Study on Properties of High Strength Concrete Using Silica Fume and Rice Husk Ash

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Abstract. This study focuses on the various strength and durability performance of high-strength concrete (HSC) combining different low-carbon and high-silica content percentages of Rice Husk Ash (RHA) and Silica fume (SF). RHA with proportions of 5%, 10%, 15% and 20% and 10% SF by weight of cement was compared with control mix containing 100% Portland cement. The specimens viz., cubes, cylinders and prisms were cast and tested to determine the optimum percentage of RHA to produce ternary blended concrete with enhanced performance of concrete properties. Based on the test results ternary blended concrete mix showed enhanced strength and durability performance than control mix. Micro structural characterization was studied for different mix using scanning electron microscope (SEM).

Keywords: Rice husk ash · Silica fume · Strength properties · Durability

1 Introduction

The rapid expansion of construction operations has resulted in a scarcity of traditional building materials. To make cement more sustainable, a suitable replacement must be found. Rice husk ash (RHA), an agricultural by-product that is a good pozzolanic material, is one of these materials. It can be used in place of cement in some cases. RHA is a highly reactive pozzolanic material made by burning rice husks at temperatures below 700 °C in a regulated manner. RHA can be used as an alternative cementitious material because it contains amorphous silica. SF, an industrial by product frequently used in concrete as a pozzolan, is also included in this ternary cement mortar. It improves the strength, abrasion resistance, and permeability of the material (higher corrosion resistance). Das et al. (2018) presents the benefits of adding strength-enhancing elements like SF and RHA to Geopolymer and OPC-based concrete are described in this review, along with essential comparisons from other research investigations throughout the world. Mak et al. (1995) presented the findings of a study comparing the strength improvement of HSC with and without SF when exposed to high in-situ temperatures. The results of this study reveal that heating a high-strength SF concrete in situ to 70 °C greatly enhanced its 7-day strength. Although there was no evidence of strength regression after one year, strength of SF concrete that was subjected to high early temperatures was much lower than that of concrete that was cured at normal temperatures. The rapid stabilization of

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non-evaporable water content and the subsequent reduction in concrete humidity owing to self-desiccation are both compatible with SFHSC strength development. Huang et al. (2017) studied the influence of RHA on the strength and permeability of ultrahigh-performance concrete (UHPC). The results reveal that substituting RHA for SF reduces the fluidity of the fresh UHPC mixture and entraps more air bubbles, while the refined pore structure improves the compressive strength (CS) and permeability of UHPC. Mahmud et al. (2016) RHA with high silica, low carbon content, and acceptable fineness was used to investigate the strength and durability features of HSHPC. In this research, concrete with 10%, 15%, and 20% RHA as a cement replacement with w/b ratio of 0.25 was explored. The findings also suggest that maximum of 20% RHA addition was beneficially blended with cement without compromising the performance properties of concrete. The usage of RHA has a number of technical advantages, including cost savings and a reduction in CO_2 emissions due to reduced cement consumption. The usage of partial replacements or by-products as supplementary pozzolanic materials, according to Zareei et al. (2017); was largely influenced by air pollution control regulations imposed on the cement industry. The findings of the tests revealed a good connection between 15% RHA replacement and a 20% improvement in CS. The ideal level of strength and durability attributes is normally gained with an increase of up to 20%, with a minor fall in strength parameters of about 4.5% after that. The same results are expected to be unfavorable for water absorption ratios. In comparison to starting values, chloride ions penetration increased by roughly 25% as cement replacement increased (about less than one fifth). The mixes containing 25% RHA minimised the rate of water absorption, with 4.8% at 7 days and 3% after 28 days of curing, respectively. Padhi et al. (2018) looked at how rice husk ash and coarse recycled concrete aggregates (RCA) affected the characteristics of concrete. Because of the inclusion of 15% RHA and 100% RCA in concrete mixes, the CS and split tensile strength (STS) were improved at 28 days of curing. The qualities of a ternary cement mortar incorporating RHA and waste glass powder (WG) were examined by Younes et al. (2018). The results showed that the RHA content rises, the CS values rise and water absorption percentage decreases until 5% RHA due to less pores in the mix. Sakr (2006) studied the properties of heavy weight aggregate concrete with RHA and SF and the results revealed that concrete mix with RHA performs well in mechanical and physical qualities than concrete mix. The aim of the current study is to find the optimum quantity of RHA (5%, 10%, 15% and 20%) on ternary blended concrete to enhance the strength and durability characteristics and the results have been compared with the control mix.

