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*Research Note*

# A new approach to improving durability of rice husk ash blended concrete with re-dispersible polymer powder

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Ultrasonic pulse velocity.

**Abstract.** An experimental investigation was conducted to improve the limitation of Rice Husk Ash (RHA) blended concrete in terms of durability by incorporating re-dispersible polymer powder. To investigate the durability properties of Rice Husk Ash Polymer-Modified Concrete (RHAPMC) matrix, the RHAPMC mix of 1:2:3 proportions was used to prepare specimens. To prepare Rice Husk Ash-Modified Mix (RHAMM), 10% of RHA was replaced with cement. RHAPMC was made with the inclusion of polymer at a ratio of 1 to 7.5% by the weight of cement. The most common durability-related properties including water absorption, density, water permeability, ultrasonic pulse velocity, and compressive strength were experimentally investigated. The results showed a remarkable improvement in durability characteristics in the newly developed matrix of RHAPMC, which could be used as a repair material in an aggressive environment.



## 1. Introduction

Efforts are made to utilize waste materials, produced from various sources, as a supplementary cementing material in the construction industry to reduce environmental problems. Rice Husk Ash (RHA) is one of such waste materials, which is obtained as an agrarian by-product of rice crop. RHA could be used as a source of supplementary cementing material in cement concrete and cement mortar. In the U.S., RHA is successfully registered by the trade name Agrosilica, which gives excellent pozzolanic property [1]. In case of 10% cement replacement, the workability and permeability of concrete greatly improved and decreased, respectively [1]. Almost 600 million tonnes of rice generates about 20 million tonnes of RHA annually [2]. In Pakistan, rice is considered one of the cash crops and its cultivation comprised around 6.64 million tonnes in 2016/2017, which can cause a huge amount of waste material in the form of husk [3].

Rice husk is composed of mainly silica and carbon and has $SiO_2$ from 90.02 to 96.71 wt% and carbon from 2.18 and 8.63 wt% [4,5]. Nearly 200 kg of husk is obtained from every one tonne of pulverized paddy, and about 25% of RHA is yielded upon burning [2]. Extracting non-crystalline silica from the husk involves proper burning [6]. RHA particles are porous and characterized by a honeycombed microstructure [7]; as a result, the specific surface area of RHA is enormously

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high, which is 50 to 100 $m^2$/g for amorphous RHA [8]. Consequently, mechanical and durability properties of concrete (i.e., water penetration, water absorption, ultra-pulse velocity, and density) and mortar are greatly affected. Extra fineness of RHA is required in order to achieve the maximum compressive strength of RHA-blended concrete. Habeeb and Mahmud [9] increased the fineness of RHA and concluded that fined RHA blended concrete gained more strength than coarse RHA and normal concrete. However, attaining ultra-fine RHA requires extra efforts in terms of cost and time. In addition, permeability is considered to be as important as compressive strength of cement concrete and mortar. The addition of much water as per more RHA demand in concrete can result in porous medium in RHA blended concrete and mortar. The permeability of hydrated cement paste is by and large a function of capillary porosity.

Polymer is an additive that is being used throughout the world to improve the mechanical and durability properties of concretes, mortars, and composites [10]. The inclusion of polymeric compounds in mortars and concretes may or may not have a significant effect on compressive strength [11–13]; however, it has a significant impact on the permeability of cement concrete and mortar. Ramli and Tabassi [14] concluded that incorporating 15% of polymer latexes could enhance the inbred properties of ordinary cement mortar by approximately 4 to 5 times.

In this paper, an attempt is made to introduce an entirely new technique for improving the durability property of RHA blended concrete by using redispersible polymer powder instead of making ultra-fineness of RHA. In this approach, the pores of RHA blended concrete are blocked due to film-forming ability of polymer, resulting in the improved properties of the newly developed composite. To the best of authors' knowledge, no such composite is presented in the literature.

