DURABILITY OF IGBOKODA CLAY AND SILICA SAND AS A SYNTHETIC MOULDING SAND

BY

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ABSTRACT

Mechanical test experiments have been performed on the synthetic mould sand made from the clay and silica sand obtained from Igbokoda in Ondo State, Nigeria, to determine its durability of use. The synthetic moulding sand was further admixed with sodium carbonate, cassave flour and coal dust additives in an attempt to enhance the clay bonding properties. After each casting, the synthetic moulding sand was re-used and this was repeated several times. This paper reports the result of the mechanical properties obtained and hence the durability of the synthetic moulding sand. The results showed that the Igbokoda clay-bonded-silica sand has very good durability up to five times re-use. There was improved mechanical properties/durability when the additives were used. Castings made during the experimental period were sound. The additives gave improved bonding property.

INTRODUCTION

Clay obtained from Igbokoda in the South Western part of Nigeria (Ondo State), has been characterised, analysed and developed as a binder for synthetic moulding sand. The effects of some additives on the mechanical properties of the synthetic moulding sand has also been investigated[1]. Results from the previous studies have been reported (2,3,1).

Comprehensive investigations have been performed on various aspects of moulding sand development and testing (4,5,6). Despite the huge amount of investigations carried out on clay development so far, literature work on the durability of bonding clays is still minimal. However, the work of sanders and Doelman (7-9) made a significant contribution to the present day knowledge of this subject.

Igbokoda clay which is mainly kaolinitic in structure had been put to practical moulding test in casting and its performance was generally good. In an attempt to further develop the clay, the determination of the durability of its bonding property is considered necessary as part of the clay's available data. This is the object of the present investigation. The number of time that the synthetic moulding sand could be re-used will determine, in part, its economic justification for continued use.

The results of the effect of some additives, such as sodium carbonate, cassave flour and coal dust on the synthetic mould sand properties of the clay/silica sand, reported in the previous studies and mentioned above, were impressive (3,1). This has given further encouragement to the use of the same types of additives in this present work to determine their synergistic effect on the clay's bonding durability/performance.

EXPERIMENTAL PROCEDURES

Separation of clay from sand

The experimental procedures used here are described in the previous work of Loto and Omotosho (2). The as-received clay contained much of coarse particles mainly quartz. Due to their widely varying size ratio, the clay and the quartz were separated using gravity sedimentation techniques. Wet sieving was done to remove light coarse particles which could float in the suspension.

The clay was dissolved in water and thoroughly dispersed with $1.5g/dm^3$ calgon (sodium hexametaphosphate). The jar's content was allowed to settle for about 5 minutes after stirring for about 30 minutes. The quartz sediment and the clay particles in suspension were separated by decantation. The sediment consisting of quartz was discarded, while the clay suspension was retained for subsequent separation treatment.

A laboratory centrifuge consisting of four 55 cm^3 tubes radially arranged and traces of 70mm radius when rotating, was used to further separate the clay particles. The tubes were filled with slurry obtained from the gravity separation suspension, and allowed to rotate under a centrifugal force of 19kN at 15,000 rev./min for 30 min. The clear water suspension obtained was discarded and the clay sediment removed for further use. The fine clay sediment obtained was sun-dried for 10 days and then oven dried with a laboratory Gallenkamp oven at a temperature of 50°C for 15 hrs. The dried mass was crushed in a laboratory mill and subsequently sieved.

EDAX analysis of the clay performed previously (1) has given the composition to consist qualitatively of silicon, alimunium, magnesium, phosphorus, calcium, sulphur, potassium, titanium and iron. It was more enriched with silicon and aluminium. The partical chemical and physical quantitative composition of the clay, (2) are given in Tables I and II. The pH of the clay had been found (1) to be 4.2 and thus acidic.

Preparation of the base silica sand

The base silica sand used was washed several times with water and sun-dried for 10 days. The size and distribution of the sand grains was determined by the sieve analysis test method of the A.F.S. (10) (American Foundryman Society). The average grain fineness used was 36.40.

