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EFFECT OF USING RICE HUSK ASH AS PARTIAL REPLACEMENT OF CEMENT ON PROPERTIES OF FRESH AND HARDENED CONCRETE

Ali AJWAD [a], Sameel AHMAD [b], ABDULLAH [c], Syed Taseer Abbas JAFFAR [d]*, Usman ILYAS [a], Muhammad Ahmad ADNAN [a]

[a] Assistant Prof., MSc; Department of Civil Engineering, School of Engineering, University of Management and Technology, Lahore Punjab 54770, Pakistan

[b] MSc; CES Professionals, Lahore, Punjab, 54770, Pakistan

[c] MSc; Department of Civil Engineering, School of Engineering, University of Management and Technology, Lahore Punjab 54770, Pakistan

[d] Assistant Prof., PhD; Department of Civil Engineering, School of Engineering, University of Management and Technology, Lahore Punjab 54770, Pakistan
*Corresponding Author: *taseer.jaffar@umt.edu.pk*

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Abstract
Rice husk disposal has become a great challenge for Pakistan being one of the largest rice producer across the globe. Rice Husk Ash (RHA) contains sufficient pozzolanic properties which opens up opportunities for its usage as cementitious material as partial replacement of Ordinary Portland Cement (OPC). In this research RHA was added as cement replacement in different percentages by weight of cement i.e. 0%, 6%, 12%, 18% and 24% at constant mix ratio of 1:2:4 and water-cement ratio of 0.6 that is M15 grade concrete with a target strength of 15-20 MPa. The properties of concrete like workability, compressive strength, tensile strength, flexure strength, and water permeability were investigated by casting standard concrete samples in the form of cubes, cylinders and beams in addition to cost comparison study The outcomes show that workability of fresh concrete increases with an increase in RHA content and almost all concrete properties studied in this research gave more favorable results at 6% replacement level compared with the control mix.

Keywords: **Rice Husk, Pozzolana, Brick kiln, Workability, Tensile strength, Compressive strength, Permeability, Flexural strength.**

