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Deterioration of moulding sand properties with number of castings

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Abstract

An investigation has been made to determine the deterioration of moulding sand properties as it is used continually for casting. This is because a lot energy and time is put into the reclamation of moulding sands in the foundry due to its deterioration thereby leading to the production of castings with defects. To be able to determine the deterioration level, three moulding sand samples were collected within Niger State of Nigeria from three locations of Bida, Tagwai and Zungeru and investigated for the deterioration of their moulding properties after fifty consecutive numbers of casting operations. The deterioration level was determined by testing the moulding properties of the sands after usage and compared to the properties of the moulding sands before casting operations. The results obtained after fifty number of casting operations showed that all the sand samples deteriorated in their moulding properties as the number of castings increased with Tagwai moulding sand showing the least level of deterioration compared to those of Bida and Zungeru. The knowledge of deterioration rate of moulding sand will enhance the reduction of defects in castings.

Keywords

Moulding sand; Casting; Compressive strength; Moisture content; Permeability; Bulk density; Porosity; Clay content

Introduction

Sand casting is the most widely used metal casting process in manufacturing. Almost all metals can be produced by sand casting. Some examples of items manufactured in modern industry by sand casting processes are engine blocks, machine tool bases, cylinder heads, pump housings, and valves. Many foundry men prefer using sand casting over many of the other forms of casting processes because it is cheap and the sand used is readily available. Many experienced foundry men have to use sand casting even though their abilities and resources allow them to use the other metal casting methods like Lost Wax Casting or Investment Casting. Sand casting involves less material and less effort than the other casting methods. Sand casting is a gate way for new casters to get into the trade.

Sand being the principal moulding material in foundry shop possesses some vital properties required for moulding. The most important of these properties are porosity, flow ability, collapsibility, adhesiveness, cohesiveness or strength, and refractoriness [1]. Useable natural moulding sand can be found in many parts of this country. They are found along river bank or in a creek bed and in dunes among other places [2]. The quality of a moulding sand has a definite impact on the quality of castings. During sand casting process, moulding sand in contact with molten metal is heated to an excessive high temperature changing the physical properties of the moulding sand and eventually leading to it deterioration with number of castings, hence the need to recondition moulding sand for better casting quality. The properties of moulding sand will have deteriorated over a period of usage but the deterioration may differ for different moulding sand since their properties are not the same.

Properties of natural moulding sand have been investigated in various part of the Nigeria to determine their suitability for foundry applications. The suitability of moulding sand along the Rivers Niger and Benue [3] showed good moulding properties of grain fines, clay content and chemical composition for the casting of small to medium size ferrous and non-ferrous metals. The natural sands of Ilesha [4] in the south west of Nigeria was found to have good moulding properties for the casting of non-ferrous metals by varying the moisture content between 8% to 9%. The addition of bentonite and dextrin as binders [5] to recycle Ilaro sand improved the sand for the casting of medium to heavy casting, and River Kaduna sand [6] of Northern Nigeria was found to have adequate permeability for the casting of common metals. The aim of this investigation was to determine the deterioration of properties of moulding sand as it is continually used for casting purpose with a view to identifying the sand with better casting performance before reconditioning.

Material and method

The moulding sands selected for investigation were collected from different locations within Niger State of Nigeria. These locations are Tagwai, Zungeru and Bida. The Tagwai moulding sand was collected at Tagwai Dam road by the bank of the river, the Zungeru moulding sand was collected near Zungeru River and the Bida moulding sand was collected at Bida junction along Bida-Abuja highway. The sequence of experimental procedures is shown in Figure 1 and the properties investigated and procedure for each is presented as follows.