Preparation of test samples

From the preliminary tests performed on the test samples, an optimum clay of 17% by weight and 5% by weight tempering water were used for all the test samples in this work. Two different types of test samples were made, viz:

1) the samples containing the clay, silica sand and tempering water only. These are referred to in this report as test sample I.

2) the samples containing the clay, silica sand, tempering water and additives. These are referred to as test sample II. The details for these are given in Tables III and IV.

The base silica sand, 78% by weight; a predetermined amount of clay, 17% by weight; and known amount of tempering water, 5% by weight, were mechanically mixed by mulling apparatus and this mixture was used as test sample I. Similarly, the base silica sand, 74% by weight; clay - 17% by weight; 5% by weight tempering water; coal dust - 2% by weight; sodium carbonate - 0.5% by weight; and cassave flour - 0.5% by weight; were mechanically mixed by a mulling apparatus and used as test sample II. After mixing, each of the above samples was stored in polytene bags to prevent air - drying.

Cylindrical test specimens conforming to the AFs standard specimen of 50mm were prepared and used for the mechanical tests. An amount of sand mixtures adequate to form standard test specimens of 50mm diameter 50mm high after three rams, were determined and measured out. In all the experiments, the sample weight used ranged from 150 to 170g depending on the sand/clay ratio. The ramming device was securely mounted, the sand poured into the specimen tube and rammed by impact with three blows of a 6.50kg weight. By the manually operated device, the weight was dropped from a height of 50mm + 0.125. Three rams normally produce a specimen 50mm + 0.79 in height provided the proper weight of sand is put in the specimen tube. Guage marks are shown at the top of the rammer to measure the specimen height. The specimen was removed from the tube by means of a stripping post.

Green compression test

The green compression test was performed to determine the compressive stress in kN/m² necessary to cause rupture of the standard cylindrical specimen using a compression testing machine. Details of the green compression test, testing procedures and equipment are contained in the AFs' 'Foundry Sand Handbook' (1963)[10]. Green compressive strength tests were performed immediately after the specimen was stripped from the tube to air-drying with increase in exposure time. The compressive strength was determined by axially loading the cylindrical specimen through the flat faced holders of the compression testing machine.

Green shear test

The test was performed on the Universal testing machine. This was done by changing the loading surfaces on the testing machine from compression to shear plates. The specimen then ruptured by shear along its longitudinal axis when sufficiently loaded. The standard test procedures for the green shear test are set forth in the AFs 'Foundry Sand Handbook' (1963)[10].

Dry compression and shear tests

These tests followed the same procedures as for the green compression and green shear tests (American Foundrymen Soceity 1963[10]). The dry compression and shear tests were carried out by drying the specimen in an oven at 100 - 110°C for 2 hours before testing. Since dry compression strength is usually much greater than green strength, higher loads were required on the universal test machine.

Shatter index tests

The shatter index tests were performed in the shatter index tester, which is designed to drop a rammed specimen of mould sand from a height of 1.85m on to a steel anvil. To determine the shatter index of the moulding sand, an AFs standard test specimen was prepared without stripping. The tube containing the rammed specimen was in position in the top casing below the plunger. The specimen was ejected from its tubular mould by gently pulling down the handle. The fragments were collected in a 12.5mm mesh B.S. sieve.

Basically, the shatter index value was used to determine the toughness and collapsibility of the moulding sand.

For toughness determination:

$$\text{Shatter index} = W_1/W \times 100$$

For collapsibility:

$$\text{Shatter index} = W_1/W;$$ where W is weight of specimen, and W_1 is weight of sand remaining on the sieve.

Surface hardness

The hardness of a rammed surface was determined using an indentation tester. For the measurement of green hardness, a spring loaded spherical indenter was used, the depth of penetration from the flat reference surface of the instrument corresponding to an empirical scale of hardness from 0 - 100 units was determined. The surface hardness of the prepared moulds was measured to check the ramming density of the moulds.

Permeability

Permeability was determined by measuring the rate of flow of air through a compacted specimen under standard conditions. The test for green permeability was performed on the A.Fs standard cylindrical specimen, retained in its ramming tube.