1. INTRODUCTION

Pakistan is the 14th largest producer of the rice crop and its yearly production of rice paddy is 9.4 million tons while that of milled rice is about 6.7 million tons. The total yield of rice husk is approximately 1.9 million tons per annum, the disposal of which is a great challenge. The main dumping of waste rice husk is in paper manufacturing where the boilers are run by burning it or it is used in burning kilns as fuel for production of brick masonry [1]. Keeping in view day by day increasing price of building constituents like cement, a good choice can be to utilize natural waste products in construction materials in order to save cost and introduce economy in construction without compromising on quality [2]. Many researches have concluded so far that little quantity of inert fillers can be used as cement replacement material, but the replacing material should be pozzolanic in nature [3]. It won't just grant specialized preferences to the subsequent concrete but additionally permits accomplishment of concrete replacement in greater quantities. There are many focal points in utilizing pozzolans in concrete [4]. Pozzolans improve workability at little replacement stages and through pozzolans of small carbon percentages, reduced segregation and bleeding, results in low hydration heat as well as low creep and shrinkage [5]. Rice husk ash has been found suitable for masonry mortar, foundation concrete and mass concrete work [6]. Being a finely isolated powder comprising of silica-alumina glass of different structures, RHA in solid capacities as filler between cement grains and aggregate, and as a powerful folio giving a cementitious property [7]. RHA can also be used in concrete as a corrosion deterrent material [8]. In 2012, Maurice included RHA in concrete and discovered that it brought about expanded water request, increment in workability and improved quality contrasted with the control test. He also concluded that by the addition of 5-10% RHA, compressive strength of concrete increases while on further addition up to 20%, compressive strength decreases by 15% of control mix [9]. Sandesh found out that unit weight of concrete decreases with the increase of rice husk ash content [10]. Satish Kumar concluded in 2012 that RHA concrete involves more volume than typical concrete for a similar weight. So the aggregate volume of the rice husk powder concrete increments for a specific weight when contrasted with ordinary concrete which brings about economy [11]. Alireza and Suraya claimed that RHA blended concrete is associated with improved workability, compressive strength, tensile strength and flexure strength [12]. In 2010, Uduweriya found that execution of the concrete would rely on upon fineness of the RHA. The finesses of RHA would expand the compressive quality and part rigidity of the concrete. By addition of 20% RHA, compressive strength increases by 18% and split cylinder strength increases by 20% of control mix. Such properties can be hard to accomplish with utilization of unadulterated Portland cement alone [13]. Pravin et al. stated that compressive quality increments with the expansion in the rate of Rice Husk Ash up to expansion of 12.5% by weight of cement. It was found that when Rice Husk burns properly, produces more than 80% of silica. Hence it gives phenomenal warm protection [14]. Kartini emphasized the review led on RHA in deciding the reasonableness to concrete substitution material. The compressive quality, workability and sturdiness execution of Grade 30, Grade 40 and Grade 50 N/mm^2 concrete with incomplete bond substitution of RHA were accounted for [15]. Chik introduced a lab considered on the impact of gasses burning rice husk fiery debris on properties of concrete block and discovered that the compressive quality of the OPC and RHA concrete pieces increments with age at curing and abatements as the rate of RHA substance increments. The review touched base at an ideal substitution level of 15% [16]. "S.A. Zareei et al. introduced various ratios of rice husk ash (RHA) on concrete indicators using different mix proportions of 5, 10, 15, 20, and 25% RHA by weight of cement along with 10% micro- silica (MS) for comparison with 100% Portland cement". The findings of the tests revealed an optimistic relationship between 15% RHA replacement and a 20% improvement in compressive strength. The optimum level of strength and durability properties are normally gained with an increase of up to 20%, with a minor fall in strength parameters of around 4.5 percent after that. The same outcomes are expected to be unfavorable for water absorption ratios. In comparison to baseline values (less than one fifth), chloride ions penetration increased by roughly 25% with increased cement replacement [17]. J. Alex et.al developed a Taguchi L27 fractional-factorial matrix to analyze the key process indicators like RHA size, curing time, RHA loading, bulk density and pozzolanicity. According to the findings, mechanical strength enhanced as Rice Husk Ash size decreased, and 20 wt% Rice Husk Ash replacement is optimal for 15 and 60 min grounded samples [18]. R. Bhushan et al. investigated the possibility of using partial rice husk ash into cement in order to address concerns of pollution, price, quality and availability. Solid masonry blocks of size 150×150×15 of M20 grade were produced by replacing cement with Rice Husk Ash by weight at 0%, 5%, 10%, 15%, 20%, 25%. After 7 days of curing in water, the cubes were ready for testing. Strength properties, workability and cost analysis were all investigated. The test findings indicated that the workability and strength of the concrete are to some extent improved comparing to normal concrete, as long as the limitations established by the standard are met. Cost savings of 3.08% was also noticed compared to reference values [19]. Wide studies have been carried out worldwide indicating that RHA can be beneficially utilized in concrete; however, the potential of very cheaply available Pakistani Rice Husk Ash to be used as cement replacement material was still demanding attention, however, very limited amount of research has been done on local rice husk ash. This investigation was planned:

a. studying the physical and mechanical properties of fresh and hardened concrete by adding in 0%, 6%, 12%, 18% and 24% of RHA.
b. studying the effect on cost and quality of M15 grade [20] concrete cast by using RHA in partial replacement of cement.

In the light of results from this research, a complete figure will be available regarding the effect of partial replacement of cement by local Rice Husk Ash on properties of fresh and hardened cement and concrete.

2. EXPERIMENTAL INVESTIGATION

2.1. Materials:

Different materials that were used in the research conducted are described below.

2.1.1. Cement

Ordinary Portland cement (Type I) was used in this research which belonged to one of the leading brands of Pakistan namely "Bestway cement". Its chemical compositions as well as physical properties are shown in Table 1.

