QUALITY OF SANDCRETE BLOCKS PRODUCED IN KANO STATE

BY

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CERTIFICATION

This thesis entitled "Quality of Sandcrete blocks produced in Kano State" by Mohammed, Musa meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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D E C L A R A T I O N

I hereby declare that this thesis is a record of my own research work. It has not been presented by me in any previous application for a higher degrees.



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D E D I C A T I O N

This thesis is dedicated to the entire members of my family, my wife Mallama Halima Musa Mohammed and my sister Hajiya Amina Muhammad in Particular.

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ABSTRACT

The thesis aims at studying the quality of the sandcrete blocks produced in Kano State and as such journals, codes, standards and other research materials were consulted and looked into carefully.

The tests carried out include development strength test (wet and dry), wet compressive test, drying shrinkage, moisture movement and density in accordance with established standards the details of which are presented in chapter three.

The last chapter (chapter 4) discusses the findings of the research oy indicating that the quality of sandcrete blocks produced in Kano is low since the compressive strength lies between (0.25 and 0.92) N/mm^2 compared with the minimum value of 2.50 N/mm^2 specified by the code.

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CHAPTER ONE

INTRODUCTION

Sandcrete blocks are the most prominent of the concrete masonry units in the building industry today especially in the construction of residential, industrial and commercial buildings. They could be used as external walls of buildings (i.e. 460mm thick blocks or as partition walls (150mm thick blocks and are usually non load bearing). They are made from a cement/sand mix usually 1 part of cement to 6 or 8 parts of sand (1:6 or 1:8) with a water/ cement ratio of between fifty and seventy five (75%) percent.

Historically, most concrete masonry units are manufactured on the local level and industry standards are not always adhered to. Variations in shape, size and surface texture are common features. There is no complete standardisation of sizes in the industry for sandcrete blocks and sizes must be checked in each locality.

This thesis investigates into the development strength tests (wet and dry), the wet compressive strength tests, shrinkage, moisture movement and the mode of production of sandcrete blocks within Kano state.

The test results show that the strengths of the sandcrete blocks produced in the state lie between (0.25 to 0.92) N/mm^2 and hence is very low. Curing of the sandcrete hollow blocks within the state are also very poor with poor materials used for production.

CHAPTER TWO

LITERATURE REVIEW

Research is still being carried out in order to evolve a comprehensive standard for sandcrete blocks produced in the country. However, there are some contributions from related studies on soilcrete blocks and a few journals regarding sandcrete blocks were also consulted.

According to Professor Adepegba /conference/, the strength of cement stabilised laterite and cement stabilised sand (sandcrete) increases with cement content and that at high cement content, the granules of sandcrete blocks behave elastically. He further observed that for cement content lower than 22 percent, the compressive strength as well as the tensile strength of sandcrete is lower than that of latecrete and above this percentage, the strengths of sandcrete attain higher values.

Ejeh (1982) observed that "the most economic range of the use of cement stabilised sand lies between 0 - 10 percent cement content by weight". In conclusion, he showed that soilcrete increases in its dry compressive strength after curing.

B.S. 2028: 1968, gives specification for precast concrete blocks which describes solid, hollow and cellular blocks as presented below:

	Voids pefent of total volume up
solid	to 25 percent

Hollow: large holes or cavities pass through the block — more than 25 percent but not more than 50 percent

cellilar: large holes or cavities with one bed, face closed (usually laid uppermost).

It stated further that the total width of cavities measured at right angles to the face of the blocks as laid in a wall must not exceed 65 - percent of the block thickness. The following table (table 1): gives the dimensions for the three types of blocks described in the British standard.

TABLE 1: DIMENSIONS FOR THE THREE TYPES OF BLOCKS IN BRITISH STANDARD

Type	Type	Dimension	To bond with B 7mm bricks size specified for manufactured (mm)	Sizes dimensionally conditioned on the nominal 102mm basis. Size specified for manufacture (mm)
Length	Length		448	397 or 499
A		Height	143 or 219	92 or 194
		Thickness	51,64,76,102,152or219	76,92,102,148,178or194
		Length	448	397,499 or 600
B		Height	219	194 or 295
		Thickness	76,89,102,152,203, or 219	76,92,102,143,178 or 194
		Length	448	397,499 or 600
		Height	219	194 or 295
		Thickness	51 or 64	51 or 64

The standard (BS 2028), describes type A blocks as "dense" i.e having a density of not less than 1500 kg/m^3 and include the strongest blocks the use of which is permitted in all positions. Types B and C are "lightweight" concretes having densities less than 1500kg/m^3, made with a "lightweight" - aggregate or aerated cement with or without fine aggregate, high pressure steam autoclaved.

Lightweight blocks provide thermal conductivities as low as 0.08 w/m deg C. Fixing and chasing is easier done than with dense clay and concrete units although drying shrinkage is more troublesome and precautions should be taken to prevent cracking of blockwork.

Blocks of good appearance include those with exposed aggregates and having special facing mixes. The sound absorption of open textured blocks is good.

Units for masonry wall construction are usually turned out from machines in which an earth-moist mix is heavily rammed or pressed into a collapsible steel mould. A pallet is used in the bottom of the mould, and the blocks or bricks are removed immediately. Moist cement/sand mix is fed to the block making machine and compacted. The mould box is immediately lifted away, three cycles per minute being a normal production rate.

Care should be taken to avoid the use of too dry a mix, since this would cause a loss of strength, friable corners and high permeability. The mix for sandcrete blcks is specified as 1:6 or 1:8 (i.e. one part of cement to six or

eight parts of sand. The minimum levels of performance of blocks and bricks are given in BS 6073 (1981), precast concrete nuts and masonry units. This standard deals with solid blocks, cellular blocks made with a variety of aggregates including lightweight blocks and blocks made with autoclaved acrated concrete. The standard also deals with solid bricks, hollow bricks and cellular bricks.

The minimum strength requirement for blocks (which are more than 75mm thick) and for bricks are based on a sample of ten units for which the average crushing strength must be

(a) not less than Q and

(b) not less than 0.9Q + 0.62 S

where Q = 2.8 N/mm^2 as a minimum for concrete blocks and S is the standard deviation for the ten units.

The compressive strength often referred to for sandcrete/masonry is based on the gross area of the unit, that is, the total area including any core spaces. The primary factors influencing the compressive strength of a unit are the type and amount of cement, type and gradation of aggregate, degree of compaction, amount of water used, and moisture content and temperature of the units at test period.

Specifications available from some codes are presented in table 2 below:

TABLE 2: Compressive strength for sandcrete/masonry

STANDARD	AVERAGE STRENGTH N/mm^2	LOWEST STRENGTH N/mm^2	NUMBER OF BLOCKS TESTED	IMMERSION DAYS	CONTACT LAYER
NIS 74	2.50	not specified	about 6 blocks	1 & 3	Plywood
FMW 1979	2.10	1.70	3 "	not specified	not specified
BS2028/A	3.50	2.80	12 blocks	7 to 8	cement mortar
BS2028/B	2.80	2.25	12 blocks	7 to 8	cement mortar

NIS 74 - Nigerian Industrial Standard
- Specification for Burnt clay unit
FMW - Federal Ministry of works
BS 2028: 1963

DRYING SHRINKAGE AND WETTING EXPANSION

According to BS 2028 (Appendix E 1968); drying shrinkage and wetting expansion are determined by taking four (4) blocks at random from the sampled blocks unless four (4) blocks sampled were specifically set aside for the test in accordance with clause 17. This clause covers the requirements for independent tests and sampling.

According to BS 2028 (App. E), a measuring apparatus incorporating a micrometer gauge (strain gauge) or a suitable

dial gauge measuring to an accuracy of 0.001mm would be suitable.

This gauge has a face diameter of 5.5mm to 6.5mm which can be located on a 6.3mm to 6.5mm diameter stainless steel ball cemented in the specimen using a suitable fixing agent such as synthetic resin, so that the ball is in close contact with the base of the hole so that about half of the ball is exposed to provide a hemispherical bearing. After fixing, the exposed hemisphere is to be wiped clean and coated with lubricating grease to prevent corrosion.

Thereafter the four specimens should be labelled accordingly and completely immersed in water at room temperature for a minimum of four days and a maximum of seven days and the water should be maintained at a temperature of 20 $\pm$ 1^{o}C for the final four hours.

Each specimen should be measured to determine the distance over the steel balls to the nearest 1mm and the distance minus 13mm gives the length.

For wet measurement of specimens, the standard specifies that immediately after removal of the specimens from water, the grease should be wiped off from the steel balls and the length of each specimen measured accurately to 0.001mm by the same strain gauge.

Furthermore, the specimen should be placed between the recessed seating of the frame and the recessed end of the gauge. The specimen or frame should then be rotated and

the minimum reading observed. The specimen should then be reserved end to end and the measurement taken again. The average of the two readings give the value of the original wet measurement. The measurement required is not the absolute length of the speciment but the difference in length between the specimen and the reference rod of approximately the same length.

The specimens are to be dried in the oven operating at a temperature of not less than 55°C. A time of at least four hours will be required to attain the above temperature.

The drying shrinkage value of each specimen is calculated as the difference between the original wet measurement and the dry measurement expressed as a percentage of the length.

For the determination of the wetting expansion, after testing the specimens for drying shrinkage, the British standard BS 2028; states that; the stainless steel balls should be coated with lubricating grease and immersed in water for four (4) days and maintained at room temperature ($20 \pm 1^{o}C$) for the final four hours. Immediately after removal of the specimen from the water, the grease is to be wiped off from the steel balls and the length of each specimen measured as described for determining the original wet measurement. The corrected length represents the final wet measurement and the wetting expansion or moisture movement of each specimen is calculated as the difference between the dry measurement and the final wet measurement expressed as a percentage of the length.

Table 3 - Below gives the maximum allowable value of the drying shrinkage for the three types of blocks.

TABLE 3: MAXIMUM VALUE OF THE DRYING SHRINKAGE

BLOCK TYPE	AVERAGE COMPRESSIVE STRENGTH (N/mm^2)	BLOCK DENSITY KG/m^3	MAXIMUM DRYING SHRINKAGE %
A	Less than 10.5	All	0.05
	10.5 and above	All	0.06
B	Less than 7.0	Over 620	0.07
		625 and less	0.09
C	All blocks	Over 625	0.08
		625 and less	0.09

DENSITY

The density of the sandcrete blocks are to be determined by weighing the blocks and dividing the resultant mass by the gross volume and expressing the result in kg/m^3. An average of three sample blocks are sufficient.

WET COMP. STRENGTH (Bedded with Mortar)

PREPARATION OF TEST SPECIMENS

According to BS 2028 (1968); App. C each specimen should be immersed in water at a temperature of $20 \pm 2^{o}C$ for at least 16 hours, and allowed to drain for about 30 minutes under damp sacking or similar material, before capping with mortar.

Mortar for the capping should be prepared from one part by weight of rapid - hardening portland cement complying with BS 12, to one part by weight of sand complying with the requirements of grading zones 2 or 3 of BS 882, but from which has been rejected material retained on a No. 7 fine mesh normal or special test sieve as specified in part 1 of BS 410. A measured quantity of water sufficient enough to produce a mortar having a consistency value of not less than 6mm and not more than 9mm when measured by the test for the determination of consistence by the dropping ball method should be added.

Cubes or prisms should be made from the mortar and the compressive strengths tested. Sufficient specimens should be made to determine the age at which the mortar attains an average of compressive strength of at least 28.0 N/mm^2; this should normally occur between two to four days.

The machined face of the steel plate (capping plate, at least 25mm longer and wider than the block to be capped, and not less than 19mm thick) should be covered with an appropriate release material oil or a sheet of paper to prevent any mortar from adhering to it.

A uniform layer of the mortar, about 5mm thick should be placed on the plate consequently pressing one bed face of the specimen into the mortar layer. The specimen has to be covered with a damp cloth which should be kept damp.

The specimen should be allowed to remain undisturbed for at least 16 hours and the second bed face is then bedded in

in a similar manner if the first bed face is free from defects (BS 2028: C 3:3:1).

After this treatment, the specimens should then be immersed in water at a temperature of 20 $\pm$ 2^{o}C until the mortar used for the bed faces has attained the required minimum strength.

METHOD FOR DETERMINATION OF COMPRESSIVE STRENGTH

BS 2028: Appendix C: 4:1, indicates that the specimen should be placed centrally on the seated platen and load applied centrally without shock while continuously increasing it at a rate at which failure will occur within $\frac{1}{2}$ to 1$\frac{1}{2}$ minutes, but for blocks assumed to have a compressive strength of less than 7.0 N/mm^2, the period could be increased to 3 minutes.

FACTORS INFLUENCING QUALITY OF SANDCRETE BLOCKS

According to Murdock, Brook and Dewar (1991), tests for compressive strength are widely accepted as the most convenient means of quality control and this quality is largely dependent upon the type and properties of the constituent materials.

CEMENT: The cement used by the Industries is basically from Ashaka cement factory (which is ordinary portland cement and hence has a good quality. Poor quality of cement would lead to very weak blocks. Methods for testing cement is given in BS 12.

SAND:

Neville (1987), discribes sand as a natural aggregate that can be separated by such gentle mechanical means as agitation in water which implies that, it is a cohesionless aggregate of rounded angular or subangular fragments of more or less unaltered rocks or minerals. Particles with a size of up to 5mm are referred to as sand.

Sand comprises of more than 80 percent of the cement - sand mix. The term aggregates include the natural sands, gravels and crushed stone used for making mortars and concretes and it is also applied to special materials used in the production of light and heavy weight concretes.

Sand is a form of fine aggregate with the smallest size greater than 0.06mm. Cleanliness, soundness, strength and particle shape are important features in any aggregate . Aggregates are considered clean if they are free from excess foreign materials e.g. silt, clay, mica and organic matter. For an aggregate to be physically sound, it has to retain dimensional stability under temperature or moisture change and be able to resist weathering without being decomposed. Strength is indicated if an aggregate is able to develop the full strength of the cementing matrix.

Processes have been evolved for improving the quality of aggregates. Washing could be used to remove particle coatings or to change aggregate gradation. Heavy media separation, using a variable specific gravity liquid

such as suspension of water and firely ground magnetite and ferrosilocon can be used to improve coarse aggregates. Deleterious lightweight material is removed by floatation.

GRADING

The grading and maximum size of aggregates are important because of their effect on relative proportions, workability, economy, porosity and shrinkage. The particle size distribution is determined by separation of a series of standard screens (Sieves).

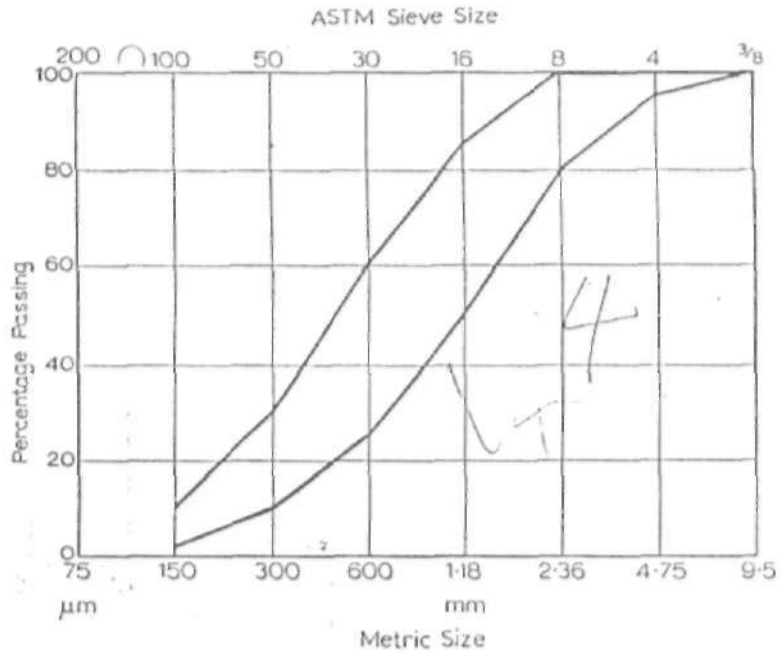
FINE AGGREGATES

Formerly two classes of fine aggregates were recognised but the 1954 revision of BS 882 altered the classification to four grading zones. The grading zones are represented below:

Table 4 *BS and ASTM Grading Requirements for Fine Aggregate*

Sieve size		Percentage by weight passing sieves				
		BS 882:1973				ASTM Standard C 33–78
BS	ASTM No.	Grading zone 1	Grading zone 2	Grading zone 3	Grading zone 4	
9·5 mm	⅜ in.	100	100	100	100	100
4·75 mm	³⁄₁₆ in.	90–100	90–100	90–100	95–100	95–100
2·36 mm	8	60–95	75–100	85–100	95–100	80–100
1·18 mm	16	30–70	55–90	75–100	90–100	50–85
600 µm	30	15–34	35–59	60–79	80–100	25–60
300 µm	50	5–20	8–30	12–40	15–50	10–30
150 µm	100	0–10*	0–10*	0–10*	0–15*	2–10

* For crushed stone sands the permissible limit is increased to 20 per cent.



.. ASTM Standard C33–78 grading limits for fine aggregate

The coarse sand of zone 1 produces a harsh mix, and a high sand content may be necessary for higher workability. This type of sand is more suitable for rich mixes or for use in mixes of low workability.

Zone 2 represents a medium sand generally suitable for "standard" 1:2 fine to coarse.

Zone 4 represents a fine grading which will be cohesive but not very workable since the greater part of this sand is smaller than the 600 m (No. 30 ASTM) sieve.

There is no clear distinction between zone 3 and 4.

Coarser grained soils and aggregates are well described by their particle size distribution curves. The most common form of the plot is the cumulative diagram displaying the percentage by weight of the material finer than any given size as shown in the figures above. Individual soil samples are nearly equidimensional and when the particles are matched against sieves of known aperture sizes a satisfactory estimate of the amounts of material finer than each size is easily obtained. The lower limit of size analysed by sieving is usually fine sand at 63 m according to BS 1377, but here the limit was taken as 150 m (in accordance with BS 882).

WATER

Water fit for drinking could be used for the production and for local curing.

BRICKS

Bricks are investigated because like blocks they are also used as walling units. BS 3921:1969 describes a brick as a walling unit designed to be laid in mortar and not more than 337.5mm long, 225.0mm wide and 112.5mm high, as distinct from a block which is defined as a unit having one or more of these dimensions larger than those quoted.

Strength and durability should be sufficient for the conditions in which the brick is to be used. Where necessary, bricks should be of good appearance or provide a good base for rendering, plastering or decoration. The size and shape of bricks should be regular to facilitate bonding. In its most common form, a brick can be held in one hand, and its length of 215.0mm is equal to twice its width of 102.5mm plus one 10mm joint. The height of 65mm allows for laying four courses of brickwork with four 10mm joints to 300mm.

SIZES

BS 3921: part 2; 1969 specifies only one standard format designated 225, 112.5, 75 and of the following dimensions.

TABLE 5: BS 3921: Part 2: 1969 bricks dimensions

	Actual dimensions (mm)	Overall measurement of 24 bricks (mm)
Length	215	5160 $\pm$ 75
Width	102.5	2460 $\pm$ 45
Height	65	1560 $^{+\ 60}_{-\ 30}$

Samples to be taken in accordance to clause 37 and 38 and to be tested in accordance to clause 39.

STRENGTH

Although clay bricks may have strength up to 175 N/mm^2, considerably lower strength are adequate for the loadings which are usual in small buildings. The building Regulations 1965 require only 2.75 N/mm^2 for two storey houses or two storey buildings divided into flats and the LCC construction Bylaws 1965 are satisfied with a minimum of 13.8 N/mm^2 for internal non - load bearing walls.

Table 6 below gives the minimum average compressive strengths for clay bricks.

TABLE 6:

TABLE 6: Minimum Average compressive strength for clay bricks

Designation	Class	Minimum Average Compressive strength (N/mm^2)
Engineering brick	A	69.0
	B	48.5
Load - bearing brick(for brickwork designed in accordance with CP111)	15	103.5
	10	69.0
	7	48.5
	5	34.5
	4	27.5
	3	20.5
	2	14.0
	1	7.0
Bricks for damp-proof courses d.p.c"		
Bricks for load bearing brickwork not designed (in accordance with CP 111)	-	5.2 or higher strengths as required
Bricks for non-load bearing partitions	-	1.4

CHAPTER THREE

OBSERVATION, EXPERIMENTATION AND TEST RESULTS

3.1. OBSERVATION

Before collection of samples and experimentation, a general visit to most of the industries within Kano State was made. The purpose of the visit was to get a general information about the block industries within the state.

These information include mode of production, type of materials used, mode of curing used by the industries, production capacity, cost of blocks, source of water and the staff strength of the industries.

After the above information were obtained, five industries fairly scattered within the state were chosen for sample collection and detailed study. The first industry is located in the centre of Kano town which is the state capital and is labelled industry A; Industry B is located in Gezawa town in Gezawa local government about 20km to the east of Kano; while C is in Tudun Wada town in Tudun Wada local government about 80km from Kano to the west. Industries D and E are located in Gwarzo town, headquarter of Gwarzo local government about 55km to the west of Kano and Wudil town in Wudil local government about 40km south east respectively.

3.2. EXPERIMENTATION

The localities above were so chosen because of accessibility and for the mere fact that they are the major block producing industries in the area. The rest localities have blocks that are produced only locally and not for commercial purposes and even then only when there is a need for a minor construction exercise.

It is worth noting however, that the labels A,B,C,D and E of the industries do not necessarily have anything to do with the quality of the block concerned but are just mere labels for identifying the block samples.

