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STRENGTH AND FLOW BEHAVIOR OF RICE HUSK ASH BLENDED CEMENT PASTE AND MORTAR

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ABSTRACT

In this study, compressive strength and flow behavior for rice husk ash incorporated cement paste and mortar are investigated. The workability is ensured through Marsh cone and flow table tests for rice husk ash blended cement paste and mortar respectively. The test result shows that compressive strength increases with age as expected in all cases and an empirical relationship for compressive strength of blended cement paste and mortar with mix factors such as w/(c+rha) ratio, rha/c ratio and age is also proposed. The estimated compressive strength versus w/(c+rha) ratio curves follows the similar nature of Abrams' strength versus w/c ratio curves.

Keywords: Paste; mortar; RHA; workability; strength

1. INTRODUCTION

A large number of researches have been directed towards the utilization of waste materials. For the construction industry, the development and use of blended cements is growing rapidly. The possible utilization of Rice Husk Ash (RHA) in Portland cement concrete has received attention especially in South East Asia and Pacific primarily for economic, energy and environmental considerations [1]. Since their uses generally improve the properties of the blended cement concrete and particularly RHA has been used as a highly reactive pozzolanic material to improve the microstructure of the interfacial transition zone (ITZ) between the cement paste and the aggregate in high-performance concrete [2, 3]. Rice husk ash improves the properties of concrete or cement paste due to the pozzolanic reaction and its role as a micro-filler. It is often thought that the first function (pozzolanic reaction) is most important. The partial replacement of cement by rice husk ash in cement paste and

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mortar would provide micro-structure improvement, pore filling effect and better packing characteristics of the mixer. The workability of the blended cement paste and mortar is greatly modified due to the finer Pozzolana particles such as rice husk ash, fly ash, silica fume etc. This addition depends both on the quality of rice husk ash and the stipulated requirements of strength and durability. Presently, rice husk ash and cement contents in a mix are determined by laboratory trials. The first requirement to be met is usually the workability of the mixture, which is controlled by the water- cementitious-material ratio. To decide upon the extent to which rice husk ash can be used at the lowest possible water-cementitious-material ratios, different workability tests are conducted to optimize the proportion of rice husk ash.

The workability of the cementitious product has been attained by some compatible water reducing admixtures like super-plasticizers. The cement super-plasticizer compatibility is affected by the following parameters related to the cement: chemical and phase composition, especially C_3A content, alkali content, amount and type of calcium sulphate (dihydrate, bassanite, anhydrite), cement fineness and free lime content. Taking into account the properties of a super-plasticizer, the following factors are of great importance: its chemical nature and average molecular weight, super-plasticizer degree of sulphonation, admixture dosage and addition method [4]. The determination of the optimum dosage of super-plasticizer for blended paste and mortar are generally carried out by different methods such as Marsh cone test, flow table test and mini slump cone test.

According to Kondraivendhan and Bhattacharjee, the strength of cement paste can be estimated from the information of w/c ratio, age and fineness of cement by calculating mean distribution radius ($r_{0.5}$) through a model proposed by them [5]. But in this investigation, an empirical relationship for compressive strength of rice husk ash blended cement paste and mortar as a function of w/(c+rha) ratio, rha/c ratio and curing age is proposed.

In this study, the rice husk ash blended cement paste and mortar specimens are investigated for compressive strength and the foremost workability requirement is carried out by Marsh cone test and flow table test for rice husk ash blended cement paste and mortar respectively. The compressive strength is determined experimentally and a relationship for compressive strength with mix parameters is developed for rice husk ash blended cement paste and mortar specimens as well. The estimated compressive strength of rice husk ash blended cement paste and mortar is plotted against w/(c+rha) ratio for various curing ages and rha/c ratios.