Table 1.
Composition of OPC and RHA

Chemical composition (%)	OPC	RHA
Silicon dioxide (SiO_2)	22.0	77.34
Aluminum oxide (Al_2O_3)	5.50	6.92
Ferric oxide (Fe_2O_3)	3.50	4.89
Calcium oxide (CaO)	64.25	3.56
Magnesium oxide (MgO)	2.50	1.59
Sulfur trioxide (SO_3)	2.90	0.34
Sodium oxide(Na_2O)	0.20	1.27
Potassium Oxide (K_2O)	1.00	2.69
Loss on ignition	0.64	4.81
Physical properties		
Specific gravity	3.04	2.13
Specific surface (m^2/kg)	308	600
Compressive strength 3 days (MPa)	20.76	
7 days	31.89	
28 days	39.41	
56 days	42.52	
Consistency (%)	29.25	
Initial Setting Time (min)	110	
Final Setting Time (min)	228	

Table 1 compares the properties of ordinary Portland cement and Rice husk ash and it clearly indicates that RHA contains more than 70% of (SiO_2+Al_2O_3+Fe_2O_3) content, thus fulfils requirement to be used as pozzolana as per ASTM C 618:2003.

2.1.2. Fine Aggregate

The fine aggregate utilized was Lawrencepur sand. Sieve analysis was completed by using ASTM C136-06. Results are shown in Table 2 and comparison gradation curve is demonstrated in Figure 1. Fineness modulus was ascertained as the aggregate of total rates held on sieves and it was computed as 1.66. The specific gravity of sand was calculated as 2.71 (ASTM C128-79). Water absorbed by sand during 24 hours immersion was noted as 1.20%.

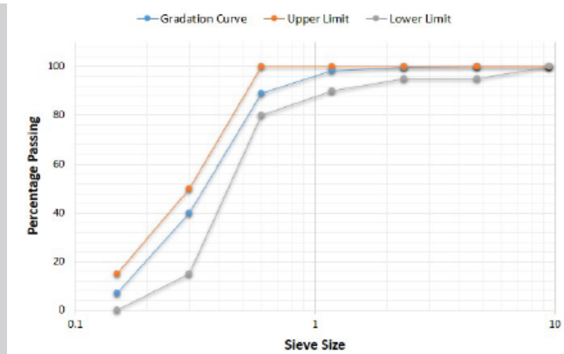

Figure 1.
Gradation curve of fine aggregates

2.1.3. Coarse Aggregate

Best quality Margalla crush was used in the research. Sieve analysis of coarse aggregate was performed as per ASTM C 136-06 to show the grading of coarse aggregates and figure 2 presents the results obtained. The specific gravity test was also carried out, conforming to ASTM C 127-81, which gave specific gravity of coarse aggregate as 2.68. The water absorbed by coarse aggregate during 24 hours immersion was found to be 0.80%. The moisture content of coarse aggregate measured as per ASTM C 566-78 was found to be only 1%. So, it was assumed that aggregates were dry, as the moisture content was below 10%.

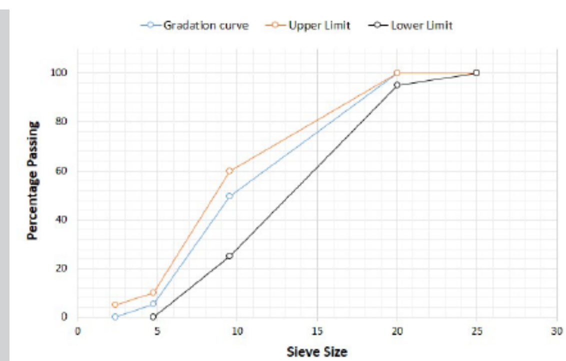

Figure 2.
Gradation curve of coarse aggregates

2.1.4. Water

The water used for mixing of concrete was ordinary tap water of. The chemical analysis report of water proved it to be fit for drinking as per World Health Organization (WHO) standards.

