EFFECTS OF TEMPERATURE ON STRENGTH CHARACTERISTICS OF STEEL SLAG STABILIZED BURNT BRICKS

By

E. O. Akanbi
Department of Civil and Environmental Engineering
University of Lagos
Akoka, Lagos. Nigeri.

ABSTRACT

The influence of firing temperature on the crushing strength of steel slag stabilized lateritic proctor-sized bricks was investigated. The laboratory tests were carried out according to BS 1775:1990. The lateritic soil used for the bricks attains its maximum dry density of 1621kg/m³ at an optimum moisture content of 19.5%. Stabilization of the soil with steel slag reveals that 7.5% steel slag is required to optimally fill the air voids in the soil. The results showed that the crushing strength of the stabilized bricks is about two and half times that of unstabilized. The crushing strength of 7.5% steel slag stabilized bricks increases with increase in temperature up to 750°C, after which it reduces drastically, inferring that the soil-slag bond is completely formed at 750°C. At 1000°C, the bricks became weak and friable. The strength of the fired stabilized brick at 750°C is almost twice the unfired brick. The bricks were also found to be durable under normal condition of exposure. It is concluded that properly prepared steel stabilized lateritic-fired bricks have potentials of being used in low cost housing construction.

KEYWORDS: *Lateritic burnt bricks, temperature effect, steel slag, strength, durability.*

INTRODUCTION

Over the years, the extensive recovery and usage of natural resources has led to a shortage of quality natural materials being experienced all over the world. At the same time, disposal of industrial waste or by-products has become more difficult and expensive as a result of increasing stringent environmental regulations and shortages of suitable nearby disposal sites. Given this scenario in developing countries with minimal infrastructural development, there should be a lot of attention in the area of investigating the possibility of improving the quality of available natural resources with industrial wastes, in the production of building or road construction materials.

Laterite is a product of tropical weathering and is widely distributed all over the tropical regions of the world, including those of African continent. However, laterite or lateritic soil, as a result of its texture, mineralogical and chemical composition, behaviour in the presence of moisture, etc is known to exhibit some properties which are not desirable when the soil is used for engineering purposes. Such properties include iron impregnation, disintegration of the apparent large grains into finer grains when in contact with water, swelling and shrinkages [1]. Some of these properties have been successfully curtailed or minimized through soil stabilization. Stabilization may take the form of mechanical stabilization (compaction, consolidation, addition of additives, etc.) thermal or electrical stabilization. Slags are waste, glass-like products formed by fusion of oxides in the manufacturing process of iron and steel. Slags have been successfully used in the past as stabilizing agents[2, 3].

Subjecting a soil to heat is thermal stabilization. A sizeable proportion of lateritic soil is made up of clay. On being heated, adsorbed water in clay is removed at 100°C. Further heating leads to decomposition and dehydration of clay minerals, especially kaolinite, which looses its hydroxyl group as water [4]. Clay hardens on heating, and if heated to a high enough temperature, it may remain hard. At temperatures above 400°C, changes in crystalline structure of clay minerals occur, including the loss of the hydroxyl group. These changes are irreversible and give rise to other significant changes in the physical properties of the soil [5]. Naturally occurring clay in general contains minerals other than kaolinite, the most common being mica and minor constituents like pyrites (FeS). Oxides of iron, Calcite ($CaCO_3$), dolomite ($CaMgCO_3$), gypsum ($CaSO_4.2H_2O$) and anatase (TiO_2) have also being reported as being present in traces [4]. Knight and Knight [6] reported that chemically combined water in burnt bricks is not driven out until a little below red heat, occurring at temperatures between 400°C and 600°C. The fluxing ions (Na^+, K^+, Ca^{2+} and Mg^{2+}) derived from micas and other compounds, when present lower the melting point of the system, and in particular react with silica at 1000°C to form viscous liquid, which on cooling solidified to form glass. This complex glass is responsible for the vitrification and fired strength of such clay [4].

