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Effect of cassava flour and coal dust additions on the mechanical properties of a synthetic moulding sand

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ABSTRACT

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An investigation has been made into the effects of cassava flour and coal dust additions on the mechanical properties of a newly developed synthetic moulding sand made from Igbokoda clay and silica sand. The results showed overall improved mechanical properties for both the cassava flour and coal dust additions though with a slight tolerable decrease in toughness. The improved mechanical properties, which resulted from the effective bonding property of cassava flour (starch) and fine bituminous coal particles, were obtained when a certain optimum level of each of the additives were used with the optimum percent clay and tempering water.

INTRODUCTION

In previous studies, (Loto and Adebayo, 1990; Loto and Omotosho, 1990), clay obtained from Igbokoda in Ondo State, Nigeria, has been characterised, analysed and developed as a binder for synthetic moulding sand. The Igbokoda silica sand has also been analysed, characterised and used as a base sand with the local clay as the binder in combination with some quantity of sodium carbonate as an activating additive, in order to develop an efficient synthetic moulding sand (Loto and Adebayo, 1990). Space will not permit the review of the above studies' results, upon which the present investigation is based. However, Igbokoda silica sand exhibits an optimum green compression and shear strengths at 13% tempering water. The dry compression and shear strength values of the synthetic moulding, sand are also reasonable. Tables I and II, and Figs. 2, 3 and 4 are taken from the previous studies (Loto and Adebayo, 1990; Loto and Omotosho, 1990) and are included in this report to show and justify some of the basis of the present experimental data as contained in the respective figures.

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For a long term, the development of moulding sand and techniques of its testing, has been a subject of investigation. This has culminated in the characterisation of clay (from different deposits) and base silica sands used in synthetic moulding sands. While the various works of Sanders and Doelman (1967, 1968, 1969) on durability of bonding clays are particularly significant in this respect, other contributors (Grim and Cuthbert, 1945; Heine et al., 1957; Vingas and Zrimsek, 1960; Wenninger, 1963; Lawrence, 1961; Williams, 1961; Dietert and Graham, 1968; Balogun and Adepoju, 1980) in this research field have also performed comprehensive studies on various aspects of moulding sand development and testing. In addition, the clay – silica – water bond relationship has also been comprehensively examined in different reports (Caine and Toepke, 1967, 1968; Wenninger and Lang, 1969).

The primary function of starch which has been in use of foundry industries, such as corn flour, is to provide green strength through the formation of a starch bond. It has also the advantage of charring and collapsing after, being exposed to the heat of casting. On the other hand coal dust is added to moulding sand in an attempt to provide a reducing atmosphere, which leads to better surface finish on the casting. Cassava which is abundantly produced locally is expected to provide the above-mentioned primary functions of starch addition to the synthetic moulding sands. It is therefore considered pertinent to have its mechanical properties tested to be able to characterise its viability for further industrial and laboratory applications. It is also similarly considered appropriate to look into the effect of coal dust addition on the mechanical properties of the moulding sand. These, briefly, are the objects of the present investigation. A good (positive) result from this work will hopefully be economically beneficial to the foundry industries and the the nation. This work is a further attempt to develop the local clay as a binder for synthetic moulding sand and as a substitute for the imported bentonite clays.

In general, the desirable properties of a moulding sand include strength, plasticity, collapsibility and sufficient gas permeability. Sufficient strength of moulding sands is required, among others, to prevent a collapse in the mould or its partial destruction during conveying or turning over. High plasticity is required of a moulding sand to obtain a good impression of the pattern in the mould. Plasticity of moulding sand refers to its ability to acquire predetermined shape under pressure and to retain this shape when the pressure is removed. Moulding sands require an adequate amount of collapsibility. This is the ability of the moulding sands to decrease in volume to some extent under the compressive factors developed by the shrinkage of the metal during freezing and subsequent cooling. Insufficient gas permeability of moulding sand may lead to the formation of holes and pores in the casting. Lack of adequate experimental research facilities has not made it possible to test for all the properties required of a moulding sand in this work. Usually, typical moulding sands run from about 30 to 150 kN/m^2 green compressive strength depending on their type. Typical; dry compression values on green sands are 130 to 1,722 kN/m^2, depending on their type. Green moulding sands usually have about 10 to 48 kN/m^2 green shear strength (Heine et al., 1977). Previous studies (Loto and Adebayo, 1990; Loto and Omotosho, 1990) using the same type of clay and base silica sand have shown the values obtained to be comparable and are within the above-mentioned mouldable ranges.

