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ORIGINAL PAPER

# Effect of fly ash and rice husk ash on strength and durability of binary and ternary blend cement mortar

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## Abstract

This research paper describes the parametric study on the binary and ternary blend cement mortar prepared with the fly ash (FA) and rice husk ash (RHA) as partial substitute of ordinary portland cement (OPC). These byproducts are having high pozzolanic reactivity. In this research, the composition of the binary blend was used with the variation of 5–20% FA and RHA as partial substitute of OPC and for ternary blend 10% RHA along with 10, 20 and 30% FA as partial substitute of cement. The compressive strength, the microstructure of mortar matrix and durability were tested on mortar cubes. The test result shows that the maximum compressive strength was attained using 10% RHA, 10% FA for binary blend and for ternary blend 10RHA10FA and beyond that, the strength was similar to control mix (CM). The durability test for all specimen of the binary and ternary blend of cement mortar shows the satisfactory result. This type of mix is very effective in enhancing the strength and durability of cement mortar by saving cement and also environmental friendly.

**Keywords** Rice husk ash · Fly ash · Cement mortar · Compressive strength · Electrical resistivity · Water absorption

## Introduction

The cement is a major ingredient used in concrete and mortar. A huge quantity of $CO_2$ is emitted through the production of cement and this has significantly affected environmental pollution. This problem has been gradual rises in recent years. As an alternative to this, researchers utilized partially or fully substitute of OPC by industrial and agricultural by-product like fly ash (FA) (Zhang et al. 2001) and rice husk ash (RHA) (Ganesan et al. 2008) to produce sustainable cement mortar, concrete, bricks in construction industries (Raut et al. 2011, 2013; Kanthe et al. 2017). It is known that the high reactive pozzolanic material can be utilized in cement mortar or concrete for improving the strength and durability of the cement mortar and concrete.

Many studies were focused on mechanical properties of binary cement mortar or concrete mix at partial substitute of OPC using FA and RHA (Lee et al. 2014). The FA can improve the workability, shrinkage, long-term strength, and durability of concrete or mortar as reported by various researchers (Lddaw et al. 2015). And it was well known that FA gives less strength at early age due to its low reactivity. From the literature, we found that the use of RHA in cement mortar or concrete improved the mechanical properties in all ages (Abalaka 2013; Gastaldini and Silva 2014); hence, to improve the early age strength of FA mortar the RHA can be used along with OPC as secondary cementitious material to form a ternary blend. The literature review shows that very few researches have been done on the blend of FA and RHA as partial substitute of OPC for cement mortar as ternary blends (Kanthe et al. 2018).

The paddy rice husk is an agricultural byproduct and it is available in huge quantity in the Chhattisgarh state of India. The RHA is formed by burning of paddy rice husk at a controlled temperature in the industrial furnace (Alex et al. 2016). RHA has a higher percentage of amorphous silica ($SiO_2$) content which is more useful for forming C–S–H gel in the cement mortar or concrete(Mehta and Pitt 1976). In the year 2017, the annual worldwide production of paddy rice was 734.21 million tons and around 26.43 million tons RHA. The Indian paddy rice production is second highest in the world that was 161.26 million tons and 5.80 million tons of RHA produced(International Rice

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Research Institute (IRRI) 2017). In the Chhattisgarh state, FA and RHA are easily available. In the year 2015, the paddy rice production in the Chhattisgarh state was 4802.04 metric tons and around 172.87 metric tons RHA produced (Department of Agriculture Chhattisgarh India 2015; C. Departmental of Agriculture Raipur 2013.

The FA is generated from the ignition of coal in the thermal power plant and it is widely utilized as supplementary cementitious material in cement mortar or concrete. The use of FA in cement mortar or concrete enhances the compressive strength (Moon et al. 2016). The generation and utilization of FA during the year 2015 and 2016 in India as per the central electricity authority New Delhi were around 176.74 million tons generated from 151 thermal power station and out of this only 107.77 million tons utilized and in the Chhattisgarh state of India around 24.22 million tons generated from 19 thermal power station and out of this only 7.9 million tons FA utilized.

The safe disposal or utilization of such waste byproducts from the industries and agriculture tends to be an interest in research. The main objective of this research is to know the effect of the combined use of FA and RHA on the properties of cement mortar with locally available material and reduce the landfill area for dumping these materials.

