
1:11	76	0.75	0.76
1:11	77	0.76	
1:11	77	0.76	
1:12	71	0.70	0.67
1:12	66	0.65	
1:12	67	0.66	

A – 125: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand C Immersed in Water for 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	476	4.70	4.40
1:4	425	4.20	
1:4	435	4.30	
1:5	279	2.76	2.50
1:5	227	2.24	
1:5	253	2.50	
1:6	216	2.13	2.10
1:6	211	2.08	
1:6	212	2.09	
1:7	223	2.10	1.93
1:7	191	1.99	
1:7	172	1.70	
1:8	167	1.65	1.66
1:8	169	1.67	
1:8	169	1.67	
1:9	130	1.28	1.25
1:9	124.5	1.23	
1:9	126.5	1.25	
1:10	101	1.00	1.02
1:10	104	1.03	
1:10	104	1.03	
1:11	87	0.86	0.80
1:11	77	0.76	
1:11	79	0.78	
1:12	73	0.72	0.72
1:12	74	0.73	
1:12	72	0.71	

A – 126: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand D Immersed in Water for 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	212	2.10	1.82
1:4	159	1.57	
1:4	180	1.78	
1:5	169	1.67	1.60
1:5	148	1.47	
1:5	168	1.66	
1:6	106	1.05	1.09
1:6	106	1.05	
1:6	117	1.16	
1:7	106	1.05	1.01
1:7	106	1.05	
1:7	95.3	0.94	
1:8	74	0.73	0.77
1:8	85	0.84	
1:8	74	0.73	
1:9	74	0.73	0.73
1:9	74	0.73	
1:9	74	0.73	
1:10	68.7	0.68	0.70
1:10	74	0.73	
1:10	68.7	0.68	
1:11	63.3	0.63	0.63
1:11	63.3	0.63	
1:11	63.3	0.63	
1:12	43	0.43	0.49
1:12	53	0.52	
1:12	53	0.52	

A – 127: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand D Immersed in Water for 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	201	1.99	2.04
1:4	201	1.99	
1:4	217	2.15	
1:5	191	1.89	1.85
1:5	191	1.89	
1:5	180	1.78	
1:6	168	1.66	1.09
1:6	106	1.05	
1:6	106	1.05	
1:7	106	1.05	1.01
1:7	79	1.05	
1:7	85	0.94	
1:8	85	0.84	0.82
1:8	79	0.78	
1:8	85	0.84	
1:9	85	0.84	0.77
1:9	74	0.73	
1:9	74	0.73	
1:10	74	0.73	0.73
1:10	74	0.73	
1:10	74	0.73	
1:11	63	0.63	0.63
1:11	63	0.63	
1:11	63	0.63	
1:12	53	0.52	0.52
1:12	53	0.52	
1:12	53	0.52	

A – 128: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand D Immersed in Water for 7 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	233	2.31	2.17
1:4	212	2.10	
1:4	212	2.10	
1:5	191	1.89	1.91
1:5	191	1.89	
1:5	196	1.94	
1:6	185	1.26	1.40
1:6	148	1.47	
1:6	148	1.47	
1:7	108	1.07	1.03
1:7	95	0.94	
1:7	109	1.08	
1:8	95	0.94	0.96
1:8	95	0.94	
1:8	101	1.00	
1:9	74	0.81	0.82
1:9	74	0.93	
1:9	74	0.73	
1:10	82	0.81	0.79
1:10	78	0.77	
1:10	80	0.79	
1:11	76	0.75	0.75
1:11	69	0.70	
1:11	81	0.80	
1:12	57	0.56	0.54
1:12	54	0.53	
1:12	54	0.53	

A – 129: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand D Immersed in Water for 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	229	2.27	2.25
1:4	229	2.27	
1:4	223	2.21	
1:5	212	2.10	2.07
1:5	207	2.05	
1:5	208	2.06	
1:6	169	1.67	1.59
1:6	169	1.67	
1:6	145	1.43	
1:7	132	1.30	1.31
1:7	134	1.32	
1:7	133	1.30	
1:8	122	1.20	1.23
1:8	127	1.25	
1:8	127	1.25	
1:9	108	1.07	1.04
1:9	107	1.06	
1:9	100	0.99	
1:10	101	1.00	0.96
1:10	95	0.94	
1:10	95	0.94	
1:11	74	0.73	0.87
1:11	95	0.94	
1:11	95	0.94	
1:12	63.3	0.63	0.59
1:12	58	0.57	
1:12	58	0.57	

A – 130: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand D Immersed in Water for 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	241	2.38	2.36
1:4	241	2.38	
1:4	235	2.32	
1:5	227	2.24	2.23
1:5	227	2.24	
1:5	225	2.22	
1:6	182	1.80	1.79
1:6	183	1.81	
1:6	178	1.76	
1:7	162	1.60	1.62
1:7	174	1.72	
1:7	156	1.54	
1:8	132	1.30	1.33
1:8	137	1.35	
1:8	137	1.35	
1:9	132	1.30	1.27
1:9	126.5	1.25	
1:9	129	1.27	
1:10	116	1.15	1.15
1:10	116	1.15	
1:10	117	1.16	
1:11	101	1.00	0.98
1:11	101	1.00	
1:11	95	0.94	
1:12	71	0.70	0.66
1:12	63	0.62	
1:12	68	0.67	

A – 131: Wet Compressive Strength of Hollow 9” Sandcrete Blocks Moulded with Machine from Portland Cement Brand D Immersed in Water for 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	258	2.55	2.49
1:4	243	2.40	
1:4	255	2.52	
1:5	239	2.36	2.40
1:5	239	2.36	
1:5	251	2.48	
1:6	204	2.02	2.02
1:6	213	2.10	
1:6	198	1.96	
1:7	191	1.89	1.88
1:7	190	1.88	
1:7	190	1.88	
1:8	152	1.50	1.48
1:8	152	1.50	
1:8	146	1.44	
1:9	146	1.44	1.45
1:9	146	1.44	
1:9	149	1.47	
1:10	132	1.30	1.31
1:10	137	1.35	
1:10	130	1.28	
1:11	111	1.10	1.10
1:11	111	1.10	
1:11	110	1.09	
1:12	74	0.73	0.72
1:12	72	0.71	
1:12	73	0.72	

A – 132: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand E Immersed in Water for 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	95.3	0.94	1.12
1:4	117	1.16	
1:4	127	1.26	
1:5	97	0.96	0.94
1:5	93	0.92	
1:5	95	0.94	
1:6	87	0.86	0.84
1:6	87	0.86	
1:6	81	0.80	
1:7	85	0.84	0.73
1:7	74	0.73	
1:7	64	0.63	
1:8	64	0.63	0.66
1:8	74	0.73	
1:8	64	0.63	
1:9	64	0.63	0.63
1:9	64	0.63	
1:9	64	0.63	
1:10	58	0.57	0.56
1:10	58	0.57	
1:10	53	0.52	
1:11	54	0.53	0.53
1:11	54	0.53	
1:11	54	0.53	
1:12	53	0.52	0.47
1:12	43	0.42	
1:12	48	0.47	

A – 133: Wet Compressive Strength of Hollow 9” Sandcrete Blocks Moulded with Machine from Portland Cement Brand E Immersed in Water for 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	119	1.16	1.16
1:4	115	1.14	
1:4	117	1.16	
1:5	109	1.08	1.01
1:5	106	1.05	
1:5	104	1.03	
1:6	74	0.73	0.87
1:6	95	0.94	
1:6	95	0.94	
1:7	80	0.79	0.79
1:7	81	0.80	
1:7	80	0.79	
1:8	85	0.84	0.73
1:8	74	0.73	
1:8	64	0.63	
1:9	64	0.63	0.66
1:9	74	0.73	
1:9	64	0.63	
1:10	64	0.63	0.63
1:10	64	0.63	
1:10	64	0.63	
1:11	53	0.52	0.55
1:11	61	0.60	
1:11	54	0.53	
1:12	43.5	0.43	0.48
1:12	43.5	0.43	
1:12	58	0.57	

A – 134: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand E Immersed in Water for 7 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	128	1.26	1.29
1:4	139	1.37	
1:4	128	1.26	
1:5	106	1.05	1.05
1:5	106	1.05	
1:5	106	1.05	
1:6	95	0.94	0.87
1:6	85	0.84	
1:6	85	0.84	
1:7	85	0.84	0.86
1:7	89	0.88	
1:7	87	0.86	
1:8	85	0.84	0.84
1:8	85	0.84	
1:8	85	0.84	
1:9	69	0.68	0.68
1:9	64	0.63	
1:9	74	0.73	
1:10	64	0.63	0.65
1:10	68	0.67	
1:10	66	0.65	
1:11	65	0.64	0.61
1:11	58	0.57	
1:11	62	0.61	
1:12	53	0.52	0.50
1:12	53	0.52	
1:12	47	0.46	

A – 135: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand E Immersed in Water for 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	159	1.57	1.40
1:4	138	1.37	
1:4	127	1.26	
1:5	111	1.10	1.09
1:5	111	1.10	
1:5	109	1.08	
1:6	109	1.08	1.07
1:6	108	1.07	
1:6	108	1.07	
1:7	85	0.84	0.88
1:7	86	0.85	
1:7	96	0.95	
1:8	85	0.84	0.85
1:8	86	0.85	
1:8	86	0.85	
1:9	74	0.73	0.75
1:9	74	0.73	
1:9	79	0.78	
1:10	69	0.68	0.68
1:10	64	0.63	
1:10	74	0.73	
1:11	64	0.63	0.65
1:11	66	0.65	
1:11	69	0.68	
1:12	53	0.52	0.54
1:12	64	0.63	
1:12	49	0.48	

A – 136: Wet Compressive Strength of Hollow 9” Sandcrete Blocks Moulded with Machine from Portland Cement Brand E Immersed in Water for 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	160	1.58	1.53
1:4	160	1.58	
1:4	145	1.43	
1:5	121.5	1.20	1.15
1:5	118	1.17	
1:5	109	1.08	
1:6	111	1.10	1.08
1:6	111	1.10	
1:6	104	1.03	
1:7	101	1.00	0.96
1:7	102	1.01	
1:7	86	0.85	
1:8	92	0.91	0.90
1:8	91	0.90	
1:8	91	0.90	
1:9	85	0.84	0.84
1:9	89	0.88	
1:9	81	0.80	
1:10	81	0.80	0.70
1:10	61	0.60	
1:10	71	0.70	
1:11	71	0.70	0.69
1:11	71	0.70	
1:11	67	0.66	
1:12	61	0.60	0.59
1:12	61	0.60	
1:12	59	0.58	

A – 137: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand E Immersed in Water for 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	172	1.70	1.66
1:4	166	1.64	
1:4	166	1.64	
1:5	155	1.53	1.50
1:5	150	1.48	
1:5	152	1.50	
1:6	122	1.20	1.19
1:6	123	1.21	
1:6	117	1.16	
1:7	115	1.14	1.14
1:7	117	1.16	
1:7	113	1.12	
1:8	108	1.08	1.10
1:8	108	1.08	
1:8	115	1.14	
1:9	99	0.98	0.96
1:9	98	0.97	
1:9	94	0.93	
1:10	76	0.75	0.73
1:10	76	0.75	
1:10	71	0.70	
1:11	73	0.72	0.72
1:11	73	0.72	
1:11	72	0.71	
1:12	67	0.66	0.63
1:12	64	0.63	
1:12	61	0.60	

A – 138: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand F Immersed in Water for 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	129	1.27	1.25
1:4	130	1.28	
1:4	121.5	1.20	
1:5	121.5	1.20	1.19
1:5	121.5	1.20	
1:5	119	1.18	
1:6	97	0.96	0.97
1:6	100	0.99	
1:6	97	0.96	
1:7	81	0.80	0.72
1:7	71	0.70	
1:7	67	0.66	
1:8	71	0.70	0.69
1:8	71	0.70	
1:8	68	0.67	
1:9	46	0.45	0.44
1:9	41	0.41	
1:9	45.6	0.45	
1:10	43	0.42	0.42
1:10	43	0.42	
1:10	42	0.41	
1:11	41	0.40	0.36
1:11	33	0.33	
1:11	35	0.35	
1:12	30	0.30	0.32
1:12	30	0.30	
1:12	36	0.36	

A – 139: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand F Immersed in Water for 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	154	1.52	1.51
1:4	153	1.51	
1:4	152	1.50	
1:5	141	1.39	1.40
1:5	144	1.42	
1:5	141	1.39	
1:6	124.5	1.23	1.23
1:6	124.5	1.23	
1:6	125.6	1.24	
1:7	91	0.90	0.89
1:7	92	0.91	
1:7	87	0.86	
1:8	73	0.72	0.71
1:8	72	0.71	
1:8	72	0.71	
1:9	50.6	0.50	0.50
1:9	52.7	0.52	
1:9	48	0.47	
1:10	48	0.47	0.48
1:10	48	0.47	
1:10	50	0.49	
1:11	40.5	0.40	0.40
1:11	40.5	0.40	
1:11	41.5	0.41	
1:12	35.4	0.35	0.34
1:12	35.4	0.35	
1:12	32.4	0.32	