Below is an account of the investigation conducted for each industry.

Industry A

This industry is located along new Bayero University campus road. The type of cement used is Ashaka cement which is ordinary portland cement. The producer claims that he produces about 40 blocks per each bag of cement and that he uses a mix of 1 part cement to 4 parts coarse sand and 2 parts fine sand (1:6). The detailed result of the sieve analysis on the soil sample obtained from the industry is presented in table 7. The blocks are produced by means of an automatic block machine which compact and vibrate the mix in a steel mould. A very dry mixture of cement, aggregates and water is used and the moulds are removed

immediately after compaction. This machine produces four 460mm x 225mm x 225mm blocks simultaneously. The machine has a production capacity of about one thousand five hundred (1,500) per day.

The blocks were sold at a cost of ₦6.60k per block as at the time of purchase. The source of water in the industry is a tap located at the corner. The industry has a staff strength of about ten (10) men. Fifty blocks were bought from the industry. The method of curing is by spraying the blocks with water mornings and evenings for seven (7) days. The name of the block making machine the vibrobloc model V5.

INDUSTRY B

This industry is located at the edge of Gezawa town. Here the cement used is also of Ashaka cement factory (ordinary portland cement). Here the producer claims that he produces between thirty five (35) to thirty nine (39) blocks per bag of cement and that he uses a cement to sand mix of one (1) part of cement to six parts of sand. The detailed result of the sieve analysis on the sand sample obtained from the industry is presented in table 8. The block making machine is also of the automatic type with a production capacity of at least one thousand blocks per day. The machine also produces four 460mm x 225mm x 225mm blocks simultaneously. The blocks were sold at a cost of ₦6.40k per block and a total of fifty blocks were bought from the

industry. The source of the water in the industry is a tap water. The industry has a staff strength of twelve (12) men. The method of curing is by spraying with water mornings and evenings for at least 3 days. The block making machine used by this industry is the vibrobloc model V5.

INDUSTRY C

The industry is located in Tudun Wada town, the cement used is also Ashaka cement. The owner did not specify the number of blocks he produces per bag of cement. The cement/sand mix here is also one part cement to six parts of sand.

The detailed result of the sieve analysis on the soil sample obtained from the industry is presented in table 9. The block making machine has a production capacity of eight hundred 460mm x 225mm x 225mm at the cost of N6.20 per block. The source of water used is water obtained from a borehole. The industry has a staff strength of seven men. The method of curing is by spraying with water mornings and evenings for at least 3 days. This industry uses Bolyn model 2 block making machine.

INDUSTRY D

This industry is located in Gwarzo town. The producer uses ordinary portland cement from Ashaka cement factory. The cement/sand mix is one part cement to six parts of sand. The detailed result of the sieve analysis conducted on the soil sample is presented in table 10. The block making machine is a manually operated type and the production

capacity is five hundred and fifty blocks per day. The blocks were sold at the cost of ₦6.00 per block and a total of fifty blocks were bought. The source of water is from a tap located within the industry. The block making machine used is vibro-block model 3. The industry has a staff strength of 11 men. The method of curing is by spraying with water mornings and evenings for at least 3 days. The type of block making machine machine used by this industy is the vibrobloc model 5.

INDUSTRY E

This industry is located in Wudil town. The cement used by the producer is Ashaka brand of the ordinary portland cement. The cement/sand mix is one part cement to six parts of sand. The detailed result of the sieve analysis conducted on the soil sample obtained from the industry is presented in table 11. The block making machine is of the automatic type and has a production capacity of about one thousand blocks per day. The blocks were sold at ₦6.00 per block and a total of fifty blocks were bought from the industry. The water used for the production and curing is tap water. The method of curing is by spraying the blocks with water for a minimum period of three days and a maximum period of seven days. The staff strength of the industry is about fifteen (15) men. The industry uses block making machine model 4 - vibrobloc.

MAP OF KANO STATE

SHOWING 34 LOCAL GOVERNMENTS

AND LOCATIONS FROM WHICH SAMPLES WERE TAKEN

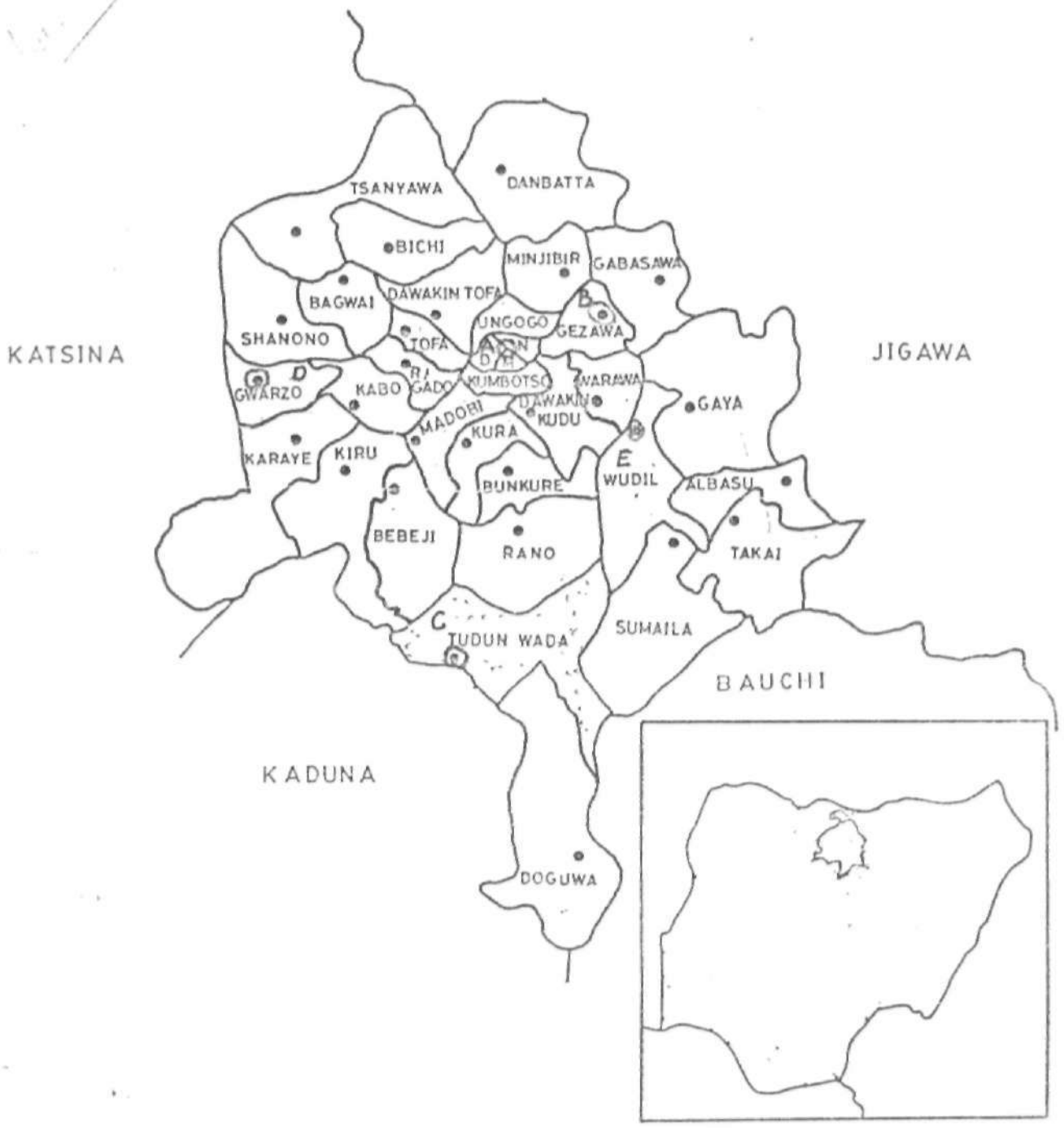


TABLE 7: SIEVE ANALYSIS RESULT FOR INDUSTRY A

Sieve size mm	Weight Retained (gms)	Weight Passing (gms)	Percentage Passing
6.30	0	1000	100
4.75	0	1000	100
2.00	127	873	87.3
1.18	221	652	65.2
600m	348	304	30.4
300 m	166	138	13.8
150 m	16	78	7.8
Pan	78	-	-

TABLE 8: SIEVE ANALYSIS RESULT FOR INDUSTRY B

Sieve size	Weight Retained (gms)	Weight Passing (gms)	Percentage
6.30 mm	0	1000	100
4.75mm	0	1000	100
2.00 mm	100	900	90.0
1.18mm	202	698	69.8
600 m	360	338	33.8
300 m	182	156	15.6
150 m	90	66	6.6
Pan	66	-	

TABLE 9: SIEVE ANALYSIS RESULT FOR INDUSTRY C

Sieve size	Weight Retained (gms)	Weight passing (gms)	Percentage passing
6.30 mm	0	1000	100
4.75 mm	0	1000	100
2.00 mm	82	918	91.8
1.18 mm	240	678	67.8
600 m	372	306	30.6
300 m	208	98	17.6
150 m	40	58	9.8
Pan	58	-	

TABLE 10: SIEVE ANALYSIS RESULT FOR INDUSTRY D

Sieve size	Weight Retained (gms)	Weight Passing (gms)	Percentage Passing
6.30 mm	0	1000	100
4.75 mm	0	1000	100
2.00 mm	60	940	94.0
1.18mm	200	740	74.0
600 m	400	340	34.0
300 m	265	75	7.5
150 m	70	5	0.5
Pan	5	-	

TABLE 11: SIEVE ANALYSIS RESULT FOR INDUSTRY E

Sieve Size	Weight Retained (gms)	Weight Passing (gms)	Percentage Passing
6.30 mm	0	1000	100
4.75 mm	0	1000	100
2.00 mm	110	890	89.0
1.18 mm	230	660	66.0
600 mm	352	308	30.8
300 m	171	137	13.7
150 m	88	54	5.4
Pan	54	-	-

As earlier stated, a total of about two hundred and fifty (250) block samples were collected from five local Governments which are well spread in Kano State. In each local Government, fifty (50) block samples were collected. These block samples were subjected to various tests in the structural laboratory of the department of civil Engineering, Ahmadu Bello University, Zaria.

The tests carried out include dry development strength test, wet development test, wet compressive test, shrinkage sieve analysis and moisture movement.

DRY DEVELOPMENT TEST

After production, the blocks are cured by spraying with water and covered with a water proof material like cellophine. The samples are tested for compressive strength at different ages (i.e. 3, 7, 14, 21 and 28 days) until the compressive strength remains almost constant. Fifteen samples from each of the industries A,B,C,D,E were tested (3 samples for each age). The average values for the different ages from industries A, B, C, D and E are shown in tables 12, 13, 14, 15 and 16 respectively.

TABLE 12: DRY DEVELOPMENT STRENGTH VALUES FOR INDUSTRY A

DATE OF TEST	AGE (DAYS)	AVERAGE LENGTH (mm)	AVERAGE WIDTH (mm)	AVERAGE HEIGHT (mm)	FAILURE (KN)	AVERAGE DENSITY kG/m^3	AVERAGE STRENGTH N/mm^2
23/7/92	3	460	229	230	50.5	1045.83	0.48
27/7/92	7	459	230	228	76.2	1058.30	0.72
3/8/92	14	461	230	229	94.2	1109.69	0.89
10/8/92	21	458	230	230	96.3	1136.08	0.91
17/8/92	28	460	229	230	97.3	1170.83	0.92

Mean value = 0.79 N/mm^2

Standard deviation = 0.17 N/mm^2, covariance = 21.5%

TABLE 13: DRY DEVELOPMENT STRENGTH VALUES FOR INDUSTRY B

DATE OF TEST	AGE (DAYS)	AVERAGE WIDTH mm	AVERAGE WIDTH (mm)	AVERAGE HEIGHT (mm)	FAILURE (KN)	AVERAGE DENSITY kG/m^3	AVERAGE STRENGTH N/mm^2
23/7/92	3	459	227	230	40.2	1033.30	0.38
27/7/92	7	461	228	229	63.5	1048.61	0.60
3/8/92	14	460	230	229	77.2	1068.02	0.73
10/8/92	21	459	230	230	81.5	1099.97	0.77
17/8/92	28	460	230	230	82.5	1116.63	0.78

Mean value = 0.65 N/mm^2

Standard deviation = 0.15 N/mm^2 V Covariance = 23.08%

TABLE 14: DRY DEVELOPMENT STRENGTH VALUES FOR INDUSTRY C

DATE OF TEST	AGE (DAYS)	AVERAGE LENGTH (mm)	AVERAGE WIDTH (mm)	AVERAGE HEIGHT (mm)	FAILURE LOAD (KN)	AVERAGE DENSITY kG/m^3	AVERAGE STRENGTH N/mm^2
4/6/92	3	460	229	229	36.0	1012.47	0.34
8/6/92	7	459	230	229	44.5	1030.42	0.42
15/6/92	14	461	228	228	53.0	1033.60	0.50
22/6/92	21	461	229	227	56.0	1043.30	0.53
29/6/92	28	459	230	230	58.2	1064.58	0.55

Mean = 0.47 N/mm^2

Standard deviation = 0.08 N/mm^2 Covariation = 17.02%

TABLE 15: DRY DEVELOPMENT STRENGTH VALUES FOR INDUSTRY D

DATE OF TEST	AGE (DAYS)	AVERAGE LENGTH (mm)	AVERAGE WIDTH (mm)	AVERAGE HEIGHT (mm)	FAILURE LOAD (KN)	AVERAGE DENSITY kG/m^3	AVERAGE STRENGTH N/mm^2
23/7/92	3	459	229	230	26.5	1005.56	0.25
27/7/92	7	459	230	228	33.9	1019.44	0.32
3/8/92	14	460	228	229	42.3	1029.86	0.40
10/8/92	21	461	230	228	46.6	1043.02	0.44
17/8/92	28	460	229	229	48.7	1056.91	0.46

Mean = 0.37 N/mm^2

Standard deviation = 0.08 N/mm^2

coefficient of variation = 21.62%

TABLE 16: DRY DEVELOPMENT STRENGTH VALUES FOR INDUSTRY E

DATE OF TEST	AGE (DAYS)	AVERAGE LENGTH (mm)	AVERAGE WIDTH (mm)	AVERAGE HEIGHT (mm)	FAILURE LOAD (KN)	AVERAGE DENSITY kG/m^3	AVERAGE STRENGTH N/mm^2
2/4/92	3	460	229	228	49.7	1019.41	0.47
6/4/94	7	460	230	229	67.7	1035.72	0.64
13/4/92	14	460	230	230	79.4	1062.08	0.75
20/4/92	21	459	229	230	87.8	1067.60	0.83
27/4/92	28	459	230	230	91.0	1090.97	0.86

Mean = 0.72 N/mm^2

Coefficient of variation = 19.44%

Standard deviation = 0.14 N/mm^2

3.3. WET DEVELOPMENT STRENGTH

This test was carried out immediately after the block samples were removed from water for strength at the age of 3, 7, 14, 21 and 28 days. The samples were then immersed in water and the wet strength values were recorded for the soaking age of 3, 7, 14, 21 and 28 days . The dimensions of the blocks were measured prior to testing. The wet development values for industries A, B, C, D and E are presented in table 17, 18, 19, 20 and 21 respectively.



PLATE 1: SAMPLES IN THE CURING TANK IN READINESS FOR THE COMPRESSIVE STRENGTH TESTS AND WET DEVELOPMENT STRENGTH TESTS.

TABLE 17: WET DEVELOPMENT STRENGTH VALUES FOR INDUSTRY A

DATE OF TEST	AGE DAYS	AVERAGE LENGTH (mm)	AVERAGE WIDTH (mm)	AVERAGE HEIGHT (mm)	FAILURE LOAD (KN)	AVERAGE DENSITY kG/m^3	AVERAGE STRENGTH N/mm^2
18/8/92	3	461	229	229	40.20	1229.17	0.38
22/8/92	7	460	230	230	46.50	1368.06	0.44
29/8/92	14	459	230	230	61.4	1448.61	0.58
5/9/92	21	460	229	230	62.40	1530.52	0.59
12/9/92	28	460	230	230	62.42	1562.5	0.59

Mean = 0.52 N/mm^2

Standard deviation = 0.09N/mm^2, Covariance = 17.31%

TABLE 18: WET DEVELOPMENT STRENGTH VALUES FOR INDUSTRY B

DATE OF TEST	AGE DAYS	AVERAGE WLENGTH (mm)	AVERAGE WIDTH (mm)	AVERAGE HEIGHT (mm)	FAILURE LOAD (kN)	AVERAGE DENSITY kG/m^3	AVERAGE STRENGTH N/mm^2
18/8/92	3	460	229	230	27.50	1154.17	0.26
22/8/92	7	459	229	229	31.70	1334.72	0.30
29/8/92	14	459	230	230	42.32	1427.78	0.40
5/9/92	21	459	230	230	44.50	1458.33	0.42
12/9/92	28	461	230	229	45.50	1495.83	0.43

Mean = 0.36 N/mm^2

Standard deviation = 0.07N/mm^2

Covariance = 19.44%

TABLE 19: WET DEVELOPMENT STRENGTH VALUES FOR INDUSTRY C

DATE OF TEST	AGE DAYS	AVERAGE LENGTH (mm)	AVERAGE WIDTH (mm)	AVERAGE HEIGHT (mm)	FAILURE LOAD kN	AVERAGE DENSITY kG/m^3	AVERAGE STRENGTH N/mm^2
30/6/92	3	460	230	229	23.30	1095.83	0.22
4/7/92	7	461	230	230	29.60	1136.11	0.28
11/7/92	14	460	230	229	35.90	1188.89	0.34
18/7/92	21	460	229	230	38.00	1204.17	0.36
25/7/92	28	459	230	230	39.10	1270.83	0.37

Mean = 0.31 N/mm^2

Standard deviation = 0.06 N/mm^2

Covariance = 19.35%

TABLE 20: WET DEVELOPMENT VALUES FOR INDUSTRY D

DATE OF TEST	AGE DAYS	AVERAGE LENGTH (mm)	AVERAGE WIDTH (mm)	AVERAGE HEIGHT (mm)	FAILURE LOAD (KN)	AVERAGE DENSITY kG/m^3	AVERAGE STRENGTH N/mm^2
18/8/92	3	461	229	229	19.00	1132.92	0.18
22/8/92	7	461	230	228	23.30	1197.22	0.22
29/8/92	14	460	230	230	29.60	1287.50	0.28
5/9/92	21	460	230	229	31.70	1327.77	0.30
12/9/92	28	459	229	229	31.72	1405.55	0.30

Mean = 0.26 N/mm^2

Standard deviation = 0.05 N/mm^2 Covariance = 19.23%

TABLE 21: MET DEVELOPMENT STRENGTH VALUES FOR INDUSTRY /E

DATE OF TEST	AGE DAYS	AVERAGE LENGTH (mm)	AVERAGE WIDTH (mm)	AVERAGE HEIGHT (mm)	FAILURE LOAD (KN)	AVERAGE DENSITY kG/m^3	AVERAGE STRENGTH N/mm^2
28/4/92	3	460	228	230	39.20	1150.00	0.37
2/5/92	7	460	229	229	46.50	1194.45	0.44
9/5/92	14	459	229	229	56.00	1302.78	0.53
16/5/92	21	459	230	229	61.40	1437.50	0.58
23/5/92	28	451	230	229	63.50	1479.17	0.60

Mean = 0.50 N/mm^2

Standard deviation = 0.09 N/mm^2

Covariance = 18.00%

3.4. WET COMPRESSIVE STRENGTH

This test was carried out in accordance with BS 2028, Appendix C. The value shown as average compressive strength in table 22 is an average of ten sample blocks. The values are as presented in table 22 below:

TABLE 22: WET COMPRESSIVE STRENGTH VALUES FOR THE FIVE INDUSTRIES

SERIAL NUMBER	INDUSTRY A(N/mm^2)	INDUSTRY B(N/mm^2)	INDUSTRY C(N/mm^2)	INDUSTRY D(N/mm^2)	INDUSTRY E(N/mm^2)
DATE	23/8/92	23/9/92	5/7/92	23/8/92	3/5/92
1	0.60	0.47	0.37	0.30	0.61
2	0.72	0.35	0.30	0.32	0.65
3	0.65	0.39	0.29	0.24	0.62
4	0.54	0.42	0.39	0.28	0.53
5	0.47	0.36	0.40	0.26	0.51
6	0.49	0.32	0.38	0.29	0.49
7.	0.50	0.36	0.37	0.28	0.50
8	0.58	0.43	0.35	0.27	0.60
9.	0.62	0.40	0.32	0.25	0.62
10.	0.63	0.40	0.33	0.21	0.57
Mean value	0.58N/mm^2	0.39N/mm^2	0.35N/mm^2	0.27N/mm^2	0.57N/mm^2

The mortar cubes were tested for compressive strength from 48 hours until the desired strength was attained after

6 days immersion. The tables on pages 38 and 39 show the result of the compressive strength of the mortar cubes. All the cubes are of the general dimension 70.7mm x 70.7mm x 70.7mm (tables 20A - 20 E) .

