A New Approach to Improve Durability of Rice Husk Ash Blended Concrete with Re-Dispersible Polymer Powder

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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 examine durability properties of Rice Husk Ash Polymer-Modified Concrete (RHAPMC) matrix, the RHAPMC mix of 1:2:3 proportions was used to prepare the 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 the ratio of 1 to 7.5% by the weight of cement. Most common durability related properties, i.e. water absorption, density, water permeability, ultrasonic pulse velocity and compressive strength were experimentally investigated. The results showed a remarkable improvement in durability characteristics in newly developed matrix of rice husk ash polymer modified concrete and could be used as a repair material in aggressive environment.

Keywords: Durability, Polymer, RHA, RHAPMC, Permeability, Water Absorption, Ultrasonic Pulse Velocity.

1. Introduction

Efforts are being made to utilize waste materials, produced from the 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 agrarian by-product of rice crop. RHA could be used as a source of supplementary cementing material in cement concrete and in cement mortar. In USA, RHA is successfully registered in the trade name Agrosilica which gives excellent pozzolanic property [1]. Up to 10% cement replacement, it greatly improves workability and decreases permeability of the concrete [1]. Almost 600 million tonne of rice generates about 20 million tonne of RHA annually [2]. In Pakistan, rice is considered to be one of the cash crops and its cultivation is around 6.64 million tonne in the year 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 it has SiO₂ 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 of non-crystalline silica from the husk involves a proper burning [6]. RHA particles are porous and have a honeycombed microstructure [7], as a result, the specific surface area of RHA is enormously high, which is 50 to 100 m²/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 needed in order to achieve 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 in comparison to coarse RHA and normal concrete. However, attaining ultra-fineness of RHA involves extra efforts in terms of cost and time. In addition to this, permeability is considered to be as important as compressive strength of cement concrete and mortar. Adding more water as per more demand of RHA 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]. Inclusion of polymeric compounds in mortars and concretes may or may not have a significant effect on compressive strength [11-13] but it has significant impact on permeability of cement concrete and mortar. Ramli and Tabassi [14] concluded that by incorporating 15% of polymer latexes, the inbred properties of ordinary cement mortar can be enhanced approximately 4 to 5 times.

In this paper, an attempt is made to introduce an entirely new technique of improving durability property of RHA blended concrete by using re-dispersible 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 improved properties of the newly developed composite. To the authors’ best of 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 having maximum size of 4.75 mm and 19 mm have been used respectively. In Rice husk ash blended concrete, 10% of cement was substituted with the extracted RHA. The 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 unit weight of 550 kg/m$^3$, its particle size is 4% retained on 400 µm. It alters the basic chemistry of cement by emulsification. The Peramin Sulfonated Melamine Formaldehyde has been utilized as plasticizer to enhance workability of concrete. Silicon dioxide in RHA as shown in Table 1 is 91.74% which meets requirement as pozzolanic material as per ASTM 618-03. The authors are of the view that RHA polymer modified concrete presented in this study is newly developed composite.

Place Table 1 here.

2.2 Experimental Program

2.2.1 Concrete Mix

A concrete mix design having 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 with slump range of 25 to 50 mm was used to investigate the durability related properties of RHAPMC. For studying durability aspects, concrete mix was prepared, i.e. Control Mix (CM); 10% RHA substituted with cement in Rice Husk Ash Modified mix (RHAMM) and Rice Husk Ash Polymer-modified Concrete mix (RHAPMM1-RHAPMM7.5) with inclusion of polymer at the ratio of 1 to 7.5% by the weight of cement as shown in Table 2. It is to be noted that when 10% of cement was replaced with RHA, the compressive and tensile strength of the mix was equal to that of control mix. The slump of control mix, at 10% replacement of cement with RHA and at the addition of 7.5% dosage of RPP is 30, 26 and 37 mm, respectively.

Place Table 2 here.

2.2.2 Ultrasonic Pulse Velocity
For determination of Ultrasonic Pulse Velocity, a total of 30 number cubes of sizes 100 x 100 x 100 mm were cast by using mix design and de-moulded after 24 hours. The control mix (unmodified) and Rice husk ash modified concrete 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 kept in air for 21-days for air dry curing as per JIS A 1171-2000 [16]. Ultrasonic pulse velocity of each specimen was determined by using Ultrasonic Non-Destructive Digital Indicating Tester (Pundit) [17].