A – 140: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand F Immersed in Water for 7 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	185	1.83	1.83
1:4	185	1.83	
1:4	186	1.84	
1:5	157	1.55	1.54
1:5	157	1.55	
1:5	154	1.52	
1:6	131.6	1.30	1.31
1:6	132	1.30	
1:6	135	1.33	
1:7	103	1.02	1.01
1:7	104	1.03	
1:7	101	1.00	
1:8	84	0.83	0.85
1:8	85	0.84	
1:8	89	0.88	
1:9	71	0.70	0.68
1:9	71	0.70	
1:9	65	0.64	
1:10	65	0.64	0.64
1:10	66	0.65	
1:10	65	0.64	
1:11	58	0.57	0.55
1:11	58	0.57	
1:11	52	0.51	
1:12	39.5	0.39	0.38
1:12	39.5	0.39	
1:12	37.5	0.37	

A – 141: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand F Immersed in Water for 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	190	1.88	1.95
1:4	201	1.99	
1:4	200	1.98	
1:5	172	1.70	1.70
1:5	172	1.70	
1:5	173	1.71	
1:6	147	1.45	1.42
1:6	147	1.45	
1:6	138	1.36	
1:7	138	1.36	1.36
1:7	138	1.36	
1:7	137	1.35	
1:8	128.5	1.27	1.25
1:8	128.5	1.27	
1:8	122.5	1.21	
1:9	91	0.90	0.91
1:9	91	0.90	
1:9	95	0.94	
1:10	81	0.80	0.76
1:10	71	0.70	
1:10	78	0.77	
1:11	66	0.65	0.63
1:11	64	0.63	
1:11	63	0.62	
1:12	55.6	0.55	0.53
1:12	58	0.57	
1:12	50.5	0.50	

A – 142: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand F Immersed in Water for 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	210	2.07	2.05
1:4	210	2.07	
1:4	205	2.02	
1:5	182	1.80	1.84
1:5	182	1.80	
1:5	191	1.89	
1:6	164	1.62	1.68
1:6	162	1.60	
1:6	184	1.82	
1:7	152	1.50	1.41
1:7	142	1.40	
1:7	134	1.32	
1:8	126.5	1.25	1.28
1:8	127.5	1.26	
1:8	136	1.34	
1:9	116	1.15	1.15
1:9	116	1.15	
1:9	117	1.16	
1:10	111	1.10	1.12
1:10	111	1.10	
1:10	116	1.15	
1:11	104	1.03	1.01
1:11	104	1.03	
1:11	97	0.96	
1:12	55.5	0.55	0.56
1:12	55.5	0.55	

1:12	58.0	0.57	

A – 143: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand F Immersed in Water for 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	233	2.30	2.30
1:4	233	2.30	
1:4	232	2.29	
1:5	224	2.21	2.20
1:5	213	2.10	
1:5	233	2.30	
1:6	182	1.80	1.80
1:6	182	1.80	
1:6	181	1.79	
1:7	150	1.48	1.50
1:7	153	1.51	
1:7	152	1.50	
1:8	131.6	1.30	1.31
1:8	134	1.32	
1:8	131.6	1.30	
1:9	121.5	1.20	1.24
1:9	127.5	1.26	
1:9	121.5	1.20	
1:10	109	1.08	1.07
1:10	109	1.08	
1:10	107	1.06	
1:11	106	1.05	1.05
1:11	109	1.08	
1:11	104	1.03	
1:12	79	0.78	0.77

1:12	81	0.80
1:12	74	0.73

A – 144: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand G Immersed in Water for 1 Day Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	138	1.36	1.33
1:4	132	1.30	
1:4	135	1.33	
1:5	126.6	1.25	1.24
1:5	126.6	1.25	
1:5	122.5	1.21	
1:6	91	0.90	0.90
1:6	90	0.89	
1:6	92	0.91	
1:7	81	0.80	0.82
1:7	81	0.80	
1:7	88	0.87	
1:8	76	0.75	0.73
1:8	76	0.75	
1:8	71	0.70	
1:9	63	0.62	0.63
1:9	61	0.60	
1:9	69	0.68	
1:10	61	0.60	0.60
1:10	62	0.61	
1:10	61	0.60	
1:11	59	0.58	0.57
1:11	61	0.60	
1:11	53	0.52	
1:12	55.7	0.55	0.55
1:12	57.5	0.57	
1:12	54.5	0.54	

A – 145: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand G Immersed in Water for 3 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	140	1.39	1.39
1:4	140	1.39	
1:4	140	1.39	
1:5	93	0.92	0.99
1:5	103	1.02	
1:5	103	1.02	
1:6	84.5	0.84	0.84
1:6	84.5	0.84	
1:6	84.5	0.84	
1:7	65	0.64	0.71
1:7	84.5	0.84	
1:7	65	0.64	
1:8	75	0.74	0.74
1:8	75	0.74	
1:8	75	0.74	
1:9	47	0.47	0.55
1:9	65	0.64	
1:9	56	0.55	
1:10	52	0.51	0.51
1:10	56	0.55	
1:10	47	0.47	
1:11	47	0.47	0.47
1:11	47	0.47	
1:11	47	0.47	
1:12	38	0.38	0.41
1:12	38	0.38	
1:12	47	0.47	

A – 146: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand G Immersed in Water for 7 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	175	1.73	1.71
1:4	175	1.73	
1:4	168.5	1.67	
1:5	122	1.21	1.05
1:5	103	1.02	
1:5	94	0.93	
1:6	65	0.64	0.66
1:6	65	0.64	
1:6	70	0.69	
1:7	65	0.64	0.64
1:7	65	0.64	
1:7	65	0.64	
1:8	56.3	0.56	0.56
1:8	56.3	0.56	
1:8	56.3	0.56	
1:9	56.3	0.56	0.54
1:9	52	0.51	
1:9	56.3	0.56	
1:10	56.3	0.56	0.50
1:10	47	0.47	
1:10	47	0.47	
1:11	47	0.47	0.47
1:11	47	0.47	
1:11	47	0.47	
1:12	42	0.42	0.39
1:12	38	0.38	
1:12	38	0.38	

A – 147: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand G Immersed in Water for 14 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:04	206	2.04	2.07
1:04	224	2.22	
1:04	196	1.94	
1:05	112	1.11	1.11
1:05	112	1.11	
1:05	112	1.11	
1:06	75	0.74	0.71
1:06	75	0.74	
1:06	65	0.64	
1:07	56	0.55	0.58
1:07	65	0.64	
1:07	56	0.55	
1:08	52	0.51	0.54
1:08	61	0.60	
1:08	52	0.51	
1:09	47	0.47	0.47
1:09	47	0.47	
1:09	47	0.47	
1:10	47	0.47	0.47
1:10	47	0.47	
1:10	47	0.47	
1:11	47	0.47	0.47
1:11	47	0.47	
1:11	47	0.47	
1:12	38	0.38	0.38
1:12	38	0.38	
1:12	38	0.38	

A – 148: Wet Compressive Strength of Hollow 9” Sandcrete Blocks Moulded with Machine from Portland Cement Brand G Immersed in Water for 21 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	169	1.67	1.82
1:4	191	1.89	
1:4	191	1.89	
1:5	95	0.94	1.15
1:5	95	0.94	
1:5	159	1.57	
1:6	117	1.16	0.98
1:6	79	0.78	
1:6	101	1.00	
1:7	106	1.05	0.93
1:7	90	0.89	
1:7	85	0.84	
1:8	117	1.16	1.05
1:8	117	1.16	
1:8	85	0.84	
1:9	138	1.37	1.29
1:9	127	1.26	
1:9	127	1.26	
1:10	111	1.10	1.17
1:10	117	1.16	
1:10	127	1.26	
1:11	95	0.94	0.89
1:11	85	0.84	
1:11	90	0.89	
1:12	85	0.84	1.02
1:12	117	1.16	
1:12	106	1.05	

A – 149: Wet Compressive Strength of Hollow 9" Sandcrete Blocks Moulded with Machine from Portland Cement Brand G Immersed in Water for 28 Days Curing Age (w/c = 0.45).

Mix Ratio	Load (kN)	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (N/mm^2)
1:4	169	1.67	1.82
1:4	191	1.89	
1:4	191	1.89	
1:5	95	0.94	1.15
1:5	95	0.94	
1:5	159	1.57	
1:6	117	1.16	0.98
1:6	79	0.78	
1:6	101	1.00	
1:7	106	1.05	0.93
1:7	90	0.89	
1:7	85	0.84	
1:8	117	1.16	1.05
1:8	117	1.16	
1:8	85	0.84	
1:9	138	1.37	1.29
1:9	127	1.26	
1:9	127	1.26	
1:10	111	1.10	1.17
1:10	117	1.16	
1:10	127	1.26	
1:11	95	0.94	0.89
1:11	85	0.84	
1:11	90	0.89	
1:12	85	0.84	1.02
1:12	117	1.16	
1:12	106	1.05	

A-150: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Curing Age – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	21.12	1605	1610
1:4	21.25	1615	
1:4	21.19	1610	
1:5	20.82	1582	1580
1:5	20.82	1582	
1:5	20.74	1576	
1:6	20.28	1541	1540
1:6	20.27	1540	
1:6	20.27	1540	
1:7	20.07	1525	1525
1:7	20.06	1524	
1:7	20.07	1525	
1:8	19.90	1512	1515
1:8	19.90	1512	
1:8	20.02	1521	
1:9	19.90	1512	1512
1:9	19.90	1512	
1:9	19.90	1512	
1:10	19.88	1511	1510
1:10	19.88	1511	
1:10	19.86	1509	
1:11	19.81	1505	1505
1:11	19.81	1505	
1:11	19.81	1505	
1:12	19.74	1500	1503
1:12	19.88	1510	
1:12	19.74	1500	

A-151: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Curing Age – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	22.24	1690	1691
1:4	22.24	1690	
1:4	22.27	1692	
1:5	21.60	1641	1643
1:5	21.60	1641	
1:5	21.65	1645	
1:6	21.45	1630	1630
1:6	21.45	1630	
1:6	21.45	1630	
1:7	21.28	1617	1617
1:7	21.24	1614	
1:7	21.32	1620	
1:8	21.19	1610	1611
1:8	21.20	1611	
1:8	21.20	1611	
1:9	21.64	1644	1643
1:9	21.61	1642	
1:9	21.64	1644	
1:10	21.72	1650	1651
1:10	21.72	1650	
1:10	21.74	1652	
1:11	20.94	1591	1590
1:11	20.94	1591	
1:11	20.90	1588	
1:12	20.93	1590	1590
1:12	20.93	1590	
1:12	20.92	1589	

A-152: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Curing Age – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	23.8	1808	1813
1:4	24.0	1823	
1:4	23.8	1808	
1:5	23.5	1785	1788
1:5	23.5	1785	
1:5	23.6	1793	
1:6	23.6	1793	1793
1:6	23.6	1793	
1:6	23.6	1793	
1:7	23.3	1770	1773
1:7	23.3	1770	
1:7	23.4	1778	
1:8	23.4	1778	1768
1:8	23.2	1763	
1:8	23.2	1763	
1:9	23.2	1763	1763
1:9	23.2	1763	
1:9	23.2	1763	
1:10	22.1	1679	1735
1:10	23.2	1763	
1:10	23.2	1763	
1:11	22.1	1679	1679
1:11	22.1	1679	
1:11	22.1	1679	
1:12	22.1	1679	1679
1:12	22.1	1679	
1:12	22.1	1679	

A-153: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Curing Age – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	24.8	1884	1884
1:4	25.0	1899	
1:4	24.6	1869	
1:5	24.4	1854	1859
1:5	24.2	1839	
1:5	24.8	1884	
1:6	24.2	1840	1840
1:6	24.2	1840	
1:6	24.23	1841	
1:7	24.02	1825	1825
1:7	24.03	1826	
1:7	24.02	1825	
1:8	23.96	1820	1820
1:8	23.98	1822	
1:8	23.92	1817	
1:9	23.2	1763	1752
1:9	22.9	1740	
1:9	22.9	1740	
1:10	22.9	1740	1742
1:10	23.0	1747	
1:10	22.9	1740	
1:11	22.9	1740	1740
1:11	22.9	1740	
1:11	22.9	1740	
1:12	22.7	1725	1694
1:12	22.4	1702	
1:12	21.8	1656	

A-154: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Curing Age – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	23.7	1801	1801
1:4	23.7	1801	
1:4	23.7	1801	
1:5	23.7	1801	1793
1:5	23.4	1778	
1:5	23.7	1801	
1:6	23.3	1770	1775
1:6	23.4	1778	
1:6	23.4	1778	
1:7	23.2	1762	1762
1:7	23.2	1762	
1:7	23.2	1762	
1:8	23.2	1762	1759
1:8	23.1	1754	
1:8	23.2	1762	
1:9	23.1	1754	1754
1:9	23.1	1754	
1:9	23.1	1754	
1:10	21.9	1667	1714
1:10	22.9	1738	
1:10	22.9	1738	
1:11	21.7	1651	1709
1:11	22.9	1738	
1:11	22.9	1738	
1:12	22.9	1738	1738
1:12	22.9	1738	
1:12	22.9	1738	

A-155: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Curing Age – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	24.1	1831	1826
1:4	24.0	1823	
1:4	24.0	1823	
1:5	23.9	1816	1816
1:5	23.9	1816	
1:5	23.9	1816	
1:6	23.7	1801	1798
1:6	23.6	1793	
1:6	23.7	1801	
1:7	23.3	1770	1778
1:7	23.4	1778	
1:7	23.5	1785	
1:8	23.2	1763	1765
1:8	23.3	1770	
1:8	23.2	1763	
1:9	23.2	1763	1765
1:9	23.2	1763	
1:9	23.3	1770	
1:10	23.2	1763	1760
1:10	23.2	1763	
1:10	23.1	1755	
1:11	23.1	1755	1755
1:11	23.1	1755	
1:11	23.1	1755	
1:12	23.0	1747	1747
1:12	23.0	1747	
1:12	23.0	1747	

