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EFFECT OF COMPACTIVE EFFORTS ON THE PLASTICITY AND STRENGTH PROPERTIES OF RECONSTITUTED LATERITE

BY

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ABSTRACT

The results of the laboratory investigation carried out on reconstituted laterite in order to evaluate the effect of fines content on the strength properties of the lateritic soil compacted at three energy levels: British Standard Light (BSL), West Africa Compaction (WAS) and British Standard Heavy (BSH) are presented. The reconstituted laterite soil gave rise to samples having fines content passing sieve 425 µm ranging from 0 to 85 %. The compressive strength generally increased at higher compaction energy and or with higher fines content, plasticity modulus, plasticity product and grading modulus. However, at 10 % fines content the compressive strength obtained at the three energy levels all met the minimum required compressive strength of 200kN/m² for liners and covers.

KEYWORDS: Atterberg limits, Reconstituted laterite soil, Plasticity Product, Plasticity Modulus, Grading Modulus.

1.0 INTRODUCTION

The term *laterite* first appeared in scientific literature a little over a hundred and seventy years ago. Several theories have been advanced to account for the origin and formation of laterite. Historically, three periods can be distinguished. The earliest hypothesis, dating from the first half of the nineteenth century and based on description of materials and their mode of occurrence, related to studies carried out in India. In the second period chemical, and to some extent, mineralogical analysis helped to widen the definition of the term laterite. The period started at the end of the nineteenth century and continued until very recently.

The word laterite describes material with no reasonable constant properties. Laterites have been given many definitions, and because of the various views of researchers this generated a lot of controversies. De Graft – Johnson (1975) stated that lateritic soil is a 'residual' or colluvial soil, usually with some shade of red formed under tropical conditions, enriched of bases and silica. Osinubi (2001) stated that laterite soil is the conventional material routinely used in most tropical countries for pavement construction even though; most lateritic soils and gravels are at best suitable mainly for sub-base course material.

The International Society for Soil Mechanics and Foundation Engineering (ISSMFE) progress report (Peculiarities 1985) defines lateritic soils as soils belonging to horizon A or B of well drained profiles developed under humid tropical climates, its clay fraction constituted essentially of the kaolinite group and of iron or aluminium hydrated oxides and these components are assembled in peculiar porous and highly stable aggregated structure. The geotechnical characteristics and field performance of laterite soils are considerably influenced by the mode of formation, morphological characteristics, degree of weathering and the chemical and mineralogical composition, all of which are related to the weathering systems determined by the joint effects of the pedogenic factors.

Laterites and lateritic soils form a group comprising a wide variety of red, brown and yellow, fine-grained residual soils of light texture as well as nodular and cementing soils. They may vary from a loose material to a massive rock (Gidigasu 1976). They are characterized by the presence of iron and aluminium oxides or hydroxides. For engineering purposes, the term 'laterite' is confined to the coarse-grained vermicular concrete material, including massive laterite. The term 'lateritic soil' refers to materials with lower concentrations of oxides. Laterization is the removal of silicon through hydrolysis and oxidation that results in the formation of laterites and lateritic soil. The degree of laterization is estimated by the silica-sesquioxide ratio (SiO_2/FeO_3 + Al_2O_3)

There have been several attempts to classify laterites in terms of their chemical composition, (Fermor1911). Classification based on chemical composition led to two major groups of laterites. They are the aluminous (bauxitic) and ferruginous laterite. Aluminous laterites are those laterites that more of the oxide compositions are those dominated by aluminium oxides, while ferruginous laterites are those dominated by iron oxide, (Gidigasu 1976).

In recent years, researchers from various fields have attempted to solve environmental problems posed by the production of wastes, (Kamon and Nontananandh 1991). The aspect of geotechnical engineering which deals with the management of wastes is referred to as geo-environmental engineering. Engineering of waste containment facilities such as solid and hazardous waste landfills, liquid impoundments, and mine waste repositories began in the 1970s with the introduction of clay liners and clay caps. The objective was to limit discharge of toxic contaminants to groundwater, Benson (2000).

