ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 17, NO. 7(2016)
PAGES 887-898

RICE HUSK AS A CONCRETE CONSTITUENT: WORKABILITY, WATER ABSORPTION AND STRENGTH OF THE CONCRETE

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Received: 20 November 2015; **Accepted:** 15 February 2016

ABSTRACT

In an attempt to reduce the cost of concrete production, efforts are being made to utilize part of the waste generated during rice production. This research work investigates the effects of partially replacing sand with rice husk on the structural properties of fresh and hardened concrete. Laboratory tests to determine the workability, air content, compressive strength and water absorption properties of the concrete, with varying proportion of rice husk as partial replacement of the fine aggregate, were conducted. The workability of the concrete was improved as its rice husk content increased. The unit weight and compressive strength of the concrete decreased with increasing rice husk content while the concrete specimens absorbed more water and have increased air content with increasing rice husk content. The use of not more than 12.5% rice husk, as replacement of sand, was recommended for producing concrete that will be used for load-bearing applications.

Keywords: Agricultural building; lightweight concrete; low-cost concrete; rice husk; rice hull; waste management.

1. INTRODUCTION

Rice is one of the major food crops in the world. In 2013, global production of unmilled rice was about 741 million metric tonnes [1] while that for milled rice was about 470.2 million metric tonnes [2]. The production of rice leaves rice husk (also called rice hull) as a waste and from these statistics, it can be deduced that a large quantity of rice husk is usually generated from rice production. Majority of rice husks are discarded as waste. Rice husk is a source of concern to rice farmer / producers [3]. In other to minimize the nuisance caused by rice husks, some farmers resort to gathering and burning them in open air, which itself is an environment-

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unfriendly approach. Researchers have been concerned with finding profitable use of this enormous waste. The use of untreated or modified rice husk for the removal of heavy metals such as cadmium, copper and lead has been reviewed by Chuah et al. [4] and Ngah and Hanafiah [5]. Givi et al. [6], Ganesan et al. [7] and de Sensale [8] utilized rice husk ash as a pozzolanic (supplementary cementitious) material in concrete. The conversion of rice husk, via pyrolysis, to bio-fuel has been reported by Ji-lu [9], Lu et al. [10] and Tsai et al. [11].

Research works that have investigated the use of rice husk, in its original form and not in the form of ash, as an admixture to the typical ingredients used in producing plain concrete are rare. Sisman et al. [12] evaluated the possibility of using cement, rice husk and natural zeolite for producing lightweight concrete.

The purpose of this study is to investigate the effect of the partial replacement of sand with rice husk on the workability, air content, unit weight, water absorption and compressive strength of the resulting concrete. The workability of fresh concrete gives an idea of the frictional behaviour of the concrete from the time it is mixed to the time it is compacted. It has four major components viz: the ability of the concrete to be mixed, transported, moulded and compacted. Among other factors, the size, surface texture, shape and grading of the aggregates in the concrete influence its workability. Slump, which is determined by carrying out slump test on freshly-mixed concrete, is a measure of the workability of the concrete.

The most common strength test performed on hardened concrete is compressive strength test. It is a major structural design requirement that indicates the capacity of a concrete structure to withstand compressive load. It is also a measure of the durability of concrete [13]. One of the major factors that influence the durability of concrete is its porosity. Air content and water absorption tests on concrete provide additional measure of its durability.

The constituents of rice husk are cellulose (25–35%), hemicelluloses (18–21%), lignin (26–31%), silica (15–17%), soluble (2–5%), and moisture (<7.5%) [14–16]. According to Ngah and Hanafiah [5], rice husk is insoluble in water, has good chemical stability, has high mechanical strength and possesses a granular structure. Consequently, this research work seems attractive because of its potential to rid rice farms of the environmental nuisance associated with rice husk disposal.

2. MATERIALS AND METHODS

2.1 Materials and preparation

The rice husk used in this study was collected from a farm in Ota, Nigeria. It was washed with potable water in order to remove dirts from it and it was subsequently air-dried for 7 days to ensure that it is dry. The particles of rice husk used are finer than the sieve with 4.75 mm openings. It is fibrous in nature (Fig. 1) and its surface has bump-like protrusions (Fig. 2), which are more evident when viewed at microscopic level.