The changes in structure of clay minerals brought about by heating of clay soils result in hard durable road material. The resulting material is of relatively low quality when compared with normal type of stone used in road construction but can be used to advantage, especially when high quality materials are not available [7]. The heating of clay soils leads to decrease in Plasticity Index (PI),while compressibility, and permeability generally increase due to shrinkages of clay by desiccation and formation of cracks and fissures [7].

The foregoing has revealed that engineering behavior of clay or lateritic soil could be considerably altered at elevated temperatures, and this can be taken advantage of. What then is the potential of combining thermal stabilization with mechanical stabilization (i.e. addition of binder) in the production of burnt bricks? Akinmusuru [8] studied the influence of firing temperatures and cement with pebble addition on crushing strength of bricks made from lateritic soil. He reported that while bricks with no cement at all (plain bricks) attained their maximum crushing strength at 900°C, a much lower temperature of 500°C is adequate for soil-cement bricks, to attain their maximum strengths. Deodhar and Kute [2] investigated the effects of fly ash and temperature on properties of burnt clay bricks. The researchers tested about 1000 bricks in the laboratory, using different proportion of fly ash with clay and varying the baking (firing) temperature. They observed that the compressive strength of bricks can be improved 4 to 5 times, for certain proportion of fly ash and certain firing temperature. The durability (in terms of water absorption) can also be improved.

The principal constituents of steel slag are Silica (SiO_2), Alumina (Al_2O_3), Calcia (CaO) and Magnesia (MgO), which take up to 95% of the component [9]. Minor elements include manganese, iron, and sulphur compounds, as well as trace amount of several others. An admixture of Ordinary Portland Cement (OPC) and Blast Furnace Slag (BFS) has proved successful in stabilizing a potentially expansive black cotton soil [3]. Specifically, the researchers reported that a combination of 8% OPC and 7.5%BFS reduced Plasticity Index (PI), free soil (FS) and Potential Volume Change (PVC) by 63.7%, 58.7% and 70.8% respectively.

Although clay bricks are used in the building industry in Nigeria and many other developing countries of Africa, especially for decorative walls, the extensive use of lateritic bricks for housing development is yet to be properly investigated. Also, yet to be given some noteworthy attention is the use of an industrial waste (such as steel slag, saw dust, etc) to stabilize laterite, meant for producing lateritic burnt bricks. The aim of this study therefore, is to examine the potential of steel slag stabilized lateritic burnt bricks. The optimum condition (i.e. binder content, firing temperature) that could give strong and durable bricks are to be determined.

MATERIALS

The lateritic soil was obtained from a borrow pit in Ojota along Ojota-Ikorodu axis of Lagos state in Nigeria. The soil is reddish brown, fine-grained in texture with some intercalations of coarse particles. The result of the wet sieving analysis (see Table 1) shows that the soil contains 48.5% clay and silt size particles, 34.5% sand size grains and only about 16.1% of the grain sizes are greater than sand size particles. The soil has a coefficient of uniformity and curvature of 121 and 0.15 respectively. The natural moisture content of the soil is 2.5%. The liquid limit (LL) and the Plastic Limit (PL) are respectively 56.3 and 51.6 (see Table 2) resulting in a Plasticity Index (PI) of 4.7%. The soil has a Group Index of 3.92 with the index properties of the soil, and under the AASHO classification system, the soil is an A-5 soil (i.e. a silt-clay material). Under the Unified Soil Classification System (USCC), the soil is a silty-fine sand.

Samples of steel slag for this work was obtained from Aladja Delta steel Company in Warri, Niger Delta region of Nigeria. The company uses Electric Arc Furnace Method for its steel production and so the slag sample is an Electric Arc Furnace (EAF) slag. This is steel slag and is the impurity that floats on top of an EAF furnace, during the production of steel. The slag samples results from air-cooled process. The grain size ranges from microscopic (clay and cement sizes) to sand size (2.00mm) and up to gravel size (19mm or greater).