A-156: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Curing Age – Cement Brand B (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	23.0	1750	1750
1:4	23.0	1750	
1:4	23.0	1750	
1:5	22.8	1731	1730
1:5	22.45	1730	
1:5	22.45	1730	
1:6	22.24	1690	1690
1:6	22.27	1692	
1:6	22.21	1688	
1:7	22.03	1674	1670
1:7	21.98	1670	
1:7	21.94	1667	
1:8	21.47	1631	1630
1:8	21.48	1632	
1:8	21.43	1628	
1:9	21.19	1610	1610
1:9	21.17	1608	
1:9	21.20	1611	
1:10	21.17	1608	1608
1:10	21.17	1608	
1:10	21.17	1608	
1:11	20.9	1590	1590
1:11	20.9	1590	
1:11	20.9	1590	
1:12	20.8	1580	1580
1:12	20.8	1580	
1:12	20.8	1580	

A-157: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Curing Age – Cement Brand B (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	25.14	1910	1910
1:4	25.17	1912	
1:4	25.11	1908	
1:5	24.05	1827	1829
1:5	24.05	1827	
1:5	24.13	1833	
1:6	23.72	1802	1800
1:6	23.67	1798	
1:6	23.68	1799	
1:7	23.56	1790	1790
1:7	23.56	1790	
1:7	23.57	1791	
1:8	23.46	1782	1780
1:8	23.40	1778	
1:8	23.43	1780	
1:9	23.17	1760	1760
1:9	23.17	1760	
1:9	23.17	1760	
1:10	23.10	1755	1755
1:10	23.17	1760	
1:10	23.03	1750	
1:11	22.90	1740	1740
1:11	22.92	1741	
1:11	22.90	1740	
1:12	22.77	1730	1730
1:12	22.71	1725	
1:12	22..84	1735	

A-158: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Curing Age – Cement Brand B (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	30.2	2294	2306
1:4	30.7	2332	
1:4	30.2	2294	
1:5	30.2	2294	2217
1:5	29.1	2185	
1:5	28.6	2173	
1:6	28.6	2173	2148
1:6	28.1	2135	
1:6	28.1	2135	
1:7	28.1	2135	2110
1:7	27.6	2097	
1:7	27.6	2097	
1:8	27	2051	2051
1:8	27	2051	
1:8	27	2051	
1:9	27	2051	2026
1:9	26.5	2013	
1:9	26.5	2013	
1:10	26.1	1983	1983
1:10	26.1	1983	
1:10	26.1	1983	
1:11	25.9	1967	1944
1:11	25.9	1967	
1:11	25	1899	
1:12	25.1	1907	1907
1:12	25.1	1907	
1:12	25.1	1907	

A-159: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Curing Age – Cement Brand B (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	31.2	2370	2395
1:4	31.2	2370	
1:4	32.2	2446	
1:5	31.3	2378	2378
1:5	31.3	2378	
1:5	31.3	2378	
1:6	31.2	2370	2360
1:6	30.8	2340	
1:6	31.2	2370	
1:7	29.4	2234	2305
1:7	30.4	2310	
1:7	31.2	2370	
1:8	31.2	2370	2352
1:8	31.5	2393	
1:8	30.2	2294	
1:9	30.3	2302	2302
1:9	30.4	2310	
1:9	30.2	2294	
1:10	28.6	2173	2203
1:10	29.2	2218	
1:10	29.2	2218	
1:11	29.1	2211	2186
1:11	29.1	2211	
1:11	28.1	2135	
1:12	28.1	2135	2079
1:12	27.0	2051	
1:12	27.0	2051	

A-160: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Curing Age – Cement Brand B (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	32.25	2450	2445
1:4	32.18	2445	
1:4	32.11	2440	
1:5	31.20	2370	2370
1:5	31.21	2371	
1:5	31.20	2370	
1:6	30.60	2325	2325
1:6	30.62	2326	
1:6	30.60	2325	
1:7	30.01	2280	2280
1:7	30.01	2280	
1:7	30.01	2280	
1:8	30.71	2333	2330
1:8	30.63	2327	
1:8	30.67	2330	
1:9	29.50	2241	2240
1:9	29.50	2241	
1:9	29.44	2237	
1:10	28.83	2190	2180
1:10	28.56	2170	
1:10	28.69	2180	
1:11	28.30	2150	2140
1:11	28.30	2150	
1:11	28.04	2120	
1:12	27.19	2066	2060
1:12	27.14	2062	
1:12	27.00	2052	

A-161: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Curing Age – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	32.9	2499	2484
1:4	32.9	2499	
1:4	32.3	2454	
1:5	31.3	2378	2353
1:5	30.8	2340	
1:5	30.8	2340	
1:6	29.2	2218	2271
1:6	29.2	2218	
1:6	31.3	2378	
1:7	29.3	2226	2226
1:7	29.3	2226	
1:7	29.3	2226	
1:8	29.3	2226	2170
1:8	28.2	2142	
1:8	28.2	2142	
1:9	27.5	2089	2135
1:9	28.4	2158	
1:9	28.4	2158	
1:10	27.5	2089	2089
1:10	27.5	2089	
1:10	27.5	2089	
1:11	26.8	2036	2071
1:11	27.5	2089	
1:11	27.5	2089	
1:12	27	2051	2000
1:12	26	1975	
1:12	26	1975	

A-162: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Curing Age – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	21.45	1630	1630
1:4	21.45	1630	
1:4	21.44	1629	
1:5	21.39	1625	1625
1:5	21.39	1625	
1:5	21.39	1625	
1:6	20.93	1590	1590
1:6	21.06	1600	
1:6	20.80	1580	
1:7	20.80	1580	1580
1:7	20.86	1585	
1:7	20.73	1575	
1:8	20.67	1570	1570
1:8	20.67	1570	
1:8	20.68	1571	
1:9	20.40	1550	1550
1:9	20.43	1552	
1:9	20.39	1549	
1:10	20.39	1549	1548
1:10	20.38	1548	
1:10	20.38	1548	
1:11	20.34	1545	1545
1:11	20.35	1546	
1:11	20.34	1545	
1:12	20.30	1542	1540
1:12	20.30	1542	
1:12	20.23	1537	

A-163: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Curing Age – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	22.24	1690	1685
1:4	22.11	1680	
1:4	22.48	1685	
1:5	22.11	1680	1670
1:5	21.85	1660	
1:5	21.99	1671	
1:6	22.05	1675	1665
1:6	21.78	1655	
1:6	21.93	1666	
1:7	21.93	1660	1660
1:7	21.93	1660	
1:7	21.73	1659	
1:8	20.93	1590	1611
1:8	20.7	1574	
1:8	22	1670	
1:9	20.9	1590	1617
1:9	20.9	1590	
1:9	22.0	1670	
1:10	22.0	1670	1617
1:10	20.9	1590	
1:10	20.9	1590	
1:11	20.9	1590	1617
1:11	22.0	1670	
1:11	22.0	1670	
1:12	20.9	1590	1617
1:12	20.9	1590	
1:12	22.0	1670	

A-164: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Curing Age – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	23.5	1785	1772
1:4	23.0	1747	
1:4	23.5	1785	
1:5	23	1747	1747
1:5	23	1747	
1:5	23	1747	
1:6	22.8	1732	1742
1:6	23	1747	
1:6	23	1747	
1:7	23	1747	1772
1:7	23.5	1785	
1:7	23.5	1785	
1:8	23	1747	1747
1:8	23.5	1785	
1:8	22.5	1709	
1:9	22.5	1709	1709
1:9	22.5	1709	
1:9	22.5	1709	
1:10	23	1747	1747
1:10	23	1747	
1:10	23	1747	
1:11	23	1747	1747
1:11	23	1747	
1:11	23	1747	
1:12	22.8	1732	1742
1:12	223	1747	
1:12	23	1747	

A-165: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Curing Age – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	24.5	1861	1861
1:4	25	1899	
1:4	24	1823	
1:5	24	1823	1813
1:5	23.8	1808	
1:5	23.8	1808	
1:6	23.6	1793	1788
1:6	23.6	1793	
1:6	23.4	1778	
1:7	23.5	1785	1785
1:7	23.5	1785	
1:7	23.5	1785	
1:8	24	1823	1798
1:8	23.5	1785	
1:8	23.5	1785	
1:9	24	1823	1823
1:9	24	1823	
1:9	24	1823	
1:10	23.4	1778	1760
1:10	23	1747	
1:10	23.1	1755	
1:11	23.5	1785	1760
1:11	23	1747	
1:11	23	1747	
1:12	22.6	1716	1727
1:12	22.8	1732	
1:12	22.8	1732	

A-166: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Curing Age – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	24.5	1861	1871
1:4	24.6	1869	
1:4	24.8	1884	
1:5	24.4	1854	1849
1:5	24.2	1839	
1:5	24.4	1854	
1:6	25	1899	1886
1:6	24.5	1861	
1:6	25	1899	
1:7	24.2	1839	1841
1:7	24.5	1861	
1:7	24	1823	
1:8	24	1823	1826
1:8	24	1823	
1:8	24.1	1831	
1:9	24.5	1861	1851
1:9	24.1	1831	
1:9	24.5	1861	
1:10	24.1	1831	1831
1:10	24.2	1839	
1:10	24	1823	
1:11	24.5	1861	1848
1:11	24.5	1861	
1:11	24.5	1861	
1:12	24.1	1831	1836
1:12	24.2	1839	
1:12	24.2	1839	

A-167: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Curing Age – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	24.5	1861	1874
1:4	24.5	1861	
1:4	25.0	1899	
1:5	24.0	1823	1823
1:5	24	1823	
1:5	24	1823	
1:6	24	1823	1823
1:6	24	1823	
1:6	24	1823	
1:7	23.96	1820	1821
1:7	23.96	1820	
1:7	23.98	1822	
1:8	23.97	1821	1821
1:8	23.97	1821	
1:8	23.96	1820	
1:9	23.96	1820	1820
1:9	23.96	1820	
1:9	23.94	1819	
1:10	23.96	1820	1820
1:10	23.96	1820	
1:10	23.96	1820	
1:11	23.96	1820	1820
1:11	23.92	1817	
1:11	23.98	1822	
1:12	23.96	1820	1820
1:12	23.96	1820	
1:12	23.96	1820	

A-168: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Curing Age – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	21.59	1640	1630
1:4	21.32	1620	
1:4	21.47	1631	
1:5	21.32	1620	1610
1:5	21.06	1600	
1:5	21.19	1610	
1:6	20.69	1572	1570
1:6	20.69	1572	
1:6	20.61	1566	
1:7	20.31	1543	1540
1:7	20.32	1544	
1:7	20.19	1534	
1:8	20.14	1530	1530
1:8	20.14	1530	
1:8	20.13	1529	
1:9	20.07	1525	1525
1:9	20.08	1526	
1:9	20.06	1524	
1:10	20.00	1520	1520
1:10	21.03	1522	
1:10	19.98	1518	
1:11	19.74	1500	1500
1:11	19.74	1500	
1:11	19.76	1501	
1:12	19.61	1490	1480
1:12	19.35	1470	
1:12	19.48	1480	

A-169: Dry Density of Hollow 9” Sandcrete Blocks Moulded with Machine at 3 Days Curing Age – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	22.5	1709	1736
1:4	23.0	1749	
1:4	23.0	1749	
1:5	23.9	1813	1789
1:5	23.2	1765	
1:5	23.5	1789	
1:6	23.0	1749	1723
1:6	23.0	1749	
1:6	21.9	1670	
1:7	21.4	1630	1603
1:7	20.9	1590	
1:7	20.9	1590	
1:8	20.9	1590	1590
1:8	20.9	1590	
1:8	20.9	1590	
1:9	20.9	1590	1590
1:9	20.9	1590	
1:9	20.9	1590	
1:10	20.67	1570	1570
1:10	20.67	1570	
1:10	20.68	1571	
1:11	20.40	1550	1550
1:11	20.53	1560	
1:11	20.28	1541	
1:12	20.40	1550	1545
1:12	20.27	1540	
1:12	20.35	1546	

A-170: Dry Density of Hollow 9” Sandcrete Blocks Moulded with Machine at 7 Days Curing Age – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	24	1823	1823
1:4	24.2	1838	
1:4	23.8	1808	
1:5	23.2	1763	1765
1:5	23	1747	
1:5	23.5	1785	
1:6	23	1747	1747
1:6	23	1747	
1:6	23	1747	
1:7	22.38	1700	1695
1:7	22.44	1705	
1:7	22.11	1680	
1:8	23	1747	1752
1:8	23.2	1763	
1:8	23	1747	
1:9	22.24	1690	1690
1:9	22.24	1690	
1:9	22.23	1689	
1:10	21.93	1666	1665
1:10	21.92	1665	
1:10	21.92	1665	
1:11	21.72	1650	1650
1:11	21.69	1648	
1:11	21.74	1652	
1:12	21.48	1632	1630
1:12	21.49	1633	
1:12	21.39	1625	

A-171: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Curing Age – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	23.5	1785	1800
1:4	23.8	1808	
1:4	23.8	1808	
1:5	23.2	1763	1844
1:5	24.6	1869	
1:5	25	1899	
1:6	23.5	1785	1778
1:6	23.2	1763	
1:6	23.5	1785	
1:7	23.1	1755	1770
1:7	23.2	1763	
1:7	23.6	1793	
1:8	23.0	1747	1765
1:8	23.2	1763	
1:8	23.5	1785	
1:9	23.2	1763	1776
1:9	23.7	1801	
1:9	23.2	1763	
1:10	23	1747	1752
1:10	23.2	1763	
1:10	23.2	1747	
1:11	23	1747	1747
1:11	23	1747	
1:11	23	1747	
1:12	23	1747	1737
1:12	22.8	1732	
1:12	22.8	1732	