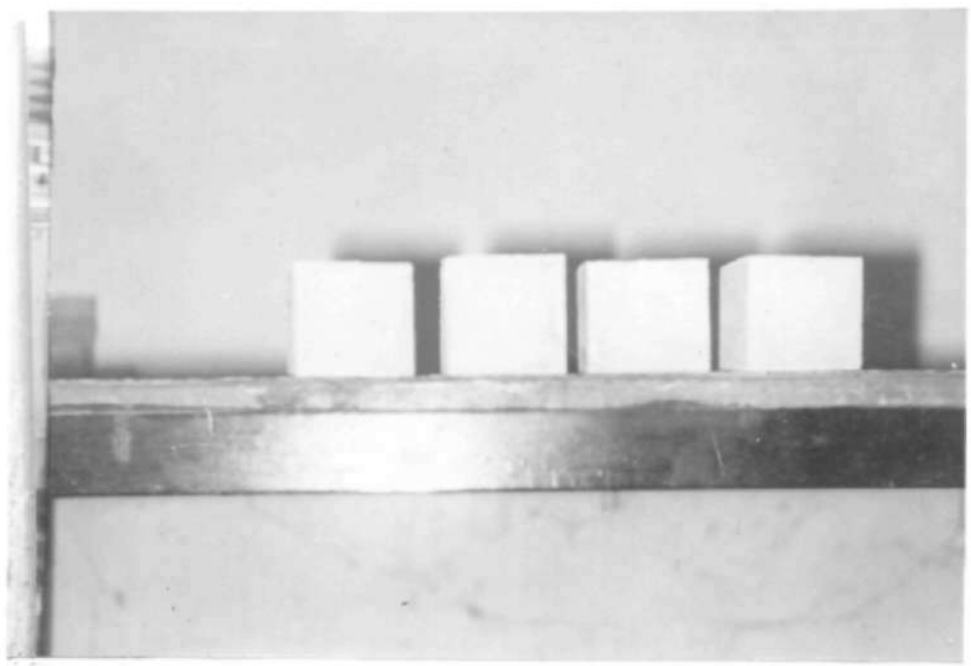


PLATE II: SOME TEST CUBES (70.7mm x 70.7mm) READY FOR CRUSHING



PLATE III: A SAMPLE UNDER THE COMPRESSION TESTING MACHINE READY FOR CRUSHING

All Values are average over 3 samples

TABLE 23A; INDUSTRY A

DATE OF TEST	AGE (DAYS)	FAILURE LOAD (KN)	AREA (mm^2)	STRENGTH N/mm^2
19/8/92	2	50.00	4998.49	10.00
20/8/92	3	85.00	"	17.00
21/8/92	4	127.50	"	25.50
22/8/92	5	138.50	"	27.71
23/8/92	6	139.89	"	27.99

TABLE 23B: INDUSTRY B

DATE OF TEST	AGE (DAYS)	FAILURE LOAD (KN)	AREA (mm^2)	STRENGTH N/mm^2
19/8/92	2	49.50	4998.49	9.90
20/8/92	3	86.50	"	17.31
21/8/92	4	125.00	"	25.00
22/8/92	5	137.00	"	27.41
23/8/92	6	140.50	"	28.11

TABLE 23C: INDUSTRY C

DATE OF TEST	AGE (DAYS)	FAILURE LOAD(KN)	AREA mm^2	STRENGTH N/mm^2
1/7/92	2	47.50	4998.49	9.50
2/7/92	3	74.00	"	14.80
3/7/92	4	123.50	"	24.70
4/7/92	5	130.20	"	26.05
5/7/92	6	137.50	"	27.51

TABLE 23D: INDUSTRY D

DATE OF TEST	AGE (DAYS)	FAILURE LOAD (KN)	AREA mm^2	STRENGTH N/mm^2
19/8/92	2	49.50	4998.49	9.90
20/8/92	3	69.50	"	13.90
21/8/92	4	117.20	"	23.45
22/8/92	5	123.80	"	24.77
23/8/92	6	136.90	"	27.39

TABLE 23E: INDUSTRY E

DATES OF TEST	AGE (DAYS)	FAILURE LOAD (KN)	AREA mm^2	STRENGTH N/mm^2
29/4/92	2	58.00	4998.49	11.60
30/4/92	3	88.50	"	17.71
1/5/92	4	98.70	"	19.75
2/5/92	5	128.50	"	25.71
3/5/92	6	139.50	"	27.91

3.5. DRYING SHRINKAGE

Drying shrinkage was determined in accordance with BS 2028, Clause 17,. After curing and testing the dry development strengths for 28 + days, the sandcrete blocks were prepared for the drying shrinkage tests by means of strain tips (small aluminium pellets) glued to the surface of the blocks approximately 20cm apart and immersed in water for 24 hours and removed with the resulting expansion measured and noted by means of a strain gauge. Thereafter, they are oven dried for 2 days (48 hours) with the measurements taken again. The difference between the two readings expressed as a percentage over the original measurement gives a measure of the dry shrinkage.

Four blocks taken at random from the sampled blocks were used for this test and for wetting expansion or moisture movement tests.

Values for the drying shrinkage are as shown in table 24 below:

TABLE 24: DRYING SHRINKAGE VALUES FOR INDUSTRIES A,B,C,D,E

SHRINKAGE VALUE %	INDUSTRY A	INDUSTRY B	INDUSTRY C	INDUSTRY D	INDUSTRY E
	0.03	0.04	0.07	0.07	0.03
	0.02	0.06	0.05	0.08	0.03
	0.04	0.04	0.05	0.06	0.04
	0.03	0.04	0.05	0.06	0.03

3.6. MOISTURE MOVEMENT/WETTING EXPANSION

For the determination of moisture movement or wetting expansion, after testing the specimens for drying shrinkage, the steel balls were coated with lubricating grease and the specimens immersed in water for four days. After removing the specimens from water, the grease was wiped off the steel balls and the length of each specimen was measured in a manner similar to that for the drying shrinkage.

The corrected length represents the final wet measurement. The wetting expansion of each specimen is calculated as the difference between the dry measurement and final wet measurement expressed as a percentage of the length.

The values for the wetting expansion for Industries A, B, C, D and E are presented in table 25 below:

TABLE 25: THE VALUES FOR THE WETTING EXPANSION FOR INDUSTRIES A, B, C, D, and E

MOISTURE MOVEMENT %	INDUSTRY A	INDUSTRY B	INDUSTRY C	INDUSTRY D	INDUSTRY E
	0.02	0.03	0.04	0.03	0.02
	0.02	0.02	0.04	0.04	0.02
	0.03	0.02	0.05	0.04	0.03
	0.02	0.03	0.03	0.04	0.03
	0.023	0.025	0.04	0.038	0.025

Average = 0.030%

CHAPTER FOUR

DISCUSSION AND CONCLUSION

Considering the methods and procedures of the tests conducted in the previous chapters, it is important to present the following observations and conclusion on the nature and quality of the sandcrete blocks produced in Kano State.

(a) The strength of sandcrete blocks produced in the industry (i.e. Kano town) attained after 28 days is higher than that of any other industry (0.92 N/mm^2) in the dry development stage. However, this is much lower than the minimum value of 2.50 N/mm^2 as specified by Nigerian Industrial Standard. The wet development strength has a maximum value of 0.59 N/mm^2 for the industry as compared with the minimum of 2.50 N/mm^2. It is also worth noting that the strength attained after 7 days (1 week) is up to 80 percent of the strength developed after 28 days.

(b) The 28 days dry development strengths for industry A,B,C,D and E are 0.92 N/mm^2, 0.78N/mm^2, 0.55N/mm^2, 0.46 N/mm^2, and 0.86 N/mm^2 respectively while the 28 days wet development strengths for the industries are 0.59N/mm^2, 0.43N/mm^2, 0.37N/mm^2, 0.30N/mm^2 and 0.50N/mm^2 respectively.

(c) The overall average dry development strength value is 0.58 N/mm^2 and that of the wet development strength is 0.39 N/mm^2 (i.e. about 67 percent of the dry development strength value).

(d) The quality of sandcrete blocks depend mainly on the quality and nature of the constituent materials viz:- cement, sand and water/cement ratio respectively.

(e) All the sand particles used by industries A,B,C,D and E fall within zone 1 of the grading curve of BS 882.

(f) The shrinkage values and moisture movement values fall within the periphery of desired specification.

CONCLUSION

From the above discussion, the following are the reasons for the low quality of the blocks produced in the state.

(1) Poor mix: the producers are not actually adhering to a mix of 1 part cement to 6 parts of sand or 1 part cement to 8 parts of sand as is required.

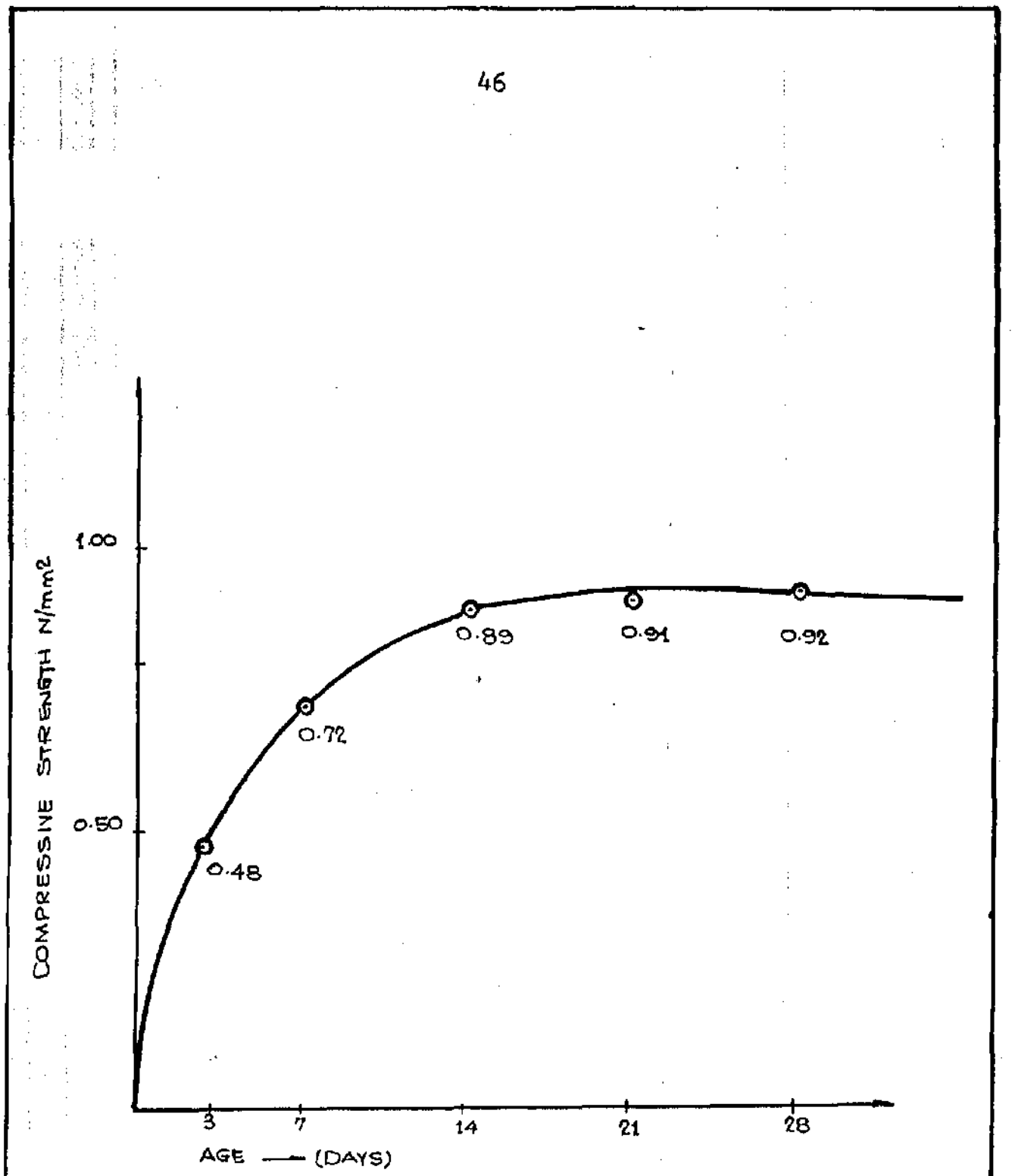
ii) Use of higher quantity/percentage of coarse sand than is required which leads to drier mixes

iii) Producers in their desire to maximise profit usually increase the proportion of sand and this consequently leads to inferior blocks

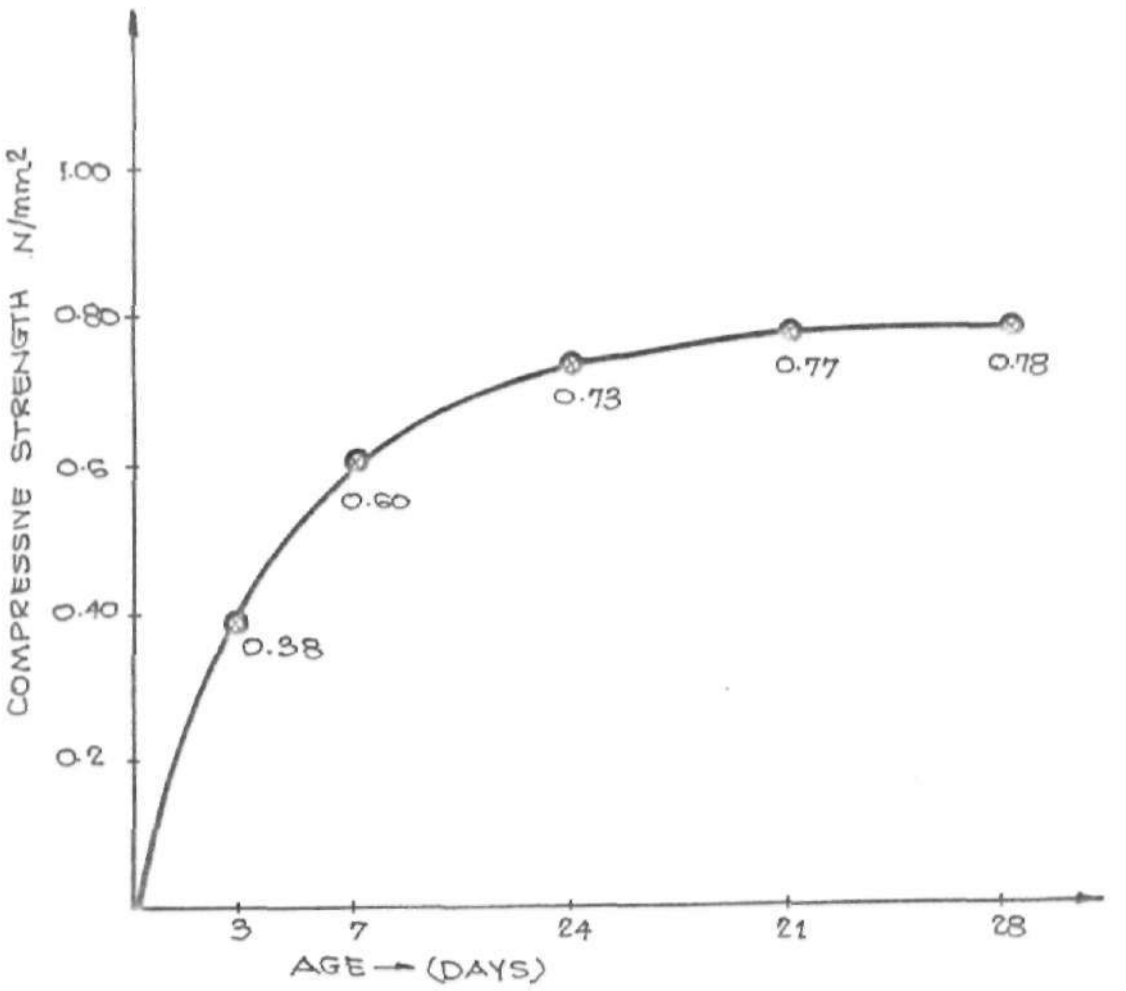
iv) The graphs show that about 80% of the strength of the blocks is attained after 7 days of curing.

RECOMMENDATION

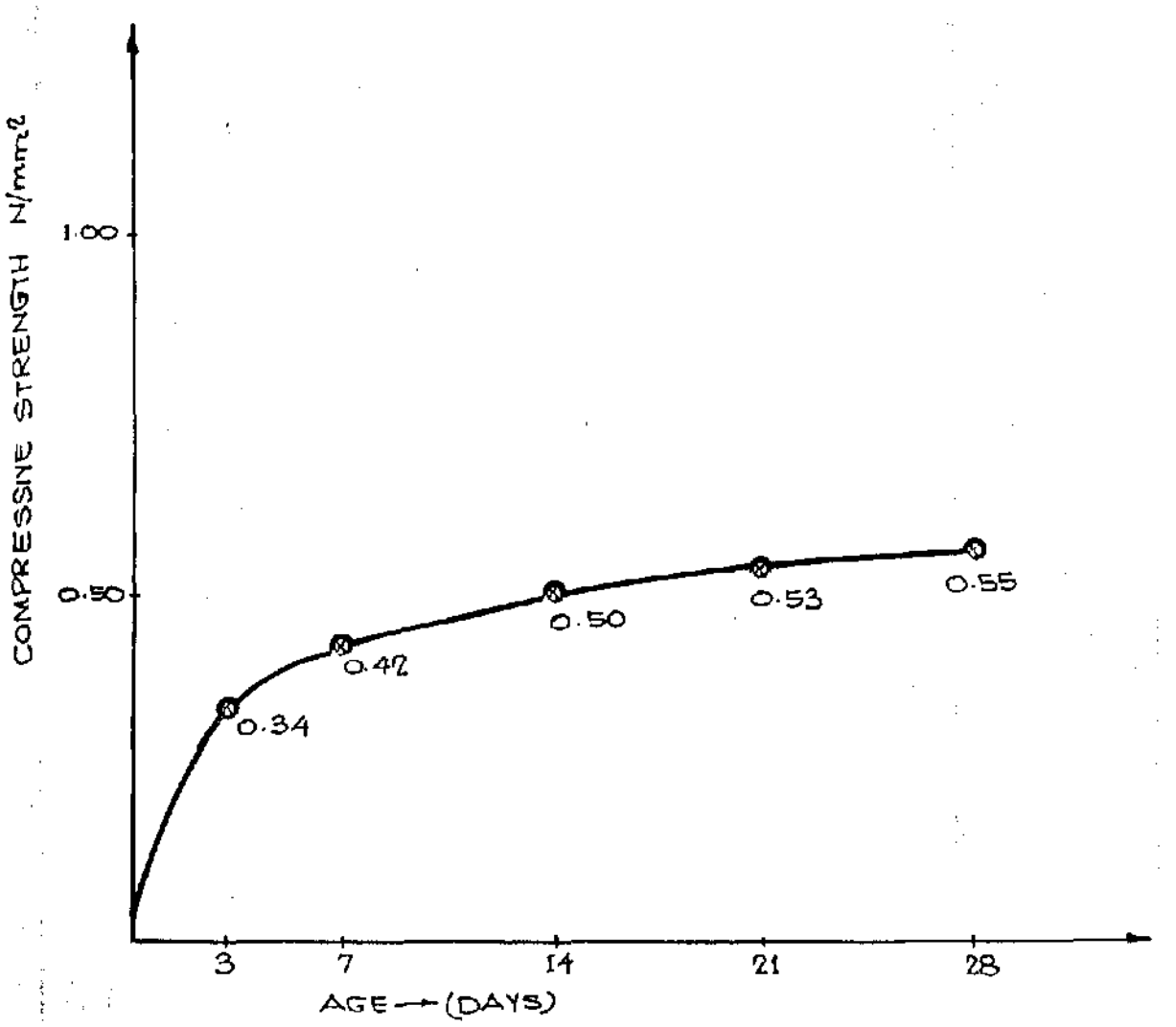
A workshop should be organised periodically to enlighten the producers of sandcrete blocks on the importance of adhering to standard specifications and strict penalties should be meted out to erring producers by the Nigerian Industrial Standard Organisation.



