Effect of Some Polysaccharide Starch Extracts on Binding Characteristics of Foundry Moulding Sand

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Abstract- This work investigated the properties of foundry moulding sand using different polysaccharide starch extracts as binders.Apart from the availability of these polysaccharides, the extracts are non-toxic. Three polysaccharide (rice, maize and cassava) starch extracts were added in varying quantities with fixed amount of pulverbond (bentonite + coaldust) to silica sand and various indicaltests such as permeability, moisture content, green compression and shear strength, dry compression strength, shatter index and compatibility were carried out on specimens prepared according to ASTM standards.Results showed sand properties were affected by the type and quantity of starch binder used. Green compression strengths of moulding sand for all three starch binders increased from 20% and peaked at 40% binder additive. Permeability increased as well from.....and peaked at 40% starch addition. Shatter index value rose sharply from.....and reached a maximum value at 40% starch addition. The dry compression strength for rice and maize starches decreased while that of cassava starch increased from 20% and peaked at 40% starch addition. From all the three sourced starches under consideration, it could be concluded that cassava starch was found suitable as an alternative for use as binder in foundry moulding applications.

Index Terms- Silica sand, polysaccharide starch binders, foundry moulding sand

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1 INTRODUCTION

One of the major problems confronting foundry industries is the use of the adequate moulding binding additives [1],[2],[3]. Compounding the problem for some states is the bottleneck associated with foreign exchange processing. Over the decades, bentonite has been a major binder for silica sand moulding. However, Small and Medium Scale enterprises (SMEs) have always been on the lookout for more affordable and locally available substitutes[4].

Commonly used for substitutes are local starch and dextrin which are derived from polysaccharide carbohydrate.Polysaccharide carbohydrate is a starch consisting of a large number of glucose units joined together by glycosidic bonds. It is produced by all green plants as an energy store and it is the most important carbohydrate in the human diet. It is contained in such staple foods as rice, wheat, maize, cassava and potatoes. Starch is one of the most abundant substances in nature, a renewable and almost unlimited resource [5]. Starch is produced from grain or root crops. It is mainly used as food but is also readily converted chemically, physically and biologically into many useful products. Starch is used to produce such diverse products as food, paper, textiles, adhesives, beverages, confectionery, pharmaceuticals and building materials.

Starch can be classified into two types; native and modified. In the unmodified form, starches have limited use in the food industry. In general, native starches produce weak-bodied, cohesive, rubbery pastes when heated and undesirable gels when the pastes are cooled [6]. The properties of starches can be improved by various modifications. Researchers have developed methods to modify starch, which requires the usage of chemicals and enzymes. Physical modification involves pre-gelatinization, and heat-treatment of starch [7].Pre-gelatinized starches are pre-cooked starches that can be used as thickener in cold water. While the heat-treatment processes include heat–moisture and annealing treatments, both which cause a physical modification of starch without any gelatinization or damage to granular integrity. The native starch granules hydrate easily when heated in water, swell and gelatinize, with viscosity increasing to a peak value. It has poor tolerance to acidity and low resistance to shear pressure. However, sectors like food, metallurgical, mining, chemical, construction, cosmetics, pharmaceutical among others use native starch in its traditional form. Modified starch is a food additive which is prepared by treating starch or starch granules, causing the starch to be partially degraded. The purposes of this modification are to enhance its properties particularly in specific applications such as to improve the increase in water holding capacity, heat resistant behaviour, reinforce its binding, minimize synthesis of starch and improved thickening [7].

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This study focussed on the use of polysaccharide starch derived from rice, maize and cassava as binders for foundry moulding applications.

2. METHODOLOGY

Three polysaccharide based starches were extracted from their various plants as follows:

2.1 Extraction of starch from rice

Extraction of starch from rice was done by the wet process as shown in figure.1. Here, the broken rice was steeped in caustic soda for about twelve hours. This gives the nutrient tissue a more elastic structure, allowing it to be split open. Disintegration was effected in mills and the nutrient tissue was broken so that the components present in suspensionwere separated out. In the extraction stage, all the relatively large plant fibres were separated out of the suspension so that the suspension only contains starch particles, fine fibres and protein residues. Then a 3-stage starch concentration and washing process with 3-phase nozzle separators was carried out in order to separate the flow into pure starch milk. Decanters were used for the final dewatering and the milky starch obtained was sun dried.

