

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

Cementitious Composites Using Rice Husk Ash

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ABSTRACT: Rice Husk Ash (RHA) is currently an unwanted by-product of the agricultural sector which contains high amount of Silicon Di-Oxide (SiO_2) that can be used as a pozzolanic material. In this paper, the detailed experimental investigation was done study to the effect of addition of Rice Husk Ash (RHA) into Cement in various proportions (from 5% to 15%). The tests on hardened cement mortar and cement concrete cubes were destructive in nature. Compressive strength tests on cement mortar cubes (70.1 x 70.1 x 70.1 mm), concrete cube of size (150 x 150 x 150 mm) at 7 and 28 days as per IS: 516-1959 were tested and Flexural Strength tests on beams of size (100 x 100 x 500 mm) at 28 days of curing as per IS: 516 1959 were conducted using UTM. The work presented in this report reveals the effects on the behaviour of cementitious composites produced as combination of cement and RHA at different proportions on the mechanical properties such as compressive strength and flexure strength. Ultimately, from this study it is found that 5% addition of RHA in cement is optimum level for gain in strength, while for the given duration of testing (28 days), control specimen of cement concrete beams was found to possess the maximum strength. The results of the study and possible reasons for the results obtained have been discussed.

KEYWORDS: Rice Husk Ash, Eco Friendly Concrete, Sustainable Development

I. INTRODUCTION

Sustainable development of cement and concrete industry requires the utilization of industrial and agricultural waste components. At present for a variety of reasons the construction industry is not sustainable. Firstly it consumes huge quantity of virgin materials which can remain for upcoming generations. Secondly, the production of Portland cement is a major contributor to greenhouse gas emissions that are implicated in global warming and climate change. Thirdly, many concrete structures suffer from lack of durability which may waste the natural resources. So, finding the solution to substitute a particle recycled product for part of the cement seems to be desirable for sustainable development. [1-4] Recycling of waste components contributes to energy savings in cement production, to conservation of natural resources, and to protection of environment. Furthermore, the use of certain components with potentially pozzolanic activity can significantly improve the properties of concrete [5-8]. One of the most suitable resources of pozzolanic material among the agriculture waste components is Rice husk, as it is available in large quantities and contains a relatively large amount of silica. When rice husk is burnt, about 20% of weight of the husk is recovered as Ash in which more than 75% by weight is Silica. Unlike natural pozzolana, this ash is an annually renewable source of silica. It is worth to mention that the use of RHA in cement mortar and concrete may lead to improved workability, the reduced heat evolution, the reduced permeability and the increased strength at longer ages. [9-11] India is a major Rice producing country and the husk produced during milling is treated as waste causing pollution of environment and disposal problems. Due to increasing environmental concern and need to preserve energy and resources efforts have been made to burn the husk under controlled conditions and to utilize the resultant ash as a building material. [7-8]

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The use of Rice Husk Ash in concrete was patented in the year 1924 [8]. Up to 1978 all researchers were concentrated to utilize ash derived from uncontrolled combustion. After that several published papers dealing with RHA established that burning Rice Husk under Controlled Temperature time conditions produces RHA containing silica in amorphous form. [12]. Depending on produced method the utilization of RHA as a pozzolanic material in cement and concrete provides several advantage such as improved strength and durability properties. Generally there are two types of RHA in concrete; the type of RHA that is suitable for pozzolanic activity is amorphous rather than crystalline. Therefore, substantial researches have been carried out to produce amorphous silica. The results have shown that RHA quality depends on temperature and burning time.

Apparently, for an incinerator temperature up to 700 degree Celsius, the silica is in amorphous form and silica crystals grow with time of incineration. The combustion environment also affects specific surface area, so that time, temperature and environment also must be considered in the processing of rice husks to produce ash of maximum reactivity. [3, 4]

1.1. High strength cementitious composites

In concrete, the use of a low water cement ratio and a special admixture, such as a combination of a high range water reducer (HRWR) or superplasticizer and some suitable pozzolanic material is intended to achieve a higher-than-standard strength.

High-strength concrete has a compressive strength greater than 60 MPa. High-strength concrete is specified where reduced weight is important or where architectural considerations call for small support elements. By carrying loads more efficiently than normal-strength concrete, high-strength concrete also reduces the total amount of material placed and lower the overall cost of the structure. The most common use of high-strength concrete is for construction of high-rise buildings.