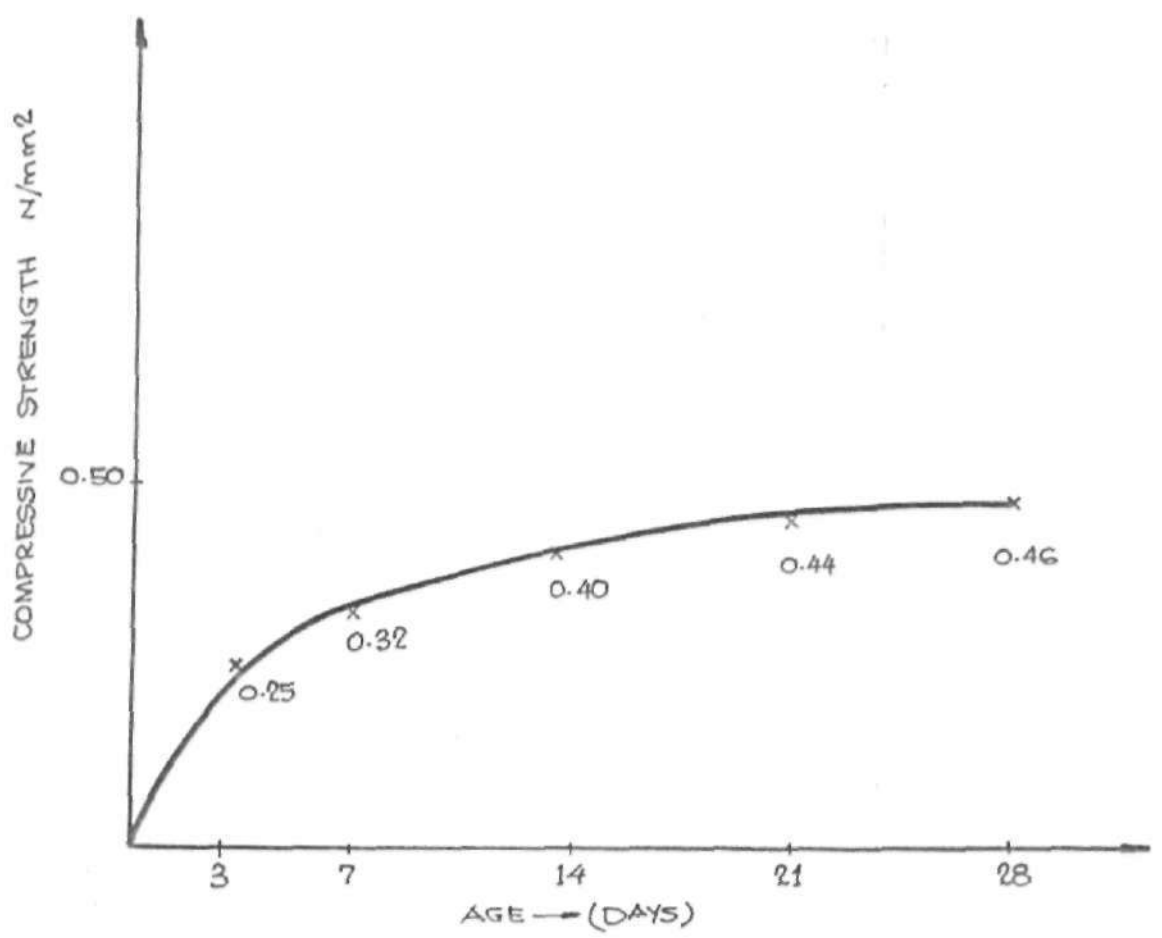
GRAPH Nº 1: DRY DEVELOPMENT FOR INDUSTRY A



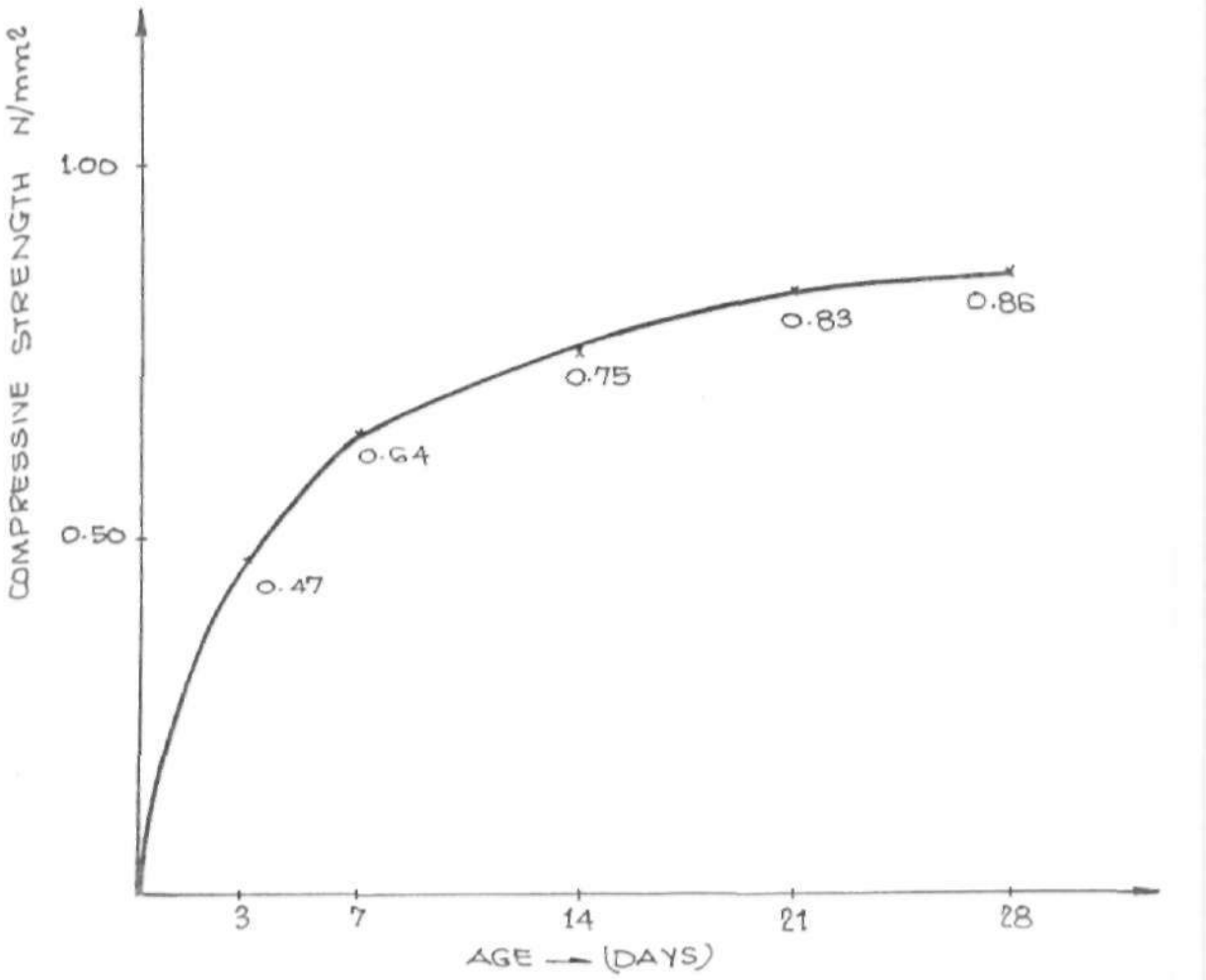
GRAPH Nº 2: DRY DEVELOPMENT FOR INDUSTRY B



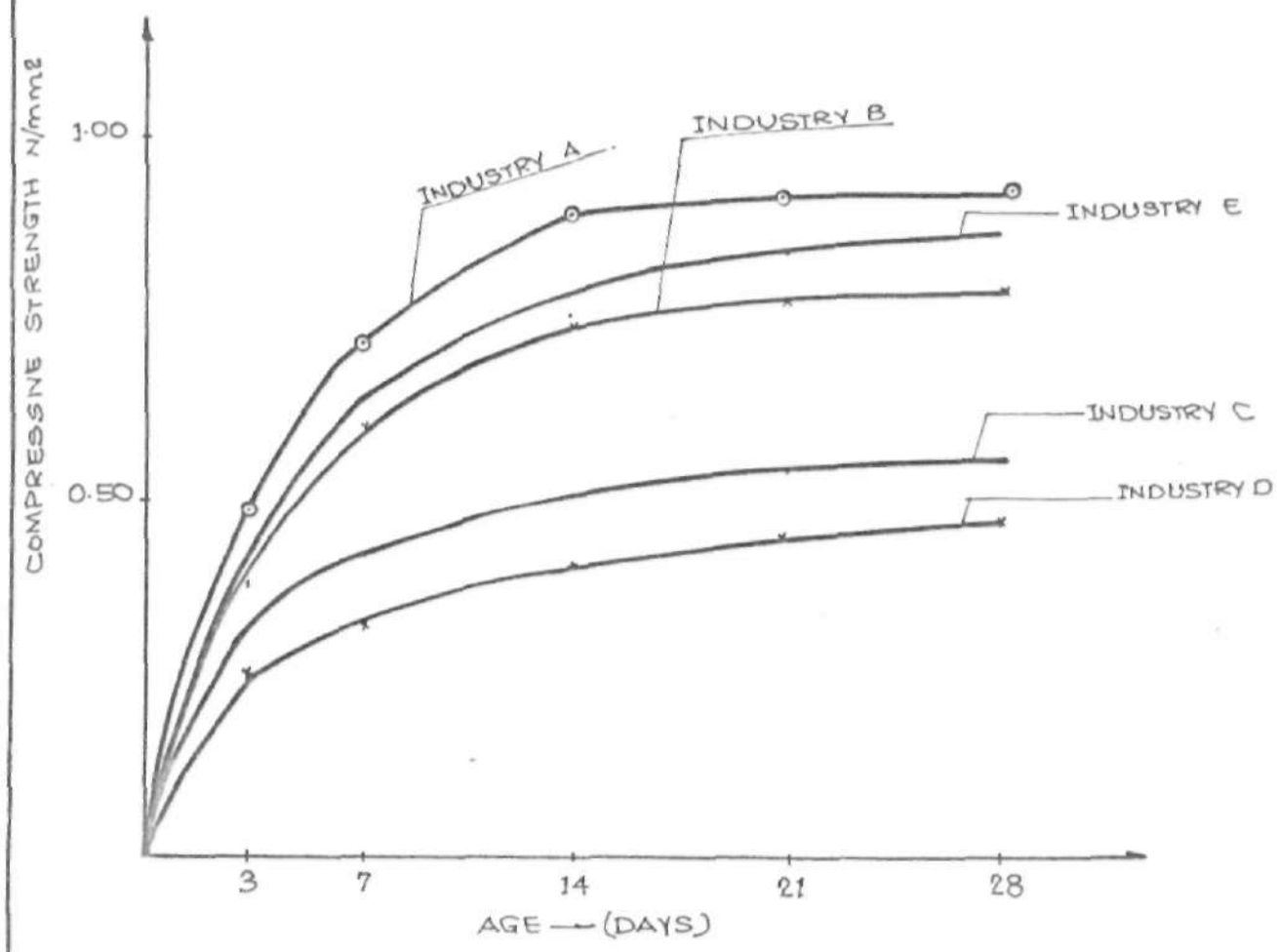
GRAPH Nº 3: DRY DEVELOPMENT FOR INDUSTRY C



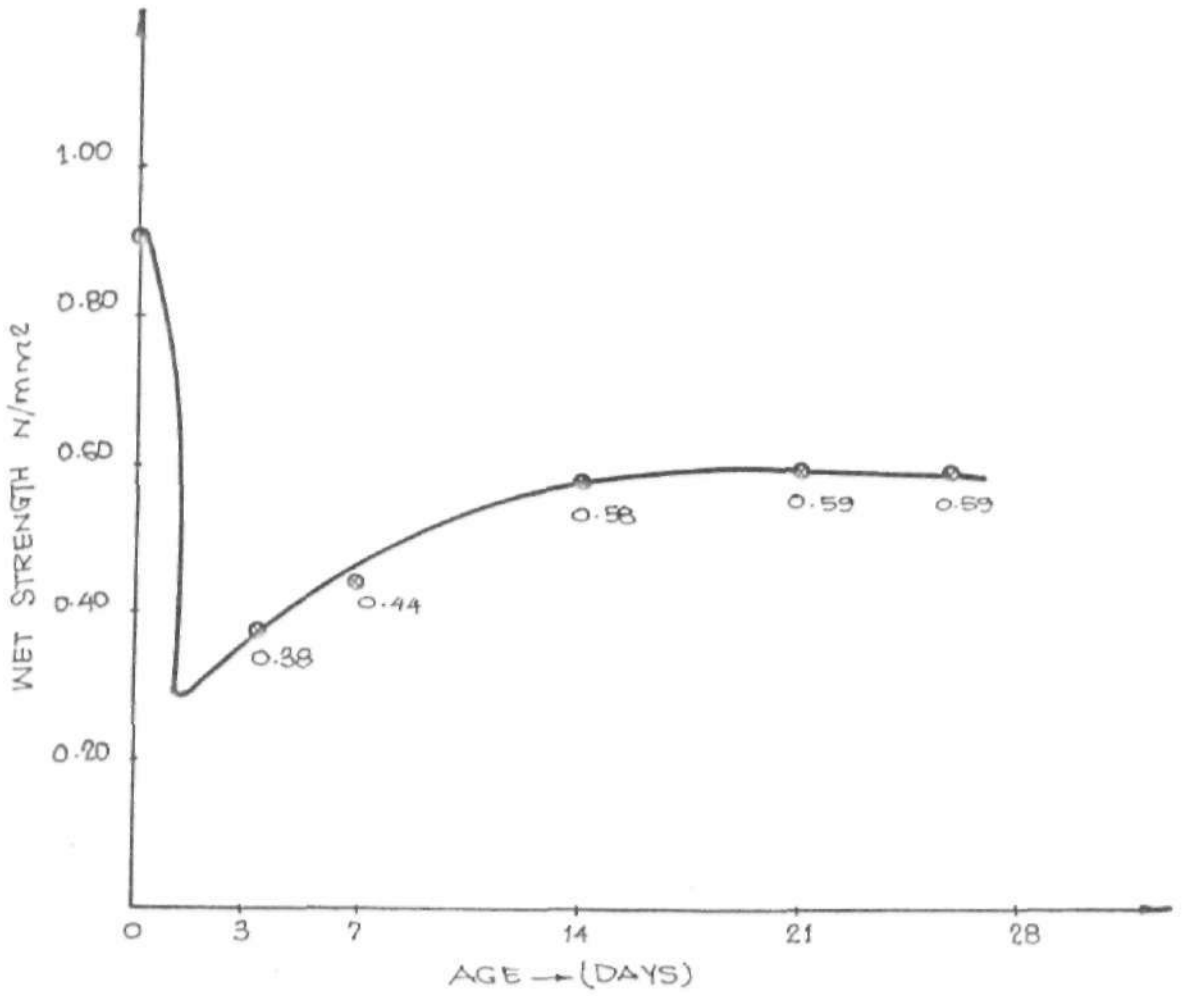
GRAPH Nº 4: DRY DEVELOPMENT FOR INDUSTRY D



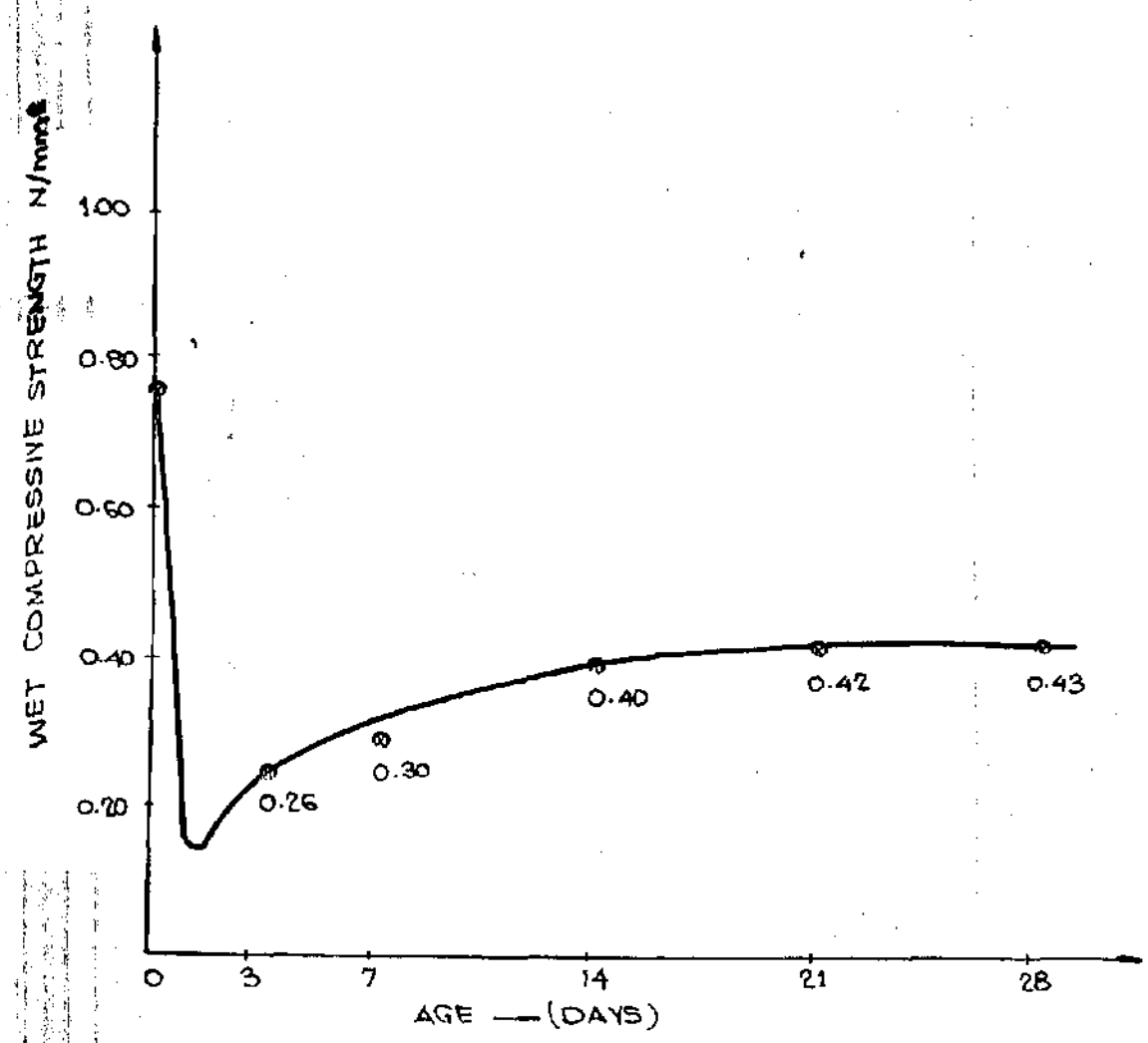
GRAPH Nº 5: DRY DEVELOPMENT STRENGTH FOR INDUSTRY E



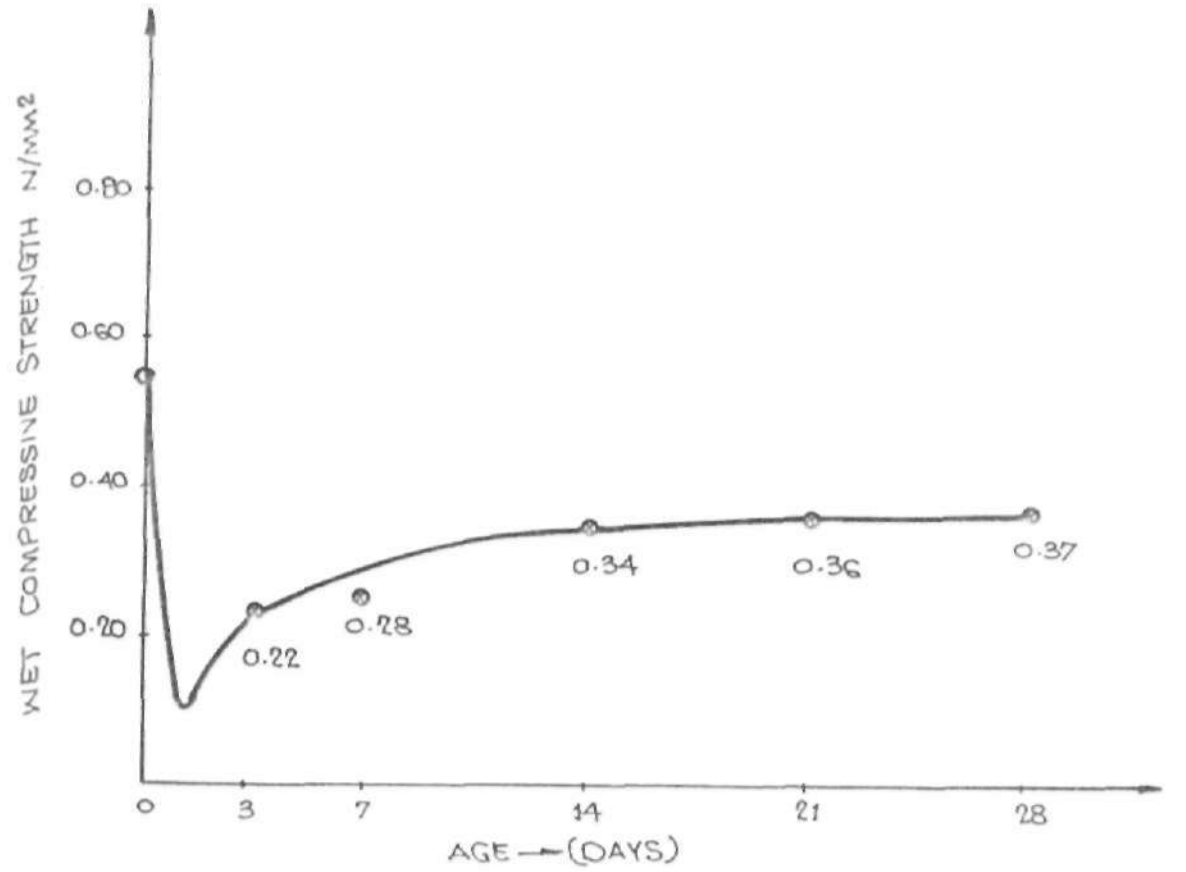
GRAPH NO. 5A: Dry Development for industries A - E



