Journal of Physical Science, Vol. 25(1), 113–122, 2014

Influence of Cement-Silica Ratio on the Moulding Properties of Portland Cement Bonded Sand

Ibitoye Simeon Ademola, Olawale John Oluyemi* and Shittu Moshood Dehinde

Department of Materials Science and Engineering,
Obafemi Awolowo University, 220005 Ile-Ife, Osun State, Nigeria

*Corresponding author: jooolawale@yahoo.com

Abstract: *Experimental investigations were carried out to determine the influence of cement-silica ratio on the moulding properties of Portland cement bonded sand. Test specimens, comprising silica sand and additives, namely wood flour and dextrin, as well as molasses, with varying cement to silica sand ratio (R_{CS}), were prepared. The specimens were subjected to tests in accordance with American Foundrymen's Society (AFS) standard procedure to determine properties such as bulk density, mould hardness, permeability, compression strength and shear strength. Findings revealed that R_{CS} and additives have significant effects on all properties developed in the moulding sand. As R_{CS} increases, the bulk density, mould hardness, green compression strength and shear strength increases while permeability and shatter index decreases. However, R_{CS} of 0.105 gives suitable properties for moulding work meant for iron castings.*

Keywords: Portland cement, silica sand, permeability, bulk density, mould hardness, shatter index

1. INTRODUCTION

Moulding sand is one of the materials used particularly in metal foundries for making moulds and cores. Despite its name, moulding sand is not sand alone but a composite material made from several other materials to give some amount of heat resistance, porosity, strength and binding qualities necessary to create moulds and cores.

The refractoriness of the moulding sand must be high to resist high temperature of the molten metal without breaking down or fuse with metal.[1] It must be permeable to allow the steam and other gases to pass through the sand mould. The permeability of sand depends upon its grain size, grain shape, moisture and clay contents of the moulding sand.[2,3] If the sand is too fine, the porosity will be low. In moist state, the green sand particles must have the ability to cling to each other to impart sufficient strength to the mould. The moulding sand must have enough strength so that the constructed mould retains its shape. It must have sufficient plasticity to flow to all portions of the moulding box and to produce a good mould. The sand grain must possess good adhesiveness and cohesiveness in order to cling to the sides of the moulding box and stick together during ramming.[4]

Moulding sands are composite materials made of mixtures of three or more ingredients. One of the primary components of moulding sand is base sand. Most often this is fine grain sand such as silica or zircon. Silica sand has the benefit of being both inexpensive and readily available. In his study, Orumwense found out that synthetic moulding sand mixtures prepared from some Nigeria indigenous sands and clays are suitable for steel and general-purpose casting.[5] Additives such as sea coal, coal dust, wood flour, silica flour and iron oxide are another constituent of moulding sand. Adedayo et al. have also successfully used snail shell to improve the properties of moulding sand.[6] Additives control the expansion of sand, improve its collapsibility and flowability, and enhance stripping quality and surface finishing of the mould.[7–9]

A binding agent is another component of moulding sand. Appropriate binders include organic binders (dextrin, molasses, cereal, linseed oil and resin) and inorganic binders (clay, Portland cement and sodium silicate). The clay binders have a high capacity for water absorption and exceptionally favourable bonding characteristics. Cereal and dextrin binders develop a gelatinous bond with water,[10] and they are normally employed in conjunction with other binders such as clay-bonded moulding sands and in traditional oil and resin bonded sand. Oil binders are traditionally core binder. Sodium silicate (gas and vapour hardening) binders are extensively used for rapid volume production of cores. Resin bonding systems have good breakdown properties, and can be readily reclaimed. Ademoh et al. also recommended the use of gum Arabic as a binder in moulding sand.[11] Cement bonded silica sand have been found to be strong, rigid and refractory. They have been proved highly suitable for the production of heavy steel castings as well as other alloys.[12]

Several studies have been conducted on moulding sand, binders and additives which have been widely reported in literatures. However, the influence of cement-silica ratio on the moulding properties of Portland cement bonded silica sand has not been investigated, hence this study. The objective of the study therefore is to assess the effect of cement to silica sand ratio on the moulding properties of cement-bonded silica sand using molasses and dextrin separately as additives.