2.1.5. Rice Husk Ash

The RHA was obtained from standard block kiln situated near Lahore, Pakistan, where rice husk is regularly burnt for burning of bricks. The ash was brought to laboratory, cleared from debris and other unwanted materials manually and then passed from sieve #4 first and then through sieve #40 for further refining. Material was then ground in a laboratory ball mill for considerable time until it gave sufficient fineness. Chemical analysis of finally prepared RHA was carried out by XRF-Cement Spectrometer in the chemical lab of Local Cement factory. The results of chemical analysis are shown in Table 1. Specific gravity of collected RHA was found to be 3.11. The X-Ray Diffraction analysis of RHA sample was carried out and shown in Fig. 3. Scanning Electron Microscope (SEM) test was also performed and the results are shown in Figure 4. As RHA is a very fine material, its fineness was found using sieve analysis (ASTM C 184-76) and Blaine's Air Permeability Apparatus (ASTM C 204-94). By sieve analysis, it was found that percentage retained on sieve #200 was 10 and specific surface area was found to be exact 600 m^2/kg by Blaine's Air Permeability apparatus. According to chemical analysis results shown, collected RHA has high level of silica i.e., sample contains more than 70% of (SiO_2+Al_2O_3+Fe_2O_3) content, thus fulfils requirement to be used as pozzolana as per ASTM C 618:2003. The X-Ray Diffraction (XRD) report for RHA can be seen in figure 3 and Scanning Electron Microscope (SEM) images for samples can be seen in Fig. 4.

The XRD graph of ground RHA confirms the presence of Quartz mainly in the form of crystalline. The SEM micrograph shows that RHA has multilayered, angular and micro porous surface, which explains its high specific surface area.

2.2. Casting schedule

Six concrete mixes were cast by adding RHA as cement replacement material in different ratios by weight of cement i.e, 0%, 6%, 12%, 18% & 24%. Concrete mix with 0% RHA was declared as control mix. Results of different tests performed on other mixes were compared with those on control mix to ascertain characteristics of RHA blended concrete. Complete casting schedule and details of test specimens are presented in Table 2. After casting, test specimens were de-molded after 24 hours and were kept in the curing tanks until the specified time of testing.

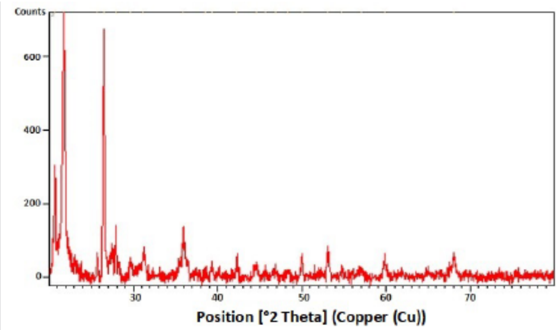

Figure 3.
XRD report of RHA sample

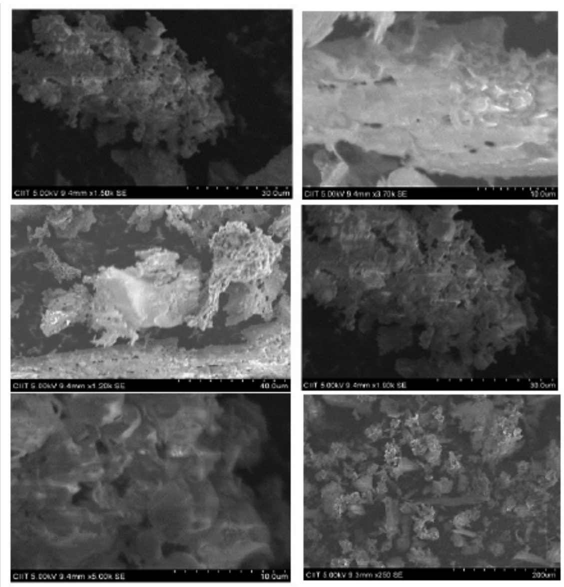

Figure 4.
SEM images of RHA sample

2.3. Mix design

RHA is used as partial replacement of OPC in different percentages by weight of cement i.e. 0%, 6%, 12%, 18% and 24% at constant mix ratio 1:2:4 and water binder ratio 0.6. Total weights of the material mix are shown in Table 3. After casting, test specimens were de-molded after 24 hours and were kept in the curing tanks until the specified time of testing.