GRAPH Nº 6: WET DEVELOPMENT STRENGTH FOR INDUSTRY A

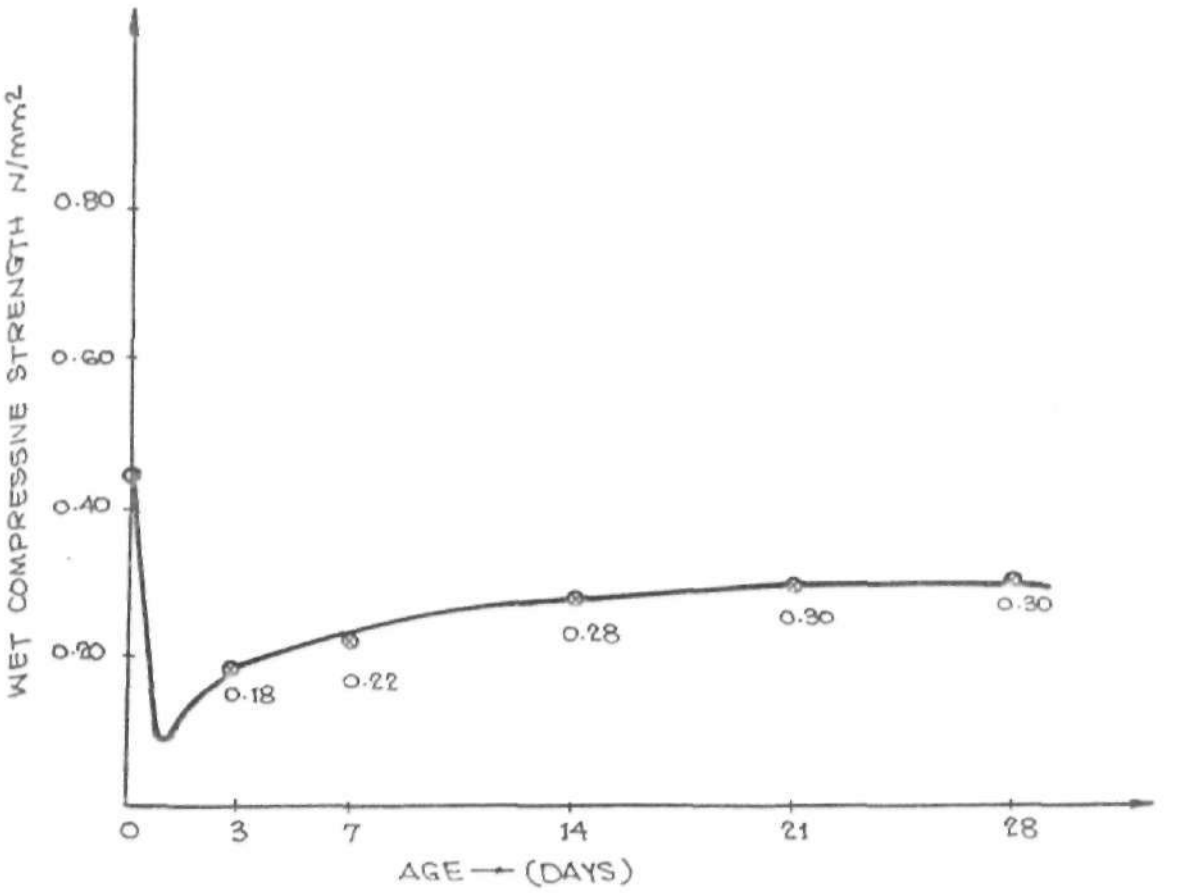


GRAPH Nº7: WET DEVELOPMENT STRENGTH FOR INDUSTRY B



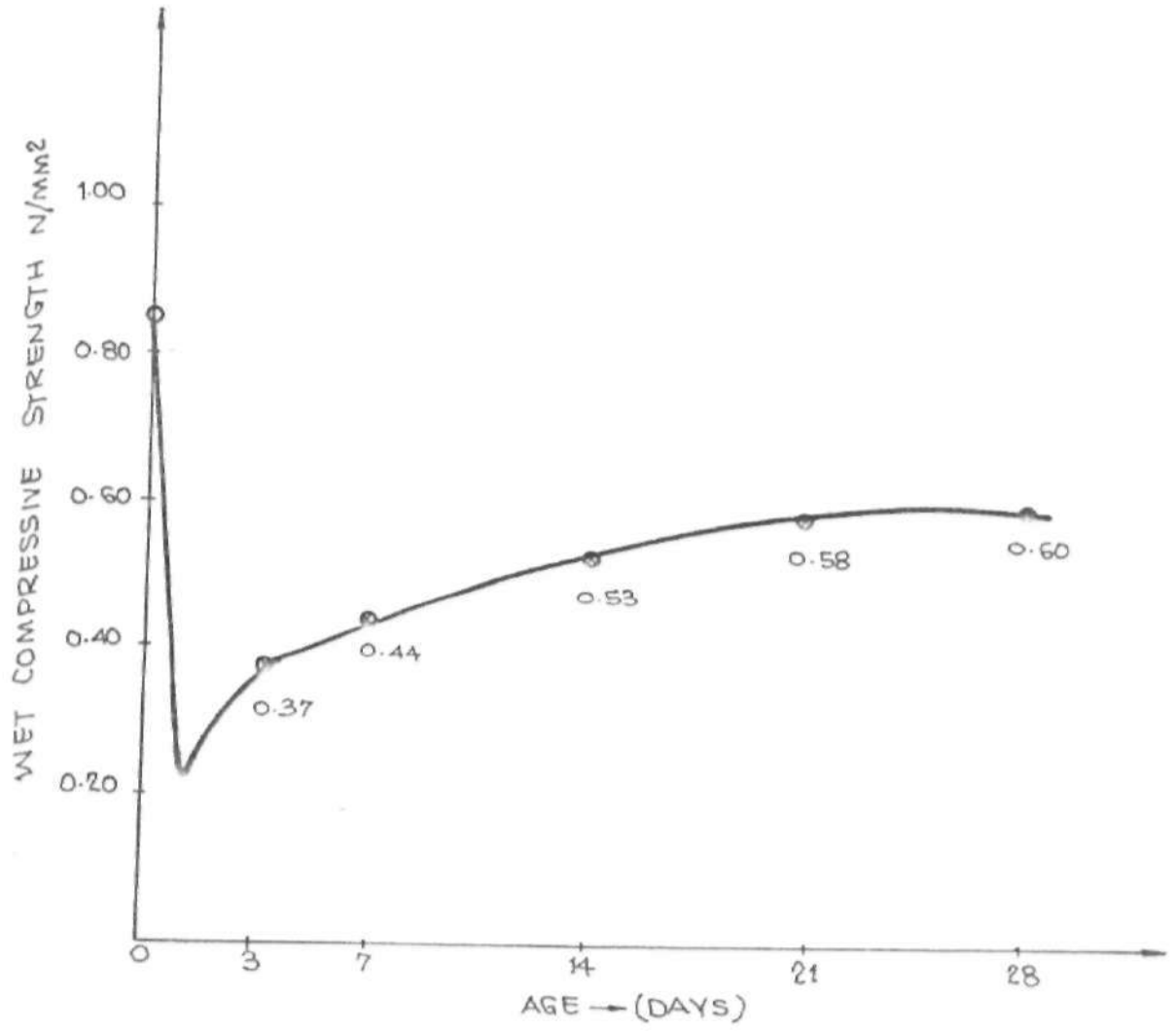
GRAPH Nº 8: WET DEVELOPMENT STRENGTH FOR INDUSTRY C

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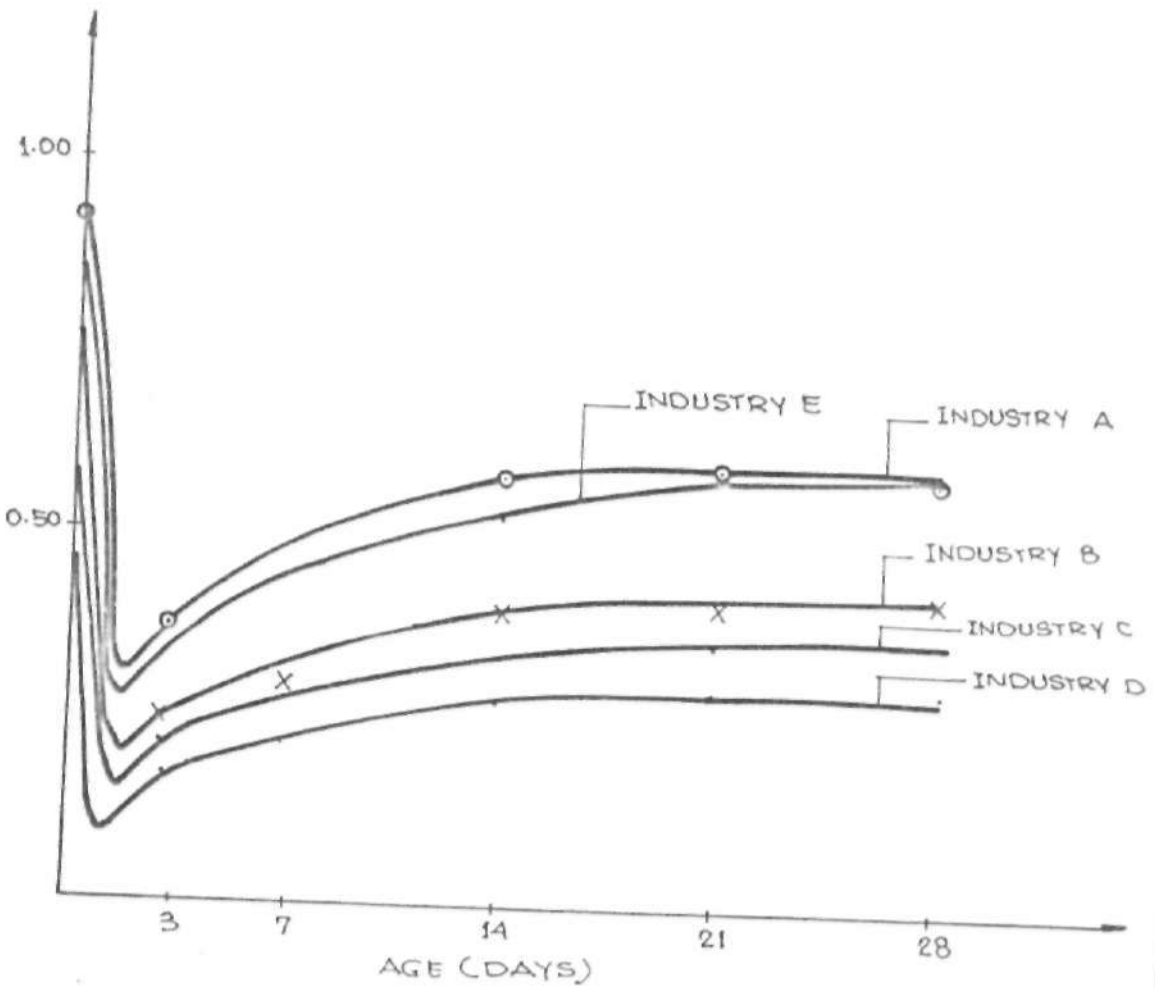


GRAPH Nº 9: WET DEVELOPMENT STRENGTH FOR INDUSTRY D

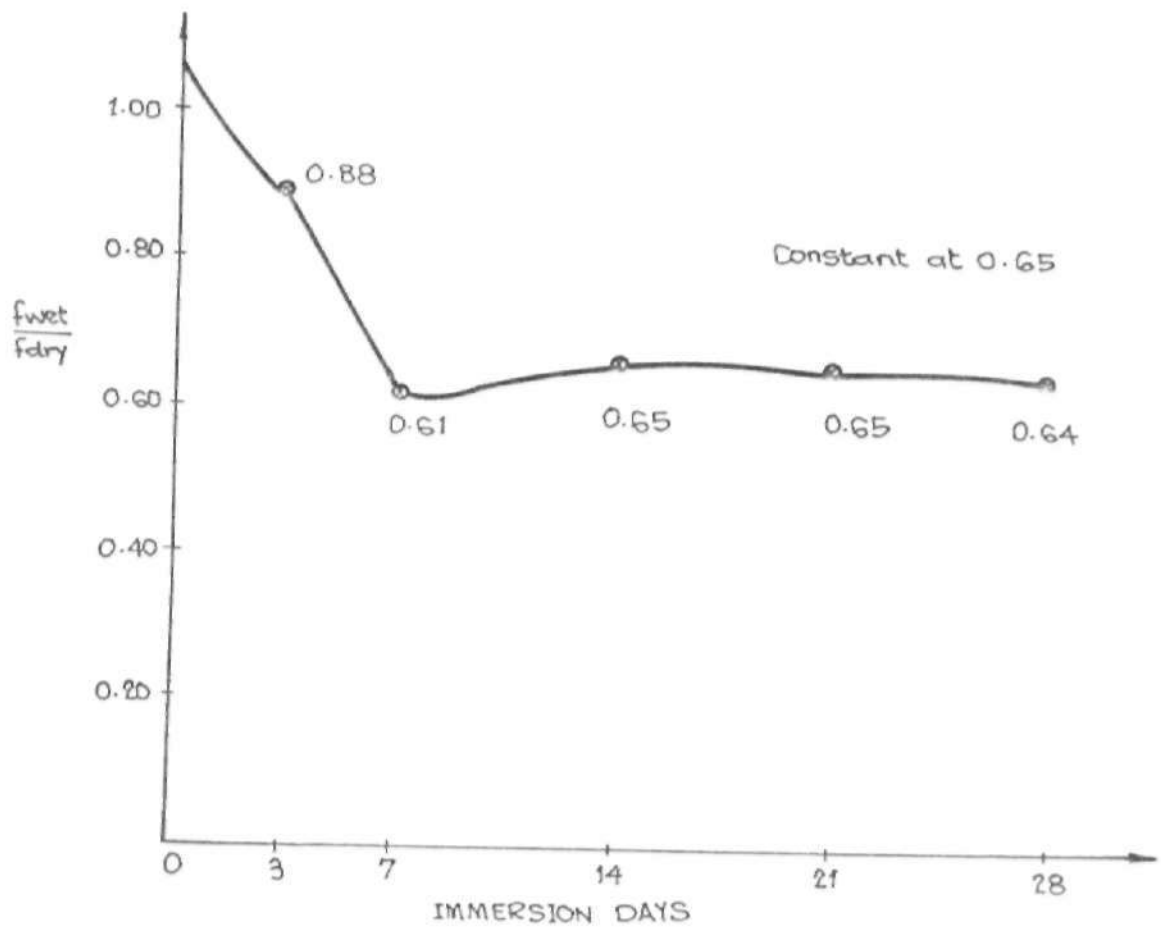
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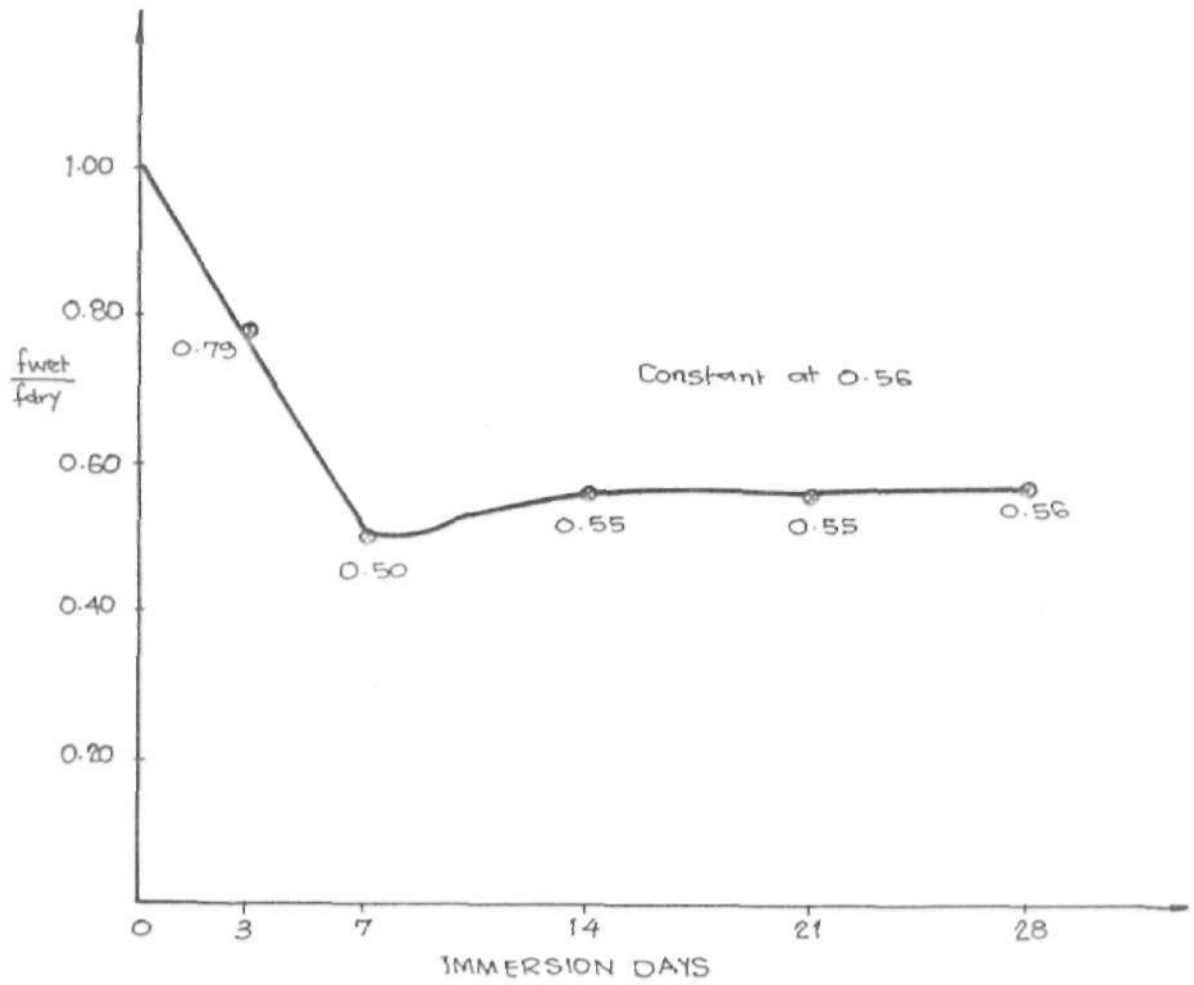
GRAPH Nº 10: WET DEVELOPMENT STRENGTH FOR INDUSTRY E