Castings

All the tests described above for determining the moulding properties of the synthetic moulding sand, were again repeated, in turns, after each casting. The sand was re-used five times. Cast numbers 1 to 3 were used to cast aluminium objects while 4 to 5 were used to cast cast-iron. The successive number of castings performed by re-using the synthetic sand, was to determine its moulding properties and its durability.

RESULTS AND DISCUSSION

Results of the durability of the Igbokoda clay and silica sand based on the number of re-used time are reported and discussed here in terms of the synthetic sand's moulding properties. The effect of the additives on the durability of the synthetic moulding sand is also presented and discussed here. The summary of the results are presented in Figures 1 to 8.

The results obtained for the green compression strength versus the number of casts, that is, number of times the sand was re-used or re-cycled, is presented in Figure 1. The green compression strengths for the two different samples used, - one without additive (test sample I); and the other with additives (test sample II), decreased with increasing number of casts, that is, the number of times the same sand was re-used for casting. The range of decrease in the compressive strength up to cast number 4, (11 kN/m²) was not much for test sample I; the last cast gave a very low green compressive strength for this sample. Test sample II (with additives) gave a range of 15 and 16 Kn/m² up to cast numbers 4 and 5 respectively. The trend of the decreasing green compressive strength relative to the number of casts remained almost similar to cast number 4 for both test samples. The loss in green compression strength was more gradual in cast numbers 1 to 3 than in 3 to 5.

The green compresion strength up to cast number 4, of 59 kN/m² for sample I and 60 kN/m² for sample II, confirmed the durable quality of the synthetic moulding sand and hence the bonding property of the clay. The range of decrease of the compression strength within these number of casts (11 and 15 kN/m²) for samples I and II respectively, is low. This further indicates that the moulding sand was reasonably durable. The castings made within these number of casts were of good quality. Those made at cast number 5 were also very sound. The cast items were further machined to a depth of 5mm and were found to possess very good surface finish, without blow holes, sand inclusion and burn-on. After cast number 5, the sand was found to be no longer bonding.

The first three casts, that is, cast numbers 1 to 3 were used for aluminum alloy casting; while cast numbers 4 and 5 were used for casting cast iron. The difference in the gradual loss of green compression strength up to cast number 3 and the more loss of green compression strength in cast numbers 4 and 5, could be associated with the effect of the different metals cast. The sand to metal ratios in terms of weight was 3:1 for the cast aluminium products; and 1:1 for the cast iron products. This could account for the more reduction in the sand's mechanical properties when cast iron was cast. The effect of heat on the durability of the synthetic moulding sand as indicated by the mechanical properties results obtained will be discussed later in this report. The effect of additives would also be discussed under separate sub-heading.

Variation of dry compression strength of the synthetic moulding sand with the number of casts made for the test samples I and II, is presented in Figure 2. The first time the sand was recycled, the dry compression strengths for the two samples were very high and were slightly less than the compressive strengths at the initial casts. After the first re-cycling, the dry compression strength gave a steep loss of strength relative to the number of casts and this trend continued throughout the whole experimental period covering cast numbers 1 to 5, except for cast number 3 in sample II; a phenomenon which is difficult to explain. With each successive number of casts made re-using the sand, there was aging of the sand, loss of moisture from the surfaces of the clay platelets and also from between the Si-O layers; loss of lattice or constitutional water, and structural changes of the clay/sand composition - all due to the effect of heat. The combined effect of these would be that of loss of dry compression strength values with the increasing number of casts made with the same sand being re-used. However, up to cast number 5, the dry compression strength values were still under the normal range of use; and the casts made were good. The clay/sand was durable to cast number 5, after which no reasonable bonding was obtained.

The curves of green hardness (B scale) versus the number of casts for the two samples (I and II) are shown in Figure 3. The green hardness of the two test samples decreased with the increasing number of casts. Sample II containing additives had higher hardness values in all the different tests. The loss of green hardness values in all the different tests. The loss of green hardness with the increasing number of casts and/or sand re-use was due to the increasing loss of clay bonding property due to the heat from the very high casting process temperature. This also led to the softening of the clay-sand mixture. Structural changes within the synthetic moulding sand resulting from the heat effect could also make a significant contribution to the loss of green hardness with the increasing number of casts made.

