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Production and Utilisation of Rice Husk Ash in Concrete and its Comparison with Silica Fume

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***Abstract:** In this study, the detailed experimental investigation was carried out to understand the effect of partial replacement of cement by Rice Husk Ash (RHA) and Silica Fume (SF) in various proportions, RHA varying from 15% to 30% and SF from 5% to 10%. The tests on hardened concrete were destructive in nature, which included compressive strength of cube (150 mm size) at 7, 28, 56 and 90 days of curing in water. Compressive strength tests were also carried out on cylinders of 150 mm diameter and 300 high at 7,28,56 and 90 days of curing in water to study slenderness effect. Flexural strength tests on prism of size 100 x 100 x 500 mm at 7, 28, 56 and 90 days of curing in water. Drop weight impact tests in accordance with ACI 544 were carried out on discs of size 150 mm diameter and 60 mm high. The tests results revealed the effects on the behaviour of concrete produced from partial replacement of cement with RHA and SF in different proportions on the mechanical properties of concrete such as compressive strength, flexural strength and impact resistance. Based on test results it is concluded that 25% cement replacement with RHA and 7.5% cement replacement by SF are the optimum level of replacements.*

***Keywords:** Rice husk ash, silica fume, compressive strength, flexural strength, impact resistance and cement replacement in concrete.*

INTRODUCTION

Despite of wide spread used of High Performance Concrete (HPC) in developed countries, it is difficult to define HPC in a unified way. ACI defines HPC as the concrete that meets special performance and uniformity requirements that may not always be obtained using conventional ingredients, normal mixing procedures and typical curing practices [1] and these may include enhancement of ease of placement without segregation, long term mechanical properties, early age strength, toughness, volume stability and long service life in severe environments. Brandt [2] reported that HPC is one which gives 28 days compressive strength greater than or equal to 60MPa and very high performance concrete (VHPC) has 28 days compressive strength in the range of 120 MPa or greater. He stated that HPC differs from ordinary concrete in terms of high strength, lower w/c ratio, increased fraction of fine and very fine grains and use of superplasticizer (SP) to get higher flow of around 180 – 250 mm slump with the retention time of 1 – 1.5 hours and smaller fraction of coarse aggregates and smaller maximum grain dimensions.

Enhancement in ease of placement without segregation has been considered as criterion of high performance of the cementitious systems in this work. Ease of placement without segregation is a special characteristics of self compacting cementitious system (SCCS), which do not require any mechanical vibration for their compaction.It is desirable feature of concrete in heavily reinforced sections. This is why that many research papers call self compacting concrete (SCC) as HPC [3 - 6]. Because of important role of paste component on the overall response of mortars and concretes, the response of high performance self compacting paste (SCP) systems was studied in detail before start of research work. These are one component primary cementitious system and it is very well known that the mechanical properties, volume stability and durability of mortars and concretes depend to a great extent on the durability of their paste component. Durable or high performance paste components systems are obtained by incorporating secondary raw materials.

The use of supplementary cementitious materials (SCM) can significantly improve the transport properties and durability of concrete. However, different dosage and combinations of supplementary cementitious materials can yield dramatically response [7]. The use of SCM in concrete may bring lots of benefits like reduced water demand, increased flow, strength and reduced shrinkage etc. But some problems may also be caused. So, one has to be careful regarding selection of type and amount of SCMs to be used in applications. The effects of flyash and to a lesser degree that of slag and condensed silica fume on the properties are well documented. In general, SCMs have both positive and at times negative effects on water demand, temperature rise, strength development, freeze-thaw resistance, chemical attack resistance, alkali-silica reaction, alkali-carbonate reaction control [8]. They also have effect on volume stability and micro-structure etc. necessitating their careful selection for an application. With continuously graded aggregates, the use of SCMs in presence of super-plasticizer usually results in minimizing the voids, paste and hence cement requirement. They also add stability to the system. This could result in increased economy, high performance and increased durability.

NEED OF THE RESEARCH

Rice mills generate a by-product known as husk. This surrounds paddy grains. During milling of paddy about 78% of weight is received as rice, broken rice and bran, rest 22% of the weight of paddy is received as husk. This husk is used as fuel in rice mills to generate steam. The husk contains about 75% organic volatile matter and the balance 25% of weight of husk is converted into ash during firing process, is known as rice husk ash (RHA). This RHA contains about 85% – 90% amorphous silica. Improper burnt RHA cannot be used in concrete beneficially, also imposing a great environmental threat causing damage to the land and surrounding area in which it is dumped or used as landfill. The use of RHA decreases demand for cement in the construction industry, reduces the cost of concrete production and reduces negative environmental impact of CO_2 emissions due to production of cement.