EXPERIMENTAL PROCEDURES

Separation of clay from sand

The experimental procedures used here are described in the previous work of Loto and Adebayo (1990). The as-received clay contained up to 5% coarse grain particles, mainly quartz. Gravity sedimentation was used to separate the coarse quartz particles from the clay.

The clay was dissolved in water and thoroughly dispersed with 1.5 g/dm^3 calgon (sodium hexametaphosphate). The jar's content was allowed to settle for about 5 min after stirring for about 20 min. 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 7 cm radius when rotating, was used to further separate the clay particles. The tubes were filled with the slurry obtained from the gravity separation suspension, and allowed to rotate under a centrifugal force of 19 kN at 15,000 rev./min for 30 min. The clear water suspension obtained was discarded and the clay sediment removed for further use. The composition of the clay (Table I) has previously been determined (Loto and Omotosho, 1990).

The fine clay sediment obtained was oven-dried with a laboratory Gallenkamp oven at a temperature of 50°C for 15 h.

pH measurement. 10 g of the fine clay material was dissolved in 50 cm^3 of

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

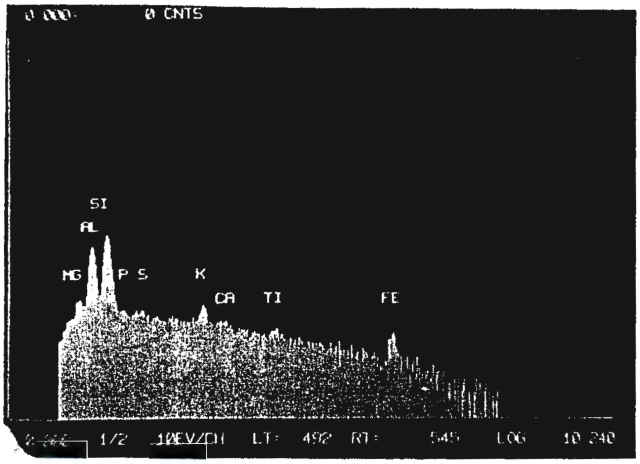

Fig. 1. SEM/EDS qualitative chemical analysis of Igbokoda clay: *MG*=magnesium; *AL*=aluminium; *SI*=silicon, *P*=phosphorus; *S*=sulphur; *K*=potassium; *CA*=calcium; *TI*=titanium; *FE*=iron.

distilled water contained in a beaker and thoroughly stirred. Its pH was measured by a pH meter and recorded.

SEM analysis. A scanning electron microscope (SEM) equipped with an energy dispersive spectrophotometer (EDS) was used to analyse qualitatively the chemical composition of the clay (Fig. 1).

Preparation of the base silica sand

The base silica sand used was obtained from Igbokoda in the southwestern part of Nigeria (Ondo State). The silica sand is about 98% pure. The sand was washed several times with water and sun-dried for ten days. The size and distribution of the sand grains were determined by the (American Foundryman Society) sieve analysis test method (Table II; Loto and Adebayo, 1990). A dried 50-g sample of the sand was used. The sample was placed on top of a series of BSS 410 sieves and shaken with the vibrating sieve shaker for 15 min. The sand retained on each sieve after shaking and at in the bottom pan was weighed. Its percentage of the total sample was determined. The additives used were cassava flour and coal dust.