The purpose of reconstituting the lateritic soil was to simulate the variation in particle size distribution which occurs in lateritic soil deposits. Based on the findings of Osinubi and Ijimdiya (2007), reconstituted laterite soil with 10 % fine content satisfies the minimum strength requirement of 200 kN/m^2 for a material to be used as a liner and cover in waste containment facilities. The purpose of this study therefore, is to investigate the effect of the different energy levels used, on the index properties and the plasticity characteristics of the reconstituted lateritic soil.

MATERIALS AND METHODS

The soil used for this investigation is reddish brown in colour and was collected by method of disturbed sample from Zaria, (Latitude 11° 15' N and longitude 7° 45' E). It was air-dried and crushed using metal roller to remove soil clods. The soil was than sieved through 425 μm diameter sieve This soil belongs to the group of ferruginous tropical soils derived from acid igneous and metamorphic rocks (Osinubi 1998a,b; Osinubi and Nwaiwu 2006). The soil is classified as lean clay with sand (CL) according to the Unified Soil Classification System (USCS). The specific gravity of the natural soil is 2.39, with percent passing BS No. 200 sieve being 68.2. The X-ray diffraction (XRD) and differential thermal analysis (DTA) of soil from the study borrow area carried out by Osinubi (1998 a,b) showed that the predominant clay mineral is kaolinite. All tests were conducted in accordance with BS 1377 (1990).

RECONSTITUTION OF LATERITIC SOIL

In preparing for the compaction of the material passing sieve 425 μm was weight out in percentages of 0, 10, 25, 40, 55, 70 and 85 % by weight of dry soil corresponding to samples S_0 to S_6 respectively. A total percentage mix weight of 3000g used for the compaction test after being properly mixed to obtain homogenous mixtures. The compaction energies used in the study are British Standard Light, BSL, West African Standard, WAS and British Standard Heavy, BSH which simulate the compactive efforts used in the field (see Table 1).

The reason for the reconstitution of the soil is (1) the amount of fines content in a soil fraction affects its resistance to fluid flow. This in turn affects the soil's hydraulic conductivity which is a major factor to consider in the design and construction of landfill barriers for industrial or municipal solid waste systems (MSW) (2) lateritic soil profile is characterized by the presence of three major horizons below the humus-stained topsoil. It was reported by Gidigasu and Kuma (1987), as well as Osinubi and Nwiawu (2006) that these horizons include (a) the sesquioxide rich lateritic horizon (sometimes gravelly and/or hardened in situ as crust; (b) the mottled zone with evidence of enrichment of sesquioxide, and (c) the pallied or leached zone (rock suffering chemical and mineralogical change, but retaining physical appearance). It was shown by Gidigasu (1980) that the particle size distribution, Atterberg limits, compaction characteristics, swell and bearing capacity for soils in the three horizons vary considerably.

Table 1: Compaction Energies Utilized

Compaction energy	No. of blows	Weight of rammer (kg)	Height of fall (m)	Number of layers	Compaction energy (kN/mm^2)
BS Light	27	2.5	0.3048	3	595.96
West African Standard	10	4.5	0.457	5	993.26
BS Heavy	27	4.5	0.457	5	2681.81

Compaction Tests

Compaction test was carried out to determine the relationship between dry unit weight and moulding water content. This is important because most of the engineering properties of the soil are dependent on the moisture-density relationship. Factors that affect the degree of compaction are the moisture content, soil type and the compactive effort per unit volume. Generally, specimens were moulded using different water contents and different energy levels similar to the various compactive efforts expected to be achieved on the site. The three compactive efforts (BSL, WAS and BSH) were applied in the study using a 1000 cm^3 compaction mould with a diameter of 101.6 mm (see Table 1) .

RESULTS AND DISCUSSIONS

Index Properties

Natural Soil

The index properties of the natural soil are summarized in Table 2 while the particle size distribution is shown in Fig. 1. The natural soil is reddish brown in color with specific gravity 2.37 and percentage passing BS No. 200 sieve is 68.2 %. The Atterberg limits of the soil shows that the liquid limit is 32.9 %, plastic limit 18 % and plasticity index is 14.9 %.