## 2. Materials and methods

### 2.1. Materials

In this study, ordinary Portland cement was used. For making concrete, fine and coarse aggregates with maximum sizes of 4.75 mm and 19 mm have been used, respectively. In RHA blended concrete, 10% of cement was replaced with the extracted RHA. Specific gravity and Blaine fineness were found to be 2.05 and 2251 ($cm^2$/g), respectively. The chemical composition of RHA is shown in Table 1.

In this study, the re-dispersible polymer powder, VINNAPAS 5044 N, produced by Wacker was used as a cement modifier. It is white powder in appearance. It has a unit weight of 550 kg/$m^3$ and its particle size is 4% retained on 400 $\mu$m. It alters the basic chemistry of cement by emulsification. The peramin sulfonated melamine formaldehyde has been utilized as a plasticizer to enhance the workability of concrete. Silicon dioxide in RHA, as shown in Table 1, is 91.74% which meets the requirement as pozzolanic material as per ASTM 618-03. The authors are of the view that RHA Polymer-Modified Concrete (RHAPMC) presented in this study is a newly developed composite.

**Table 1.** Chemical properties of Rice Husk Ash (RHA).

| Elements of RHA (%) | | | | | | |
|---|---|---|---|---|---|---|
| $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | LOI |
| 91.74 | 1.12 | 0.98 | 0.81 | 2.18 | 0.00 | 1.50 |

### 2.2. Experimental program

#### 2.2.1. Concrete mix

A concrete mix design having a characteristic strength of 26 MPa was used to check the concrete durability in terms of resistance against water penetration, water absorption, and its qualitative characteristics. A ratio of 1:2:3 in the slump range of 25 to 50 mm was used to investigate the durability properties of RHAPMC. For studying durability aspects, concrete mix was prepared, i.e., Control Mix (CM); 10% RHA was replaced by cement in Rice Husk Ash-Modified Mix (RHAMM) and Rice Husk Ash Polymer-Modified Concrete mix (RHAPMM1-RHAPMM7.5) with the inclusion of polymer at a ratio of 1 to 7.5% by the weight of cement, as shown in Table 2. Of note, when 10% of cement was replaced with RHA, the compressive and tensile strength of the mix was found equal to that of the CM. Given 10% replacement of cement with RHA and the addition of 7.5% dosage of Redispersible Polymer Powder (RPP), the slump of control mix is 30, 26, and 37 mm, respectively.

#### 2.2.2. Ultrasonic Pulse Velocity

To determine Ultrasonic Pulse Velocity (UPV), a total of 30 cubes sized 100 × 100 × 100 mm were cast using mix design and, then, de-molded after 24 hours. The CM (un-modified) and RHAMC samples were cured for 28 days in moist curing as per ASTM C 192 [15] and polymer-modified concrete samples were first kept in wet curing for 7 days and, then, air dried for 21 days for curing as per JIS A 1171-2000 [16]. UPV of each specimen was determined using Ultrasonic Non-Destructive Digital Indicating Tester (Pundit) [17].

#### 2.2.3. Density and water absorption

To evaluate the density and water absorption capacity of the mix, cylindrical concrete samples of size 150×300 mm were cast to determine the density of each mix. After de-molding, all the specimens were prepared, de-molded, and cured, as specified in Section 2.2.2. Density and water absorption of each specimen were

**Table 2.** Concrete mix design of Control Mix (CM), Rice Husk Ash Modified Mix (RHAMM), and Rice Husk Ash Polymer Modified Concrete (RHAPMM) as per ACI211.1-91.