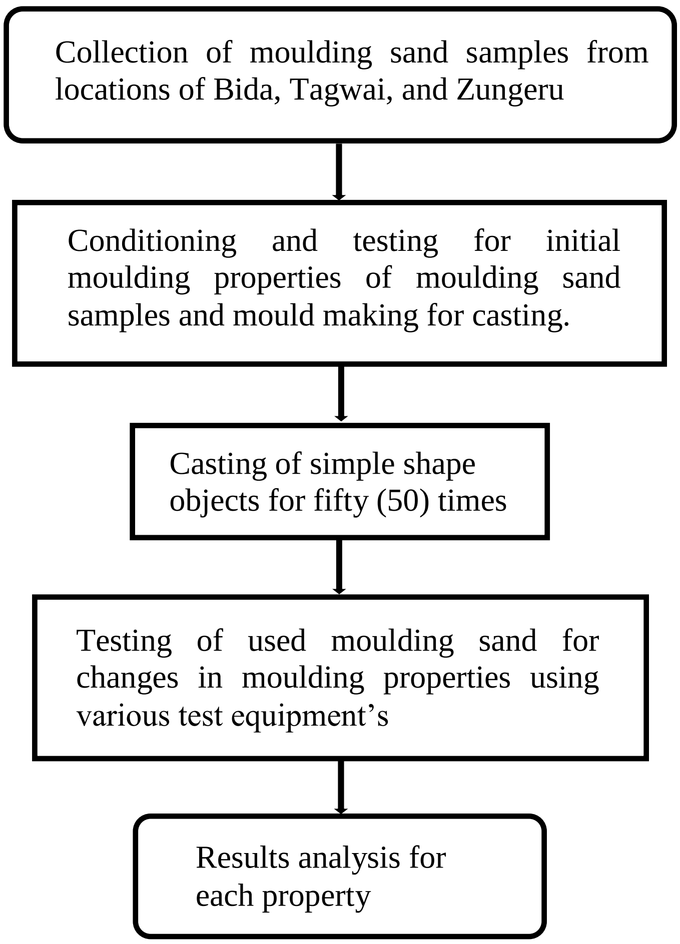

Figure 1. Experimental sequence

Six moulding sand samples were collected within these areas of investigation as three fresh samples and three used samples. The sand samples were conditioned for uniform distribution of clay and moisture content. The moulding sands were used for casting operation in a local foundry shop fifty consecutive times with only water as additive. Some portion of moulding sands before casting was prepared for laboratory analysis as well as the used moulding sand after the casting operations. The tests to determine the physical properties of the collected samples were carried out. These tests include: moisture content, clay content, sieve analysis, specific gravity, loss on ignition, particle size, bulk density, green and dry compression, shatter index, compactibility, and permeability. Each of these tests leads to obtaining specific property of the moulding sand which can be crucial to quality casting [7].

Moisture content

To determine the moisture, content an empty moisture can was weighed and recorded as M_1. Representative sample of moulding sand in small quantity was placed in the moisture can, weighed and recorded as M_2. The sample of moulding sand and the can were placed in an oven at 105°C to 110°C for 24 hours to dry to a constant mass. A pair of tongs was used to remove the specimen container from the oven and allowed to cool in a desiccator for 30 minutes before determining the mass of sample left. This procedure was carried out simultaneously for each of the moulding sand sample. The moisture content was then computed as percentage of dry mass [8] using equation (1).

$$W(\%) = \frac{M_2 - M_1}{M_3 - M_1} \times 100 \qquad (1)$$

Where: M_1 - mass of clean and dry moisture can; M_2 - mass of wet sand and moisture can; M_3 - mass of dry sand and moisture can.

Clay content

The clay content of the moulding sand samples was determined by washing the sand. A standard dried sand sample (50g) was put in a mixing device along with distilled water and 1% of NaOH solution. The mixture was stirred for 5 minutes and allowed to settle for 10 minutes. The dirty water was siphoned off from the top. The operation was repeated until the water above the sand in the mixer was clean. The sand was dried and weighed to determine the loss of weight which gives the clay content [9] which can be calculated using equation (2).

$$C(\%) = (50 - W_c) \times 2 \qquad (2)$$

Where: W_c - the weight of dry clay free sand.

Sieve analysis (Grain fineness)

The dried clay free measured sand grains were placed on the top of sieve arranged on a sieve shaker. The sieve was shaken continuously for a period of 10 minutes and each of the sieves with the left-over sand sieve was carefully weighed. The sand retained on each sieve expressed as percentage of the total mass was plotted against the sieve number. The grain fineness number which was a quantitative indication of the grain distribution was calculated using equation (3) by multiplying the amount retained on each sieve by the respective weight factor, summed up and then divided by the total mass of the moulding sand retained.

$$R = \frac{M_R}{M_T} \times 100 \qquad (3)$$

Where: M_R - mass of moulding sand retained; M_T - total mass of moulding sand.

The cumulative percent of moulding sand retained is calculated from equation (4).

$$C_R = \sum_{i-1}^{i-n} R \qquad (4)$$

Where: *n* - sieve number.

Grain fineness number is given by equation (5).

$$GFN = \frac{R_{sp}}{R_{\%s}} \qquad (5)$$

Where: R_{sp} - sum of products of moulding sand retained; $R_{\%s}$ - sum of percentages of sand retained on each sieve.