High-strength concrete is made by lowering the water-cement (W/C) ratio to 0.35 or lower. Often siliceous material is added to prevent the formation of free calcium hydroxide crystals in the cement matrix, which might reduce the strength at the cement-aggregate bond. The primary difference between high-strength concrete and normal-strength concrete relates to the compressive strength that refers to the maximum resistance of a concrete sample to applied pressure. Low W/C ratios and the use of silica fume make concrete mixes significantly less workable, which is particularly likely to be a problem in high-strength concrete applications where dense rebar cages are likely to be used. To compensate for the reduced workability, superplasticizers are commonly added to high-strength mixtures.

Manufacture of high-strength concrete involves making optimal use of the basic ingredients that constitute normal-strength concrete. Aggregate must be selected carefully for high-strength mixes, as weaker aggregates may not be strong enough to resist the loads imposed on the concrete and cause failure to start in the aggregate rather than in the matrix or at a void, as normally occurs in regular concrete. In addition to selecting a high-quality Portland cement, producers optimize aggregates, then optimize the combination of materials by varying the proportions of cement, water, aggregates, and admixtures. When selecting aggregates for high-strength concrete, producers consider the strength of the aggregate, the optimum size of the aggregate, the bond between the cement paste and the aggregate, and the surface characteristics of the aggregate. Any of these properties could limit the ultimate strength of high-strength concrete.

1.2. Rice Husk Ash (RHA)

Rice milling generates a by-product known as husk. This surrounds the paddy grain. 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 the rice mills to generate steam. This husk produces about 20% ash by weight during burning process, it is known as Rice Husk Ash (RHA). This RHA in turn contains more than 70% amorphous silica. So for every 1000 kg of paddy milled, about 200 kg of husk is produced. India is a major rice producing country and the husk generated during milling is mostly burned as fuel, producing energy through direct combustion. Due to the low nutritional property of Rice-husk, it is not appropriate for use as a feed for animals. Moreover, its siliceous composition is resistant to natural degradation, which can produce a large environmental load. About 20 million tons of RHA is produced annually. This RHA is a great environment threat causing damage to the land and the surrounding area in which it is dumped. Lots of ways are being thought of for disposing them by making commercial use of this RHA. Earlier this

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RHA was used in landfills. This use of RHA decreases the demand for cement in construction industry, reduces the cost of concrete production and reduces the negative environments impact that CO₂ emission represent in the production of cement.

II. LITERATURE REVIEW

Studies at the University of California at Berkeley indicate that the silica of soil migrates in the plant in shape of monosilicic acid which concentrates there by evaporation. Electron microscope studies have shown dispersion of silica throughout the cellular structure of the husk. The unburnt rice husk contains about 50% cellulose, 25-30% lignin and 15-20% of silica. The former two components are removed by burning, leaving behind silica ash. Completely burnt husk is grey or whitish in color, while partially burnt husk is blackish.

In 1973, Mehta investigated the effect of pyro processing on the pozzolanic reactivity of RHA. Based on his work, Pitt developed a fluidized bed furnace for the controlled combustion of rice husk. It was found that when the temperature of burning and the residency time inside the furnace are controlled, highly pozzolanic RHA could be produced. Mehta observed that when the burning temperature, to get RHA, is high, the RHA goes into the crystalline stage while low burning yields RHA in amorphous form which is highly pozzolanic in character as compared to the crystalline form of RHA. Mehta suggested that essentially amorphous silica can be produced by maintaining the combustion temperature below 500°C under oxidizing conditions for prolonged periods or up to 680°C with a hold time less than 1 min. However, Yeoh et al. report that RHA can remain in the amorphous form at combustion temperatures of up to 900°C if the combustion time is less than 1 h, while crystalline silica is produced at 1000°C with combustion time greater than 5 min. Using X-ray diffraction, Chopra et al. observed that at burning temperatures up to 700°C, the silica was in an amorphous form. The effect of different burning temperatures and the chemical composition of rice husk (Taiwan RHA) were studied by Hwang and Wu. It was observed that at 400°C, polysaccharides begin to depolymerize. Above 400°C, dehydration of sugar units occurs. At 700°C, the sugar units decompose. At temperatures above 700°C, unsaturated products react together and form a highly reactive carbonic residue. The X-ray data and chemical analyses of RHA produced under different burning conditions given by Hwang and Wu show that the higher the burning temperature, the greater the percentage of silica in the ash. K, S, Ca, Mg as well as several other components were found to be volatile. Chopra used RHA obtained from burnt rice husks (used as fuel for boilers resulting in crystalline RHA) to develop masonry cement by inter grinding this ash with freshly burnt quick lime and slaked lime in the ratio of 60:30:10 respectively with desired results but with quality control problems. This was achieved by grinding the mixture in a ball mill for 7 h. Studies by Mehta had confirmed that the best contribution of RHA on the strength of concrete was obtained when the RHA was in amorphous form obtained by low burning of rice husks.