2. EXPERIMENTAL INVESTIGATION

The main objective of this experimental investigation is to study the strength and workability for rice husk ash blended cement paste and mortar. The experimental factors and their levels have been chosen accordingly as follows;

2.1. Materials

2.1.1. Cement

To investigate upon the response of strength improvement and workability, one grade of cement as defined in Indian Standard (IS) was used namely ordinary Portland cement OPC 43 grade conforming to IS 8112:1989 [6] and ASTM Type 1 specifications. The mean particle diameter of cement is 17μ which is determined by laser based Time of Transition method using a particle size analyzer. The physical and chemical composition of cement is given in Tables 1 and 2.

Table 1: Physical properties of ordinary Portland cement

S.No	Characteristics	Results obtained	Requirement as per IS: 8112-1989
1	Normal consistency (%)	29	
2	Initial setting time (min)	115	Min 30
3	Final setting time (min)	165	Max 600
4	Specific gravity	3.15	
5	Blaine's fineness(m^2/kg)	335	Min 225
6	Soundness(mm)	1	Max 10
7	Compressive strength (MPa)		
	3 days	34	Min 23
	7 days	42	Min 33
	28 days	51.5	Min 43

Table 2: Chemical properties of ordinary Portland cement and rice husk ash

Oxide composition	(wt %)	
	ordinary Portland cement	Rice husk ash
Cao	59.98	1.58
SiO_2	21.18	90.23
Al_2O_3	5.36	2.54
Fe_2O_3	3.48	0.21
MgO	2.05	0.53
SO_3	2.8	–
Na_2O	0.36	–
K_2O	0.69	0.39
LOI	2.67	3.57
Carbon	–	2.23
Insoluble residue	2.32	–
Free lime	1.06	–
Water soluble content	–	1.34

2.1.2. Sand

Natural river sand owing to their rounded shape was used in this work as it ensures better packing characteristics than the crushed sand. Locally available two types of river sand having the fineness modulus values of 2.66 and 2.08 were mixed in the proportion of 70% and 30% respectively so as to obtain packing density value of 0.61. The grading of sand satisfies the Indian standard IS: 383-1970 [7] and is given in Table 3.

Table 3: Grading of Sand for cement rice husk ash sand mortar

Sieve size	**Sand (S1) % passing**	**Sand (S2) % passing**	**Blended sand (S1, 70%+ S2, 30%)**
4.75 mm	100	100	100.00
2.36 mm	98	100	98.60
1.18 mm	80	98.28	85.48
600 micron	50	29.17	43.75
300 micron	10.5	5.77	9.08
150 micron	1.5	0.63	1.24
Specific gravity	2.6	2.65	2.65
Bulk density	1.586	1.587	1.583

2.1.3. Ricehusk ash

Rice husk ash obtained from a rice husk ash processing plant in Odisha, India with a specific gravity of 2.3 was used. The mean particle diameter of rice husk ash is 8.3µ which is also determined by laser based Time of Transition method using a particle size analyzer. The particle size distribution of the rice husk ash and its chemical compositions are given in Table 2.

2.1.4. Mix Proportions and experimental factors

In this investigation, mixes have been chosen over a wide range of water to binder ratios namely 0.25, 0.35, 0.45 and 0.55 for cement paste and mortar blended with rice husk ash. Both cementitious paste and mortar specimens are tested at 7, 28 and 90 days. Rice husk ash replacement levels 0 - 40% by weight of cement are implemented. The volume of paste content was 20% greater than the volume of voids of non compacted sand. The mix proportions of rice husk ash blended cement sand mortar are given in Table 4.

