CHARACTERISTICS OF BURNT CLAY BRICKS CONTAINING POLYTHENE AND SAWDUST AS ADDITIVES

BY

Emmanuel, Didam ABBA BSc. BUILDING (ABU) 2012
P13EVBD8068

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE DEGREE IN CONSTRUCTION TECHNOLOGY

DEPARTMENT OF BUILDING,
FACULTY OF ENVIRONMENTAL DESIGN
AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA

MARCH, 2017

Declaration

I declare that the work in this dissertation entitled Characteristics of Burnt Bricks Containing Polythene and Sawdust as additives has been carried out by me in the department of building, under the supervision of Dr. Dauda Dahiru. The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

ABBA, Emmanuel Didam	_____	_____
(P13EVBD8068)	Signature	Date

Certification

This dissertation entitled "CHARACTERISTICS OF BURNT BRICKS CONTAINING POLYTHENE AND SAWDUST AS ADDITIVES" by Emmanuel, Didam ABBA meets the regulations governing the award of the degree of M.Sc Construction Technology of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Dr. Dauda D. Danwata	_____	_____
(Chairman, Supervisory Committee)	Signature	Date
Mal. Ismail M. Khalil	_____	_____
(Member, Supervisory Committee)	Signature	Date
Dr. Dikko Kado	_____	_____
(H. O. D. Building Department)	Signature	Date
Prof. Sadiq Z. Abubakar	_____	_____
(Dean, School of Post Graduate Studies)	Signature	Date

Acknowledgement

My profound gratitude goes to God Almighty who in His infinite mercy, love and kindness saw me through the course of my studies and my research work.

My appreciation also goes to my supervisors, Dr. Dauda Danwata and Mal. Ismail Khalil who put me through in the course of my research work, they were the pillars behind this great success. Despite your tight schedule, you always made time for me. They read and made all necessary corrections without delay thereby making things so easy for me. My profound thanks goes to Mal. Abdulázeez, Mal. Aminu and other laboratory technologist. I sincerely appreciate your effort. May God bless and replenish your effort.

My appreciation goes out to my family for their love encouragement and support. Thank you very much, I love you all.

My appreciation goes out to Dr. Stanley Mhya and family. Words alone cannot express how grateful I am for your love, support and encouragement to work hard towards realization of this work. I owe you a thousand thanks and God in His mercies rewards you abundantly. Thank you very much for being there always. Also to the family of Mr. and Mrs. Bitrus Kwanta, thank you very much for your assistance. Not forgetting my fiancé Sharon Layas, my friends Adejo Jacob, Samuel Nnali, Emeka Uche and my colleagues M.Sc construction technology, Benjamin Adegboye, Theophilus Omebije, Paul Johnson, Tolulope Ogunleye, George Bala, Yakubu Ibrahim and Bello Abdula'zeez amongst many others. I really appreciate your support and encouragement. Thank you so much.

Dedication

This research is dedicated to the memory of my beloved father, Late Mr. Lucius Albert Abba.

TABLE OF CONTENT

Title Page - - - - - - - - - i
Declaration - - - - - - - - - - ii
Certification - - - - - - - - - iii
Acknowledgements - - - - - - - - - iv
Dedication - - - - - - - - - v
Table of Content - - - - - - - - - vi
List of Tables - - - - - - - - - viii
List of Figures - - - - - - - - - ix
List of Plates - - - - - - - - - x
List of Appendices - - - - - - - - - xi
Abstract - - - - - - - - - xii

1.0 INTRODUCTION - - - - - - - 1
1.1 Background - - - - - - - - 1
1.2 Problem Statement - - - - - - - 4
1.3 Justification - - - - - - - - 5
1.4 Aim and Objectives - - - - - - - 6
1.5 Scope and Limitations - - - - - - - 7

2.0 LITERATURE REVIEW - - - - - - 8
2.1 Preamble - - - - - - - - - 8
2.2 Raw Material - - - - - - - - 13
2.2.1 Clays - - - - - - - - - 13
2.2.2 Stages of Clay and Clay Preparation - - - - - 14
2.2.3 Manufacture of burnt clay bricks - - - - - 15
2.3 Sawdust - - - - - - - - - 17
2.3.1 Uses of Sawdust- - - - - - - - - 18
2.4 Polythene - - - - - - - - - 19
2.4.1 Properties of polythene- - - - - - - - 20
2.4.2 Status of Polythene Pollution - - - - - - 20
2.4.3 Environmental issues on disposal of plastic waste - - - 22
2.5 Burnt Clay Bricks - - - - - - - 23
2.5.1 Durability and Serviceability - - - - - - 23
2.6 Properties of Burnt Clay Bricks - - - - - 24
2.6.1 Physical properties - - - - - - - 24
2.6.2 Mechanical properties - - - - - - - 27
2.7 Ingredient of Good Earth Bricks- - - - - - 28
2.8 Waste Recycling - - - - - - - - 32
2.8.1 Fly ash - - - - - - - - - 33
2.8.2 Sludge - - - - - - - - - 35
2.8.3 Other waste - - - - - - - - 38
2.9 Concept of Sustainability- - - - - - - 39

3.0 MATERIALS AND METHODS - - - - - 43
3.1 Materials - - - - - - - - - 43
3.1.1 Clay - - - - - - - - - 43
3.1.2 Sawdust - - - - - - - - - 43
3.1.3 Polythene - - - - - - - - - 43
3.1.4 Sulphuric acid (H_2SO_4) - - - - - - - 43
3.1.5 Water - - - - - - - - - 44
3.2 Methods - - - - - - - - - 44
3.3 Chemical properties - - - - - - - 45
3.4 Manufacture of bricks - - - - - - - 45
3.5 Test and testing procedures - - - - - - 48
3.6 Method of data analysis - - - - - - - 50

4.0 DATA PRESENTATION AND ANALYSIS - - - - 52
4.1 Presentation of Results - - - - - - - 52
4.2 Chemical and Physical Properties of Materials - - - - 52
4.3 Compressive Strength of Bricks Fired at 800^0C, 900^0C and 1000^0C - 55
4.3.1 Wet Compressive Strength - - - - - - 56
4.3.2 Dry Compressive Strength - - - - - - 57
4.4 Abrasion Test - - - - - - - - 57
4.5 Water Absorption Test - - - - - - - 58
4.6 Exposure to Sulphuric Acid - - - - - - 59
4.7 Exposure to Elevated Temperature - - - - - 62

5.0 SUMMARY CONCLUSION AND RECOMMENDATIONS - 64
5.1 Summary of the Research Findings - - - - - 64
5.2 Conclusions - - - - - - - - - 65
5.3 Recommendations - - - - - - - - 66
5.4 Recommendations for further Studies - - - - - 66
5.5 Contributions to Knowledge - - - - - - 67
REFERENCES - - - - - - - - - 68

LIST OF TABLES

Table 2.1	Classification of bricks based on compressive strength -	32
Table 3.0	Proportion of clay mix, sawdust and polythene additives in prepared samples -	46
Table 3.1	Bricks samples and test on samples - - - -	47
Table 4.2.1	Chemical composition of clay and sawdust - - -	53
Table 4.2.2	Specific gravity of materials - - - - -	53
Table 4.2.3	Bulk density of materials - - - - -	53
Table 4.2.4.1	Samples description of greyey clay - - - -	77
Table 4.2.4.2	Plastic limit determination - - - - -	54
Table 4.3.1	Cold compressive strength of samples fired at 800^0C, 900^0C and 1000^0C.	77
Table 4.3.2	Dry compressive strength of samples fired at 800^0C, 900^0C and 1000^0C. -	77
Table 4.4.1	Abrasion of samples fired at 800^0C - - - -	77
Table 4.4.2	Abrasion of samples fired at 900^0C - - - -	78
Table 4.4.3	Abrasion of samples fired at 1000^0C - - - -	78
Table 4.5.1	Water absorption of samples fired at 800^0C - - -	78
Table 4.5.2	Water absorption of samples fired at 900^0C - - -	78
Table 4.5.3	Water absorption of samples fired at 1000^0C - - -	78
Table 4.6.1	Bricks fired at 800^0C exposed to sulphuric acid - -	59
Table 4.6.2	Bricks fired at 900^0C exposed to sulphuric acid - -	60
Table 4.6.3	Bricks fired at 1000^0C exposed to sulphuric acid - -	61
Table 4.7.1	Dry compressive strength of bricks fired at 1100^0C - -	79

LIST OF FIGURES

Figure 4.3.1 Cold compressive strength of bricks fired at 800^0C, 900^0C and- 1000^0C 56

Figure 4.3.2 Dry compressive strength of bricks fired at 800^0C, 900^0C and- 1000^0C 56

Figure 4.4.1 Showing abrasion test on brick types fired at 800^0C, 900^0C - and 1000^0C 57

Figure 4.5.1 relationship between percentages and brick types (water absorption)- 58

Figure 4.7 Bricks exposed to elevated temperature of 1100^0C - - 62

LIST OF PLATES

Plate I Clay sieved with 5mm sieve - - - - - - 73

Plate II Sawdust samples. - - - - - - - 73

Plate III Shredder used for cutting polythene - - - - - 73

Plate IV Shredded polythene - - - - - - - 74

Plate V unburnt specimen samples made - - - - - 74

Plate VI Arrangement of bricks before and after firing at 800^0C - - 74

Plate VII Collapse of biometric cone in the kiln at 800^0C - - - 74

Plate VIII showing bricks after firing at 900^0C - - - - 75

Plate IX showing samples fired at 1000^0C - - - - - 75

Plate X specimen samples fired at 1100^0C - - - - - 75

Plate XI Burnt specimen samples distorted after burning in kiln at 12000^0C- 75

Plate XII Abrasion test on sample - - - - - - 76

Plate XIII Collapsed biometric cone after firing - - - - 76

Appendices - - - - - - - - - 80
Appendix I Calculations of bulk density of materials - - - 81
Appendix II Calculations of specific gravity of materials - - - 82
Appendix III Calculations of abrasion resistance - - - - 83
Appendix IV Calculations of water absorption test - - - - 84
Appendix V Calculations of compressive strength test - - - 85

Abstract

Over the years excessive energy consumption is one of the major problems associated with burnt bricks production. This study assessed the characteristics of burnt bricks containing polythene and sawdust as additives. Trial test was prepared from standard mix obtained from literature. It was done for different percentages of additives (0%, 5%, 10%, 15%, and 20%) blend of sawdust and polythene. A total of 324 bricks samples were cast out of which 216 were used for dry and wet compressive strength. Specimen samples were fired at temperatures of 800^0C-1300^0C. The results obtained showed that the highest dry compressive strength obtained in the control samples fired at 1100^0C with 15N/mm^2 and a minimum dry compressive strength of 12N/mm^2 when fired at 800^0C. Specimen samples A containing 20% polythene fired at 1100^0C had dry compressive strength of 13.1N/mm^2 and a minimum of 7N/mm^2 at 800^0C. Samples E containing 20% sawdust fired at 1100^0C had a dry compressive strength of 6N/mm^2 and a minimum of 4N/mm^2 at 800^0C. It was observed that there was a decrease in compressive strength as the percentage of polythene decreases and sawdust increases. It further reveals that the control at temperatures of 800^0C, 900^0C and 1000^0C exhibited low water absorption capacity of 11%, 11.6% and12.8% respectively, compared to the polythene and sawdust with 13%, 13.5% , 14% and 15%, 15.2 and 15.4% respectively. However both the control and samples containing additives showed 0.5% resistance to abrasion at firing temperatures of 800^0C-1000^0C. The research concluded that regarding the dry compressive strength, wet compressive strength and abrasion resistance, the samples met the minimum strength requirement specified by (IS: 1077) at temperatures of 800^0C, 900^0C, 1000^0C and 1100^0C considered and have good resistance to abrasion according to (Gupta and Gupta, 2004) hence are suitable for use in the construction of buildings as a walling material. It was

also concluded that samples with additives are more stabilised before firing than the control, though higher strength was obtained in the control than the samples with additives and both met the specification by (IS 1077: (1992).The research recommends that bricks with polythene and sawdust are badly distorted at temperature of 1200^0C which may be attributed to the internal heating contributed by the additives.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Clay is regarded as a kind of natural earth. When mixed with water it becomes plastic, mouldable and becomes hard again on drying and firing. Clay is a very fine grained, unconsolidated rock matter, which is plastic when wet, but becomes hard and stony when heated. It has its origin in natural processes, mostly complex weathering, transported and deposited by sedimentation within geological periods. It is composed of silica (SiO_2), Alumina (Al_2O_3) and water (H_2O) plus appreciable concentration of oxides of iron, alkali and alkaline earth, and contains groups of crystalline substances known as clay minerals such as quartz, feldspar and mica (Folaranmi, 2009).

According to Hendry and Khalaf (2001) clays used for brick making vary broadly in their composition and are dependent on the locality from which the soil originates. Different proportions of clays are composed mainly of silica, alumina, lime, iron, manganese, sulphur and phosphates. The principal properties of bricks that make them superior building units are their strength, fire resistance, durability, beauty and satisfactory bond and performance with mortar.

Additionally, Mamlouk and Zaniewski (2006) bricks do not cause indoor air quality problems. The thermal mass effect of brick masonry can be a useful component for fuel-saving, natural heating and cooling strategies such as solar heating and night-time cooling. They have moderate insulating properties, which make brick houses cooler in summer and warmer in winter, compared to houses built with other construction materials. Clay bricks are also non-combustible and poor conductors.

Environmentally friendly waste recycling has been one of the very important research fields for many decades. Mamlouk and Zaniewski (2006) established that a popular

trend by researchers has been to incorporate wastes into fired clay bricks to assist the production of lightweight bricks. The utilisation of these wastes reduces the negative effects of their disposal. Many attempts have been made to incorporate waste in the production of bricks including rubber, limestone dust, wood sawdust, processed waste tea, fly ash, polystyrene and sludge. Researchers investigated on the potential use of uncontrolled burning rice husk ash to produce lightweight fired-clay brick and revealed that lightweight brick could be produced by increasing the RHA replacement. Though, the compressive strength of the brick was reduced (Danupon, T., Perapong, T., and Sarawut, J., 2008)

Wastes can be recycled by incorporating them into building materials and is a practical solution to pollution problem. The utilisation of wastes in clay bricks usually has positive effects on the properties, although the decrease in performance in certain aspects will also be observed. Vieira, C. M. F., Andrade, P. M., Maciel, G. S., Vernilli, Jr. F., and Monteiro, S. N., (2006) states that the positive effects of utilizing these wastes to the production of lightweight bricks with improved shrinkage, porosity, thermal properties and strength can be obtained by incorporating the recycled wastes. Most importantly, the high temperature in clay brick firing process allows volatilisation of dangerous components, changing the chemical characteristics of the materials, and incorporation of potentially toxic components through fixation in the vitreous phase of the waste utilised (Vieira *et al*., 2006).

Lightweight bricks are generally preferred because they are easier to handle and thus their transportation costs are lower. The development of lightweight bricks allows brick manufacturers to reduce the total clay content through the introduction of holes or incorporation of combustible organic waste particles that reduce the mass of the brick while maintaining the required properties. Moreover, lower energy consumption

during firing from the contribution of the high calorific value provided by many types of waste has also been studied (Dondi, M., Marsigli, M., & Fabbri, B., 1997).

Furthermore, Demir (2008) also utilised various organic residues such as sawdust, tobacco residues and grass from industrial and agricultural waste. These residue materials have long cellulose fibres. Differing amounts of waste were incorporated in the clay bricks – 0%, 2.5%, 5% and 10%. All samples were fired at 900°C while one batch was left unfired. According to Demir (2008), while maintaining acceptable mechanical properties, these wastes could act as an organic pore forming agent in clay bricks and increased the porosity, thus, improving the insulation properties. Adding organic residues increased the plasticity and, thus, increased the water content required. A residue addition of 10% is not suitable as the drying shrinkage increased excessively due to the effect of cellulose fibres. The dry strength of the brick increased but the compressive strength of the fired samples reduced by the addition of the residues.

Kayali (2005), made bricks with 100% fly ash as the solid ingredient called FlashBricks. The equipment and techniques used in manufacturing the bricks were similar to those used in the clay brick industry. Samples were fired at 1000°C to 1300°C and were formed into moulds. Fired Flash Bricks produced bricks that were 28% lighter than standard clay bricks. In terms of appearance, the fired Flash Bricks have a reddish colour similar to a standard brick but a rougher texture was observed on the surface of the brick. In a similar study by Pimraksa, K., Wilhelm, M. and Wruss, W. (2001) bricks were also made using 100% lignite fly ash. The effect on the mechanical properties of four different treatments of fly ash: sieved -63+40 μm fly ash, sieved -40 μm fly ash, ground 5 hour fly ash and ground 10 hour fly ash were investigated. The optimal firing temperature was between 900°C to 950°C at 3°C/min

for each type of the manufactured samples. Most samples tested demonstrated less than 4% of weight loss and less than 3% of shrinkage value. The results from the experimental work conducted demonstrated that bricks manufactured with -40 μm fly ash and fired at 950°C obtained better results in mechanical strength, specifically, in compressive strength (5.63 MPa) and bending strength (1.31 MPa) compared to red fired clay bricks, common clay bricks and facing bricks.