Specific gravity of moulding sand is the ratio of a unit weight of the moulding sand to a unit weight of equal volume of distilled water [10]. Each sample of the moulding sand was placed in an evaporating dish in an electric oven at 105^0C to 110^0C for 24 hours to dry to constant mass. The evaporating dishes from the oven were allowed to cool in a desiccator for about 30 minutes and 50g of the dried sand as well as water was measured in a density bottle.

The specific gravity of the moulding sand is calculated from equation (6) [8].

$$P_s = \frac{(M_2 - M_1)}{[(M_2 - M_1) - (M_3 - M_2)]} \qquad (6)$$

Where: P_s - specific gravity of moulding sand; M_1 - mass of density bottle; M_2 - mass of bottle and dried moulding sand; M_3 - mass of density bottle, moulding sand and water; M_4 - mass of bottle and water.

The organic content of aggregates and other organic soils such as peats, organic clays, and silts was determined by loss on ignition method. To determine the organic content in the moulding sand, 10g of dried samples from each location was baked in a muffle furnace held at a temperature of 440ºC for 30 minutes to burn off the organic matter, leaving the inorganic ash (sand fraction that is not burnt). The loss on ignition is determined by calculating the loss of weight of the sample [8] to the nearest 0.1% as ash content (A_c) using equation (7).

$$A_c(\% = \frac{M_2}{M_1} \times 100 \qquad (7)$$

Where: M_1 - mass of dried specimen; M_2 - mass of ash.

Therefore, loss on ignition (LoI is given by equation (8).

$$LoI = 100 - A_c(\%) \qquad (8)$$

The percentage of silt and clay was determined by treating a weighed soil sample with a sodium compound and dispersing it by means of a shaker. Dispersion breaks the soil aggregates apart so the particles act individually in the analyses. The determination of the various components of the sand is given by [11] as follows using equations (9-11).

$$\%Sand = 100 - [H_1 + 0.36(T_1 - 20) - 2] \times 2 \qquad (9)$$

$$\%Clay = [H_2 + 0.36(T_2 - 20) - 2] \times 2 \qquad (10)$$

$$\%Silt = 100 - (\%Sand + \%Clay) \qquad (11)$$

Where: H_1 - hydrometer reading at time of 4 seconds; T_1 - thermometer reading at time 4 seconds; H_2 - hydrometer reading at time 2 hours; T_2 - thermometer reading at time 2 hours.

The bulk density is the mass per unit volume of the sand sample including its water content. The bulk density of sands can be determined by forming it into a standard cylindrical shape of 50 mm height by 50 mm diameter and whose volume can be calculated by linear measurement method [12]. Figure 2 (a), (b) and (c) shows the various apparatus for this test which include sand rammer, weighing balance and split specimen tube.

(a) (b) (c)

Figure 2. (a) Sand rammer (b) Weighing balance (c) Split specimen tube

Sample of moulding sand is weighed with the weighing balance and placed in the specimen tube which is then placed in the sand rammer and subjected to three blows from the ramming weight to produce a compacted specimen. The bulk density is calculated using equation (12).

$$P_b = \frac{M}{V} \tag{12}$$

Where: M - mass of moulding sand; V - volume of moulding sand.

Similarly, the porosity (P_o) of the moulding sand is calculated using equation (13).

$$P_o = 1 - \frac{P_b}{P_s} \tag{13}$$

Where: P_s - specific gravity of moulding sand.

Green compressive strength and dry compressive strength

The green compressive strength is the maximum compressive stress that a sand mixture containing moisture is capable to withstand ramming during moulding and casting weight without breaking under standard conditions. Dry compressive strength is the maximum load a sand mixture dried in an oven at 110^0C for 2 hours can withstand before fracturing. Moulding sand well prepared for casting was filled into a specimen tube and rammed to produce cylindrical specimens of 50 mm × 50 mm of both the wet and dried sand. These freshly prepared standard samples were placed between the grips of the compression testing machine and then compressive force was applied until the specimen collapsed [13]. The compressive strength of both green and dry specimens were determined by dividing the compressive force with the total surface area of the cylindrical specimen using equation (14).

$$\rho_c = \frac{F_c}{A_s} \tag{14}$$

Where: F_c -compressive force; A_s - total surface area of specimen.

Deformation

The deformation, also called plasticity of sand, is indicated by the decrease in height of the sand specimen during its green compressive strength test. The decrease in height occurring due to compressive load just before the specimen fails is measured [14].