In Figure 4, the variation of permeability of the synthetic moulding sand with the number of casts representing number of times of re-use, is presented. Permeability values decreased with the increasing number of casts. The decreasing values were particularly drastic, the last two casts of each of the test samples and the curves became steeper. The last two casts were for the cast iron. This had high melting point than the aluminium casting which was used during the first three castings (cast numbers 1 to 3). Because of the very high temperature involved, there was fusion of the moulding sand and hence the decreasing permeability with the increasing number of casts and increasing magnitude of fusion. In both ferrous and non-ferrous founding, permeability in the range 25 to 90 are quite usual. The permeability of the samples used in this work are within the range of 56 - 81.

The curves of green shear strength versus number of casts are presented in Figure 5. Up to the fourth (4th) cast, the green shear strength decreased very gently with the increasing number of casts. From the fourth to the fifth cast, the decrease in the value of green shear strength was very drastic and it attained the low values of 12.50 and 10 kN/m² for samples I and II respectively. This sudden change from the fourth cast will undoubtedly be due to the high temperature (heat) effect of cast iron casting. It caused the loss of moisture content and hence contributed to the loss of clay-silica-water bond. The high temperature also softened the moulding sand and thereby reducing the green strength. However, the green shear strength values up to cast number 4, were within the acceptable range.

Figure 6 shows the curves of the dry strength of tested samples I and II versus the number of casts. Sample I, showed a drastic decrease of strength values from 45 to 43 kN/m² from the first re-use (cast number 1) to the second re-use (cast number 2) of the synthetic moulding sand. From cast number 2 to 3, it maintained the same strength of 43 kN/m²; after which it decreased steadily to cast number 5. Sample II (with additives) also decreased steeply from 46 to 45kN/m² in cast number 1 to 2 and it remained in this constant strength value of 45 kN/m² to cast number 5. Apparently, the samples with additives (sample II), gave higher dry strength values in all the casts. The constant strength value maintained in sample II from cast number 2 to 5, is difficult to explain. It however, confirms that there was no further deterioration in the strength value after cast number 2. The synergistic beneficial effect of the additives could not be ruled out as making a positive contribution to this observation. The trend of the decrease of dry strength values with the increasing number of casts in sample I (without additive) indicates loss of clay-silica-water bond within the structure of the moulding sand due to the repeated high temperatures used in casting. The sand thus became fused and softened.

The curves for the collapsibility for the two samples - I and II versus the number of casts made with them are presented in Figure 7. Collapsibility decreased with the increasing number of casts throughout the experiments except in cast number 4 in the samples without additives (sample I); and cast number 2 in the samples with additives (sample II). These phenomena could be an experimental anomaly. The decreasing collapsibility with the increasing number of casts could be attributed more to the effect of heat causing the fusion of the clay/sand mixture (synthetic moulding sand), at the very high casting temperatures. The fusion did not only take place within the moulding sand, there was also sticking of the sand to the mould wall.

The toughness of the tested sand samples increased with the increasing number of casts, Figure 8. The range of 66 - 100 is within the acceptable range. However, loss of water, softening and fusing of the moulding sand by the action of heat at high temperature(s), made it tougher with the increasing number of casts.

Effect of additives

The effect of additives is apparent from all the results obtained as presented in Figures 1 - 8. The additives increased the green and dry compression strengths, green hardness, permeability, green and dry shear strengths, collapsibility and toughness of the synthetic moulding sand and hence its improved durable properties. The individual effect of the additives could not be indicated here. The overall effect is that of synergism. The effect of all the additives used has, however, been individually treated in previous studies (Loto, 1990; Loto and Adebayo, 1990). The improved durability contributed by the additives results mainly from the effective bonding property of cassave flour and fine coal dusts and the change in the chemistry of the clay due to the Na^+ from the Na_2CO_3 addition.