Reconstituted Soil

The index properties of the reconstituted soil showed slight changes as the fine content was being varied. The particle size distribution of the reconstituted soil is shown in Fig. 1 while the Atterberg limits of the reconstituted soil is shown in Fig. 2 .It is generally observed that there were slight increases in the Atterberg limits with increase in the fines content of the soil. The liquid limit increased from 32 to 34.18 % for samples S-1, containing 10 and S-6 containing 85 percent fines content. The plastic limit increased from 17 to 25 % for samples S-1 and S-2 containing 10 and 25 percent fines content respectively. The plasticity index also increased from 15 to 17.55 % for samples S-1 and S-6. The linear shrinkage increased from 7 to 9 % for samples S-1 to S-6. The slight increases in the liquid limit, plasticity index and linear shrinkage with increase in the fine content are consistent with the findings of D'Appolonia (1980). The fines content of a soil affects the ease with which fluid flows. The increase in fines content results in a decrease in porosity which is as a result of the clogging of the pores between the coarser soil materials. Therefore, the hydraulic conductivity of a soil depends on the porosity which is itself determined by the particle size distribution.

Plasticity Characteristics of the Reconstituted Soil

The variation of the maximum dry unit weight and optimum moisture content with plasticity product and plasticity modulus are shown in Figures 4 – 6. Generally it was observed that the maximum dry unit weight initially increased and peaked at S-1 containing 10 % fines content and with further increase in either plasticity product or plasticity modulus, there was a corresponding decrease in the maximum dry density for the BSL, WAS and BSH compaction energy while in the case of the optimum moisture content there was an initial decrease in the optimum moisture content for sample S-1 and then slight increases with increase in either plasticity product or plasticity modulus for the BSL, WAS and BSH compaction energy. For sample S-1 with plasticity product and plasticity modulus as 69.75 and 207.3 respectively, the maximum dry unit weight were 1.88, 1.89, 1.91 Mg/m^3 at the BSL, WAS and BSH compaction energy and for sample S-6 having 85 % fines content with plasticity product and plasticity modulus of 110.1 and 317.9 respectively; the maximum dry unit weight were 1.83, 1.85 and 1.87 this clearly shows a decrease in the maximum dry unit weight for BSL, WAS and BSH compactive efforts. The optimum moisture content initially decreased with the least values at sample S-1 as follows: 15, 14, and 11 %. As the plasticity product or plasticity modulus increases, there was a corresponding increase in the optimum moisture content while as the compactive effort increases there was a reduction in the optimum moisture content at the three energy levels considered. Therefore, for sample S-6 the optimum moisture content was as follows: 16.5, 15, and 14.5 % at BSL, WAS and BSH compaction energy.

Plasticity product is defined as the product of the plasticity index and the percentage of soil fraction passing 425μm sieve (CIRIA, 1988; Osinubi and Nwaiwu, 2006). The plasticity product is the product of plasticity index and percentage of fines (soil fraction passing 75 μm sieve). Benson and Boutwell, 1992; Osinubi and Nwaiwu 2006 refers to plasticity product as "Clay index" (CI), which is (1) a measure of the quantity and type of hydrated fine-grained particles in a soil (2) increase as the percentage of fines increases or as the clay component becomes more active; (3) is the best characterization of composition.

In figures 4 – 6, there were generally increases in the maximum dry unit weight with increase in either the plasticity product or plasticity modulus. Figures 5 and 7 also show that as the plasticity product or plasticity modulus increases, the optimum moisture content increases. Therefore, the maximum dry unit weight values generally increased with the plasticity modulus and plasticity product for each of the compactive efforts used. In like manner also, the optimum moisture contents increased as either the plasticity product or the plasticity modulus increased. The trend suggest that variations in optimum moisture content depend on the soil plasticity and fines content as well as other soil characteristics for a given compactive effort.