2. EXPERIMENTAL

The materials used in this study are silica sand, Portland cement, dextrin, molasses and woodflour which were all locally sourced. Some quantity of silica sand (obtained from Osun River band) was washed, dried and sieved through 0.01 mm sieve aperture to remove coarser materials. The woodflour was sieved through the same sieve aperture.

The prepared silica sand and Portland cement were thoroughly mixed in different ratio with 2 wt% wood flour and 4 wt% dextrin on one hand, and 4 wt% of molasses on the other hand. Six experimental mixes in which Portland cement to silica sand ratio (R_{CS}) were 0.075, 0.09, 0.105, 0.120, 0.135 and 0.150 respectively were prepared. The choice of these proportions of Portland cement and silica was based on the result of the trial test which showed better moulding properties within the range. Thereafter, 5% water was added to each mix and thoroughly mixed for about 15 min using laboratory muller. In accordance with AFS standard procedure, cylindrical specimens (5 cm by 5 cm by 5 cm) were produced from each mix.[13] Thereafter, with the use of universal testing machine, the specimens were tested for compression strength, shear strengths and mould hardness. Their permeability, shatter index and bulk density were also measured using the AFS standard procedures.

3. RESULTS AND DISCUSSION

3.1 Results

The results of the bulk density are presented in Figure 1. There is an observed rapid increase in the bulk density of mixes containing dextrin while that of molasses increased very slightly with increase in R_{CS}. The results of the hardness is presented in Figure 2 in which there is a very slight increase as the R_{CS} increases for mixes containing dextrin while those with molasses increases rapidly.

The permeability and shatter index results are presented in Figure 3 and Figure 4 respectively in which former decreases rapid and the later slightly decreases as R_{CS} increases for sand mixes containing the two additives. The results of compression strength are presented in Figure 5. There is an observed increase in the compression strength with increase in R_{CS} for mixes containing either dextrin or molasses. The results of the shear strength are presented in Figure 6 and are similar to that of the compression strength for each of the mixes containing dextrin and molasses.

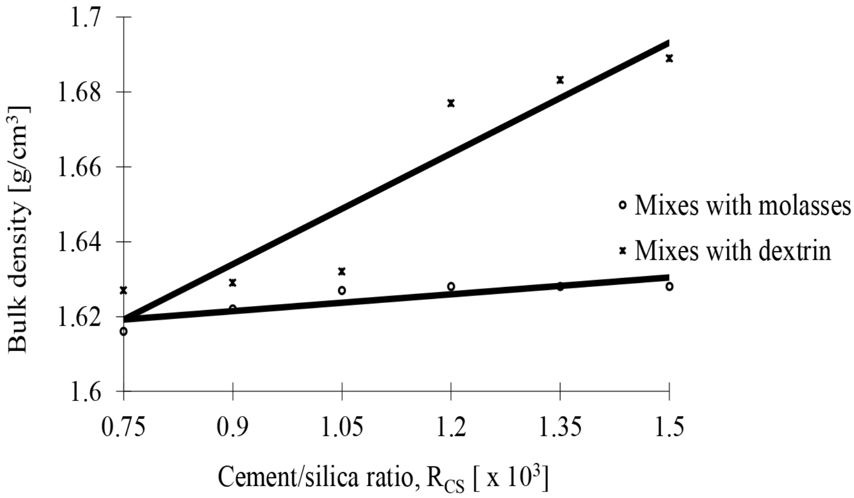


Figure 1: Changes in the bulk density with increasing cement/silica ratio, R_{CS}.