<u>Effect of heat</u>

Clearly, the general performance/durability of the tested clay/sand, in synthetic moulding sand sample forms, was controlled by the heat effect due to the very high liquid metal temperature during casting. The high casting temperature caused loss of adsorbed moisture from the surfaces of the plates and also from between the Si-O layers. It also caused loss of lattice or constitutional water. These affected adversely the bonding characteristics of the synthetic moulding sand. The alumina, silica, and kaolinite constituents of the clay/sand were also affected and were subject to modification or change of structure by the effect of heat at very high casting temperature(s), especially the casting of cast iron items. During the cast iron casting, there was the probability of occurrence of crystallisation of alumina and followed by the conversion of silica to cristobalite and the ultimate combination of these to form mullite ($3Al_2O_3 . 2SiO_2$). In the temperature range of 850 - 1050°C, kaolinite crystallizes above 1350°C and tridymite converts to cristobalite at 1470°C. These structural changes after many repeated use would cause the aging of the clay/sand mixture and hence renders it less durable as observed in this experimental work.

Fusion and softening of clay apparently occurred at the high temperatures used and this increased after repeated use of the sand. Loss of constitutional water means that the clay has lost its layer lattice structure and is non-binding. Structural changes, fusion and softening of the sand/clay made further deteriorating contribution. The combination of these phenomena gave rise to dead clay in cast moulds and necessitated addition of fresh clay to compensate for loss of bond strength when the sand from the knock out system was re-used for moulding. In fact, the sand was no longer bonding when mixed at the end of cast number 5.

<u>CONCLUSION</u>

1. The Igbokoda clay has very good and durable property.

2. The synthetic moulding sand made from the clay and the silica sand can be re-used up to five times and still producing good casting.

3. The additives improved the bonding property of the clay and thus enhancing the durability of the moulding sand and gave its improved mechanical properties.

4. The deterioration in the mechanical properties of the synthetic moulding sand with the increasing number of times it was re-used for casting, was due to the effect of casting heat at high temperatures leading to the gradual loss of bonding, adsorbed and constitutional water, fusion and softening of clay, crystallisation of alumina and structural changes in the clay and silica sand.

<u>ACKNOWLEDGEMENT</u>

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TABLE I

Partial Chemical Composition of Igbokoda Clay (Loto and Omotosho, 1990)

Elements	Concentration (ppm)	%
K^+	300	0.03
Na^+	1710	0.171
Ca^+	1120	0.112
Fe	8080	0.808

TABLE II

Physical Properties of Igbokoda clay (Loto and Omotosho, 1990)

Property		Value
% Clay bond		
(1)	as received	78%
(2)	quartz-free	100%
	specific gravity	2.22
	colour	grey
	Loss on ignition % at 100°C	15.7

TABLE III

Composition of Test Sample I

Materials	% Weight	Quantity (Kg)
Clay (Igbokoda)	17	0.85
Tempering Water	5	0.25
Base silica sand	78	3.90
	Total wt. =	5.0

TABLE IV

Composition of Test Sample II

Materials	% Weight	Quantity (Kg)
Clay (Igbokoda)	17	0.85
Sodium carbonate	0.5	0.025
Bituminous coal dust	0.5	0.10
Cassava flour	0.5	0.025
Tempering Water	5.0	0.25
Base silica sand	74	3.70
	Total weight. =	5Kg.

LIST OF FIGURES/LEGENDS

1. Variation of green compression strength with the number of casts for the Igbokoda clay-bonded-silica sand.

   = without additive
   ● = with additives.

2. Variation of dry compression strength with the number of casts for the Igbokoda clay-bonded-silica sand.

   = without additive
   ● = with additives.

3. Variation of green hardness with the number of casts for the Igbokoda clay-bonded-silica sand.

   = without additive
   ● = with additives.

4. Variation of permeability with the number of casts for the Igbokoda clay-bonded-silica sand.

   = without additive
   ● = with additives.

5. Variation of green shear strength with the number of casts for the Igbokoda clay-bonded-silica sand.

   = without additive
   ● = with additives.

6. Variation of dry shear strength with the number of casts for the Igbokoda clay-bonded-silica sand.

   = without additive
   ● = with additives.