A-172: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Curing Age – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	24.0	1823	1844
1:4	24.2	1839	
1:4	24.6	1869	
1:5	23.5	1785	1780
1:5	23.5	1785	
1:5	23.3	1770	
1:6	23.2	1763	1765
1:6	23.3	1770	
1:6	23.2	1763	
1:7	23.2	1763	1758
1:7	23.2	1763	
1:7	23	1747	
1:8	23	1747	1752
1:8	23	1747	
1:8	23.2	1763	
1:9	23	1747	1747
1:9	23	1747	
1:9	23	1747	
1:10	22.8	1732	1737
1:10	22.8	1732	
1:10	23	1747	
1:11	22.8	1732	1722
1:11	22.6	1717	
1:11	22.6	1717	
1:12	22.5	1709	1709
1:12	22.5	1709	
1:12	22.5	1709	

A-173: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Curing Age – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	26.2	1991	1960
1:4	26.2	1991	
1:4	25	1899	
1:5	23.5	1785	1778
1:5	23.2	1763	
1:5	23.5	1785	
1:6	23	1747	1765
1:6	23.5	1785	
1:6	23.2	1763	
1:7	22.90	1740	1740
1:7	22.90	1740	
1:7	22.89	1739	
1:8	22.77	1730	1730
1:8	22.77	1730	
1:8	22.77	1730	
1:9	21.85	1660	1650
1:9	21.72	1650	
1:9	21.60	1641	
1:10	21.59	1640	1640
1:10	21.61	1642	
1:10	21.56	1638	
1:11	21.32	1620	1620
1:11	21.32	1620	
1:11	21.32	1620	
1:12	21.18	1609	1610
1:12	21.18	1609	
1:12	21.18	1611	

A-174: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Curing Age – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	19.09	1450	1450
1:4	19.15	1455	
1:4	19.02	1445	
1:5	18.89	1435	1430
1:5	18.89	1435	
1:5	18.69	1420	
1:6	18.69	1420	1420
1:6	18.68	1419	
1:6	18.69	1420	
1:7	18.43	1400	1400
1:7	18.44	1401	
1:7	18.43	1400	
1:8	18.30	1390	1390
1:8	18.36	1395	
1:8	18.23	1385	
1:9	18.28	1389	1388
1:9	18.30	1390	
1:9	18.23	1385	
1:10	18.16	1380	1385
1:10	18.24	1386	
1:10	18.28	1389	
1:11	18.20	1383	1383
1:11	18.19	1382	
1:11	18.20	1383	
1:12	18.16	1380	1380
1:12	18.16	1380	
1:12	18.16	1380	

A-175: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Curing Age – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	20.9	1590	1585
1:4	20.9	1590	
1:4	20.7	1574	
1:5	22.0	1670	1617
1:5	20.9	1590	
1:5	20.9	1590	
1:6	20.9	1590	1590
1:6	20.9	1590	
1:6	20.9	1590	
1:7	20.7	1574	1566
1:7	20.4	1550	
1:7	20.7	1514	
1:8	20.7	1574	1571
1:8	20.4	1550	
1:8	20.9	1590	
1:9	20.7	1574	1585
1:9	20.9	1590	
1:9	20.9	1590	
1:10	20.7	1574	1579
1:10	20.9	1590	
1:10	20.7	1514	
1:11	20.4	1550	1577
1:11	20.9	1590	
1:11	20.9	1590	
1:12	20.4	1550	1550
1:12	20.4	1550	
1:12	20.4	1550	

A-176: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Curing Age – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	29.1	2212	2159
1:4	28.1	2133	
1:4	28.1	2133	
1:5	28.1	2133	2159
1:5	28.1	2133	
1:5	29.1	2212	
1:6	28.1	2133	2133
1:6	27.0	2054	
1:6	29.1	2212	
1:7	26	1975	1975
1:7	26	1975	
1:7	26	1975	
1:8	27	2054	1986
1:8	26	1975	
1:8	25.5	1936	
1:9	26	1975	1949
1:9	26	1975	
1:9	25	1896	
1:10	23.9	1817	1738
1:10	22.9	1736	
1:10	21.8	1659	
1:11	21.8	1659	1633
1:11	20.8	1580	
1:11	21.8	1659	
1:12	21.8	1659	1593
1:12	20.3	1541	
1:12	20.8	1580	

A-177: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Curing Age – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	29.1	2212	2159
1:4	28.1	2133	
1:4	28.1	2133	
1:5	28.1	2173	2199
1:5	29.1	2212	
1:5	29.1	2212	
1:6	27.0	2054	2159
1:6	30	2291	
1:6	28.1	2133	
1:7	27.1	2056	2021
1:7	26.7	2031	
1:7	26	1975	
1:8	26	1975	1949
1:8	25	1896	
1:8	26	1975	
1:9	27.6	2094	1988
1:9	26	1975	
1:9	25	1896	
1:10	25	1896	1843
1:10	23.9	1817	
1:10	23.9	1817	
1:11	23.9	1817	1764
1:11	21.8	1659	
1:11	23.9	1817	
1:12	24.4	1857	1725
1:12	21.8	1659	
1:12	21.8	1659	

A-178: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Curing Age – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	29.48	2240	2235
1:4	29.48	2240	
1:4	29.29	2225	
1:5	29.22	2220	2220
1:5	29.24	2222	
1:5	29.19	2218	
1:6	28.96	2200	2195
1:6	28.96	2200	
1:6	28.76	2185	
1:7	26.83	2038	2040
1:7	26.88	2042	
1:7	26.85	2040	
1:8	26.46	2010	2010
1:8	26.47	2011	
1:8	26.44	2009	
1:9	26.19	1920	1990
1:9	26.19	1990	
1:9	26.18	1980	
1:10	26.06	1982	1980
1:10	26.09	1978	
1:10	26.04	1775	
1:11	23.36	1775	1775
1:11	23.36	1776	
1:11	23.38	1750	
1:12	23.03	1748	1747
1:12	23.00	1744	
1:12	22.96	1749	

A-179: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Curing Age – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	29.8	2266	2239
1:4	28.8	2186	
1:4	29.8	2266	
1:5	29.3	2226	2253
1:5	29.8	2266	
1:5	29.8	2266	
1:6	28.5	2163	2184
1:6	28.3	2147	
1:6	29.5	2242	
1:7	27.2	2067	2048
1:7	27.2	2067	
1:7	26.5	2011	
1:8	26.2	1988	2020
1:8	23.3	2004	
1:8	27.2	2067	
1:9	26.2	1988	2014
1:9	26.7	2027	
1:9	26.2	1988	
1:10	25.1	1908	1895
1:10	25.1	1908	
1:10	24.6	1868	
1:11	23.4	1781	1786
1:11	23.2	1765	
1:11	23.9	1813	
1:12	23	1749	1749
1:12	23	1749	
1:12	23	1749	

A-180: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Curing Age – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	21.78	1655	1650
1:4	21.77	1654	
1:4	21.60	1641	
1:5	21.10	1603	1610
1:5	21.20	1611	
1:5	21.27	1616	
1:6	20.93	1590	1590
1:6	20.93	1590	
1:6	20.94	1591	
1:7	20.18	1533	1530
1:7	20.18	1533	
1:7	20.07	1525	
1:8	19.48	1480	1480
1:8	19.48	1480	
1:8	19.48	1480	
1:9	18.76	1425	1420
1:9	18.76	1425	
1:9	18.56	1410	
1:10	18.69	1420	1418
1:10	18.69	1420	
1:10	18.61	1414	
1:11	17.97	1365	1360
1:11	17.97	1365	
1:11	17.76	1350	
1:12	17.76	1350	1350
1:12	17.76	1350	
1:12	17.78	1351	

A-181: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Curing Age – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	21.98	1670	1660
1:4	21.72	1650	
1:4	21.85	1660	
1:5	21.72	1650	1650
1:5	21.72	1650	
1:5	21.72	1650	
1:6	21.35	1622	1620
1:6	21.35	1622	
1:6	21.27	1616	
1:7	20.67	1570	1572
1:7	20.67	1570	
1:7	20.73	1575	
1:8	19.84	1508	1510
1:8	19.84	1508	
1:8	19.91	1513	
1:9	19.35	1470	1470
1:9	19.35	1470	
1:9	19.35	1470	
1:10	19.11	1452	1450
1:10	19.14	1454	
1:10	19.00	1444	
1:11	18.03	1370	1370
1:11	18.02	1369	
1:11	18.02	1470	
1:12	17.91	1361	1360
1:12	17.91	1361	
1:12	17.87	1358	

A-182: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Curing Age – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	22.31	1695	1720
1:4	23.31	1771	
1:4	22.31	1695	
1:5	22	1671	1709
1:5	23	1747	
1:5	22.5	1709	
1:6	23	1747	1696
1:6	23	1747	
1:6	21	1595	
1:7	22.8	1732	1640
1:7	22	1671	
1:7	20	1519	
1:8	20	1519	1552
1:8	22	1671	
1:8	19.3	1466	
1:9	21	1595	1544
1:9	21	1595	
1:9	19	1443	
1:10	19	1443	1494
1:10	20	1519	
1:10	20	1519	
1:11	19.3	1466	1425
1:11	18	1368	
1:11	19	1443	
1:12	19	1443	1418
1:12	18	1368	
1:12	19	1443	

A-183: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Curing Age – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	22.5	1709	1810
1:4	24	1823	
1:4	25	1899	
1:5	24	1823	1874
1:5	26	1975	
1:5	24	1823	
1:6	23.17	1760	1762
1:6	23.17	1760	
1:6	23.24	1766	
1:7	21.26	1615	1665
1:7	21.24	1614	
1:7	21.26	1615	
1:8	21.06	1519	1600
1:8	21.19	1709	
1:8	20.93	1519	
1:9	20.9	1588	1618
1:9	23	1747	
1:9	20	1519	
1:10	20.80	1580	1580
1:10	20.80	1580	
1:10	20.78	1579	
1:11	19.91	1513	1519
1:11	19.93	1514	
1:11	19.97	1517	
1:12	19.74	1519	1493
1:12	19.48	1519	
1:12	19.61	1443	

A-184: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Curing Age – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	24.75	1880	1875
1:4	24.75	1880	
1:4	24.55	1865	
1:5	24.48	1860	1860
1:5	24.35	1850	
1:5	24.61	1870	
1:6	23.03	1750	1752
1:6	23.03	1750	
1:6	23.10	1756	
1:7	21.85	1660	1665
1:7	21.98	1670	
1:7	21.91	1664	
1:8	21.06	1600	1600
1:8	21.19	1610	
1:8	20.93	1590	
1:9	20.93	1590	1590
1:9	20.86	1585	
1:9	20.99	1595	
1:10	20.80	1580	1580
1:10	20.93	1590	
1:10	20.68	1571	
1:11	19.94	1515	1515
1:11	19.87	1510	
1:11	20.00	1520	
1:12	19.61	1490	1490
1:12	19.74	1500	
1:12	19.48	1480	

A-185: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Curing Age – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	24	1823	1924
1:4	26	1975	
1:4	26	1975	
1:5	25	1899	1798
1:5	22	1671	
1:5	24	1823	
1:6	22.6	1717	1699
1:6	21.9	1664	
1:6	22.6	1717	
1:7	23	1747	1641
1:7	20.9	1588	
1:7	20.9	1588	
1:8	22	1671	1608
1:8	20	1519	
1:8	21.5	1633	
1:9	20.80	1580	1580
1:9	20.82	1582	
1:9	20.77	1578	
1:10	20.40	1550	1550
1:10	20.40	1550	
1:10	20.39	1549	
1:11	19.48	1480	1480
1:11	19.49	1481	
1:11	19.48	1480	
1:12	19.34	1470	1460
1:12	19.09	1450	
1:12	19.22	1460	

A-186: Dry Density of Hollow 9” Sandcrete Blocks Moulded with Machine at 1 Day Curing Age – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	18.30	1390	1380
1:4	18.03	1370	
1:4	18.16	1380	
1:5	18.16	1380	1378
1:5	18.16	1380	
1:5	18.09	1374	
1:6	18.09	1370	1370
1:6	18.09	1370	
1:6	18.02	1369	
1:7	17.77	1350	1350
1:7	17.90	1360	
1:7	17.64	1340	
1:8	17.64	1340	1340
1:8	17.64	1340	
1:8	17.65	1341	
1:9	17.49	1329	1330
1:9	17.49	1329	
1:9	17.53	1332	
1:10	16.98	1290	1290
1:10	16.91	1285	
1:10	17.05	1295	
1:11	16.72	1270	1275
1:11	16.85	1280	
1:11	16.90	1284	
1:12	16.58	1260	1260
1:12	16.58	1260	
1:12	16.57	1259	

A-187: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Curing Age – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	19.87	1510	1500
1:4	19.87	1510	
1:4	19.48	1480	
1:5	19.22	1460	1460
1:5	19.22	1460	
1:5	19.23	1461	
1:6	19.15	1455	1450
1:6	18.89	1435	
1:6	19.10	1451	
1:7	18.82	1430	1420
1:7	18.56	1410	
1:7	18.69	1420	
1:8	18.56	1410	1410
1:8	18.56	1410	
1:8	18.55	1409	
1:9	18.44	1401	1400
1:9	18.43	1400	
1:9	18.41	1399	
1:10	18.22	1384	1380
1:10	18.19	1382	
1:10	18.10	1375	
1:11	17.77	1350	1350
1:11	17.77	1350	
1:11	17.76	1349	
1:12	17.55	1333	1330
1:12	17.55	1333	
1:12	17.44	1325	