1.2 Statement of Research Problem

Recycled materials such as Sawdust and Polythene are wastes that are generated from either postconsumer or post-industrial (pre-consumer) sources. Rebecca (2013) in her research revealed that the bulk of waste generated in Nigeria constitute about 57% food waste, 13% plastic waste and 8% paper waste. These wastes amongst others contribute to degradation of our environment (Pappu, A., Saxena M., and Asolekar S. R., 2007). Clay is the most important raw material for burnt bricks. They acquire their strength and durability when they are heated to redness. Problems associated with high energy consumption in burnt bricks production and environmental degradation motivated researchers to work on alternative ways of solving this problems.

Quarrying operations for obtaining the clay are energy intensive, adversely affect the landscape, and generate high level of wastes. The high temperature kiln firing not only consumes significant amount of energy, but releases large quantity of greenhouse gases. Clay bricks, on average, have an embodied energy of approximately 2.0 kWh and release about 0.41 kg of carbon dioxide (CO_2) per brick (Alonso-Santurde, R., Coz, A., Viguri, J.R., Andres, A., 2012) and (Danupon, T., Perapong, T., and Sarawut, J., 2008) recommended that this problem can be reduced by addition of fuels to the clay such as sludge, polystyrene, sawdust, rice husk etc. High cost is involved in cleaning up waste from disposal sites and activities to do away with such waste which

causes air pollution through burning fossil fuel, gas, coal, and oil amongst others and releases harmful gases such as carbon dioxide, carbon monoxide, nitrogen oxides, sulphur dioxide, and tiny solid particles into the atmosphere. These wastes must, in no way, present a threat to human health, to the air, to surface water and groundwater, or to the land. One possible means of safe disposal would consist of high-temperature incineration under rigidly controlled conditions. Effective utilisation of these wastes will likely help to reduce the negative effects of their disposal. However, in order to reduce these problems the potential wastes can only be recycled if the properties and the environmental pollutant of the new manufactured brick meet the specific requirements and comply with the relevant standards (Christine, 2004).

Rebecca (2013), highlighted that sustainable waste management is therefore critical in ensuring both the current and future generation have access to a clean and productive environment. It was stated that proper waste management structure such as recycling and collection of waste from the point source should be enacted to prevent further accumulation of solid waste. Also extensive waste management on how to recycle, reuse, reduce and respond to waste. Waste management is a challenge, but there are sustainable solutions to it.

1.3 Justification for the study

The use of burnt bricks in buildings is not very common as compared to concrete blocks despite the availability of clay used in its production. It is also common that certain additives are added to burnt brick raw mixes to produce different effects in the finished product. It is expected that the additives used in this research will serve as fuels which will provide more heating to the firing process thereby reducing the fuel and power consumption in burnt bricks production. It will also provide pores in the

bricks which will allow the heat from the firing to quickly reach the innermost part of the bricks cores and as a result avoid unburnt core of the bricks

According to (Emmanuel A., 2008) the additives acts as a consolidating or fusing agent. It is also expected that the additives used in this research will help to increase the bonding of the particles and as such help to increase the strength of the bricks and also increase its resistance to abrasion. Introduction of this waste materials as additives will help to reduce the waste in the environment and reduce cost of purchasing clay for bricks. According to (Ayangade, J. A., Olusola, K. O., Ikpo, I. J. and Ata, O. 2004) cost of materials in construction account for two-third of the total construction cost.

1.4 Aim and Objectives

1.4.1 Aim

The aim of the research is to assess the combined effect of polythene and sawdust on the properties of burnt bricks with a view to establishing their suitability for use in burnt bricks production.

1.4.2 Objectives

i. To determine the physical and chemical properties of Bomo clay and sawdust ash.

ii. To establish the mechanical properties of burnt bricks produced with additives (polythene and sawdust).

iii. To determine the durability properties of burnt bricks produced with additives (polythene and sawdust).

1.5 Scope and Limitations

1.5.1 Scope

This research is focused on assessing the properties of burnt bricks made with polythene and sawdust as additives by determining its wet and dry compressive strength, abrasion resistance, water absorption, exposure to sulphuric acid at 800^0C, 900^0C, 1000^0C and exposure to elevated temperatures of 1100^0C, 1200^0C and 1300^0C.

1.5.2 Limitations

In view of the wide range of properties of burnt bricks and the non-availability of some vital apparatus/equipment tests such as thermal insulation, thermal conductivity, tensile strength, refractoriness, shrinkage and porosity were not assessed.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Preamble

Brick is defined as a rectangular block of clay or similar material (i.e. laterite) that is baked until is hard and is used for building houses, walls or other permanent structures. The soil used for brick making is often called different names such as earth, clay or laterite but the term “laterite” originates from the Latin word later meaning brick. Laterite is defined as red tropical soil: a reddish mixture of clayey iron and aluminium oxides and hydroxides formed by the weathering of basalt under humid, tropical conditions. Brick is one of the most accommodating masonry units due to its properties. The firing process affects the physical and mechanical properties, colours and appearance of the manufactured brick.

a. Clay Brick Masonry

Many studies have been carried out by manipulating the firing of manufactured bricks at different temperature, utilizing fast firing and traditional firing but most research are more focusing on the physical and mechanical properties of fired clay bricks only (Rasmussen K. L., De La Fuente G. A., Bond A. D., Matheesen K. K. & Vera S. D. 2012). Costigan, A. and Pav, S. (2009). Determined the compressive, flexural and bond strength of brick masonry with lime mortar. The behaviour of masonry constructed with hydraulic and non-hydraulic lime mortar was studied. The masonry wallets were subjected to lateral and vertical loads. The mechanical properties and modes of failures of each of the two type of lime mortar masonry was compared. It was reported that when masonry units were stronger than mortar then the masonry compressive strength is not sensitive to bond strength variations. Two cases of failures

were observed, vertical splitting when mortar is stronger than brick and bond failure when brick is stronger than mortar.

Christy, C., F. Tensing, D. and Shanthi, R., M. (2012) critically reviewed the various literatures that studied the in-plane shear behaviour of brick masonry. It was reported that, during earthquakes, severe in-plane and out-plane forces act on the masonry wall out of which in-plane force resist the action of earthquake to a large extent. Shear bond strength of masonry was reported to be the main source of resisting force for lateral loads. Hence, it was suggested that the parameters such as shear bond strength should be well analysed for designing of structure with infill earthquake prone areas. The different construction methods and practices which could enhance the shear behaviour of masonry infill were reported.

Palanisamy, M. and Premalatha, J. (2012) evaluated experimentally the properties of brick masonry infill. The compressive strength tests were conducted on brick prisms with different mortar grades and the elastic modulus of prisms were calculated. The results of clay brick were compared with that of fly ash brick prisms. It was observed that y ash brick masonry prisms show more strength and elastic modulus values as compared to clay brick masonry prism after 28days of curing.

Ravi, S., Selvakumar, V., Thanikasalapradeep, N., Srinivas, V. and Premavathi, N. (2014). reviewed the material behaviour of brick masonry by experimental and numerical investigations. Different material properties such as compressive strength, modulus of elasticity and stress-strain relationship was found for brick units, mortar cubes and masonry triplets. The constitutive relations were used to study the behaviour of masonry by performing element modelling in ANSYS. Macro and micro models of masonry triplets were developed for numerical study. The results from numerical investigations were compared with experimental results.

Vimala, S. and Kumarasamy, K.(2014). Studied the strength of stabilised mud block masonry using different mortar proportions. The compressive strength was found in both wet state and dry state. It was found that the dry compressive strength of stabilised mud block and prism was higher than that of wet compressive strength. The dry and wet strength of prisms was found to increase with increase in mortar strength.

Keshava, M., Vijayendra, K., V, and Raghunath, S. (2010) studied the strength efficiency of block masonry. The blocks were made with y ash, marble dust, granite powder and cement. Different tests such as water absorption, compressive strength, and elastic modulus were conducted on block units, mortar cubes and stack bonded brick prisms. It was observed that most of the prisms failed by vertical cracking. Permissible compressive stress of masonry was derived based on two approaches from Indian standard IS 3495:1992.

Rushad, S. T., Kumar A., Duggal, S. K. and Mehta, P.K. (2012) investigated the properties such as water absorption and compressive strength of bricks made from y ash, lime and local soil in different proportions. Hand moulded and pressure moulded y ash bricks were used for experiments. It was found that bricks with y ash and lime in the ratio 40:60 satisfied the requirements of Indian standard IS 3495:1992 with regard to both water absorption and compressive strength.

Dhami, N. K., Reddy, M. S. and Mukherjee, A. (2012) used bacterial calcite in y ash bricks to enhance the strength properties of y ash bricks. Bacteria called bacillus megaterium was added to the mix which produced calcite in y ash bricks. The calcite was found to be useful for filling the pores, increasing the compressive strength, reducing the water absorption and frost action. The durability of the bricks was thus

reported to be enhanced. Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD) study confirmed the presence of calcite crystals on the surface of bricks.

Christy, C. F., Tensing, D. and Shanthi, R.,M. (2013) found the compressive strength and elastic modulus of fly ash brick masonry prisms experimentally and compared the result with clay brick masonry prisms. Both reinforced and unreinforced masonry prisms were considered for the two brick types. An equation to determine the compressive strength of prism was proposed on the basis of compressive strength of brick units and mortar.

Shakir, A. A., Naganathan, S. and Mustapha K., N. (2013) studied the properties of bricks made using fly ash, quarry dust and billet scale mixed in different ratios. Non-conventional methods were used for production of bricks. The mechanical properties such as compressive strength, pulse velocity, initial rate of absorption and water absorption of bricks and their durability were tested. The optimum ratio of the raw materials was arrived at on the basis of test results. It was suggested that these bricks could be used in place of traditional clay bricks.

Vidhya, K., Kandasamy, S., Malaimagal, U., Karthikeyan, U., Basha, G.S. and Junaid, T. H. (2013) experimentally studied the properties of bricks made from fly ash, pond ash, lime and gypsum in different mix proportions. The composition and microstructure of bricks were studied using XRD analysis and SEM images. From the experimental tests it was found that the bricks having higher percentage of pond ash showed increased compressive strength and reduced water absorption. From the review of literature for clay brick masonry it is observed that most of the papers focussed on the following mechanical properties: initial rate of absorption, water absorption, compressive strength and constitutive relation including elasticity modulus. With regards to y ash bricks, the literatures are mainly based on the study of

environmental impact of y ash bricks and devising various mix proportions of y ash with other waste materials for production of good strength bricks.

Lumantarna, R., Biggs, D. T. and Ingham J. M. (2012) performed experiments on existing masonry buildings (using lime mortar) constructed between 1800 and 1940. The in-situ samples were extracted from six heritage structures and compressive, bond wrench (flexural) and shear bond strength tests were performed on the samples. The experimental results indicated that the mortar compressive strength could be aptly related by flexural bond strength and bed-joint cohesion. The studies on bond strength of brick masonry under flexural, tensile and shear loading is discussed in this section. The bond strength of clay brick and soil cement block masonry is studied while y ash brick masonry has not got the attention. It is reported that the brick mortar shear bond strength is dependent on various factors such as surface characteristics of bricks, property of mortar, etc. From critical review of past studies it is found that the variations in shear bond strength due to changes in the moisture level in bricks at the time of construction is studied only by a few researchers for clay bricks and soil-cement block masonry. However, the same for fly ash brick masonry is studied by none.

Raut S. P., Rohant S., Sunil D., Ralegaonkar R.V., Sachin A., and Mandavgane A. (2011), made fired bricks using clay–sand mixes with different percentages of rice husk ash. The firing durations at 1000^0C were respectively 2, 4 and 6 h. The effects of rice husk ash content on workable mixing water content, Atterberg limits, linear shrinkage, density, compressive strength and water absorption of the bricks were investigated. The results indicated that the inclusion of rice husk ash increased the compressive strength of bricks, the optimum firing duration was 4 h at 1000^0C, and bricks made of clay–sand–rice husk ash mixes could be used in load bearing walls.

Faria K. C. P., Gurgel R. F., and Holanda J. N. F., (2012) investigated the recycling of sugarcane bagasse ash waste as a method to provide raw material for clay brick production. Brick samples were produced by using up 20% of sugarcane bagasse ash waste to replace natural clay, and then tested to determine their physical and mechanical properties. It was found that the sugarcane bagasse ash waste was mainly composed of crystalline silica particles and could be used as filler in clay bricks.

2.2 RAW MATERIALS

2.2.1 Clay

In brick-making terms, clay is the major raw materials which are used to manufacture bricks. It is defined as a mixture of natural deposits of fine grained earthen material which contains clay minerals and is formed by the weathering of certain rocks. It is usually plastic and cohesive, shrinking when dry and expanding when wet. It gains strength with retention of shape on firing and with particle size range of 2μm and below (BSI, 1990). The clays vary considerably in physical properties, colour, hardness etc., and mineralogical content. They do, however, have certain properties in common. This can then be fired to a high temperature during which process it attains a hard, weather resistant characteristic. The key, in geological terms, is the mineral content of the raw material. This is common to all clay types. Pure clay mineral is formed from the erosion and weathering of primary igneous rocks. The clay mineral is eroded away by the action of water, wind, ice etc., and re-deposited elsewhere. In the process it picks up a number of impurities, Quartz, mica, Calcium Carbonate (lime), Iron Oxide etc. The subsequent deposit becomes a sedimentary rock. The variances in the age of the deposit, the conditions of its deposition and the impurities brings about variations between different clay types and even on occasions within the same deposit.

These variations may affect the brick making process and the properties of the finished product.

2.2.2 Stages of Clay and Clay Preparation

a. Stages of Clay

1. Slip-watered down clay in a muddy form

2. Plastic-workable stage; molding stage; can recycle; can join to other pieces

3. Leather-hard-stiff and will hold its shape; join to other pieces; carve into; recycle

4. Greenware-bone dry; can be carved into; very fragile; can recycle

5. Bisqueware-fired once in kiln; can not be recycled; glazing stage

6. Earthenware (Glazeware)--second fire-low fire; can not be recycled

7. Stoneware (Glazeware)--second fire-high fire; can not be recycled; vitrified

b. Clay Preparation

i. Clay Aging and Plasticity

Aging of clay is a very important step in improving workability and plasticity of clay bodies because it takes time for water to penetrate between the clay particles and produce a good and permanent bond. Bacterial growth also has a definite effect on improving plasticity of the clay. It is suggested that some old clay should be left in the container where new clay is added to accelerate bacterial growth in the clay. Bacterial gels (mold) will be noticed sometimes in a marbleized pattern on clay. Such clay has a very good feel to it when wedging, which should be done to achieve maximum plasticity and uniformity.

ii. Wedging

Wedging is used for eliminating lumps and air bubbles, drying the clay, and organizes the clay particles to lye in the same direction for strength. Wedging homogenizes or makes the clay consistent. To see of a ball of wedged clay is free of lumps or air bubbles and is homogenized, cut through it with a wire tool and look at the two halves. Wedging should be done on as low a surface as is comfortable. You may need to add grog also known as fire sand to the clay while wedging. Grog helps strengthen the clay when sculpting. Your body should be higher than the table for good body leverage, so that you can use your body as well as your wrists and arms. Your body should be involved in the rolling action or you will get tired. The wedging surface should be firm and well anchored to make wedging easier.

Two Methods of Wedging

1. Ram's Head

Pushing the clay down and out releases trapped air, eliminates lumps, and makes the clay homogeneous. The clay resembles a ram's head after each motion.

2. Spiral

Using a slight twist of the hands opens up all parts of the clay ball, allowing any air bubbles to escape. Spiral wedging also lines up the clay particles.

2.2.3 Manufacture of burnt clay bricks

The production of burnt clay bricks is in four stages namely winning and clay preparation, moulding, drying and firing.

i. Winning and clay preparation

The first step of clay preparation in the production of burnt clay bricks is termed winning. The top soil containing stones, pebbles, gravel and roots are removed after clearing the trees and vegetation (Brownel, 1976). After removing the vegetation and the top layer of the earth, the soil mass can be manually excavated and accumulated, it

is then moved to an open air storage area puddled, watered and rummaged in order to reduce soluble salts to a minimum and obtain a more homogeneous material (Brownel, 1976). The resulting mix must be plastic enough to facilitate moulding but not too plastic as that could result in warping, twisting or cracking during the drying phase. Sand can then be added to reduce severe shrinkage (Weaver, 1997; Vekey, 1998). The admixed is then left over for weathering and subsequent processing. Vitruvius (1960) stated that the choice of raw material was essential to improve the performance and durability of burnt clay bricks. The digging operation is usually done before rains and the raw material selection is dependent on availability and proximity to the factory location.

ii. **Moulding**

Moulding is a process of giving a required shape to the brick from the prepared brick earth. This brick is known as green brick (Brownell, 1976). Moulding may be carried out by hand or by machines.

iii **Drying**

Before the bricks can be fired, as much moisture as possible must be removed or they will explode in the kilns. Drying involves the removal of water from the wet brick in such a way as to dry them out evenly from inside out. If the outer skin of the brick dries first it becomes impossible for the moisture inside to escape. In the kiln the extreme temperatures will force out this moisture and some cracking may occur. To prevent this happening the dryers are kept at temperatures of about 80–120 degrees centigrade and the atmosphere is very humid keeping the exterior of the brick as moist as possible. This is monitored very closely to reduce surface cracking. The bricks will shrink in the dryers as the clay particles come together and they become strong enough to be stacked, but at this stage they have no weather resistant qualities. Drying schedules vary but between 18 to 40 hours is typical for an automated plant. Special

shapes and large units can take up to a week or more. The dry bricks are then set onto kiln cars ready to be fired.

iv. **Firing**

Firing is the critical stage in the manufacture of burnt clay bricks is the firing stage; it determines the shape, colour and the durability of the burnt bricks. The clay after drying is allowed to dehydrate, the water which has been retained in the pores is driven off and the clay loses its plasticity. At temperatures of approximately 450^0C the clay structures begins to break down due to the decomposition of the hydroxyl (OH) groups (McConville, 2005) and organic matter starts to burn off. After the reaction, an amorphous or glassy structure is formed. At 863^0C calcium carbonate present in the raw material begins to decompose into calcium oxide and carbondioxide. This reaction triggers molecular rearrangement causing shrinkage (McConville, 2005). Sulphur oxide and nitrous oxides are evolved between 950-1200^0C. During this process a strong glassy matrix is created that surrounds the brick material. Cracking or bursting of the bricks occurs if heating is done rapidly usually at temperatures above 200^0C/hr. This is due to the formation of an impermeable vitrified outer skin preventing the loss of gases such as water vapour and CO_2 from the interior of the clay (Jordan *et al*., 1999). However, scum is produced on the bricks surface if the clay contains alkali and heating is done slowly i.e. at temperatures far below 200^0C/hr.