7. Collapsibility versus number of casts for the Igbokoda clay-bonded-silica sand.

   = without additive
   ● = with additives.

8. Toughness versus number of casts for the Igbokoda clay-bonded-silica sand.

   = without additive
   ● = with additives.

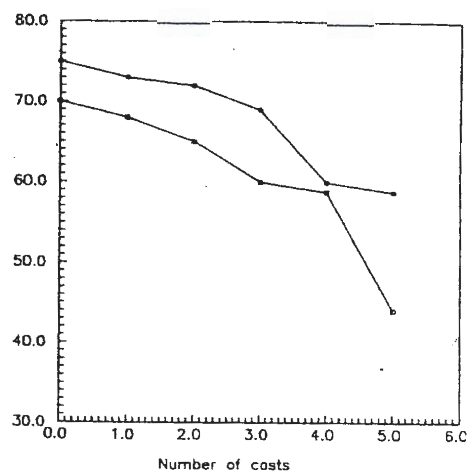

Figure 1: Green Compression Strength (kN/m²)

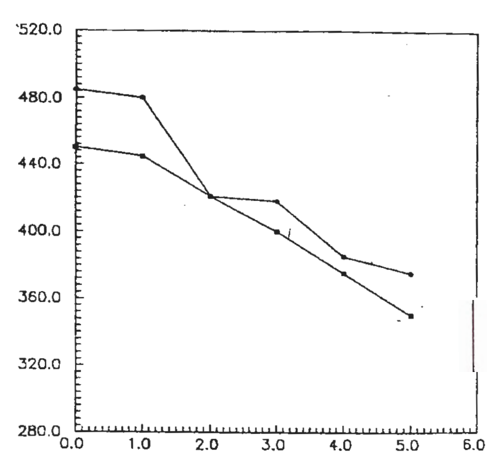

Figure 2: Dry Compression Strength (kN/m²)

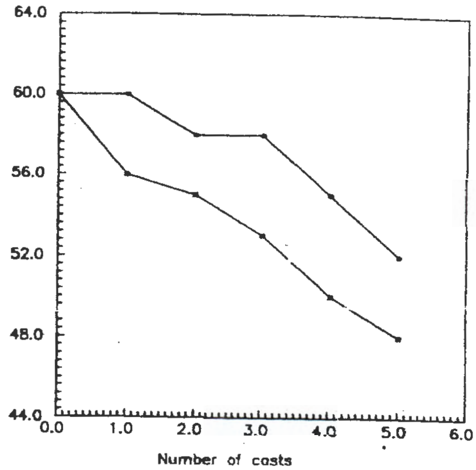

Figure 3: Green Hardness (B scale)

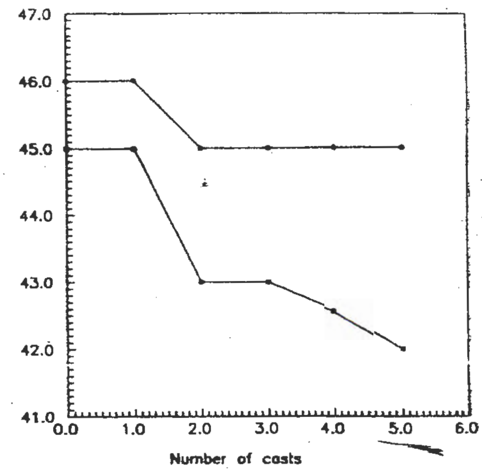

Figure 6: Dry Shear Strength (kN/m²)