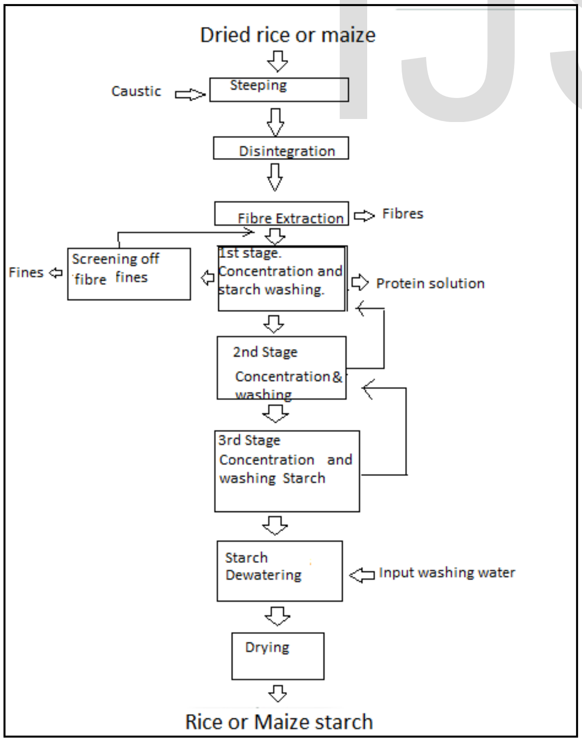

Figure 1. Integrated process for obtaining rice and maize starch [adapted from (7)]

2.2 Extraction of starch from maize

The wet milling process used for rice starch extraction (Figure 1) was used for maize starch extraction as well. The maize was steeped for about 30 – 48 hours which resulted in slight fermentation. The germ was separated from the endosperm and these two components were ground separately (still soaked). The starch was then removed by washing and dried.

2.3 Extraction of starch from cassava

Cassava starch extraction was relatively simpler than that of the rice/maize extraction as there were only small amounts of secondary substances, such as protein in the tubers. The tubers were peeled, washed, grated, mixed with water, filtered and allowed to settle down. On settling down, the starch was dewatered in a clean bag by pressing. The starch obtained was then dried and milled. The extraction process is presented in figure 2.

2.4 Determination of shatter index, compressive and shear strength

Sand mixes were prepared and fully rammed to rigid standard cylindrical shapes of 50 mm diameter by 50 mm height according to ASTM standards. Samples of this dimension were prepared from 150 g of each of the sand mixes with the polysaccharide starches with 12 g pulverbond and 40 cm^3 water. The sand and the binder were first dry-milled for five minutes, then water was added and milled for an additional ten minutes. The compressive strength (green and dry), the shear strength (green and dry) and the shatter index were carried out using these standard specimens. All the tests were carried out according to standard procedures (Burns, 1989).

2.5 Determination of sand moisture content

The Moisture Teller machine was used to determine the moisture content of the 200 g freshly prepared silica sand sample. The scale pan of the machine was pre-heated for 3 minutes before the sample was spread over it and heated for an additional 2 minutes. The sample was allowed to cool to room temperature on the scale pan before weighing. The moisture content was determined as follows:
Initial sample mass before heating = 200g
Final sample mass after cooling to room temperature = X (g)
% moisture content = $\frac{200-x}{200} x$ 100%(3)

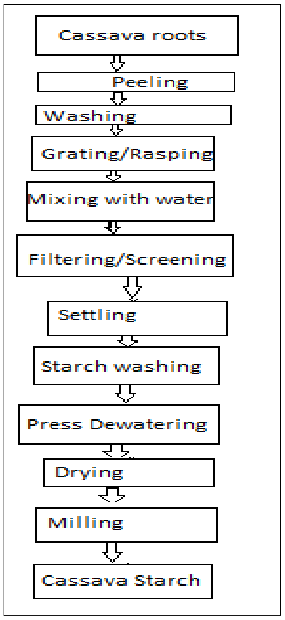

Figure 2. Cassava starch extraction process

2.6 Determination of clay content

Dry sand of initial mass x (g) obtained after moisture test was used. It was washed in water four times and then oven-dried on a stainless plate. The final mass X_1(g) was taken. The clay content was calculated using the following equation:

$$\% \text{ clay content} = \frac{initialmass - finalmass}{initialmass} x\ 100\% \quad (4)$$

$$= X - \frac{X1}{X} x\ 100\%$$

2.7 Sieve analysis test

Particle size distribution analysis was done using sieves mounted on an electric vibrator set at 3 Hertz. A thoroughly dried 100 g silica sand sample was subjected to 15 minutes vibration in an assembly of sieves (1.40, 1.00, 0.71, 0.50, 0.355, 0.25, 0.18, 0.125, 0.09 and 0.063 mm meshes). After 15 minutes, the sand particles retained on each sieve and the bottom pan were collected, weighed and recorded accordingly.

2.8 Green compression strength and green shear strength tests

150 g of standard samples of 50 mm diameter by 50 mm height were rammed and subjected to green compression strength test using the universal sand strength machine. Steadily increasing load was applied on the samples until failure occurred and the load at which the sample collapsed was recorded. For the green shear strength, appropriate accessories were mounted on the universal sand test machine and the same procedure was repeated for another set of standard samples. Each of the samples was subjected to gradual load at a rate of 25 kN/m^2 in every 10 seconds.

2.9 Dry compression strength test

The prepared standard sample of 50mm diameter x 50mm height was dried in an oven at a temperature of 110°C for a period of 30 minutes and then removed and allowed to cool in the air to ambient temperature. After cooling, the sample was fixed into the universal sand testing machine with the compression head in place. The compressive load was applied and the samples failed at the ultimate compressive strength of the sample. The point at which the failure occurred was recorded.

2.10 Shatter index test

A shatter index tester was used to test standard samples, the samples were tested while still encased in the steel tube used to mould them to shape. The test sample was prepared without stripping. The sand test piece was positioned at the top of a tower 1.83m high and ejected from a specimen tube by gently pulling down the handle unto a steel anvil head 75mm in diameter. On impact, the test piece shatters, some of the sand remaining on the anvil and some being projected on to 12.5µm mesh B.S sieve. The sand which passes through the sieve into the sieve pan was weighed and the shatter index was computed.

2.11 Permeability test

150g of the sample was weighed and transferred to a specimen sleeve with the base already plugged to a socket. The sample was rammed three times and then removed from the sleeve and placed on an electric permeability tester in an inverted form in which standard air pressure of 9.8 x10^2N/m^2 was passed through the specimen tube that contained sand placed in the parameter of the permeability tester and time for 2000cm^3 was recorded. The permeability tester was then switched on and allowed to settle down. The lever was then moved to check the position and then the value read off.

2.12 Compatibility test

The compatibility test was carried out in conjunction with a sand rammer. This test was to measure the decrease in height of a riddled mass of sand under the influence of standard compacting force to measure the degree of temper of sands.

3.0 RESULTS AND DISCUSSSION

3.1 Results

TABLE 1
SIEVE ANALYSIS OF SILICA SAND

Mesh size (mm)	Weight of sand retained (g)	Multiplier	Result obtained (g)	Cumulative retained sand
1.40	0.7	6	4.2	0.7
1.00	2.9	9	26.1	3.6
0.71	6.2	15	93	9.8
0.50	8.0	25	200	17.8
0.355	16.7	35	584.5	34.5
0.25	23.0	45	1035	57.5
0.18	32.8	60	1968	90.3
0.125	5.0	81	405	95.3
0.09	3.0	118	354	98.3
0.063	0.3	164	49.2	98.6
Sieve pan	0	275	0	98.6
	98.6		4719	

Grain fineness index(G.F.I) = 4719/98.6
= 47.86%

TABLE 2
FOUNDRY MOULDING PROPERTIES OF SAND BONDED WITH VARYING WEIGHTS OF CASSAVA STARCH

Properties	**Cassava starch addition (%)**			
	20	**30**	**40**	**50**
Green compression (gm/cm^2)	290	452	620	560
Green shear (gm/cm^2)	230	352	480	600
Dry compression(gm/cm^2)	450	620	800	750
Permeability(vol./min)	156	243	275	410
Compactibility(%)	590	610	640	670
Shatter index (%)	310	420	560	350