Table 2.
Casting schedule and details of test specimens

Test details	Specimen details	Age (days)				Total for (1 mix)	Total (5 mixes)
		3	7	28	56		
Compressive strength	Cubes (150 × 150 x 150 mm)	3	3	3	3	12	60
Split cylinder test	Cylinders (150 mm high × 300 mm dia.)	3	3	3	3	12	60
Flexural strength test	Beams (100 × 100 × 500 mm)	-	-	3	-	3	15
Water permeability test	Cube (96.8 mm × 96.8 mm × 150 mm)	-	-	3	3	6	240 (48 for each mix)
	Cube (146.9 mm × 146.9 mm × 150 mm)	-	-	3	3	6	
	Cylinder (96.8 mm high × 150 mm diameter)	-	-	3	3	6	
	Cylinder (146.9 mm high × 150 mm diameter)	-	-	3	3	6	

Table 3.
Weights of the material mix

Mixture No:	Mixture Type	Water (kg)	OPC (kg)	Rice Husk Ash (kg)	Sand (kg)	Coarse Aggregates (kg)	Slump flow (mm)
SM1	OPC	33.10	55.17	0	111.42	222.86	95
SM2	6% Replacement	33.10	51.84	3.31	111.42	222.86	105
SM3	12% Replacement	33.10	48.55	6.62	111.42	222.86	112
SM4	18% Replacement	33.10	45.24	9.93	111.42	222.86	123
SM5	24% Replacement	33.10	41.93	13.24	111.42	222.86	135
	Total	**139.25**	**242.75**	**33.1**	**557.1**	**1114.3**	

3. RESULTS AND DISCUSSION

3.1. Characteristics of RHA

According to chemical analysis results shown in Table 1, collected RHA has high level of silica i.e., sample contains more than 70% of (SiO_2+Al_2O_3+Fe_2O_3) content, thus fulfils the requirement to be used as pozzolana as per ASTM C 618:2003. The XRD graph of ground RHA (Fig. 3) confirms the presence of quartz mainly in the form of crystalline. The SEM micrograph (Fig. 4) shows that RHA has multilayered, angular and micro porous surface, which explains its high specific surface area.

3.2. Workability

The workability of concrete for specified replacement levels of RHA, at constant mix and water-cement ratio, was measured by slump test and results are shown in Figure 5. There is a slight increase in the workability of concrete as replacement level increases for 0% to 24%. These results are very much similar to what Maurice determined in 2012 [9]. Molding of test specimens and handling of RHA blended concrete show plasticizing effect of fine particles in increasing the mobility of aggregates in the concrete. So it is concluded that RHA is more plastic and leads to more economical and easier placing of concrete.

3.3. Compressive strength

The results of compressive strength test are plotted in Fig. 5 which show that for all ages, compressive strength of concrete samples is maximum at 6% replacement level and for greater replacement levels it is less which are in-line with study conducted by Alireza in 2010 and Zareei in 2017 [12]. The same is also clear from Fig. 7 which shows Box Whisker Plots of overall compressive strength at all ages.