EXPERIMENTAL PROCEDURE

Apparatus and Equipment

The proctor mould of 105mm diameter by 115.5mm high in dimension was used in the compaction test. The metallic rammer is of 2.5kg type, with 50mm dia circular face. The firing of the lateritic bricks was achieved through a Gallenkamp muffled furnace, which can take up to four standard proctor sized bricks, and capable of firing up to 1100^{o}C. Avery Denison Compression Machine (Universal Testing Machine) was used to crush the fired and dried bricks. The machine was set to a loading range of 20tonf with an accuracy of +0.05tonf.

Determination of the Optimum Moisture Content

Compaction test was first carried out to determine the optimum moisture content (OMC) to which the lateritic bricks should be moulded. The preparation of the soil sample and the test procedure were in accordance with BS 1775 (1990). Having determined the OMC, all the lateritic bricks for this experiment were compacted and moulded at OMC.

Stabilization with Steel Slag

In order to determine the optimum binder content (steel slag) that can be used to stabilize the lateritic soil sample, the soil was stabilize with different percentages (0%., 2.5%, 5%,7.5%,10% and 12.5%) of steel slag. The different soil samples with specific level of slag content were used in moulding bricks at optimum moisture content, after which their crushing strengths were determined. This stabilization is the mechanical type, which involves the addition of additive (steel slag in this case) to a soil to improve it and make it more stable. The concept behind this process is the continuous filling of air voids in the soil with an additive (or binder) until all the air voids are completely filled. At this point, the soil attains its maximum dry density and the binder content is the optimum. Any further increment of the binder content after the maximum dry density has been attained leads to progressive loss in dry density. This is due to the fact that any further binder introduced to the soil occur in a free stage, and does not form any bond with the soil grains.

Method of Curing

Altogether, 270 bricks (i.e.9no bricks of 6 different binder levels at 5 different firing temperatures) were prepared and air cured. The bricks were air cured at room temperature (25°C) for 8 days. This curing and drying method has been found to be adequate, since it allows for gradual and uniform drying of the bricks [10].

Firing Process

The aim of firing is to drive out residual water in bricks, to enable the bricks to be less water sensitive and non-expansive, and finally to effect sintering together of the fine grains (clay particles) in the bricks. Proctor sized bricks prepared at OMC and stabilized with optimum binder content were fired to different temperatures in the muffle furnace. The intention behind firing different set of bricks to different temperatures is to obtain the temperature at which the bricks will acquire their maximum crushing strength. The firing temperatures adopted are 25°C (room temperature, i.e. for dried or unfired bricks), 250°C, 500°C, 750°C ad 1000°C. The specific steps adopted are in firing the bricks to each of these temperature are hereby highlighted:

Three bricks prepared at OMC and optimum binder level were arranged in a furnace, with the temperature of the furnace set to 250°C, and left for 2.5 hours. This is to allow sufficient time for heat to penetrate the bricks. After this time duration, the furnace was switched off and its door was opened to ensure gradual cooling of the bricks.

Similar procedure as above was adopted for firing to 500°C. However the temperature of the furnace was first set to 250°C and left 2.5hrs, after which it was raised to 500oC. This temperature was maintained for another 2.5hrs. Thus, the attainment of 500°C was done gradually at an increment of 250°C in 2.5hrs (rate of 100°C/hr). The total time taken to fire a set of three bricks was 5hrs. This gradual rate of firing was adopted to avoid 'caking', which is the phenomenon by which bricks develop hard shell, while inside is not adequately affected by the firing process. As in the case of firing to 250°C, cooling of the fired bricks was gradual.

The attainment of 750°C for a set of three bricks was again done stepwise, i.e. at the rate of 250°C in 2.5hrs, for the same reason. Thus, the total time taken to fire the set of bricks to 750°C was 7.5hrs. Cooling was also gradual.

Firing to 1000°C was also gradual except that the furnace was allowed to operate at 1000°C for 3.5hrs. Thus the time taken to fire a set of three bricks to 1000°C was 11hrs. Cooling was also gradual.

Unconfined Compression Test

In determining the crushing load of the fired bricks with the compression machine, 5 to 7 circular steel plates, each about 3cm thick were initially placed on the lower circular plate. This arrangement is to reduce the space between the lower and the upper compression plate, which tend to be too much for a proctor-sized brick. The brick to be crushed was centrally placed to ensure it would be centrally loaded. Adopting an average uniform loading rate of 20tons per minute(giving an average of between 10 to 15 seconds to crush a brick), the crushing load was obtained for each brick and for each set of bricks tested.