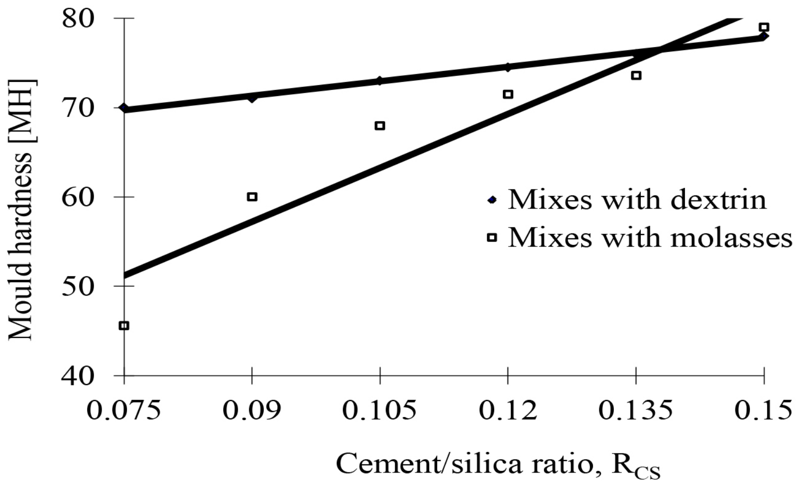


Figure 2: Changes in mold hardness with increasing cement/silica ratio, R_{CS}.

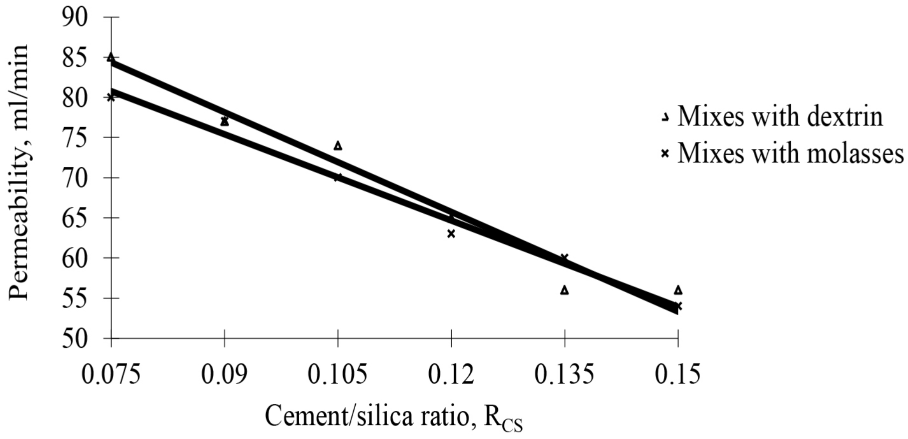


Figure 3: The changes in permeability with increasing R_{CS}.

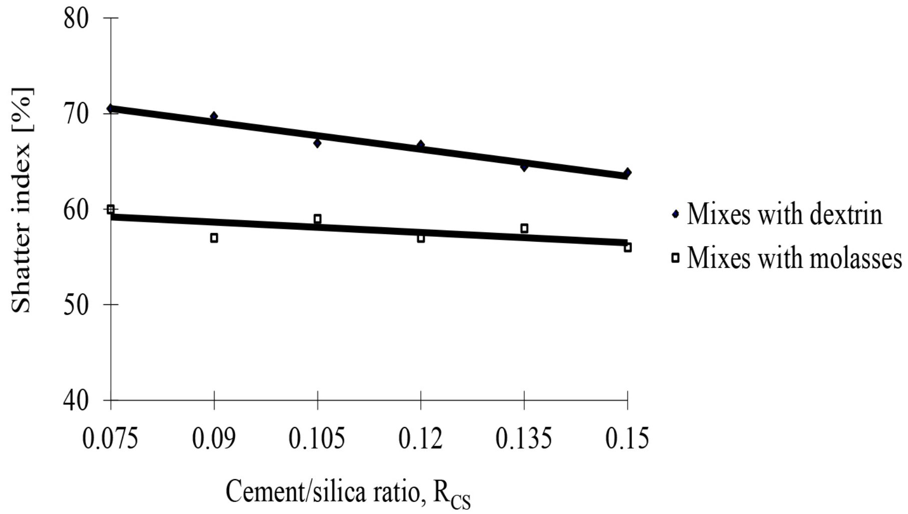


Figure 4: Shatter index versus R_{CS} for different additives.