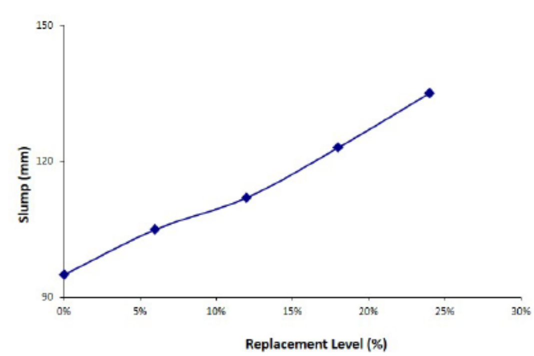

Figure 5.
Replacement level versus slump of concrete

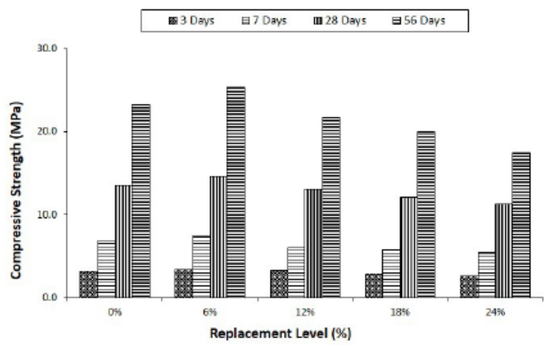

Figure 6.
Replacement level versus compressive strength at different ages

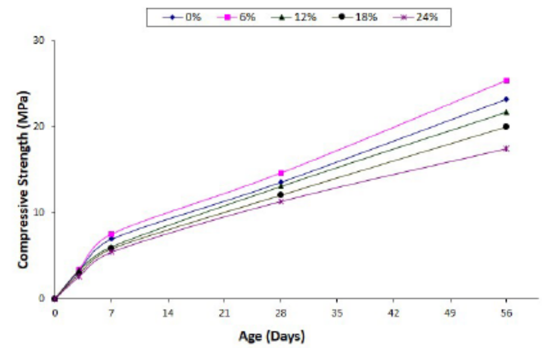

Figure 8.
Rate of gain of compressive strength of concrete with age

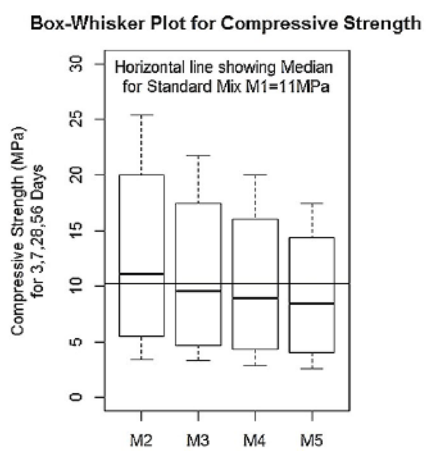

Figure 7.
Box Whisker plot for compressive strength at all ages

Table 4 shows strength activity index of concrete samples for all ages after partial replacement of cement by RHA. Figure 8 presents the rate of gain of compressive strength of concrete samples with age. These clearly indicate that gain of strength for 6% replacement dominates 0% replacement level (control mix) right from the early age. As the age increases, the pattern of strength gain for 6% replacement is nearly constant but higher than 0% replacement. For other replacement levels the gain in strength is below 90% of control mix, but the trend is nearly same.

The results also show that at early ages, the strength is comparable at replacement level of 6%. The strength at the age of 28 days for the same level of replacement is higher than the control sample. This is due to the fact that the higher fineness of RHA allowed it to increase the reaction with $Ca(OH)_2$ to produce more calcium silicate hydrate (C-S-H) resulting in higher compressive strength. Additionally the finer RHA particles contribute to the strength development. The optimum replacement level therefore comes out to be 6% by weight of cement with corresponding compressive strength as 3.380 MPa at the age of 3 days, 7.535 MPa at the age of 7 days, 14.640 MPa at the age of 28 days and 25.404 MPa at 56 days.

3.4. Tensile strength

The tensile strength of concrete is measured by split cylinder test and results are illustrated in Table 5 and Figures 9, 10 & 11.

Table 4.
Strength Activity Index of concrete samples

Strength Activity Index								
Ratio	3 Days		7 Days		28 Days		56 Days	
	Compressive Strength (MPa)	S.A.I	Compressive strength (MPa)	S.A.I	Compressive strength (MPa)	S.A.I	Compressive strength (MPa)	S.A.I
0%	3.229	100.0	6.932	100.0	13.563	100.0	23.251	100.0
6%	3.380	104.7	7.535	108.7	14.640	107.9	25.404	109.3
12%	3.294	102.0	6.050	87.3	13.090	96.5	21.744	93.5
18%	2.885	89.3	5.813	83.9	12.056	88.9	20.022	86.1
24%	2.583	80.0	5.425	78.3	11.303	83.3	17.438	75.0

Table 5.
Split cylinder strength activity index of concrete

	Split cylinder strength activity index							
Ratio	3 Days		7 Days		28 Days		56 Days	
	Split cylinder strength (MPa)	S.A.I	Split cylinder strength (MPa)	S.A.I	Split cylinder strength (MPa)	S.A.I	Split cylinder strength (MPa)	S.A.I
0%	0.953	100.0	1.179	100.0	1.891	100.0	3.358	100.0
6%	1.000	105.0	1.281	108.7	2.124	112.3	3.563	106.1
12%	0.863	90.6	1.014	86.0	1.275	67.4	3.049	90.8
18%	0.884	92.8	0.932	79.1	1.597	84.4	2.844	84.7
24%	0.836	87.8	0.891	75.6	1.329	70.3	2.570	76.5