## Experimental work and methods

### Material

The locally available materials utilized in this research work consisted of OPC, river sand, water, FA, and RHA. The FA was collected from power plant located at Bhilai, Chhattisgarh, India and the pulverized RHA was collected from the local vendor. Table 1 shows the physical and chemical properties of the material utilized in the research. Figure 1a–c illustrates the SEM images of RHA, FA, and OPC sample. The pore structure of RHA particle is clearly shown in Fig. 1a; the similar image was also found by other researchers (Bui and Chen 2012). The pore structure of RHA helps to reserved water in it at the time of cement mortar mixing and release afterward and it helps for hydration process as an internal curing agent (Van Tuan et al. 2011). Figure 1b shows the spherical shape of FA particle which helps to improve the workability. Figure 1c shows the irregular shape of OPC particle.

### Compressive strength

The compositions of various cement mortar mixes for binary and ternary blend are shown in Table 2. The binary mix for RHA varies from 5 to 20% partial substitute of OPC and similarly, for FA, it was 5–20%. The ternary mix (R10FA10) was a combination of 10% RHA and 10% FA. In this R10FA10 mix OPC was partially replaced with 10% RHA and 10% FA. The percentage of RHA was fixed at 10% as per previous literature (Nuruddin et al. 2014; Xu et al. 2012) and FA changed by 10, 20 and 30%. The cement to fine aggregate mix ratio contents were used (1:3). The 50 mm size cube molds were used for casting of each mix. Then, the specimens were left in the mold covered with gunny bag for 24 h after that they were demolded and immersed in the water tank for 28 days curing. The compressive strength of cement mortar was tested after the specified curing periods on the compression testing machine conforming to IS: 516(1959) (Bureau of Indian Standard 1959).

### SEM/EDX: (scanning electron microscope) and (energy dispersive X-rays)

The SEM analysis with high resolution was used to study the microstructure of samples. The EDX was used to determine the elemental contents present in the given sample. For observation of SEM, the sample was coated with gold in sputter coater to obtain clear SEM images (Ramachandran et al. 1995). The testing was done on scanning electron microscope machine available at NIT Raipur.

### Water absorption

The test method of water absorption was determined by the procedure explained in ASTM-C 642-13 ( 2008). The requirement of such test is to examine the permeability of cement mortars. The 50 mm × 50 mm × 50 mm cube samples were used to examine the water dispersion of all mortar mix at ages of 28 days. According to the test

**Table 1** Physical and chemical properties of material

| Chemicals elemental contents (%) | (Si) | (Ca) | (Al) | (Fe) | (Mg) | (K) | (Na) |
|---|---|---|---|---|---|---|---|
| FA | 64.01 | 1.22 | 24.51 | 5.02 | 0.50 | 2.5 | 0.12 |
| RHA | 93.01 | 1.9 | 0.81 | 1.22 | 0.40 | 3.3 | 0.10 |
| OPC | 16.01 | 69.01 | 4.65 | 3.76 | 1.66 | 2.35 | 0.37 |
| Specific gravity | 2.2 | 2.5 | 3.14 | | | | |
| Specific surface area ($m^2$/kg) | 315 | 292 | 590 | | | | |

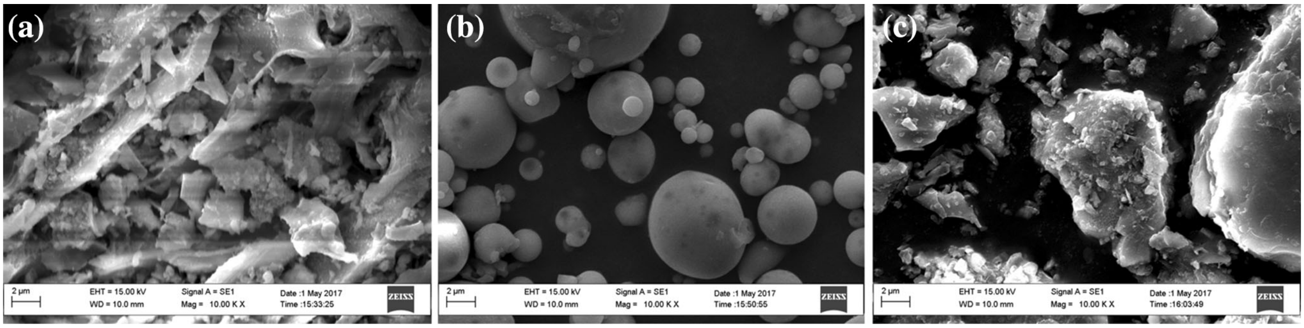



**Fig. 1** **a** The pore structure of RHA particle, **b** the spherical shape of FA particle, **c** the irregular shape of cement particle