2.3 SAWDUST

Sawdust also known as wood dust is a by-product of cutting, grinding and drilling, sanding or otherwise pulverizing wood with a saw or other tool, it is composed of fine particles of wood. It is also the by-product of certain animals, birds and insects which live in wood such as woodpeckers and carpenter ant. It can present a hazard in the manufacturing industries, especially in terms of its flammability. Sawdust is the main component of particleboard.

2.3.1 Uses of sawdust

A major use of sawdust is for particle board; coarse sawdust may be used for wood pulp. Sawdust has a variety of other practical uses including serving as a mulch, as an alternative to clay cat litter or as a fuel. Until the advent of refrigeration, it was often used in ice houses to keep ice frozen during the summer. It has been used in artistic displays and as scatter. It is also sometimes used to soak up liquid pills, allowing the spill to be easily collected or swept aside. As such it was formally common on barroom floors (Felman, 2005).

Sawdust is used in the manufacture of charcoal briquettes. The claim for the invention of the first commercial charcoal briquettes goes to Henry Ford who created them from the wood scrap and sawdust produced by his automobile factory (Green, 2006)

Airborne sawdust and sawdust accumulation present a number of health and safety hazards. Wood dust becomes a potential health problem for example such as sanding becomes airborne and are inhaled. Certain wood and their dust contain toxins that can produce severe allergic reactions. Water borne bacteria digest organic materials in leachate, but use up much of the available oxygen. This high "biological oxygen demand" can suffocate fish and other organisms. There is equally detrimental effect on beneficial bacteria so it is not advisable to use sawdust within homes. Sawdust is flammable and accumulation provide a ready source of fuel. Airborne sawdust can be ignited by sparks or heat even heat accumulation and results in explosions.

a. Environmental effects

At sawmills unless reprocessed into particle board, burned in a sawdust burner or used to make heat for other milling operations, sawdust may collect in piles and add harmful leachates into local water systems creating an environmental hazard. This has placed small sawyers and environmental agencies in deadlock.

2.4 POLYTHENE

These are any one of various light thermoplastic materials made from ethylene with properties depending on the molecular weight of the polymer. The common forms are a waxy flexible plastic (low-density polythene) and a tougher rigid more crystalline form (high-density polythene). Polythene is used for packaging, moulded articles, pipes and tubing, insulation, textiles, and coatings on metal. Systematic name is polyethene also called polyethylene.

Low-density polyethylene (LDPE) is a thermoplastic made from the monomer ethylene. It was the first grade of polyethylene, produced in 1933 by Imperial Chemical Industries (ICI) using a high pressure process via free radical polymerization (Denis, 2010).

2.4.1 Properties

LDPE is defined by a density range of 0.910–0.940 g/cm^3. It is not reactive at room temperatures, except by strong oxidizing agents, and some solvents cause swelling. It can withstand temperatures of 80°C continuously and 95°C for a short time. LDPE has more branching (on about 2% of the carbon atoms) than HDPE, so its intermolecular forces (instantaneous-dipole induced-dipole attraction) are weaker, its tensile strength is lower, and its resilience is higher. Also, since its molecules are less tightly packed and less crystalline because of the side branches, its density is lower. LDPE contains the chemical elements carbon and hydrogen.

a. Chemical resistance

Their resistance to dilute and concentrated acids, alcohols, bases and esters is excellent.as well as having a good to aldehydes, ketones and vegetable oils. It has limited or moderate resistance to chemical reactions and is suitable for short-term use only to aliphatic and aromatic hydrocarbons, mineral oils, and oxidizing agents, Poor

resistance, and not recommended for use with halogenated hydrocarbons (DOW LDPE 5004I)

2.4.2 Status of polythene pollution

The use of plastic, especially polythene is increasing daily. Every year 25 million tons of synthetic plastics are being accumulated in the sea coasts and terrestrial environment. Polythene constitutes 64% of the total synthetic plastic as it is being used in huge quantity for the manufacture of bottles, carry bags, disposable articles, garbage containers, margarine tubs, milk jugs, and water pipes (Lee *et al*., 1991). Similarly, in the marine environment alone, out of total marine waste, plastic shares about 60-80% by mass (Derraik, 2002). All the polythene waste along with other plastic wastes generated by the human activity finally enters into marine water through rivers, canals/channels and municipal drainages. Therefore, the beaches were reported to be the excellent depository sites for the polythene (plastic) wastes. At dumping sites, polythene waste degraded with both chemical and mechanical weathering but it takes long time for mineralization and may remain in the microscopic form for long time (Corcoran *et al*., 2009). Annually 500 billion to 1 trillion polythene bags are being used routinely all over the world. Polythene is strong and highly durable and takes up to 1000 years for natural degradation in the environment. Furthermore, plastic degrades by sunlight into smaller toxic parts contaminating soil and water where they can be accidentally ingested by animals and thereby enter the food chain especially in the marine biota (Denuncio *et al.,* 2011). To the marine life polythene waste is recognized as a major threat. Sometimes, it could cause intestinal blockage in the fishes, birds and marine mammals. As per report (Coe 1997) due to plastic pollution in the marine environment minimum 267 species are being affected which includes all mammals, sea turtles (86%) and seabirds (44%). The death of terrestrial animals such as cow was reported due to consumption of polythene carry bags (Singh, 2005). The

polythene leads to blockage of their digestive tract. It is also found that the polythene remains undigested in the stomach of the animals, after the death of the animals the polythene is again being eaten by some other animal and the cycle continues. The undigested polythene was found to be responsible for various problems in the animals such as

1. During the digestion the fermentation process and mixing of the other contents were hampered due to ingested polythene and leads to indigestion;
2. The ingested polythene blocks the opening between omasum and reticulum which leads to death of the animal if the polythene will not be removed,
3. Impaction: due to accumulation of large quantity of polythene bags rumen becomes impact which leads to remenatony;
4. Tympany: due to blockage of the reticulum and omasum with polythene, accumulation of gases takes place in rumen, which leads to death of the animal if not removed properly.
5. Polybezoars: In the digestive track around the polythene deposition of salt takes place that leads to formation of stone like structure which hampers the food passages and leads to pain and inflammation of rumen;
6. Immunosuppression: the accumulation of polythene in the stomach of the animals (cow) leads to increased sensitivity to infections such as haemorrhagic septicemia (Singh 2005). The widely used packaging plastic (mainly polythene) constitutes about 10% of the total municipal waste generated around the globe (Barnes, 2009). The use of polythene is increasing every day and its degradation is becoming a great challenge. In the year 2000 about 57 million tons of plastic waste was generated around the world annually

(Lederberg 2000). Only a fraction of this polythene waste is recycled whereas most of the wastes enter into the landfills and take hundreds of years to degrade.

2.4.3 Environmental issues on disposal of Plastic Waste

Indiscriminate littering of unskilled recycling/reprocessing and non-biodegradability of plastic waste raises the following environmental issues (Mato, Y., Isobe, T., Takada H., and Ohtake, C., 2001).

1. During polymerization process fugitive emissions are released.
2. During product manufacturing various types of gases are released.
3. Indiscriminate dumping of plastic waste on land makes the land infertile due to its barrier properties.
4. Burning of plastics generates toxic emissions such as Carbon Monoxide, Chlorine, Hydrochloric Acid, Dioxin, Furans, Amines, Nitrides, Styrene, Benzene, 1, 3-butadiene, CCl4, and Acetaldehyde.
5. Lead and Cadmium pigments, commonly used in LDPE, HDPE and PP as additives are toxic and are known to leach out.
6. Non-recyclable plastic wastes such as multilayer, metalised pouches and other thermoset plastic poses disposal problems.
7. Sub-standard plastic carry bags, packaging films (<40μ) etc. pose problem in collection and recycling.
8. Littered plastics give unaesthetic look in the city, choke the drain and may cause flood during monsoon .
9. Garbage mixed with plastics interferes in waste processing facilities and also cause problems in landfill operations.
10. Recycling industries operating in non-conforming areas are posing threat to environment to unsound recycling practices.

2.5 BURNT CLAY BRICKS

Clay has been the raw material used over thousands of years in construction and building which has either been baked in the sun or fired in the kiln (Bourgeois, 1987; Kostof, 1995). Burnt clay bricks are made by firing clay at high temperatures to stone hardness (Ahmed *et al*., 2008). It is a very durable building material which over the years has seen many civilizations appreciating its unique properties. The physical, chemical and mechanical properties of a burnt clay bricks are dependent on the raw materials and the processes of manufacture and all these ultimately vary the durability of the bricks (Binda *et al*., 2000; Lopez-Arce *et al*., 2003).

2.5.1 Durability and serviceability

Hendry and Khalaf (2001) defines durability as the property of a material when it remains in its original form, structure and appearance for the expected lifetime without excessive or unexpected maintenance. Searls (1996) defines serviceability as the property of a material to require service in order to remain in its original form, structure and appearance it was intended to for its lifetime. Durability and serviceability refer to the material's ability to resist change from external environmental factors throughout the lifetime of the structure. These changes occur in the microstructure of the material causing damage to it. (Collepardi, 1990) found that changes in the microstructure of the burnt clay brick promoted sites for salt crystallization and these sites cause flaking and spalling. Researchers have over the years measured durability by the magnitude of stresses imposed during salt crystallization (Evans, 1958; Khaimov-Mal'kov, 1956; Knofel, 1987). Fracturing of the microstructure of the burnt clay brick by crystallization of water in colder regions also affect durability and serviceability. It has also been reported that microbiological

species can cause damage to the microstructure of burnt clay bricks affecting their durability (Koestler, 1996).

2.6 Properties of Burnt Clay Bricks

2.6.1 Physical properties

In the evaluation of strength and durability, properties relating to the quality of raw clay and the manufacturing process must be evaluated.

a. Porosity

Porosity as defined by (Fernandes *et al*., 2006) is the ratio of the volume of voids spaces (pores and cracks) to the total volume of bricks and expressed as a percentage. This property has effect on the chemical reactivity, mechanical strength, durability and the brick quality in general hence, a vital parameter. The quality of the raw material, the presence of additives or impurities, the amount of water and the firing temperature all influence the size and distribution of pores.

Bricks that are porous with a high percentage of pores measuring less than 1-2.5μm in radius have a tendency to decay because salt crystallization is highly dependent on pore structure parameters (Benavente *et al*., 2006). Old clay bricks usually have high porosity values of between 15 and 40 vol%. About 70–80% of the pores had a diameter size of 70–250 μm, independently of the type and origin of the clay. When the firing temperature is increased it will result in an increase the proportion of large pores (3–15 μm) (Mamillan, 1979; Cultrone *et al*., 2004). This allows connectivity between pores to be reduced, whereas the amount of small pores diminishes. Large pores are not easily attacked by soluble salts and hence have a good effect on brick durability.

Cultrone *et al*. (2004) and (Elert *et al*., 2003) reported that the presence of carbonates in the raw clay affects porosity evolution during firing. Firing causes mineralogical, textural and physical changes that depend on many factors that influence porosity. At

temperatures of 800 to 1,000°C, calcite is transformed into lime (CaO). This reaction causes an increase in porosity with small pore sizes of 1μm. Smaller pore sizes affect the quality of bricks by increasing its ability to absorb and retain water. (Winslow *et al*., 1988) drew similar conclusions for bricks with a pore size smaller to 1.5 μm. In the presence of water, calcium oxide is converted into portlandite ($Ca(OH)_2$). This becomes $CaCO_3$ in the presence of atmospheric carbon dioxide. These reactions according to (Laird and Worcester, 1956) result in an increase in volume causing fissures to be created, a phenomenon known as lime blowing resulting in further increases in porosity. The transformation of dolomite also contributes to the porosity increase.

b. Bulk density

Bulk density is a useful property in assessment of brick durability. A decrease in the bulk density of brick decreases its strength and increases its water absorption capacity. When the water absorption of bricks increases, it results in the bricks exhibiting larger pore sizes and hence low bulk density. According to (Nwobodo and Davies, 2000), bulk density provides a general indication of brick quality.

c. Water absorption

Another relevant parameter is water absorption which is a measure of available pore space and is expressed as a percentage of the dry brick weight. It is affected by properties of clay, types of additives used, method of manufacturing and degree of firing. Water absorption capacity of the brick affects the surface finishing of the brick-laid wall (Cultrone *et al*., 2004). Water absorption determines the capacity of fluid to be stored and to circulate within the brick. This increases deterioration and reduces mechanical strength. In countries where temperatures fall below 0°C, the water inside the pores can freeze leading to surface delaminations, disintegration or cracking. Deterioration occurs on the surface of the brick rendering it unappealing aesthetically.

The volume increase caused by the crystallization of the salts can cause severe damage. The water is sucked by the pores as a result of capillary tension along the walls of the pores. (López-Arce *et al*., 2003), pointed out that tension is stronger in small pores than in large ones.

The essential requirements for building bricks are sufficient strength in crushing, regularity in size, a proper suction rate, and a pleasing appearance when exposed to view.

1. **Shape and size:** The bricks should have uniform size and plane, rectangular surfaces with parallel sides and sharp straight edges.

IS 1077 recommended that the standard modular sizes of common building bricks are as follows:

Length (L)	Width (w)	Height (H)
mm	mm	mm
190	90	90
190	90	40

The following non-modular sizes of the bricks may also be used

Length (L)	Width (w)	Height (H)
mm	mm	mrn
230	110	70
230	110	30

2. **Colour:** The brick should have a uniform deep red or cherry colour as indicative of uniformity in chemical composition and thoroughness in the burning of the brick.

3. **Texture and compactness:** The surfaces should not be too smooth to cause slipping of mortar. The brick should have precompact and uniform texture. A fractured surface should not show fissures, holes grits or lumps of lime.

2.6.2 Mechanical properties

In order to assess the safety of a brick masonry structure, the mechanical property is a very relevant parameter. All masonries are made of heterogeneous materials whether brick, mortar or mortar–interface with their compressive strength dependent on the strength of their component. Bricks used in the construction of columns, walls, arches and vaults are subjected to compressive stresses and hence should possess reasonable strength in compression and low strength in tension.

a. Compressive strength

Compressive strength is influenced by the production process and the raw material characteristics. Compressive strength evolution correlates to textural and microstructural changes in the bricks, including increasing vitrification and reductions in porosity both resulting in an increase in the mechanical strength (Bucea *et al*., 2005). In the American Society for Testing Materials (ASTM) specifications for solid bricks (ASTM C62-00), the minimum compressive strength (kg/cm^2) is correlated with weathering resistance, and three different grades are specified: bricks resistant to severe weathering-211 kg/cm^2; bricks resistant to moderate weathering-176 kg/cm^2; and bricks resistant to negligible weathering- 106 kg/cm^2. Most studies indicate low values for compressive strength and a large dispersion of the values, with coefficients of variation ranging between 25 and 55%; but unusual strengths, higher than 50 MPa, were reported by (Pauri *et al*. 1994).Brick earth should be free from stones, kankars, organic matter, saltpetre, etc.

b. Abrasion resistance

Abrasion resistance is the measure of resistance of aggregate to surface wear by abrasion. Guptta and Gupta., (2004) explain that abrasion value should not be more than 30% for wearing surface and 50% for other surfaces.

2.7 Ingredient of Good Earth Brick

For the preparation of bricks, clay or other suitable earth is moulded to the desired shape after subjecting it to several processes. After drying, it should not shrink and no crack should develop. The clay used for brick making consists mainly of silica and alumina mixed in such a proportion that the clay becomes plastic when water is added to it. It also consists of small proportions of lime, iron, manganese, sulphur, etc.

According to IS:1077 The proportions of various ingredients are as follows:

Silica 50–60%

Alumina 20–30%

Lime 10%

Magnesia < 1%
Ferric oxide < 7% } Less than 20%
Alkalis < 10%

Carbon dioxide
Sulphur trioxide } Very small percentage
Water

a. Functions of various ingredients

1. Silica: It enables the brick to retain its shape and imparts durability, prevents shrinkage and warping. Excess of silica makes the brick brittle and weak on burning. A large percentage of sand or uncombined silica in clay is undesirable. However, it is added to decrease shrinkage in burning and to increase the refractoriness of low alumina clays. Alumina absorbs water and renders the clay plastic. If alumina is present in excess of the specified quantity, it produces cracks in brick on drying. Clays having exceedingly high alumina content are likely to be very refractory.

Lime normally constitutes less than 10 per cent of clay. Lime in brick clay has the following effects:

i. . Reduces the shrinkage on drying.

ii. Causes silica in clay to melt on burning and thus helps to bind it.

iii. In carbonated form, lime lowers the fusion point.

iv. Excess of lime causes the brick to melt and the brick looses its shape.

v. Red bricks are obtained on burning at considerably high temperature (more than 800°C) and buff-burning bricks are made by increasing the lime content.