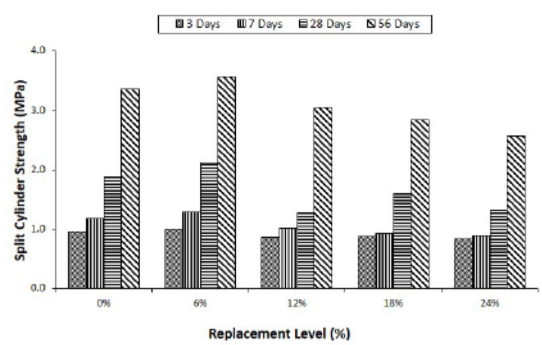

Figure 9.
Replacement level versus split cylinder strength of concrete

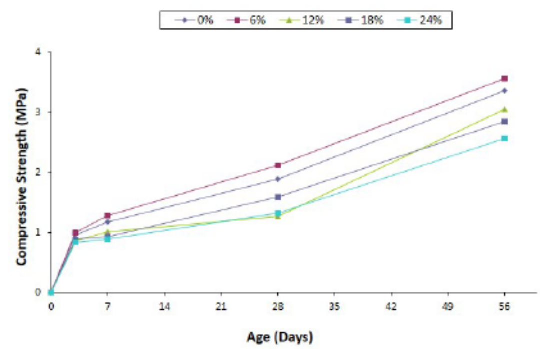

Figure 11.
Rate of gain of split cylinder strength of concrete with age

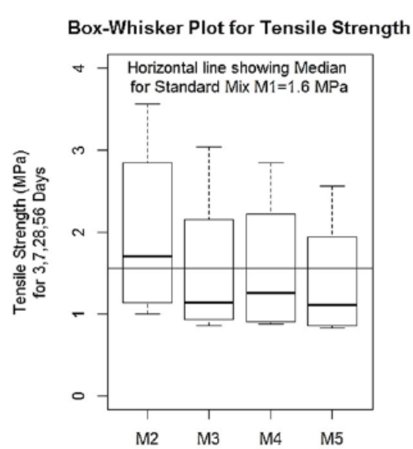

Figure 10.
Box Whisker plot for Tensile strength at all ages

Figure 9 presents the split cylinder strength of blended concrete cylinders at different ages whereas Fig. 10 shows box whisker plots for overall tensile strength at 3, 7, 28, & 56 days. It is concluded that again tensile strength of concrete is highest at 6% replacement of cement by RHA. The same discussion may follow here as done in case of compressive strength. The strength at optimum replacement level i.e. 6% is 1.0005 MPa at the age of 3 days, 1.2814 MPa at the age of 7 days, 2.1243 MPa at the age of 28 days and 3.5633 MPa at the age of 56 days. Figure 11 reveals the trend of rate of gain of tensile (split cylinder) strength of concrete casted by blended cement. It is clearly shown that the pattern of increase in strength for all replacement levels is almost similar but at early ages i.e. from 3 days to 7 days it is abruptly high for replacement levels 0% and 6%. However, after 7 days all samples follow the same pattern of strength gain.

3.5. Modulus of rupture

The modulus of rupture was experimentally measured by three point loading test, and results are illustrated in Fig. 12. It shows the test results of 3 point load test carried out to determine the flexural strength of concrete beams. It reveals that the trend of strength gain is similar to other test results i.e. 6% replacement level gives better strength as compared to 0% (control mix) replacement level. But for all other replacement levels the difference in flexural