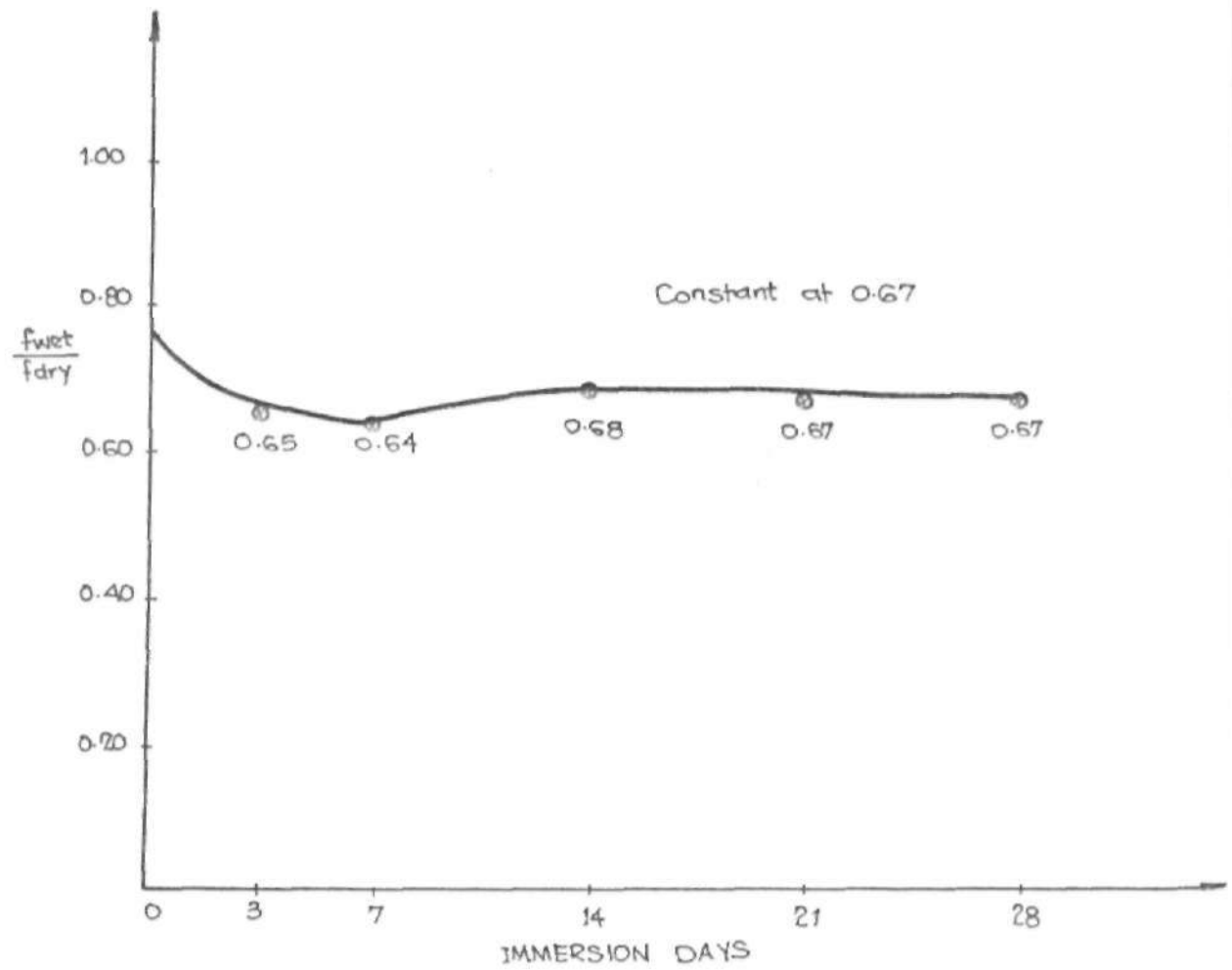
GRAPH NO 10A: WET DEVELOPMENT STRENGTH FOR INDUSTRIES A- E



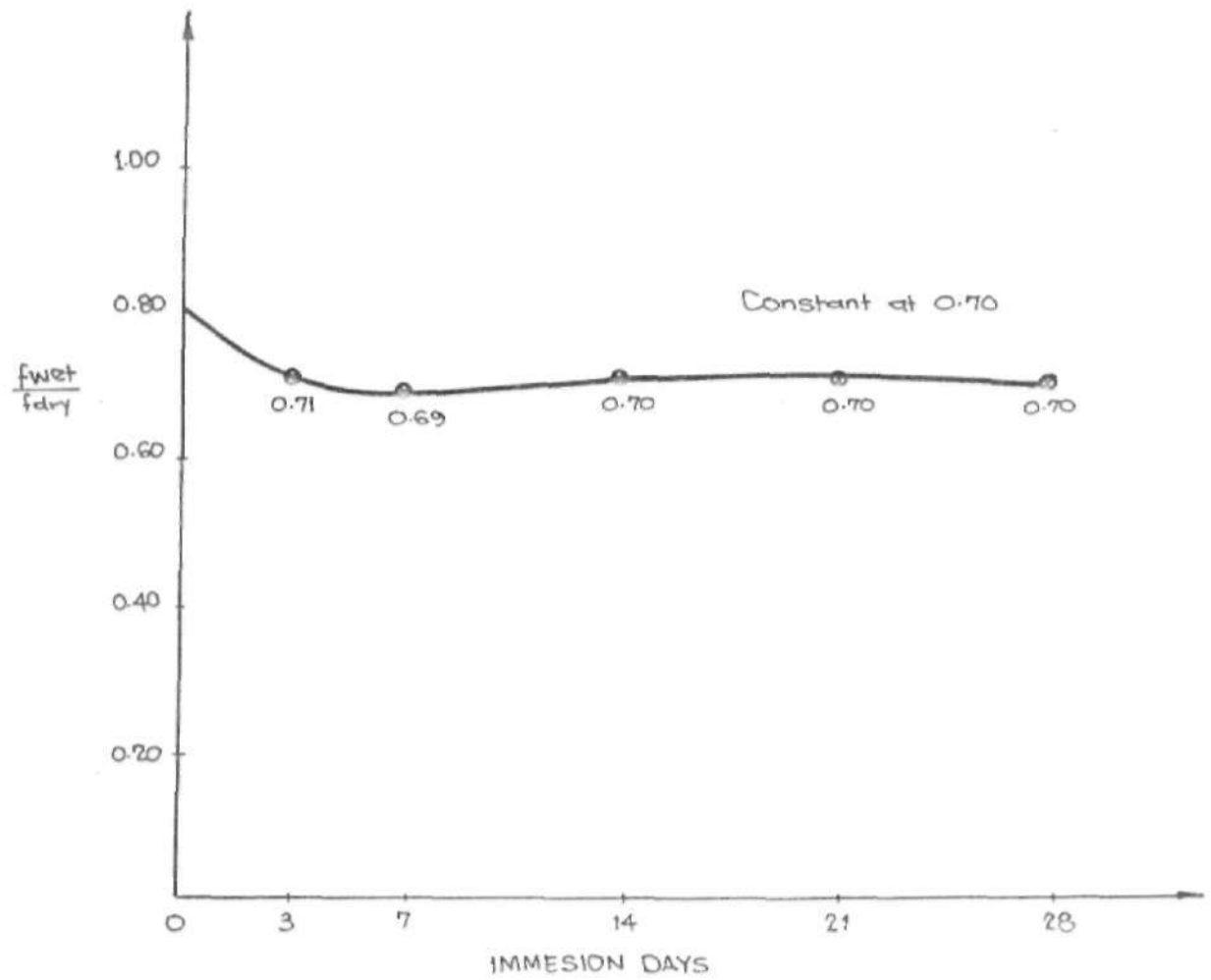
GRAPH Nº 11: RATIO OF (WET TO DRY) DEVELOPMENT STRENGTH FOR INDUSTRY A



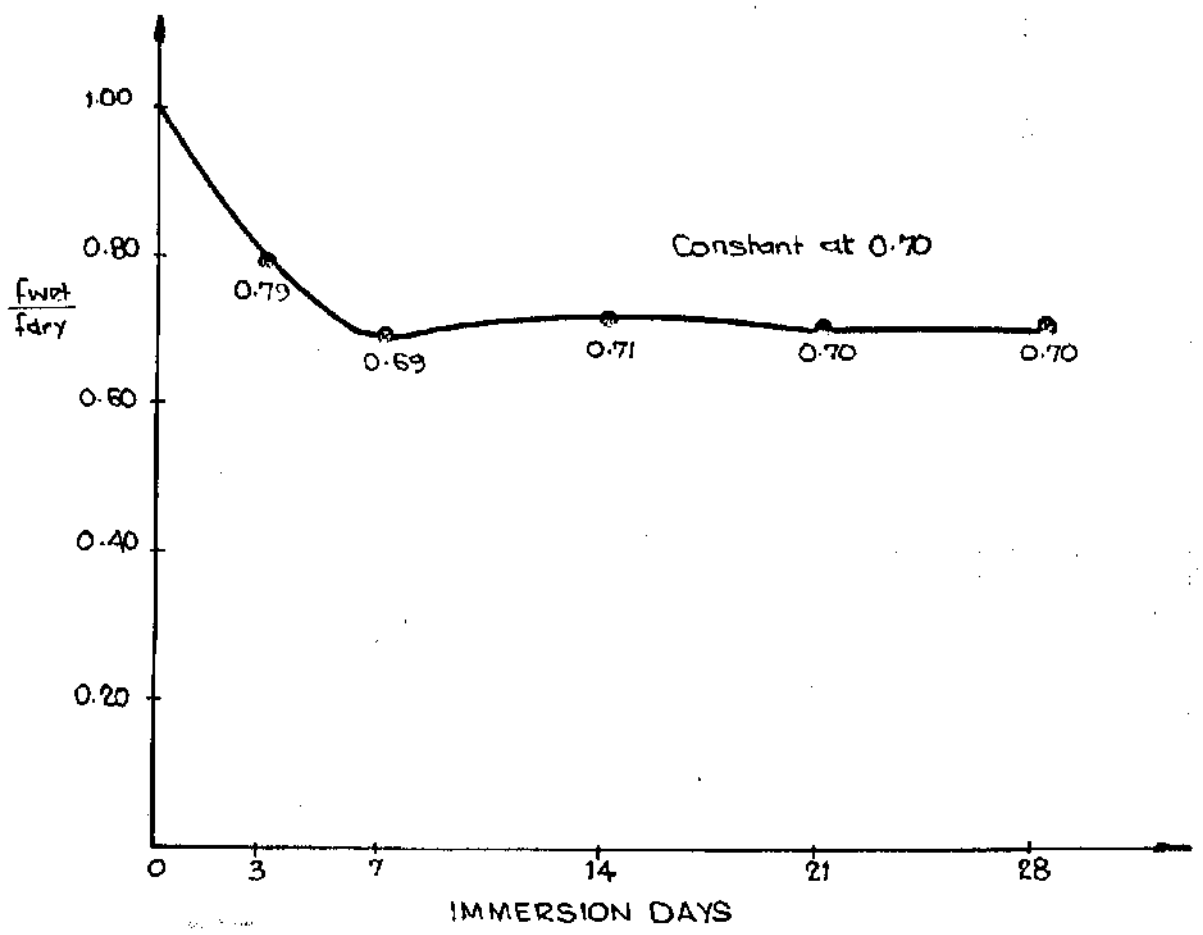
GRAPH Nº 12: RATION OF (WET TO DRY) DEVELOPMENTS FOR INDUSTRY B



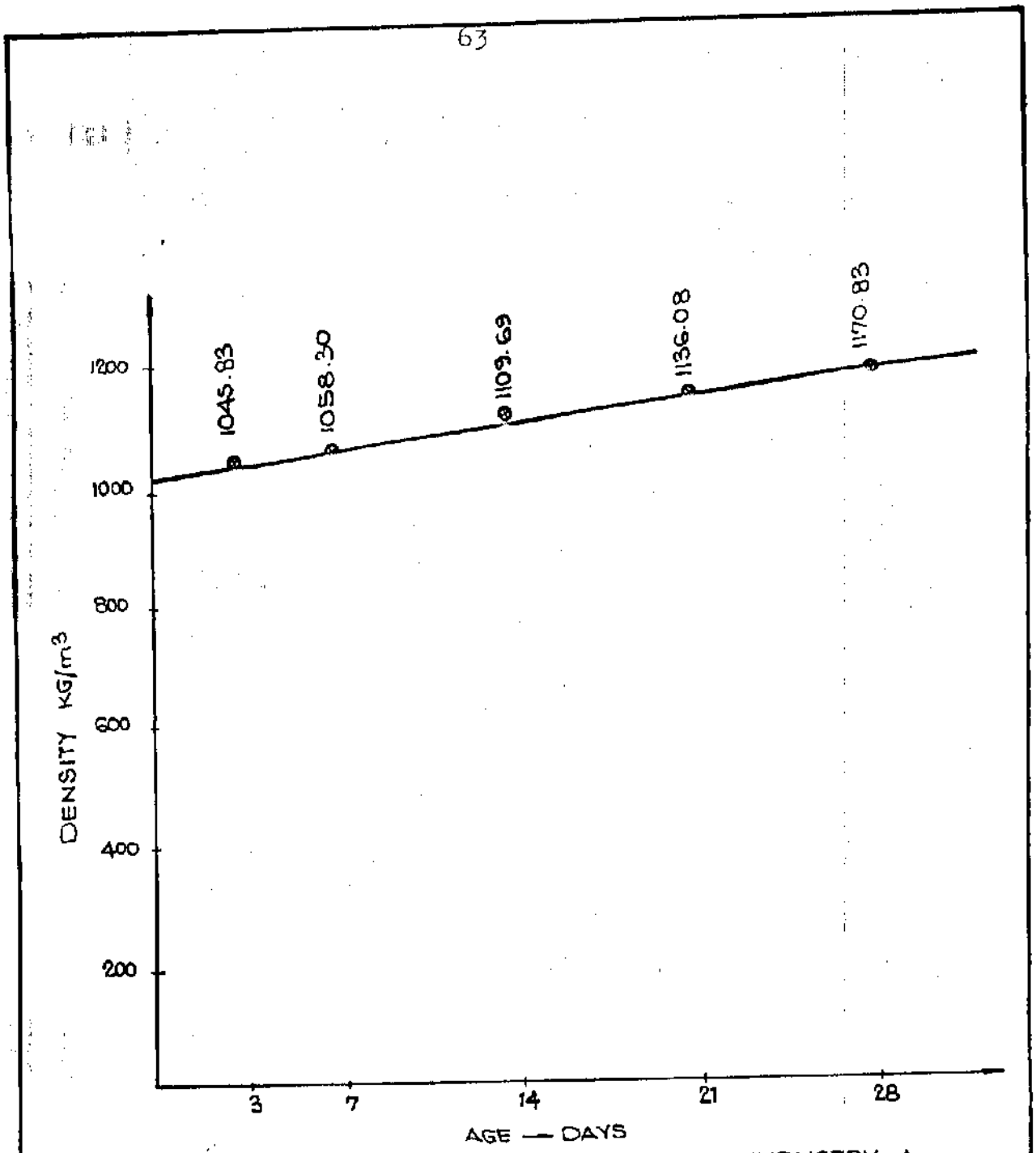
GRAPH Nº 13: RATIO OF (WET / DRY) DEVELOPMENT FOR INDUSTRY C



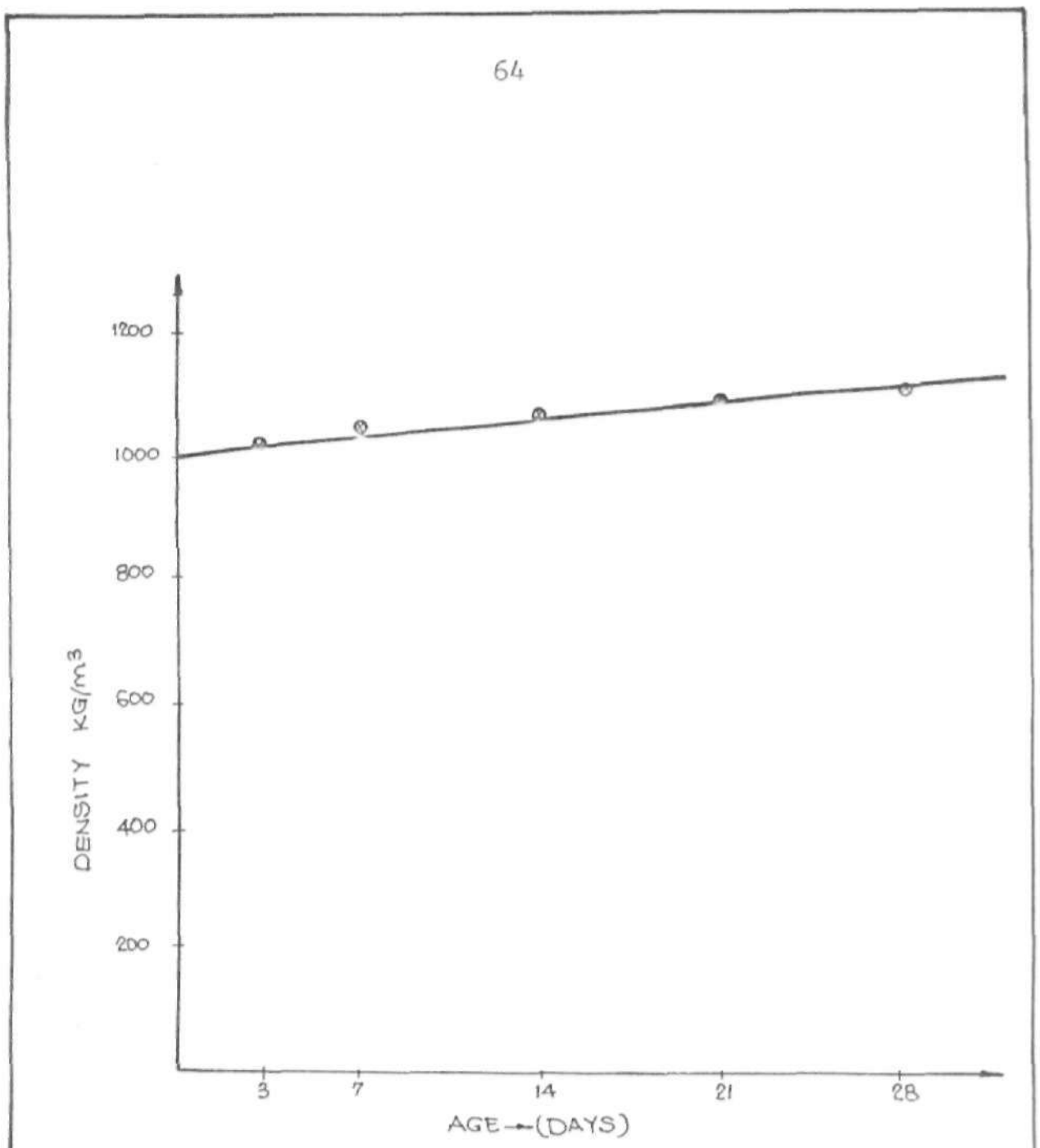
GRAPH Nº 14: RATIO OF (WET/DRY) DEVELOPMENT FOR INDUSTRY D



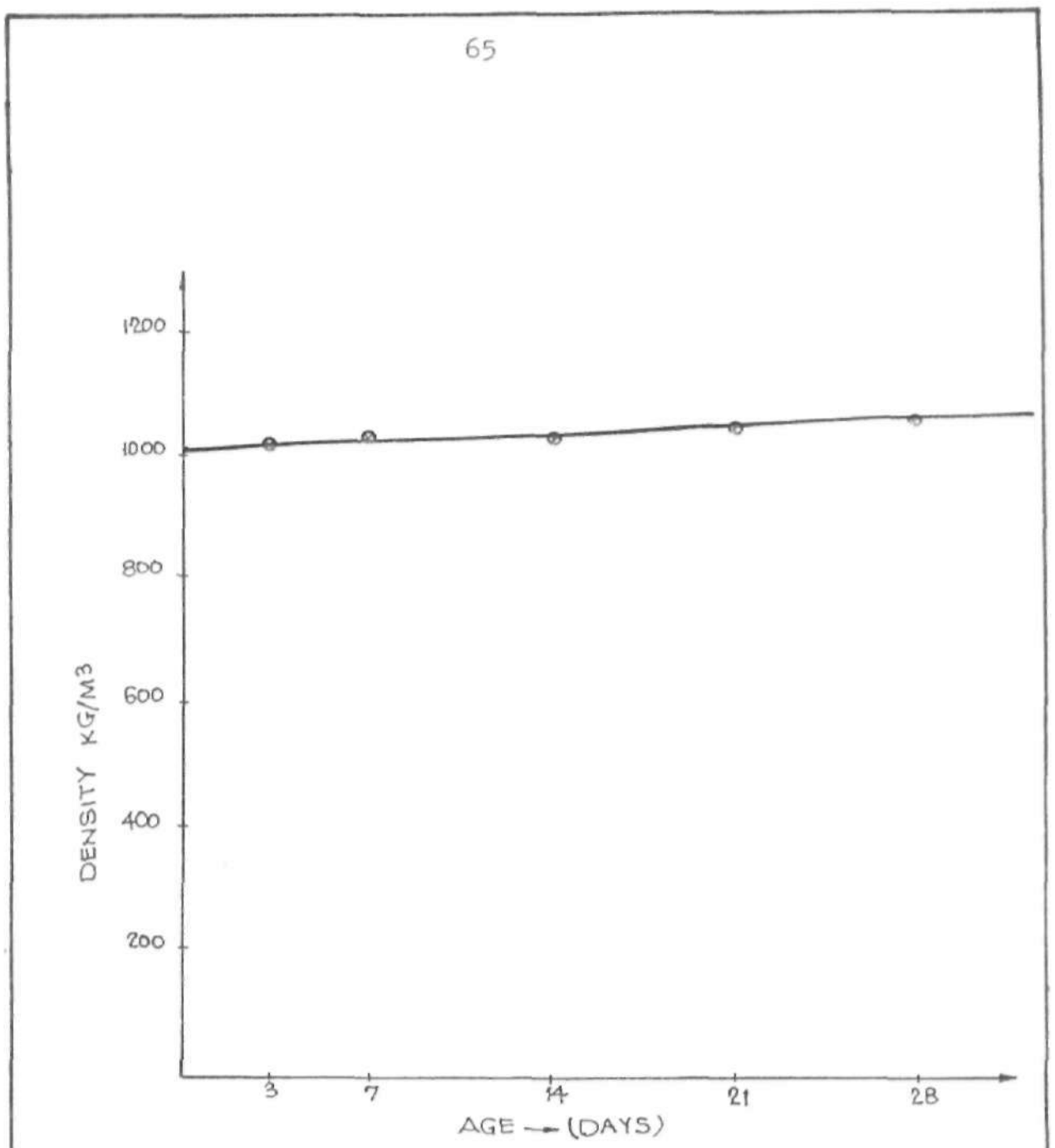
GRAPH Nº 15: RATIO OF (WET/ DRY) DEVELOPMENT FOR INDUSTRY E



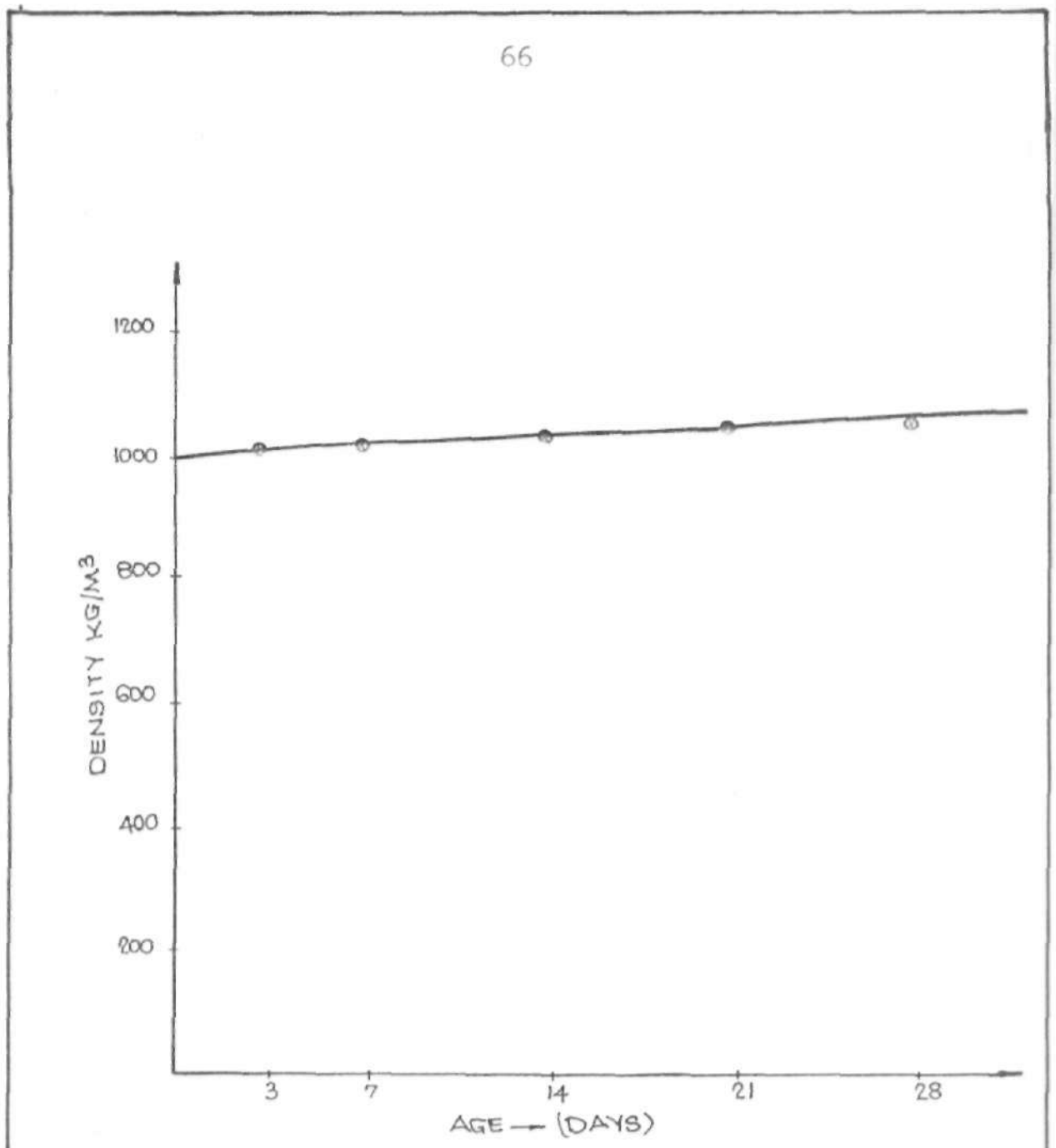
GRAPH Nº 16: DRY DENSITY VALUES FOR INDUSTRY A