A-188: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Curing Age – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	22.4	1702	1707
1:4	22.4	1702	
1:4	22.6	1717	
1:5	23.4	1778	1735
1:5	22.6	1717	
1:5	22.5	1709	
1:6	21.5	1633	1633
1:6	21.5	1633	
1:6	21.5	1633	
1:7	21.4	1626	1626
1:7	21.4	1626	
1:7	21.4	1626	
1:8	21.5	1633	1612
1:8	21.0	1595	
1:8	21.2	1595	
1:9	21.5	1633	1608
1:9	21.0	1595	
1:9	21.0	1595	
1:10	22.4	1702	1702
1:10	22.4	1702	
1:10	22.4	1702	
1:11	22.4	1702	1702
1:11	22.4	1702	
1:11	22.4	1702	
1:12	21.0	1595	1595
1:12	21.0	1595	
1:12	21.0	1595	

A-189: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Curing Age – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	22.7	1725	1727
1:4	22.7	1725	
1:4	22.8	1732	
1:5	22.7	1725	1722
1:5	22.6	1717	
1:5	22.7	1725	
1:6	22.6	1717	1714
1:6	22.6	1717	
1:6	22.5	1709	
1:7	22.6	1717	1709
1:7	22.4	1702	
1:7	22.5	1709	
1:8	22.4	1702	1704
1:8	22.4	1702	
1:8	22.5	1709	
1:9	22.4	1702	1702
1:9	22.4	1702	
1:9	22.4	1702	
1:10	22.4	1702	1699
1:10	22.4	1702	
1:10	22.3	1694	
1:11	22.3	1694	1694
1:11	22.3	1694	
1:11	22.3	1694	
1:12	22.2	1686	1686
1:12	22.2	1686	
1:12	22.2	1686	

A-190: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Curing Age – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	23.46	1782	1780
1:4	23.40	1778	
1:4	24.43	1780	
1:5	23.17	1760	1760
1:5	23.18	1761	
1:5	23.17	1760	
1:6	23.03	1750	1750
1:6	23.05	1751	
1:6	23.01	1748	
1:7	22.77	1730	1720
1:7	22.51	1710	
1:7	22.64	1720	
1:8	22.57	1715	1715
1:8	22.57	1715	
1:8	22.57	1715	
1:9	22.48	1708	1710
1:9	22.48	1708	
1:9	22.56	1714	
1:10	22.44	1705	1705
1:10	22.46	1706	
1:10	22.44	1705	
1:11	22.11	1680	1674
1:11	22.11	1680	
1:11	21.92	1665	
1:12	21.98	1670	1672
1:12	21.98	1670	
1:12	22.07	1677	

A-191: Dry Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Curing Age – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	20.8	1800	1800
1:4	20.8	1800	
1:4	20.8	1800	
1:5	23.4	1778	1778
1:5	23.4	1778	
1:5	23.4	1778	
1:6	23.3	1770	1773
1:6	23.4	1778	
1:6	23.3	1770	
1:7	22.8	1732	1730
1:7	22.7	1726	
1:7	22.8	1732	
1:8	22.4	1702	1722
1:8	22.8	1732	
1:8	22.8	1732	
1:9	22.4	1702	1702
1:9	22.4	1702	
1:9	22.4	1702	
1:10	22.4	1702	1692
1:10	22.4	1702	
1:10	22.3	1702	
1:11	22.2	1687	1687
1:11	22.2	1687	
1:11	22.2	1687	
1:12	21.8	1656	1656
1:12	21.8	1656	
1:12	21.8	1656	

A – 192: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Immersion in Water – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	23	1749	1749
1:4	23	1749	
1:4	23	1749	
1:5	24	1829	1802
1:5	23	1749	
1:5	24	1829	
1:6	23	1749	1749
1:6	23	1749	
1:6	23	1749	
1:7	23	1749	1749
1:7	23	1749	
1:7	24	1829	
1:8	23	1749	1749
1:8	23	1749	
1:8	23	1749	
1:9	23	1749	1776
1:9	23	1749	
1:9	24	1829	
1:10	24	1829	1802
1:10	23	1749	
1:10	24	1829	
1:11	23	1749	1723
1:11	22	1670	
1:11	23.5	1789	
1:12	23	1749	1723
1:12	23	1749	
1:12	22	1670	

A – 193: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Immersion in Water – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24	1829	1855
1:4	25.1	1908	
1:4	24	1829	
1:5	24	1829	1829
1:5	24	1829	
1:5	24	1829	
1:6	24	1829	1855
1:6	24.6	1868	
1:6	24.6	1868	
1:7	24	1829	1802
1:7	23	1749	
1:7	24	1829	
1:8	24	1829	1829
1:8	24	1829	
1:8	24	1829	
1:9	24	1829	1829
1:9	24	1829	
1:9	24	1829	
1:10	23	1749	1802
1:10	24	1829	
1:10	24	1829	
1:11	23	1749	1802
1:11	24	1829	
1:11	24	1829	
1:12	23	1749	1749
1:12	23	1749	
1:12	23	1749	

A – 194: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Immersion in Water – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24	1829	1829
1:4	24	1829	
1:4	24	1829	
1:5	25.1	1908	1868
1:5	24	1829	
1:5	24.6	1868	
1:6	24	1829	1829
1:6	24	1829	
1:6	24	1829	
1:7	24	1829	1802
1:7	24	1829	
1:7	23	1749	
1:8	24	1829	1829
1:8	24	1829	
1:8	24	1829	
1:9	24	1829	1829
1:9	24	1829	
1:9	24	1829	
1:10	24	1829	1829
1:10	24	1829	
1:10	24	1829	
1:11	24	1829	1829
1:11	24	1829	
1:11	24	1829	
1:12	24	1829	1829
1:12	24	1829	
1:12	24	1829	

A – 195: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Immersion in Water – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	25.1	1908	1882
1:4	25.1	1908	
1:4	24	1829	
1:5	24	1829	1829
1:5	24	1829	
1:5	24	1829	
1:6	23	1749	1749
1:6	23	1749	
1:6	23	1749	
1:7	24	1829	1829
1:7	24	1829	
1:7	24	1829	
1:8	24.25	1835	1833
1:8	24.16	1830	
1:8	24.21	1834	
1:9	24.16	1830	1831
1:9	24.16	1830	
1:9	24.20	1833	
1:10	24.16	1830	1830
1:10	24.16	1830	
1:10	24.16	1830	
1:11	24.16	1830	1830
1:11	24.16	1830	
1:11	24.16	1830	
1:12	24.16	1830	1830
1:12	24.16	1830	
1:12	24.16	1830	

A – 196: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Immersion in Water – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24.42	1850	1855
1:4	24.55	1860	
1:4	24.47	1854	
1:5	24.29	1840	1840
1:5	24.29	1840	
1:5	24.27	1839	
1:6	24.16	1830	1825
1:6	24.02	1820	
1:6	24.10	1826	
1:7	23.96	1815	1815
1:7	23.96	1815	
1:7	23.94	1814	
1:8	23.89	1810	1809
1:8	23.89	1810	
1:8	23.84	1806	
1:9	23.84	1806	1806
1:9	23.83	1805	
1:9	23.85	1807	
1:10	23.83	1805	1804
1:10	23.83	1805	
1:10	23.80	1803	
1:11	23.81	1804	1802
1:11	23.76	1800	
1:11	23.79	1802	
1:12	23.63	1790	1790
1:12	23.79	1800	
1:12	23.50	1780	

A – 197: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Immersion in Water – Cement Brand A (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	23.89	1810	1815
1:4	24.03	1821	
1:4	23.94	1814	
1:5	23.76	1800	1800
1:5	23.76	1800	
1:5	23.76	1800	
1:6	23.76	1800	1790
1:6	23.50	1780	
1:6	23.63	1790	
1:7	23.36	1770	1775
1:7	23.47	1778	
1:7	23.46	1777	
1:8	23.36	1770	1770
1:8	23.50	1780	
1:8	23.23	1760	
1:9	23.36	1770	1765
1:9	23.25	1761	
1:9	23.28	1764	
1:10	22.97	1740	1740
1:10	22.99	1742	
1:10	22.95	1739	
1:11	22.78	1726	1725
1:11	22.78	1726	
1:11	22.74	1723	
1:12	22.57	1710	1710
1:12	22.57	1710	
1:12	22.56	1709	

A – 198: Wet Density of Hollow 9" Sandcrete Blocks Moulded With Machine at 1 Day Immersion in Water – Cement Brand B

$W/C = 0.45$

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	23	1749	1749
1:4	23	1749	
1:4	23	1749	
1:5	22	1670	1670
1:5	22	1670	
1:5	22	1670	
1:6	22	1670	1670
1:6	22	1670	
1:6	22	1670	
1:7	22	1670	1670
1:7	22	1670	
1:7	22	1670	
1:8	22	1670	1696
1:8	22	1670	
1:8	22	1670	
1:9	22	1670	1670
1:9	22	1670	
1:9	22	1670	
1:10	22	1670	1670
1:10	22	1670	
1:10	22	1670	
1:11	22	1670	1670
1:11	22	1670	
1:11	22	1670	
1:12	22	1670	1670
1:12	22	1670	
1:12	22	1670	

A – 199: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Immersion in Water – Cement Brand B (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	24	1829	1829
1:4	24	1829	
1:4	24	1829	
1:5	24	1829	1829
1:5	24	1829	
1:5	24	1829	
1:6	23	1749	1802
1:6	24	1829	
1:6	24	1829	
1:7	22.94	1738	1735
1:7	22.92	1736	
1:7	22.84	1730	
1:8	22.84	1730	1730
1:8	22.84	1730	
1:8	22.84	1730	
1:9	22.84	1730	1730
1:9	22.84	1730	
1:9	22.83	1729	
1:10	22.70	1720	1720
1:10	22.70	1720	
1:10	22.69	1719	
1:11	22.69	1719	1718
1:11	22.66	1717	
1:11	22.69	1719	
1:12	22.68	1718	1718
1:12	22.68	1718	
1:12	22.66	1717	

A – 200: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Immersion in Water – Cement Brand B (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24.22	1840	1838
1:4	24.22	1840	
1:4	24.14	1834	
1:5	24.48	1860	1860
1:5	24.48	1860	
1:5	24.48	1860	
1:6	24.00	1829	1829
1:6	24.00	1829	
1:6	24.00	1829	
1:7	23.20	1765	1786
1:7	23.20	1765	
1:7	24.00	1829	
1:8	23.30	1770	1768
1:8	23.28	1769	
1:8	23.24	1766	
1:9	23.30	1770	1768
1:9	23.28	1769	
1:9	23.23	1765	
1:10	23.17	1760	1758
1:10	23.17	1760	
1:10	23.10	1755	
1:11	23.03	1750	1752
1:11	23.03	1750	
1:11	22.97	1745	
1:12	23.03	1750	1750
1:12	23.02	1749	
1:12	23.03	1750	

A – 201: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Immersion in Water – Cement Brand B (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24.6	1868	1842
1:4	24	1829	
1:4	24	1829	
1:5	23.5	1789	1868
1:5	25.1	1908	
1:5	25.1	1908	
1:6	23.5	1789	1868
1:6	24	1829	
1:6	25.1	1908	
1:7	23.5	1789	1802
1:7	24	1829	
1:7	23.5	1789	
1:8	23.5	1789	1789
1:8	24	1829	
1:8	23	1749	
1:9	23	1749	1789
1:9	23.5	1789	
1:9	24	1829	
1:10	23.56	1785	1784
1:10	23.56	1785	
1:10	23.54	1783	
1:11	23.50	1780	1780
1:11	23.51	1781	
1:11	23.50	1780	
1:12	23.48	1779	1778
1:12	23.46	1777	
1:12	23.47	1778	

A – 202: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Immersion in Water – Cement Brand B (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24.16	1830	1828
1:4	24.14	1829	
1:4	24.09	1825	
1:5	24.55	1860	1862
1:5	24.55	1860	
1:5	24.63	1866	
1:6	24.58	1862	1862
1:6	24.59	1863	
1:6	24.55	1860	
1:7	23.69	1795	1796
1:7	23.69	1795	
1:7	23.73	1798	
1:8	23.50	1780	1780
1:8	23.63	1790	
1:8	23.36	1770	
1:9	23.50	1780	1780
1:9	23.50	1780	
1:9	23.48	1779	
1:10	23.43	1775	1775
1:10	23.43	1775	
1:10	23.42	1774	
1:11	23.36	1770	1770
1:11	23.36	1770	
1:11	23.36	1770	
1:12	23.36	1770	1768
1:12	23.34	1768	
1:12	23.31	1766	

A – 203: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Immersion in Water – Cement Brand B (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	23.76	1800	1800
1:4	23.76	1800	
1:4	23.77	1801	
1:5	24.42	1850	1840
1:5	24.16	1830	
1:5	24.27	1839	
1:6	24.29	1840	1840
1:6	24.29	1840	
1:6	24.29	1840	
1:7	23.50	1780	1780
1:7	23.56	1785	
1:7	23.56	1775	
1:8	23.36	1770	1760
1:8	23.11	1751	
1:8	23.23	1760	
1:9	23.23	1760	1760
1:9	23.22	1760	
1:9	23.22	1759	
1:10	23.10	1750	1750
1:10	23.10	1750	
1:10	23.09	1749	
1:11	23.09	1749	1747
1:11	23.03	1745	
1:11	23.05	1746	
1:12	23.03	1745	1745
1:12	23.05	1746	
1:12	23.03	1745	