**Table 2** The mix proportion of cement mortar (kg/m$^3$)

| Mix | Cement | RHA | FA | Sand | Water |
|---|---|---|---|---|---|
| 100C0R0F | 500 | 0 | 0 | 1500 | 230 |
| 95C5R0F | 475 | 25 | 0 | 1500 | 230 |
| 90C10R0F | 450 | 50 | 0 | 1500 | 230 |
| 85C15R0F | 425 | 75 | 0 | 1500 | 230 |
| 80C20R0F | 400 | 100 | 0 | 1500 | 230 |
| 95C0R5F | 475 | 0 | 25 | 1500 | 230 |
| 90C0R10F | 450 | 0 | 50 | 1500 | 230 |
| 85C0R15F | 425 | 0 | 75 | 1500 | 230 |
| 80C0R20F | 400 | 0 | 100 | 1500 | 230 |
| 80C10R10F | 400 | 50 | 50 | 1500 | 230 |
| 70C10R20F | 350 | 50 | 100 | 1500 | 230 |
| 60C10R30F | 300 | 50 | 150 | 1500 | 230 |

system, the samples were placed in the oven at the steady temperature of 110 °C for 24 h drying period in for dry out all the present water in their pores. Then, the specimens were placed in the water bath to prevent water absorption. And the percentage of water absorption for cement mortar was calculated at 3 and 24 h intervals. The water absorption was determined by Eq. (1)

$$\text{Water absorption}\,(\%) = \left[\frac{(B-A)}{A}\right] \times 100, \tag{1}$$

where $B$ is the weight of specimen after water absorption and $A$ is the initial weight of the specimen.

### Electrical resistivity (ER)

After the desired curing period, the cubes were taken out from the tank and tested for bulk electrical resistivity test. The saturated wet cubes were placed in between two parallel metal plates with the moist sponge of electrical resistivity meter. The voltage between two ends of the cement mortar specimen was calculated by applying small alternating current at intended frequency. The electrical resistivity of cement mortar was determined using the following Eq. (2) (Rath et al. 2017),

$$\rho = \frac{A}{L} \times z, \tag{2}$$

where ($\rho$) is the resistivity of cement mortar (Ωcm), ($A$) is the cross-sectional area of the specimen (cm$^2$), ($L$) is the length of the specimen (cm) and ($Z$) denotes the impedance measured by the device (Ω).

### Ultrasonic pulse velocity (UPV)

The UPV test was conducted to check the quality of cement mortar cubes for internal cracks and denseness. The 50 mm × 50 mm × 50 mm cube specimens were prepared for the UPV test of each mortar mixture. After casting, these samples were cured for 28 days. The test was conducted at ages of 28 days in accordance with IS: 13311 (part I): 1992 (Bureau of Indian Standard 1992).

## Result and discussion

### Compressive strength

The result of compressive strength of cement mortar is illustrated in Fig. 2. It indicates that the ternary blend of RHA, FA and OPC has contributed to improve the strength of cement mortar than the binary cement mortar mix. The ternary cement mortar mix R10FA10 and R10FA20 has improved the strength by 25.06% and 19.95% over with the control mortar mix whereas for binary mortar mix has improving the strength only 18.49% and 9.0% contrasted with the control mortar mix at 28 days. An increment in strength may be due to the better packing microstructure of the mortar mix, the high reactivity of RHA and pozzolanic reaction. It also showed that by increasing the FA and RHA content at 40% the strength was decreased in average by 6.7%.