Water Absorption (or Durability) Test

Water absorption is an index for assessing the durability of clay bricks. In general the higher the water absorption, the lower the durability The optimum condition (i.e. optimum moisture content, optimum steel slag content and optimum firing temperature) that produced the best (in terms of crushing strength) bricks was adopted to produce a different set of bricks for durability test. This was done according to NIS water absorption test [12].

RESULTS, ANALYSIS AND DISCUSSION

Compaction Test

The density-moisture content curve resulting from the compaction test is illustrated in Figure 2. The maximum dry unit weight of the soil is 1621kg/m^3, obtainable at optimum moisture content of 19.5%. The maximum dry unit weight of 1621kg/m^3 is generally on the low side compared to between 1760-1920 kg/m^3 recommended for pavement material [13]. This can be attributed to the high silt and clay content in the soil as given in Figure 1, since fine-grained soils give a relatively lower dry unit weight compared with coarse-grained soil on compaction [13].

Effects of Steel Slag Stabilization and Firing to Different Temperatures

The results of stabilization of the lateritic bricks with varying percentages of steel slag and firing to different temperatures are presented in Table 1 and Figure 3.The Figure shows that the crushing strength of laterized dried (unfired, i. e. at 25^{o}C) bricks rose gradually from 673kN/m^2 at 0% slag content (unstabilized) to 1713kN/m^2 at 7.5% slag content. The crushing strength of stabilized unfired bricks thereafter falls sharply to 1530kN/m^2 at 12.5% binder level. Thus, at a constant temperature of 25^{o}C, the strength of the stabilized bricks rose steadily from 0% slag content to a maximum, at 7.5% binder level, after which it started dropping. At a constant firing temperature of between 250^{o}C and 1000^{o}C, the strength characteristics of the bricks are similar, except that there was a rise in crushing strength with increase in temperature up to 750 ^{o}C, after which it started falling. Thus at a constant temperature of 750^{o}C, the crushing strength of 0%, 2.5%, 5%, 7.5%, 10% and 12.5% steel slag stabilized bricks are 1958, 2243, 2631, 3182, 2937,and 2693kN/m^2 respectively. Also the crushing strength of 7.5% steel slag stabilized bricks at 25 ^{o}C , 250 ^{o}C ,500 ^{o}C , 750 ^{o}C and 1000 ^{o}C are respectively 1713, 2380, 2876, 3182 and 2147 kN/m^2 .This shows that the percentage of steel slag that can best stabilize the soil is 7.5%. In effect 7.5% steel slag is required to completely fill the air voids in the soil, and the soil's performance at this binder level is best. Steel slag in excess of this is not accepted into the interstices of the soil grains and does not form any bond with the soil. It may cause adverse effects in the bricks, as suggested by the progressive reduction in their crushing strengths.

The effects of temperature on the crushing strength of the bricks are equally revealing. The crushing strength of unstabilized bricks increased steadily from 673 kN/m^2 at 25^{o}C to 1958 kN/m^2 at 750 ^{o}C , after which there was no appreciable gain in strength. At a constant binder content of 2.5%, the crushing strength of the bricks rose steadily from 979 kN/m^2 at 25^{o}C to 2243 kN/m^2 at 750^{o}C after which it fell sharply to 1713 kN/m^2. The behaviour of 5%, 7.5%, 10% and 12.5% steel slag stabilized bricks followed the same pattern, except that there was a rise in crushing strength with increase in slag content up to 7.5%, after which the strength continues to decrease sharply. Thus, there was a gradual rise (at a rate of 2.03kN/m^2 per ^{o}C rise in temperature) in crushing strength of 7.5% steel slag stabilized bricks from 1713kN/m^2 at 25^{o}C (dried stage) to 3182kN/m^2 at 750^{o}C. Thereafter, the crushing strength started reducing (at a rate of 4.16kN/m2 per ^{o}C fall in temperature) to 2142kN/m^2 at a firing temperature of 1000^{o}C.