A – 204: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Immersion in Water – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	23.03	1750	1749
1:4	23.02	1749	
1:4	23.02	1749	
1:5	23.02	1749	1749
1:5	23.02	1749	
1:5	23.02	1749	
1:6	23.02	1749	1749
1:6	23.02	1749	
1:6	23.02	1749	
1:7	22.57	1715	1715
1:7	22.56	1714	
1:7	22.57	1715	
1:8	22.77	1725	1723
1:8	22.77	1725	
1:8	22.64	1720	
1:9	22.64	1720	1723
1:9	22.68	1723	
1:9	22.72	1726	
1:10	22.17	1685	1684
1:10	22.17	1685	
1:10	22.14	1682	
1:11	22.16	1684	1684
1:11	22.15	1683	
1:11	22.16	1684	
1:12	22.84	1735	1736
1:12	22.84	1735	
1:12	22.88	1738	

A – 205: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Immersion in Water – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density kg/m^3)
1:4	25.10	1908	1881
1:4	24.60	1868	
1:4	24.60	1868	
1:5	25.10	1908	1855
1:5	24.00	1829	
1:5	24.00	1820	
1:6	23.90	1816	1816
1:6	23.90	1816	
1:6	23.91	1815	
1:7	23.90	1816	1816
1:7	23.89	1815	
1:7	23.90	1816	
1:8	23.03	1750	1749
1:8	23.03	1750	
1:8	23.00	1747	
1:9	23.02	1749	1749
1:9	23.02	1749	
1:9	23.02	1749	
1:10	23.02	1749	1749
1:10	23.02	1749	
1:10	23.01	1748	
1:11	23.02	1749	1749
1:11	23.01	1748	
1:11	23.02	1749	
1:12	23.02	1749	1749
1:12	23.02	1749	
1:12	23.02	1749	

A – 206: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Immersion in Water – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	25.54	1935	1932
1:4	25.54	1935	
1:4	25.42	1926	
1:5	24.95	1890	1885
1:5	24.95	1880	
1:5	24.88	1885	
1:6	24.90	1892	1877
1:6	24.90	1892	
1:6	25.10	1907	
1:7	24.00	1829	1829
1:7	24.00	1829	
1:7	24.00	1829	
1:8	23.43	1775	1776
1:8	23.44	1776	
1:8	23.44	1776	
1:9	23.00	1749	1776
1:9	23.50	1789	
1:9	23.50	1789	
1:10	23.36	1770	1770
1:10	23.36	1770	
1:10	23.37	1771	
1:11	22.80	1733	1765
1:11	23.00	1749	
1:11	23.90	1813	
1:12	23.23	1760	1760
1:12	23.23	1760	
1:12	23.22	1759	

A – 207: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Immersion in Water – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	25.1	1908	1948
1:4	26.2	1988	
1:4	25.6	1948	
1:5	25.6	1948	1895
1:5	25.1	1908	
1:5	24.6	1868	
1:6	25.6	1948	1908
1:6	25.1	1908	
1:6	24.6	1868	
1:7	23.5	1789	1929
1:7	24	1829	
1:7	24.6	1868	
1:8	23.63	1790	1790
1:8	23.63	1790	
1:8	23.64	1791	
1:9	23.63	1790	1790
1:9	23.63	1790	
1:9	23.63	1790	
1:10	23.5	1789	1789
1:10	24	1829	
1:10	23	1749	
1:11	23.43	1775	1776
1:11	23.46	1777	
1:11	23.44	1776	
1:12	23.36	1770	1770
1:12	23.30	1765	
1:12	23.43	1775	

A – 208: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Immersion in Water – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	25.48	1930	1925
1:4	25.34	1920	
1:4	25.40	1924	
1:5	24.88	1885	1885
1:5	24.88	1885	
1:5	24.87	1884	
1:6	24.82	1880	1878
1:6	24.80	1879	
1:6	24.75	1875	
1:7	24.79	1878	1878
1:7	24.79	1878	
1:7	24.79	1878	
1:8	23.43	1775	1776
1:8	23.43	1775	
1:8	23.47	1778	
1:9	23.44	1776	1776
1:9	23.44	1776	
1:9	23.43	1775	
1:10	23.36	1770	1772
1:10	23.36	1770	
1:10	23.44	1776	
1:11	23.36	1770	1770
1:11	23.36	1770	
1:11	23.35	1769	
1:12	23.34	1768	1768
1:12	23.35	1769	
1:12	23.34	1768	

A – 209: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Immersion in Water – Cement Brand C (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24.85	1888	1887
1:4	24.86	1889	
1:4	24.80	1884	
1:5	24.42	1855	1857
1:5	24.42	1855	
1:5	24.51	1862	
1:6	24.42	1850	1848
1:6	24.52	1850	
1:6	24.34	1844	
1:7	24.35	1845	1846
1:7	24.35	1845	
1:7	24.39	1848	
1:8	23.34	1768	1760
1:8	23.13	1752	
1:8	23.13	1761	
1:9	23.23	1760	1760
1:9	23.10	1750	
1:9	23.36	1770	
1:10	23.23	1760	1758
1:10	23.24	1761	
1:10	23.13	1753	
1:11	23.10	1750	1750
1:11	23.10	1750	
1:11	23.10	1750	
1:12	23.09	1749	1750
1:12	23.10	1750	
1:12	23.16	1750	

A – 210: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Immersion in Water – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	22.24	1685	1683
1:4	22.18	1680	
1:4	22.23	1684	
1:5	22.18	1680	1680
1:5	22.18	1680	
1:5	22.18	1680	
1:6	22	1670	1670
1:6	22	1670	
1:6	22	1670	
1:7	22	1670	1657
1:7	21.5	1630	
1:7	22	1670	
1:8	22	1670	1670
1:8	22	1670	
1:8	22	1670	
1:9	22.5	1709	1656
1:9	21.5	1630	
1:9	21.5	1630	
1:10	21.5	1630	1643
1:10	22	1670	
1:10	21.5	1630	
1:11	21.65	1640	1630
1:11	21.4	1620	
1:11	21.5	1630	
1:12	20.4	1550	1563
1:12	20.9	1590	
1:12	20.4	1550	

A – 211: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Immersion in Water – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	25.74	1950	1951
1:4	25.74	1950	
1:4	25.79	1953	
1:5	25.28	1915	1913
1:5	25.28	1915	
1:5	25.21	1910	
1:6	23	1829	1874
1:6	25.6	1948	
1:6	24.28	1845	
1:7	24	1829	1829
1:7	24	1829	
1:7	24	1829	
1:8	24	1829	1829
1:8	24	1829	
1:8	24	1829	
1:9	23.5	1789	1816
1:9	24	1829	
1:9	24	1829	
1:10	23.88	1809	1810
1:10	23.91	1811	
1:10	23.88	1809	
1:11	24	1829	1749
1:11	23	1749	
1:11	22	1670	
1:12	23.10	1750	1740
1:12	22.84	1730	
1:12	22.98	1741	

A – 212: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Immersion in Water – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	26.20	1988	1961
1:4	25.60	1948	
1:4	25.60	1948	
1:5	25.26	1914	1913
1:5	25.26	1914	
1:5	25.24	1912	
1:6	25.34	1920	1920
1:6	25.34	1920	
1:6	25.33	1919	
1:7	25.08	1900	1902
1:7	25.08	1900	
1:7	25.15	1905	
1:8	24.55	1860	1860
1:8	24.55	1860	
1:8	24.54	1859	
1:9	24.01	1819	1820
1:9	24.00	1818	
1:9	24.06	1823	
1:10	23.96	1815	1815
1:10	23.96	1815	
1:10	23.97	1816	
1:11	23.50	1780	1782
1:11	23.54	1783	
1:11	23.51	1781	
1:12	23.23	1760	1762
1:12	23.23	1760	
1:12	23.30	1765	

A – 213: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Immersion in Water – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	26.20	1988	1961
1:4	26.20	1988	
1:4	25.10	1908	
1:5	25.60	1948	1956
1:5	25.60	1948	
1:5	26.00	1972	
1:6	25.74	1950	1950
1:6	25.74	1950	
1:6	25.74	1950	
1:7	24.95	1890	1880
1:7	24.68	1870	
1:7	24.82	1880	
1:8	24.68	1870	1869
1:8	24.68	1870	
1:8	24.63	1866	
1:9	24.00	1829	1829
1:9	24.00	1829	
1:9	24.00	1829	
1:10	24.16	1830	1829
1:10	24.16	1830	
1:10	24.16	1827	
1:11	24.00	1829	1816
1:11	23.50	1789	
1:11	24.00	1829	
1:12	23.77	1801	1802
1:12	23.79	1803	
1:12	23.78	1802	

A – 214: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Immersion in Water – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	25.61	1940	1930
1:4	25.34	1920	
1:4	25.46	1929	
1:5	25.28	1915	1915
1:5	25.28	1915	
1:5	25.26	1914	
1:6	25.19	1908	1907
1:6	25.15	1905	
1:6	25.19	1908	
1:7	24.68	1870	1871
1:7	24.68	1870	
1:7	24.84	1882	
1:8	24.55	1860	1858
1:8	24.54	1859	
1:8	24.49	1855	
1:9	24.09	1825	1825
1:9	24.09	1825	
1:9	24.10	1826	
1:10	24.02	1820	1820
1:10	24.02	1820	
1:10	24.02	1819	
1:11	23.89	1810	1810
1:11	23.89	1810	
1:11	23.89	1810	
1:12	23.89	1800	1795
1:12	23.89	1800	
1:12	23.56	1785	

A – 215: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Immersion in Water – Cement Brand D (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	25.21	1910	1910
1:4	25.21	1910	
1:4	25.20	1909	
1:5	25.08	1900	1890
1:5	24.82	1880	
1:5	24.95	1890	
1:6	24.88	1885	1883
1:6	24.88	1885	
1:6	24.80	1879	
1:7	24.68	1870	1865
1:7	24.55	1860	
1:7	24.63	1866	
1:8	24.42	1850	1850
1:8	24.42	1850	
1:8	24.42	1850	
1:9	24.05	1822	1822
1:9	24.05	1825	
1:9	24.01	1819	
1:10	23.81	1804	1805
1:10	23.84	1806	
1:10	23.83	1805	
1:11	23.77	1801	1802
1:11	23.77	1801	
1:11	23.81	1804	
1:12	23.76	1800	1790
1:12	23.51	1781	
1:12	23.63	1790	

A – 216: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Immersion in Water – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	22.5	1709	1722
1:4	23	1749	
1:4	22.5	1709	
1:5	23	1749	1749
1:5	23	1749	
1:5	23	1749	
1:6	22	1670	1696
1:6	23	1749	
1:6	22	1670	
1:7	22	1670	1696
1:7	23	1749	
1:7	22	1670	
1:8	22	1670	1657
1:8	22	1670	
1:8	22	1670	
1:9	22	1670	1670
1:9	22	1670	
1:9	22	1670	
1:10	22	1670	1670
1:10	22	1670	
1:10	22	1670	
1:11	22	1670	1670
1:11	22	1670	
1:11	22	1670	
1:12	21.89	1663	1660
1:12	21.78	1655	
1:12	21.88	1662	

A – 217: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Immersion in Water – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	24	1829	1829
1:4	24	1829	
1:4	24	1829	
1:5	25.1	1908	1802
1:5	23	1749	
1:5	23	1749	
1:6	23	1749	1749
1:6	23	1749	
1:6	23	1749	
1:7	23	1749	1696
1:7	22	1670	
1:7	22	1670	
1:8	23	1749	1696
1:8	22	1670	
1:8	22	1670	
1:9	22	1670	1670
1:9	22	1670	
1:9	22	1670	
1:10	22	1670	1696
1:10	23	1749	
1:10	22	1670	
1:11	22.11	1675	1670
1:11	22.98	1665	
1:11	22.06	1671	
1:12	21.98	1665	1666
1:12	21.98	1665	
1:12	22.02	1668	

A – 218: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Immersion in Water – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)
1:4	23	1749	1762
1:4	23	1749	
1:4	23.5	1789	
1:5	23.2	1765	1821
1:5	24	1829	
1:5	24.5	1868	
1:6	23.17	1755	1752
1:6	23.10	1750	
1:6	23.11	1751	
1:7	23	1749	1736
1:7	23	1749	
1:7	22.5	1709	
1:8	22.77	1725	1723
1:8	22.77	1725	
1:8	22.70	1720	
1:9	23	1749	1696
1:9	22	1670	
1:9	22	1670	
1:10	22.44	1700	1702
1:10	22.44	1700	
1:10	22.51	1705	
1:11	23	1749	1749
1:11	23	1749	
1:11	23	1749	
1:12	22	1670	1670
1:12	22	1670	
1:12	22	1670	

A – 219: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Immersion in Water – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24.00	1829	1855
1:4	25.10	1908	
1:4	24.00	1829	
1:5	24.29	1840	1835
1:5	24.16	1830	
1:5	24.20	1834	
1:6	24.20	1833	1832
1:6	24.20	1834	
1:6	24.16	1830	
1:7	23.63	1790	1786
1:7	23.56	1785	
1:7	23.54	1783	
1:8	23.47	1778	1773
1:8	23.36	1770	
1:8	23.36	1770	
1:9	23.36	1770	1769
1:9	23.35	1769	
1:9	23.35	1769	
1:10	23.15	1754	1753
1:10	23.10	1750	
1:10	23.17	1755	
1:11	23.10	1750	1750
1:11	23.10	1750	
1:11	23.10	1750	
1:12	22.67	1722	1722
1:12	22.68	1723	
1:12	22.67	1722	