Preparation of test samples

The base silica sand, a varying pre-determined percentage of clay by weight, known amounts of tempering water and a specified amount of coal dust and cassava flour (starch) were mechanically mixed by a mulling apparatus. The coal dust and cassava flour were separately used as additives to the silica sand/

TABLE 2
AFS sieve analysis of Igbokoda silica sand (Loto and Adebayo, 1990)

Sieve number	Amount of 50 g sample retained on sieve		Multiplier	Product
	grams	%		
8	0.00	0.00	–	–
16	0.12	0.24	10	2.4
22	1.24	2.48	16	39.68
30	8.81	17.62	22	387.64
52	24.85	49.72	30	1491.60
60	7.29	14.58	52	758.16
100	5.29	10.58	60	634.80
200	1.19	2.38	100	238.00
300	0.00	0.00	200	0.00
PAN	0.00	0.00	–	0.00
Total	48.79	97.58	–	3552.28

$$\text{Average grain fineness} = \frac{3552.28}{97.58} = 36.40$$

clay mixture. The effects of each of the additives on the properties of the synthetic moulding sand were determined by adding varying amounts of each to the base silica sand bonded with 13% by dry weight clay content and 3% by weight tempering water. These percentages of optimum clay addition and tempering water have been previously determined (Loto and Adebayo, 1990).

The amounts of cassava flour (dry) added to the moulding sand ranged from 0.3% by weight to 15% by weight of the moulding sand, and the amounts of coal dust similarly added varied from 1% to 8% by dry weight. After mixing of the above, the sample was stored in polyethylene bags to prevent air-drying.

Cylindrical test specimens conforming to the AFS standard specimen of 50 mm by 50 mm were prepared and used for the mechanical tests. An amount of sand mixtures adequate to form standard test specimens of 50 mm diameter and 50 mm high after three rams, were determined and measured out. In all the experiments, the sample weight used ranged from 150 to 170 g 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 6.50-kg weight. By the manually operated ramming device the weight was dropped from a height of 50 mm $\pm$ 0.125. Three rams normally produce a specimen 50 mm $\pm$ 0.79 in height provided the proper weight of sand is put in the specimen tube. Gauge 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

Details of the green compression test, testing procedures and equipment are contained in the AFS "Foundry Sand Handbook" (1963). The green compression test was carried out to determine the compressive stress in kN/m^2 necessary to cause rupture of the standard cylindrical specimen using a compression testing machine. Green compressive strength tests were performed immediately after the specimen was stripped from the tube to prevent any increase in green strength due 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 standard test procedures for the green shear test are set forth in the AFS "Foundry sand Handbook" (1963). 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.

Dry compression and shear tests

These tests followed the same procedures as for the green compression and green shear tests. The tests were carried out by drying specimen in an oven at

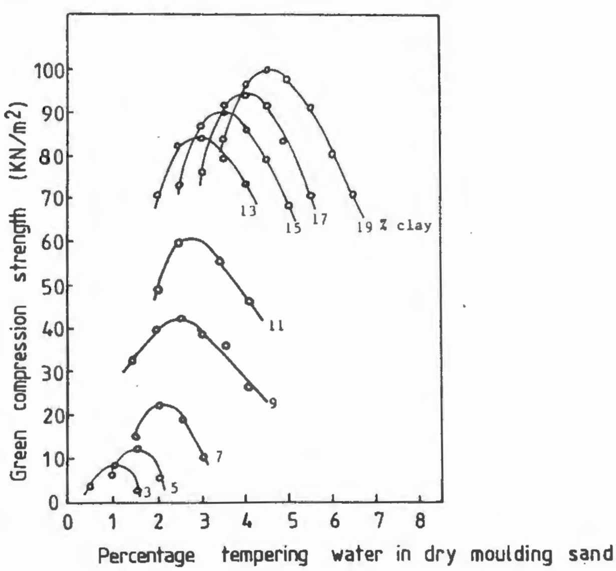

Fig. 2. Variation of green strength with clay and percentage of tempering water for Igbokoda clay-bonded silica sand.