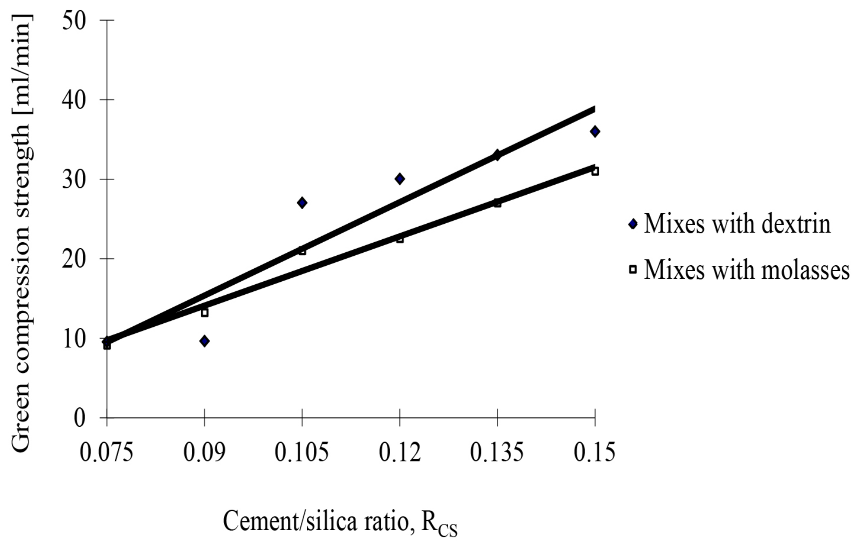


Figure 5: The green compression strength profile with increasing R_{CS}.

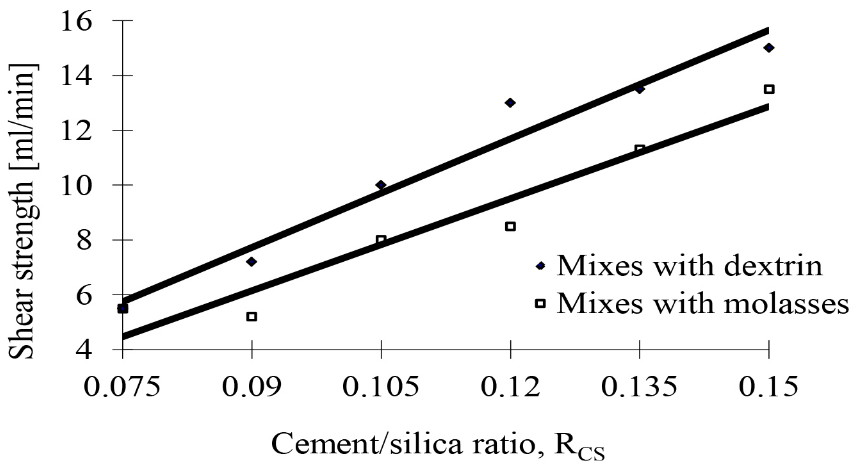
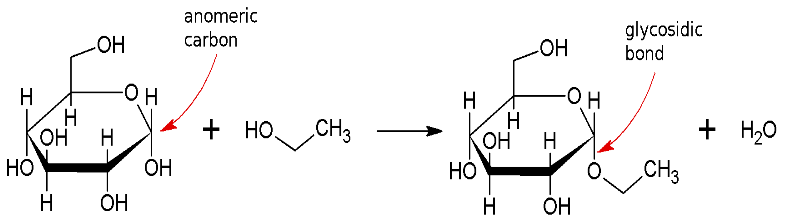


Figure 6: The shear strength profile with increasing R_{CS}.