2 Experimental Programme

2.1 Cement

Ordinary Portland Cement (OPC) with a specific gravity (SG) of 3.15 was used. Fine aggregates passing through 4.75 mm and retaining on 150 mhu are taken. The SG and fineness modulus of river sand are 2.38 and 2.3. Aggregates passing through 20 mm sieve and retaining on 10 mm sieve is used as coarse aggregate. The SG and fineness modulus of coarse aggregates are 2.7 and 5.25. Cement replacement material (CRM) RHA and SF are shown in Fig. 1 and 2 and the chemical properties are shown in Table 1.

SG of RHA and SF are 2.25 and 2.26 respectively. In this study, superplasticizer named Tech Mix 550 was used.

Fig. 1. RHA.

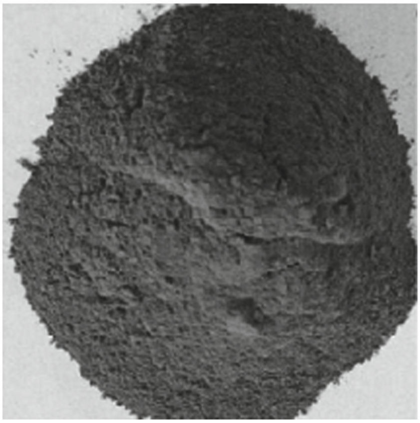

Fig. 2. SF.

Table 1. Chemical properties RHA and SF

Formula	RHA (%)	SF (%)
SiO_2	89.18	97.48
P_2O_5	3.32	0.07
Al_2O_5	2.42	0.73
K_2O	1.80	0.30
MgO	1.65	0.53
CaO	1.14	0.11
Fe_2O_3	0.46	0.15
SO_3	0.41	0.51
Na_2O	0.27	0.06
TiO_2	0.08	0.01

2.2 Details of Mix and Cast Specimens

The mix design was done as per IS 10262 2019 to achieve a characteristic CS of 60 MPa. Table 2 shows the mix proportions of concrete incorporating RHA and SF. The water cement ratio of 0.28−0.32 was considered in this study to maintain the medium workability. The OPC was replaced with different percentages of RHA and 10% Silica Fume (SF). Ternary blended concrete with partial replacement of cement by RHA in proportions of 5%, 10%, 15%, 20% and 10% SF by cement weight. The optimum percentage of RHA was determined based on the different properties of ternary blend concrete. Specimens such as Cubes (100 mm × 100 mm × 100 mm) for CS, acid and sulphate resistance, cylinders (100 mm diameter × 200 mm long) for STS, prisms (500 × 100 × 100 mm) for flexural strength (FS) and cylinders (50 mm × 100 mm) for sorptivity, water absorption and porosity were cast and tested for different properties.

Table 2. Mix proportions

Mix proportion	W/B	SP (%)	Cement (kg/m^3)	RHA (kg/m^3)	SF (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)
Control	0.28	1.5	560	–	–	603	1043
5%RHA + 10% SF (M1)	0.28	2	500.01	19.9	40.05	603	1043
10%RHA + 10% SF (M2)	0.29	2	480.08	39.87	40.05	603	1043
15%RHA + 10%SF (M3)	0.3	2	460.14	59.81	40.05	603	1043
20%RHA + 10%SF (M4)	0.32	2	440.2	79.75	40.05	603	1043

@ Mass of CRM = [Replacement % of RHA and SF/100] *[SG of RHA and SF/SG of Cement].

3 Results and Discussion

3.1 Compressive Strength (CS)

Figure 3 shows the CS results of various mixes at 7 and 28 days. The results show that highest CS was obtained for 5% RHA and 10% SF replacement in ternary blended concrete. From the results we infer that concrete containing RHA and SF attained high strength in early age than CM after that strength seems to be decreasing. The increase in CS is due to the pozzolanic reaction and the presence of reactive silica in RHA. The reduction in CS is because of presence of more silica content which cannot react with calcium hydroxide during reaction time.

3.2 Split Tensile Strength (STS)

The STS of different mix was calculated for 28 days of curing. Figure 4 shows the strength of various mix and percentage increase. The strength obtained for CM, M1, M2, M3 and M4 were 5.45, 6.34, 6.08, 5.76, 5.63 MPa. The percentage increase in strength was 16.33%, 11.56%, 5.7%, 3.3% when compared to CM.

