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Research Article

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Experimental Study on the Partial Replacement of Nano Zirconia and Rice Husk Ash in Mortar

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Abstract

This paper investigates the effect of using zirconia (ZrO_2) powder and rice husk ash (RHA) as a partial replacement for cement and sand, on mechanical properties and water absorption of mortar. The rice manufacturing industry produces a large amount of RHA waste, which is an ecologically beneficial pozzolanic substance and low-cost. Cement mortar is mixed with a 1:3 cement/sand ratio, with nano zirconia as a replacement for cement in different content (1%, 2%, 3%, 4%, and 5% by the weight of cement) and RHA as a replacement for fine aggregate in various amounts (10%, 20%, 30%, 40%, 50%, 60%, and 70% by the weight of fine aggregate). The mechanical properties and water absorption tests were done after curing for 7, and 28 days. The replacement, of cement with zirconia at 3% has a strength of 35.8 MPa, and 45.7 MPa, and sand with RHA at 50% has a strength of 22.64 MPa, and 36.78 MPa at 7, and 28 days, respectively, showed a better effect on mechanical properties than the other sample. The result revealed replacement of combined zirconia and RHA has shown better properties on the mechanical characteristics of mortar. The highest compressive and tensile strength value in 28 days is 46.61 MPa and 4.87 MPa for replacement mortar.

Keywords

Zirconia, Rice husk ash, Compressive and tensile strength, Water absorption, Scanning electron microscope

Introduction

Mortar mostly consists of sand, water, and cement. Ordinary Portland cement (OPC) plays a main character like the binder in mortar. Mortar with sand or cement replacement of mineral and fine particles is known as modified mortar [1]. Mortar is a main factor used in construction, at this time requirement for mortar is very high or increases in construction sites because the world population increasing day by day and increasing the construction of schools, residential buildings, office buildings, etc. [2]. Cement manufacturers produce around 7.5% of global greenhouse gas emissions and production of global greenhouse gas emissions is rising by the day, Cement demand is high on construction sites across the world [3]. River sand is an important resource as a filler in the production of tiles, glass, mortar, ceramics, concrete, and other products [4]. Globally, the building industry utilizes around 40% of river sand, equal to approximately 10 billion tons per year [5]. Overuse of river sand has a serious effect on the ecosystem, economy, and society [6]. Zirconia is a nonreactive ceramic material that has many varieties of uses due to its exceptional mixture of mechanical properties and physical, chemicals, including high strength, high chemical stability, and resistance to corrosion by acid, salt water, etc. This has been shown by the finding that increasing the percentage of zirconia reduces the workability of the mortar [7]. Rice mills process large amounts of rice husk is an agro waste. It has been used by several nations, primarily Sri Lanka, as a significant biomass source to produce fuel and energy source for the creation of electricity [8]. In the past 20 years, Sri Lanka has increased its yearly rice production to almost 4.6 million metric tons, producing 0.89 million tons of waste rice husk waste. Normally, rice husks are discarded in free spaces, damaging water, and using a large amount of land while doing little good for the environment. The most popular method of getting rid of rice husks is open burning, which generates a lot of RHA waste in rural areas and causes air pollution, heart disease, and airborne disease. This RHA waste management cannot be regarded as an entirely clean production. As a result, the aim of this study was to partially replace cement with zirconia and sand with RHA, and investigate the effects such as mechanical strength, and water absorption.

Materials and Method

Materials

Cement

In the current study (OPC) 43 grade was used and bought from JK super cement (Table 1). Company of Kharar Punjab follows ASTM C150 standards should be presented.

Fine aggregate/sand

Fine aggregate is easily available in Kharar River sand with particles passing through a 4.75 mm sieve.

Nano zirconia powder

Nano zirconia with a size of 30 - 50 nm was acquired from Nano Research Lab, Jamshedpur, Jharkhand (India) as received, it has been used (Table 2 and table 3).

RHA

Rice husk should be burned at 600 to 700 °C in the furnace for a minimum of 2 h to form RHA. The specific gravity of RHA is 2.14 (Table 4).

Mix design - mortar preparation

Mortar is mixed with a 1:3 cement/sand ratio. The mortar was a mixture of cement, river sand, zirconia powder, RHA, and water. Firstly, sand and RHA are mixed properly for a few minutes again cement and zirconia powder are added and then are mixed all together for a few minutes. It is levelling and then water is added and again mixed properly for 3 - 5 min to form mortar. The prepared mortar is collected by trowel and wet mortar is filled in the molds (cube and briquette), compacting of mortar was done by using a vibrating machine and levelling by trowel. On the next day of casting, all the molds will be removed from the mortar and put inside the water for curing. All the samples are curing for 7, and 28 days as required (Figure 1).

Experimental work

Compressive test

Compressive strength tests were performed on the cube mortar sample. The compressive strength must be calculated by taking three cubic samples on average at 7, and 28 days after curing.

