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USE OF RICE HUSK IN CONCRETE: REVIEW OF MECHANICAL PROPERTIES

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Abstract

Recently, there has been huge interest in the use of supplementary cementitious materials (SCMs) as a partial replacement for ordinary Portland cement (OPC) in concrete. This urge to replace OPC is due to the high carbon dioxide emitted into the environment during its production. Rice husk ash (RHA) is one of the types of SCM that can be used to replace OPC in concrete, and it is the waste product of rice production. This paper presents a detailed and recent review of the mechanical properties reported by various studies. It was concluded that with the right proportion of RHA incorporated into concrete, enhanced mechanical properties can be achieved. In addition, the use of RHA in concrete reduces the overall embodied carbon of the concrete, while reducing cost and utilizing waste generated by the agricultural industry.

1. Introduction

Concrete is the most consumed building material in the world, and the second most used material after water. As billions of tons of concrete are produced annually, a correspondingly large amount of materials is being consumed. And the concrete industry has been ascribed to the industry that consumed the highest amount of natural resources. Apart from the depletion of these natural resources, the production of ordinary Portland cement (OPC) which is the main binder in concrete is one of the major contributors to the world's human-induced carbon dioxide. And more carbon emission from OPC production is expected due to the exponential increase in the demand for concrete/cement predicted for coming years. Therefore, there is an urgent need for the concrete industry to find to reduce or replace the amount of natural resources including OPC used in concrete.

Several ways such as partial to total replacement of OPC, use of waste materials as aggregate in concrete, use of wastewater, etc., have been explored over the years. One of the major ways to reduce the embodied carbon of concrete is by partial replacement of OPC with supplementary cementitious materials. SCMs are mostly waste materials that possess pozzolanic and hydraulic properties. SCMs such as fly ash, slag, silica fume, metakaolin, rice husk ash (RHA), etc., have been used as a partial replacement over the decades. Use of SCMs in concrete also creates an avenue to manage these waste, thereby preventing any negative impact that could be made on the environment as a result of their disposal. These SCMs have varying effects on the fresh and hardened properties of concrete, and proper selection of type and OPC replacement level has been reported to be the most effective way to incorporate these waste materials into concrete.

RHA which is a type of SCM and an agricultural waste has been found to enhance both mechanical and durability properties of concrete. RHA is a preferred SCM compared to that of fly ash and silica fume due to its high reactivity and silica content. The high reactivity of RHA is associated with its large surface area and high amount of amorphous silica [1,2]. Incorporation of RHA as SCM into concrete has been reported to create a less permeable matrix and induce high early strength. However, in order to incorporate RHA into concrete, it must meet the requirements of ASTM C618 [3]. ASTM C618 requirements stated that the loss of ignition (LOI) of the RHA must not be 12% maximum, and the summed composition of aluminum dioxide, iron oxide, and silicon dioxide must not exceed 70%.

To foster more research and utilization of RHA as a partial replacement for OPC in concrete, this paper gathers the results of several studies on the application of RHA in concrete. The main objective of this paper is to explore the effect of incorporation of RHA into concrete, focusing on its effect on the major mechanical properties of concrete. It is anticipated that this review will serve as a guidebook for several researchers working on making the construction industry more sustainable in terms of building materials. This review will also be a propeller for more research and development in the use of RHA in concrete.

2. Sources and processing of rice husk ash

RHA is a waste product from the agricultural industry. RHA is obtained by burning of rice husk at elevated temperatures. The type of RHA produced is dependent on the time and temperature of burning. Also, the chemical and physical properties of the produced RHA is determined by the climate of the region where the rice was grown, the composition of the soil, and type of paddy [4]. Multhadhi et al. [5] and Maeda et al [6] also found out that the type of fertilizer used might affect the produced RHA. Silica content in RHA is in the range of 85% to 95%, however the silica content in the rice husk before burning is about 20% by weight of the rice husk. About one-fourth by mass of RHA is produced with every quantity of rice husk combusted, and rice husk is about one-fifth the amount of rice paddy milled.