| Serial no. | Concrete mix | Cement ($kg/m^3$) | RHA ($kg/m^3$) | RPP ($kg/m^3$) | Total binder ($kg/m^3$) | Plasticizer ($kg/m^3$) | Water ($kg/m^3$) | F.A ($kg/m^3$) | C.A ($kg/m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | CM | 346 | 0 | 0.0 | 346.0 | 0.0 | 190.3 | 692 | 1038 |
| 2 | RHAMM | 311.4 | 34.6 | 0.0 | 346.0 | 0.0 | 205.8 | 692 | 1038 |
| 3 | RHAPMM1 | 311.4 | 34.6 | 3.1 | 349.1 | 2.79 | 205.8 | 692 | 1038 |
| 4 | RHAPMM2.5 | 311.4 | 34.6 | 7.8 | 353.8 | 2.83 | 205.8 | 692 | 1038 |
| 5 | RHAPMM5 | 311.4 | 34.6 | 15.6 | 361.6 | 2.89 | 205.8 | 692 | 1038 |
| 6 | RHAPMM7.5 | 311.4 | 34.6 | 23.4 | 369.4 | 2.95 | 205.8 | 692 | 1038 |

Note: Average of five specimens was taken. CM: Control Mix; RHAMM: Rice Husk Ash-Modified Mix; RHAPMM1 to 7.5: Rice Husk Ash Polymer Modified Mix (i.e., incorporation of redispersible polymer powder from 1 to 7.5% by the weight of cement).

determined as per ASTM C1754 [18] and ASTM C1585 [19] standards, respectively.

*2.2.4. Water penetration*

Specimens were prepared, de-molded, and cured, as previously shown in Section 2.2.2. Water pressure of 0.5 MPa was applied for 72 hours, as specified in BS EN 12390-8 [20]. After subjecting the required water pressure, the specimens were split into two halves and water-penetrated moistened surface measured as water penetration depth.

*2.2.5. Compressive strength*

Cylindrical specimens of size $150 \times 300$ mm were cast and kept in curing tank for curing. The CM (unmodified) and Rice Husk Ash-Modified Concrete Mix samples were cured for 28 days in moist curing as per ASTM C-192 [15], and Polymer Modified Concrete Mix samples were first kept in wet curing for 7 days and, then, air dried for 21 days for curing as per JIS A1171-2000 [16].

## 3. Results and discussion

### *3.1. Ultrasonic Pulse Velocity (UPV)*

UPV is an additional, imperative characteristic of concrete that represents its porosity and density. In order to verify the taxonomy of RHA, Scanning Electron Microscopy (SEM) was performed. The SEM results obtained at various resolutions showed that the RHA was multifaceted and angular with micro absorbent surface and, also, was characterized by high specific surface, as shown in Figure 1(a)-(e).

The UPVs of CM, RHA modified at 10% cement replacement mix, and RHAPMC with the incorporation of polymer from 1–7.5% were determined in 28 days. As shown in Figure 2, the UPV of RHAMM is less than that of the CM. The decreasing trend of UPV in RHAMM illustrates that the quality of RHAMM in terms of porosity is affected by the addition of RHA. As shown in Figure 2, with the addition of RPP in RHAMM, an improving trend in UPV has been observed because of the pore-filling ability of the polymer. The increased ultrasonic velocity of RHAPMC reveals that cracks are sealed and blocked by polymers, thus improving the quality of concrete more than that of RHA blended concrete. From the results, UPV of the RHAPMC ranges from 4.24 to 4.26 mm/$\mu$s which falls within the prescribed limit of medium to excellent quality (3.660–4.575 mm/$\mu$s) [21]. Based on the provided range, RHAPMC falls in the excellent quality of concrete.

### *3.2. Density*

Given the 10% cement replacement with RHAMM and RHAPMM by incorporating polymer from 1 to 7.5%, densities of the CM were determined in 28 days. As shown in Figure 3, the density of RHAMM is less than that of the CM. The decreased density of RHAMM mainly results from the low specific gravity of the ash. As shown in Figure 3, the inclusion of RPP in the RHA-blended concrete causes a further reduction in the densities of rice husk ash polymer-modified mixes because of air entrapping characteristics of the polymer from the environment; these findings are validated in [22]. It is found that the density of RHA polymer-modified specimens ranges from 2377.92 to 2406.23 $kg/m^3$, which comes within the limit of density of normal concrete [23].