TABLE 3
MEASURED FOUNDRY PROPERTIES OF SAND BONDED WITH VARYING WEIGHTS OF RICE STARCH

Properties	**Rice starch addition (%)**			
	20	**30**	**40**	**50**
Green compression (gm/cm^2)	210	190	550	620
Green shear (gm/cm^2)	170	150	360	250
Dry compression(gm/cm^2)	350	300	540	650
Permeability(vol./min)	122	156	226	341
Compactibility(%)	620	640	650	660
Shatter index (%)	390	420	500	460

TABLE 4
MEASURED FOUNDRY PROPERTIES OF SAND BONDED WITH VARYING WEIGHTS OF MAIZE STARCH

Properties	**Maize starch addition (%)**			
	20	**30**	**40**	**50**
Green compression (gm/cm^2)	430	350	520	250
Green shear (gm/cm^2)	340	280	250	210
Dry compression(gm/cm^2)	500	420	350	400
Permeability(vol./min)	156	243	450	350
Compactibility(%)	640	650	660	670
Shatter index (%)	450	490	550	500

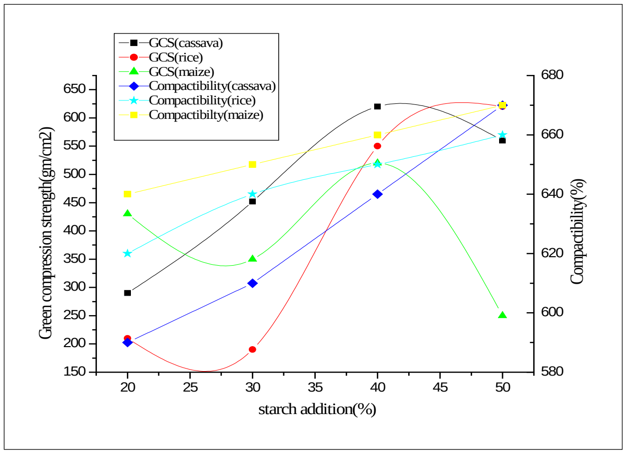

Fig.3. Effect of cassava, rice & maize starch on green compression strength and compactibility.

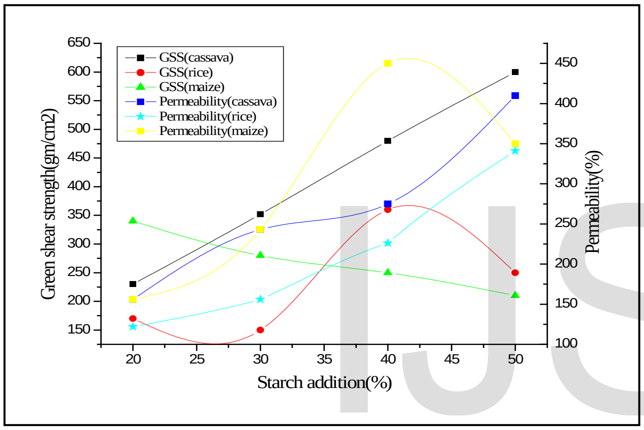

Figure 4. Effect of cassava, rice & maize starch on green shear strength and permeability.

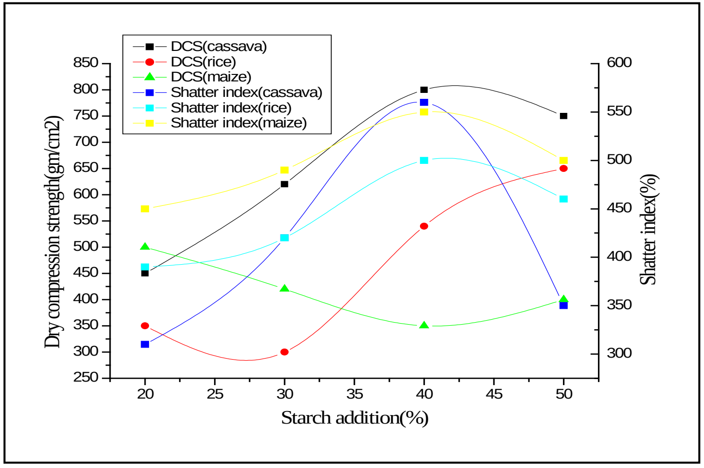

Figure 5. Effect of cassava, rice & maize starch on dry compression strength and shatter index

3.2 Discussion

3.2.1 Moisture content and clay content

From the moisture content and clay content result as shown in table 1 and 2, the result obtained compares well with the acceptable values which fall between 2.5 - 9.0% and 0- 4.0% for the moisture and clay content respectively (Burns, 1989). The relevance of the test is to determine the suitability of the sand to be used in moulding practices so as to have properties such as good flowability.