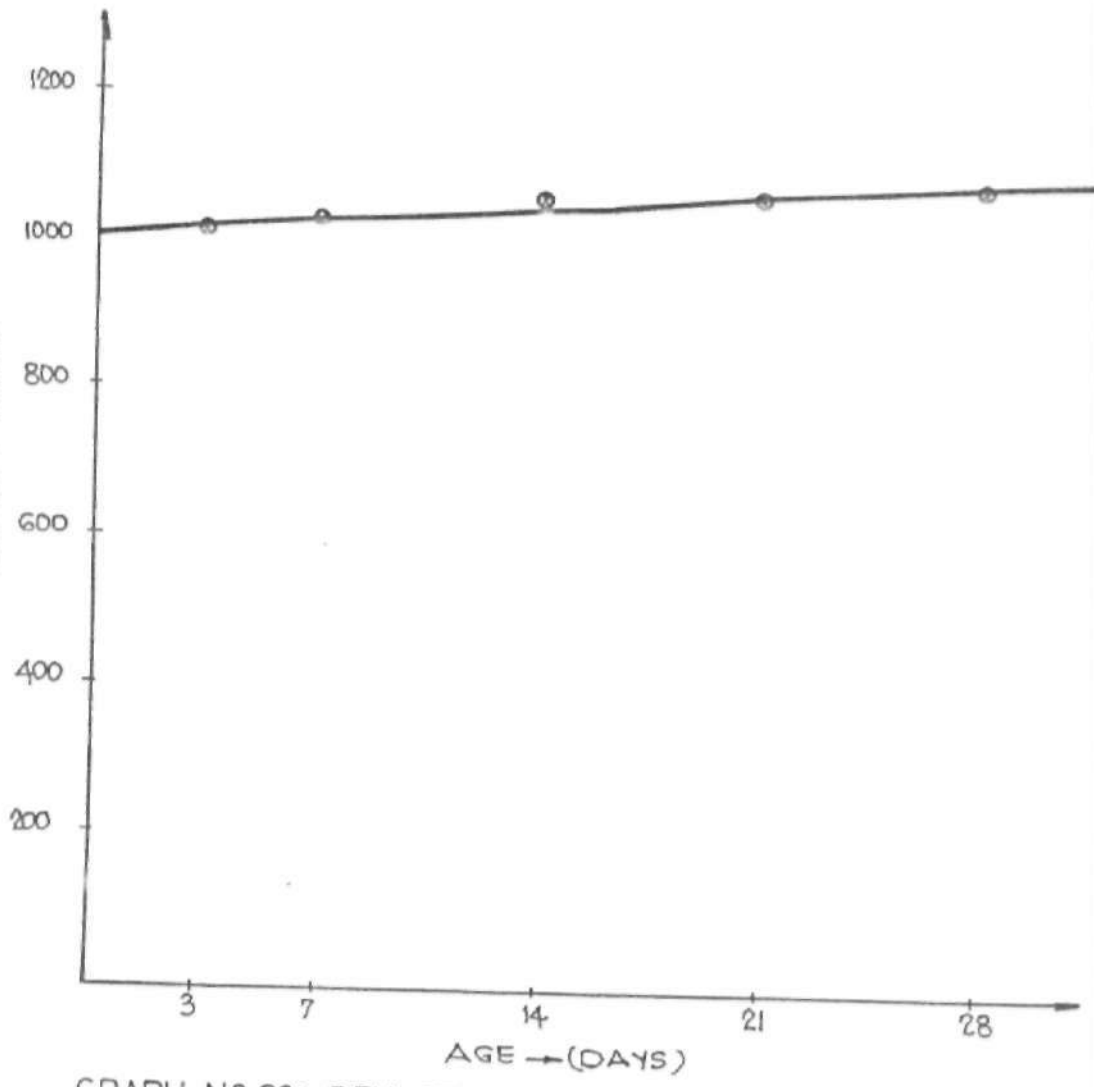
GRAPH Nº 17: DRY DENSITY VALUES FOR INDUSTRY B



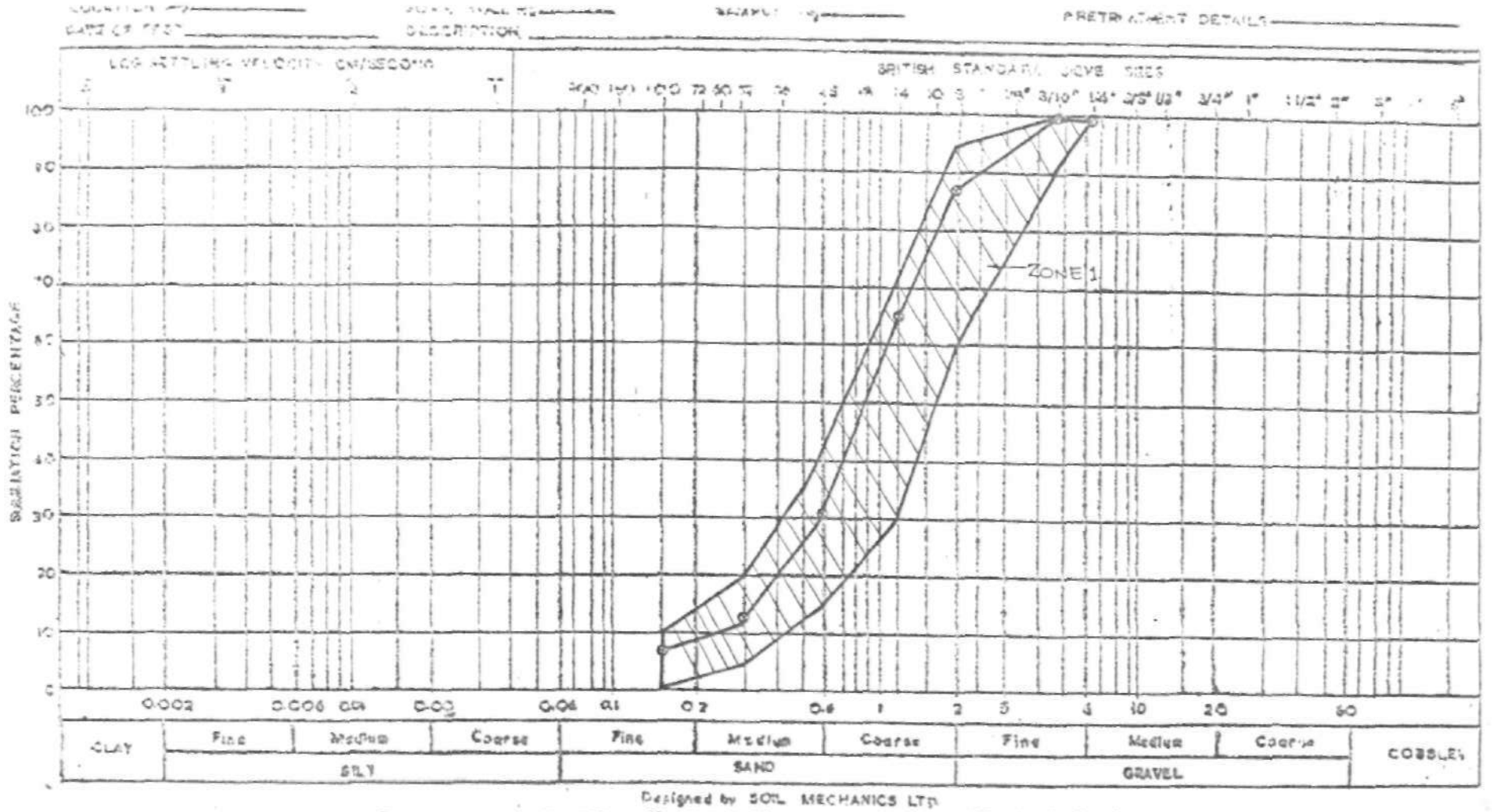
GRAPH Nº 18: DRY DENSITY VALUES FOR INDUSTRY C



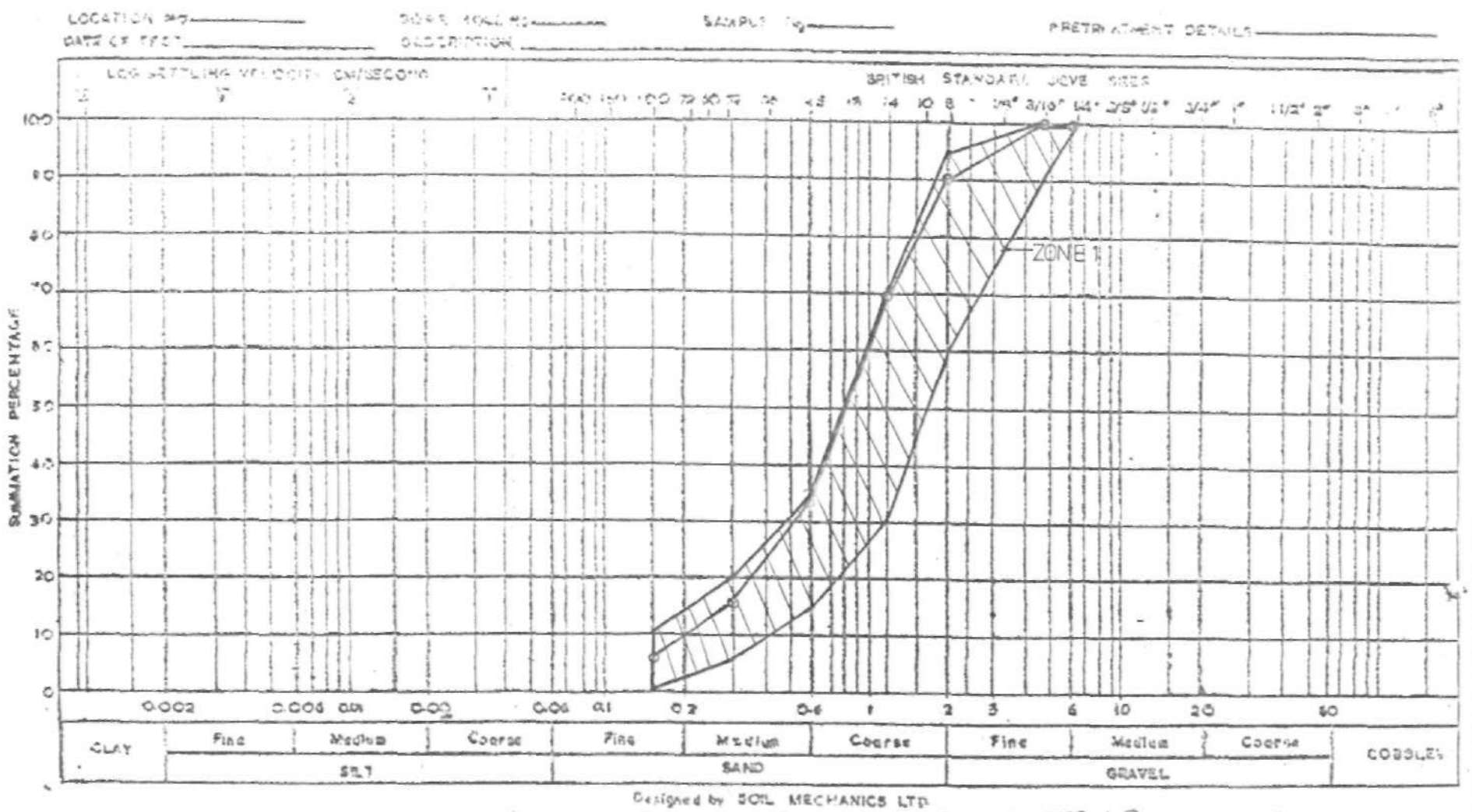
GRAPH Nº19: DRY DENSITY VALUES FOR INDUSTRY D