2.2.3 Density and Water Absorption
For evaluation of density and water absorption capacity of the mix, cylindrical concrete samples of size 150 x 300 mm were cast to determine the density of each mix. After de-moulding all the specimens were prepared, de-moulded and cured as specified in section 2.2.2. Density and water absorption of each specimen was determined as per ASTM C1754 [18] and ASTM C1585 [19] standards, respectively.

2.2.4 Water Penetration
Specimens were prepared, de-moulded and cured as specified in section 3.22. Water pressure of 0.5 MPa was applied for the period of 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 specimen of size 150 x 300 mm were cast and were kept in curing tank for curing. The control mix (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 kept in air for 21 days for air dry curing as per JIS A1171-2000 [16].

3. Results and discussion
3.1 Ultrasonic Pulse Velocity (UPV)
It is an additional imperative characteristic of concrete which represent its porosity and density. In order to verify the taxonomy of RHA, Scanning Electron Microscopy (SEM) was performed. The SEM results obtained at various resolution show that the RHA is multifaceted, angular with micro absorbent surface, having high specific surface, Figure 1(a-e).

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

Place figures 1 (a-e)

Place figure 2

3.2 Density

Densities of control mix, 10% cement replacement with RHAMM and RHAPMM with incorporation of polymer from 1 to 7.5% were determined at 28-days. As shown in Figure 3, the density of rice husk ash-modified mix is less than that of control mix. The decreased density of rice husk ash-modified is mainly due to the low specific gravity of the ash. As shown in Figure 3, the inclusion of RPP in the RHA blended concrete causes further reduction in the densities of rice husk ash polymer-modified mixes because of air entrapping characteristic of the polymer from the environment, such findings are validated by [22]. It is remarked that the density of RHA polymer modified specimens ranges from 2377.92 to 2406.23 kg/m³ which comes within the limit of density of normal concrete [23].
A comparison is drawn between the UPV and densities of the mixes and is shown in the Figure 3. It can be interestingly observed that on the one hand the density of RHAPMC is decreasing and on the other hand the quality of concrete, in terms of UPV, is improved because of sealing of pores by the polymer.

**Place Figure 3.**

**3.3 Water Absorption**

Water absorption results of the all mixes are shown in Figure 4. The figure shows the water absorbing capacity of 10% cement replaced concrete (i.e. RHAMM) is increased with respect to control mix because of following reasons. The first reason is 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 the ash is one of the water absorbing materials in nature and when the ash is blended in concrete, it leaves interconnected voids in the concrete. It is clear in the figure when polymer re-dispersible powder was added in rice husk ash modified concrete; a reduction in the water absorption capacity of the concrete is noticed. This is because larger pores are filled and blocked by the cement modifier or sealed by the continuous polymer films that give rise a higher connectivity of the porous network as compared to non modified mortar [11, 24] thereby forming of a network structure having finer porosity. Moreover, polymer is deemed to be water-impermeable material that distributes in the pores of the concrete and results in blocking the water to ingress in interconnected voids [11]. As shown in Figure 4, the water absorbing capacity of rice husk ash-modified mix is 4.1% with an increase of 43.36% from the control mix. The increasing water absorbing capacity of rice husk ash-modified mix is primarily due to reduction in its density. The decreasing trend of density of RHA modified mix illustrates that the quality of the mix, in terms of porosity, is affected due to the addition of RHA and thus the decreased density causes decreasing impermeability. Furthermore, the water absorbing capacity of rice husk ash-modified mix is reducing with further addition of re-dispersible polymer powder. With the addition of 7.5% of RPP in RHA modified concrete, the maximum water absorbing capacity is 2.5 % (with
12.59% less) as compared to control concrete mix has been noticed. It means that the quality of concrete is improved with the inclusion of RPP.

Place Figure 4.

3.4 Water Permeability
Water penetration results of the all mixes are shown in Figure 5. The figure shows a plot of water penetration depth of control mix (CM), 10% cement replaced with RHA modified mix (RHAMM) and Rice husk ash polymer modified concrete mixes (RHAPMC). The permeability of RHAMM is increased than that of the CM because RHA is more water absorbent in nature. The ash requires more water for mixing in concrete and mortar mixes. At the hardened stage when water dries out it leaves a porous medium in the concrete there by causing a less dense concrete. By incorporating more quantity of polymer in the RHA concrete, the impermeability characteristics of the all mixes was increased. On the one hand, total porosity of the concrete increased with the addition of RPP due to the entrained air generated in the mixing process and 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, permeability of rice husk ash-modified mix increases about 30% than that of control mix. The increasing permeability trend of husk ash-modified mix illustrates that the porosity of RHA mix is affected due to the substitution of the cement with the ash and thus the decreased density causes decreasing impermeability. A remarkable increase in the water impermeability of the rice husk ash-modified mix has been observed with the addition of varying percentage dosages of RPP. At 7.5% dosage of RPP, the rice husk ash polymer-modified mix becomes more impermeable with an increase of about 15 & 34% water impermeability than that of as control and rice husk ash-modified mix respectively. This is because the impermeable characteristic of the modified mixes increases due to fact that the polymer has the pore-filling and sealing effect property, such findings are also ratified by Ohama [27] and Kardon [28].