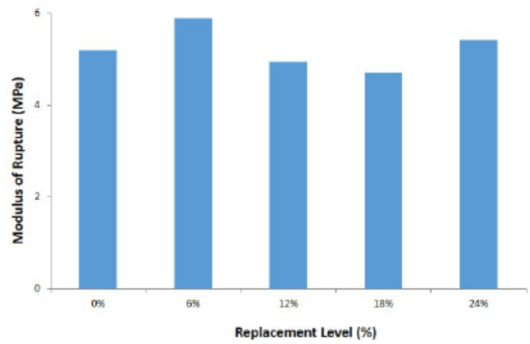

Figure 12.
Replacement level versus modulus of rupture of concrete

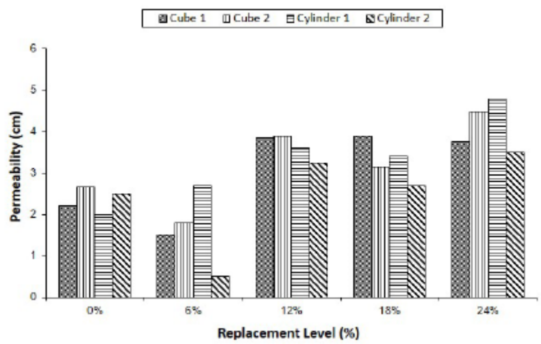

Figure 13.
Replacement level versus water permeability through concrete

strength is not significant as strength lies between 4 MPa to 6 MPa.

3.6. Water permeability

Water permeability of concrete was checked by the water penetration test at the age of 28 days. The results are graphically presented in Fig. 13 which revealed that water penetration decreases as the replacement ratio is 6% of cement by weight than control mix. This is so because the pores in concrete are filled by the finer particles of RHA, and the penetration of water reduces. But as the replacement level increases the water penetration increases, due to reduction of binder content in concrete. This outcome strengthens Maurice discovery regarding enhanced water demand of RHA reinforced concrete [7]. However the reduction of water penetration at 6% replacement level is greatly reduced.

3.7. Cost comparison

As concrete is the basis of construction industry, any sort of change in the cost of concrete can affect the budget of whole project. In order to perform a cost comparison between normal concrete and 6% RHA blended concrete 1 m^3 (35.31 cft) concrete has been considered. By taking mix ratio of 1:2:4 and water-binder ratio 0.6, quantities of materials have been calculated both in cft and kg for ease. The detailed comparison is given in Table 6. It is clear that in addition to the enhanced characteristics of 6% RHA blended concrete; it is 2.2% cheaper than normal concrete while 6% RHA blended cement is 6% cheaper as compared to pure cement. Similar sort of saving of around 3% was also concluded by Bhushan in his 2017 study which ensures that using RHA as cement replacement does contribute to cost-cutting with added benefits [19].

Table 6.
Cost comparison between normal and blended concretes

Items		Quantity of concrete	Quantity of cement	Quantity of RHA (6%)	Quantity of fine aggregates	Quantity of coarse aggregates
Weight of materials	Raw concrete	1 m^3 (35.31 cft) 2415 kg	8.62 cft 345 kg	---	15.73 cft 690 kg	31.47 cft 1380 kg
	Blended concrete	1 m^3 (35.31 cft) 2415 kg	8.10 cft 324.3 kg	1.38 cft 20.7 kg	15.73 cft 690 kg	31.47 cft 1380 kg
Cost of materials	Raw concrete	USD 21.57/-	USD 13.80/-	---	USD 2.0/-	USD 5.77/-
	Blended concrete	USD 21.09/-	USD 12.97/-	USD 0.35/-	USD 2.0/-	USD 5.77/-
	Difference in cost	USD 0.47/- (2.2% of normal concrete)	USD 0.82/- (6% of pure cement)	---	---	---

4. CONCLUSIONS & RECOMMENDATIONS

4.1. Conclusions

1. There is increase in workability of concrete as the replacement level of cement by RHA increases from 0 to 24%.
2. Compressive, Tensile & Flexure strengths of blended concrete increases at 6% replacement level than for control mix. For all other replacement levels, the gain in strength is not significant as it is even less than control mix.
3. The water permeability of concrete decreases as compared to control mix at 6% replacement level.
4. The use of RHA as pozzolanic material is an environmental friendly option, as it resolves the serious issue of disposing wastes of Rice Husk as well as Rice Husk Ash.
5. It has been seen by cost comparison that in addition to the enhanced characteristics of 6% RHA blended concrete; it is 2.2% cheaper than normal concrete while 6% cheaper as compared to pure cement. Along these lines, minimal effort concrete can be created by substituting RHA as partial substitution of cement without trading off on its attractive parameters.

4.2. Recommendations

6% replacement of cement by Pakistani RHA is hereby recommended for construction industry. It will not only save overall cost of cement but also solve the major environmental issue of disposal of rice husk ash from brick kilns.

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