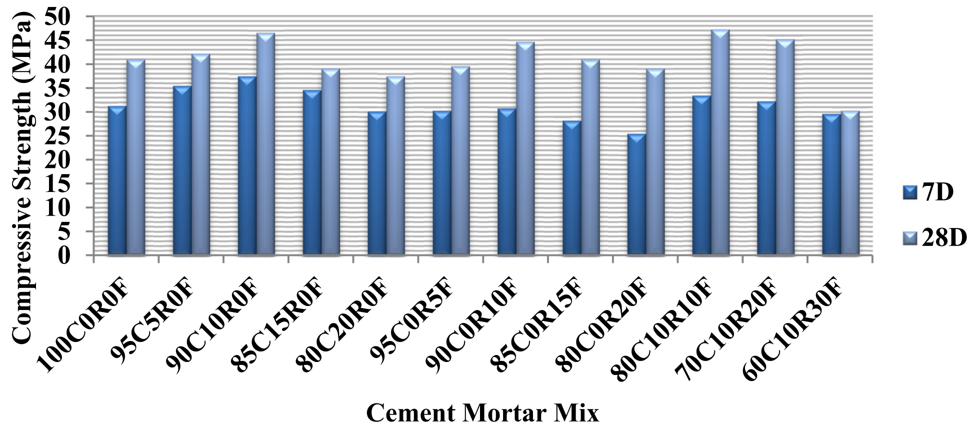



**Fig. 2** The result of compressive strength

## Microstructure of cement mortar

The SEM images of the control mortar mix and the ternary and binary blend mortar mix are shown in Fig. 3a–c. The maximum content of unhydrated cement and voids was observed in the control cement mortar mix, whereas it is reduced in the binary and ternary blend mortar mix. It means more packing of particle occurred in binary and ternary mortar mix. It has achieved in 25.06% higher strength than control mortar mix. In addition, secondary C–S–H gel is observed. It is the most important component in concrete or mortar as it provides cementitious or binding properties to the final product hence it improved the strength of mortar.

## Water absorption and porosity

The test result of water absorption for the binary and ternary blend of RHA and FA mortar mix was carried out at 28 days of curing as shown in Fig. 4. The result shows that the percentage of water absorption of cement mortar specimen decreases around 65% with rising the percentage of FA and RHA. The water absorptions of both binary and ternary blend mortars were lesser than control cement mortar sample at 28 days curing for various time intervals. Hence, it can be noted that with the percentage increment of FA and RHA as replacement of cement in mortar can reduced the porosity. This was due to the higher pozzolanic reactivity of RHA, packing of FA and RHA particles effect and compact secondary C–S–H gel agent which fill the micropores. The similar result was also found by other researchers (Balapour et al. 2017). Therefore, a ternary blend cement mortar showed better results.

## Electrical resistivity (ER)

Bulk electrical resistivity test was carried out with resistivity meter as per the guidelines of ASTM C 1202. The data were generated for all binary and ternary cement mortar mixes at the age of 28 days. Figure 5 shows increase in the electrical resistivity by increasing the percentage of FA and RHA in binary and ternary mortar mixes than control mortar mix; the similar results were found by other researchers (Bureau of Indian Standard 1992; Arenas-piedrahita et al. 2016; Mehdizadeh et al. 2016). In addition, Fig. 5 also shows the higher ER of ternary mortar mix than control and binary. It was happened due to the increase in percentage of FA and RHA which respond with the calcium hydroxide to produce extra C–S–H gel. This clearly improve influences the microstructure of the cementitious

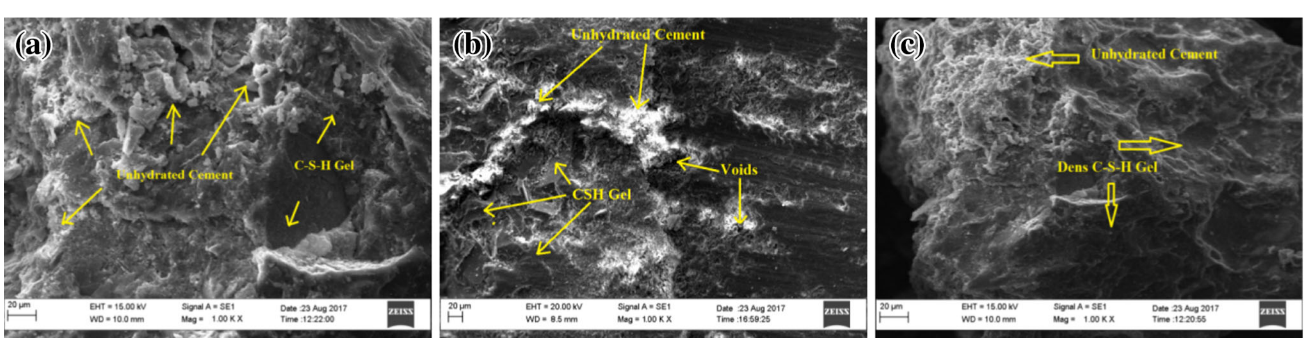



**Fig. 3** **a** Microstructure of control cement mortar, **b** microstructure of binary blend cement mortar, **c** microstructure of ternary blend cement mortar