In the literature, it was found that RHA is used only up to 70 MPa and also it depends on the burning condition of the rice husk and on the quality of rice husk. The silica content of RHA depends on the burning conditions. The more will be silica content, better will be RHA. RHA used in the present study was having 94% silica.

LITERATURE REVIEW

Higher concrete strength without durability is undesirable and is wastage of costly materials. Various options are available to enhance durability i.e. by including the use of SP, low w/c ratio and using suitable fillers. In fact pozzolanic fillers along with SP and low w/c ratio are main controlling parameters of HPC systems. In HPC, high amount of fine fillers and super plasticizers are essentially used for desired workability, strength and durability requirements. This minimizes the fluid transport within the concrete mass and would result in high strength as well. It was therefore decided to have an improved microstructure of cementitious system by the joint application of SP and fillers in the investigations reported herein. The fillers with pozzolanic properties were found more efficient [9].

SCMs are used to replace a part of cement, an expensive material in ready mixed concrete, mortars and concretes. Reduction of cement translates into reduced shrinkage and heat of hydration [10]. These SCMs are industrial by products that are easily available, require little or no pyroprocessing and have inherent or latent cementitious properties. Use of flyash in concrete is on increase. SCMs used in present study are RHA and SF.

Fillers are generally added to HPC systems to reduce water demand, to increase paste volume and stability, to improve finished surface, to improve pumping etc. and to reduce shrinkage. Appropriate choice of filler is very important for a material engineer at site for a given placement. Traditionally very fine particles were believed to increase the water requirement of concrete and therefore harmful to concrete. Mathematical particle packing theories, however, show the opposite. In concrete, fine powder particles comprising binder and mineral powder (MP) fill the spaces between aggregate particles. The space remaining between fine powder particles is then filled with water and to a lesser extent with air also. For workability, some excess water is needed for particle mobility. The role of super-plasticizers is to disperse the particles into spaces within their size range. In mixes without super-plasticizer, fine particles are flocculated and cannot fill spaces of their own class size, which is why often require more water. The first condition that must be met for densest packing is the use of super-plasticizer, to break flocculation and hence achieve uniform packing.

Crushed aggregate particles are irregular in shape and pack more poorly together than naturally formed gravel. The space between them being comparatively large requires more water and cement to meet workability and strength requirements. In order to reduce cement quantity, MP looks like a possible solution. The function of MP particles drives from their filler and binder effects and for this, the particles have to be extremely fine. In practice, MPs are mainly industrial by products. The filler effect includes particle packing and involvement in chemical reactions as nucleation sites. The binder effect results from reaction products of true chemical hydration and pozzolanic reactions.

It is found that moduli of elasticity of rocks from which coarse aggregate is received is the controlling factor of the modulus of elasticity of resulting concrete. In other words, concrete with higher elastic modulus is only obtained with rocks of higher modulus from which aggregates are made. The increase of 172.5% in the modulus of elasticity of rocks may result in corresponding 48% increase in modulus of elasticity of concrete [11].

Role of SCM in Strength Enhancement

Incorporation of flyash (FA) in cement based materials generally reduces water demand, increases setting times and reduces the early shrinkage due to delayed hydration. Packing effect is dominant for FA systems during 3-28 days [11] and pozzolanic effect becomes more pronounced thereafter and that the pozzolanic reaction of FA decreases with increase in its particle size. Quantification of SF in concrete system has shown that up to an age of 7days, physical effects contribute to the compressive strength while beyond that chemical effects become significant [12]. Increase in strength of a cementitious system brought about by the inclusion of amorphous RHA in a replacement mode is due to its packing effect, pore refinement effect, reduction of effective w/c ratio due to absorption of water in internal porosity of RHA particles, improvement of cement hydration and to the pozzolanic reaction between silica and $Ca(OH)_2$ [13]. By virtue of its reduced pozzolanic activity, crystalline RHA shows lesser strength enhancement than amorphous RHA and its filler effect dominates the pozzolanic one.