2. Magnesia: It rarely exceeding 1 per cent, affects the colour and makes the brick yellow, in burning; it causes the clay to soften at slower rate than in most case is lime and reduces warping.

3. Iron oxide: It constitutes less than 7 per cent of clay, imparts the following properties:

i. Gives red colour on burning when excess of oxygen is available and dark brown or even black colour when oxygen available is insufficient, however, excess of ferric oxide makes the brick dark blue.

ii. Improves impermeability and durability.

iii. Tends to lower the fusion point of the clay, especially if present as ferrous oxide.

iv. Gives strength and hardness.

c. Additives in the manufacture of bricks

Certain additives such as fly ash, sandy loam, rice husk ash, basalt stone dust, etc. are often required not only to modify the shaping, drying and firing behaviour of clay mass, but also to help conserve agricultural land and utilise waste materials available in large quantities (Duggal, 2008). These additives should, however, have a desirable level of physical and chemical characteristics so as to modify the behaviour of clay mass within the optimum range without any adverse effect on the performance and durability.

d. Classification of bricks

On field practice IS1077 classified clay bricks as first class, second class, third class and fourth class based on their physical and mechanical properties.

First class bricks

1. These are thoroughly burnt and are of deep red, cherry or copper colour.

2. The surface should be smooth and rectangular, with parallel, sharp and straight edges and square corners.

3. These should be free from flaws, cracks and stones.

4. These should have uniform texture.

5. No impression should be left on the brick when a scratch is made by a finger nail.

6. The fractured surface of the brick should not show lumps of lime.

7. A metallic or ringing sound should come when two bricks are struck against each other.

8. Water absorption should be 12–15% of its dry weight when immersed in cold water for 24 hours.

9. The crushing strength of the brick should not be less than 10 N/mm2. This limit varies with different Government organizations around the country.

Uses: **First class bricks** are recommended for pointing, exposed face work in masonry structures, flooring and reinforced brick work.

Second class bricks are supposed to have the same requirements as the first class ones except that

1. Small cracks and distortions are permitted.

2. A little higher water absorption of about 16–20% of its dry weight is allowed.

3. The crushing strength should not be less than 7.0 N/mm2.

Uses: Second class bricks are recommended for all important or unimportant hidden masonry works and centering of reinforced brick and reinforced cement concrete (RCC) structures.

Third class bricks are under burnt. They are soft and light-coloured producing a dull sound when struck against each other. Water absorption is about 25 per cent of dry weight.

Uses: It is used for building temporary structures.

Fourth class bricks are over burnt and badly distorted in shape and size and are brittle in nature.

Uses: The ballast of such bricks is used for foundation and floors in lime concrete and road metal.

e. On strength

The Bureau of Indian Standards (BIS) classified bricks on the basis of compressive strength and is as given in table 2.1.

Table 2.1 Classification of bricks based on compressive strength (IS:1077)

Class	Average Compressive strength not less than (N/mm^2)
35	35
30	30
25	25
20	20
17.5	17.5
15	15
12.5	12.5
10	10
7.5	7.5
5	5
3.5	3.5

Source: Duggal (2008)

2.8 Waste Recycling

Due to the demand of bricks as building materials, many researchers have investigated the potential wastes that can be recycled or incorporated into fired clay bricks. Owing to the flexibility of the brick composition (Lynch, 1994; Dondi *et al.*, 1997a; Christine, 2004), different types of waste have been successfully incorporated into fired clay bricks by previous researchers, even in high percentages. From the literature reviews related to the inclusion of waste materials, they apparently vary from the most commonly used wastes such as the various types of fly ash and sludge, to sawdust,

kraft pulp residues, paper, polystyrene, processed waste tea, tobacco, grass, spent grains, glass windshields, PVB-foils, label papers, butts. The utilisation of these wastes helps to reduce the negative effects of their disposal. However, the potential wastes can only be recycled if the properties and the environmental pollutant of the new manufactured brick meet the specific requirements and comply with the relevant standards.

As recycling waste is highly encouraged, the historical development of recycling waste in clay brick production has also been reviewed. Research has been conducted with a wide range of successfully recycled materials and their effect on the physical and mechanical properties of bricks. Most of the recycled waste demonstrated both advantages and disadvantages in the brick manufacturing process. Some wastes used in bricks production are described as follows

2.8.1 Fly ash

(Kayali 2005), produced bricks with 100% fly ash as the solid ingredient. It is called FlashBricks. The equipment and techniques used in manufacturing the bricks were similar to those used in the clay brick industry. The samples were fired at 1000°C to 1300°C and were formed into moulds. Fired FlashBricks produced bricks that were 28% lighter than standard clay bricks. The results show that FlashBricks improved most of the properties compared to those of a standard brick. The compressive strength obtained was 43 MPa and the tensile strength was improved almost three times compared to that of a standard clay brick. In addition, the brick also achieved a bond 44% higher than a standard clay brick and the resistance to salt exposure with zero loss of mass was excellent. In terms of appearance, the fired FlashBricks have a reddish colour similar to a standard brick but a rougher texture was observed on the surface of the brick.

In a similar study (Pimraksa *et al*., 2001), produced bricks using 100% lignite fly ash. The effect on the mechanical properties of four different treatments of fly ash: sieved with 63μm and 40μm fly ash sieve, ground 5 hour fly ash and ground 10 hour fly ash were investigated. The optimal firing temperature was between 900°C to 950°C at 3°C/min for each type of the manufactured samples. Most samples tested demonstrated less than 4% of weight loss and less than 3% of shrinkage value. The results from the experimental work conducted demonstrated that bricks manufactured with -40μm fly ash and fired at 950°C obtained better results in mechanical strength, specifically, in compressive strength (5.63 MPa) and bending strength (1.31 MPa) compared to red fired clay bricks, common clay bricks and facing bricks. Also, some bricks manufactured with the other three types of fly ash also performed better than red fired clay bricks and common clay bricks. Other properties determined in this study complied with the standards and the requirements of the market demand. As for (Lin 2006), this study used fly ash slag from the municipal solid waste incinerator (MSWI) to make fired clay bricks. The percentage of added waste varied from 10% to 40% and the bricks were fired at 800°C, 900°C and 1000°C. The results of the physical and mechanical properties indicated that using a high amount of fly ash slag increased the dry density and compressive strength value but decreased the water absorption rate. Nevertheless, all the values determined for both parameters met the Chinese National Standard (CNS) building requirements for second-class bricks. The degree of shrinkage in the firing process also decreased with the addition of fly ash slag to the mixture, which is a good indicator of the potential of the waste as a replacement for clay in bricks. All the heavy metal concentrations measured by the Toxicity Characteristics Leaching Procedure (TCLP) met the current regulatory thresholds.

2.8.2 Sludge

This category includes sludge from sewage treatment plant, sludge from paper industry, iron and arsenic sludge, sludge ash and tannery sludge. (Rouf and Hossain, 2003), used 5%, 15%, 25% and 50% of iron and arsenic sludge in clay bricks with firing temperatures of 950°C, 1000°C and 1050°C. In this study, they claimed that 15% to 25% by weight with 15% to 18% optimum moisture content is the appropriate percentage of sludge mixture to be incorporated. The compressive strength test indicated that the strength of the brick depends significantly on the amount of sludge in the brick and the firing temperature. The results showed that 15% by weight is the optimum amount of sludge with a 1000^{o}C firing temperature. However, the strength of the brick can be as high as normal clay bricks with up to 25% sludge at a firing temperature of 1050°C. The specific surface area of the corresponding mixture, the particle fineness and water requirement increased proportionally to the amount of sludge added to the clay. However, it decreased the plastic behaviour of the clay. The water absorption of the brick also decreased when the amount of sludge was reduced with an increased firing temperature. The quantity of sludge added to the mixture is inversely relative to the bulk dry density. With the right amount of moisture content in the mixture, any deformation or uneven surface were not occurred on the manufactured samples at all firing temperatures. The leaching of arsenic resulting from the TCLP test was far below the regulated TCLP limits and the quantity of metal sludge was less than dried sludge. The study concluded that the proportion of sludge and firing temperature are the two main factors in controlling the shrinkage in the firing process and for producing a good quality brick at the same time. Sludge proportions of 15% to 25% sludge and firing at 1000°C to 1050°C were suggested by (Rouf and Hossain 2003), for producing good quality sludge bricks. They demonstrated that the original characteristics of normal clay bricks are retained with

the addition of 25% sludge and that arsenic leaching is significantly reduced when bricks are burnt at a high temperature. (Basegio *et al,* 2002) discussed the utilisation of tannery sludge as a raw material for clay products. Tannery sludge and clay were mixed together with different proportions (9%, 10%, 20% and 30%) as the raw materials in this study. The brick was fired at 1000°C, 1100°C and 1180°C and was shaped in the mould using the hydraulic pressing method. Specific testing for clay bricks was conducted on the samples to determine the mechanical properties. Water absorption increased with the increased in percentage of sludge. With an increased firing temperature the water absorption and porosity decreased considerably. A higher firing temperature and a lower amount of sludge showed the greatest dry density of all. The maximum shrinkage occurred between 1100°C and 1180°C. Samples containing 30% sludge showed the lowest dry density and highest linear shrinkage. The bending strength increased with a higher firing temperature and lower sludge addition with a maximum of 25 MPa with 0% and 10% sludge at 1180°C. Porosity also has an influence on the mechanical properties of the material. According to the Brazilian Standard, the results collected from the leaching test in this research show that the main sludge contaminant, which is chromium, might have been immobilised in the finished clay product, however 30% sludge was recommended as the raw material to prevent lead in the leachable waste. As for the gas emissions, the clay product did not immobilise the gas, thus, sulphur, zinc and chlorine were detected during the test. Still, the bricks application complied with the minimum requirements for the building industry and 10% tannery sludge was deemed a safe amount to be used in respect of the environmental characteristics of the product.

Another sludge that was recycled by (Tay *et al*., 2001) was industrial sludge. Bricks were manufactured from industrial sludge from 30% up to 100%. The employed firing temperature was 1050°C. During the observation, cracks were prone to occur during

firing with 100% sludge and 90% sludge with 10% clay. The water absorption limit of 7% was verified for bricks of all mixtures except for bricks that contained 50% of clay. Tay *et al* (2002) also reported that 'biobricks' were manufactured by mixing clay and shale with sludge with a solid content ranging between 15% to 25%. As for (Liew *et al*., 2004), they discussed the incorporation of sewage sludge in clay bricks and its characterisation. In this study, 10% to 40% dry weight of sludge was added to produce clay bricks. The manufactured brick was hand moulded by the compaction method and fired at 985°C. Although the surface and exterior of the sludge enhanced clay bricks were rather rough and poor a sludge content of up to 40% still complied with the required standards in terms of the physical and chemical properties. Nevertheless, the researchers concluded in this study that the maximum percentage of sludge should not be more than 30% by weight due to its fragility and that the addition of 20% sludge would maintain the functional characteristics of the brick. In general, a high amount of sludge added into the clay brick increased the drying shrinkage but decreased the firing shrinkage. The water absorption value increased by up to 37% compared to the control brick (23.6%) and the compressive strength decreased to 2 N/mm2 against 15.8 N/mm2 for the control brick, which was obtained with the addition of 40% sludge. Gases included steam and CO_2, which were emitted during the firing process due to the combustion of the organic content in the sludge. At the same time, cracking and bloating were also observed at the fired brick. The cross sections of the brick also revealed black coring attributed by the organic matter. A significant growth of pores was also identified and contributed to the mechanical properties that were achieved with the inclusion of 10% to 40% sludge. Because of all the weaknesses, the bricks produced in this study were only appropriate for use as common bricks because of the poor exterior surface.

2.8.3 Other wastes

Krebs and Mortel (1999) investigated various waste additives for inclusion within the bricks such as fly ash, sludge and spent grains that can be used directly in the brick. However, some types of waste had to be processed before it could be used, for example, windshield glass, PVB-foils and label papers. The main objective of these additives is to act as pore formers in the manufactured brick after firing is done. The pores formed in the brick reduce both the clay content thereby producing light weight bricks. A combination of pelletised old labels and fly ash obtained good results. No problem occurred during the production process. The residues utilised reduced the dry density while maintaining similar or achieving an even higher compressive strength. Significant porosity growth was also observed with the burn out of the label pellets. The PVB-polymer, which was produced from windshield glass, also demonstrated positive results on the fired brick. Energy usage was reduced by recycling this pore forming agent inside the brick due to its high calorific value (28,260 kJ/kg), which contributed to the firing process. Hence, gas emissions have to be monitored as the combustion of PVB-polymer almost completely turned into CO_2 and H_2O. Crushed PVB-polymer additives confer more positive results to the brick. The PVB-pellets improved the drying shrinkage of the green brick tremendously and increased the porosity of the bricks produced accordingly.

a. Alternative Fuel for Brick Firing

Many alternative sources of fuel can replace coal and firewood, the most common fuels used to fire a kiln. Alternative fuels can be used to partially replace these conventional fuels by more than 50% of the total fuel quantity. In areas where firewood is already scarce, they can help reduce pressure on the resource. Alternative fuel materials range from agro/ bio-waste like sawdust, husks from coffee and rice, coconut shells, dry stalks; to industrial waste for instance, from the sponge iron

industry. Bio-briquettes are another alternative fuel which can be produced through high pressure compression of a mix of locally available coal/ lignite with up to 30% by Weight of different biomass. Finer fuels such as sawdust, husks and coal powder can be added directly to the clay mix. The fuel will burn completely within the kiln and also help reduce the chances of cracking during the drying process. Another way to use alternative fuel is to charge conventional fuels like coal, where the fuel will burn and release a sudden burst of high energy (Mohammad S. A., and Pawade, P. Y. 2014)

b. Advantages of mechanised internal fuel bricks

Following are the advantages of using mechanized internal fuel brick making technology:

i. Can be used in any firing technology
ii. Reduces external coal consumption by more than 25-60%
iii. Improves environmental efficiencies by more than 50-70%
iv. Consistent and improved quality product resulting in higher returns
v. Low cost technology
vi. Can be easily integrated into existing brick production system

2.9 Concept of sustainability

Sustainability means meeting our own needs without compromising the ability of future generations to meet their own needs. Environmental sustainability is the ability to maintain the qualities that are valued in the physical environment such as human life, the capabilities that the natural environment has to maintain the living conditions for people and other species (e.g. clean water and air, a suitable climate), the quality of life for all people and beauty of the environment (Weaver *et al.*, 2000). Threats to these aspects of the environment mean that there is a risk that these things will not be

maintained. For example, the large-scale extraction of non-renewable resources (such as minerals, coal and oil) or damage done to the natural environment can create threats of serious decline in quality or destruction or extinction.

Traditionally, when environmental problems arise environmental managers work out how to reduce the damage or wastage. But it is not always easy to work out exactly when and where threats will have their effects and often the impacts are hard to reverse. So increasingly environmental managers adopt strategies aimed to prevent damage being done in the first place. A full sustainability program needs to include actions to prevent threats and impacts from arising, actions to protect the environment from threats and damage, and restoration to reverse damage already done.

Sustainability issues arise wherever there is a risk of difficult or irreversible loss of the things or qualities of the environment that people value. And whenever there are such risks there is a degree of urgency to take action. Environmental sustainability programs include actions to reduce the use of physical resources, the adoption of a 'recycle everything/buy recycled' approach, the use of renewable rather than depletable resources, the redesign of production processes and products to eliminate the production of toxic materials, and the protection and restoration of natural habitats and environments valued for their liveability or beauty.

These sustainability programs need to operate on an adequate scale and need to continue operating reliably for as long as the threats continue. Some of the issues that pose major environmental sustainability problems include:

1. destruction of the living environments (habitats) of native species
2. discharge of polluting chemicals and other materials into the environment
3. emission of greenhouses gases into the atmosphere than can cause climate change
4. depletion of low cost oil and other fossil fuels

Some environmental issues are largely of local significance while others have regional or even global relevance. At the personal or household level, there are a host of actions that people can take to contribute to environmental sustainability at home, when travelling or accessing services or goods, at work, or when acting as a community member or citizen or as an investor of personal funds. Some include living close to work where possible and walking, using a bike or using public transport. These are good options to save energy and reduce greenhouse gases. Buying products made of recycled materials will generally save materials and energy, cut greenhouse gases and toxic pollution, and reduce impacts on living things in the wild.

a. Sustainable waste management

The following are some ways wastes generated in our environment can be managed

1. support local sustainable business
2. Recycle organic waste with a compost or waste bin for garden waste
3. Take recycle waste to Council Resource Recovery Centres
4. Reuse containers, papers, green bags

Disposal is the least preferred option. Council facilities will ensure the safe and contained burial of waste not able to be recoverable or recycled.

b. How can organic waste contribute to greenhouse gases and climate change

Organic waste can be materials such as food, garden waste, paper, cardboard, timber, textiles, rubber and sludge (solids from the sewage treatment process). Burying organic waste in a landfill is of concern and not just because of the resource we lose. Organic waste in a landfill will begin to decompose aerobically (with oxygen). Once this oxygen is depleted, the process changes to anaerobic (without oxygen) decomposition. Anaerobic decomposition produces carbon dioxide and methane gases generated (both greenhouse gases), which enter the atmosphere and enhance the greenhouse effect, contributing to global warming and climate change.