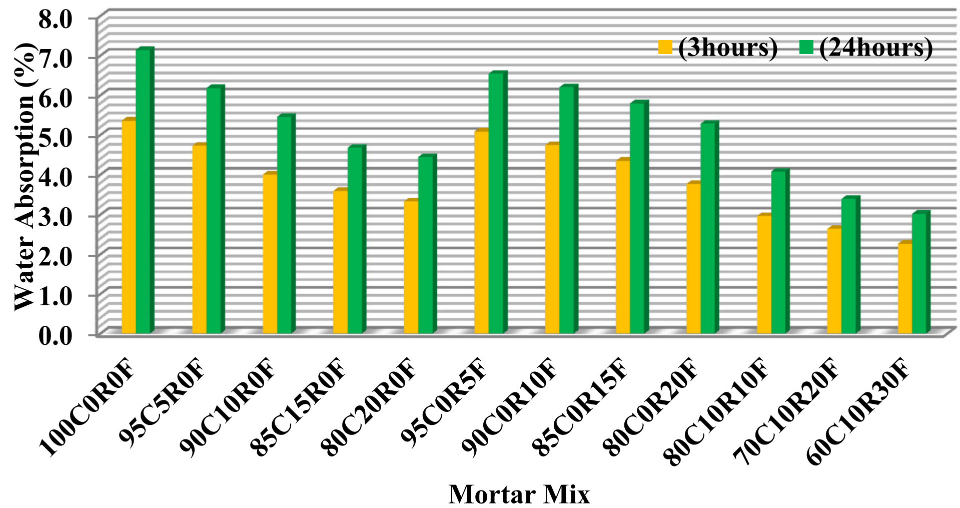



**Fig. 4** Water absorption result from various mortar mixes

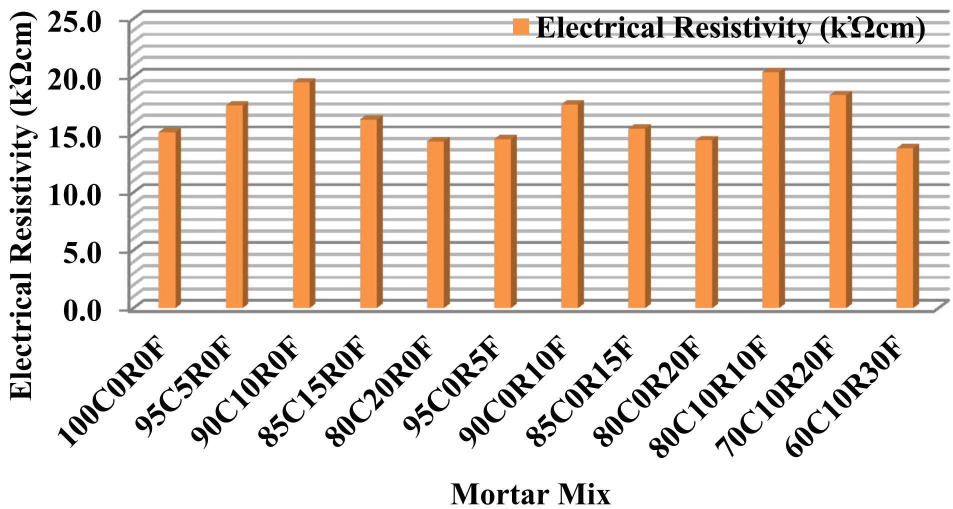



**Fig. 5** Results of electrical resistivity

lattice on the grounds that the resulting formation of denser lattice and decline in the voids and the interconnectivity of pores. The connection between the rate of corrosion and ER is given in Table 4.1, as indicated by the ACI Committee 222 (ASTM-222-R-01 2001). As it was clear, the increase in percentage of FA and RHA offers to mount to a lower corrosion. The cement mortar blends contain RHA and FA found in a low to moderate scope of corrosion as per ACI committee 222.