Super-Plasticizers

High range water reducers (HRWRs) improve the flow ability of HPC by their liquefying and dispersing action. They reduce the yield stress and plastic viscosity of concrete by their liquefying action [14], and thus provide a good flowing ability in HPC. In addition, the HRWRs de-flocculate the cement particles and free the trapped water by their dispersing action [15] and hence enhance flowing ability of concrete. In dispersing action, the inter-particle friction and thus flow resistance are also decreases therefore, flow ability of concrete is improved.

An admixture influences the properties of fresh and/or hardened concrete and is generally added during mixing process. Both HPC and SCC are characterized by dense particle packing, a high/ medium amount of powder and low w/c ratio or water binder (w/b) ratio to increase flow, to reduce heat of hydration and shrinkage especially at early ages. The type of powder to be employed for a given application should be carefully selected considering its advantages/ disadvantages it brings with it. High range water reducers can either increase the strength by lowering quantity of water for a given flow ability or reduce both cement and water contents to achieve a given strength and flow ability [16].

Rice Husk Ash (RHA)

Rice husk is the outer covering part of rice kernel and consists of two interlocking halves. It is removed from the rice grain because husk is not edible. Rice husk is a by product of the process of obtaining rice grain. Bulk of rice husk is disposed of by setting it on fire. On combustion, cellulose-lignin matrix of rice husk burns away leaving behind a porous silica skeleton with extremely small domains of 3 – 120 nm in size called RHA [17] which is rich in silica. The highly porous structure of ash gives rise to a large surface area, depending strongly on burning regime parameters like temperature, its duration and environment.

Ibrahim et. al. [17] boiled the rice husk with water, washed it and then dried. For a constant burning time of 3 hours, the surface area of ash was found to increase from 200 - 274 m^2/g on heating husk from 500 to 600^0C.

Reactivity and water demand are two main parameters of RHA. The reactivity of RHA depends on the content of amorphous silica and on its porous structure. If porous structure gets minimized by milling process in an effort, to reduce particle size, the reactivity decreases. The reactivity of RHA contributes to strength of RHA containing cement based materials by pozzollanic reaction between silica and calcium hydroxide liberated during hydration process of cement. These reactions produce additional amounts of CSH that makes denser microstructure of the product and enhances strength. The water demand depends on the specific surface and pore volume. Since, un-burnt carbon has very high specific surface due to its very porous particles, water demand is higher for such ash samples which have higher un-burnt carbon content [18]

The formation of calcium hydroxide (CH) at the surface of RHA may be due to adsorption by cellular structure of RHA. The adsorbed water enhances reaction inside the inner cellular space and results in significant strength gain. After 40 hours, pozzolanic reaction further binds SiO_2 in RHA with CH to form CSH and solid structures.

Silica Fume (SF)

SF is an industrial by product mainly from Ferro-silicon industries during reduction of high purity quartz with coal or coke in an electric arc furnace during reduction of Silicon metal or Ferro-silicon alloy. The SiO_2 of SF is highly dependent on the type of alloy product which varies from 61% to 98%. SF comes in various forms including powder SF, slurried SF, densified SF and pelletized SF. SF generally produces filler and pozzolanic effects when added into cement based materials. The pozzolanic reactivity is due to the reaction between silica of SF and CH produced during hydration of cement.

The transition zone, also sometimes known as interfacial transition zone (ITZ) is the inter-phase between aggregate and hydrated cement paste. It is very important both from view point of mechanical strength as well as durability. With the increase of w/c ratio, both the thickness of ITZ and the degree of orientation of CH crystals is increased due to internal bleeding. Addition of SF improves the microstructure in ITZ and also control alkali silica reaction if SF replacement level is 15% or more [19].

Comparative Hydration of SF and RHA Pastes

In HPC, high powder content with low mixing water in the cementitious systems is generally the basic requirements. Such systems have high water demand, which are generally reduced by using the 3^{rd} generation super plasticizers based on poly carboxylate ethers [16].

The mechanism through which SF and RHA improve some of the properties of resulting concrete are densification of hydrating gel structure, filler action, more pozzolanic action between silica rich SF particles and Portlandite a by product of cement hydration resulting in pore size refinements with SF particles acting as nucleation sites for Portland cement hydration [20]. High surface area of RHA is sometimes pozzolanic than SF and its pozzolanic activity can still be further increased by treating husk with 1N HCL aqueous solution [13] so that about 50% of the lime reacts within first 24 hours.