In 2006-2007 Australia generated an estimated 20.06 million tonnes of organic waste. Of that organic waste, only 32% was diverted to landfill (Nation Waste Overview 2009). Through improving and increasing this diversion rate, we can make a positive contribution towards the reduction of greenhouse gas emissions and abate the threat and long term impact of climate change.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used for the experiment are clay, sawdust, polythene, water, and Sulphuric Acid (H_2SO_4).

3.1.1 Clay

It was obtained at Bomo Tsakiya Bomo village and kept in saturated surface dry (SSD) condition prior to use in laboratory of Department of Building A.B.U. It was sieved using 5mm sieve to distribute the particles in their required sieve sizes and also remove impurities. Bereau of Indian Standard (1990) stated that the particle size of clay should range between 5mm and below.

3.1.2 Sawdust

The sawdust used for this research was obtained from timber sawmill Sabon Gari, Zaria. Kaduna State. Part of it was incinerated in chemical engineering department of the university at a control temperature of 800^{o}C. X-Ray Fluorescence (XRF) test was carried out to determine its chemical composition.

3.1.3 Polythene

Low density polythene was used for the experiment. It was collected from residential buildings within Samaru and Sunpat pure water factory located at government reserved area Zaria.

3.1.4 Sulphuric acid (H_2SO_4)

Sulphuric Acid (H_2SO_4) used in this research was purchased from the local supplier in bulk at Mercy holdings Zaria.

3.1.5 Water

Portable water fit for drinking was used for this research. It was used for mixing the sulphuric acid and also used for the production of the specimens.

3.2 Methods

3.2.1 Physical properties of clay

This stage of experiment involves the preliminary tests to determine the specific gravity, bulk density and particle size distribution of the clay soil. Atterberg limit test to determine the liquid limit and plastic limit of the clay soil was conducted.

3.2.2 Physical properties of sawdust

The physical properties that was determined for the sawdust include the following

a. Specific gravity

The specific gravity (Gs) of the sawdust was determined by using pyconometer method in accordance to ASTM C 127-1993. The relationship that was used to find the specific gravity and is given by;

$$\text{Specific gravity } (G_S) = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where: W_1 = Weight of density bottle

W_2 = Weight of density bottle + Sample

W_3 = Weight of density bottle + Water (full) + Sample

W_4 = Weight of density bottle + Water (full)

b. **Bulk density**

Bulk density was conducted in accordance with BS 812-2 (1995). This test was conducted for the three materials used in this experiment i.e. clay, polythene and sawdust. The result was used in the calculation of materials used in the experiment.

$$\text{Bulk Density} = \frac{D}{W-S} \quad (g/cm^3) \quad \ldots\ldots(3.2)$$

Where:

D = Weight of dried specimen

S =Weight of dried specimen suspended in water,

W = Weight of soaked specimen suspended in air.

3.3 Chemical Properties

Chemical test was conducted to determine the chemical composition and loss on ignition of clay and sawdust. The analysis was carried out at the Defence Industries Corporation of Nigeria (DICON), Kakuri Industrial Layout, Kaduna State Nigeria using XRF test to determine the oxide composition such as Silicon Oxide (SiO_2), Aluminum Oxide (Al_2O_3), Iron Trioxide (Fe_2O_3) and others.

3.4 Manufacture of Bricks

To determine the desired mix proportion, trial mix was prepared from standard mix obtained from literature and the desired one used for the casting of bricks. The trials was done for different percentages of additives (0%, 5%, 10%, 15% and 20%) of the sawdust and polythene and incorporated in the clay to predict their various properties.

The clay was weighed on a scale and mixed with water. The water mixed to the clay was determined from the trials which was equivalent to 30% dry weight of the clay. It was then covered for 7days to ensure uniform distribution of the water in the mix. It was then moulded again and mixed with 5% mixing water. 0%, 5%, 10%, 15% and

20% of the volume of clay was replaced with sawdust and polythene and thoroughly mixed.

Table 3.0 Proportions of clay mix, sawdust and polythene additives in prepared samples

Samples Volume	Clay Mix, Volume (%)	Sawdust volume (%)	Polythene volume (%)	Total (%)
X	100	0.0	0.0	100
A	80	0.0	20.0	100
B	80	5.0	15.0	100
C	80	10.0	10.0	100
D	80	15.0	5.0	100
E	80	20.0	0.0	100

The samples were moulded into rectangular shapes mould of size 230x110x70mm and are left for 2 weeks to ensure uniform drying in the laboratory environment. The samples are then preheated at 110±5°C in a Kiln to remove any moisture likely to be present. Subsequently the samples were fired at 800^0C, 900^0C, 1000^0C, 1100^0C, 1200^0C and 1300^0C in a Kiln at a temperature rise of 200^0C/hour. The experiment was carried out at industrial design laboratory. Table 3.1 present the tests to determine it's mechanical and durability properties.

Table 3.1 Bricks samples and test on samples

S/N	Tests	Sample X	A	B	C	D	E	Total
Fired at 800^{O}C								
I.	Dry compressive strength	3	3	3	3	3	3	18
ii.	Wet compressive strength	3	3	3	3	3	3	18
iii.	Abrasion	3	3	3	3	3	3	18
iv.	Water absorption	3	3	3	3	3	3	18
v.	Exposure to H_2SO_4	3	3	3	3	3	3	18
Fired At 900^{O}C								
i.	Dry compressive strength	3	3	3	3	3	3	18
ii.	Wet compressive strength	3	3	3	3	3	3	18
iii.	Abrasion	3	3	3	3	3	3	18
iv.	Water absorption	3	3	3	3	3	3	18
v.	Exposure to H_2SO_4	3	3	3	3	3	3	18
Fired At 1000^{O}C								
i.	Dry compressive strength	3	3	3	3	3	3	18
ii	Wet compressive strength	3	3	3	3	3	3	18
iii.	Abrasion	3	3	3	3	3	3	18
iv.	Water absorption	3	3	3	3	3	3	18
v.	Exposure to H_2SO_4	3	3	3	3	3	3	18
Exposure to Elevated Temperature								
i.	Fired at 1100^{O}C	3	3	3	3	3	3	18
ii.	Fired at 1200^{O}C	3	3	3	3	3	3	18
iii.	Fired at 1300^{O}C	3	3	3	3	3	3	18
Total								**324**

The tests conducted for determination of the mechanical properties are

i. Compressive strength

ii Abrasion

Tests for the determination of durability include;

iii. Water Absorption

iv. Exposure to H_2SO_4

v. Exposure to elevated temperature

Results were analysed using statistical tools such as percentages, and charts.

3.5 Tests and Testing Procedures

All samples were produced using the same dimension as specified by (IS: 1077) for burnt clay i.e. mould of 230x110x70mm dimensions.

i. **Compressive strength test**

The compressive stress test was conducted using the compressive strength machine which requires electricity to operate. The control and sample specimens which are measured 230mmx110mmx70mm each and cubical in shape were then removed from the mould and fired in a kiln at 800^0C, 900^0C 1000^0C, 1100^0C, 1200^0C and 1300^0C. They were allowed to cool in the air for two days before the test was carried out on the mechanical strength testing machine. A total of 108 specimens were tested for compressive strength and it was done as stipulated by BS 1881, part 116 (1983). Three (3) cubes each were tested to failure for all specimens. The maximum failure load was then recorded and the compressive strength calculated (wet and dry compressive strength) using the equation below:

$$\text{Compressive strength} = \frac{\text{Maximum load (KN)} \times 1000}{\text{Cross- sectional Area (mm}^2\text{)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

ii. **Abrasion resistance:** Abrasion Resistance is the measure of resistance of aggregate to surface wear by abrasion. Samples were tested in accordance to BS 812-110: 1990. A total of 54 samples were tested fired in a kiln at 800^0C, 900^0C and1000^0C. Samples were first weighed on a scale and then a load of 3600g was attached to the brush. The wire brush was used to brush the surface of the bricks

repeatedly for a minute which is equivalent to 60 to and fro movement. The abrasion values was determined using the relationship below:

$$\text{Abrasion resistance} = \frac{W_1 - W_2}{W_2} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (3.4)$$

Where,

$W_1 =$ Initial weight of a brick specimen

$W_2 =$ Final weight of the specimen after brushing.

iii. Water absorption test

This test was conducted on bricks fired at 800^0C, 900^0C and1000^0C. Samples were tested in accordance with BS 1881-122: (1983). A total of 54 samples were tested for absorption capacity and on each day of testing, three cubes each were placed in the electric oven to dry the specimens at 105^0C for 24 hours. The specimens were removed from the oven and allowed to cool at room temperature before determining the initial weight which was recorded as (W_1). The final weight was determined after the sample specimens has been immersed in water for 24hrs. It was removed and dried with a piece of cloth, re- weighed and recorded its weight as W_2.

The equation was used to compute the absorption capacity for the specimens is given as:

$$\text{Percentage Water Absorption} = \frac{\text{Wet weight - Dry weight}}{\text{Dry weight}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

iv. Exposure to sulphuric acid:

After burning specimens in a kiln, they were left in the kiln to cool off for 2 days before removing them from the oven. The specimens were then cured in Sulphuric acid (H_2SO_4) for a period of 3days, 6days and 9 days before testing. Same samples were cured in water for 3days, 6days and 9days. A total of 54 cubes were immersed in

H_2SO_4 solution and 54 cubes in water to serve as the control. The concentration of H_2SO_4 used was 2%, which was categorized by Gupta and Gupta (2012) as a severe attack. The relationship adopted by Ibrahim (2015) was used to achieve the quantity of H_2SO_4 that gives the concentration. The relationship is thus:

If 50 liters of water = 5000g by weight

5000g of water = 100% concentration

Xg=2% concentration

Therefore,

$$Xg = \frac{500g \times 2}{100} \quad \text{..... (3.6)}$$

Therefore, for every 5000g of water, 100g of H_2SO_4 was dissolved in the water.

It was prepared as stipulated by ASTM C1012 and ASTM C452. Method of chemical to water addition was used for the sulfuric acid and they were all prepared in the laboratory. Compressive strength of the sample was determined after the curing days were completed for the sample immersed in the sulfuric acid solution. Results were compared with results of samples immersed in water which served as the control.

v. Exposure to elevated temperature

The burnt bricks specimen were heated in a kiln at 1100^{o}C, 1200^{0}C and 1300^{o}C (Chesti, 1986). The compressive strength was determined after it has been allowed to cool at room temperature.

3.6 Method of Data Analysis

The result of the various test conducted were analyzed using arithmetic mean and percentages. The mean was used to analyse the result of the cold and dry compressive

strength after firing and immersion in water by summing the strength of the crushed bricks and divided by the numbers of bricks crushed. Percentages was used to analyse the result of abrasion resistance and water absorption by calculating the percentage of water absorption for the entire bricks samples and the percentage of weight loss.

CHAPTER FOUR

4.0 DATA PRESENTATION, ANALYSIS AND DISCUSSION

4.1 Presentation of Results

Results presented in this chapter are based on the tests carried out on the type of materials and bricks samples used for this research. The chemical analysis test for the clay and sawdust ash and the physical properties tests for the materials used in the experiment as well as the test results for both the samples containing additives and without additives are presented and discussed in this chapter.

4.2 Chemical and Physical Properties of Materials

Table 4.2.1 presents the chemical composition of Bomo clay and sawdust. The clay sample was noted to be light brown in colour and have a high quantity of Silica (SiO_2 = 61.1 %), average Iron Oxide and Aluminium content ($Fe2O_3$ = 14.95 % and $Al2O_3$ = 28.9 %) and can be classified to be Aluminium clay but not bauxite in line with (ASTM C60-200) classification since the Aluminium content is higher than the Iron content. The soil thereby conforms to Rajput (2006) requirement for a good brick making earth on basis of the Alumina (Al_2O_3) or clay and Silica (SiO_2) content.

Also the silica (SiO2) content of Bomo clay was 61.1% and meet the standard for fireclay refractory. (ASTM, 1982). This means that the clay can be used for lining of heat treatment furnaces and portions of blast furnaces in accordance with the Annual Book of ASTM Standards, 1982. The iron oxide content of 9.3% in clay and 10.8% in sawdust samples will impart a reddish colour to the clay when fired.

Table 4.1 Chemical composition of clay and sawdust

Compound	Concentration Unit (%)	
	Clay	Sawdust Ash
Al_2O_3	19.6	14
SiO_2	61.1	25
SO_3	0.099	2.4
K_2O	2.43	11.4
CaO	1.81	24.5
MnO	0.051	0.88
Fe_2O_3	9.321	10.8
CuO	0.021	0.31
ZnO	0.002	0.21
SeO_2	--	4.5
Total SiO_2+Al_2O_3+Fe_2O_3	89.9	

Source: Laboratory research work (2016)

4.2.1 Physical properties of the research materials

Table 4.2.1 summarizes the results for specific gravity of the sawdust, clay and polythene was determined using pyconometer method in accordance with ASTM C 127-1993. It was calculated using the relationship in equation (3.1).

The specfic gravity for clay was found to be 2.0, that of sawdust was 1.5 and polythene was 1.2. This shows that the result of specific gravity of clay falls within the range of 2.0 to 2.4 as given by Sanjay, N. P., Anil, K. G. and Subhash, S. D. (2013)

Table 4.2.3 Specific gravity of materials

Materials	**Specific gravity**
Clay	2.0
Sawdust	1.5
Polythene	1.2

Source: Laboratory research work (2016)

Table 4.2.4 summarises the bulk density test which was conducted in accordance with BS 812-2 (1995). The relationship in equation (3.2) was used to determine the bulk density of the samples namely clay, sawdust and polythene. Clay had a bulk density of 1550g/cm^3, sawdust had 200g/cm^3, and polythene having 100g/cm^3.

Table 4.2.4 Bulk density of materials

S/N	Materials	Volume of container	Bulk density (g/cm^3)
1.	Clay	0.001575	1550
2.	Sawdust	0.001575	200
3.	Polythene	0.001575	100

Source: Laboratory Research Work (2016)

4.2.4 Atterberg limit test

Table 4.2.4.2 summarises the result of Atterberg limit test conducted on Bomo clay based on the moisture content of the soil. The plasticity indices for the clay investigated fell within the recommended 10-60% for ceramic clays (Nnuka and Enejor, 2001). For low shrinkage property the plasticity index (PI) should be within 10-20% (BS 1377-7:1990). The plastic limits for the clay was 15%. The difference in liquid limit and plastic limit gives the plasticity index value which is 11%.

Table *4.2.4.2* Plastic limit determination

Sample No.	1	2	3
Moisture can and lid number	7	14	13
Mc= Mass of empty clean can + lid (grams)	7.78	7.78	15.16
Mcms= Mass of can, lid and moist soil (grams)	16.39	13.43	21.23
Mcds= Mass of can, lid and dry soil (grams)	15.28	12.69	20.43
Ms= Mass of soil solids (grams)	7.5	4.87	5.27
Mw= Mass of pores water (grams)	1.11	0.74	0.8
W=Water Content (w%)	14.8	15.2	15.1

Plastic Limit (PL) = Average w% = $\frac{14.8+15.2+15.2}{3}$ =15.0

Final Results:

Liquid Limit = 26

Plastic Limit = 15

Plastic Index = 11

4.3 Compressive Strength of Bricks Fired at 800^0C, 900^0C and 1000^0C

Figure 4.3 shows the cold compressive strength of burnt bricks at three different temperatures namely 800^0C, 900^0C and 1000^0C. The result shows that the control and sample specimen A, fired at 800^0C meet up with the minimum strength requirement of second class bricks. The brick had strength of above 7N/mm^2. While samples B, C, D and E at this temperature are third class bricks as specified by Duggal (2010).

The control samples fired at 900^0C and 1000^0C have cold compressive strength above 10 N/mm^2 hence meet the minimum standard of first class bricks. Sample specimen A at this temperatures increased in wet compressive strength from 8.2 N/mm^2 to 9.4 N/mm^2. Hence meets up with second class classification. Sample B at 900^0C had wet compressive strength of 6.9N/mm^2 and increased to 7N/mm^2 at 1000^0C where as the Sample C, D and E had wet compressive strength of 6.5N/mm^2 to 7N/mm^2, 5.6N/mm^2 to 6N/mm^2, and 5N/mm^2 to 5.6N/mm^2 at an increase of temperature from 900^0C to 1000^0C respectively and are third class bricks. The polythene melts in the bricks during firing and forms a bond within the clay while the sawdust burn to ashes. Samples with polythene had a better strength while there was decrease in compressive strength with increase in the sawdust content. This implies that when the percentage of sawdust increases the compressive strength did not comply with Duggal (2008) recommendation of burnt bricks and can't be used for construction of buildings as a walling material.