Table 4: Mix proportions of rice husk ash blended cement mortar

Cement	rha/c ratio	Sand		w/(c+f) ratio	Cement	rha/c ratio	Sand		w/(c+f) ratio
		S1	S2				S1	S2	
1	0	1.186	0.508	0.25	1	0	1.603	0.686	0.45
1	0.1	1.238	0.530	0.25	1	0.1	1.641	0.703	0.45
1	0.2	1.327	0.568	0.25	1	0.2	1.730	0.741	0.45
1	0.3	1.415	0.606	0.25	1	0.3	1.818	0.779	0.45
1	0.4	1.504	0.644	0.25	1	0.4	1.907	0.817	0.45
1	0	1.394	0.597	0.35	1	0	1.811	0.775	0.55
1	0.1	1.439	0.616	0.35	1	0.1	1.843	0.789	0.55
1	0.2	1.528	0.654	0.35	1	0.2	1.931	0.827	0.55
1	0.3	1.617	0.692	0.35	1	0.3	2.020	0.865	0.55
1	0.4	1.706	0.730	0.35	1	0.4	2.109	0.903	0.55

3. FLOW BEHAVIOR OF CEMENTITIOUS PASTE AND MORTAR

The workability of rice husk ash blended cement paste and mortar are attained by using the optimum dosage of super-plasticizers. The optimum dosage of super-plasticizer is determined by Marsh cone and flow table test for cement blended rice husk ash paste and mortar respectively.

3.1. Marsh cone test

Several commercially available super-plasticizer were investigated upon, through a test scheme to select the most compatible and suitable super-plasticizer. For determining the optimum dosage of super-plasticizer for different water to binder ratios, 1.2 liters of paste were prepared in a standard mortar mixer and were poured in Marsh cone with a nozzle having an opening of 5 mm diameter and 50 mm length. Time taken for the first 200 ml of paste to flow through cone was measured. This is called flow time. The saturation point is obtained from the flow time versus super-plasticizer dosage curves at the dosage value beyond which the super-plasticizer would not decrease the flow time with increase in dosage of super-plasticizer (i.e. super-plasticizer has no further plasticizing effect) [8]. Commercially available Polycarboxylate ether based super-plasticizer namely "CEMWET SP-3000" exhibited minimum flow time and produced a completely dispersed system of paste and the same was chosen and used throughout for different water to binder ratio for cement blended rice husk ash paste. The dimensions of the Marsh cone is given in Figure. 1 and the optimum dosages of super-plasticizer for cement blended rice husk ash paste with corresponding water to binder ratios are presented in Figure. 2.

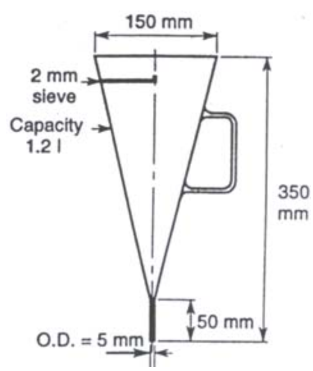

Figure 1. Marsh cone

It is observed that as the water to binder ratio decreases paste mixes tend to become stiff even with super-plasticizer addition as indicated by increase in flow time. So the required flow is fixed as 100 ml. It is worth mentioning at this stage that for the selected dosage of super-plasticizer no segregation was observed at any time. Thus optimum dosages of super-plasticizer were determined for all 20 paste mixes at water cementitious ratios 0.25, 0.35, 0.45 and 0.55 with rice husk ash replacement level of 0, 10, 20, 30 and 40 % for each water cementitious ratio. The time taken for the first 100 ml of paste to flow through the cone is measured. This is called flow time. Three flow time determinations were carried out for each paste and the mean value was used. However as a cross check flow time for 200 ml of paste was measured for water cementitious ratio 0.35 and 0.45 it was observed that optimum dosages remains same. The super-plasticizer for water cementitious ratio 0.55 is not required due to its high water content itself imparts the sufficient flow within 6 seconds. The saturation point is obtained from the flow time versus super-plasticizer dosage curves, at the dosage value beyond which super-plasticizer will not decrease the flow time with increase in dosage of super-plasticizer.