A – 220: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Immersion in Water – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24.29	1840	1832
1:4	24.21	1834	
1:4	24.66	1823	
1:5	24.02	1820	1820
1:5	24.02	1820	
1:5	24.02	1820	
1:6	23.96	1815	1815
1:6	23.98	1817	
1:6	23.93	1813	
1:7	23.50	1780	1780
1:7	23.50	1780	
1:7	23.48	1779	
1:8	23.36	1770	1760
1:8	23.10	1750	
1:8	23.22	1759	
1:9	23.10	1750	1752
1:9	23.10	1750	
1:9	23.19	1757	
1:10	22.47	1740	1740
1:10	22.97	1740	
1:10	22.95	1739	
1:11	22.84	1730	1730
1:11	22.84	1730	
1:11	22.84	1730	
1:12	22.72	1721	1720
1:12	22.72	1721	
1:12	22.69	1719	

A – 221: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Immersion in Water – Cement Brand E (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	23.83	1805	1805
1:4	23.89	1810	
1:4	23.76	1800	
1:5	23.76	1800	1800
1:5	23.76	1800	
1:5	23.76	1800	
1:6	23.69	1795	1792
1:6	23.63	1790	
1:6	23.63	1790	
1:7	23.03	1745	1740
1:7	22.90	1735	
1:7	22.98	1741	
1:8	22.82	1729	1730
1:8	22.82	1729	
1:8	22.88	1733	
1:9	23.10	1750	1748
1:9	23.10	1750	
1:9	23.02	1744	
1:10	22.84	1730	1733
1:10	22.90	1735	
1:10	23.09	1749	
1:11	22.84	1730	1728
1:11	22.81	1728	
1:11	22.80	1727	
1:12	22.70	1720	1720
1:12	22.72	1721	
1:12	22.70	1720	

A – 222: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Immersion in Water – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	21.12	1600	1596
1:4	21.09	1598	
1:4	20.99	1590	
1:5	20.59	1560	1560
1:5	20.67	1566	
1:5	20.53	1555	
1:6	20.72	1570	1570
1:6	20.72	1570	
1:6	20.71	1569	
1:7	20.66	1565	1560
1:7	20.53	1555	
1:7	20.59	1560	
1:8	20.09	1522	1520
1:8	20.04	1518	
1:8	20.08	1521	
1:9	19.87	1505	1504
1:9	19.87	1505	
1:9	19.84	1503	
1:10	19.67	1490	1490
1:10	19.67	1490	
1:10	19.65	1489	
1:11	19.31	1463	1460
1:11	19.31	1463	
1:11	19.19	1454	
1:12	19.67	1490	1490
1:12	19.67	1490	
1:12	19.67	1490	

A – 223: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Immersion in Water – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	21.78	1650	1650
1:4	21.78	1650	
1:4	21.79	1651	
1:5	21.52	1630	1630
1:5	21.46	1626	
1:5	21.57	1634	
1:6	21.71	1645	1644
1:6	21.71	1645	
1:6	21.67	1642	
1:7	21.12	1600	1600
1:7	21.12	1600	
1:7	21.11	1599	
1:8	21.78	1650	1650
1:8	21.78	1650	
1:8	21.78	1650	
1:9	21.65	1640	1636
1:9	21.58	1635	
1:9	21.56	1633	
1:10	21.38	1620	1620
1:10	21.41	1622	
1:10	21.37	1619	
1:11	21.38	1620	1620
1:11	21.38	1620	
1:11	21.38	1620	
1:12	21.32	1615	1615
1:12	21.36	1618	
1:12	21.28	1612	

A – 224: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Immersion in Water – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	23.03	1745	1744
1:4	23.05	1746	
1:4	22.97	1740	
1:5	22.77	1725	1724
1:5	22.77	1725	
1:5	22.72	1721	
1:6	22.92	1736	1736
1:6	22.90	1735	
1:6	22.92	1736	
1:7	22.70	1720	1724
1:7	22.70	1720	
1:7	22.81	1728	
1:8	22.51	1705	1708
1:8	22.57	1710	
1:8	22.56	1709	
1:9	22.44	1700	1700
1:9	22.44	1700	
1:9	22.44	1700	
1:10	22.18	1680	1682
1:10	22.18	1680	
1:10	22.24	1685	
1:11	22.18	1680	1680
1:11	22.18	1680	
1:11	22.18	1680	
1:12	22.18	1680	1678
1:12	22.18	1680	
1:12	22.10	1674	

A – 225: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Immersion in Water – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24.42	1850	1840
1:4	24.16	1830	
1:4	24.29	1840	
1:5	24.16	1830	1830
1:5	24.16	1830	
1:5	24.16	1830	
1:6	23.89	1810	1811
1:6	23.88	1809	
1:6	23.96	1815	
1:7	23.76	1800	1794
1:7	23.71	1796	
1:7	23.58	1786	
1:8	23.50	1780	1780
1:8	23.63	1790	
1:8	23.36	1770	
1:9	23.30	1765	1764
1:9	23.30	1765	
1:9	23.26	1762	
1:10	23.10	1750	1750
1:10	23.10	1750	
1:10	23.11	1751	
1:11	22.84	1730	1730
1:11	22.82	1729	
1:11	22.84	1730	
1:12	22.64	1715	1715
1:12	22.62	1714	
1:12	22.65	1716	

A – 226: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Immersion in Water – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	23.69	1795	1794
1:4	23.68	1794	
1:4	23.68	1794	
1:5	23.68	1794	1794
1:5	23.68	1794	
1:5	23.68	1794	
1:6	23.50	1780	1782
1:6	23.58	1786	
1:6	23.50	1780	
1:7	23.23	1760	1764
1:7	23.34	1768	
1:7	23.30	1765	
1:8	23.10	1750	1748
1:8	23.10	1750	
1:8	23.05	1746	
1:9	22.70	1720	1717
1:9	22.64	1715	
1:9	22.65	1716	
1:10	22.57	1710	1712
1:10	22.57	1710	
1:10	22.64	1715	
1:11	22.55	1708	1708
1:11	22.53	1707	
1:11	22.55	1708	
1:12	22.47	1702	1703
1:12	22.47	1702	
1:12	22.51	1705	

A – 227: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 28 Days Immersion in Water – Cement Brand F (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	23.56	1785	1784
1:4	23.56	1785	
1:4	23.52	1782	
1:5	23.31	1760	1764
1:5	23.31	1766	
1:5	23.23	1760	
1:6	22.97	1740	1738
1:6	22.97	1740	
1:6	22.90	1735	
1:7	22.77	1725	1725
1:7	22.77	1725	
1:7	22.76	1724	
1:8	22.68	1718	1717
1:8	22.64	1715	
1:8	22.68	1718	
1:9	22.44	1700	1700
1:9	22.44	1700	
1:9	22.44	1700	
1:10	22.44	1700	1697
1:10	22.43	1699	
1:10	22.33	1692	
1:11	22.31	1690	1690
1:11	22.31	1690	
1:11	22.32	1691	
1:12	22.31	1690	1687
1:12	22.24	1685	
1:12	22.26	1686	

A – 228: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 1 Day Immersion in Water – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	21.19	1605	1606
1:4	21.19	1605	
1:4	21.23	1608	
1:5	21.12	1600	1601
1:5	21.12	1600	
1:5	21.16	1603	
1:6	20.99	1590	1590
1:6	20.99	1590	
1:6	20.97	1589	
1:7	20.72	1570	1569
1:7	20.72	1570	
1:7	20.67	1566	
1:8	20.33	1540	1543
1:8	20.33	1540	
1:8	20.45	1549	
1:9	20.25	1535	1530
1:9	20.13	1525	
1:9	20.18	1529	
1:10	19.93	1510	1512
1:10	19.93	1510	
1:10	20.01	1516	
1:11	19.96	1512	1512
1:11	19.96	1512	
1:11	19.96	1512	
1:12	19.93	1510	1511
1:12	19.93	1510	
1:12	19.96	1512	

A – 229: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 3 Days Immersion in Water – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	22.63	1715	1711
1:4	22.57	1710	
1:4	22.55	1708	
1:5	22.77	1725	1725
1:5	22.77	1725	
1:5	22.77	1725	
1:6	22.73	1722	1720
1:6	22.73	1722	
1:6	22.65	1716	
1:7	22.63	1715	1715
1:7	22.63	1715	
1:7	22.62	1714	
1:8	22.57	1710	1711
1:8	22.57	1710	
1:8	22.58	1712	
1:9	22.51	1705	1704
1:9	22.51	1705	
1:9	22.47	1702	
1:10	21.12	1600	1598
1:10	21.12	1600	
1:10	21.04	1594	
1:11	20.86	1580	1580
1:11	20.86	1580	
1:11	20.87	1581	
1:12	20.86	1580	1580
1:12	20.86	1580	
1:12	20.86	1580	

A – 230: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 7 Days Immersion in Water – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	23.50	1780	1788
1:4	23.63	1790	
1:4	23.68	1794	
1:5	23.56	1785	1784
1:5	23.56	1785	
1:5	23.54	1783	
1:6	23.32	1767	1767
1:6	23.32	1767	
1:6	23.34	1768	
1:7	23.03	1745	1744
1:7	23.03	1745	
1:7	23.01	1743	
1:8	23.01	1743	1743
1:8	23.01	1743	
1:8	23.01	1743	
1:9	22.99	1742	1740
1:9	22.97	1740	
1:9	22.94	1738	
1:10	22.70	1720	1718
1:10	22.70	1720	
1:10	22.76	1724	
1:11	22.57	1710	1710
1:11	22.57	1710	
1:11	22.57	1710	
1:12	22.56	1709	1707
1:12	22.51	1705	
1:12	22.52	1706	

A – 231: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 14 Days Immersion in Water – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24.55	1860	1860
1:4	24.55	1860	
1:4	24.55	1860	
1:5	24.55	1860	1860
1:5	24.55	1860	
1:5	24.55	1860	
1:6	24.50	1855	1850
1:6	24.35	1845	
1:6	24.42	1850	
1:7	24.21	1834	1833
1:7	24.22	1835	
1:7	24.16	1830	
1:8	23.89	1810	1811
1:8	23.89	1810	
1:8	23.92	1812	
1:9	23.69	1795	1794
1:9	23.69	1795	
1:9	23.67	1793	
1:10	23.63	1790	1790
1:10	23.63	1790	
1:10	23.64	1791	
1:11	23.63	1790	1790
1:11	23.63	1790	
1:11	23.63	1790	
1:12	23.63	1790	1788
1:12	23.58	1786	
1:12	23.59	1787	

A – 232: Wet Density of Hollow 9" Sandcrete Blocks Moulded with Machine at 21 Days Immersion in Water – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24.35	1845	1840
1:4	24.22	1835	
1:4	24.30	1841	
1:5	24.22	1835	1830
1:5	24.22	1835	
1:5	24.26	1838	
1:6	24.26	1825	1824
1:6	24.26	1825	
1:6	24.06	1823	
1:7	24.02	1820	1820
1:7	24.02	1820	
1:7	24.02	1820	
1:8	23.76	1800	1800
1:8	23.76	1800	
1:8	23.75	1799	
1:9	23.56	1785	1784
1:9	23.50	1780	
1:9	23.59	1787	
1:10	23.50	1780	1780
1:10	23.50	1780	
1:10	23.50	1780	
1:11	23.43	1775	1777
1:11	23.43	1775	
1:11	23.51	1781	
1:12	23.23	1760	1761
1:12	23.25	1761	
1:12	23.25	1761	

A – 233: Wet Density of Hollow 9” Sandcrete Blocks Moulded with Machine at 28 Days Immersion in Water – Cement Brand G (w/c = 0.45)

Mix Ratio	Mass (kg)	Wet Density (kg/m^3)	Average Wet Density (kg/m^3)
1:4	24.16	1830	1833
1:4	24.22	1835	
1:4	24.21	1834	
1:5	24.02	1820	1820
1:5	24.01	1819	
1:5	24.02	1820	
1:6	23.88	1809	1810
1:6	23.91	1811	
1:6	23.89	1810	
1:7	23.87	1808	1808
1:7	23.89	1810	
1:7	23.84	1806	
1:8	23.63	1790	1790
1:8	23.63	1790	
1:8	23.61	1789	
1:9	23.50	1780	1780
1:9	23.55	1784	
1:9	23.43	1775	
1:10	23.32	1767	1766
1:10	23.34	1768	
1:10	23.27	1763	
1:11	23.10	1750	1750
1:11	23.10	1750	
1:11	23.10	1750	
1:12	23.10	1750	1750
1:12	23.10	1750	
1:12	23.10	1750	

A-234: Water Absorption Test for Blocks

Cement Brand	Mix Ratio	Dry Weight of Block W_1 (kg)	Wet Weight of Block W_2 (kg)	Absorption Of Block (%)	Average Absorption (%)	Absorption in (kg/m^3)
Ashaka	1:6	20.50	22.00	7.32	5.61	112.60
	1:6	21.00	22.00	4.76		75.00
	1:6	21.00	22.00	4.76		75.00
Atlas	1:6	20.00	21.00	5.00	5.00	75.00
	1:6	20.00	21.00	5.00		75.00
	1:6	20.00	21.00	5.00		75.00
Burham	1:6	20.50	22.00	7.32	7.32	112.60
	1:6	20.50	22.00	7.32		112.60
	1:6	20.50	22.00	7.32		112.60
Dangote	1:6	21.00	22.00	4.76	4.69	75.00
	1:6	22.00	23.00	4.55		75.00
	1:6	21.00	22.00	4.76		75.00
Eagle	1:6	20.00	21.00	5.00	4.92	75.00
	1:6	21.00	22.00	4.76		75.00
	1:6	20.00	21.00	5.00		75.00
Elephant	1:6	21.00	22.00	4.76	4.80	75.00
	1:6	20.50	21.50	4.87		75.00
	1:6	21.00	22.00	4.76		75.00
Sokoto	1:6	20.00	21.00	5.00	5.00	75.00
	1:6	20.00	21.00	5.00		75.00
	1:6	20.00	21.00	5.00		75.00

Appendix A – 235: Cost Estimation of a Sandcrete Hollow Block

According to Olanitori (2005) the average number of full head pan of sand in a tipper load of sand is 120. A 50kg of cement contains approximately 2 head pans of cement.