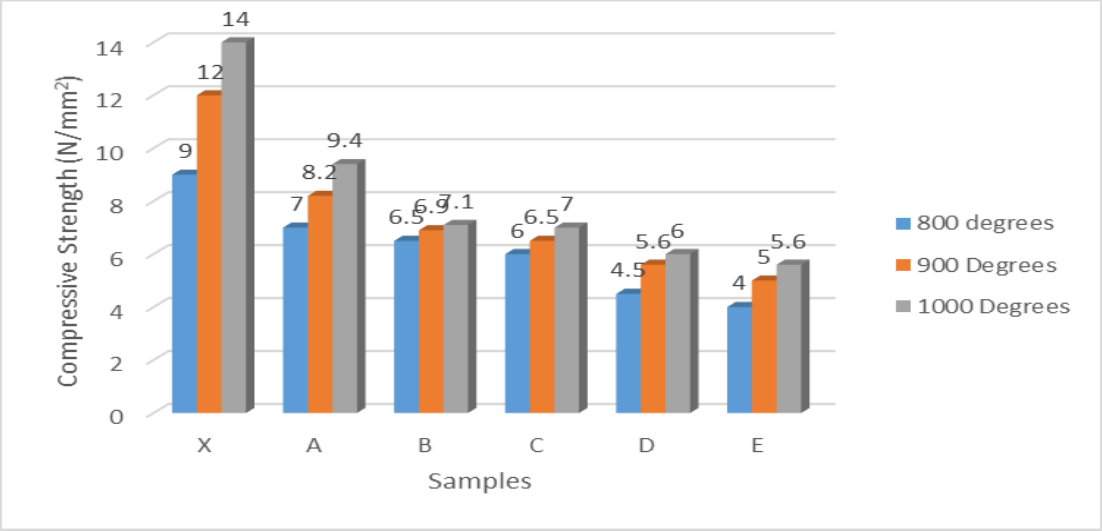


Figure 4.3.1 Compressive strength of bricks fired at 800^{0}C, 900^{0}C and 1000^{0}C (wet compressive strength).

Figure 4.3.2 shows that the control has a compressive strength of 12N/mm^2, 13N/mm^2 and 14N/mm^2 when fired at 800^{0}C, 900^{0}C and 1000^{0}C respectively and are first class bricks, sample A fired at 800^{0}C and 900^{0}C has 7.5N/mm^2 and 8.2 N/mm^2 and are second class bricks while sample A burnt at 1000^{0}C has a strength of 12.1 N/mm^2 which is above the minimum strength of 10 N/mm^2 specified for first class bricks. Samples B, C and D burnt at 1000^{0}C has strength above 7 N/mm^2 hence are second class bricks while for temperatures of 800^{0}C and 900^{0}C has compressive strength below 7 N/mm^2 which are third class.

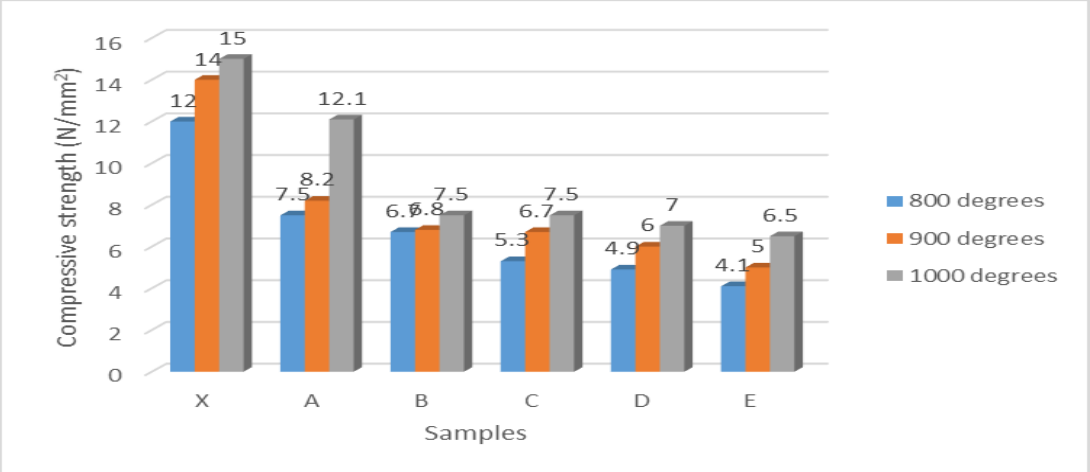


Figure 4.3.2 Compressive strength bricks fired at 800^{0}C, 900^{0}C and 1000^{0}C (dry compressive strength).

Figure 4.4 summarise the results of abrasion test conducted on samples fired at 800^0C, 900^0C and 1000^0C. It was observed that control samples had better resistance to abrasion with a value of about 0.45% of the dry weight of the bricks after firing at the three temperatures. Samples specimen A had an average value of 0.47%, Sample specimen B had an average of 0.48%, sample specimen C with 0.49%. From the result it was observed that abrasion was higher in sample specimen D and E with abrasion value of 0.50% though all the samples at the three temperatures met the requirement specified by BS 812-110: (1990). Guptta and Gupta., (2004) explain that abrasion value should not be more than 30% for wearing surface

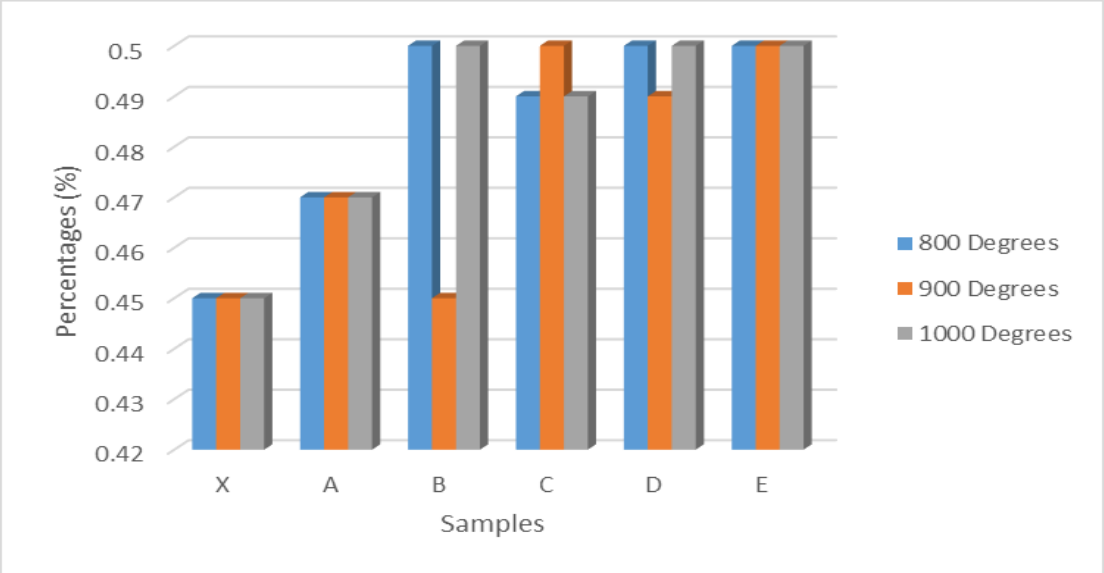


Figure 4.4 Abrasion test on brick samples fired at 800^0C, 900^0C and 1000^0C

Figure 4.5 shows that the water absorption was less in the control with 11%, 11.5% and 12.8% increase in its dry weight at temperatures of 800^0C, 900^0C and 1000^0C respectively. Sample specimen A had water absorption capacity of 13%, 13.14% and 14% at temperatures of 800^0C, 900^0C and 1000^0C respectively. Sample C had 13.8%, 14.4% and 14.8% while Sample specimen E burnt at 800^0C, 900^0C and 1000^0C had 15%, 15.2% and 15.4% increase in its dry weight respectively. It was observed that the additives burn out leaving pores in the bricks, retaining water and increasing it's water bearing capacity. It was also observed that as the percentage of sawdust increases with

decrease in polythene the water absorption capacity increases. From fig 4.5 it can be seen that the samples met the requirement of water absorption of first class bricks as specified by (IS: 1077) which states that the water absorption should not exceed 12-15% of its dry weight.

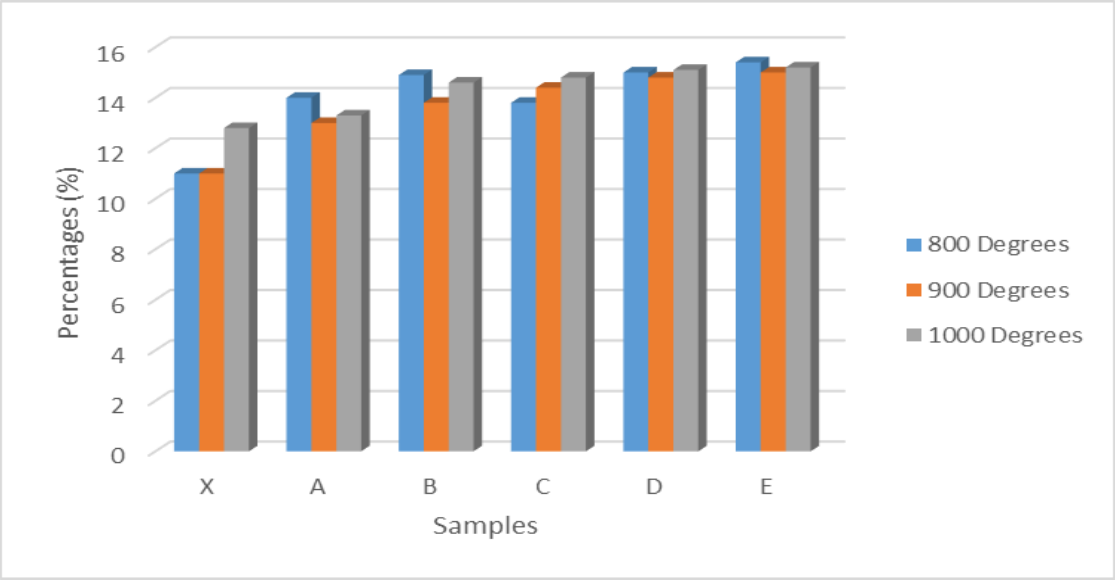


Figure 4.5 showing water absorption in brick samples fired at 800^0C, 900^0C and 1000^0C

4.6. Samples exposed to sulphuric acid

Table 4.6.1 summarises the result of compressive strength of burnt bricks fired at 800^0C and exposed to severe concentration of 2% sulphuric acid solution and water for a period of 30days, 60days and 90days. The control samples decreased in compressive strength by 10% to 38% when exposed in sulphuric acid between 30days to 60 days and 60 to 90days of exposure to sulphuric acid respectively. Control samples in water over same period reduced in compressive strength by 9% to 34%. Specimen sample A exposed to same acidic concentration decrease in compressive strength by 3% and 8% within 30days to 60days and 60 to 90 days of exposure. In water the specimen sample A decreases by 2%-12% in compressive strength within 30 to 60days and 60days to 90days of exposure respectively. Sample C decreases in compressive strength by 15% to 34%, and 8% to 33% when exposed to acid

concentration and water within 30days to 60days and 60days to 90days respectively. Sample specimen E in concentration of sulphuric acid decreases in compressive strength by7% and 13% and decreases by 3% to 6% in water within 30days to 60days and 60days to 90days of exposure. It can be deduced that bricks fired at 800^{o}C had reduction in strength values in all environments with more damaging effect in H_2SO_4. This confirms the result of Adjei, H., D. (2014) which stated that the bricks fired at 800^{o}C had reduction in strength values in all environments with more damaging effect in Na_2SO_4.

Table 4.6.1 Bricks fired at 800^{0}C exposed to sulphuric acid

S/N	Samples	Compressive Strength N/mm^2					
		After 30days		After 60days		After 90days	
		Acid	water	Acid	Water	Acid	Water
1	X	11.2	11.4	10.0	10.2	7.0	7.5
2	A	6.5	6.7	6.3	6.5	6.0	6.3
3	B	6.2	6.4	6.2	6.2	5.0	5.9
4	C	6.1	6.1	5.2	5.6	4.0	4.0
5	D	4.9	5.3	4.5	4.8	4.1	4.5
6	E	3.3	3.8	3.2	3.5	3.1	3.3

Source: Laboratory research work (2016)

Table 4.6.2 summarises the result of compressive strength of burnt bricks fired at 900^{0}C and exposed to severe concentration of 2% sulphuric acid solution and water for a period of 30days, 60days and 90days. The control samples decreased in compressive strength by 6.2% to 29% when exposed in sulphuric acid between 30days to 60 days and 60 to 90days of exposure to sulphuric acid respectively. Control samples in water over same period decrease in compressive strength by 8% to 26%. Specimen sample A exposed to same acidic concentration decrease in compressive strength by 12% and 16% within 30days to 60days and 60 to 90 days of exposure. In water the specimen sample A decreases by 11%-13% in compressive strength within 30 to 60days and 60days to 90days of exposure respectively. Sample C decreases in compressive strength by 5% to 14%, and 2% to 5% when exposed to acid

concentration and water within 30days to 60days and 60days to 90days respectively. Sample specimen E in concentration of sulphuric acid decreases in compressive strength by7% and 17% and decreases by 4% to 8% in water within 30days to 60days and 60days to 90days of exposure. This results shows that bricks fired at 900^{o}C had reduction in strength values in all environments with more damaging effect in H_2SO_4. It implies that the acid concentration is a more aggressive media to the specimen than when they are exposed in water over same period of time and condition. This also could be attributed to the sulphuric acid reacting with calcium oxide in the chemical compositions of the clay weakens the bond with a decrease in strength (Gupta and Gupta, 2012).

Table 4.6.2 Bricks fired at 900^{0}C exposed to sulphuric acid

S/N Samples		Compressive Strength N/mm^2					
		After 30days		After 60days		After 90days	
		Acid	water	Acid	Water	Acid	Water
1	X	11.3	11.8	10.6	10.9	8.0	8.7
2	A	7.7	7.9	6.8	7 .0	6.5	6.9
3	B	6.5	6.8	6.4	6.6	6.0	6.3
4	C	5.8	6.0	5.5	6.0	5.0	6.1
5	D	4.9	5.1	4.3	5.3	3.9	5.2
6	E	4.1	5.0	3.8	4.8	3.4	4.6

Source: Laboratory research work (2016)

Table 4.6.3 summarises the result of compressive strength of burnt bricks fired at 1000^{0}C were also exposed to severe concentration of 2% sulphuric acid solution and water for a period of 30days, 60days and 90days. The control samples decreased in compressive strength by 11% to 18% when exposed in sulphuric acid between 30days to 60 days and 60 to 90days of exposure to sulphuric acid respectively. Control samples in water over same period decrease in compressive strength by 15% to 24%. Specimen sample A exposed to same acidic concentration decrease in compressive strength by 10% and 32% within 30days to 60days and 60 to 90 days of exposure. In water the specimen sample A decreases by 3%-12% in compressive strength within 30

to 60days and 60days to 90days of exposure respectively. Sample C decreases in compressive strength by 18% to 25%, and 7% to 10% when exposed to acid concentration and water within 30days to 60days and 60days to 90days respectively. Sample specimen E in concentration of sulphuric acid decreases in compressive strength by 3% and 22% and decreases by 2% to 9% in water within 30days to 60days and 60days to 90days of exposure. In comparism with Bricks fired at 800^{o}C and 900^{o}C had reduction in strength values in all environments with more damaging effect in H_2SO_4. The results show that burnt bricks fired at higher temperatures are more durable and have better chances of survival in aggressive environments than bricks fired at low temperatures over a period of 90days. It can therefore be concluded that brunt bricks fired at high temperatures have high durability in aggressive environments.

Table 4.6.3 Bricks fired at 1000^{0}C exposed to sulphuric acid

S/N	Samples	Compressive strength N/mm^2					
		After 30days		After 60days		After 90days	
		Acid	water	Acid	Water	Acid	Water
1	X	12.0	13.2	10.7	11.2	9.8	10.0
2	A	8.0	12.0	7.8	10.8	7.1	8.2
3	B	6.3	9.2	6.0	8.0	6.8	7.7
4	C	6.1	8.2	5.7	6.1	5.8	6.7
5	D	5.0	6.9	4.9	6.0	4.0	5.6
6	E	5.0	5.8	4.9	5.6	3.9	5.3

Source: Laboratory research work (2016)

4.7 Exposure to Elevated temperatures

Figure 4.7 summarises the compressive strength test carried out on bricks exposed to elevated temperature of 1100^{0}C. Average compressive strength of 16N/mm^2 was obtained on the control samples. A drop in strength was recorded by 18% in specimen sample A. Samples B with average compressive strength of sample B,C,D decreased by 38%, 44% and 56% respectively. The lowest strength of 63% decrease was obtained in sample E. the control, sample specimen A and B having strength above

10N/mm^2 are classified as first class burnt bricks and they are recommended for flooring, mansonry structures and reinforced brick works while Samples C, D, and E also have appreciable strength above 7N/mm^2 and are classified as second class bricks (Duggal, 2008).

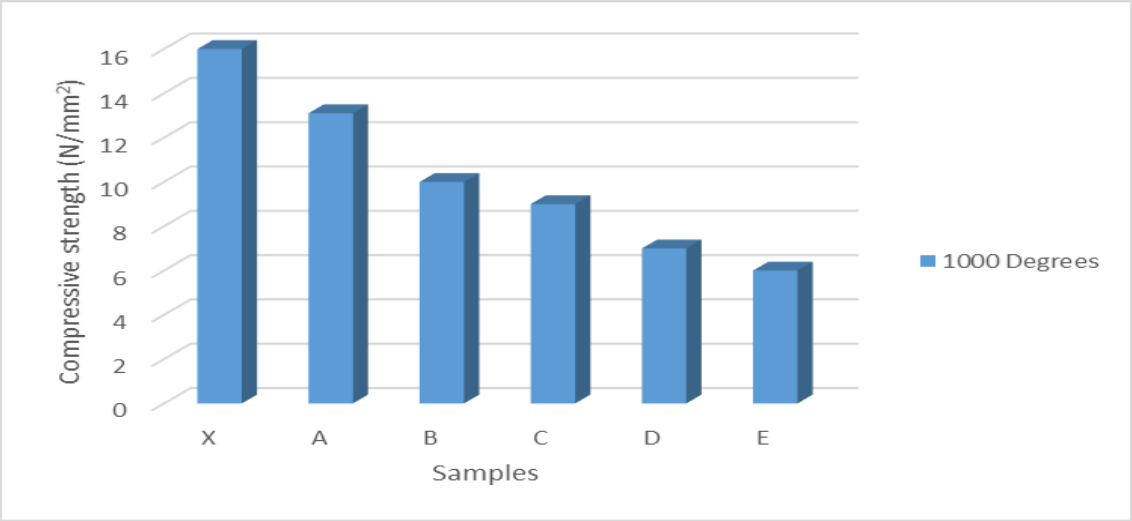


Figure 4.7 ***Bricks exposed to elevated temperature of 1100^{0}C (dry compressive strength)***

4.7.1 Bricks fired at 1200^{0}C

The bricks produced at this temperature were over burnt. They had cracks on the faces and lateral cracks by the side of the bricks attributed to the internal heating contributed by the additives. They had black and glassy honey comb spots/patches of the melted polythene on the surface of the bricks.