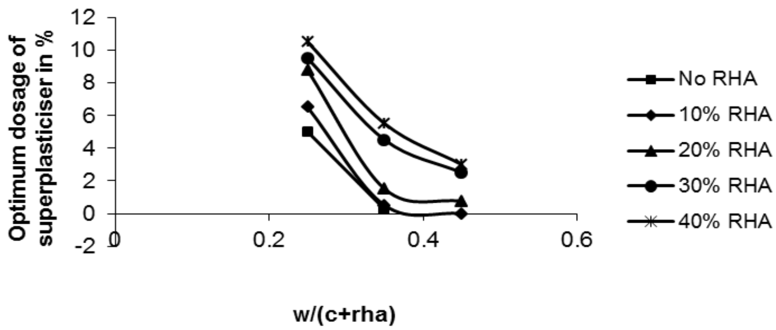

Figure 2. Optimum dosages of super-plasticizer for rice husk ash blended cement paste

3.2. Flow table test

For determining the optimum dosage of super-plasticizer for different water to binder ratios, the flow table test is used for cement blended rice husk ash mortar. First, flow table top was cleaned and dried. Mould was placed at the centre of table and filled in three layers of about 25 mm thickness. Each layer is tamped 20 times with a tamping rod. Tamping pressure was just sufficient to ensure uniform filling of mould. Excess mortar was cut off from table top to obtain a plane surface flush with the top of mould by drawing a straight edge. Table top was cleaned and mould was lifted. Immediately table was dropped, through a height 12.5 mm, twenty five times in fifteen seconds. The flow is the resulting increase in average base diameter of the mortar mass, measured on at least four diameters at approximately equally spaced intervals expressed as a percentage of the original base diameter [9]. According to IS 1727-1967, the amount of water for gauging shall be equal to that required to give a flow of 105 ± 5 percent with 25 drops in 15 seconds [10]. The flow table test setup is shown in Figure. 4.

Figure 3. Flow table test setup

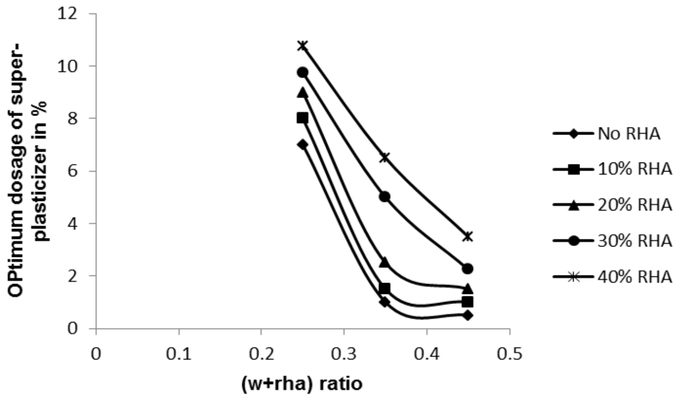

Figure 4. Optimum dosages of super-plasticizer for rice husk ash blended cement mortar

The optimum dosage is obtained from the percentage flow versus super-plasticizer dosage curves at the dosage value beyond which the super-plasticizer would not increase the flow with increase in dosage of super-plasticizer (i.e. super-plasticizer has no further plasticizing effect). The same polycarboxylate ether based super-plasticizer used for rice husk ash blended cement paste exhibited required flow in low dosage and produced a completely dispersed system of mortar and the same was selected and used through out for different water to binder ratios of cement blended rice husk ash mortar. The optimum dosages of super-plasticizer for cement blended rice husk ash mortar with water binder ratios are presented in Figure. 5.