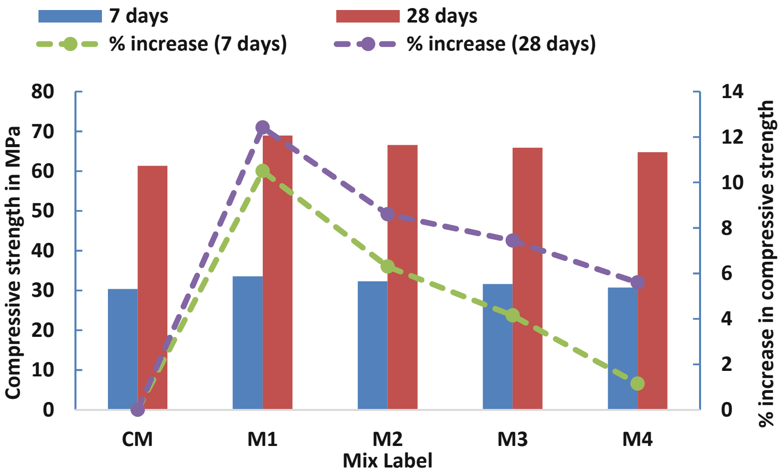

Fig. 3. Compressive strength results for 7 and 28 days.

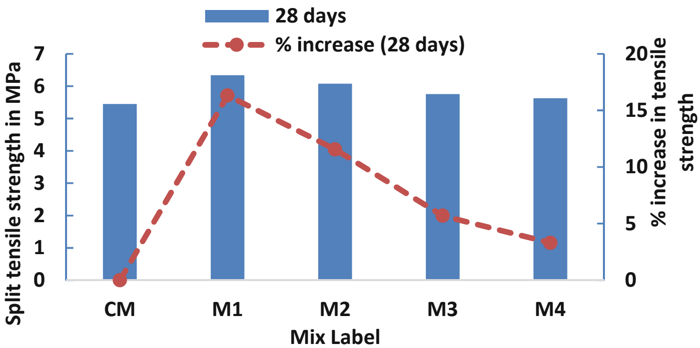

Fig. 4. Split tensile strength results.

3.3 Flexural Strength (FS)

FS was shown in Fig. 5. It shows that modulus of rupture for control concrete is 5.89 MPa. For 5% RHA and 10% SF concrete the modulus of rupture is 7.43 MPa which is higher than control concrete. The strength seems to be decreasing after 5% RHA replacement. The result obtained was similar to that of CS results.

3.4 Sorptivity Test

Sorptivity test was performed as per ASTM 1585, where all sides of the specimen except the side exposing to water was sealed with tape to ensure the flow is one-directional only. The water was present for 3 mm deep which was absorbed by the specimen by capillary suction. Weight was noted at regular time intervals. The cylinder of size 50 mm × 100 mm. The quantity of water absorbed in various time periods was measured. The obtained

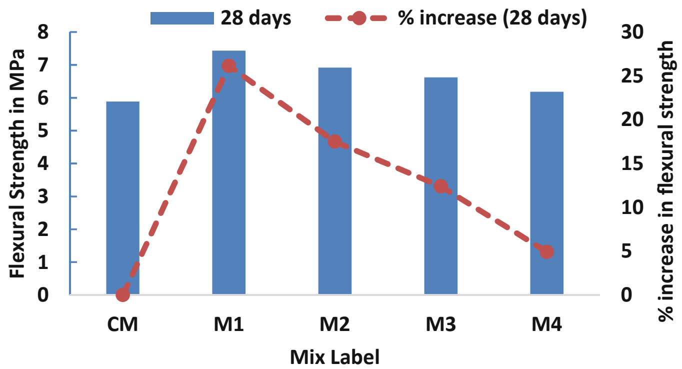

Fig. 5. Flexural strength results.

values of sorptivity test were plotted for square root of t vs I to determine the coefficient of sorption was shown in Fig. 6. Hence sorption coefficient was high for control concrete than other concrete mix which implies that strength properties of control specimens were relatively low than mix with RHA and silica fume. Among five mixes, sorption coefficient is lower for 5% RHA and 10% SF concrete (M1).