3. Mechanical properties

3.1 Compressive strength

Compressive strength of concrete is the major mechanical properties of concrete, and all other mechanical properties are related to it. Earlier studies showed that concrete with no RHA has been reported to have higher compressive strength than those with RHA at replacement levels from 20 to 30% [7]. Concrete incorporating no SCM and those with silica fume (SF) as 10% replacement of OPC have reported a higher compressive strength compared to those incorporating RHA at the same replacement level [8]. However, Wada et al. [9] reported a contradicting result indicating concrete incorporating RHA has a higher compressive strength compared to those without RHA. Higher compressive strength up to 91 days was also reported by De Sensale [10]. He also concluded that a 20% replacement level of OPC with RHA produced the highest compressive strength. The study by Habeeb and Mahmud [11] also supported that the maximum OPC replacement level with RHA as 20%, as there might be detrimental effects on the properties of concrete after this replacement level. Replacement level of OPC with RHA less than 5% has been found to be insufficient to improve the early age compressive strength of [11]. This has been attributed to the low amount of silica available in the pore structure to react with the calcium hydroxide, thereby producing less amount of calcium silicate hydrate. However, at later ages; concrete with 5% replacement level of OPC with RHA was found to have compressive strength compared to the control without RHA. Habeeb and Mahmud [11] concluded from their study that the optimum OPC replacement level with RHA is 10% as there's reduction in compressive strength below and above this level at later ages. The decrease in compressive strength at levels above 10% was ascribed to excess silica available to react with the produced calcium hydroxide in the cementitious matrix. The unreacted silica will be left in the matrix has a stable material and will not contribute to any chemical reaction. However, at 20% replacement level of OPC with RHA, the compressive strength achieved was similar to that of OPC. The effect of replacement level of OPC with RHA on the compressive strength of concrete is presented in **Fig. 1.** It will be observed from **Fig. 1** that the compressive strength of all mixes increases with age. However, replacement level of 10% has the highest compressive strength at all ages. Kartini [12] also suggested the optimum replacement level of OPC with RHA to be 10% as a decrease in compressive strength was observed when the amount of RHA increased.

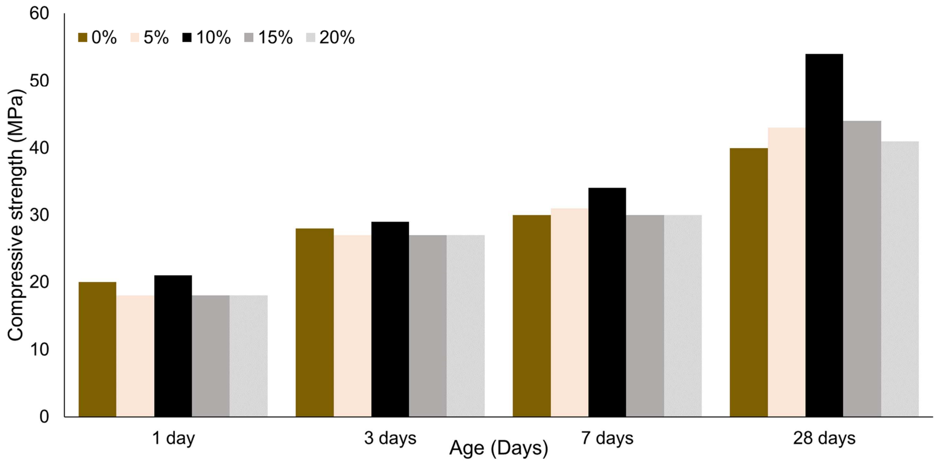

Fig. 1. Effect of RHA replacement levels and age on compressive strength (data from [11])

Though for all particle size of RHA, a similar higher compressive strength was reported at early ages. However, at later ages; concrete with finer particle size exhibited higher strength [11]. This higher strength has been reported to be as a result of an increase in fineness which increased the reactivity of the RHA, thereby producing more products (i.e. calcium silicate hydrate) when reacted with the calcium hydroxide in the concrete's pore solution. Production of more reaction products leads to densification of the concrete matrix, directly increasing the strength of the concrete. Also, increase in strength associated with concrete with finer RHA can be as a result of the RHA acting as a micro-filler, thereby improving the cement microstructure. Earlier studies by Ismail and Walliuddin [13] on high strength concrete also observed similar results when finer RHA was used as a partial replacement for OPC.

3.2 Split tensile strength

Concrete is strong in compression but weak in tension. However, enhancing the tensile strength of concrete is essential in applications where the load will pose a tensile force on the concrete element. The tensile strength of concrete is determined using the split tensile test. Higher split tensile strength has been reported for incorporation of RHA as a partial replacement of OPC in concrete [10]. The higher tensile strength has been ascribed to the pozzolanic and filler effect of RHA. Ramezanianpour et al. [14] also reported an increase in tensile strength with use of RHA as a partial replacement for OPC. The spilt tensile strength of concrete incorporating RHA was found to increase up to 20% OPC replacement level. **Fig. 2** shows the effect of the size of RHA particles on the split tensile and flexural strength of concrete. It will be observed that there's a reduction in the tensile strength with increasing replacement level of OPC with RHA. Foong et al. [15] and Le et al. [16] showed an increase in split tensile strength to 15% RHA. Khassaf et al. [17] also reported an increase in tensile strength to 10% RHA. Ganesan et al [18] observed an increase in split tensile strength up to 20% replacement of OPC with RHA. However, the split tensile strength at 30% was found to be similar to that of concrete without RHA [18] Water to cement ratio was also stated to play a significant role in the split tensile strength of concrete incorporating RHA as partial replacement of OPC [17].