3.2 Discussion

As noted earlier, the bulk density increases as the R_{CS} increases in the sand mix (Figure 1). This is particularly true bearing in mind that an increase in R_{CS} increases the ratio of binder in the sand mix. For this reason, more silica sand will be held firmly together within a unit volume. This implies that the quantity of sand mass within a unit volume increases as the Rcs increases. The general increase in the bulk density with R_{CS} is observed to vary with the type of additive used.

When dextrin is used as an additive, the increase in the bulk density increases very rapidly as the R_{CS} rises. The rapid increment can be attributed to glycosidic bond. Dextrins are a group of low-molecular-weight carbohydrates produced by the hydrolysis of starch or glycogen. They are mixtures of polymers of D-glucose units linked by α-(1→4) or α-(1→6) glycosidic bonds. Glucose and ethanol combine to form ethyl glucoside and water. The reaction often favours formation of α glycosidic bond as shown in Equation 1 due to the anomeric effect. This is a type of covalent bond and it is very strong.



(1)

The hardness of the mould was affected by R_{CS}, i.e., as this ratio increases the mould hardness also increases (Figure 2). It was also observed that the mould hardness with molasses additives increases rapidly as against dextrin which was gradual, although for each of the ratio the mix with molasses has the lowest hardness until after R_{CS} 0.135. This is because dextrin as a binder influences the bonding properties of the mix more than molasses.

Dextrin develops a gelatinous bond with water which is higher than binding strength produced by molasses. The increase in the molasses mix is rapid because as the ratio of R_{CS} increases, the quantity of cement in the mix also increases and in the presence of molasses hardening action increases. This continues until an R_{CS} of 0.135 is reached where the hardening action set-up by cement-molasses ratio in the presence of CO_2 is higher than binding strength produced by dextrin. This is because cement contains a limited amount of calcium sulphate which controls the hardening action of cement in the presence of molasses and CO_2, and as calcium sulphate increases the mix becomes hardened.

On the other hand, permeability and shatter index decreases with increases in Rcs (Figure 3 and Figure 4). Permeability is the physical property of the moulded mass of sand mixture, which permits the flow of air/gas through it. It depends on the amount of binder. Thus, as the amount of binder increases, the quantity of air/gas flow through the moulded mass mixture decreases under standard condition and in prescribed time. Consequently, the observed decrease in permeability as R_{CS} increases.

Shatter index is a measure of sand toughness, particularly the capacity of sand to withstand rough handling and strain during pattern withdrawal. A low value of shatter index is an indication of poor lift, or friability in pattern withdrawal and subsequent handling, whilst too high a value is associated with unsatisfactory moulding qualities resulting from excessive binder or water content. According to Beeley, values of 50–85 represent the mouldable range.[14] The values of shatter index obtained for mixes with dextrin (64–70.5) and mixes with molasses (57–60) meet this standard in the range of R_{CS} considered.

Like bulk density and mould hardness, the green compression strength and shear strength increases with R_{CS} (Figure 5 and Figure 6). This observed trend can be explained by the increase in the quantity of binder (cement) as R_{CS} increases. The sand mixes with dextrin are also higher than the one mixes with molasses. This is because dextrin developed higher binding strength as discussed earlier. Hence, green compression strength and shear strength are related to mould hardness. There is a progressive increase in green compressive strength with mould hardness.[4,5] However, the green compressive at a given mould hardness depends on the additives in the sand mix. The molasses mix been always have the least values for a given R_{CS}.

