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Comparison of the Effect of Local Binders on the Green and Dry Compression Strength of Cores

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Abstract

This research was carried out to investigate the effect of local binders on the green and dry compression strength of sand cores. The local binders used were composed of corn, cassava, and yam starch. The green compression strengths of the samples were observed to increase with increasing percentage of the binders. The maximum compressive strengths obtained were 45.78 kN/m^2, 42.89 kN/m^2, and 47.24 kN/m^2 for yam, corn, and cassava starch, respectively. The optimal value obtained from the cassava starch corresponds to the standard green compression strength for the cores used for casting malleable iron. Furthermore, an increase in moisture content was also observed to lead to a corresponding increase in green compression strength. The optimal value of 47.24 kN/m^2 was obtained from 20% cassava starch, 7% moisture content, and 200g of silica sand.

Keywords: Cores, Green compression strength, Dry compression strength, Sand.

1 | Introduction

Cores are embedded into moulds to create features in the castings that the mould itself cannot form; these include the interior passage, holes, undercuts, and small angles [1]. Sand grains cannot stick to each other without the use of binders that cause them to adhere together and produce the cavity into which molten metal is poured [2]. Binders are the adhesive kind of materials used for binding sands [3]. The addition of binders to sand is to glue or bind the sand particles together, thereby making the sand easily mouldable. This imparts the sand with sufficient strength and plasticity when mixed with the right quantity of water [4]. Moisture content is an important factor that impacts the features of a core since if the water is much, the core loses

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strength, thereby weakening the mould [5]. The purpose of core binders is to maintain the cohesiveness of the sand grains and to increase impact strength, resistance to erosion and breakage, and collapsibility [6]. There are different types of binders, and each of them imparts some desired property on a core for a particular use or purpose [6].

Fortini [1] opined that the quality of inorganic sand cores is comparable to their organic counterparts. The green compression strength is an important mechanical property that must be taken into consideration when casting green sand moulds[7], [8], and it can be defined as the maximum compressive strength that a mixture is capable of sustaining when prepared, rammed and tested according to standard procedure [7]. Green sand is mostly used for large casting (450 kg), while dry sand is usually for smaller castings (25 kg) [9]. A green compression strength value of 10.34 kPa and above is required for a sand mixture to be mouldable [8].

Grain size is a key factor in determining the green compression strength of moulds, cores, and surface finish of green sand castings. The finer the sand grains, the better the green compression strength is compared to coarser sand grains.

2 | Materials and Methods

2.1 | Materials

The silica sand employed for this study was obtained from the Bob-H community in Gwagwalada Metropolis of the Federal Capital Territory (FCT), Nigeria. The binders used (yam starch, cassava starch, and corn starch) were purchased from the Gwagwalada local market.

The equipment and apparatus used for the work include a weighing balance (ELE international; 88-1044/02; UK), Sieve, and sieve shaker (ELE International; 80-0200/01; UK) for percolating silica sand to obtain finer particles and to conduct sieve analysis; ramming machine (SIMPSON; 42100; Germany) to obtain a uniform pattern of sand mould; moisture teller machine (ELE international; 23-7462; UK) for determining the moisture content of the sample; mixing jar, for ensuring the homogeneity of the silica sand and binder mixture, and Universal Sand Strength testing Machine (USSM) (Kelsons Testing Machines; Universal strength machine (Hydraulic); Kolhapur, Maharashtra, India.) for measuring the green compressive strength.

2.2 | Methods

2.2.1 | Sand specimen preparation

Certain impurities, such as hard and big lumps, metallic objects, and stones, were first removed from the silica sand. The sand was then washed several times until it was clean, and a large quantity of its clay content was removed. Thereafter, it was left in the sun to dry for a week.