Table 1: Properties of OPC cement.

Material	Cement (%)
Al_2O_3	5.2
MgO	6.51
CaO	53.41
Fe_2O_3	3.62
SiO_2	21.76
K_2O	0.96
SO_3	3.8
Na_2O	0.17
Loss on ignition	3.27

Table 2: Physical properties of zirconia powder.

Name of product	Nano zirconia powder
Purity	99.55
Color	White
Specific surface	40 - 45 m^2/g
Ture density	5.89 g/cm^3
Atomic weight	123.218 g/mol
Melting point	2715 °C
Boiling point	4300 °C

Table 3: Chemical properties of zirconia powder.

ZrO_2	Al	Fe	Pb
99.5%	<0.06%	<0.02%	<0.02%

Table 4: RHA properties.

Al_2O_3	0.21
SiO_2	89.7
Fe_2O_3	0.11
SO_3	0.85
CaO	2.21
Na_2O	0.81

Tensile test

Tensile strength tests were performed on mortar briquette test specimens. The tensile strength of mortar must be calculated by taking an average of six briquette samples at 7, 14, and 28 days.

Water absorption

The water absorption of cement mortar was tested in accordance with ASTM C642-13. Weighing the cubes was used for calculating water absorption. Three cubes of cement mortar were tested for water absorption after 28 days of curing. (Step 1) All the sample was 24 h oven-dried at 100 - 105 °C. (Step 2) All the sample was submerged inside the water tank for 24 h. Measuring all the sample weights for both steps 1 and 2. The below calculation is applied to find the water absorption. In this calculation, the mass value was taking an average of three cubes for each mix design.

$$Water\ absorption(\%) = \frac{D_2 - D_1}{D_1} \text{ x } 100 \qquad (1)$$

Figure 1: **(a)** Mixing, **(b)** Casting, **(c)** Curing, and **(d)** Tensile strength.

Where D_1 = weight of the mortar in oven dries for 24 h and D_2 = weight of the mortar that was submerged in water for 24 h.

Density test

The mortar cubes were removed from the water container after curing. A weighing balance was used to determine each cube's weight to calculate the density of the mortar cube. The density test of each cube was calculated using this equation.

$$\text{Density } (\rho)=\frac{\text{mass of mortar cube}}{\text{volume of mortar cube}}(\text{Kg/m}^3) \quad (2)$$

Microscope analysis

After the 28-day curing and the mechanical test was finished, SEM (Scanning electron microscope) test was conducted to examine the internal structure of the breaking mortar sample. This test is conducted at SEM Laboratory University Center for Research & Development (UCRD), Chandigarh University (India).

Results and Discussion

Compressive strength test

Figure 2 shows finding the optimum compressive strength for the presence of zirconia in the mortar with different percentages. The results of samples obtained after curing at 7, and 28 days were examined. It was found that zirconia mortar increases compressive strength up to 3% replacement. The compressive strength decreases after 3% of zirconia replacements. The 3% replacement has an optimum level for zirconia.

Figure 3 shows finding the optimum compressive strength for the presence of RHA in the mortar with different percentages. RHA mortar is found to increase strength up to 50% replacement. After 50% RHA replacements, the compressive strength decreases. The 50% replacement has an optimum level of RHA. As a result, the higher percent of RHA replacement in mortar is increasing the water required in the mortar. Moreover, the large specific surface area of RHA reduces workability as the replacement level rises. while more water was required to maintain workability.

Figure 4 shows the comparing compressive strength of normal mortar and combine replacement at the optimum lev-

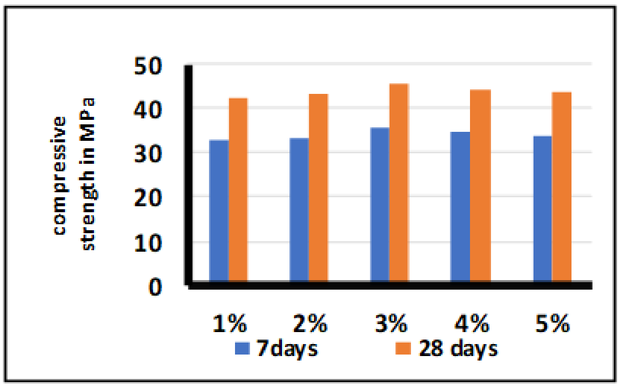

Figure 2: Compressive strength of zirconia.