## Ultrasonic pulse velocity (UPV)

The UPV test result of the binary and ternary blend of cement mortar is illustrated in Fig. 6. It was observed that all samples with 5–20% FA and 5–20% RHA as binary blend cement mortar show the highest UPV than that of the control cement mortar sample, whereas in ternary blend UPV shows highest for R10F10 and R10F20 mortar mix. The UPV test result values show above the 4.5 km/s; therefore, it may be considered an excellent result for all mortar mix as per Indian standard code. The similar trend of UPV results for binary and ternary blend cement mortar is shown by various researchers (Huynh et al. 2018). As it was evident, cement mortar mix made by FA and RHA increases the UPV by about 13.15% in contrast with control specimen. From the UPV, test results were found that the samples of ternary blend cement mortar obtained the better durability for all cement mortar mix. It was because of the rise in cement hydration content which was allied with the high content of silica present in RHA and alumina content in FA.

## Correlation between testing results

The regression analysis was used to investigate the correlation between compressive strength and UPV,

**Fig. 6** UPV result

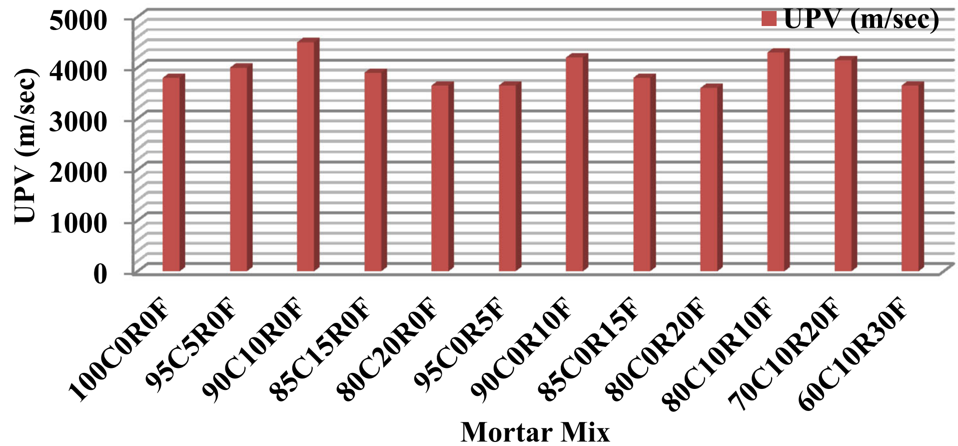



**Fig. 7** Correlation between compressive strength and ER

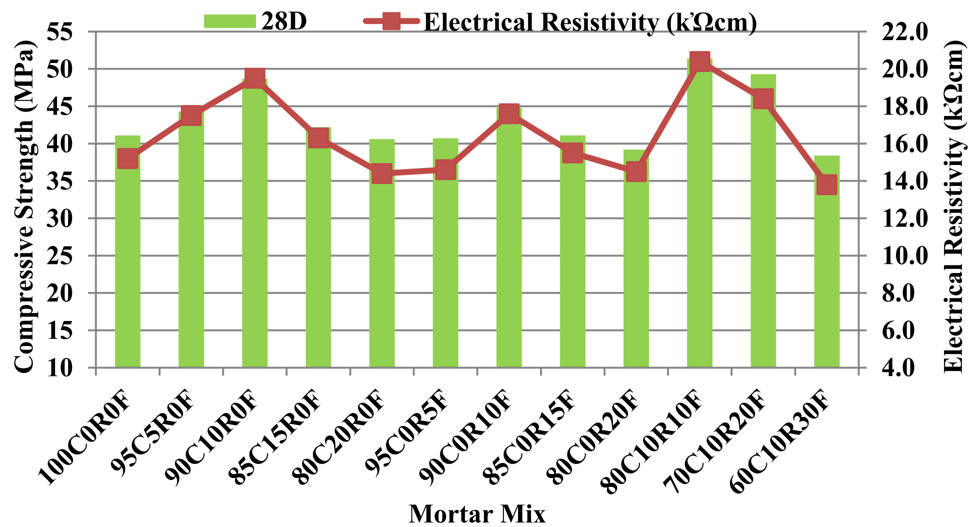
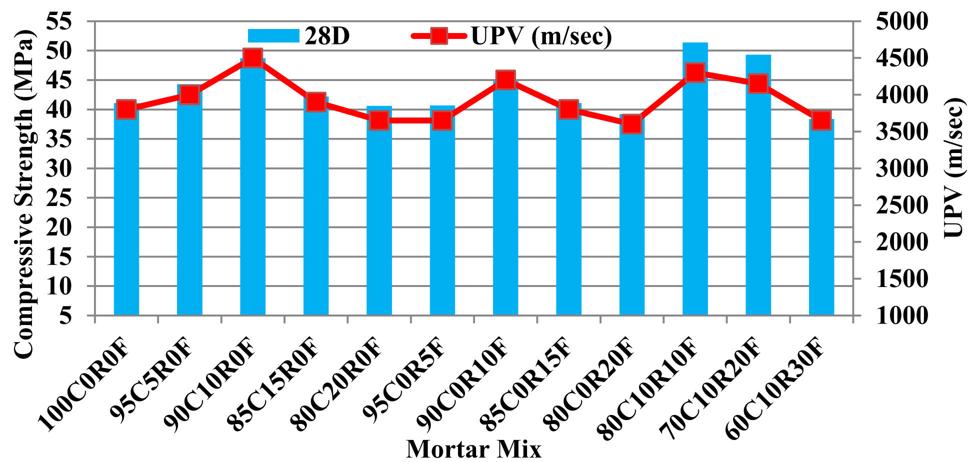



**Fig. 8** Correlation between compressive strength and UPV




compressive strength and ER from the test results. Figures 7 and 8 illustrate the correlation between the testing results. The results demonstrated a nearby relationship between these two factors, highest UPV comparing with more prominent compressive strength for the cement mortar in all samples. From the test result data plotted that the determination coefficient was obtained as shown in

**Table 3** Correlation between testing results

| Mortar mix | ER | | UPV | |
|---|---|---|---|---|
| | Linear equation | $R^2$ | Linear equation | $R^2$ |
| 100C0R0F<br>95C5R0F<br>90C10R0F<br>85C15R0F<br>80C20R0F | $y = 1.609x + 16.70$ | 0.95 | $y = 0.010x + 3.423$ | 0.97 |
| 95C0R5F<br>90C0R10F<br>85C0R15F<br>80C0R20F | $y = 1.594x + 16.69$ | 0.93 | $y = 0.008x + 8.668$ | 0.95 |