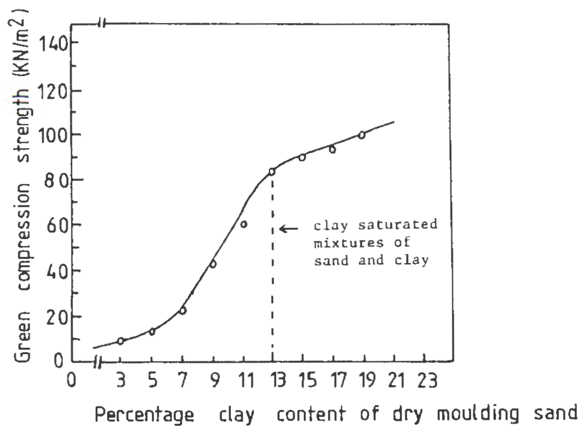

Fig. 3. Variation of optimum green compression strength with percentage clay content for the Igbokoda clay-bonded silica sand.

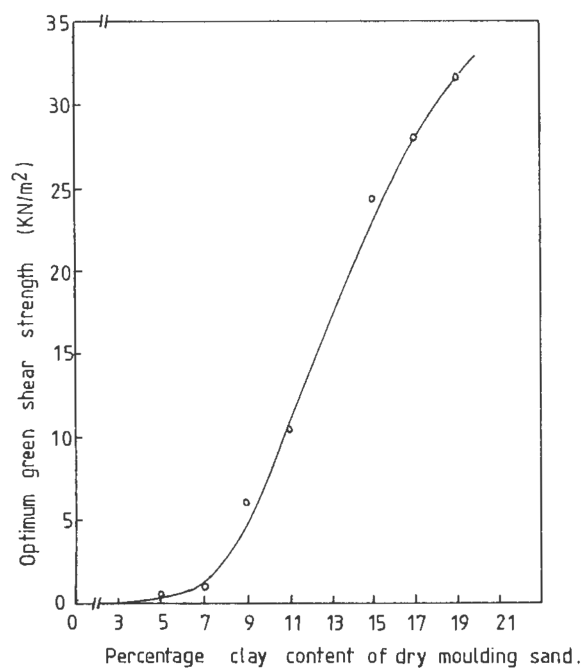

Fig. 4. Variation of optimum shear strength with percentage clay content for the Igbokoda clay bonded silica sand.

100–110°C for 2 h before testing. Since dry compression strength is usually greater than green strength, higher loads were required on the Universal sand strength testing 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 1.85 m onto 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 12.5-mm mesh B.S. sieve.

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

For toughness determination:

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

For collapsibility:

Shatter index $= W/W_1$
where W=weight of specimen, and W_1=weight of sand remaining on the sieve.

RESULTS AND DISCUSSION

All the tests carried out on the effect of the two additives on the properties of the synthetic moulding sand were based on 13% by weight dry clay at 3% by weight tempering water of the moulding sand. The pH of the clay was 4.2 and thus acidic.

Effect of cassava flour (starch)

Fig. 5 shows the effects of cassava flour (starch) addition on the green compression and shear strengths of the moulding sand. The curves of Fig. 6 indicate that both strengths increased greatly with a starch addition of 0.3% content by dry weight. Subsequent addition of starch (dry) beyond 0.3% by weight of the moulding sand gave green strength values which were smaller than obtained with an addition of 0.3% by weight. The peaks of the green strengths occurred at 0.3% by weight of dry cassava flour (starch) addition. (Values less than 0.3% by weight of cassava flour relative to the moulding sand were not tested in this investigation. Probable subsequent similar investigations could, however, take care of these). With an additional cassava flour content beyond 0.9%, these strength values fell below the initial green strength values obtained before starch addition.

The effects of cassava flour addition on the dry compression and shear

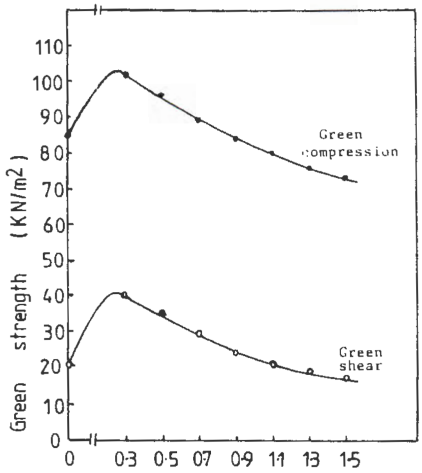

Fig. 5. Variation of green strength with percentage cassava (starch) content for the Igbokoda clay-bonded silica sand.