Place Figure 5
3.5 Compressive Strength

The mean cylindrical compressive strength results of the control mix, modified mix cast with replacement of cement with 10% of RHA and polymer modified concrete specimens with dosage from 1-7.5 % are shown Figure 6. Compressive strength of concrete at 10% cement replacement level with RHA is 23.64 MPa which is 2.78 % higher than that of control concrete. By adding various polymer percentage dosages in RHA-modified concrete, the results show a slight increase in compressive strength up to 5 % inclusion of the polymer. However, the compressive strength is decreased with 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 as compared to the control mix. The increase in compressive strength of the polymer modified concrete is attributed to the pore-filling ability of the polymer and such findings are supported by the references [29-31].

4. Conclusions

This paper describes a newly conceived technique for improving durability of rice husk ash blended concrete by incorporating re-dispersible polymer powered. The main conclusions drawn from this study are:

- The ultrasonic pulse velocity of the rice husk ash polymer–modified concrete ranges from 4.24 to 4.26 mm/µs and that range falls within the prescribed limit, i.e. 3.660-4.575 mm/µs, such range demarcates the quality of RHAPMC as excellent one.
- Density of all RHAPMC mixes (with the inclusion of RPP from 1 to 7.5%) is less than that of control and rice husk ash blended concrete, but density of RHAPMC falls within the range of normal weight concrete.
- 7.5% dosage of RPP in rice husk ash concrete is the optimum mix, at which the maximum reduction is water absorption is 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 is found as 11.5 mm at 7.5% dosage of RPP which is 15% and 34% less than that of control concrete and rice husk ash blended concrete, respectively.

The compressive strength of RHAPMC is increased as compared to control mix with addition of RPP dosages from 1 to 5% and on further addition of RPP, the compressive strength is reduced.

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Biography of Authors

Daddan Khan Bangwar worked in different government organizations as “Construction Engineer” and “Assistant Manager” Civil Works. He has been working as an Assistant Professor in Civil Engineering Department at Quaid-e-Awam University of Engineering, Science & Technology since 2010. He did his Bachelor in Civil Engineering in 2001 from Muet Jamshoro, did his Master in Engineering in 2011 in the field of Structural Engineering from NED Karachi, and he did his Doctor of Philosophy (PhD) in 2016 from QUEST Nawabshah. His Research interests include “Structural Engineering, Concrete and Mortar, Supplementary Cementing Materials and Polymer Modified Concrete and Mortars.

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**Figure captions**

Figure 1(a) SEM image @ 20 kV X 100 100µm of RHA particles.

Figure 1(b): SEM image @ 20 kV X 100 500µm of RHA particles.

Figure 1(c) SEM image @ 20 kV X 500 50µm of RHA particles.

Figure 1(d) SEM image@ 20 kV X 300 50µm of RHA particles.

Figure 1 (e) SEM image@ 20 kV X 100 100µm of RHA particles.

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).
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).

Table captions

Table 1: Chemical Properties of RHA

Table 2: Concrete Mix design of CM, RHAMM and RHAPMM as per ACI211.1-91.
Figures

Figure 1(a)
Figure 1(b):

Figure 1(c)
Figure 2
**Figure 3:**

[Graph showing water absorption for different concrete types: CM, RHAMM, RHAPMM1, RHAPMM2.5, RHAPMM5, RHAPMM7.5. Water absorption values range from 2.5 to 4.3%.]

**Figure 4**
Figure 5:

Figure 6:
### Tables

#### Table 1

<table>
<thead>
<tr>
<th>Elements of RHA (%)</th>
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<tr>
<td>SiO₂</td>
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#### Table 2

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<th>S. No</th>
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<th>RPP TotalBinder/kg m³</th>
<th>Plasticizer/kg m³</th>
<th>Water/kg m³</th>
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<td>2</td>
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<td>205.8</td>
<td>692</td>
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<tr>
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Average of five specimens was taken. CM= Control Mix, RHAMM= Rice Husk Ash Modified Mix, RHAPMM1to 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).