Compaction Characteristics of Reconstituted Soil

The effect of compactive efforts on the strength properties of the reconstituted soil is shown in Fig. 3. It was observed that there was improvement in the strength properties of the reconstituted soil with higher compactive efforts. The compressive strength of the reconstituted soil with 0 % fines content compacted at the three energy levels, BSL, WAS and BSH, gave values of 105.3, 262.5, 314.9 kN/m^2 while at the 85 % fines content, there was gain in strength which yielded the following results; 577.4, 629.9, 787.4 kN/m^2 respectively. The variation of compressive strength with parameters such as plasticity product, grading modulus and plasticity modulus are shown in Figures 8 – 10. The results show that the specimens experienced increase in the compressive strength with increases in either the compaction energy or the plasticity product, grading modulus and plasticity modulus. It has been reported by Osinubi and Stephen (2006) that the increase in strength of the compacted reconstituted lateritic soil could be due to the formation of very weak bonds between the soil particles and the available water molecules. However, Renè (1972) attributed the improvement in strength to be probably due to physicochemical forces in the ionic layer surrounding the soil particles while the main binding force could be due to traction exerted by the menisci of capillary water on the adjoining particles.

Table 2: Test Results of Natural Soil

Property	Quantity
Natural moisture content, %	8.1
Percent Passing BS No. 200 Sieve	68.2
Specific gravity	2.39
Plastic limit, %	18.0
Plasticity Index, %	14.9
Linear Shrinkage, %	7.67
Liquid limit ,%	32.9
USCS classification	CL
Maximum Dry Density, Mg/m^3	
British Standard Light	1.81
West African Standard	1.83
British Standard Heavy	1.86
Optimum Moisture Content, %	
British Standard Light	16.6
West African Standard	15.43
British Standard Heavy	13.71
Color	Reddish Brown

CONCLUSION

The amount of fines content in the lateritic soil used was reconstituted to assess the minimum amount of fines content required in the lateritic soil fraction under study to design an acceptable and efficient landfill barrier system for optimal performance. This is because the amount of fine fraction affects its resistance to fluid flow. This in turn affects the soil's hydraulic conductivity which is a major factor to consider in the design and construction of landfill barriers for industrial or municipal solid waste systems (MSWS). The laterite is classified as CL soil using the Unified Soil Classification System (USCS). Generally, there were increases in the maximum dry unit weight with higher compaction energy for instance at 10 % fines content, the following values were obtained: 1.88, 1.89, 1.91 Mg/m^3 at the BSL, WAS and BSH compaction energy and for sample S-6 having 85 % fines content the maximum dry unit weight were 1.83, 1.85 and 1.87 Mg/m^3 . However, it is important to note from this results there was a decrease in the maximum dry unit weight for BSL, WAS and BSH compactive efforts with increase in the fines content. The optimum moisture content initially decreased with the least values at sample S-1 as follows: 15, 14, and 11 %. As the plasticity product or plasticity modulus increases, there was a corresponding increase in the optimum moisture content while as the compactive effort increases there was a reduction in the optimum moisture content at the three energy levels considered. Therefore, for sample S-6 the optimum moisture content was as follows: 16.5, 15, and 14.5 % at BSL, WAS and BSH compaction energy. At 10 % fines content the BSL meets the minimum compressive strength of 200kN/m^2 required for such compacted soils to be used as liners and covers in waste contentment facilities (Albrecht and Benson, 2001).