A comparison is made between the UPV and densities of the mixes, the results of which are shown in Figure 3. While the density of RHAPMC is decreasing, the quality of concrete has improved in terms of UPV because of the sealing of pores by the polymer.

### *3.3. Water absorption*

Water absorption results of all mixes are shown in Figure 4. The figure shows that the water absorption capacity of the 10% cement replaced concrete (i.e., RHAMM) increases with respect to the CM because of the following reasons. The first reason is the

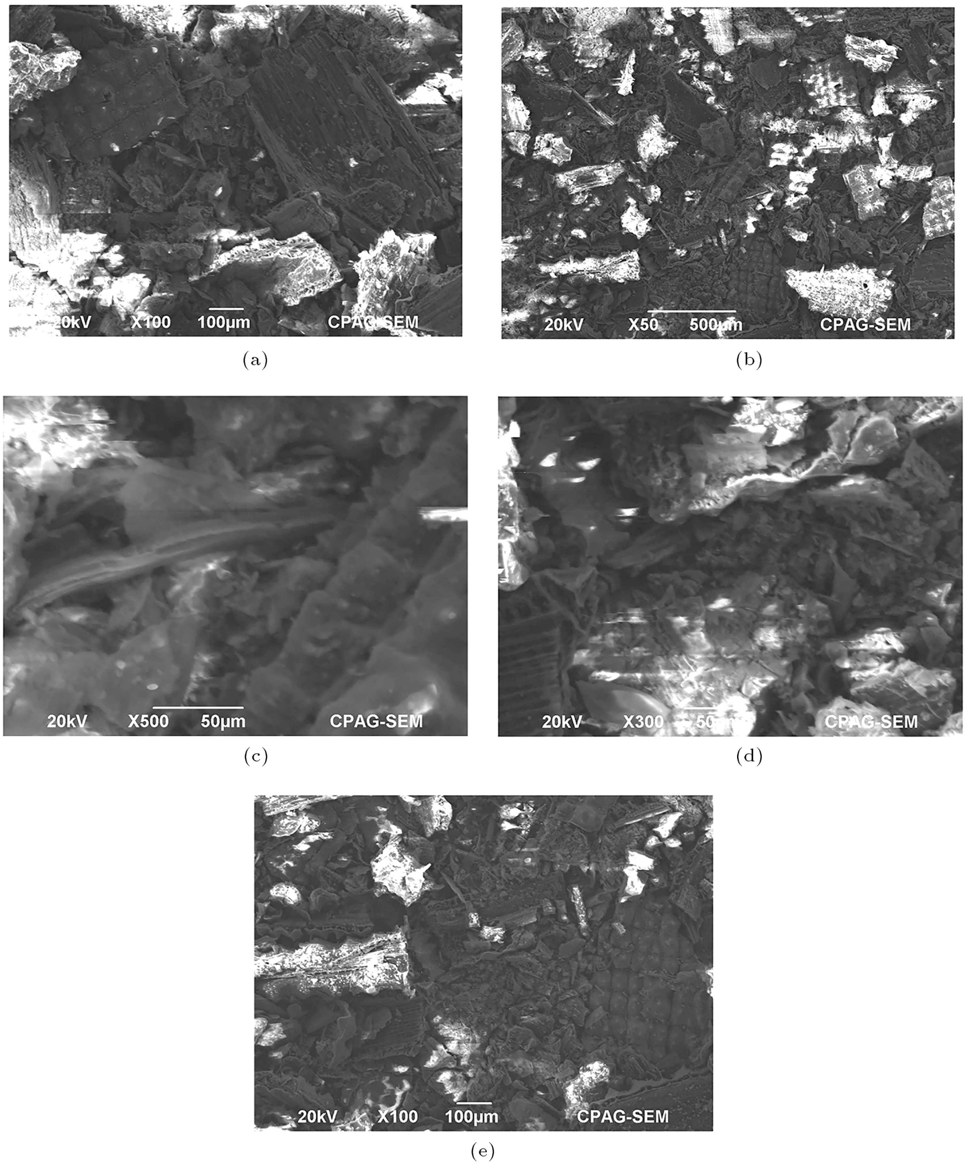


**Figure 1.** (a) SEM image @ 20 kV $\times$ 100 100 $\mu$m of RHA particles. (b) SEM image @ 20 kV $\times$ 100 500 $\mu$m of RHA particles. (c) SEM image @ 20 kV $\times$ 500 50 $\mu$m of RHA particles. (d) SEM image@ 20 kV $\times$ 300 50 $\mu$m of RHA particles. (e) SEM image@ 20 kV $\times$ 100 100 $\mu$m of RHA particles.

development of secondary Calcium Silicate Hydrated (CSH) gel due to the supplementary cementing material, which is thinner than that of the primary (CSH) gel formed by the cement. The second reason is that ash is one of the water absorption materials in nature and when it blends with concrete, it leaves interconnected voids in the concrete. Figure 4 shows that when polymer re-dispersible powder is added to the rice husk ash-modified concrete, a reduction in the water absorption capacity of the concrete is noticed. This is