2.2.2 | Sieve analysis

Sieve analysis of the sand involves dividing a sample of aggregate into its component particle sizes by sieving using British Standard (BS) sieves of mesh sizes 2.00 mm, 1.18 mm, 600 μm, 425 μm, 300 μm, 212 μm, 150 μm, 75 μm, and 63 μm. arranged in the order of decreasing mesh sizes. The arranged sieves were then placed on a sieve shaker to cause a vibration of the stack of sieves and to allow respective sizes of the dried silica sand to pass through the sieves. The vibration was allowed to go on for 15 minutes to ensure effective percolation. The test was carried out in accordance with BS 812 (1989). The significance of this test is in predicting the size distribution and the relative percentage of the particles of each sample.

The American Foundrymen Society (AFS) Grain Fineness Number (GFN) was calculated using the equation

$$\mathrm{GFN} = \frac{\text{Total product}}{\text{Total sum of percentage collected in each sieve}}. \tag{1}$$

2.2.3 | Weighing and mixing

Samples of silica sand, yam starch, cassava starch, corn starch, and water were each weighed using a digital weighing balance. Samples of silica sand were mixed thoroughly in the sand mixer for 10 minutes to ensure a uniform mixture and also to avoid segregation of some of the materials in each sample. The specimens were prepared according to ASTM (2006) C778-13 sand specimen specifications.

Five core samples were prepared from each binder mix. For the respective binders, yam starch, cassava starch, and corn starch, their percentages were increased in the steps from 4% to 20% for every 200 g silica sand used, while the same quantity of water (7%) was used throughout the experiment.

2.2.4 | Determination of moisture content

The moisture content was determined using the moisture teller machine. The scale pan of the machine was pre-heated for 2½ minutes, and 150 g of the sample mixture was spread over it and heated further for another 3 minutes. The sample was then allowed to cool to room temperature on the scale pan before it was weighed. The significance of the test is to determine the suitability of the sand to be used in foundry practices and to have properties such as excellent flowability.

The moisture content of the silica sand sample was determined from the following expression [10]:

$$\text{Moisture content (\%)} = \frac{W_{bh}-W_{ah}}{W_{bh}} \text{ x } 100\ \%, \tag{2}$$

where W_{bh} is the initial weight of the sand sample before heating, and W_{ah} is the final sample mass after cooling to room temperature.

2.2.5 | Determination of green compressive strength

The universal sand strength testing machine was used to determine the green compressive strength of the various sand samples. 150 g of the mixture, consisting of 200 g of silica sand, 7% water, and varying percentages of binders, was weighed and taken into the mixing jar. The mixing jar was placed below the ramming machine and rammed properly five times to obtain the required shape of the specimen. The specimen was thereafter placed between the compressive shackles of the universal sand strength testing machine and then subjected to loading until failure occurred. The compressive strength value of the core was then recorded.

2.2.6 | Determination of dry compression strength

The universal sand strength testing machine was also used to determine the dry compressive strength of the various sand samples. The dry strength of the sand was measured following the same procedure as the green compression test after heating each prepared sample in an oven at a standard temperature of 105°C for 1 hour and cooling for another 1 hour according to the ASTM E2349-12.

3 | Results and Discussion

3.1 | Sieve Analysis

The results of the sieve analysis of the sand are presented in *Table 1*.

The AFS GFN was used to assess the sand sample's particle size by determining the distribution of grain sizes within the sample. Sands used in foundry have a wide range of fineness numbers. *Fig. 1* shows the variation of the percentage cumulative retained on each sieve to the respective aperture sizes. The obtained GFN is 43.93, which is within the acceptable range of 40–330, stated by Fayomi et al. [11].

The graph shows the variation of the cumulative percentage of sand retained on each sieve according to their aperture sizes. As the aperture sizes increase, the percentage of the cumulative sand retained on the sieve reduces. At the aperture size of between 2 mm and Pan, there is no sieving of the retained sand, which results in the sudden increase of the percentage of cumulative sand. The amount of binder necessary to produce the required strength of a core increases and the sand becomes fines, therefore, the amount of binder needed to obtain higher green compression for the sand sample would have to be more than as received. This is because the sample obtained is of a coarse texture.

Table 1. Sieve analysis of the sand.