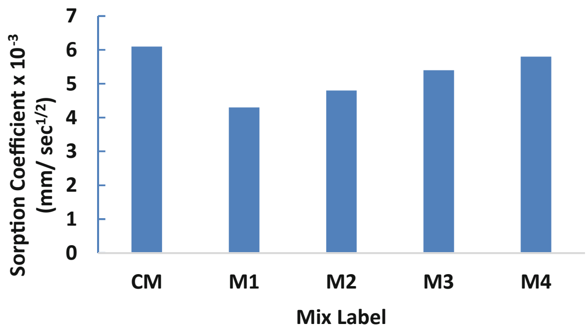

Fig. 6. Sorption coefficient results.

3.5 Water Absorption and Porosity Test

The volume of permeable pores was measured using ASTM C642 technique. In hardened concrete, this test method was used to assess density, percent absorption, and percent voids. The specimen volume must be at least 350 cm^3 for this test. After removing from the mould, the specimen was kept at a temperature of 110 °C for 24 h in hot air oven. The mass was determined after it was held at a temperature of 25 °C. The mass was then taken after 48 h of immersion in water at 21 °C. The sample was then boiled for 5 h in tap water and cooled for 14 h to a final temperature of 25 °C. Finally, the mass of the specimen was calculated by suspending it in water. The volume of voids and water absorption were calculated by substituting the values of mass in different conditions in the formula. Transporting water into the concrete matrix has a significant effect on concrete longevity. The porosity test estimated the number of pores in the concrete that were present and the results are shown in Fig. 7 and 8. As the permeability lowers, the porosity decreases. The amount of water that enters the concrete has a considerable impact on its decomposition. With a smaller void ratio, the combination has poor permeability. The M1 mix has the lowest void ratio when compared to the other mixes. The results of water absorption show that M1 fills the pores more efficiently than all other mixes and resists water penetration better than control concrete.

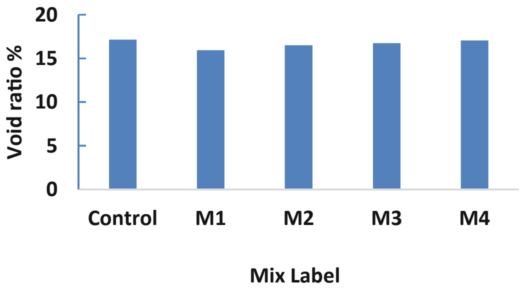

Fig. 7. Percentage of void ratio.

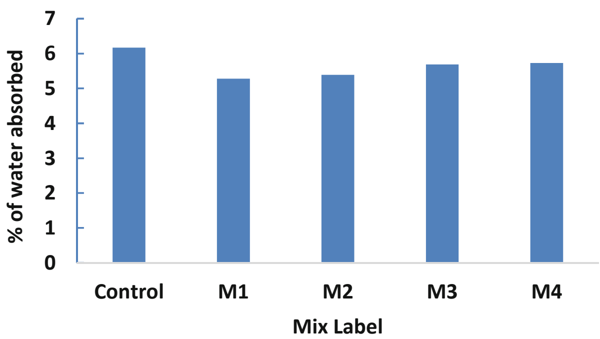

Fig. 8. Water absorption test results.

3.6 Acid and Sulphate Resistance Test

The deterioration of concrete specimen was measured in terms weight loss of specimens in percentage and reduction in strength for two different acids such as hydrochloric acid and sulphuric acid at 28 days are shown in Fig. 9. The less deterioration was observed for mix M1 compared to other mix. Mix with RHA and SF performed better under acids than CM. The deterioration was less due to less pores inside the mix and rate of water penetrated inside the matrix was minimized due to dense structure.

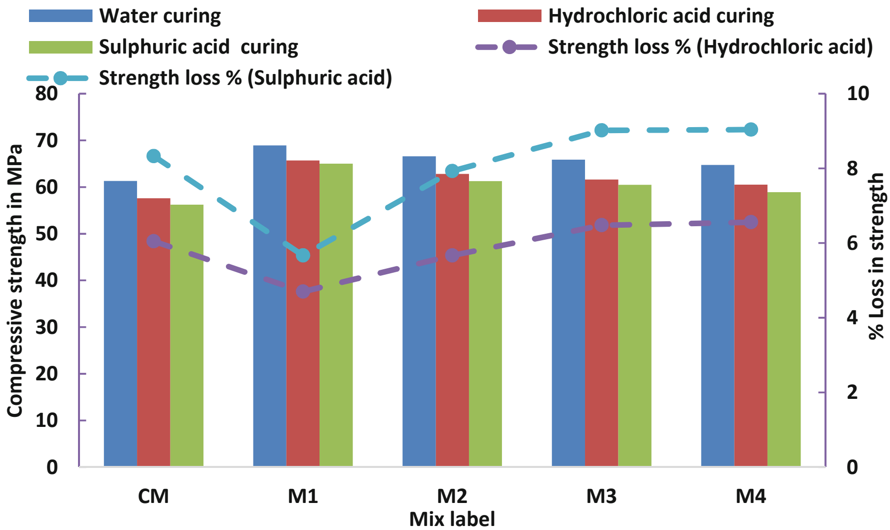

Fig. 9. Compressive strength and strength loss (%) against acids.