For the preparation of the plain concrete, ordinary Portland cement (ASTM Type I) that was obtained commercially was used. River sand having its particles size ranging from 0.075 to 4.75 mm and crushed granite having a maximum size of 20 mm; were utilized for production of the concrete used for this research work. Potable water was used for both mixing and curing of the concrete.

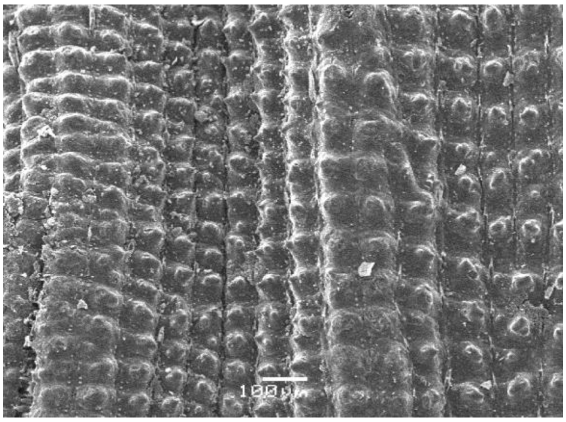

Figure 1. Typical SEM of rice husk [17]

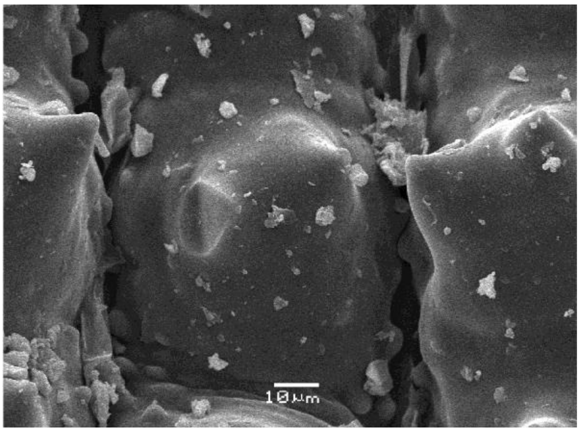

Figure 2. Typical SEM of the surface of rice husk showing protuberances [17]

2.2 Experimental work

The particle size distributions of the sand, granite and rice husk were determined by sieve analysis method. The initial and final setting times of the cement used were determined using Vicat apparatus. The ingredients for the concrete were batched by volume, since this method is more commonly used in rural communities. The concrete was batched using a ratio of 1:2:4 (cement:sand:granite) and a water-cement ratio of 0.5. Rice husk was used to partially replace sand by the following proportions: 0%, 12.5%, 25%, 37.5% and 50%. The produced concrete batches were mixed using a tilting drum mixer for 3 minutes. Slump test and pressure method apparatus were used to determine the workability and air content of the various batches of concrete, respectively. The slump and air content tests were in accordance with ASTM C143 [18] and ASTM C231 [19], respectively. Concrete cubes of 150 x 150 x 150 mm^3 were cast using steel moulds and they were removed from the moulds after 24 hours. They were labelled appropriately; with respect to the percentages by which sand was replaced with rice husk and their scheduled dates for compressive strength determination. The cubes were subsequently cured by being completely immersed in potable water, using curing tanks within the enclosure of the laboratory, for the entire period of curing [20]. Compressive strengths at ages 7, 14 and 28 days were determined for each of the batches of varying proportion of rice husk in the concrete. The compressive strengths of three concrete cubes and their average were determined for each of the curing periods and for each of the percentages of rice husk replacement of sand in the concrete. The compressive strength of concrete cubes was determined in compliance with BSI [21], using YES-2000 digital display compression machine.

Water absorption test was conducted by saturating concrete cube specimens by immersion in potable water for 24 hours. The concrete cube specimens were allowed to drain for a minute before wiping off visible surface water using a damp cloth. The saturated specimen were then oven-dried at a temperature of 105°C for not less than 24 hours but until a constant dry mass is obtained [22]. The water absorption was calculated using the following expression:

$$absorption\ (\%) = \frac{M_s - M_d}{M_s}\ x\ 100 \quad (1)$$

where M_s and M_d are the mass of the saturated and dry concrete cube specimens, respectively.

3. RESULTS AND DISCUSSION

3.1 Properties of concrete ingredients

The results of the sieve analysis carried out on the sand, granite and rice husk used in this study are presented in form of the particle size distribution curves (Fig. 3). The pattern of the particle size distribution curve for the rice husk is similar to that for sand. Consequently, rice husk can be rightly investigated as a partial replacement for sand in the production of concrete.