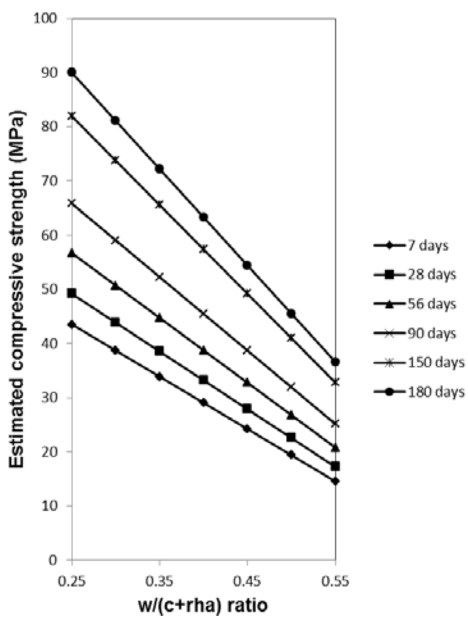

Figure 5. Estimated compressive strength versus w/(c+rha) ratio for rice husk ash blended cement paste with rha/c ratio = 0.3

3.3. Casting and testing

Four water to binder ratios, three curing ages and five wide ranges of rice husk ash replacement level with three replicates resulting 180 numbers of cement blended rice husk ash paste and same numbers of cement blended rice husk ash mortar of 5cm cubical specimens were cast. The test specimens were cast on steel mould, oil was applied on the inner side of the mould for easy removal of specimens. The cement blended rice husk ash paste and mortar was mixed by using mortar mixer. First cement, rice husk ash was mixed in dry form until uniformity was achieved, lastly fine aggregate was added. Then water was sprinkled and mixed thoroughly until a uniform mix is obtained. The mortar was then placed in suitable layers of equal thickness and was compacted on a table vibrator. The specimens were demoulded after 24 hours and the specimens were kept for curing in water tank till the age of test. After curing, the cubes were taken out from water tank and cleaned with cloth to wipe out excess water on the surfaces in order to bring them saturated surface dry condition. The cubes were tested at the age of 7, 28 and 90 days. They were tested on universal testing machine, ensuring that cast surfaces did not touch the platens. The compressive load was applied through a hydraulic jack at a constant rate of 140 kg/cm^2/minute as per IS 1727-1967 till failure. The average of failure stress of three cubes was considered as the representative compressive strength of each paste and mortar mixes.

4. RESULTS AND DISCUSSION

4.1. Flow measurement in cementitious paste

It is observed from the optimum dosage of super-plasticizer with water to binder ratio curves that the lowest water to binder ratio 0.25 needed more super-plasticizer dosage to obtain the required flow and also it gradually increases with increase in rice husk ash content. If the employed rice husk ash is finer than the cement the water demand increases with increase in rice husk ash replacement level due to the augmentation of surface area of rice husk ash particles [11]. So that the super-plasticizer dosage increases with increase in rice husk ash level and the same trend is observed in all water to binder ratios. The dosages decrease with increase in water to binder ratio was also observed.

4.2. Flow measurement in cementitious mortar

The optimum dosage is obtained from the percentage flow versus super-plasticizer dosage curves. The dosage value beyond which the super-plasticizer does not increase the flow with increase in dosage is optimal super-plasticizer dose. It is observed that percentage flow increases and optimum dosages increase with increase in rice husk ash content. Similar behavior is observed for entire water to cementitious ratio but with decrease in water to cementitious ratio, decrease in percentage flow and increase in optimum dosages was observed. And also super-plasticizer dosages are not required for water to binder ratio 0.55. This is due to the fact high water content itself provides the sufficient flow.

4.3. Compressive strength

It is observed that the compressive strength of rice husk ash blended cement paste increased with age as expected in all water to binder ratios and rice husk ash replacement levels. But the strength reduced gradually with respect to increase in rice husk ash replacement as compared to the controlled specimens. This reduction in compressive strength is due to the following reasons: the effective water to cement ratio increased with increase in rice husk ash replacement level. The pozzolanic reaction is also a slow reaction; it requires more time to react completely to attain higher strength than the controlled paste strength. It is also observed that compressive strength of cement blended rice husk ash mortar increased with age as expected but decreased with increase in rice husk ash replacement level up to 28 days of curing, then it increased the compressive strength at 90 days of curing as compared to the controlled specimens. This is due to the fact that the sluggish rice husk ash secondary reaction contributing strength at later ages.