4.7.2 Bricks fired at 1300^{0}C

The bricks are over burnt and starts melting at temperature of 1300^{0}C. The bricks produced were dark red in colour. The bricks were distorted and have no regular shape. This could be attributed to the pores produced as the additives are burnt out which permits heat to reach into the inner most part of the core, thereby avoiding unburnt cores while the additives serves as extra fuel which provides more heat for the firing (Emmanuel A. O., 2008).

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of the Research Findings

The study was conducted to assess the effect of polythene and sawdust on the properties of burnt bricks. The burnt bricks made were tested and compared for dry and cold compressive strength, abrasion resistance and water absorption, strength on exposure to elevated temperature and strength on exposure to sulphuric acid. The highlight of the major findings are as follows.

1. In terms of compressive strength, the control burnt at 800, 900, 1000 has higher cold compressive strength of 9N/mm, 12N/mm and 14N/mm respectively while the dry compressive strength of 12N/mm, 14N/mm and 15N/mm.

2. Samples A containing 20% polythene burnt at 800^{o}C, 900^{o}C and 1000^{o}C has cold compressive strength of 7N/mm, 8.2N/mm and 9.4N/mm and dry compressive strength of 7.5N/mm, 8.2N/mm and 12.1N/mm respectively which has better performance in terms of strength than sample E containing 20% sawdust with cold compressive strength of 4N/mm, 5N/mm and 5.6N/mm and dry compressive strength of 4.1N/mm, 5N/mm and 6.5N/mm respectively.

3. The density of the specimen samples was reduced to about 10% of the weight of the control samples after the firing process and the samples specimens had pore holes in them.

4. Bricks burnt at temperatures of 800^{0}C, 900^{0}C and 1000^{0}C exhibited water absorption capacity of 11%, 11.5% and 12.8% in the control samples respectively. Sample specimen A and C had water absorption capacity of 13%, 13.14% and 14% and 13.8%, 14.4% and 14.8% respectively while Sample specimen E with 15%, 15.2% and 15.4%.

5. The control and the samples made with additives showed about 0.5% resistance to abrasion at three firing temperatures. Therefore this fall within the range specified by Gupta and Gupta, (2004) which varies from 0 to 1.0.

5.2 Conclusions

Based on the experimental results obtained from this study, observations and analysis on the properties of burnt bricks made with polythene and sawdust additives. The following conclusions are drawn.

1. The XRF chemical analysis of Bomo clay shows that it has satisfied the (B.S. 1377) requirement of clay as a good material for burnt bricks.

2. In terms of the physical and mechanical performance, regarding to dry and cold compressive strength, abrasion resistance. The samples meet the minimum compressive strength requirement at 800^0C, 900^0C, 1000^0C and 1100^0C the firing temperatures and they have good resistance to abrasion.

3. Based on analysis of the results obtained the samples with additives are more stabilized before firing than the control, though higher strength was obtained in the control than the samples with additives and both samples met with the specified standards as specified by IS 1077 (1992)

4. Samples with additives shows more distortion at elevated temperature of 1200^0C and 1300^0C and begin to melt as compared with samples without additives meaning the additives contribute to internal heating to the bricks during firing.

5. Bricks fired at higher temperatures are more durable. Bricks fired at 800^oC, 900^oC, and 1000^oC had reduction in compressive strength values in all environments with more damaging effect in H_2SO_4 compared to water.

6. Light weight bricks are manufactured when polythene and sawdust are used in the production of burnt bricks and also they contribute to internal heating within the bricks.

5.3 Recommendations

1. The physical and chemical properties of Bomo clay established that it is a good material for burnt bricks production.

2. The bricks at temperatures of 800^0C, 900^0C, 1000^0C and 1100^0C could be used for load bearing walls and non-load bearing walls as they met the NIS 87:2004 specification which stipules a compressive strength of 2.8N/mm^2 for load bearing walls and 2.0N/mm^2 for non-load bearing walls.

3. Firing temperature of bricks made with polythene and sawdust as additives should not exceed 1100^0C because above this temperature bricks with additives are badly distorted which could be attributed to the heating contributed by the additives.

5.4 Recommendation for Further Studies

4. Further studies should also be conducted on bricks containing different percentages of polythene and sawdust separately and their characteristics compared.

5. Further studies should be carried out to compare the characteristics of burnt bricks made with same additives with different sources of clay.

6. Further studies should be carried out using higher percentages of the additives of 25-50% replacement and its behaviour in aggressive environment assessed.

7. Research on fire resistance, shrinkage, porosity, tensile and flexural strength of burnt bricks made with sawdust and polythene should be considered.

5.5 Contributions to Knowledge

1. The research reveals that burnt bricks combined with sawdust and polythene at 800^0C has minimum wet compressive strength of 4N/mm^2 than the conventional burnt bricks with compressive strength of 9N/mm^2 nevertheless they comply with the minimum standard of 3.5N/mm^2 specified for burnt bricks.

2. It was established that bricks made with polythene and sawdust can be used in production of light weight bricks and used for the construction of buildings as a walling material.

3. Moderate concentration of 2% Sulphuric acid is a more aggressive media to burnt bricks than when they are exposed in water over same period of time and condition. It reduces the compressive strength of the control burnt at 800^0C by 5% to 41% within 30days to 90days of exposure.

REFERENCES

Adjei H. D., (2014). Durability of locally produced burnt clay bricks. Kwame Nkrumah University of Science and Technology Kumasi, Ghana. 58-66.

Alonso-Santurde, R., Coz, A., Viguri, J. R., Andres, A., (2012). Recycling of foundry by-products in the ceramic industry: Green and core sand in clay bricks. Construction and Building Materials 27, 97–106.

ASTM (1982): Annual Book of ASTM Standards, Part 17: Refractories, Glass, Ceramic Materials, Carbon and Graphite Products Philadelphia; 7- 15, 18, 51 - 55, 59 - 61, 190- 93, 498 – 510.

ASTM, (2001). ASTM C 67-99a, Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile. Annual Book of Standards. Vol. 04.05, American Society for Testing and Materials, West Conshohocken, PA.

American Society for Testing and Material (1992). Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile.

American Society for Testing and Material (2005). Test method for Abrasion Resistance of Horizontal concrete surface. *Annual Book of ASTM Standards;* (4)2.

Ayangade, J. A., Olusola, K. O., Ikpo, I. J. and Ata, O. (2004). Effect of granite dust on the performance characteristics of kernelrazzo floor finish. *Building and Environment*, 39, 1207 – 1212.

Barnes, D. K. A., Galgani F., Thompson R. C., & Barlaz M., (2009). Accumulation and fragmentation of plastic debris in global environments. Philos Trans R Soc B Biol Sci 364: 1985–1998.

Binda, L., Saisi A., & Tiraboschi C., (2000). Investigation procedures for the diagnosis of historic masonries, Construction and Building Materials, 14, 99-233

British Standard 812 part 2 (1995). Testing aggregate part 2. Methods of determination of density. BSI Publication British Standard Institution, London.

British Standard Institute, (1990). BS3797 Specification for lightweight aggregates for masonry units and structural concrete. BSI, London

British Standard Institution, (1990). Standard methods for test for soils or civil engineering purposes, B.S. 1377, B.S.I., London, 62.

British Standard-EN 196-2 (2005). Chemical Analysis. British Standard Institute, British Standard Board, 389 Chriswick High Road, London W4 4AL.

Brownell, W. E., (1976). *Structural clay products*, New York, 1st Edition Springer-Verlag, 1-5.

Chesti, A. R., (1986). Refractories: *manufacture properties and applications 4th ed.*, Prentice Hall of India, New Delhi, India.

Christy, C., F. Tensing, D. and Shanthi, R., M. (2012). In-plane shear behavior of brick masonry. A literature review on experimental study. *International Journal of Civil and Structural Engineering*, 2(4):1144-1152.

Christy, C. F., Tensing, D. and Shanthi, R.,M. (2013). Experimental study on axial Compressive strength and elastic modulus of the clay and fly ash brick masonry. *Journal of Civil Engineering*, 4(4):134-141.

Christine, B., (2004). *Masonry Design and Detailing: For Architects and Contractors*. 5th Edition. New York, Mc-Graw Hill.

Cultrone, G., Sebastián E., Elert K., de la Torre M. J., Cazalla O., & Rodriguez–Navarro C. (2004). Influence of mineralogy and firing temperature on the porosity of bricks, *J Euro. Ceram. Soc*., 24, 547-564.

Costigan, A. and Pav, S. (2009). A Compressive, flexural and bond strength of brick/lime mortar masonry. International Conference on Protection of Historical Buildings:PROHITEC-09, June 21-24, Rome, pages 1609-1615.

Danupon, T., Perapong, T., & Sarawut, J., (2008). Effects of Rice Husk Ash on Characteristics of Lightweight Clay Brick. *Proceeding Technology and Innovation for Sustainable Development Conference*, Faculty of Engineering, Khon Kaen University, Thailand, 36-39.

Demir, I., (2008). Effect of organic residues addition on the technological properties of clay bricks, *Waste management***,** 28, 622-627.

Dhami, N. K., Reddy, M. S. and Mukherjee, A. (2012). Improvement in strength properties of ash bricks by bacterial calcite. Ecological Engineering, 39:31-35.

Dondi, M., Marsigli, M., & Fabbri, B., (1997). Recycling of Industrial and Urban Wastes in Brick Production-A review (Part 2), *Tile & Brick International*, 13 (4), 302-315.

Dolores R. M., Yebra-Rodriguez A., Dolores E., Francisco A. C., Alberto L., (2012) *Assessment of olive mill solid residue (pomace) as an additive in lightweight brick production*. Construction and Building Materials 36, 495–500

DOW LDPE 5004I. IDES – *The Plastics* Web Edition. New York, Mc-Graw Hill.

environment. Mar Pollut Bull 60: 2279-2283.

Duhham, A. C., McKnight A. S., & Warren I., (2001). Mineral assemblages formed in Oxford Clay fired under different time-temperature conditions with reference to brick manufacture, *Proceedings of the Yorkshire Geological Society Vol*. 53 (3), 221-230.

Emmanuel, A. Okunade, (2008). The Effect of Wood Ash and Sawdust Admixtures on the Engineering Properties of a Burnt Laterite-Clay Brick. *Journal of Applied Sciences* 8, 1042-1048.

Encarta English Dictionary (2009); Website: www.microsoft encarta.com.

Evans, J. L., & White J., (1958). Further studies of the thermal decomposition of clays. Brit. *Franciscana dolphins*, *Pontoporia blainvillei* (Gervais and d'Orbigny, 1844), from Argentina. Mar Pollut Bull.

Faria K. C. P., Gurgel R. F., Holanda J. N. F., (2012). Recycling of sugarcane bagasse ash waste in the production of clay bricks. *Journal of Environmental Management* 101, 7–12.

Folaranmi, J., (2009). Effect of Additives on the Thermal Conductivity of Clay. Leonardo *Journal of Sciences* 8(14), 74-77.

Gupta, B. L., & Gupta A., (2004). *Concrete Technology*, Bhargare Laser Printers, Delhi: Prabhat offset press, Delhi, 121-290.

Gupta, B. L. and Gupta A. (2012). Concrete technology, Published by A. K. Jain. For Standard Publishers Distributors. 1705-B, NaiSarak, Delhi-110006.

Hendry, A. W., & Khalaf, F. M., (2001). *Masonry Wall Construction*. Taylor & Francis Group, Spon Press London and New York.

IS 1077 (1992). Indian Standard: Common Burnt Clay Building Bricks-Specification. 5th Edition. BIS: New Delhi.

Kadir, A. A., & Mohajerani A. A., (2011). Recycling cigarette butts in light-weight fired clay bricks, *Proceedings of the Institution of Civil Engineers* (UK). Vol. 164 (5), 210-229.

Keshava, M., Vijayendra, K., V, and Raghunath, S. (2010). Strength efficiency of commonly used block work masonry. International Journal of Earth Sciences and Engineering, 3(4):586-598.

Krebs, S., & Mortel H. (1999). The use of secondary pore forming agents in brick production. *Tile & Brick International*, 15 (1), 12- 18.

Lederberg, J. (2000). Encyclopedia of Microbiology: D-K. Academic Press, New York.

Liew, A. G., Idris A., Samad A. A., Calvin, Wong H. K., Jaafar M. S., & Aminuddin M. B., (2004). Incorporation of sewage sludge in clay brick and its characterization. *Waste Management & Research*, (22), 226–233.

Lin, K. L., (2006) Feasibility study of using brick made from municipal solid waste Incinerator fly ash slag. *Journal of Hazardous Materials*, 137, 1810-1816.

López-Arce, P., Garcia-Guinea, J., Gracia, M., & Obis, J. (2003) Bricks in historical buildings of Toledo City: Characterization and restoration, Materials Characterization, 50, 59–68

Lumantarna, R., Biggs, D. T. and Ingham J. M. (2012). Compressive, exural bond, and shear bond strengths of in situ new zealand unreinforced clay brick masonry constructed using lime mortar between the 1880s and 1940s. *Journal of Materials in Civil Engineering*, 26(4):559-566.

Lynch, G. C. J., (1994). Bricks: Properties and Classifications. *Structural Survey*, 13 (4), 15-20.

McConville, C. J., & Lee W. E. (2005). Microstructural development on firing illite and smectite compared with that in kaolinite, *J. Am. Ceram*ics. Soc., 88, 2267-2277.

Mamlouk, J. P., & Zaniewski, M. S., (2006). *Materials for Civil and Construction Engineers*, 2nd Edition. Upper Saddle River, New Jersey, Pearson Prentice Hall.

Mato, Y., Isobe, T., Takada H., and Ohtake, C., (2001). Plastic resin pellet as a transport medium for toxic chemical in the environment. *Environ. Science Technology. 318-324*

Mohammad S. A., and Pawade, P. Y. (2014). Reuse of Natural Waste Material for Making Light Weight Bricks *International Journal Of Scientific & Technology Research Volume 3.*

Naliaka R., (2013). *Addressing Solid Waste management*: Reduce, Reuse, Recycle and Respond to waste generation.

Nigerian Standard Organization: Specification for burnt clay building units. Nigeria industrial Standard 74, 1976 UDC 624 0128. Federal Ministry of Industries, Lagos, Nigeria.

Nwobodo, C. S., & Davies T. J., (2000). The effect of apparent porosity on the modulus of rupture of alumina-chromia refractory matrix, *A Paper Presented at FUTO*, Annual Conference of NAMMES. 8.

Our Common Future: *Report of the World Commission on Environment and development"*. UN Documents. n.d. Web. Retrieved 27 June 2015.< http://www.un-documents.net/ocf-02.htm>

Palanisamy, M. and Premalatha, J. (2012). Experimental study on masonry in wall material properties. *International Journal of Scientific and Engineering Research*, 3(7).

Pappu, A., Saxena M., & Asolekar S. R., (2007). Solid waste generation in India and their recycling potential in building material. *Journal of Building and Environment.* Vol. - 42, 2311-2320, 2007.

Pimraksa, K., Wilhelm, M. and Wruss, W. (2001). A New Approach to the Production of Bricks made of 100% *Fly Ash Tile and Brick Int.*16, 428-433.

Pauri, M., Stazi A., Mastrosanti F., & D'Orazio M., (1994) The decay of ancient building masonry, a case study. In: *10th international brick/block masonry conference, Calgary*, 1295–1304.

Rajput, R. K. (2006). *Engineering Materials,* S. Chand & Company Limited, New Delhi, India.

Rasmussen, K. L., De La Fuente G. A., Bond A. D., Matheesen K. K. & Vera S. D. (2012). Pottery firing temperatures: *A new method for determining the firing temperature of ceramics and burnt clay, Journal of Archaeological Science* Vol. 39, 1705-1716.

Raut S. P., Rohant S., Sunil D., Ralegaonkar R.V., Sachin A., Mandavgane A., (2011). *Reuse of recycle paper mill waste in energy absorbing light weight bricks.* Construction and Building Materials 27, 247–251

Ravi, S., Selvakumar, V., Thanikasalapradeep, N., Srinivas, V. and Premavathi, N. (2014). Experimental and numerical investigations on material behaviour of brick masonry. 2nd *International Conference on Research in Science, Engineering and Technology*, March 21-22,Dubai (UAE).

Rouf, M. A., & Hossain M. D., (*2003*). Effects of using arsenic-iron sludge in brick making. *Fate of Arsenic in the Environment, Proceedings of the BUET-UNU International Symposium, 5–6 February, Dhaka, Bangladesh*, 193-208.