The initial and final setting times of the ordinary Portland cement used are 67 minutes and 173 minutes, respectively. The specific gravities of the sand, granite and rice husk are 2.65, 2.71 and 2.17, respectively.

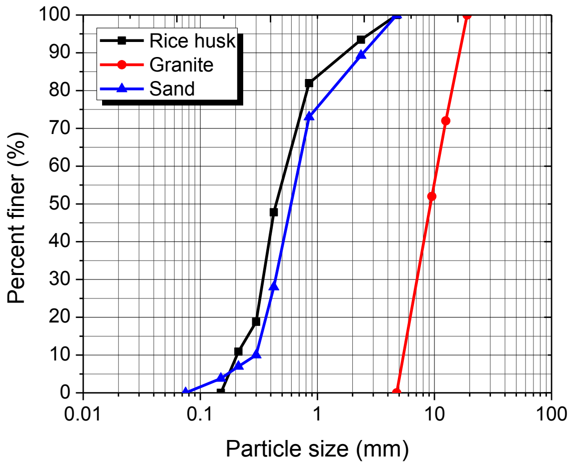

Figure 3. Particle size distribution curves for the rice husk and aggregates used

3.2 Properties of the fresh concrete

Aside the solid component, concrete is also composed of air voids and these air voids influence its properties. The variation of the air content in the fresh concrete with the rice husk content is graphically shown in Fig. 4.

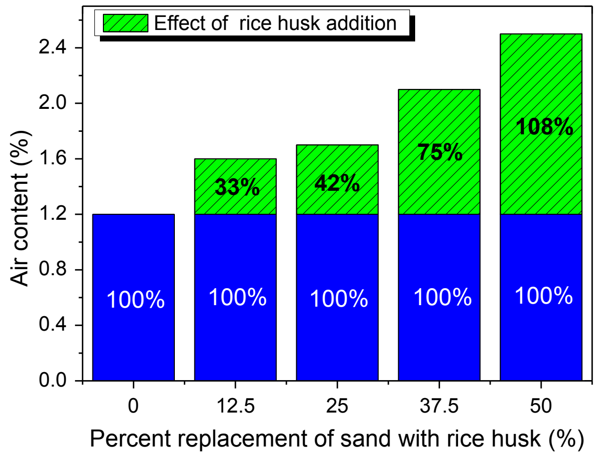

Figure 4. Variation of air content with rice husk content

The air content in the concrete increased with increasing percent replacement of sand with rice husk. This increase is strongly correlated, r = 0.986. After replacing 50% of the sand in the normal concrete with rice husk, the air content of the resulting concrete increased by 108% (Fig. 4). It is suspected that the protuberances at the surface of the rice husk (Fig. 2) are responsible for the increasing air content.

Slump of concrete is a measure of the workability of the concrete. The variation of the slump of the concrete with the rice husk content is presented in Fig. 5.

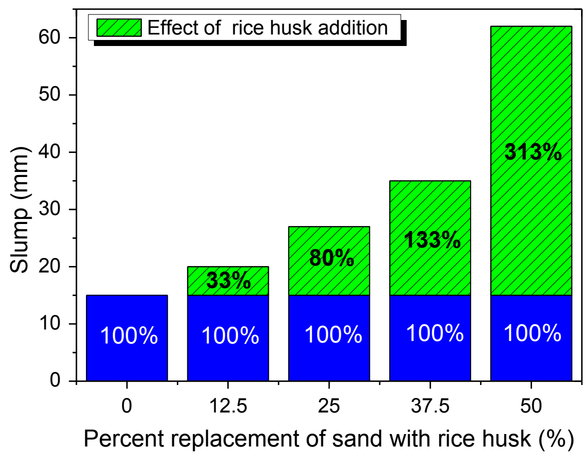

Figure 5. Variation of concrete slump with rice husk content

The slump increased with increasing percent replacement of sand with rice husk. This implies that the concrete becomes more workable with increasing percent replacement of sand with rice husk. The increase in slump with increasing percent of rice husk in the concrete is strongly correlated, r = 0.932. After replacing 50% of the sand in the normal concrete with rice husk, the slump of the resulting concrete increased by 313% (Fig. 5). The protuberances at the surfaces of the rice husks (Fig. 2) must have resulted in the introduction of, or increase in, microscopic air bubbles in the concrete during concrete mixing. In a manner similar to the use of air entraining agent in concrete, microscopic air bubbles are known to increase the slump of concrete, thereby improving its workability [13]. Considering the recommended slump for various types of construction by ACI [23], increasing percent substitution of sand with rice husk made the concrete better suited for roads, mass concrete, foundation, reinforced concrete column, beam and slab applications.