3.2.2 Sieve analysis

Table 3 shows the sieve analysis of the silica sand used in the preparation of the sand mix. The sand has a grain fineness index of 47.86 which is within the acceptable range of between 44 -54 which makes it to be coarse in nature and can effectively be used for steel castings because of its low fineness number. It is suitable for providing the necessary green and dry strength values, adequate flowability and good mouldability.

Figure 3 shows that the green compression strength (GCS) for cassava increases at various rates with increase in % starch addition until it peaks at 40% after which it starts to decrease. For rice, the GCS reduces at 30%, begins to increase and peaks at 50% while that of maize decreases at 30%, peaks at 40% and then begins to drop. It is clear that an increase in the starch content correspondingly produces an increase in the green compression strength of the sand mixes. Figure 3 also shows that the maximum green compression strength for the sand mixes containing cassava starch is 620 gcm^{-2}, rice starch is 620 gcm^{-2} while that of maize is 520 gcm^{-2}. General comparison of the green compression strength of the three starches suggests that cassava starch attains its GCS value at a faster rate compared to rice or even maize starch making it more suitable for use as a binder in moulding. Also the high value of green compression strength shows that the mould produced would have more resistance to wear and external pressure during casting.

Figure 3 shows the percentage of various starch binders of cassava, rice and maize on the properties of moulding sand. As the percentage of these starch binders increases, the various moulding properties increases, except for green compression strength (GCS) of rice and maize that first show a slight decrease and then start to increase at about 26 and 28 % starch binders additions respectively. The peaks for most of the moulding properties were reached at about 40% starch binder additions. However, the GCS for rice starch binder did not reach its peak until when about 45% rice starch binder was added. The peak value for GCS was about 620 gcm^{-2} and this same value was the peak when 40% cassava starch binder was added. The compatibility for maize, rice and cassava starch binders on moulding sand increases, however, cassava has the highest positive gradient for compatibility. The effect of this is that the same quantity of each of these starch binders gives different GCS, the highest being got from cassava starch binder. A 40% for instance, cassava, rice and maize starch binders gave 620, 520 and 480 gcm^{-2} respectively.

Figure 4 shows the effect of various starch binders on the permeability and green share strength (GSS) of moulding sand. The permeability of all the starch binders increases as the starch addition increases. But at 40% starch addition, the permeability of maize starch binder moulded sand starts to decrease. At this same 40% starch binder addition, the GSS of rice starch binder moulded sand also starts to decrease, whereas the GSS of both cassava and rice starch binders addition increase. The reverse trend is noticed for maize starch binder moulded sand. The GSS of rice on its own case first shows a slight decrease then increases sharply until a peak of about 320 gcm^{-2}is reached at about 40% starch binder addition. Permeability for rice and cassava starch binders addition has no defined peak value but maize starch binder moulded sand has at 40% starch binder addition, a peak value of 450% permeability.

Figure 5 shows the effect of various starch addition on the dry compression strength (DCS) and shatter index of moulding sand. As the cassava starch binder increases, the DCS increases until a peak of 780 gcm^{-2}is reached at about 40% starch binder addition. The rice starch binder addition first shows a slight decrease and then starts to increase from about 30% starch addition and then increases rapidly until about 50% starch binder addition when a peak is noticed. The maize starch binder addition shows a decrease from 500 gcm^{-2} to about 300 gcm^{-2} whenit starts to rise from about 40% starch addition.

The shatter index increases for all the three sourced starch binders additions and they all get to their respective peaks of 550, 500 and 530 at 40% starch binders addition for cassava, rice and maize respectively. The effect of this is that cassava is a better binder in terms of shatter index and dry compression strength.

4. CONCLUSION

From the results obtained, it was observed that permeability, compatibility, GCS,GSS nd DCS are directly proportional the amount of starch in the sand mix. Out of the three sourced starch binder additions,cassava possessed better binding properties than rice and maize. The maximum green compressive, green shear and dry compressive strengths were obtained at 40% cassava starch addition.

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