3.7 Microstructure Analysis (SEM)

From Fig. 10 CM image reveals that tiny particles and presence of RHA in mix shows combination of small and larger particles with white patches and platelets along with small CSH needle like fibers. Large crystals are loosely packed and filled with clustered white patches in the SEM image of RHA with 10% SF replaced concrete. Microcracks, on the other hand, appear when the RHA percentage exceeds 5%, and these cracks cause the concrete matrix to become less compact. As the RHA replacement level rises, SEM micrographs reveal a changed structure with a mix of large platelets and tiny clusters. In this case, the clusters are constricted, resulting in smaller porosity in the matrix microstructure than CM.

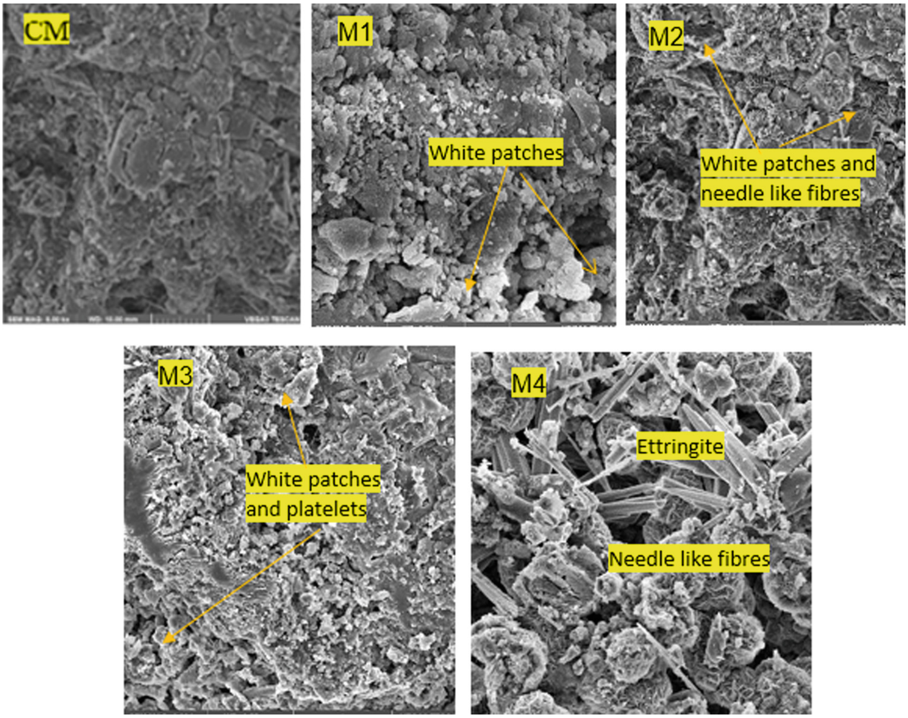

Fig. 10. SEM images.

4 Conclusions

Based on the test results and detailed discussion, the following conclusions are drawn.

1. From the tests results 5% RHA + 10% Silica Fume concrete was obtained as optimum mix based on the strength and durability results when compared with CM.
2. For the optimum mix (M1) the compressive strength was found as 35.86 MPa for 7 days and 68.03 MPa for 28 days. The CS increase was found as 10.5% at 7 days and 12.42% at 28 days compared to CM. The percentage increase in STS and FS were 16.33% and 26.15% respectively compared to CM.
3. By accelerating CSH formation through an effective pozzolanic reaction, the addition of RHA and SF results in enhanced performance in terms of strength and voids.
4. M1 mix plugs the pores more efficiently than all other mixes, and all RHA mixes are proven to resist water penetration better than CM. An inverse proportionality between strength and sorptivity was observed. RHA mixes higher the strength lowers the sorption coefficient than CM.
5. The substitution of SF and RHA shows white platelets and patches along with small CSH fibers, induces the significant modification of the microstructure, contribute to better improvement in concrete properties performance.

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