4.4. Empirical relationship for compressive strength

The compressive strength can be estimated by least square of multiple regression method, using water to binder ratio (w/(c+rha)), curing age (t), rice husk ash to cement ratio (rha/c) and the experimentally determined compressive strength. The following empirical form for compressive strength for rice husk ash blended cement paste and mortar is derived as

$$f_c = K_1\left(\frac{rha}{c}\right) + K_2\left(\frac{w}{(c+rha)}\right)t + K_3 t + K_4\left(\frac{w}{(c+rha)}\right) + K_5 \qquad (1)$$

where, K_1, K_2, K_3, K_4 and K are empirical constants and are −24.83, −0.47, 0.386, −93.28 and 72.42 for cement blended rice husk ash paste and those for cement blended rice husk ash mortar are −23.42, −0.454, 0.362, −58.21 and 59.23 respectively. The coefficients of determination are 0.87 and 0.84 respectively. Thus the compressive strength of cement blended rice husk ash paste and mortars are correlated with mix parameters. The experimental compressive strength values are presented in Table 5 and it is observed that the estimated compressive strength values are fitting reasonably well with experimental values.

4.5 Strength versus w/(c+f) relationships

By using the equation (1), the compressive strength for rice husk ash blended cement paste and mortar are estimated for various curing ages such as 7, 28, 56, 90, 150 and 180 days and all five rha/c ratios. Typical strength versus w/(c+rha) ratio plots is presented in Figures. 5 and 6 for rice husk ash blended cement paste and mortar respectively.

The nature of the compressive strength versus w/(c+rha) ratio curves follows Abram's strength versus w/c ratio curves [12]. Thus it is evident that fundamentally, the strength is governed by w/c or w/(c+rha) ratio and curing age. Therefore w/(c+rha) ratio and age controls the compressive strength of rice husk ash blended cement paste and mortar. Thus the investigation presented in this work provides a clear understanding of strength versus w/(c+rha) ratio relationship.

Table 5: Compressive strength: rice husk ash blended cement paste and rice husk ash blended

cement mortar

w/(c+f)	c/rha	Compressive strength (MPa)											
		rice husk ash blended cement paste						rice husk ash blended cement mortar					
		Experimental			Estimated			Experimental			Estimated		
		7 days	28 days	90 days	7 days	28 days	90 days	7 days	28 days	90 days	7 days	28 days	90 days
0.25	0	52	60	72	50.98	56.62	73.27	48	59.2	63.2	46.42	51.64	67.04
	0.1	44.8	53.6	64	48.50	54.14	70.78	43.2	52	61	44.08	49.29	64.70
	0.2	41.6	50.4	66	46.01	51.65	68.30	33.6	54	65	41.73	46.95	62.36
	0.3	31.2	44.2	62	43.53	49.17	65.82	29.6	40	58	39.39	44.61	60.02
	0.4	29.6	39	61.2	41.05	46.69	63.33	26.4	38	56	37.05	42.27	57.67
0.35	0	47.2	58.4	59.2	41.32	45.97	59.71	47.2	56.8	59.2	40.28	44.54	57.14
	0.1	39.2	44.2	60	38.84	43.49	57.22	39.2	45	53	37.94	42.20	54.79
	0.2	47.2	53.4	59.8	36.36	41.01	54.74	39.2	47	55	35.59	39.86	52.45
	0.3	46.4	56.3	62.4	33.87	38.53	52.26	38.4	46.2	54.3	33.25	37.52	50.11
	0.4	36.8	44.8	58.7	31.39	36.04	49.78	33.6	41	50.5	30.91	35.18	47.77
0.45	0	312	34.4	39.2	31.67	35.33	46.15	32	40	44	34.14	37.45	47.23
	0.1	23.2	31	39.2	29.18	32.85	43.67	26.4	30	38	31.80	35.11	44.89
	0.2	20.8	27.7	36.8	26.70	30.36	41.18	24	31	0	29.46	32.77	42.54
	0.3	17.6	26.8	37.8	24.22	27.88	38.70	21.2	29.2	37.5	27.11	30.43	40.20
	0.4	16	24	33	21.73	25.40	36.22	19.2	26.8	35.7	24.77	28.08	37.86
0.55	0	22.4	23.2	31.2	22.01	24.69	32.59	23.2	28	33.6	28.00	30.36	37.32
	0.1	16.8	24	31	19.53	22.20	30.11	22.4	28	34	25.66	28.02	34.98
	0.2	15.2	19	27	17.04	19.72	27.63	21.2	29.2	31.8	23.32	25.67	32.64
	0.3	12.8	17.2	25.7	14.56	17.24	25.14	20.6	30.2	32.2	20.97	23.33	30.30
	0.4	11.2	18.6	23.8	12.08	14.75	22.66	19.2	31.7	33.2	18.63	20.99	27.95