because lager pores are filled and blocked by the cement modifier or sealed by the continuous polymer films that give rise to the higher connectivity of the porous network, compared to non-modified mortar [11,24], thereby forming a network structure with finer porosity. Moreover, polymer is deemed to be a water-impermeable material that is dispersed in the pores of the concrete, resulting in blocking the penetration of water into interconnected voids [11]. As shown in Figure 4, the water absorption capacity of RHAMM is 4.1% with a 43.36% increase from the CM. The increasing water absorption capacity of rice husk ash-modified mix is primarily due to its density reduction. The decreasing trend of density of RHAMM illustrates that the quality of the mix in terms of porosity is affected due to the addition of RHA and, thus, the decreased density reduces impermeability. Furthermore, the water-absorbing capacity of RHAMM is reduced with the further addition of re-dispersible polymer powder. With the addition of 7.5% of RPP

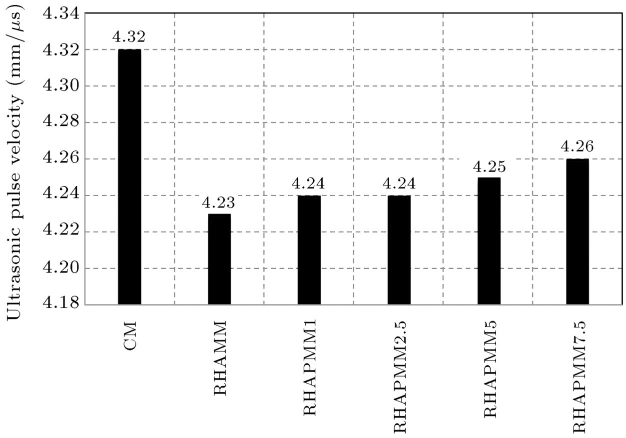


**Figure 2.** Ultrasonic Pulse Velocity (UPV) of Control Mix (CM), Rice Husk Ash-Modified Mix (RHAMM), and Rice Husk Ash Polymer Modified Mix (RHAPMM).

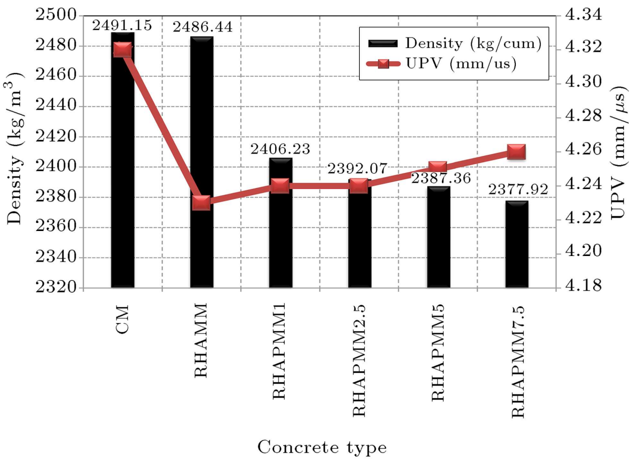


**Figure 3.** Density and Ultrasonic Pulse Velocity (UPV) of Control Mix (CM), Rice Husk Ash-Modified Mix (RHAMM), and Rice Husk Ash Polymer Modified Mix (RHAPMM).