S/N	Aperture (mm)	B.S.S no.	Weight Retained (G)	Sand Retained (%)	Cumulative Sand Retained (%)	Product
1	2.00	10	3.50	3.50	3.50	-
2	1.18	16	3.35	3.35	6.85	33.5
3	0.60	30	6.24	6.24	13.09	19.84
4	0.425	40	12.33	12.33	25.42	369.9
5	0.300	50	38.81	38.81	64.23	1552.4
6	0.212	70	19.79	19.79	84.02	989.5
7	0.150	100	10.20	10.20	94.22	714
8	0.075	200	4.41	4.41	98.63	441
9	0.063	230	0.30	0.30	98.93	60
10	PAN	-	0.46	0.46	99.39	105.8
Total			99.39	99.39		4365.94

$$\text{Average grain fineness of the sand} = Total\ Product/\%\ Retained, \\ = 4365.94/99.39, \\ = 43.93. \tag{2}$$

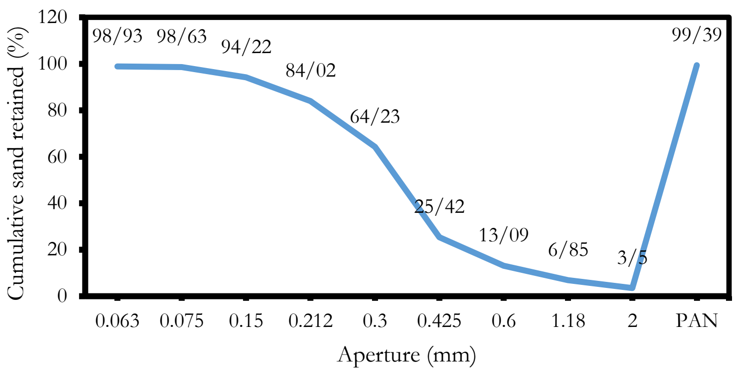

Fig. 1. Graph of percentage of cumulative sand retained vs aperture of gwagwalada municipal silica sand.

The AFS standard states that an average fineness of 40 to 330 is appropriate for foundry applications. Coarse-grained sands with lower fineness ratings are used in steel castings, while higher numbers indicate fine sands, which are typically used for light castings. The Gwagwalada sand's fineness number indicates that it is suitable for steel castings. The AFS fineness number also influences the collapsibility and permeability. A core will bake more easily if its permeability is higher, which suggests that the binder will release less gas during pouring. A core's permeability increases with its coarseness. As a result, it may provide the required dry and green strength values, as well as sufficient flowability and good moldability [6].

3.2 | Green Compression Strength

The graphical representation of the variation of the green compression strength of the samples with an increase in percentages of binders is presented in *Fig. 2*.

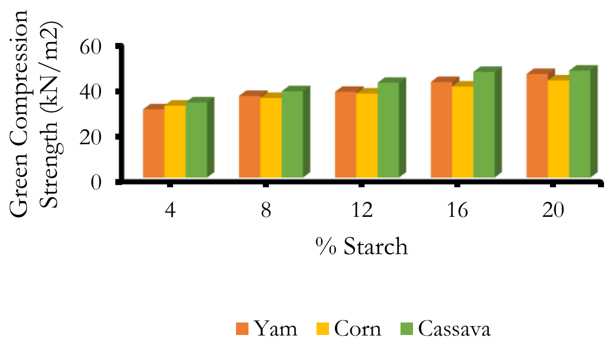

Fig. 2. The green compression strength of the sand cores with varying percentages of yam, corn, and cassava starch.

The green compression strength measures the ability of the sand cores to withstand the pressure of molten metal during casting in its green state. The results of the green compression strengths obtained for 4 – 20 % of yam, corn, and cassava starches contents are 30.12 – 45.78 kN/m^2, 31.78 – 42.89 kN/m^2, and 33.22 – 47.24 kN/m^2, respectively.