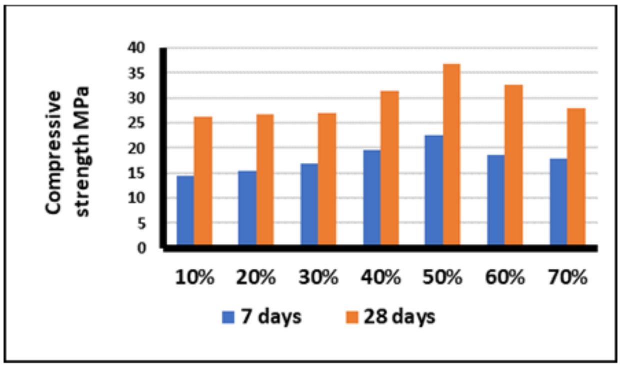

Figure 3: Compressive strength of RHA.

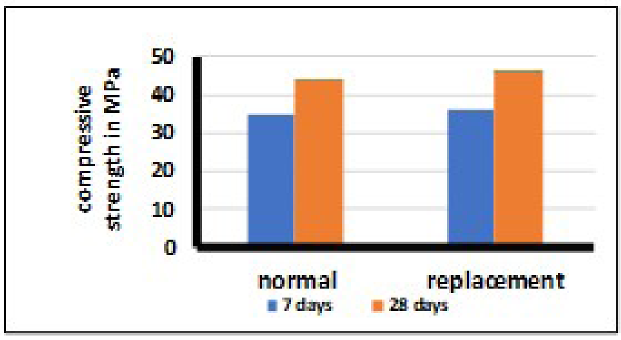

Figure 4: Compressive strength of normal and replacement mortar.

el of zirconia 3% and RHA 50% mortar for 7, and 28 days. The replacement mortar has higher compressive strength as compared to the normal mortar sample.

Tensile strength test

Figure 5 shows the result of tensile strength for normal mortar and replacement with combined zirconia nanoparticles and RHA in cement and sand in mortar for 7, and 28 days. The replacement mortar of zirconia and RHA at their optimum level (3% and 50%) respectively. The tensile strength of replacement mortar has higher strength as compared to normal mortar sample.

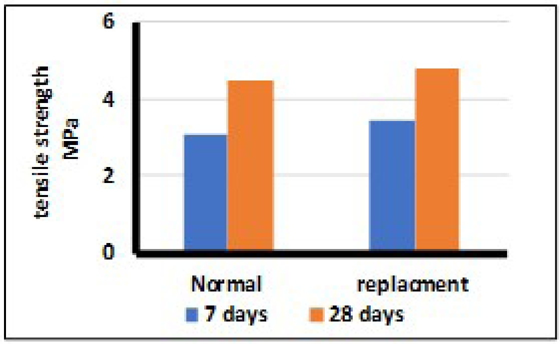

Figure 5: Tensile strength of normal and replacement mortar.

Water absorption

The results of water absorption were shown in figure 6 for normal mortar and combined replacement mortar at the optimum level of zirconia 3% and RHA 50% for 28 days. Figure 6 shows the water absorption in % of the normal mortar and replacement mortar. Replacement mortar has a higher water absorption rate than the normal mortar sample, since RHA is present in the replacement mortar. RHA has a high tendency for water absorption.

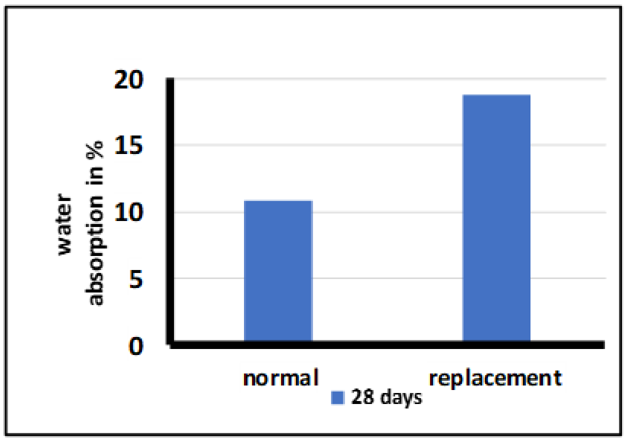

Figure 6: Water absorption of normal and replacement mortar.

Density test

Density test results were shown in figure 7 for normal mortar, combined zirconia nanoparticles, and RHA replacement of cement and sand in mortar, for 28 days. Figure 7 shows the density of mortar in % of the normal mortar and replacement mortar. The normal mortar sample has higher density than replacement mortar.

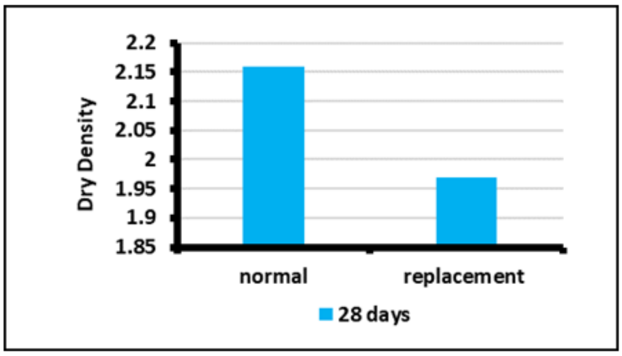

Figure 7: Density of normal and replacement mortar.