| 80C10R10F<br>70C10R20F<br>60C10R30F | $y = 2.072x + 9.925$ | 0.98 | $y = 0.020x - 37.51$ | 0.99 |

Table 3 where ($y$) is the 28 day strength and the ($x$) is the respective electrical resistivity.

## Conclusions

The following points were conclude from the experimental results in present research work:

1. The compressive strength of ternary blend cement mortar mix is higher than the binary and control cement mortar. It is due to the packing of finer particles, pozzolanic reaction.
2. The increase in compressive strengths of mortars mix observed at 7 days may not be affected by single aspect but by several aspects, for example the amorphous silica in RHA and alumina in FA contents and the surface area of RHA and FA.
3. The SEM images show the denser microstructure of cement mortar for binary and ternary mix than normal mortar mix. It is due to the extra C–S–H gel forming and hence better particle packing of material.
4. where B is the weight of absorption of ternary blend cement mortar is less than binary blend and control cement mortar. It is because the finer particles of RHA and FA play a role as filler and make the microstructure denser and, as a result, reduce the water absorption.
5. The electrical resistivity increases by the addition of FA and RHA in binary and ternary blend cement mortar than control mortar mix. It is due to dense microstructure.
6. The test result of UPV showed the improved durability of cement mortar ternary blend than binary blend by the addition of FA and RHA possibility due to the increase in cement hydration product which is related to the high content of silica present in RHA and alumina present in the FA.
7. The correlation between the test results shows the closed relationship with compressive strength and, hence, it may be considered as the given regression model is adequate.
8. This type of ternary blend can effectively utilize the locally available industrial and agricultural byproduct up to 30% reducing an environmental issue for producing better concrete.

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## Compliance with ethical standards

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

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