It can be inferred that an increase in the percentage of the starch binders led to a corresponding increase in the green compression strength of the three binders. The rate at which the bonding forces bind the sand grains together is a function of the individual binding agents. This is responsible for the increase in the green compression strength of the core.

A comparison of the green compression strength of the three starches shows that cassava starch has the highest green compression strength value compared to yam and corn starch making it more suitable for use as a binder in moulding, as it corresponds to the satisfactory mould sand property for malleable iron (45 – 55kN/m^2) [12].

Furthermore, the high value of green compression strength indicates that the mould generated during casting would be more resistant to wear and atmospheric pressure. Some additives must be added to maize and yam starch to enhance their mechanical qualities and stability so they can be used effectively.

3.3 | Dry Compression Strength

The graph for the dry compression strength of the sand cores with varying percentages of yam, corn, and cassava starch is presented in *Fig. 3*.

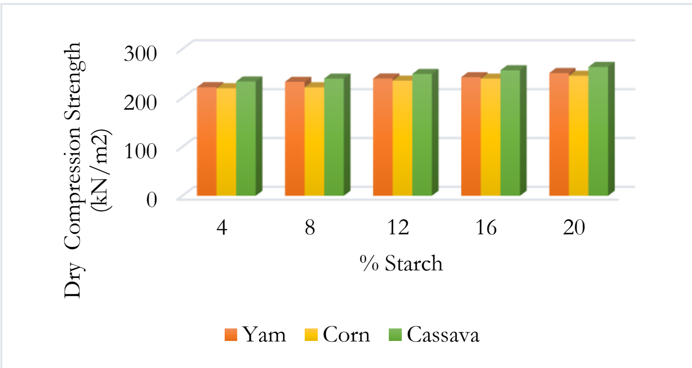

Fig. 3. The dry compression strength of the sand cores with varying percentages of yam, corn, and cassava starch.

The results for the dry compression strength obtained for 4 – 20 % yam, corn, and cassava starch contents ranged from ~222 – 251 kN/m^2, 220 – 246 kN/m^2, and 234 – 264 kN/m^2, respectively.

The results show that an increase in the percentage of the binders led to a corresponding increase in dry compression strength. The dry compressive strength was also observed to be greater than the green compressive strength for all the binders used as a result of the loss of moisture in the dry samples.

3.4 | Moisture Content of Sample

The moisture content of the sample containing yam, corn, and cassava starch is presented in *Table 2*. The moisture content test was conducted to determine the amount of dampness of the sand sample.

Table 2. Moisture content of yam, corn, and cassava starch samples.

S/N	% Starch	% Moisture Content		
		Yam	Corn	Cassava
1	4	2.55	2.02	3.47
2	8	3.27	2.98	5.02
3	12	4.33	3.14	6.38
4	16	5.32	4.35	7.12
5	20	6.18	5.22	7.89

The moisture content values obtained for 4 – 20 % yam, corn, and cassava starch contents ranged from 2.55 – 6.18 %, 2.02 – 5.22 %, and 3.47 – 7.89 %, respectively.

The results show that as the percentage of the binders in each sand sample increases, there is a corresponding moisture content increase. The obtained values are comparable with the values of the moisture content for the casting of malleable iron (5-7%) [12].

4 | Conclusion

This research work was carried out to investigate the effect of different locally sourced binders (cassava, corn, and cassava starch) on the green compression strength of cores using Gwagwalada sand as the silica sand. From the results obtained, these binders can be considered usable and effective in foundry technology.

The analysis of the results shows that the green compression strength is directly proportional to the quantity of the binders in the sample mixture. Also, from the three local binders used, the cassava starch displayed better binding properties compared to yam and corn starches. The maximum green compression strength was obtained at 20% cassava starch addition, with 7% moisture content and 150 g of sand, which yielded 47.24 kN/m^2.

It can, therefore be concluded that Gwagwalada sand is a good foundry sand with its GFN 43.93, which proves its usability for steel castings. Cassava starch is suitable as a binder for malleable iron as it corresponds to the required green compression strength of 45 – 55 kN/m^2.

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