The behaviour of steel slag stabilized bricks is suggestive of the following: At temperatures below 500^{o}C, lateritic soil-steel bond is not formed, hence increase in crushing strength with temperature is gradual. However, at above 500^{o}C, the formation of the bond begins and so the rate of strength increase is rapid. At 750^{o}C, the formation of the bond is completed, the fine grains in the bricks become sintered together. Thus, steel slag forms a homogeneous material with lateritic soil. Consequently, the crushing strength is maximum at this temperature. Above 800^{o}C, the bond begins to disintegrate gradually, thus resulting in a gradual fall in the crushing strength. At 1000^{o}C, the bond is completely weakened and the bricks become brittle, consequently their crushing strength is considerably low. The effect of firing steel slag stabilized bricks prepared at the determined optimum moisture content (19.5%) and optimum binder (steel slag) content (7.5%) is to enhance the strength potentials before the formation of lateritic soil-steel slag bond, which affect the strength adversely after the formation of the bond.

Durability Test

The result of durability test is presented in table 2. The durability is determined through a consideration of water absorption of the bricks. The average percentage water absorption of the 7.5% steel slag stabilized bricks fired to 750^{o}C is 23.99%. As obtained above, the 7.5% binder content and firing temperature of 750 ^{o}C at which the durability of the bricks was assessed is the optimum condition for the highest crushing strengths. According to the Nigerian Industrial Standard [12], with this level of water absorption, the bricks are durable. Although the clay fraction in the lateritic soil has affinity for water, the heat treatment given to the bricks has destroyed the clay structure [5], thus the bricks are less expansive and less water sensitive, resulting in a better durability. It is also believed that the introduction of steel slag, which is more stable than clay in the presence of moisture, into the fabric of the bricks, has improved its durability. Not only that. The reduction of the volume of clay with slag further enhances the durability of the bricks.

CONCLUSION AND RECOMMENDATIONS

The influence of varying firing temperature on the strength potentials of steel slag stabilized lateritic bricks has been investigated. Preliminary compaction test on the lateritic soil used for this work revealed that the soil attains its maximum density of 1621kg/m^3 at optimum moisture content of 19.5%.This rather low maximum density has been ascribed to the large clay content of the soil. The results showed that the optimum quantity of steel slag that can best be used to stabilized the lateritic soil sample is 7.5%. Steel slag in excess of this does not go into bond with soil grains, instead it affects adversely the strength of the lateritic soil bricks. The crushing strength of the 7.5% steel slag stabilized bricks is 1713kN/m^2 – more than 150% of the strength of the corresponding unstabilized bricks. Thus, the crushing strength of the 7.5% steel slag stabilized bricks fired to 750^{o}C (the firing point where the bond is expected to have been completely formed) is 3182kN/m^2. This is almost twice the unfired (dried) strength of 1713kN/m^2. The adversity of the firing beyond this temperature is depicted by the sharp drop in the crushing strength of the bricks, which reduced sharply to 2142kN/m^2 (a reduction in strength of about 33%) at 1000^{o}C.

Steel slag stabilized bricks prepared at optimum condition (7.5% steel, firing temperature up to 750^{o}C) have been found to be durable under normal condition of exposure.

Properly prepared lateritic burnt bricks with steel slag can find relevance in the production of low cost housing units, especially in the rural areas of several developing countries of Africa, where there are virgin lands containing large deposits of untapped lateritic soil.

Useful information can still be generated on lateritic burnt bricks if subsequent research is made to focus on the use of only silt and clay- size particles in producing the bricks, and the effects of shape on their crushing strengths is studied

REFERENCES

1. Gidigasu, M.D. (1976) "Laterite Soil Engineering: Pedegenesis and Engineering Principles." Elsevier Scientific Publishing Company, New York.

2. Deodhar, S.V. and Kute, S. (2003) "Effects of Fly Ash and Temperature on Properties of Burnt Clay Bricks." IE (I) Journal, Vol. 84, (Aug. 2003), pp. 82-85.