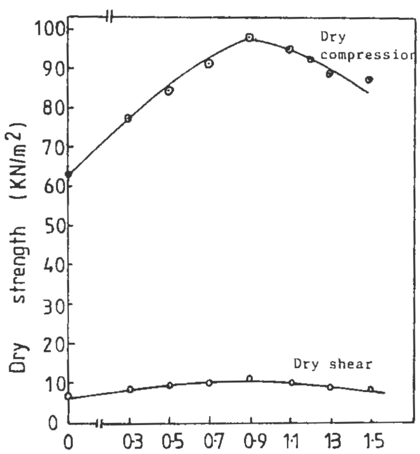

Fig. 6. Dry strength (compression and shear) versus percentage cassava (starch) content for the Igbokoda clay-bonded silica sand.

strengths of the synthetic moulding sand are shown in Fig. 6. The curves show that both the dry compression and shear strengths increased up to an addition of 0.09% by weight of dry cassava flour (starch), and beyond this value the strength began to decrease. The increase in dry compression strength between 0% starch àddition and 0.9% by dry weight was fairly high, while the increase in dry shear strength between these values was low.

Fig. 7 shows the effects of various additions of starch on the collapsibility of the synthetic moulding sand. The collapsibility increased steadily with increasing starch content.

Fig. 8 shows the effect of various percentages of cassava flour (starch) addition on the toughness of the synthetic moulding sand. It is shown in the figure that this toughness decreased steadily with increasing starch addition.

The behaviour of cassava flour addition as written above could be further explained. Cassava flour like cereal (corn) flour which has been in use in foundry industries, is expected to provide primarily green strength through the formation of a starch bond, as previously mentioned. Furthermore, it has the advantage of charring and collapsing after being exposed to the heat of casting. An optimum improved value in green strength that was obtained with

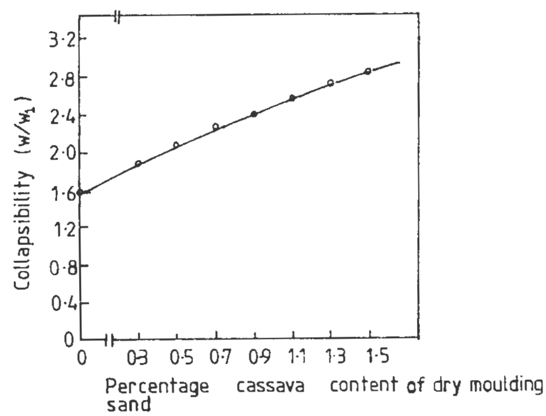

Fig. 7. Collapsibility versus percentage cassava (starch) content for the Igbokoda clay-bonded silica sand.

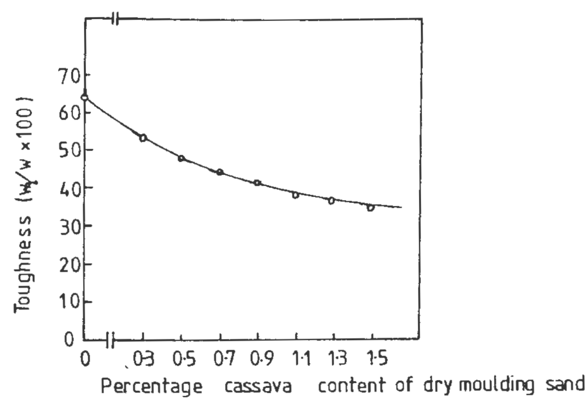

Fig. 8. Toughness versus percentage cassava (starch) content for the Igbokoda clay-bounded silica sand.

the addition of 0.3% cassava flour confirmed the effective bonding property of its starch content. Starch has great affinity to polar substrates and hence is able to form a gelatinous bond with water. The increase in both green compressive and shear strengths on a cassava flour addition of 0.3% by dry weight is due to the ability of starch to form a gelatinous bond with water. This property of starch also accounted for its improved property in both the dry compressive and shear strengths.