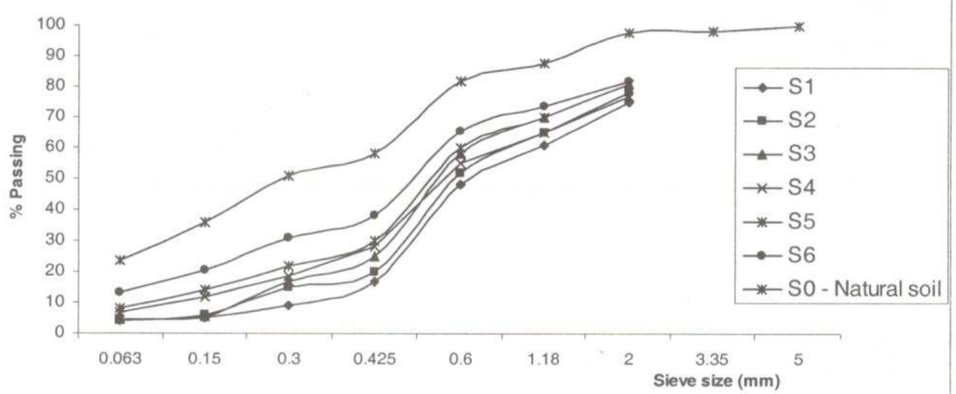

Fig. 1 Particle size distribution of natural and reconstituted laterite

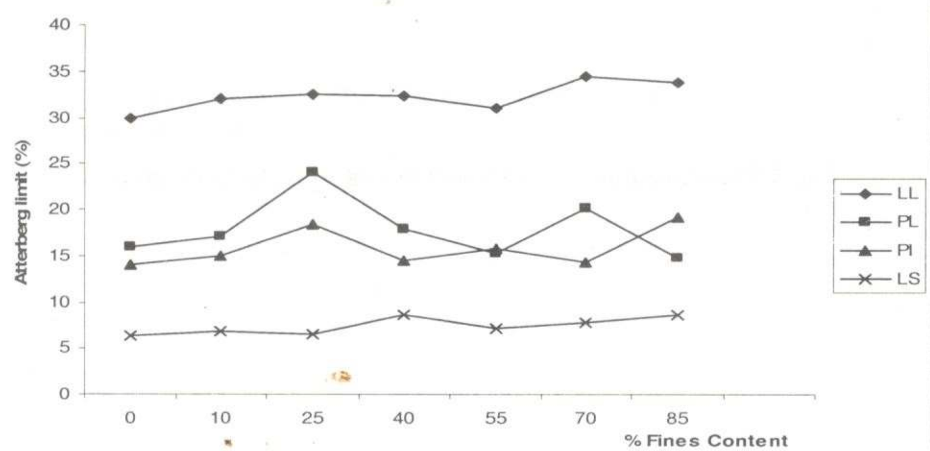

Fig. 2 Atterberg Limit values for Reconstitued soil versus percent fines content

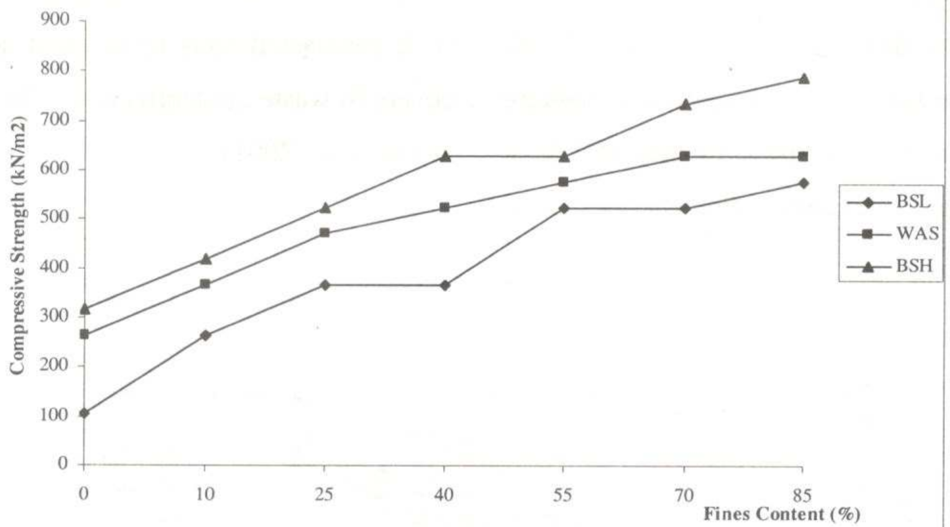

Fig. 3 Variation of compressive strength with fines content at BSL compactive effort