3.3 Properties of the hardened concrete

The change in the unit weight of the concrete with percent replacement of sand with rice husk is shown in Fig. 6. From Figs. 6(a) and 6(b), it can be seen that as the percent replacement of sand with rice husk in the concrete cube specimens cured for periods of 7 and 28 days increases, their unit weights decreases.

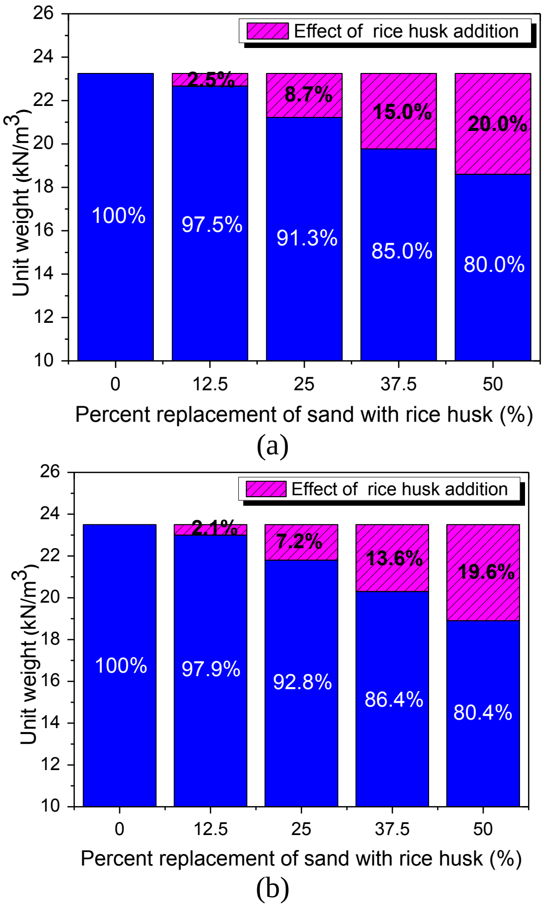

Figure 6. Variation of unit weight of (a) 7 days and (b) 28 days cured concrete with rice husk content

These decreases in the unit weight of 7 days and 28 days cured concrete are strongly correlated, r = −0.992 and r = −0.987, respectively. After replacing 50% of the sand in the normal concrete with rice husk, the unit weight of the resulting concrete decreased by about 20% (Fig. 6). The decrease in the unit weight was expected because the rice husk has a relatively lower specific gravity (2.17), when compared with that of the sand used (2.65). Partial replacement of sand with rice husk in concrete therefore produces a concrete with lighter weight relative to that of the control mix (the concrete cube specimen without rice husk). Consequently, the self-weight of a building constructed with concrete having rice husk as partial substitute for sand will be reduced.

The absorption of water by the concrete varied with the percent substitution of sand with rice husk. This variation is graphically illustrated in Fig. 7.