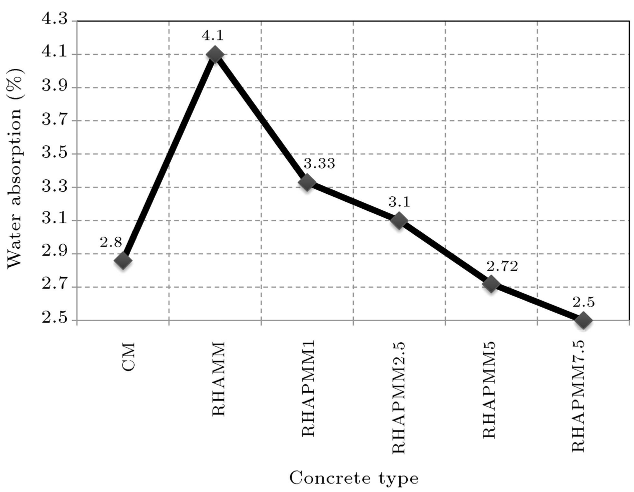


**Figure 4.** Water absorption capacity of Control Mix (CM), Rice Husk Ash-Modified Mix (RHAMM), and Rice Husk Ash Polymer Modified Mix (RHAPMM).

to the RHA-modified concrete, the maximum water absorption capacity is 2.5% (12.59% less), as compared to the control concrete mix. It is implied that the quality of concrete has improved with the inclusion of RPP.

### *3.4. Water permeability*

Water penetration results of all mixes are shown in Figure 5. The figure shows a plot of water penetration depth of CM 10% cement replaced with RHAMM, and RHAPMC. The permeability of RHAMM has increased more than that of the CM because RHA is more water absorbent in nature. Ash requires much water for mixing in the case of concrete and mortar mixes. At the hardened stage, when water dries out, it leaves a porous medium in the concrete, thereby forming a concrete of lower density. By incorporating more quantities of polymer in the RHA concrete, the impermeability of all the mixes increases. On the one hand, the total porosity of the concrete increased with the addition of RPP due to the entrained air generated in the mixing process; on the other hand, the open porosity of the concrete decreased and caused a reduction in the permeability of concrete [25,26]. As shown in Figure 5, the permeability of RHAMM increases by about 30%, compared to that of the CM. The increasing permeability trend of husk ash-modified mix illustrates that the porosity of RHA mix is affected by the substitution of the cement with the ash; thus, the reduced density causes decreasing impermeability. A remarkable increase in the water impermeability of the RHAMM due to the addition of varying percentage dosages of RPP has been observed. At 7.5% dosage of RPP, the RHAMM becomes more impermeable with the increase of about 15 and 34% water impermeability than that of control and RHAMM. This is because the impermeability of the modified mixes increases due to the fact that the polymer has the pore-filling and

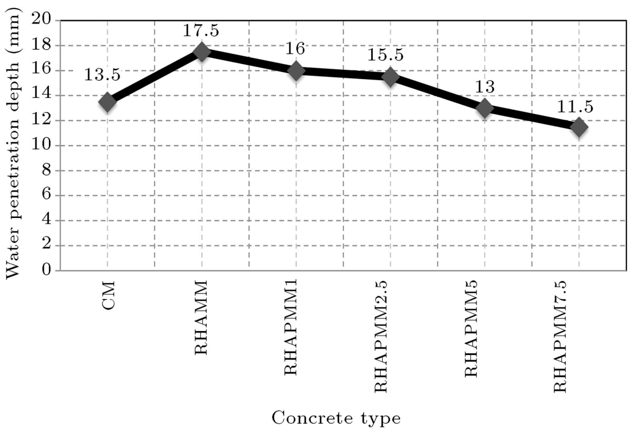


**Figure 5.** Water Permeability of Control Mix (CM), Rice Husk Ash-Modified Mix (RHAMM) and Rice Husk Ash Polymer Modified Mix (RHAPMM).