5. CONCLUSIONS

Based on the experimental investigation carried out in this study, the following conclusions has been drawn:

The dosage of super-plasticizer increases with an increase in rice husk ash content in cement blended rich husk ash paste and mortar due to the more fineness of rice husk ash particles.

Compressive strength improvement is less with respect to increase in rice husk ash content up to 90 days in case of cement blended rice husk ash paste as compared to the controlled specimens and more strength are attained only for cement blended rice husk ash mortar at the age of 90 days due to the sluggish pozzolanic reactions.

The proposed empirical relationship for compressive strength with mix factors were fitting reasonably well in cement blended rice husk ash paste as well as mortar.

The estimated compressive strength versus w/(c+rha) ratio curves for various curing ages and rha/c ratios follows the similar nature of Abrams' strength versus w/c ratio curves in both rice husk ash blended cement paste and mortar.

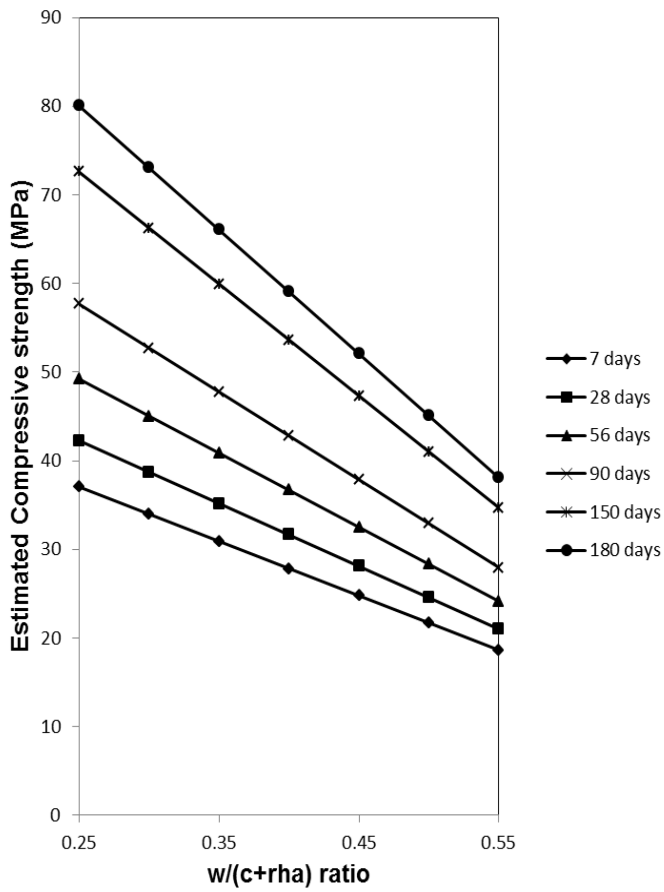

Figure 6. Estimated compressive strength versus w/(c+rha) ratio for rice husk ash blended cement mortar with rha/c ratio = 0.4

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