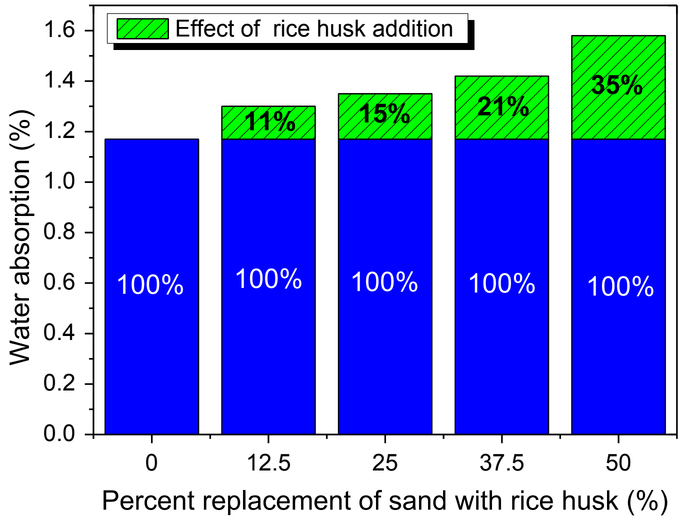

Figure 7. Variation of water absorption of the concrete with rice husk content

Fig. 7 shows that the water absorption by the concrete cube specimens increased with increasing percent substitution of sand with rice husk. This increase is strongly correlated, r = 0.982. After replacing 50% of the sand in the normal concrete with rice husk, the water absorption of the resulting concrete increased by 35% (Fig. 7). Water absorption by concrete is a measure of the concrete's total reachable pore volume; higher water absorption implies a higher porosity [22]. This result is in contrast with that obtained for rice husk ash, which has a lower water absorption with increasing rice husk ash content in concrete [24]. This difference may be due to the lower particle sizes of rice husk ash, which is pozzolanic and may serve as partial substitute to cement.

The variation of compressive strength of the concrete specimen for 7, 14 and 28 days curing periods with the percent substitution of sand with rice husk is presented in Fig. 8.

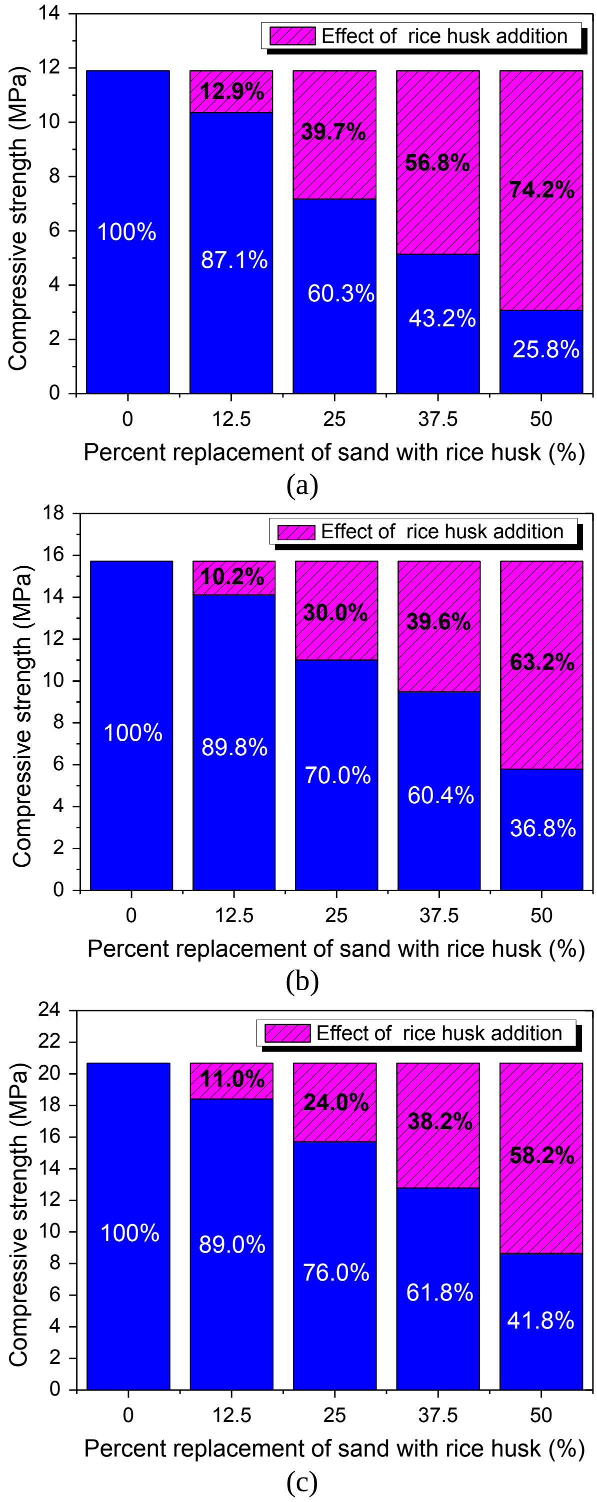

Figure 8. Variation of (a) 7 days (b) 14 days and (c) 28 days compressive strength with rice husk content

Figs. 8(a), 8(b) and 8(c) show that as the percent replacement of sand with rice husk increases, the compressive strength of the concrete decreases. The decrease in the compressive strength of the 28 days cured concrete is strongly correlated, r = −0.993. After replacing 50% of the sand in the normal concrete with rice husk, the compressive strength of the resulting concrete decreased by about 58.2% (Fig. 8(c)). This was expected since it was earlier established that higher water absorption implies a higher porosity. A higher porosity and air content usually result to a lower compressive strength [13, 25]. These relationships can also be confirmed from the graphical illustrations of the water absorption and air content (Fig. 9) and that of water absorption and compressive strength of the 28 days cured concrete (Fig. 10).