Strengthening mechanism suggested by Yu et. al. [21] include reduction in pore size, reduction of the effective w/c ratio of RHA concrete compared with control concrete due to adsorption of a portion of free water in the large number of pores existing in RHA particles, improved cement hydration and more C-S-H gel formation in RHA concrete.

The comparative response of RHA and SF based cement paste has been studied to look into the possibility of replacing SF by RHA for making HPC/ SCC especially in rice growing countries.

SELECTION OF MATERIALS AND THEIR CHARACTERISTICS

The physical characteristics of the constituent materials of concrete, the results of sieve analysis for coarse and fine aggregates, specific gravity, particle size analysis of cement and RHA is presented in this section.

Production of RHA

The rice husk required to make RHA was brought from a rice mill at Gohad, District Bhind (MP). RHA has been produced in the laboratory in a burner which was made for this purpose. The burner prepared for this purpose only is shown in Fig. 1 and 2. The burner was filled with rice husk in between both the baskets. It takes about 20 kg of rice husk to fill it completely which occupy about 0.1 m^3. Typically, one burning takes about 12 to 15 hours and produced 4 kg of rice husk ash (RHA). Three type of RHA (i.e. blackish grey, grey and whitish grey) was produced as shown in Fig. 3.

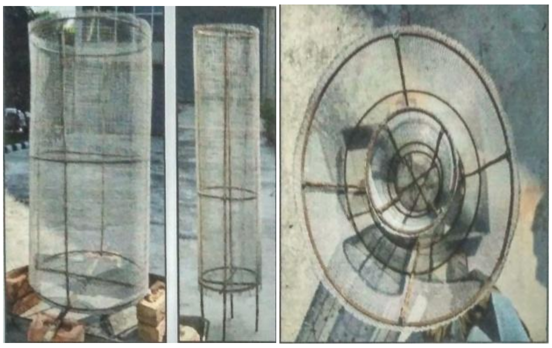

Fig. 1 outer basket, inner basket and top view of the burner

Fig. 2 elevation and top view of burner filled with rice husk

Fig. 3 different samples of RHA produced

Amorphus (non crystalline) RHA was used as a SCM. It was produced in very fine powder form with whitish grey colour. Specific gravity of RHA was found from the test as 1.978. EDAX and SEM analysis is given in Table 1, Fig. 4 and Fig. 5 respectively. The mass content of silica is about 94%. This is the main oxide component that contributes to the pozzolanic reaction or secondary hydration in concrete including RHA. The more amount of silica is present the more will be the reactivity of RHA.

Table 1 Chemical component of RHA and SF

name of element	atom % in RHA	atom % in SF
Mg	0.41	2.52
Si	94.00	89.93
K	2.65	3.10
Ca	1.23	1.07
Fe	1.72	3.38

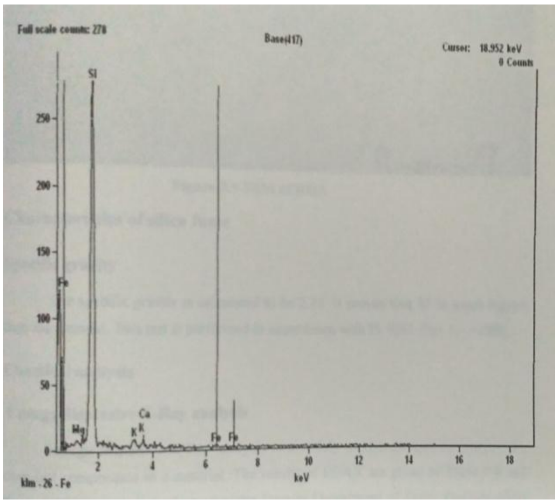

Fig. 4 results of EDAX test on RHA

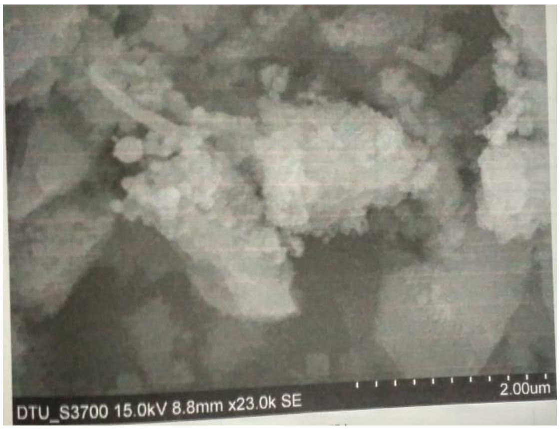

Fig. 5 SEM view of RHA

Coarse Aggregate

Locally available coarse aggregate in the form of a blend of crushed and round aggregate was used in the study. The percentage of round aggregate was about 50% of total aggregate. Sieve analysis test results of coarse aggregate are given in Table 2. The dry rodded unit weight, water absorption and specific gravity of coarse aggregate were found as 1674.59 kg/m^3, 0.56% and 2.93 respectively.