Rushad, S. T., Kumar A., Duggal, S. K. and Mehta, P.K. (2012). Experimental studies on lime-soil-ash bricks. *International Journal of Civil and Structural Engineering*, 1(4):994-1002.

Rutkowska, M., Heimowska, A., Krasowska, K., & Janik, H., (2002). Biodegradability of Polyethylene Starch Blends in Sea Water. *Polythene Journal for Environmental Studies* 11: 267-274.

Sanjay, N. P., Anil, K. G. and Subhash, S. D. (2013). Metakaolin- Pozzolanic Material for Cement in High Strength concrete. In: *Proceeding of the 2nd international Conference on Emerging Trends in Engineering* (SICETE' 13), 46-49.

Shakir, A. A., Naganathan, S. and Mustapha K., N. (2013). Properties of bricks made using fly ash, quarry dust and billet scale. Construction and Building Materials, 41:131-138.

Singh B., (2005). Harmful effect of plastic in animals. The Indian Cow 2: 10-18.

Tay, J. H., Show K. Y., & Hong S. Y., (2001). The application of industrial sludge and marine clay in brick making. *Proceedings of IWA Conference on Sludge Management Entering the 3rd Millennium. IWA, 25-28 March, Taipei, Taiwan.*R.O.C., 702-704.

Tay, J. H., Show K. Y., Wang J. Y., & Hong S. Y., (2002). Constructive approach for sludge management-new resource from sludge. *Proceedings Second International Workshop on Recycling, Japan National Institute of Advanced Industrial Science and Technology, 2-5 December, Tsukuba, Japan*.

Vekey, R. C., (1998) *Brickwork and blockwork,* In: Illston J. M. (ed) Construction materials—their nature and behaviour. E & FN SPON, London, 251–315.

Vidhya, K., Kandasamy, S., Malaimagal, U., Karthikeyan, U., Basha, G.S. and Junaid, T. H. (2013). Experimental studies on pond ash brick. *International Journal of Engineering Research and Development*, 6(5):06-11.

Vieira, C. M. F., Andrade, P. M., Maciel, G. S., Vernilli, Jr. F., & Monteiro, S. N., (2006). Incorporation of Fine Steel Sludge Waste into red Ceramic, *Material Science and Engineering*, 427(1-2)**,** 142–147.

Vimala, S. and Kumarasamy, K.(2014). Studies on the strength of stabilized mud block masonry using different mortar proportions. *International Journal of Emerging Technology and Advanced Engineering*, 4(4):720-724.

Weaver, P., Jansen, L., van Grootveld, G., van Spiegel, E., & Vergragt, P., (2000). *Sustainable technology development. Greenleaf Publishing*: Sheffield, UK.

Winslow, D. N., Kilgour C. L., & Crooks R. W., (1988). Predicting the durability of bricks. ASTM *Journal of Testing and Evaluation*, 16(6), 527–531.

Wikipedia (2011); Wikipedia: the Free Encyclopaedia –Burnt Bricks, http//en.wikipedia.org. (Accessed, 13th June.)

List of Figures

Figures in the research work



Plate I Clay sieved with 5mm sieve



Plate II Sawdust samples.



Plate III Shredder used for cutting polythene



Plate IV Shredded polythene



Plate V unburnt specimen samples made



Plate VI Arrangement of bricks before and after firing at 800^0C



Plate VII Collapse of biometric cone in the kiln at 800^0C



Plate VIII showing bricks after firing at 900^0C



Plate IX showing samples fired at 1000^0C



Plate X specimen samples fired at 1100^0C





Plate XI Burnt specimen samples distorted after burning in kiln at 12000^0C



Plate XII Abrasion test on sample



Plate XIII Collapsed pycometric cone after firing

List of Tables

Table *4.2.4.1* Sample description: Grayey clay

Samples no.	1	2	3	4
Moisture can and lid number	11	1	5	4
Mc=Mass of empty, clean can + lid (grams)	22.23	23.31	21.87	22.58
M_{CMS}= Mass of can, lid and moist soil (grams)	28.56	29.27	25.73	25.22
$M_{CDS=}$ Mass of can, lid and dry soil (grams)	27.40	28.10	24.90	24.60
$M_{s=}$ Mass of Soil solids (grams)	5.0	4.79	3.03	2.02
M_w= Mass of pores water (grams)	1.16	1.17	0.83	0.62
w= Water Content w%	23.06	24.43	27.39	30.69
No. of drops (N)	31	29	20	14

Table 4.3.1 Wet Compressive Strength of Samples fired

S/N	Samples	Density	Compressive Strength (N/mm^2)		
			800^{0}C	900^{0}C	1000^{0}C
1.	X	2.52	9.0	12.0	14.0
2.	A	2.36	7.0	8.2	9.4
3.	B	2.38	6.5	6.9	7.1
4.	C	2.30	6.0	6.6	6.7
5.	D	2.28	4.5	5.6	6.0
6.	E	2.28	4.0	5.0	5.6

Source: Laboratory research work (2016)

Table 4.3.2 Dry Compressive Strength of Samples fired

S/N	Samples	Density	Compressive Strength (N/mm^2)		
			800^{0}C	900^{0}C	1000^{0}C
1.	X	2.27	12.0	14.0	15.0
2.	A	2.07	7.5	8.2	12.1
3.	B	2.07	6.7	6.8	7.5
4.	C	2.02	5.3	6.7	7.5
5.	D	1.98	4.9	6.0	7.0
6.	E	1.98	4.1	5.0	6.5

Source: Laboratory research work (2016)

Table 4.4.1 Abrasion for samples at 800^{0}C

S/N	Samples	Initial weight	Final Weight
1	X	2.27	2.26
2	A	2.07	2.06
3	B	2.07	2.06
4	C	2.02	2.01
5	D	1.98	1.97
6	E	1.98	1.97

Source: Laboratory research work (2016)

Table 4.4.2 Abrasion for samples at 900^0C

S/N	Samples	Initial Weight	Final Weight
1	X	2.28	2.27
2	A	2.11	2.10
3	B	2.10	2.10
4.	C	2.12	2.27
5.	D	2.15	2.10
6.	E	2.12	2.10

Source: Laboratory Research Work (2016)

Table 4.4.3 Abrasion for Samples at 1000^0C

S/N	Samples	Initial weight	Final Weight
1	X	2.28	2.27
2	A	2.08	2.07
3	B	2.14	2.13
4	C	2.09	2.08
5	D	2.02	2.01
6	E	2.05	2.04

Source: Laboratory research work (2016)

Table 4.5.1 Water absorption of samples fired at 800^0C

S/N	Samples	Weight b4 emersion	Water absorption (%)
1.	X	2.27	11.0
2.	A	2.07	14.0
3.	B	2.07	14.9
4.	C	2.02	13.8
5.	D	1.98	15.0
6.	E	1.98	15.4

Source: Laboratory Research Work (2016)

Table 4.5.2 Water absorption of samples fires at 900^0C

S/N	Samples	Weight before Emersion	Water Absorption (%)
1	X	2.35	11.0
2	A	2.11	13.0
3	B	2.10	13.8
4.	C	2.08	14.4
5.	D	1.99	14.8
6.	E	2.0	15.0

Source: Laboratory Research Work (2016)

Table 4.5.3 Water Absorption of samples fired at 1000^0C

S/N	Samples	Weight before Emersion	Water Absorption (%)
1.	X	2.28	12.8
2.	A	2.08	13.14
3.	B	2.14	14.6
4.	C	2.09	14.8
5.	D	2.02	15.12
6.	E	2.05	15.18

Source: Laboratory research work (2016)

Table 4.7.1 Bricks fired at 1100^0C

S/N	Samples	Density	Compressive strength (N/mm^2)
1.	X	2.27	16.0
2.	A	2.07	13.1
3.	B	2.07	10.0
4.	C	2.02	9.0
5.	D	1.98	7.0
6.	E	1.98	6.0

Source: Laboratory research work (2016)

Appendices

Appendix I

Bulk Density of Materials

Determined using a mould size 100x100x100

Clay=1550g

Sawdust=200g

Polythene=100g

Bulk density of clay using a mould 230x110x70

Therefore, Clay=2.4kg at volume of 0.001575m^3

Add 10% waste 2.4+0.24 = 2.64kg

Samples X: 2.4kg

0.8 x 2.4= 1.92kg

Add 10% waste = 1.92+0.0192

Total=1.933kg

Sample A: 20% polythene = 0.20 x 2.4= 0.48kg

Add 10% waste = 0.48+0.048= 0.56kg

Total quantity of material=2.50kg

Sample B: 15% Polythene= 0.15x2.4=0.36kg

Add 10% waste =0.36+0.036=0.396kg

5% sawdust = 0.05x 2.4= 0.12kg

10% waste for sawdust = 0.12+0.012= 0.132kg

Total=2.5kg

Sample C: 10% sawdust and 10% polythene

For polythene

0.10x2.4=0.24kg

Add 10% waste: 0.24+0.024= 0.264kg

Sawdust: 0.10x2.4=0.24kg

Add 10% waste: 0.24+0.024= 0.264kg

Total=0.264+0.264+1.933= 2.5kg

Sample D: 15% Sawdust= 0.15x2.4=0.36kg

Add 10% waste =0.36+0.036=0.396kg

5% polythene = 0.05x 2.4= 0.12kg

10% waste = 0.12+0.012= 0.132kg

Total=2.5kg

Sample E: 20% polythene. 0.20 x 2.4= 0.48kg

Add 10% waste = 0.48+0.048= 0.56kg

Total quantity of material=0.56+1.933

=2.50kg

Appendix II

Specific gravity

$$(G_S) = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

Where: W_1 = Weight of density bottle

W_2 = Weight of density bottle + Sample

W_3 = Weight of density bottle + Water (full) + Sample

W_4 = Weight of density bottle + Water (full)

$$(G_S) \text{ of clay} = \frac{840 - 680}{(1680 - 680) - (1760 - 840)}$$

$= 2.0$

$$(G_S) \text{ of sawdust} = \frac{860 - 680}{(1680 - 680) - (1740 - 860)}$$

$= 1.5$

$$(G_S) \text{ of polythene} = \frac{900 - 680}{(1680 - 680) - (1720 - 900)}$$

$= 1.2$

Appendix III

Abrasion resistance $= \frac{W_1 - W_2}{W_2} \times 100$ …….. (3.4)

Where,

$W_{1=}$ Initial weight of a concrete specimen

$W_{2=}$ Final weight of the specimen

Samples fired at 800^0C

Samples X = $\frac{2.3 - 2.29}{2.29}$ x 100 = 0.45%

Samples A = $\frac{2.13 - 2.12}{2.12}$ x 100 = 0.47%

Samples B = $\frac{2.02-2.01}{2.01} \times 100 = 0.5\%$

Samples C = $\frac{2.06-2.05}{2.05} \times 100 = 0.49\%$

Samples D = $\frac{1.98-1.97}{1.97} \times 100 = 0.5\%$

Samples E = $\frac{1.95-1.94}{1.94} \times 100 = 0.5\%$

Samples fired at 900^0C

Samples X = $\frac{2.34-2.32}{2.32} \times 100 = 0.45\%$

Samples A = $\frac{2.15-2.14}{2.14} \times 100 = 0.47\%$

Samples B = $\frac{2.04-2.03}{2.03} \times 100 = 0.5\%$

Samples C = $\frac{2.16-2.15}{2.15} \times 100 = 0.49\%$

Samples D = $\frac{2.10-2.11}{2.11} \times 100 = 0.5\%$

Samples E = $\frac{2.10-2.09}{2.09} \times 100 = 0.5\%$

Samples fired at 1000^0C

Samples X = $\frac{2.28-2.27}{2.27} \times 100 = 0.45\%$

Samples A = $\frac{2.08-2.07}{2.07} \times 100 = 0.47\%$

Samples B = $\frac{2.14-2.13}{2.13} \times 100 = 0.5\%$

Samples C = $\frac{2.09-2.08}{2.08} \times 100 = 0.49\%$

Samples D = $\frac{2.02-2.01}{2.01} \times 100 = 0.5\%$

Samples E = $\frac{2.05-2.04}{2.04}$ x 100 = 0.5%

Appendix IV

Water absorption test

Percentage Water Absorption = $\frac{\text{Wet weight - Dry weight}}{\text{Dry weight}}$ x 100……. (3.5)

Samples Fired at 800^0C

Samples X = $\frac{2.61-2.27}{2.27}$ x 100 = 11%

Samples A = $\frac{2.39-2.07}{2.07}$ x 100 = 13%

Samples B = $\frac{2.39-2.1}{2.1}$ x 100 = 13.8%

Samples C = $\frac{2.38-2.02}{2.02}$ x 100 = 14.4%

Samples D = $\frac{2.29-1.98}{1.99}$ x 100 = 14.8%

Samples E = $\frac{2.34-1.98}{1.98}$ x 100 = 15%

Samples Fired at 900^0C

Samples X = $\frac{2.61-2.35}{2.35}$ x 100 = 11%

Samples A = $\frac{2.39-2.11}{2.11}$ x 100 = 13%

Samples B = $\frac{2.39-2.1}{2.1}$ x 100 = 13.8%

Samples C = $\frac{2.38-2.08}{2.08} \times 100 = 14.4\%$

Samples D = $\frac{2.29-1.99}{1.99} \times 100 = 14.8\%$

Samples E = $\frac{2.34-2.04}{2.04} \times 100 = 15\%$

Samples Fired at 1000^0C

Samples X = $\frac{2.61-2.28}{2.28} \times 100 = 11\%$

Samples A = $\frac{2.39-2.08}{2.08} \times 100 = 13\%$

Samples B = $\frac{2.39-2.14}{2.14} \times 100 = 13.8\%$

Samples C = $\frac{2.38-2.09}{2.09} \times 100 = 14.4\%$

Samples D = $\frac{2.29-2.02}{2.02} \times 100 = 14.8\%$

Samples E = $\frac{2.34-2.05}{2.05} \times 100 = 15\%$

Appendix V

Compressive Strength

Compressive strength (N/mm^2) = $\frac{\text{load at failure}}{\text{Cross sectional area of section}}$

Wet compressive strength

Samples Fired at 800^0C

Samples X = $\frac{189,000}{21000} = 9N/mm^2$

Samples A = $\frac{147,000}{21000} = 7N/mm^2$

Samples B = $\frac{136,500}{} = 6.5N/mm^2$

21000

Samples C = $\frac{126,000}{21000}$ = 6N/mm^2

Samples D = $\frac{94,500}{21000}$ = 4.5N/mm^2

Samples E = $\frac{84,000}{21000}$ = 4N/mm^2

Samples Fired at 900^{0}C

Samples X = $\frac{252,000}{21000}$ = 12N/mm^2

Samples A = $\frac{172,000}{21000}$ = 8.2N/mm^2

Samples B = $\frac{144,900}{21000}$ = 6.9N/mm^2

Samples C = $\frac{138,600}{21000}$ = 6.6N/mm^2

Samples D = $\frac{117,600}{21000}$ = 5.6N/mm^2

Samples E = $\frac{105,000}{21000}$ = 5N/mm^2

Samples Fired at 1000^{0}C

Samples X = $\frac{294,000}{21000}$ = 14N/mm^2

Samples A = $\frac{197,400}{21000}$ = 9.4N/mm^2

Samples B = $\frac{149,000}{21000}$ = 7.1N/mm^2

Samples C = $\frac{140,700}{21000}$ = 6.7N/mm^2

Samples D = $\frac{126,000}{21000}$ = 6N/mm^2

Samples E = $\frac{117,600}{21000}$ = 5.6N/mm^2

Dry compressive strength

Samples Fired at 800^0C

Samples X = $\frac{252,000}{21000}$ = 12N/mm^2

Samples A = $\frac{157,500}{21000}$ = 7.5N/mm^2

Samples B = $\frac{140,700}{21000}$ = 6.7N/mm^2

Samples C = $\frac{111,300}{21000}$ = 5.3N/mm^2

Samples D = $\frac{102,900}{21000}$ = 4.9N/mm^2

Samples E = $\frac{86,100}{21000}$ = 4.1N/mm^2

Samples Fired at 900^0C

Samples X = $\frac{294,000}{21000}$ = 14N/mm^2

Samples A = $\frac{172,200}{21000}$ = 8.2N/mm^2

Samples B = $\frac{142,800}{21000}$ = 6.8N/mm^2

Samples C = $\frac{140,700}{21000}$ = 6.7N/mm^2

Samples D = $\frac{126,000}{21000}$ = 6N/mm^2

Samples E = $\frac{105,000}{21000}$ = 5N/mm^2

Samples Fired at 1000^0C

Samples X = $\frac{315,000}{21000}$ = 15N/mm^2

Samples A = $\frac{254,100}{21000}$ = 12.1N/mm^2

Samples B = $\frac{157,500}{21000}$ = 7.5N/mm^2

Samples C = $\frac{151,500}{21000}$ = 7.5N/mm^2

Samples D = $\frac{147,000}{21000}$ = 7N/mm^2

Samples E = $\frac{136,500}{21000}$ = 6.5N/mm^2

Dry compressive strength of samples fired at 1100^{0}C

Samples X = $\frac{336,000}{21000}$ = 16N/mm^2

Samples A = $\frac{275,100}{21000}$ = 13.1N/mm^2

Samples B = $\frac{210,000}{21000}$ = 10N/mm^2

Samples C = $\frac{189,000}{21000}$ = 9N/mm^2

Samples D = $\frac{147,000}{21000}$ = 7N/mm^2

Samples E = $\frac{126,000}{21000}$ = 6N/mm^2