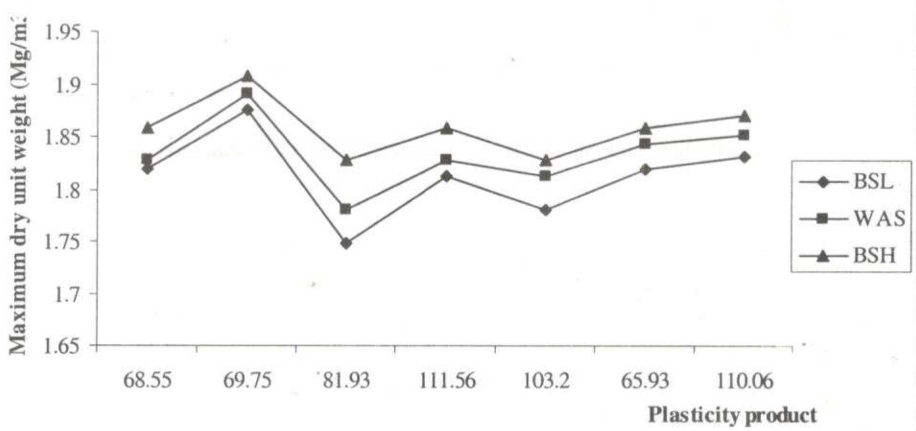

Fig. 4 Variation of maximu dry unit weight with plasticity product

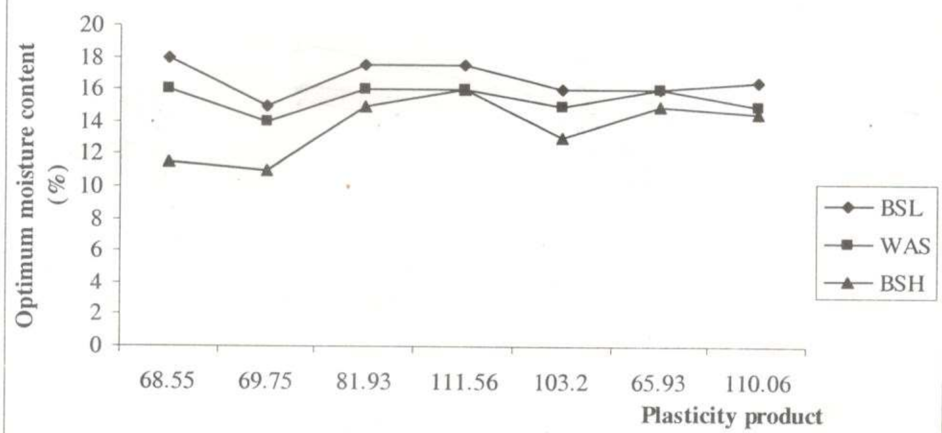

Fig. 5 Variation of Optimum moisture content with plasticity product

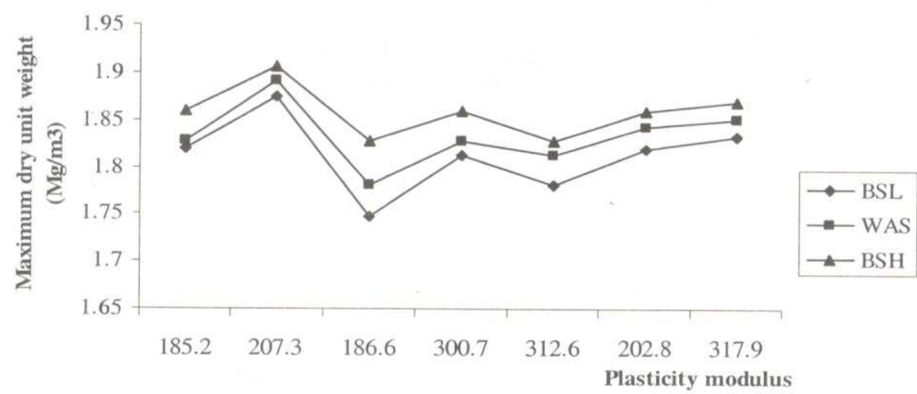

Fig. 6 Variation of maximum dry unit weight with plasticity modulus

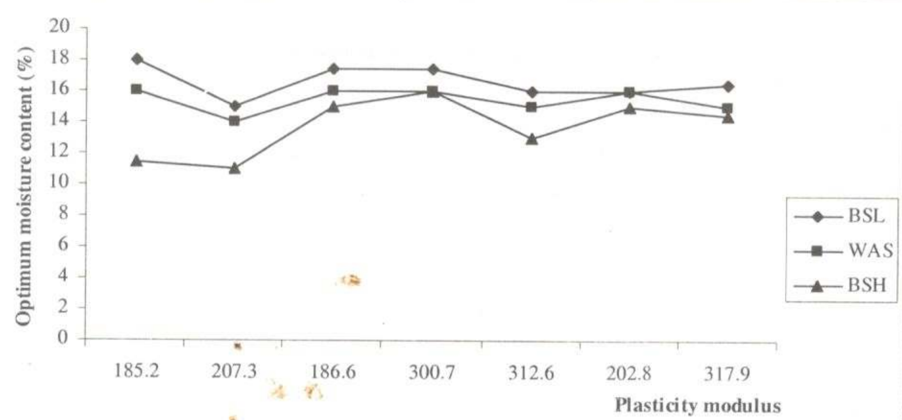