Table 2 Sieve analysis test results of coarse aggregate

sieve size (mm)	weight retained (g)	% of weight retained	cum. % of weight retained	% passing
20	141.3	2.83	2.83	97.17
16	1582.1	31.64	34.47	65.53
12.5	1532.1	30.64	65.11	34.89
10	1730.4	34.61	99.72	0.28
4.75	14.1	0.28	100	0
pan	0	0	-	-

For a given flowing ability, maximum size of coarse aggregate influences water content. Increase in maximum size of coarse aggregate decreases requirement of water content and also reduces cement content to make a workable paste [22].

Fine Aggregate

Locally available Badarpur sand was used as fine aggregate. Sieve analysis test results of sand are given in Table 3. The dry rodded unit weight, absorption and specific gravity of sand were found as 1804.17 kg/m^3, 0.66% and 2.683 respectively. Sand was considered as well graded.

Table 3 Sieve analysis test results of fine aggregate

sieve size (mm)	weight retained (g)	% of weight retained	cum. % of weight retained	% passing
4.75	20.8	2.08	2.08	97.92
2.36	164.5	16.45	18.53	81.47
1.18	233.4	23.34	41.87	58.13
0.6	198.4	19.84	61.71	38.29
0.3	173.1	17.31	79.02	20.98
0.15	144.2	14.42	93.44	6.56
pan	65.6	6.56	100	0
Fineness modulus = Σ(cum. % of weight retained)/100= 2.97				

Ordinary Portland Cement

Ordinary Portland cement of 53 grade (Wonder Brand) was used as main binding material. It complied with the requirements of IS: 269-2015. The specific gravity, initial and final setting times of the cement were found as 3.166, 105 minutes and 160 minutes respectively.

Water

Ordinary tap water of the laboratory was used in mixing and curing of the specimens.

Super Plasticizer

A poly carboxylate ether based commercially known as Master Glenium Sky 8777 (manufactured and marketed by BASF Construction Chemicals India Pvt. Ltd.) was used to produce the required flowing ability of concrete. The specific gravity of super plasticizer was 1.10.

Silica Fume

Micro silica marketed by ELKEM was used in the study. It has amorphous silicon dioxide consisting of sub-micron spherical primary particles and agglomerates of these. The size of particles was varying from 0.1 to 1 micron. Specific gravity of SF was found as 2.32. EDAX and SEM test results on SF are given in Table 1, Fig. 6 and Fig. 7 respectively. The mass content of silica is about 90%.

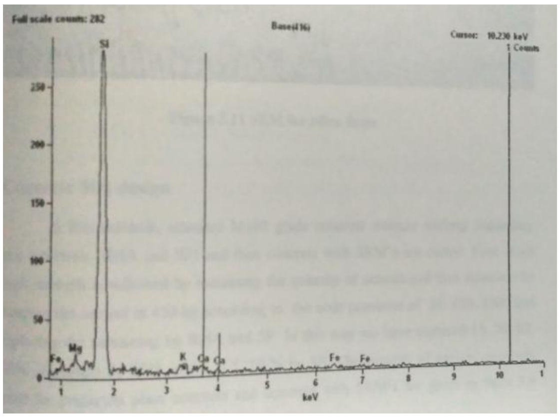

Fig. 6 results of EDAX test on SF

Concrete Mix Design

In present study, control mix of 100 MPa without SCM (i.e. RHA and SF), mixes with SCM were designed. First of all, high strength was achieved by increasing the quantity of cement then achieved by keeping cement at low content and replacing remaining cement with RHA and SF. In this way, we have replaced 15, 20, 25 and 30% cement by RHA and 5, 7.5 and 10 % cement by SF. A water cement ratio of 0.2 was maintained in all the mixes means 152.7 litres water, 1205.7 kg coarse aggregate and 11.2 kg super plasticizer was used in each mix of 1m^{3}quantity. The quantity of various other materials required for 1m^3 of concrete is given in Table 4.