SEM analysis

SEM analysis of mortars such as replacement of RHA, zirconia, and combinations of (RHA and zirconia) have been performed for the highest-strength mortar sample. The picture showed the equivalent micrograph of the surface at various magnifications of 200x - 2000x, with oscillations of roughly 10 - 100 µm visible. To conduct the analysis, the sample has been coated with gold coating (construction materials are non-conductivity), which provides improved image clearance during analysis.

In figure 8, the SEM analysis consists of RHA x2000 (Figure 8a), zirconia x2000 (Figure 8b), and combined optimum strength for both zirconia and RHA with a magnification of x2000 (Figure 8c). Figure 8a shows the microstructure of RHA mortar with the magnification of x2000. There are a number of voids or holds that are formation during the cement hydration process. The number of crystals is observed clearly inside the microstructure of mortar, they are rectangular shape, tube like structure and crystals are formation layer by layer.

Figure 8b shows the microstructure of zirconia mortar with the magnification of x2000, the least number of voids (holes) produced during cement hydration. It can be seen in the image that the crystal dispersed between the specimen and the area with interlaced crystals is in the form of a little needle matching the crystal. The crystals are formation of layer by layer in irregular shape structure.

Figure 8c shows the microstructure of combined RHA and zirconia mortar with the magnification of x2000, there are no voids (holes) produce during cement hydration, it was more compact, compared to other mortar. There are many large size crystals that are formation in difference shapes in same surface and very small rectangular shape crystals are present inside combined mortar.

Conclusions

The use of RHA as a replacement for sand in mortar gives benefits to our environment as the agricultural waste is reduced, and minimizes the use of river sand, therefore economical to the construction site. While the use of nano zirconia

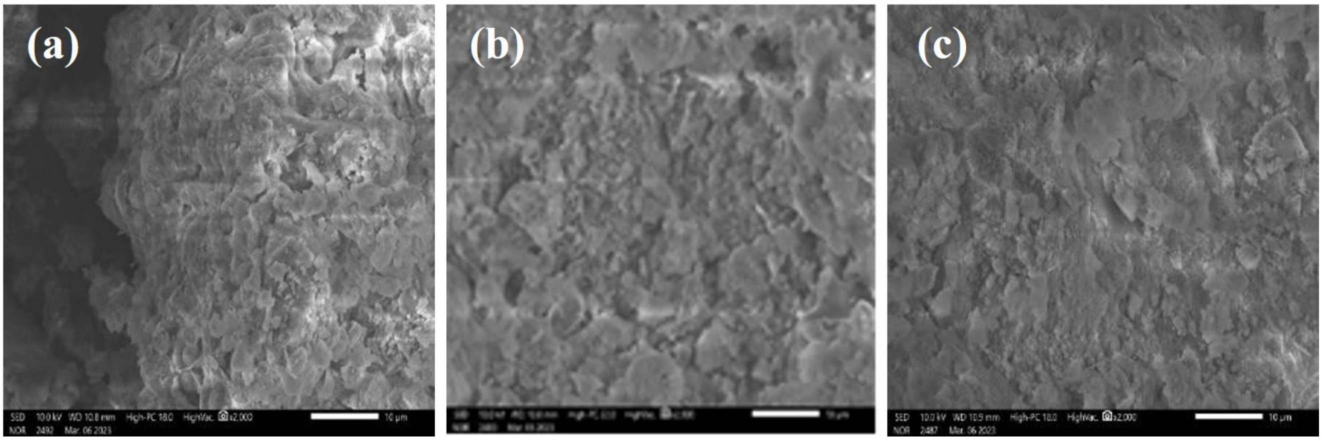

Figure 8: SEM images: **(a)** x2000RHA, **(b)** x2000 Zirconia, and **(c)** Combine x2000.

powder is a non-reactive ceramic material that has a vast range of uses on account of improved mechanical and physical characteristics, including as high strength and chemical stability, and resistance to corrosion by acid, salt water, etc. This study's conclusion is as follows:

- The replacement of cement with 3% zirconia powder gets the highest strength at 28 days as compared to the other percentage of zirconia. And for the replacement of sand with 50% RHA had more strength as compared to the other percentage of RHA at 28 days.
- While comparing the mechanical characteristics of normal mortar and combined (3% zirconia and 50% RHA) replacement mortar, it is found that combined replacement mortar has higher compressive and tensile strength for 7, and 28 days than normal mortar.
- For water absorption of normal and combined replacement mortar, the combined mortar has higher absorption properties than normal mortar.
- The normal mortar sample has a higher density than replacement mortar. The density of sand is higher than the density of RHA.

Acknowledgements

None.

Conflict of Interest

None.

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