According to NIS 87:2004, and BS 2028:1985, the standard cement to sand mix ratio is 1:6. This means one part of cement to six pars of sand.

For a mix ratio of 1:6, the number of 50kg bags of cement to be mixed with one tipper load of sand is x.

1 bag of cement contains 2 head pans of cement

therefore $\frac{1}{6} = \frac{2x}{120}$

$6x = 120$

$X = 10$ bags

But 10 bags of cement contain 20 head pans of cement

20 head pan : 120 head pans of sand

1 head pan : $\frac{120}{20} = 6$

The cost of One bag of cement is currently N1,700

$\therefore$ cost of 10 bags of cement = N1,700 x 10 = N17,000.

Current cost of 1 tipper load of sand = N12,000

w/c = 0.45 w = 0.45C = 0.45 x 50 x 10 = 225kg.

4000 litres of water cost N4000

1 litre cost N1

$\therefore$225kg of water = 225litres cost N225

Total cost of blocks/tipper load

Water	=	N225
Cement	=	N17,000
Sand	=	N12,000
		N29,225

1 bag of cement produced 15 blocks at mix ratio 1:6. 10 bags of cement produced 10 x 15 blocks = 150 blocks.

Cost of a sandcrete hollow block = $\frac{29.225}{150} = 194$

Labour = N20

Total cost = 194+20 = N214

At mix ratio of 1:6 cost of producing a sandcrete hollow block = N205.

At mix ratio of 1:8

1 Tipper sand contains 120 head pans

1:8 = x: 120 head pan

$\frac{1}{8} = \frac{x}{120}, or\ x = \frac{120}{8} =$ 15 head pans

Thus number of bags required is $\frac{15}{2}$ = 7.5/bags of cement

At mix ratio f 1:8, 20 blocks were produced per 50kg bag of cement

$\therefore$ 7.5 bags of cement produced 7.5 x 20 = 150

w/c = 0.45

w = 0.45 x 7.5 x 50 = 168.75kg

ρ = 100kg/m^3 =

Mass of water = 168.75kg

Cost of water = N168.75

Cost of Cement = 7.5 x 1.700 = N12,750

Cost of production of blocks/tipper load of sand:

- Sand = N12,000
- Cement = N12,750
- Water = N169

Total cost of material = N24,919

Cost of producing a block = $\frac{24,919}{150} = 166.1$

Cost of labour = N20

Total cost = N166.1 + N20 = N186

For mix ratio of 1:10

1 tipper load of sand is 120 head pans and 50kg of cement contain 2 head pans

1 :10

x : 120

$x = \frac{120}{10}$ = 12 head pans of cement = 6 bags of 50kg cement

Cement

The number of sandcrete hollow blocks produced was 25 per 50kg cement bag.

Total number of blocks produced per tipper load of sand = 6 x 25 = 150

1 tipper load of sand cost N12,000

6 bags of cement cost 6 x 1,700 = N10,200

Cost of water with W/c = 0.45

W = 0.45C = 0.45 x 50 x 6 = 135kg

= 135litres

135 litres x N1.00 = N135

Total cost sandcrete blocks per tipper load

Sand	=	N12,000
Cement	=	N10,200
Water	=	<u>N135</u>
		N22,335

Cost of materials per blocks = $\frac{22,335}{125}$ = 149

Labour per block = N20

Total cost per block = N20 + N149 = N169

For mix ratio of 1:12, about 30 sandcrete hollow blocks were produced per 50kg cement bag

Mix ratio of x : 120 head per 1:12

$$\frac{x}{120} = \frac{1}{12} \ or \ x = \frac{120}{12} = 10 \ head \ pans$$

This means 5 bags were used to produce blocks per tipper load

Total number of blocks per tipper load = 5 x 30 = 150

Cost of water = 0.45 x 5 x 50 = N112.5

Cost of cement = N1,700 x 5 = N8,500

Total cost of materials per tipper load

Sand	=	N12,000
Cement	=	N8,500
Water	=	N113
Total	=	N20,613

Cost of materials per sandcrete hollow block $= \frac{20,613}{150} = N137.42$

Cost of labour per block = N20. Total cost of block = 20 + 137.42 = N157.42 = N158

The cost of producing standard sandcrete hollow block at 1:6 mix ratio

= N205 and the corresponding average compressive strength was 4.5N/mm^2

When the blocks are produced at mix ratio of 1:8, the cost per block = N186 and corresponding average compressive strength = 3.80N/mm^2

Reduction in cost = N205 – N186 = N19

Percentage reduction in price = $\frac{19}{205}$ x 100 = 9.3%

Percentage reduction in compressive strength = $\left(\frac{4.5-3.80}{4.5}\right)$ x 100 = 15.55%

When blocks were produced at mix ratio of 1:10

Cost per blocks dropped to N175 and the strength reduced to 2.54N/mm^2

% reducing in cost = $\left(\frac{N205-N175}{N205}\right)$ x 100% = 14.63%

% reduction in compressive strength = $\left(\frac{4.5-2.54}{4.5}\right)$ x 100% = 43.55%

When blocks were produced at mix ratio of 1;12 the cost per block dropped to N157 while its compressive strength dropped to 1.58N/mm^2.

The percentage reduction cost = $\left(\frac{205-157}{205}\right)$ x 100 = 23.4%

The percentage reduction in compressive strength of block = $\frac{(4.50-1.58)}{4.50}$ x 100 = 64.9%

A-236: Specific Gravity of Coarse Aggregate Test

Sample No.	Mass of sample B (g)	Mass of sample + container P (g)	Mass of sample + container + water P_s (g)	Specific gravity	Average Specific Gravity Coarse Aggregate
1.	1000	1571	2190	2.62	
2.	1000	1579	2194	2.60	2.62
3.	1000	1568	2188	2.63	

A-237: Los Angeles Abrassion Test for Coarse Aggregate in accordance to ASTM C 535 1996 (500 Revolutions/minute, Passing through Sieve No. 12 or 1.7mm)

Sample No.	**Initial Mass** **P_1 (g)**	**Mass after abrasion** **P_2 (g)**	**Percentage Wear** **!00(P_1 –P_2)/P_1 (%)**	**Average** **(%)**
1.	5000	3450	31.00	

2.	5000	3514	29.72	30.34
3.	5000	3485	30.30	

A-238: Aggregate Crushing Value Test

Sample No.	Mass of Aggregate in mould M_1 (g)	Mass of Crushed Aggregate passing Sieve 2.4mm M_2 (g)	Aggregate Crushing Value $100M_2/M_1$ (%)	Average Aggregate Crushing Value (%)
1.	3500	980	27.57	
2.	3489	973	27.92	27.90
3.	3500	987	28.20	

A-239: Aggregate Impact Value Test

Sample No.	Mass of Sample before Test A (g)	Mass of sample retained on Sieve No. 7 after Test B (g)	Mass of Sample Passing Sieve No. 7 C = A – B (g)	Aggregate Impact Value 100C/A (%)	Average Aggregate Impact Value (%)
1.	700	579	121	17.29	
2.	758	614	144	17.00	17.39
3.	737	608	129	17.5	

A-240: Elongation Index of Coarse Aggregate Test

Sample No.	Mass of Dry Aggregate M_1 (g)			Mass of Elongated aggregate after passing M_2 (g)			Elongation Index $100M_1/M_2$ (%)	Average (%)
	Retained	Passing	Total	Retained	Passing	Total		

1.	1950	-	1950	480	116	596	30.56	
2.	1950	-	1950	468	115	583	29.90	30.19
3.	1950	-	1950	474	113	587	30.10	

A-241: Fakiness Index of Coarse Aggregate Test

Sample No.	Mass of Dry Aggregate M_1 (g)			Mass of Flaky aggregate after passing M_2 (g)			Flakiness Index $100M_1/M_2$ (%)	Average (%)
	Retained	Passing	Total	Retained	Passing	Total		
1.	1950	-	1950	137	46	183	9.38	
2.	1950	-	1950	138	42	180	9.21	9.27
3.	1950	-	1950	135	45	180	9.21	

A-242: Sieve Analysis of Coarse Aggregate

First Trial.

Sieve Size (mm)	Mass Retained (g)	Mass Passing (g)	Percentage Passing (g)
38.1	-	3000	100
19.05	250	2750	91.67
9.52	2700	50	1.67
4.76	46	4	0.13
Pan	4	-	-

Second Trial

Sieve Size (mm)	**Mass Retained (g)**	**Mass Passing (g)**	**Percentage Passing (g)**
38.1	-	3000	100
19.05	244	2756	91.87
9.52	2706	50	1.67
4.76	43	7	0.23
Pan	5	2	0.07

A-243: Density of Concrete Cube Produced from Cement Brand A.

Day	Mass (kg)	Density (kg/m^3)	Average Density (kg/m^3)
3	8.05	2385	
3	8.00	2370	2377
3	8.02	2376	
7	8.10	2400	
7	8.09	2397	2396
7	8.07	2391	
14	8.16	2418	
14	8.15	2415	2419
14	8.18	2424	
21	8.14	2411	
21	8.13	2409	2410
21	8.14	2411	
28	8.21	2433	
28	8.30	2459	2450
28	8.30	2459	

A-244: Density of Concrete Cube Produced from Cement Brand B.

Day	Mass (kg)	Density (kg/m^3)	Average Density (kg/m^3)
3	8.03	2379	
3	8.04	2882	2384
3	8.07	2391	
7	8.12	2406	
7	8.10	2400	2404
7	8.12	2406	
14	8.14	2411	
14	8.15	2415	2418
14	8.19	2427	
21	8.17	2421	
21	8.11	2403	2414
21	8.16	2418	
28	8.17	2421	
28	8.16	2418	2413
28	8.10	2400	

A-245: Density of Concrete Cube Produced from Cement Brand C.

Day	Mass (kg)	Density (kg/m^3)	Average Density (kg/m^3)
3	7.90	2341	
3	8.01	2373	2352
3	7.90	2341	
7	8.19	2427	
7	8.18	2424	2426
7	8.19	2427	
14	8.15	2415	
14	8.16	2418	2415
14	814	2411	
21	8.21	2433	
21	8.19	2427	2430
21	8.20	2430	
28	8.10	2400	
28	8.12	2406	2402
28	8.10	2400	

A-246: Density of Concrete Cube Produced from Cement Brand D.

Day	Mass (kg)	Density (kg/m^3)	Average Density (kg/m^3)
3	8.19	2427	
3	8.18	2424	2425
3	8.18	2424	
7	8.00	2370	
7	8.00	2370	2364
7	7.94	2353	
14	8.11	2403	
14	8.11	2403	2403
14	8.11	2403	
21	8.08	2394	
21	8.12	2406	2400
21	8.10	2400	
28	8.15	2415	
28	8.15	2415	2415
28	8.18	2424	

A-247: Density of Concrete Cube Produced from Cement Brand E.

Day	Mass (kg)	Density (kg/m^3)	Average Density (kg/m^3)
3	7.90	2349	
3	7.80	2311	2326
3	7.85	2326	
7	8.10	2400	
7	8.12	2406	2402
7	8.10	2400	
14	8.14	2411	
14	8.15	2415	2413
14	8.15	2415	
21	8.15	2415	
21	8.16	2418	2417
21	8.16	2418	
28	8.17	2421	
28	8.18	2424	2424
28	8.19	2427	

A-248: Density of Concrete Cube Produced from Cement Brand F.

Day	Mass (kg)	Density (kg/m^3)	Average Density (kg/m^3)
3	8.10	2400	
3	8.12	2406	2402
3	8.10	2400	
7	8.10	2400	
7	8.12	2406	2402
7	8.10	2400	
14	8.14	2411	
14	8.15	2415	2413
14	8.15	2415	
21	8.15	2415	
21	8.16	2418	2417
21	8.16	2418	
28	8.17	2421	
28	8.18	2424	2424
28	8.19	2427	

A-249: Density of Concrete Produced from Cement Brand G.

Day	Mass (kg)	Density (kg/m^3)	Average Density (kg/m^3)
3	7.85	2326	
3	7.90	2341	2326
3	7.80	2311	
7	8.02	2376	
7	8.02	2376	2378
7	8.04	2382	
14	8.08	2394	
14	8.07	2391	2395
14	8.10	2400	
21	8.10	2400	2401
21	8.11	2402	
21	8.11	2402	
28	8.11	2402	
28	8.11	2402	2402
28	8.11	2402	