Fig. 7 Variation of optimum moisture content with plasticity modulus

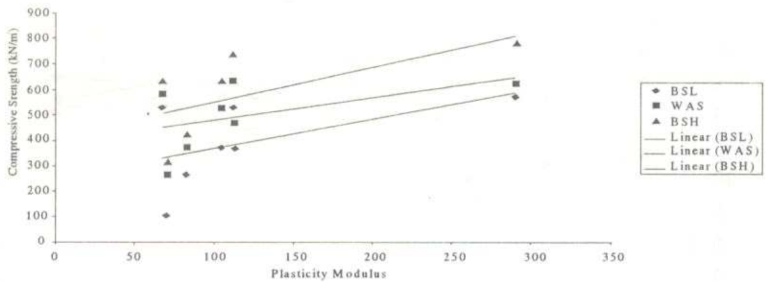

Fig. 8 Variation of Compressive Strength with Plasticity Product

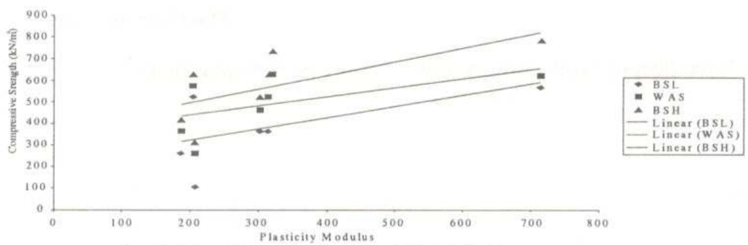

Fig. 9 Variation of Compressive Strength with Plasticity Modulus

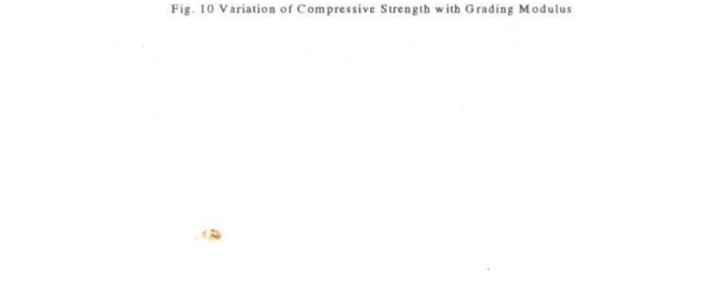

Fig. 10 Variation of Compressive Strength with Grading Modulus

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