Fig. 7 SEM view of SF

Table 4 Quantity of various other materials (kg) required for 1m^3 of concrete

mix identification	cement	RHA / SF	fine aggregate
control	749.9	0.0	426.2
SF 5	623.8	37.8	481.2
SF 7.5	563.3	55.9	509.5
SF 10	502.8	74.5	537.3
RHA 15	566.1	110.7	440.2
RHA 20	506.5	149.0	444.8
RHA 25	446.9	186.2	449.5
RHA 30	387.3	223.5	454.1

Mixing procedure

The aggregates and cement were first put into the mixer, dry mixed for about 1 minute. Thereafter, about two third of water was added to make material surface wet. Super plasticizer was mixed with remaining water and this too mixed with concrete. The mixing was continued for about 2 minutes.

EXPERIMENTAL INVESTIGATION

Consistency and Workability Test

Consistency of cement was found out first. Thereafter, consistency of binder materials i.e. 15, 20, 25 and 30 % cement replaced with RHA and 5, 7.5 and 10% cement replaced with SF was determined, which is given in Table 5.

Workability of all the design mixes were determined and these values are also given in Table 5.

Table 5 Results of consistency and workability

mix identification	consistency of binder material (min.)	workability (C.F.)
Control	28	0.88
SF 5	30	0.87
SF 7.5	31	0.86
SF 10	32	0.85
RHA 15	34	0.85
RHA 20	36	0.84
RHA 25	38	0.82
RHA 30	40	0.81

Compressive Strength on Mortar Cubes

Mortar cubes of 70.6 mm size were prepared and thereafter tested at 7, 28, 56 and 90 days of curing in water. Average cube compressive strength of various mortar mixes is presented in Table 6.

Table 6 Compressive strength of mortar cubes with RHA and SF

mix	compressive strength (MPa)

identification	7days	28days	56days	90days
Control	38.4	56.2	58.3	61.1
SF 5	37.2	56.1	57.2	60.3
SF 7.5	36.1	55.6	59.2	64.8
SF 10	35.4	55.2	56.1	60.0
RHA 15	37.1	48.3	57.3	62.3
RHA 20	35.3	49.1	56.0	63.4
RHA 25	33.4	52.2	59.9	67.0
RHA 30	31.1	45.0	48.6	55.0

Compressive Strength on Concrete Cubes

Concrete cubes of 150 mm size were prepared and thereafter tested at 7, 28, 56 and 90 days of curing in water. Average cube compressive strength of various concrete mixes is presented in Table 7.

Compressive Strength on Concrete Cylinders

Concrete cylinders of 150 mm diameter and 300 high were prepared and thereafter tested at 7, 28, 56 and 90 days of curing in water. Average cylindrical compressive strength of various concrete mixes is presented in Table 8.

Table 7 Compressive strength of concrete cubes with RHA and SF

mix identification	compressive strength (MPa)			
	7days	28days	56days	90days
Control	68.88	84.04	87.55	90.44
SF 5	66.22	86.66	95.33	97.26
SF 7.5	65.77	91.11	100.22	104.44
SF 10	63.55	83.11	91.42	93.27
RHA 15	64.44	84.44	92.88	93.33
RHA 20	63.55	87.11	93.33	95.22
RHA 25	64.00	93.77	101.77	103.84
RHA 30	61.33	77.77	85.55	87.29

Table 8 Compressive strength of concrete cylinders with RHA and SF

mix identification	compressive strength (MPa)			
	7days	28days	56days	90days
Control	55.48	61.14	65.11	67.94
SF 5	53.78	63.41	69.07	71.90
SF 7.5	52.65	66.80	73.60	78.13
SF 10	50.95	57.74	63.41	66.81
RHA 15	51.52	59.44	65.11	68.51
RHA 20	48.69	61.14	67.37	70.77
RHA 25	49.82	66.24	73.04	78.70
RHA 30	44.16	55.48	61.15	65.11

Flexural Strength on Concrete Prisms

Concrete prisms of 100x100x500 mm size were prepared and thereafter tested at 7, 28, 56 and 90 days of curing in water. Average flexural strength of various concrete mixes was determined under two point loading and the same is presented in Table 9.