3.3 Flexural strength

Flexural strength which can also be referred to as modulus of rupture is the ability of a concrete to resist deformation as a result of bending. Flexural strength of concrete with RHA as partial replacement of OPC was found to correlate to that of its split tensile strength. Talsania et al. [19] reported an increase in flexural strength to 20% OPC replacement level with RHA. However, another study by Vinothan and Baskar [20] showed an increase in flexural strength only to 10% replacement level of OPC with RHA. Khan et al. (2012) reported a lower flexural strength in concrete incorporating RHA as partial replacement of OPC. And with an increase in the percentage of RHA, the deflection at midspan of the concrete decreases (Khan et al., 2012). Zhang et al 2009) reported an enhancement in the flexural strength of concrete when RHA is used as partial replacement of OPC. This enhancement has been attributed to both pozzolanic and filler properties of RHA. Also, from **Fig. 2,** it can be concluded that the flexural strength of concrete increases with a decrease in RHA particle size.

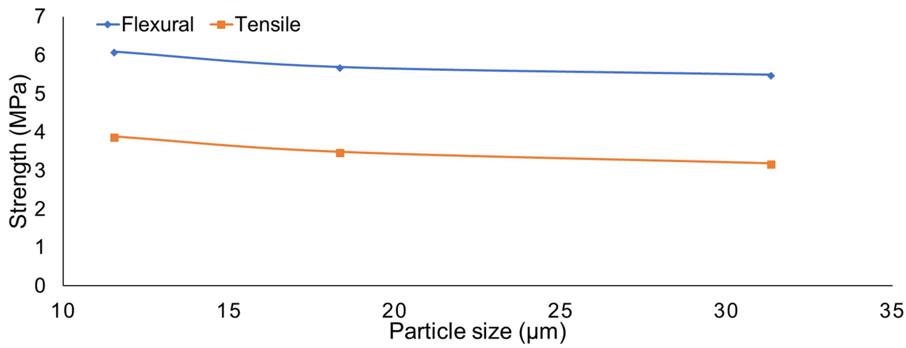

Fig. 2. Effect of RHA particle size on tensile and flexural strength at 180 days (data from [11])

3.4 Modulus of elasticity

Modulus of elasticity of concrete indicates its ability to resist elastic deformations. Concrete incorporating RHA as a partial replacement for OPC have exhibited a higher modulus of elasticity (MOE) compared to those without RHA [14]. The MOE increases with increase in RHA replacement level and age as shown in **Fig. 3.** This was also in agreement with the study by Foong et al [15] where they observed an increase in MOE with an increase in replacement level of OPC with RHA. The increase in MOE with the incorporation of RHA as partial replacement of OPC as been ascribe to the RHA particles being able to fill the pores in the matrix effectively due to their fineness. Filling of the pores leads to more refinement of the interfacial transitional zone between the aggregate and the binder matrix.

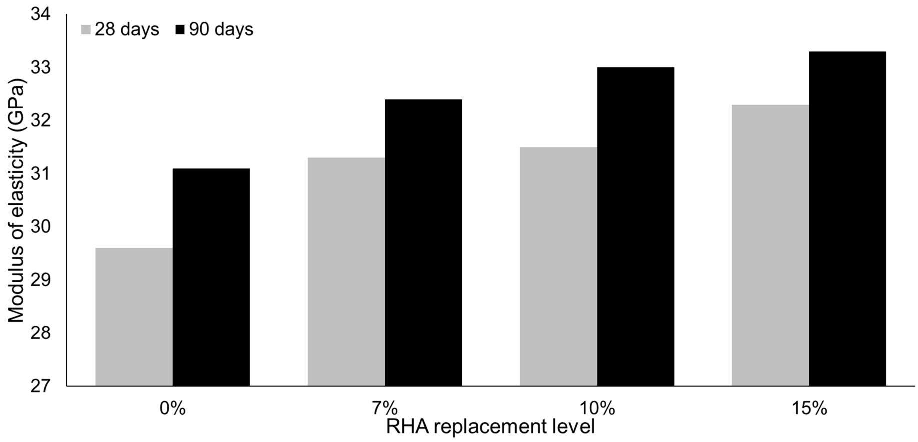

Fig. 3. Effect of RHA replacement level and age on the modulus of elasticity (data from [14])

4. Conclusion

Based on this overview, the following conclusion can be made about the use of RHA in concrete.

- Replacement of OPC with RHA in concrete enhances both its early and late mechanical strength. However, a replacement level of 10% is suggested. Enhanced mechanical strength due to use of RHA as a partial replacement for OPC is as a result of its pozzolanic and filler effects.
- Use of RHA in concrete creates an avenue to manage RHA in a sustainable and effective way. Also, a reduction in cost and carbon dioxide emission can be achieved, as OPC is the highest contributor to cost and carbon emission in concrete. In addition, high cement savings can be achieved through the use of RHA as a replacement for OPC.
- A need for more research on other mechanical properties (i.e. shear and bending strength) is necessary to better understand the overall mechanical behaviour of concrete incorporating RHA as a replacement for OPC

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