Starch (from the cassava flour) progressively increased the dry strength up to a cassava flour addition of 0.9% by weight (dry) to the moulding sand before steadily decreasing. It thus confirms that with the elimination of loosely bonded "mechanically held" water as obtained in dry sand, starch from the cassava flour has high bonding forces, with the only remaining tightly bonded water in the clay–water–silica bond. Thus the dry strength was enhanced.

The results in Figs. 7 and 8 respectively show that starch additions steadily increased collapsibility and decreased the toughness of the moulding sand progressively. The decrease in toughness due to starch addition was not expected. The reason for this behaviour is difficult to explain. However, it might be connected with the 3% by weight moisture content used, which might have been inadequate for the starch to contribute to the green toughness of the synthetic moulding sand. Starch normally confers increased toughness on moulding sand due to its strong moisture retention.

Effect of coal dust addition

The effects of adding various percentages of coal dust on the green compression and shear strengths of the moulding sand are presented in Fig. 9. Addition of coal dust (dry) up to 2% by weight relative to the moulding

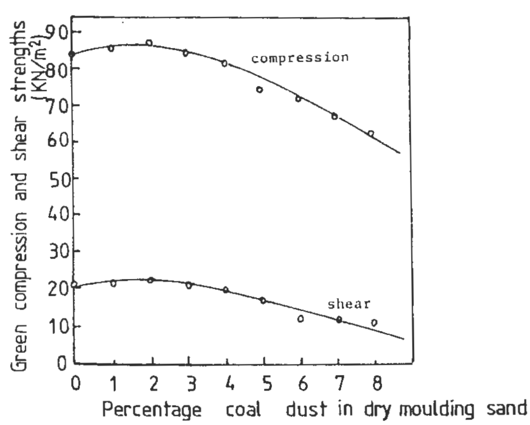

Fig. 9. Variation of green strength with percentage coal dust content for the Igbokoda clay-bonded silica sand.

sand, increased the green compression and shear strength slightly from the initial values. The peaks of these strength values occurred at a coal dust addition of 2% by weight (dry). A further addition of coal dust beyond 2% by weight relative to the moulding sand caused both strengths to fall from their peak values. At a coal dust addition beyond 6% by dry weight the green shear strength became about constant.

Fig. 10 shows the effects of coal dust addition on the dry compression and shear strengths of the synthetic moulding sand. There was a rapid increase in dry compression strength at a coal dust addition of 1% by dry weight. Beyond this percentage the dry compression strength began to decrease rapidly with increasing coal dust addition. The dry shear strength also increased appreciably with a coal dust addition of 1% by weight. However, when the addition increased beyond this value, the dry shear strength began to fall. Both the dry compression and shear strengths exhibited maximum values at coal dust additions of 1% by dry weight.

The effects of coal dust addition on the collapsibility of the synthetic moulding sand are presented in Fig. 11. The collapsibility increased steadily for coal dust additions of up to 4% by dry weight. There was a rapid increase in the collapsibility between additions of 4% and 6% by dry weight. The collapsibility became fairly constant of additions beyond 6% by dry weight.

Fig. 12 shows the steady decrease in the toughness values of the synthetic moulding sand with coal dust additions up to 4% by dry weight. Beyond this value, additional coal dust caused a rapid decrease in toughness. At values greater than 6% by dry weight the toughness became relatively constant.