Table 9 Flexural strength of concrete mixes with RHA and SF

mix identification	flexural strength (MPa)			
	7days	28days	56days	90days
Control	9.00	11.34	12.06	12.60
SF 5	10.08	12.24	13.14	13.68
SF 7.5	10.44	13.50	14.22	15.12
SF 10	11.34	12.96	13.32	14.04
RHA 15	8.46	11.16	12.24	12.96
RHA 20	9.90	11.70	12.06	12.42
RHA 25	11.70	13.86	14.58	15.30
RHA 30	10.80	11.70	12.60	12.96

Test for Impact

Impact test on concrete discs of 150mm diameter and 60 mm high were carried out at 7days and 28 days as per ACI – 544, by counting number of blows. A Schematic diagram of drop weight impact test arrangement is given in Fig. 8, while full view of the instrument is reported by Kumar and Lamba [23]. The test results are given in Table 10.

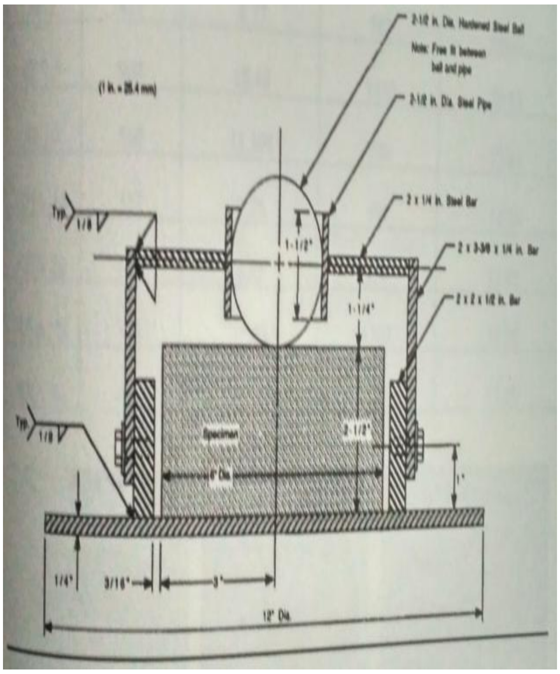

Fig. 8 schematic diagram of drop weight impact test arrangement

Table 10 Impact resistance of concrete mixes with RHA and SF

mix identification	7 day results		28 day results	
	no. of blows	energy absorbed (kNm)	no. of blows	energy absorbed (kNm)
Control	447	9.09	572	11.64
SF 5	431	8.77	887	18.05
SF 7.5	908	18.48	1430	29.10
SF 10	560	11.40	780	15.87
RHA 15	357	7.26	691	14.06
RHA 20	440	8.95	880	17.91
RHA 25	780	15.87	1709	34.78
RHA 30	461	9.38	870	17.70

Cost analysis

Cost analysis has also been done for various mixes in which cost of various materials i.e. cement, RHA, SF, sand, coarse aggregate and super plasticizers were considered as Rs. 300/- per bag of 50 kg, Rs. 4/- per kg, Rs. 1000/- per bag of 25 kg, Rs. 1120/- per m^3, Rs. 1066/- per m^3 and Rs. 270/- per litre respectively. Cost of various mixes is given in Table 11.

DISCUSSION

The test results of consistency are given in Table 5. From test results it is clear that increase in percentage of cement replacement by RHA, increases the amount of water required to maintain standard consistency due to higher specific surface of RHA. Similarly, increase in percentage of cement replacement by SF, increases the amount of water required to maintain standard consistency due to higher specific surface of SF.

Table 11 Cost analysis of various concrete mixes

mix identification	cost of the mix (Rs. per m^3)
Control	8659.78
SF 5	9454.78
SF 7.5	9836.16
SF 10	10237.18
RHA 15	8009.86
RHA 20	7808.77
RHA 25	7603.36
RHA 30	7398.27

Increase in percentage of cement replacement by RHA or SF decreases compaction factor means reduces workability of the mixes due to increase in demand of water cause by higher specific surface of RHA or SF content. These test results are also given in Table 5.

Compressive strength of mortar cubes of various mixes are given in Table 6. On comparison of these test results, it is found that up to 28 days, higher percentage of cement replacement by SF means more reduction in strength and after 28 days, 7.5 percent of cement replacement by SF gives maximum strength, while at 7days, RHA mixes shown that increase in percentage of cement replacement by RHA gives increase in strength reduction but after 7days, 25% cement replacement by RHA, gives the maximum strength at all ages. On further comparison of these two best mixes (i.e. SF 7.5 and RHA 25), it is found that SF replaced mix gives higher compressive strength of the mortar up to 28 days, at 56 days the strength of mixes are comparable, but at 90 days, RHA mix gives higher strength than the SF mix.