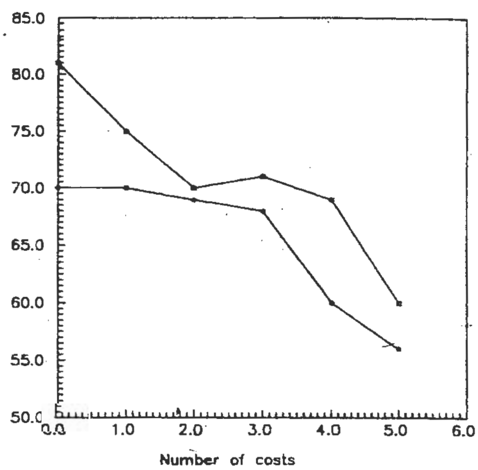

Figure 4: Permeability

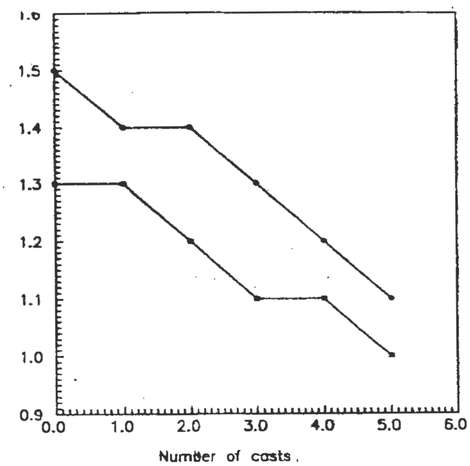

Figure 7: Collapsibility (w/w_1)

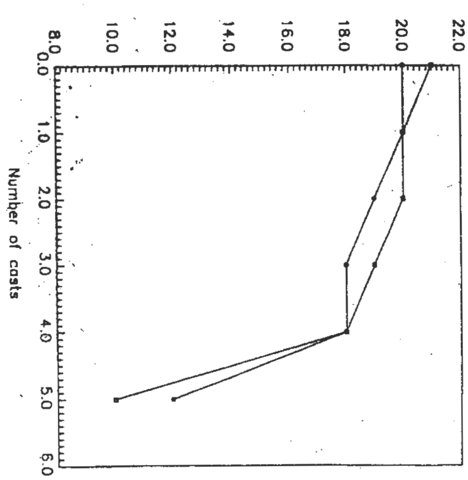

Figure 5: Green Shear Strength (kN/m²)

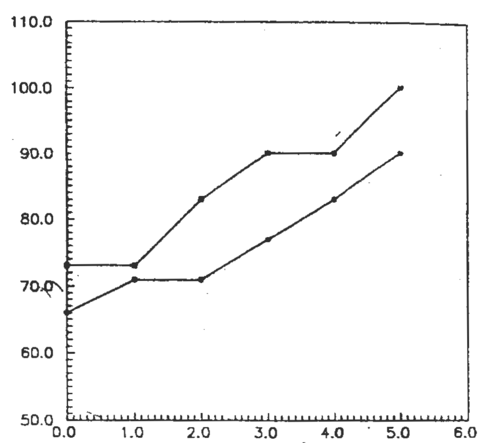

Figure 8: Toughness ($(W_1/W) \times 100$)

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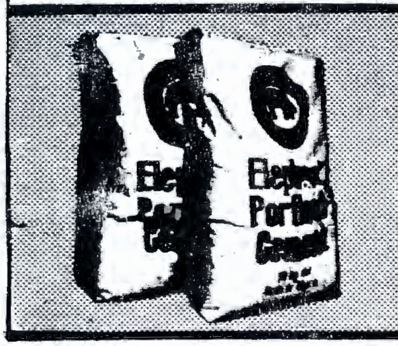

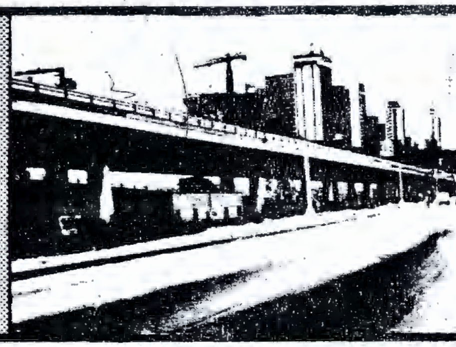

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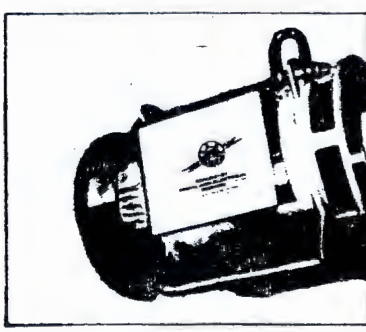

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