3. Umar, S.Y. and Osinubi, K.J. (2003) "Effects of Blast Furnace Slag (BFS) on the Index Properties of Black Cotton Soil of Borno State, Nigeria." NSE Technical Transaction, Vol.38 No. 3 (July-Sept. 2003) pp56-64.

4. Worall, W. E. (1975) "Clay and Ceramic Raw Materials." Applied Science Publishers Ltd., England.pp 147-153.

5. Bell, F. G. (1992) "Engineering Treatment of Soils." E&F SPON Publishers, London. pp 265-266.

6. Knight, B. H. and Knight, R. C. (1967) "Builders Materials." Edward Arnold Publishers Ltd, London. 3rd ed. pp3-4.

7. O'Flaherty, C. A. (1979)" Highway Engineering, Vol. 2" Edward Arnold Publishers Ltd, London. 2nd ed. Pp230-231

8. Akinmusuru, J. O. (1984) "Lateritic Soil-Cement Bricks for Rural Housing. " Journal of Cement Composites Lightweight Concrete, vol.5 No 3 (August 1984).

9. Kalyoncu, R. S. (2000) "Slag-Iron Steel". (www.http://minerals.usgs.gov/mineral/pubs/commodity/Iron_&steel_slag/79.400pdf).

10. BS 1775(1990) British Standard " Method of Test for Soils for Civil Engineering Purposes. Part 1: General Requirements and Sample Preparation" BSI 22 pp.

11. Akinmusuru, J. O. (1980) "Application of Engineering Geology to Rural Needs in Developing Countries." Bulletin of International Association Engineering Geology. No. 22 (Dec.) pp 279-282

12. Nigerian Industrial Standard (1976)" Specification for Burnt Clay Building Units." Nigeria Standard Organization, Federal Ministry of Industries, Lagos. NIS 74.

13. Emesiobi, F. C. (1986) "Testing and Quality Control in Civil and Highway Engineering". The Blueprint Limited, Port Harcourt pp 35-36.

Table 1: Effects of Slag Contents and Temperature on Crushing Strength (in kN/m^2) of Bricks

Slag content \ Temperature	25°C	250°C	500°C	750°C	1000°C
0.0%	673	1163	1621	1958	2081
2.5%	979	1530	1856	2243	1713
5.0%	1387	1386	2081	2631	1856
7.5%	1713	2325	2876	3182	2142
10.0%	1591	2183	2529	2937	1815
12.0%	1530	2018	2570	2693	1958

Table 2: Nigeria Industrial Standard Water Absorption Test

Nomenclature	Initial wt. (fired wt.) (g)	Wt. After 24hr soaking in water (g)	Water Absorption (%)	Average (%)
S7.5/750/01*	1400.08	1739.68	24.22	
S7.5750/02	1405.03	1739.43	23.80	23.88
S7.5/750/03	1397.83	1727.38	23.62	