In discussing the above results further, coal dust, in general, is added to moulding sand in an attempt, as previously mentioned in this report, to pro-

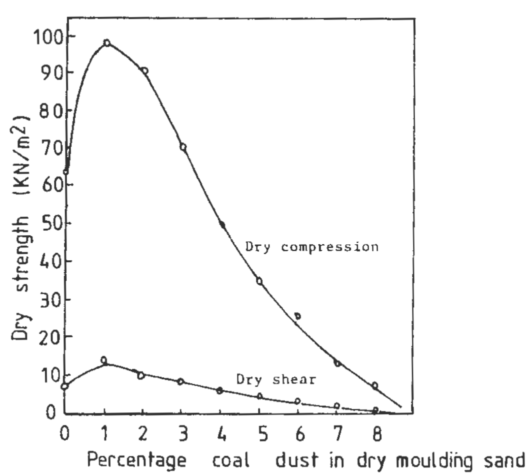

Fig. 10. Dry strength versus percentage coal dust content for the Igbokoda clay-bonded silica sand.

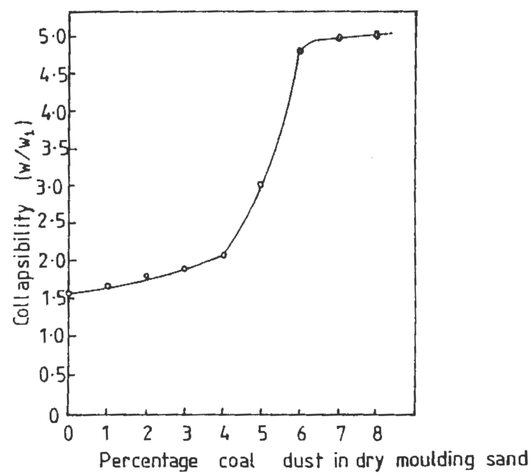

Fig. 11. Collapsibility versus percentage coal dust content for the Igbokoda clay bonded silica sand.

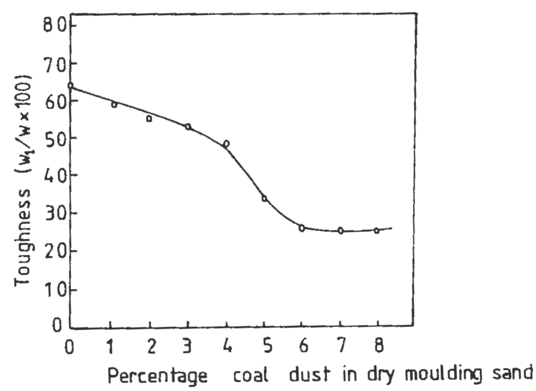

Fig. 12. Toughness versus percentage coal dust content for the Igbokoda clay-bonded silica sand.

vide a reducing atmosphere which leads to a better surface finish on the casting. However, the results obtained as expressed above have shown some effects of coal dust addition on the mechanical properties of the synthetic moulding sands – which is one of the prime objects of this investigation. There were increased green compressive and shear strengths when adding up to 2% by weight dry coal dust. This shows that the coal dust particles are also able to form good bonds with clay at the 3% by weight tempering water.

Both dry compressive and shear strength, however, increased appreciably at coal dust additions of up to 1% by weight, after which the strengths decreased steadily. This result seems reasonable, since small additions of fine grained bituminous coal at a fixed moisture content are expected to strengthen the synthetic moulding sands in the dry state because of the attendant hardening of the dried mixture due to the elimination of loosely held water and the further strengthening of the clay–coal dust particles bond. The moisture content of 3% by weight was inadequate at additions of higher percentages of coal dust to enhance the sand's dry shear and compression strengths.

Additions of coal dust increased the collapsibility and decreased the toughness. This behaviour is due to the moisture content of 3% by weight used, which was inadequate to saturate the coal fines as the quantity progressively increased.

CONCLUSION

In further developing Igbokoda clay and silica sand as an effective binder for synthetic moulding sand, this work has characterised the effects of cassava flour (starch) and coal dust, as additives, on the properties of the synthetic moulding sand, apart from their primary roles. An optimum addition of cassava flour, as obtained in the results, gives overall improved mechanical properties. This work further confirms that cassava flour can be effectively used as an additive in synthetic moulding sand without adverse effects if used within the optimum range of values. Similar improved mechanical properties of the moulding sand are also obtained by coal dust addition when the optimum amounts, as obtained in this work, are used.

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