Shatter index

Shatter index is defined as the percentage of the total weight of the fractured sand specimen which remains on the test sieve. This value when correlated with the compression strength test gives a good indication of the mould ability of the sand [7]. This test is used as an indicator of sand toughness especially the ability to deform rather than fracture under shock. A standard test specimen for green compression test is ejected from a specimen tube and allowed to fall from a fixed height of 1.83m on to a steel anvil with a BS410 sieve (12.50 mm aperture) attached. The retained fragment on the sieve was weighed. British Standard Specification BS 410: 1986 (Replaced 2000) [15] adopts a primary size of 75µm (200- mesh) with a fourth root of two progression in size and suggest that alternate sieves should normally be used for an analysis (i.e. a root two progression of sizes). Thus, the specific surface area of particles on consecutives sieves is in a 2:1 progression. Shatter index (S_i) calculated from equation (15).

$$S_i(\%) = \frac{M_r}{M_s} \tag{15}$$

Where: M_r - mass of fractured sand specimen retained of sieve; M_s - mass of sand specimen

Compatibility

Compatibility is directly related to the performance of the sand on the moulding operation and detects the degree of temper in the sand mix. Apparatus for this test include sand rammer, standard specimen tube and sieve of 9.50mm opening.

The test was run by filling a specimen tube with riddled sand through 9.50mm screen mounted at a constant weight above the tube. The excess sand was struck off the tube and sand was rammed three times. The distance from the top of the tube to the surface of the sand was read as percentage compatibility [13].

Permeability

The permeability of a moulding sand is a measure of its capacity to allow the flow of gases through it. The specimen tube was filled with moulding sand to about two-third of its height. A rubber stopper was fixed to the top of the specimen tube. The height (L) of the compacted specimen in the tube was measured. Water was allowed to flow continuously for about 10 minutes in order to saturate the specimen. Air bubbles in the plastic tube connecting the funnel to the specimen tube was allowed to escape. After a steady flow was established, that is, the head (h) difference on the permeameter was constant, the water flowing out of the constant head chamber (Q) was collected in a graduated cylinder. The collection time (t) was recorded with a stop watch. The temperature T, of the water was also recorded to the nearest degree [10]. The coefficient of permeability is determined from equation (16).

$$K = \frac{4QL}{\pi D^2 ht} \tag{16}$$

Where: L - height of the specimen; D - diameter of the specimen; t - collection time; h - height of difference.

Results and discussion

The experimental results obtained during the investigation of the moulding sand properties for both the fresh and the used moulding sand are presented as follows: Table 1 shows the moisture content, clay content and particle sizes for the locations investigated.

Table 1. Results of moisture content, clay content and particles size

Sample location	Moisture content w (%)	Clay content c (%)		Particles size (%)					
				Fresh			Used		
	Fresh	Fresh	Used	Sand	Silt	Clay	Sand	Silt	Clay
Bida	17.38	48.18	31.04	88.0	4.0	8.0	80.0	7.0	13.0
Tagwai	10.08	74.80	57.56	74.0	13.0	13.0	88.0	3.0	9.0
Zungeru	15.40	59.06	51.60	76.0	9.0	15.0	82.0	15.0	3.0

From Table 1, the moisture content of the fresh natural moulding sand was in the range of 10.08% and 17.38% and can be classified as dense uniform sand [10]. Similarly, the clay content of the samples had the highest percent of 74.8% for Tagwai, while that of Bida has the least of 48.18% for fresh sand. As a result of the moulding sand usage, there was an average reduction of between 7.2% and 17.5%. The reduction of the clay content in the moulding sand affects its permeability, shatter index, green and dry compressive strength. The comparison of the fresh and used sand particle analysis revealed that Tagwai moulding sand has the highest percentage of clay content after usage for fifty consecutive castings without addition of any additive except water as compared to Bida and Zungeru moulding sand. Table 2 presents results of grain fineness number, specific gravity and loss on ignition.