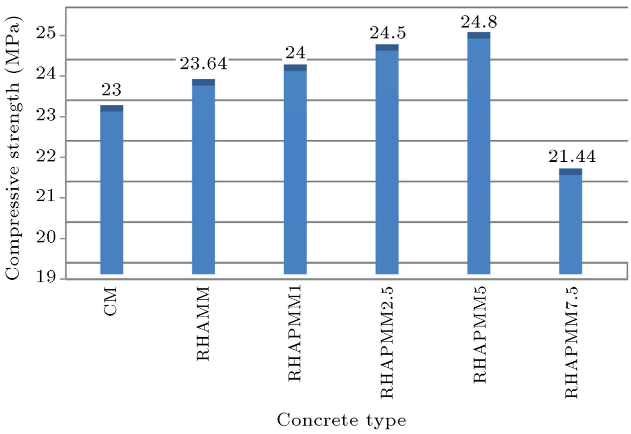


**Figure 6.** Compressive strength of Control Mix (CM), Rice Husk Ash-Modified Mix (RHAMM) and Rice Husk Ash Polymer-Modified Mix (RHAPMM).

sealing effect properties; these findings are also ratified by Ohama [27] and Kardon [28].

### *3.5. Compressive strength*

The mean cylindrical compressive strength results of the CM, modified mix cast with the replacement of cement with 10% of RHA, and polymer-modified concrete specimens with a dosage of 1–7.5% are shown in Figure 6. Compressive strength of concrete at a 10% cement replacement level with RHA is 23.64 MPa, which is 2.78% higher than that of control concrete. By adding polymer dosages to RHA-modified concrete, the results show a slight increase in compressive strength up to 5% inclusion of the polymer. However, the compressive strength decreases with the further addition of polymer dosage. Maximum compressive strength obtained at 10% cement replacement with RHA with 5% addition of re-dispersible polymer powder is 24.8 MPa, which is 7.83% more than the CM. An increase in the compressive strength of the polymer-modified concrete is attributed to the pore-filling ability of the polymer, and these findings are supported by the references [29–32].

## 4. Conclusions

This paper put forward a newly conceived technique for improving the durability of rice husk ash-blended concrete by incorporating Re-dispersible Polymer Power (RPP). The main conclusions drawn from this study are given below:

- The ultrasonic pulse velocity of the RHAPMC ranges from 4.24 to 4.26 mm/$\mu$s and that range falls within the prescribed limit, i.e., 3.660–4.575 mm/$\mu$s. This range demarcates the quality of RHAPMC as an excellent one;
- Density of all RHAPMC mixes (with the inclusion of RPP from 1 to 7.5%) was found to be lower than that of control and rice husk ash-blended concrete; however, the density of RHAPMC falls within the range of normal weight concrete;
- A 7.5% RPP dosage added to rice husk ash concrete could be considered as the optimum mix where the maximum reduction in water absorption was 2.5%, which is about 13% and 39% less than that of control mix and rice husk ash concrete, respectively;
- The lowest water penetration depth was found to be 11.5 mm at a 7.5% dosage of RPP, which was 15% and 34% less than that of control concrete and rice husk ash blended concrete, respectively;
- With the addition of RPP dosages of 1 to 5%, the compressive strength of RHAPMC increased to a greater degree than that of the control mix; then, with the further addition of RPP, the compressive strength reduced.


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## Biographies

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