7.5% Slag Stabilized Bricks, fired to 750°C

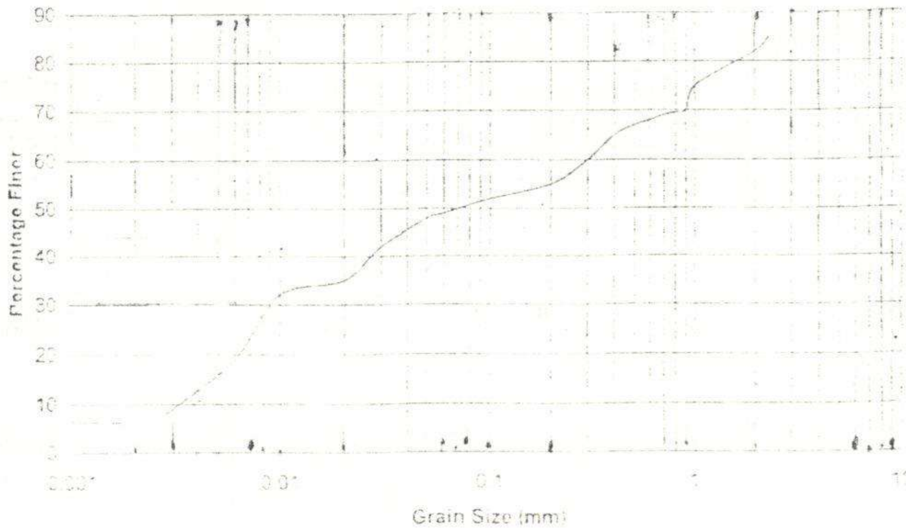

Figure 1: Particle Size Distribution Curve of the Lateritic Soil Sample

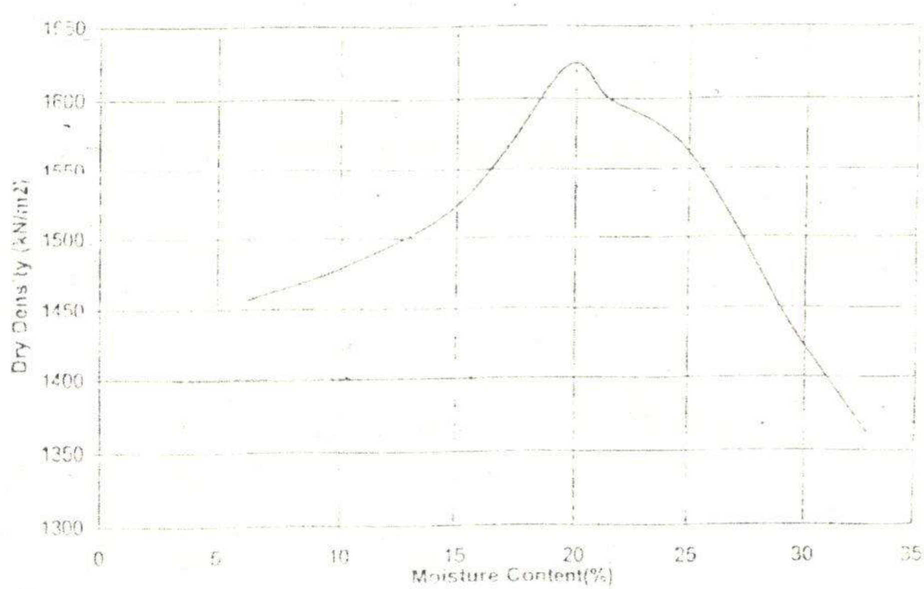

FIGURE 2: Particle Size Distribution Curve of the Lateritic Soil Sample

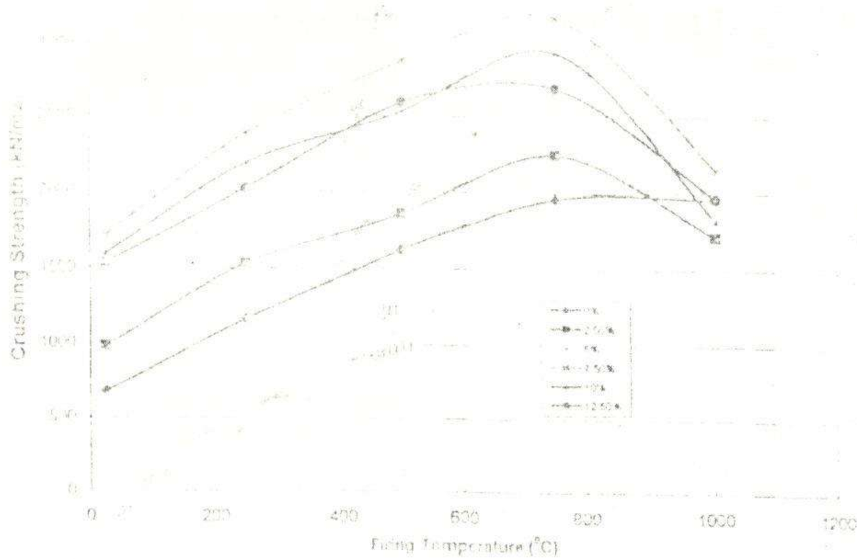

FIGURE 3: Effects of Slag Content and Temperature on Crushing Strength of Bricks