GRAPH Nº 20: DRY DENSITY VALUES FOR INDUSTRY E

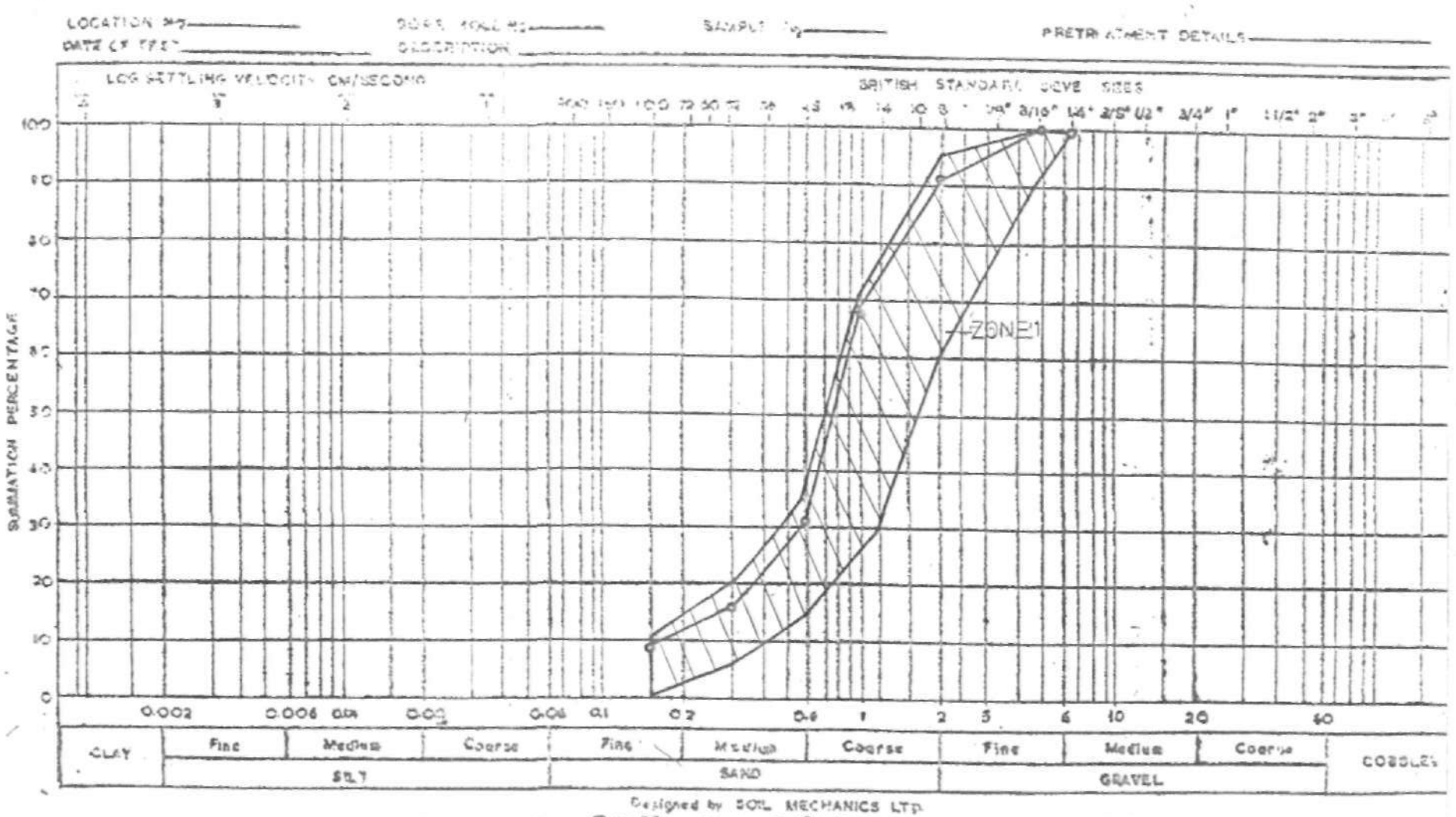


Graph 21 PARTICLE SIZE DISTRIBUTION FOR INDUSTRY A

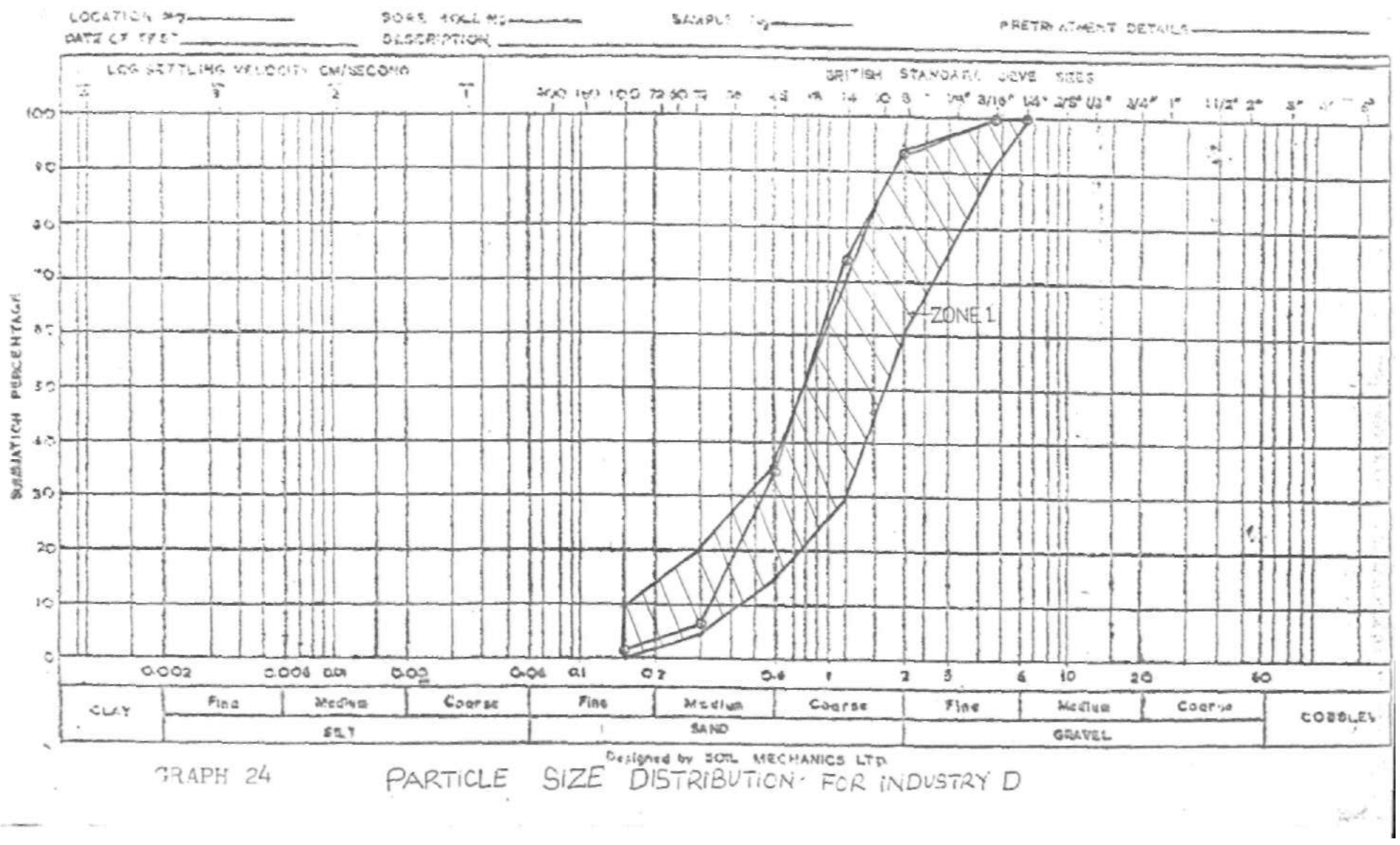


Graph 22

PARTICLE SIZE DISTRIBUTION FOR INDUSTRY B

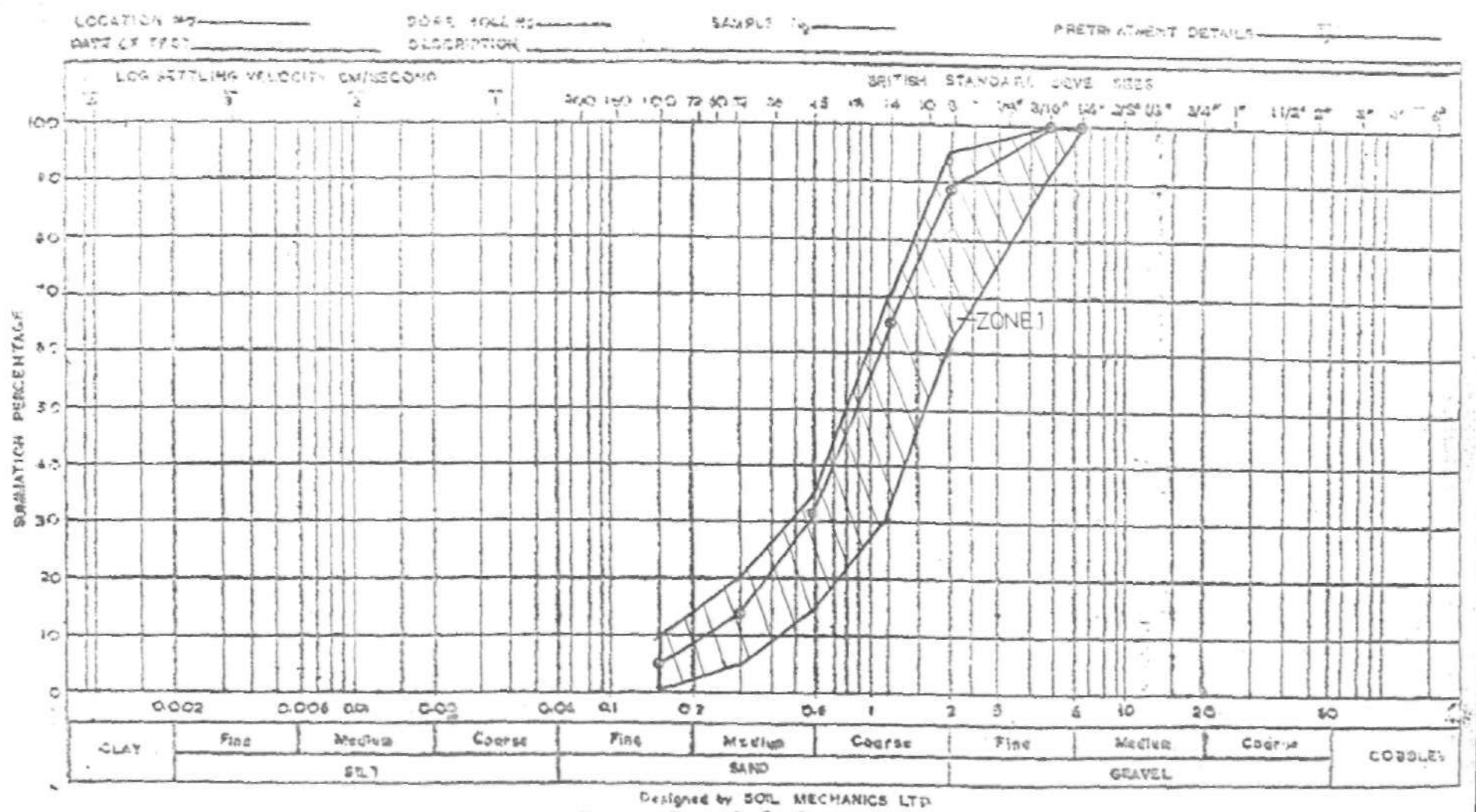


GRAPH 23 PARTICLE SIZE DISTRIBUTION FOR INDUSTRY C



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GRAPH 24 PARTICLE SIZE DISTRIBUTION FOR INDUSTRY D



GRAPH 25 PARTICLE SIZE DISTRIBUTION FOR INDUSTRY E

APPENDIX A1: RAW DATA FOR THE DRY DEVELOPMENT STRENGTH VALUES FOR INDUSTRY A

SERIAL NUMBER	DATE OF TEST	AGE (DAYS)	LENGTH (mm)	WIDTH (mm)	HT mm	SURFACE AREA (mm^2)	VOLUME (m^3)	DENSITY kG/m^3	STRENGTH N/mm^2	MASS kG
A_{11}	23/7/92	3	460	229	230	105800	0.024	1041.67	0.47	25.0
A_{12}	"	"	460	229	230	105340	"	1050.00	0.49	25.2
A_{13}	"	"	460	228	229	104880	"	1045.83	0.48	25.1
A_{21}	27/7/92	7	458	230	228	105340	"	1054.17	0.70	25.3
A_{22}	"	"	460	230	228	105800	"	1058.33	0.72	25.4
A_{23}	"	"	459	230	229	105570	"	1062.40	0.75	25.5
A_{31}	30/8/92	14	462	230	230	106260	"	1091.67	0.88	26.2
A_{32}	"	"	460	230	230	105800	"	1112.40	0.89	26.7
A_{33}	"	"	461	230	229	106030	"	1125.00	0.91	27.0
A_{41}	10/8	21	458	230	230	105340	"	1125.00	0.91	27.0
A_{42}	"	"	458	230	229	105340	"	1137.40	0.91	27.3
A_{43}	"	"	459	229	230	105111	"	1145.83	0.90	27.5
A_{51}	17/8	28	460	229	230	105340	"	1158.33	0.94	27.8
A_{52}	"	"	460	229	230	105340	"	1158.33	0.92	27.3
A_{53}	"	"	461	230	230	106030	"	1195.83	0.90	28.7

APPENDIX A2: RAW DATA FOR THE DRY DEVELOPMENT STRENGTH VALUES FOR INDUSTRY B

SERIAL NUMBER	DATE OF TEST	AGE (DAYS)	LENGTH (mm)	WIDTH (mm)	HT mm	SURFACE AREA	VOLUME m^3	DENSITY kG/m^3	STRENGTH N/mm^2	MASS
B_{11}	23/7/92	3	459	227	230	104193	0.024	1029.17	0.42	24.7
B_{12}	"	"	458	228	230	104424	"	1033.33	0.36	24.8
B_{13}	"	"	459	227	230	104193	"	1037.40	0.36	24.9
B_{21}	27/7	7	461	228	229	105108	"	1050.00	0.62	25.2
B_{22}	"	"	461	228	229	105108	"	1050.00	0.60	25.2
B_{23}	"	"	460	227	228	104420	"	1045.83	0.58	25.1
B_{31}	3/8	14	460	230	229	105800	"	1066.67	0.75	25.6
B_{32}	"	"	460	230	229	105800	"	1075.00	0.74	25.8
B_{33}	"	"	460	229	228	105340	"	1062.40	0.70	25.5
B_{41}	10/8	21	459	230	229	105570	"	1091.67	0.77	26,2
B_{42}	"	"	459	230	230	105570	"	1112.40	0.77	26.7
B_{43}	"	"	460	230	230	105800	"	1095.83	0.78	26.3
B_{51}	17/8	28	460	230	229	105800	"	1112.40	0.78	26.7
B_{52}	"	"	460	230	230	105800	"	1120.83	0.79	26.9
B_{53}	"	"	459	230	230	105800	"	1116.67	0.78	26.8

APPENDIX A3: RAW DATA FOR THE DRY DEVELOPMENT STRENGTH VALUES FOR INDUSTRY C

SERIAL NUMBER	DATE OF TEST	AGE (DAYS)	LENGTH (mm)	WIDTH (mm)	HEI-GHT	VOLUME m^3	MASS kG	DENSITY kG/m^3	STRENGTH N/mm^2	SURFACE AREA
C_{11}	23/7/92	3	460	229	229	0.027	24.20	1008.33	0.34	105340
C_{12}	"	"	460	229	229	"	24.30	1012.40	0.36	"
C_{13}	"	"	460	229	229	"	24.40	1016.67	0.32	"
C_{21}	27/7	7	459	230	228	"	24.70	1029.17	0.40	105570
C_{22}	"	"	459	230	229	"	24.77	1032.08	0.44	"
C_{23}	"	"	460	229	229	"	24.72	1030.00	0.42	"
C_{31}	3/8	14	460	228	228	"	24.80	1033.33	0.47	104880
C_{32}	"	"	461	228	228	"	24.85	1035.42	0.52	105108
C_{33}	"	"	461	228	227	"	24.77	1032.08	0.50	"
C_{41}	10/8	21	461	229	227	"	24.90	1037.40	0.53	105569
C_{42}	"	"	460	229	227	"	25.22	1050.83	0.53	105570
C_{43}	"	461	228	228	"	"	25.00	1041.67	0.54	105108
C_{51}	17/8	28	460	230	230	"	25.30	1054.17	0.57	105800
C_{52}	"	"	459	230	230	"	25.55	1064.58	0.52	105570
C_{53}	"	"	459	230	230	"	25.80	1075.00	0.56	"

APPENDIX A4: RAW DATA FOR THE DRY DEVELOPMENT STRENGTH VALUES FOR INDUSTRY D

SERIAL NUMBER	DATE OF TEST	AGE (DAYS)	LENGTH (mm)	WIDTH (mm)	HEI-GHT	VOLUME m^3	MASS kG	DENSITY kG/m^3	STRENGTH N/mm^2	SURFACE AREA
D_{11}	23/7/92	3	460	229	230	0.024	24.10	1004.17	0.25	105800
D_{12}	"	"	460	229	230	"	24.10	1004.17	0.25	"
D_{13}	"	"	460	230	229	"	24.20	1008.33	0.24	"
D_{21}	27/7	7	458	230	228	"	24.40	1016.67	0.28	105340
D_{22}	"	"	460	230	228	"	24.50	1020.83	0.32	105800
D_{23}	"	"	459	230	227	"	24.50	1020.83	0.36	105570
D_{31}	3/8	14	460	228	229	"	24.80	1033.33	0.40	104880
D_{32}	"	"	460	228	229	"	24.60	1025.00	0.40	"
D_{33}	"	"	459	229	229	"	24.75	1031.24	0.41	105111
D_{41}	10/8	21	461	230	229	"	25.00	1041.67	0.42	106030
D_{42}	"	"	460	230	228	"	24.90	1037.40	0.45	105800
D_{43}	"	"	461	229	228	"	25.20	1050.00	0.45	105569
D_{51}	17/8	28	460	229	230	"	25.40	1058.33	0.46	105340
D_{52}	"	"	460	229	229	"	25.50	1062.40	0.46	"
D_{53}	"	"	460	230	229	"	25.20	1050.00	0.47	105800

APPENDIX A5: RAW DATA FOR THE DRY DEVELOPMENT STRENGTH VALUES FOR INDUSTRY E

SERIAL NUMBER	DATE OF TEST	AGE (DAYS)	LENGTH (mm)	WIDTH (mm)	HEIGHT	SURFACE AREA	VOLUME (m^3)	MASS kG	DENSITY kG/m^3	FAILURE LOAD kN	STRENGTH N/mm^2
E_{11}	2/4/92	3	460	229	228	105340	0.024	24.30	1012.4	50.00	0.473
E_{12}	"	"	460	229	228	"	"	24.50	1020.83	49.7	0.47
E_{13}	"	"	460	228	229	104880	"	24.60	1025.00	49.4	0.47
E_{21}	8/4	7	460	230	229	105800	"	24.75	1031.24	65.7	0.62
E_{22}	"	"	460	230	229	"	"	24.87	1036.25	67.7	0.64
E_{23}	"	"	450	230	230	"	"	24.95	1029.58	69.7	0.66
E_{31}	13/4	14	460	230	230	105800	"	25.52	1063.33	79.5	0.75
E_{32}	"	"	460	230	230	"	"	25.40	1058.33	99.3	0.75
E_{33}	"	"	460	230	229	"	"	25.55	1064.58	79.4	0.75
E_{41}	20/4	21	459	229	229	105111	"	25.62	1067.40	87.8	0.83
E_{42}	"	"	460	229	230	105340	"	25.608	1066.57	87.8	0.83
E_{43}	"	"	459	229	230	105111	"	25.65	1068.74	87.7	0.83
E_{51}	27/4	28	460	229	230	105340	"	26.00	1083.33	92.0	0.87
E_{52}	"	"	459	230	230	105111	"	25.89	1078.74	90.0	0.85
E_{53}	"	"	459	230	230	"	"	26.66	1110.83	91.0	0.86

APPENDIX B2: RAW DATA FOR THE WET DEVELOPMENT STRENGTH VALUES FOR INDUSTRY A

SERIAL NUMBER	DATE OF TEST	AGE (DAYS)	LENGTH (mm)	WIDTH (mm)	HEIGHT (mm)	SURFACE AREA (mm^2)	VOLUME (m^3)	MASS (kG)	DENSITY kG/m^3	FAILURE LOAD kN	STRENGTH N/mm^2
A_{11}	18/8/92	3	461	229	229	105569	0.024	29.2	1216.67	40.00	0.38
A_{12}	"	"	460	230	229	105800	"	29.5	1229.17	40.40	0.38
A_{13}	"	"	461	229	229	105569	"	29.8	1241.67	40.20	0.38
A_{21}	22/8	7	460	230	230	105800	"	32.5	1354.17	48.00	0.45
A_{22}	"	"	460	230	230	"	"	32.8	1366.67	46.00	0.44
A_{23}	"	"	459	230	230	105570	"	33.2	1383.33	45.65	0.43
A_{31}	29/8	14	459	230	230	"	"	35.0	1458.33	61.25	0.58
A_{32}	"	"	460	230	229	105800	"	34.5	1437.50	61.55	0.58
A_{33}	"	"	459	230	230	105570	"	34.8	1450.00	61.40	0.58
A_{41}	5/9	21	460	230	229	105800	"	37.3	1554.17	62.68	0.59
A_{42}	"	"	460	230	230	"	"	36.6	1525.00	62.32	0.59
A_{43}	"	"	460	230	230	"	"	36.3	1512.40	62.20	0.59
A_{51}	12/9	28	460	230	230	"	"	36.5	1520.83	62.45	0.59
A_{52}	"	28	460	230	230	"	"	37.5	1562.50	62.40	0.59
A_{53}	"	"	460	230	230	"	"	38.5	1604.17	62.41	0.59

APPENDIX B2: RAW DATA FOR THE WET DEVELOPMENT STRENGTH VALUES FOR INDUSTRY B

SERIAL NUMBER	DATE OF TEST	AGE (DAYS)	LENGTH (mm)	WIDTH (mm)	HEIGHT	VOLUME (m^3)	MASS (kG)	DENSITY kG/m^3	FAILURE LOAD	STRENGTH N/mm^2	SURFACE AREA
B_{11}	18/8/92	3	460	229	230	0.024	27.9	1162.50	27.00	0.26	105340
B_{12}	"	"	460	229	230	"	27.5	1145.83	28.00	0.26	"
B_{13}	"	"	460	230	230	"	27.7	1154.17	27.50	0.26	105800
B_{21}	22/8	7	459	229	229	"	31.2	1300.00	30.90	0.29	105111
B_{22}	"	"	459	229	229	"	32.1	1337.50	32.00	0.30	"
B_{23}	"	"	460	230	229	"	32.8	1366.67	32.10	0.30	105800
B_{31}	29/8	14	459	230	230	"	34.6	1441.67	42.44	0.40	105570
B_{32}	"	"	458	230	230	"	34.0	1416.67	42.22	0.40	105340
B_{33}	"	"	459	229	229	"	34.2	1425.00	42.30	0.40	105111
B_{41}	5/9	21	460	230	230	"	35.2	1466.67	45.00	0.43	105800
B_{42}	"	"	459	229	230	"	34.8	1450.00	44.20	0.42	105111
B_{43}	"	"	459	230	230	"	35.0	1458.33	44.30	0.42	105570
B_{51}	28/9	28	461	230	228	"	35.5	1479.17	46.00	0.43	106030
B_{52}	"	"	460	230	229	"	36.0	1500.00	45.50	0.43	105800
B_{53}	"	"	461	230	230	"	36.2	1508.33	45.00	0.43	106030

APPENDIX B3: RAW DATA FOR THE WET DEVELOPMENT STRENGTH VALUES FOR INDUSTRY C

SERIAL NUMBER	DATE OF TEST	AGE (DAYS)	LENGTH (mm)	WIDTH (mm)	HEI-GHT	VOLUME m^3	MASS kG	DENSITY kG/m^3	FAILURE LOAD kN	STRENGTH N/mm^2	SURFACE AREA mm^2
C_{11}	30/6/92	3	460	230	229	0.024	26.00	1083.33	23.30	0.22	105800
C_{12}	"	"	460	230	230	"	26.60	1108.33	25.30	0.24	"
C_{13}	"	"	460	230	229	"	26.30	1095.83	21.30	0.20	"
C_{21}	4/7	7	461	229	229	"	27.50	1145.83	29.00	0.27	105569
C_{22}	"	"	461	230	230	"	27.00	1125.00	29.30	0.28	106030
C_{23}	"	"	460	230	230	"	27.30	1137.50	30.50	0.29	105800
C_{31}	11/7	14	460	230	229	"	29.0	1208.33	35.00	0.33	"
C_{32}	"	"	460	230	228	"	28.2	1175.00	36.00	0.34	"
C_{33}	"	"	459	230	229	"	28.4	1183.33	36.70	0.35	105570
C_{41}	18/7	21	459	229	230	"	28.7	1195.83	37.50	0.35	105111
C_{42}	"	"	460	229	230	"	28.5	1187.50	38.50	0.36	105340
C_{43}	"	"	460	230	230	"	29.5	1229.17	39.50	0.37	105800
C_{51}	25/7	28	460	230	230	"	29.7	1237.50	40.20	0.38	"
C_{52}	"	"	459	230	230	"	30.3	1262.50	38.70	0.37	105570
C_{53}	"	"	459	230	230	"	31.5	1312.50	38.50	0.36	"

APPENDIX B4: RAW DATA FOR THE WET DEVELOPMENT STRENGTH VALUES FOR INDUSTRY D

SERIAL NUMBER	DATE OF TEST	AGE (DAYS)	LENGTH (mm)	WIDTH (mm)	HEIGHT	VOLUME (m^3)	MASS (kG)	DENSITY (kG/m^3)	SURFACE AREA mm^2	FAILURE LOAD	STRENGTH N/mm^2
D_{11}	18/8/92	3	461	229	229	0.024	26.37	1098.75	105569	17.00	0.16
D_{12}	"	"	461	229	229	"	27.20	1133.33	"	19.00	0.18
D_{13}	"	"	460	229	229	"	28.00	1166.67	105340	21.00	0.20
D_{21}	22/8	7	460	230	228	"	28.20	1175.00	105800	23.50	0.22
D_{22}	"	"	461	230	229	"	28.50	1187.50	106030	23.00	0.22
D_{23}	"	"	461	230	228	"	29.50	1229.17	"	23.10	0.22
D_{31}	29/8	14	460	230	230	"	30.50	1270.83	105800	29.00	0.27
D_{32}	"	"	460	230	230	"	30.90	1287.50	"	30.00	0.28
D_{33}	"	"	460	230	230	"	31.30	1304.17	"	29.80	0.28
D_{41}	5/9	21	460	230	229	"	31.70	1320.83	"	30.00	0.28
D_{42}	"	"	460	230	230	"	31.90	1329.16	"	31.00	0.29
D_{43}	"	"	459	230	229	"	32.00	1333.33	105570	34.00	0.32
D_{51}	12/9	28	459	229	229	"	33.80	1408.33	105111	32.75	0.31
D_{52}	"	"	459	229	229	"	33.90	1412.50	"	33.50	0.32
D_{53}	"	"	458	230	230	"	33.50	1395.83	105340	28.90	0.27

APPENDIX B5: RAW DATA FOR THE WET DEVELOPMENT VALUES FOR INDUSTRY E

SERIAL NUMBER	DATE OF TEST	AGE (DAYS)	LENGTH (mm)	WIDTH (mm)	HEIGHT	VOLUME (m^3)	MASS (kG)	DENSITY kG/m^3)	SURFACE (kN)	FAILURE LOAD	STRENGTH N/mm^2
E_{11}	28/4/92	3	460	229	230	0.024	27.30	1137.50	105340	40.00	0.37
E_{12}	"	"	460	228	230	"	27.50	1145.83	104880	39.00	0.37
E_{13}	"	"	460	228	230	"	28.00	1187.50	"	38.60	0.36
E_{21}	2/5/92	7	460	229	229	"	28.50	1187.50	105340	46.50	0.44
E_{22}	"	"	460	229	229	"	28.30	1179.17	"	46.70	0.44
E_{23}	"	"	460	228	230	"	29.20	1216.67	104880	46.30	0.44
E_{31}	9/5	14	459	229	230	"	30.60	1275.00	105111	52.00	0.49
E_{32}	"	"	459	229	229	"	31.20	1300.00	"	58.00	0.55
E_{33}	"	"	460	230	229	"	32.00	1333.33	105800	58.00	0.55
E_{41}	16/5	21	460	230	229	"	33.30	1387.50	"	62.00	0.59
E_{42}	"	"	459	230	229	"	35.00	1458.33	105570	60.00	0.57
E_{43}	"	"	459	230	230	"	35.20	1466.67	"	62.20	0.59
E_{51}	23/5	28	460	230	230	"	35.30	1470.83	105800	64.50	0.61
E_{52}	"	"	461	230	229	"	35.70	1487.50	106030	61.50	0.58
E_{53}	"	"	461	230	229	"	35.50	1479.17	106030	64.50	0.61

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