Compressive strength of concrete cubes of various mixes is given in Table 7. On comparison of these test results, it is found that at 7 days, higher percentage of cement replacement by SF or RHA means more reduction in strength and after 7days, all SF and RHA replaced mixes have compressive strength better than control mix, but 7.5 percent of cement replacement by SF and 25% cement replacement with RHA gave maximum strength at 28, 56 and 90 days than any of their mixes. Also latter two mixes gave comparable compressive strengths at 28, 56 and 90 days.

Compressive strength of concrete cylinders of various mixes is given in Table 8. On comparison of these test results it is found that the ratio of cylindrical compressive strength to cube strength of various mixes is varying from 0.69 to 0.81. On further comparison it revealed that the best cement replacement mix by SF (i.e. at 7.5%) has almost the same ratio as that of control mix but the best RHA mix (i.e. at 25%) has little smaller values than the control mix.

Flexural strength of concrete prisms of various mixes is given in Table 9. On comparison, it is found for control mix, SF mixes and RHA mixes, the flexural strength is varying from 13.1% – 13.9%, 13.8% - 17.8%

and 13.0% - 18.3% respectively, while 7.5% replacement of cement with SF and 25% replacement of cement with RHA, the variation is from 14.2% - 15.9% and 14.3% - 18.3% respectively.

Tests results of impact resistance for various mixes are given in Table 10. The number blows taken by mixes are increasing as the age of concrete is increasing. At 7 days, SF 7.5 shows highest number of blows i.e. 908 against 447 of plain concrete mix and at 28 days, again SF 7.5 shows highest number of blows i.e. 1430 against 572 of plain concrete. The number of blows taken by RHA 25 at 7 and 28 days are 780 and 1709 respectively. As the number of blows increases, the amount of energy absorbed is also increases. On this basis it is concluded that at 7days SF 7.5 and at 28 days RHA 25 can absorb maximum energy.

Cost analysis for various mixes is given in Table 11. The cost of 100 MPa control mix which has been made in this project is about Rs. 8660/- per m^3. When cement is replaced by silica fume, cost of concrete is increases as the percentage replacement increases due to higher cost of SF. The cost of 7.5% cement replacement with SF mix is Rs. 9836/- per m^3 which is 13.5% higher than the cost of control mix. When cement is partially replaced with RHA, cost of concrete decreases as the percentage of cement replacement increases due to very low cost of RHA. The cost of 25% cement replacement with RHA mix is Rs. 7603/- per m^3 which is about 12.2% less than the cost of control mix. The cost to strength ratio for control mix, SF 7.5 and RHA 25 is 95.74, 94.17 and 73.21 respectively. There is about 23% reduction in cost to strength ratio of RHA 25 mix than the control mix.

CONCLUSIONS

1. The properties of hardened concrete were improved at later ages such as 28, 56 and 90 days due to more hydration of cement and enhanced pozzolanic activity of RHA and SF.
2. The improvement in concrete properties is due to micro-filling and pozzolanic effects of RHA and SF. The maximum strength achieved at 25% cement replacement with RHA and 7.5% cement replacement with SF separately.
3. The maximum flexural strength achieved at 25% cement replacement with RHA and 7.5% cement replacement with SF. The flexural strength of concrete with RHA at 25% cement replacement shows better strength than the concrete with 7.5% cement replacement with SF.
4. Impact resistance of concrete also increases with addition of RHA and SF. The maximum impact resistance (by way of absorbing highest energy) was achieved at 25% replacement of cement with RHA and 7.5% replacement of cement with SF.
5. The consistency of cement paste decreases with the use of RHA and also with the use of SF as partial replacement of cement. This is due to higher specific surface of RHA and SF particles.
6. The mortars compressive strength also shows good results. These results are in synchronization with the results obtained for compressive strength of concretes.
7. The minimum cost of concrete is made with 25% replacement of cement with RHA. Also, the minimum cost to strength ratio is for 25% cement replacement with RHA. The cost of concrete with partial replacement of cement with SF increases in comparison to plain concrete.
8. Finally it is concluded that 25% replacement of cement with RHA can be used as optimum level and also enhances the strengths at later ages in comparison to SF.

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