Table 2. Results of grain fineness number, specific gravity and loss on ignition

Sample location	Grain fineness number		Specific gravity		Loss on ignition			
					Fresh		Used	
	Fresh	Used	Fresh	Used	Ash content (%)	Organic content (%)	Ash content (%)	Organic content (%)
Bida	63.13	50.25	2.57	2.75	78.0	22.0	86.0	14.0
Tagwai	71.64	66.60	2.64	2.69	82.0	18.0	91.0	9.0
Zungeru	65.96	56.29	2.56	2.71	89.0	11.0	85.0	15.0

Table 2 shows the fresh moulding sand of Bida and Zungeru with high grain distribution on the sieve opening of 0.15 mm and gives grain fineness number of 63.13 and 65.96 respectively, and after use shows a decrease of the fineness number to 50.25 and 56.29 for Bida and Zungeru. The used moulding sand sample of Tagwai has its highest percent of grain retention of 40.76% on sieve 0.075 mm and has fineness number of 66.6. The grain fineness number has effect on the surface finish of castings. The result obtained from the investigation also shows that Bida fresh sample has 22% loss on ignition, while Zungeru and Tagwai fresh samples have 11% and 18%. This shows that Bida fresh sand sample has the highest impurities that might lead to defect in castings. The smaller the amount of percentage loss on ignition, better the moulding sand for casting purpose. It was observed that the fresh moulding sand does not produce a good casting at earliest usage as a result of the organic content present. However, after subsequent usage of the moulding sand produced castings with good surface finish were produced.

Table 3 shows the results of bulk density, porosity, shatter index and compatibility.

Table 3. Results of bulk density, porosity, shatter index and compatibility

Sample location	Bulk density		Porosity (%)		Shatter Index		Compatibility	
	Fresh	Used	Fresh	Used	Fresh	Used	Fresh	Used
Bida	1.792	1.778	30.35	35.23	8.47	7.04	36.0	40.0
Tagwai	1.798	1.768	31.84	34.28	14.50	10.61	24.0	42.0
Zungeru	1.732	1.759	32.21	35.19	36.06	30.52	46.0	48.0

The bulk density for the both the fresh and used moulding sands as presented in Table 3 are within the range of 1.732 g/cm^3 to 1.798g/cm^3 which is within the normal range of 1.1 and 1.8 g/cm^3. Porosity which also characterizes the proportion of air, water and solid in moulding sand was found to be within acceptable limit of 30% and 45% [16]. The shatter index of the fresh and used moulding sand in Table 3 indicates a reduction of 1.43%, 3.69%

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and 5.54% respectively for Bida, Tagwai and Zungeru moulding sand. This result shows that Bida moulding has the least shatter level of deterioration. Too high or too low shatter index are deleterious to the mould [14]. Table 3 also shows the comparison between the fresh and the used moulding sand compact ability property. A difference of 4%, 18% and 2% was deduced for Bida, Tagwai and Zungeru moulding sand respectively. Zungeru moulding sand has 2% difference an indication of better sand property.

Table 4 presents the results of the coefficients of permeability, green and dry comprehensive strength and deformation.

Table 4. Results of coefficient of permeability

Sample location	Coefficient of permeability		Green compressive strength ($N/mm^{2)}$		Dry compressive strength (N/mm^2)		Deformation (%)	
	Fresh	Used	Fresh	Used	Fresh	Used	Fresh	Used
Bida	0.020	0.016	0.0028	0.0017	0.0034	0.000	6.0	8.0
Tagwai	0.019	0.016	0.0031	0.0028	0.0032	0.000	1.0	2.0
Zungeru	0.028	0.014	0.0024	0.0017	0.0037	0.000	2.0	2.0

Table 4 shows the difference between the fresh and used moulding sand green compressive strength of $0.0011N/mm^2$, $0.0003N/mm^2$ and $0.0007N/mm^2$ as well as for dry compressive strength of $0.0034N/mm^2$, $0.0032N/mm^2$ and $0.0037N/mm^2$ respectively for Bida, Tagwai and Zungeru moulding sand. Tagwai has the highest green compressive strength of $0.0028N/mm^2$ among the used moulding sand, while Bida moulding sand has the highest dry compressive strength of $0.0037\ N/mm^2$. The deformation percentage of the fresh sand during green compressive strength test are 6%, 1% and 2%, while 8%, 2% and 2% are for the used sand respectively for Bida, Tagwai and Zungeru.

Conclusions

The deterioration of moulding sands from three locations of Bida, Tagwai and Zungeru were investigated. All the sand samples showed an average deterioration of 22.98% clay content; 13.75% grain fineness number; 0.79% bulk density; 18.4% shatter index; 31.81% coefficient permeability; 8.4% green compressive strength and 8.4% loss on ignition. However, there was an average increment of the values of porosity compatibility, deformation to 3.43%, 22.64% and 1.67% respectively. Dry compressive strength showed no significant change. All the samples have shown appreciable deterioration in almost all the properties investigated. Tagwai sand has least deterioration compared to those of Bida and Zungeru.

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