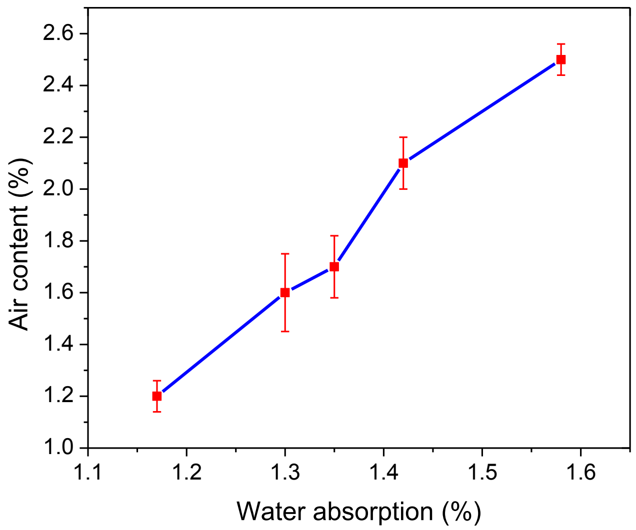

Figure 9. Relation of water absorption of the concrete with air content

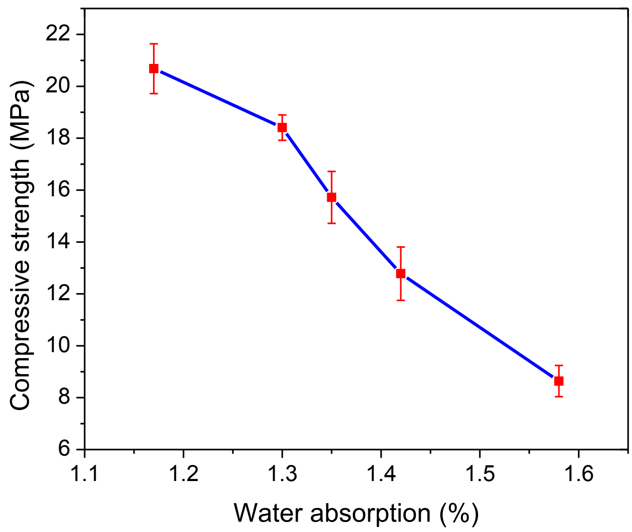

Figure 10. Relation of water absorption of the concrete with compressive strength

The decrease in compressive strength of the concrete as the water absorption increased is in agreement with Zhang and Zong [26]. The use of more than 12.5% sand substitution with rice husk during the production of concrete for load-bearing applications is not recommended, in order to ensure the development of appreciable compressive strength that can withstand at least 15 MPa. Also, this value of compressive strength should be used while producing the structural design for the various structural elements of the concrete structure.

4. CONCLUSIONS

Notably, the partial substitution of sand with rice husk in the production of concrete led to: (i) an increase in the slump and air content of the fresh concrete, thereby improving its workability; (ii) a reduction in the unit weight of the hardened concrete, thereby reducing its self-weight; (iii) an increase in the water absorption capacity of the concrete; and (iv) a reduction in the compressive strength of the concrete.

These findings are important, especially, when the concrete is used for farm and rural building construction works. This application has the potential to rid rice farms and their environs of the nuisance associated with indiscriminate rice husk disposal, while also lowering the cost and weight of concrete produced for construction works. In the nearest future, natural sand will become costlier and even depleted. Engineers and Builders may then resort to total or partial substitution of sand for concrete production.

Finally, the replacement of more than 12.5% sand, during concrete production for load-bearing farm structures, with rice husk is not recommended. This limit ensures that the compressive strength of 1:2:4 concrete due to the addition of rice husk is not below 15 MPa. Consequently, Structural Design Engineers should use this value while designing the structural elements of structures that will be constructed using concrete admixed with the recommended percentage of rice husk.

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