The properties enumerated above are crucial to the production of sound and dimensionally accurate castings. The sand must have a high degree of permeability without interfering with the rigidity and strength of the mould. According to Jain, the green compression strength for iron castings must be between 40 kgf mm^{-2} and 70 kgf mm^{-2} while permeability must be between 70 ml min^{-1} and 120 ml min^{-1}.[3] The mould hardness requirement for iron casting is between 60 and 95.[7] The strength, hardness, permeability and shatter index suitable for moulding work for iron castings are obtained when R_{CS} ratio attains the value of 0.105 with mould hardness value between 60 and 90, green compression strength above 40 kgf mm^{-2}, permeability above 70 ml min^{-1}, and shatter index value between 50 and 85.

4. CONCLUSION

From the outcome of this study the following conclusion were drawn:

1) Developed moulding properties in Portland cement-bonded silica sand are influenced by R_{CS}. The best values of bulk density, green compression strength, shear strength and shatter index are exhibited when dextrin is used as an additive for a given R_{CS}.
2) Highest mould hardness and permeability are obtained in Portland cement-bonded silica sand when cement-silica sand ratio attains the value of 0.135 (R_{CS} = 0.135) using dextrin as additive and cement-silica sand ratio greater than 0.135 (R_{CS} > 0.135) using molasses.
3) Portland cement-bonded silica sand with cement-silica sand ratio of 0.105 is found to be suitable for iron castings.

5. ACKNOWLEDGEMENT

Nigerian Machine Tools Limited Osogbo, Nigeria is acknowledged for making its facilities available in the course of this study.

6. REFERENCES

1. Solenicki, G., Budie, I. & Ciglar, D. (2010). Determination of thermal conductivity in foundry mould mixtures. *METABK*, 49(1), 3–7.
2. Aweda, J. O. & Jimoh, Y. A. (2009). Assessment of properties of natural moulding sands in Ilorin and Ilesha, Nigeria. *USEP J. Res. Inf. Civil Eng.*, 6(2), 68–77.
3. Jain, P. L. (1995). *Principles of foundry technology*, 3rd ed. New Delhi: Tata McGraw Hill Publishing.
4. Burns, T. A. (1986). *The Fosesco Foundryman's handbook*, 9th ed. Oxford: Pergamon Press.
5. Orumwense, F. F. O. (2002). Moulding properties of synthetic sand mixtures a comparative study. *Scand. J. Metall.*, 3(2), 100–106.
6. Adedayo, A. V. O. et al. (2011). Effects of snail shell and iron filings on properties of green moulding sand. *South Pac. J. Nat. Sci.*, 28(1), 58–62.
7. Hein, R. W., Loper, C. R. & Rosenthal, P. C. (1976). *Principle of metal castings*. New York: McGraw-Hill.
8. Ibitoye, S. A. (2007). Effect of bulk density variation on the compression strength of clay-sodium silicate bonded moulding sand. *J. Sci. Technol.*, 27(3), 141–148.

9. Ibitoye, S. A. (2005). Effect of the addition of sodium silicate and bulk density variation on the permeability of potter's clay-bonded moulding sand. *NSE Tech. Trans.*, 40(2), 67–77.
10. Ibitoye, S. A. & Afonja, A. A. (1996). Effect of starch addition on the bulk density, baked hardness and collapsibility of potter's clay-bonded coresand. *Ife J. Technol.*, 6(1), 35–42.
11. Ademoh, N. A. & Abdullahi, A. T. (2009). Assessment of foundry properties of steel casting sand moulds bonded with the grade 4 Nigerian acacia species (Gum Arabic). *Int. J. Phys. Sci.*, 4(4), 238–241.
12. Wiscers, P. F. (1980). *Steel casting handbook*, 6th ed. New York: Steel Founders' Society of America.
13. American Foundrymen's Society. (1963). *Foundry sand handbook*, 7th ed. New York: American Foundrymen's Society.
14. Beeley, P. (2001). *Foundry technology*. Oxford: Butterworth-Heinemann Publishing Co.