In regards to chloride penetrability, it has been seen that proportions of non-ground RHA did not significantly change the rapid chloride penetrability classification of concrete. However, using finely ground RHA reduced the rapid chloride penetrability of concrete from a moderate rating to low or very low ratings depending on the type and addition level of RHA. Therefore, RHA would not only contribute to reducing the environmental impact of uncontrolled burning or rice milling by-products but would also enhance the durability of the local concrete infrastructure.

2.1. Role of RHA in Strength enhancement

Inert and pozzolanic mineral admixtures modify the physical and chemical properties of mortars and concrete and the compressive strengths can be separated into fractions of strength related to physical and chemical effects of mineral admixtures. When mineral admixtures are added, three effects can be quantified including, dilution, heterogeneous nucleation (physical) and pozzolanic reaction (chemical) depending on the amount and solubility of amorphous silica. Heterogeneous nucleation is a physical process leading to a chemical activation of hydration of cement such that mineral admixture particles act as nucleation centres for the hydrates thus enhancing cement hydration. A smaller amount of powder has an optimum efficient and results in a large increase in compressive strength while the use of large amount of powder has a smaller effect. Incorporation of fine aggregate in cement based materials generally reduces the water demand, increases the setting times and reduces the early shrinkage due the delayed hydration. Packing effect is dominant for FA systems during 3-28 days and pozzolanic effect becomes more pronounced thereafter

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and that the pozzolanic reaction of FA decreases with increase in its particle size. Quantification of SF in concrete systems has shown that up to an age of 7 days, physical effects contribute to the compressive strength while beyond that chemical effects become significant. Increase in the 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 . By virtue of its reduced pozzolanic activity, crystalline RHA shows lesser strength enhancement than amorphous RHA and its filler effect dominates the pozzolanic one.

Since un-burnt carbon has a very large surface area, the water demand is higher for the ash samples with a higher un-burnt carbon content. A carbon rich ash is considered to be a pozzolanic material of lower quality because un-burnt carbon particles increase specific area and hence the water demand and this increase in carbon content decreases silica content. A high LOI (loss on ignition) value needs a higher dosage of superplasticizers for a give level of workability.

Reactivity and water demand are the 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 the strength of RHA containing cement based materials by pozzolanic reactions between silica and calcium hydroxide liberated during cement hydration process. These reactions produce additional amounts of CSH that makes denser microstructure of RHA containing cement based materials. The water demand depends on the specific surface area and pore volume. Since the un-burnt carbon has very high specific surface area due to its very porous particles, the water demand is higher for ash samples with higher un-burnt carbon content. Compared with ash samples free of carbon, a carbon rich ash has lower pozzolanic reactivity due to two reasons. As mentioned earlier, un-burnt carbon particles in RHA increase specific surface area which increases water demand and reduces the silica content of ash.

2.2. Rice Husk Ash (RHA) production

The quality of RHA as an additive for cement and concrete depends upon its reactivity. The reactivity of RHA contributes to the strength of RHA based materials by pozzolanic reactions between the silica and calcium Hydroxide liberated during the cement hydration process. These reactions produce additional amounts of calcium silicate hydrate that makes the microstructure of the RHA mortar and concrete denser as compared to that without RHA. The reactivity of RHA depends on the amorphous silica content available and on the porous structure of the ash. On the other hand, the ashes produced by burning rice husks under uncontrolled conditions may contain various amounts of un-burnt carbon.

Like many other countries, rice is the, most important food grain in India after wheat. Its Basmati quality is world famous and has become one of the main export items over the years. Basmati rice has various classes bit in general it is an expensive rice quality liked for its aroma, flavour and taste the world over. Rice husk is the outer covering part of the 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 the husk is disposed of by setting it on fire in fields (which creates environment related issues) although small quantities are used as low-grade fuel in brick kilns and in low-pressure steam generation etc. In the developed world, husk is used to produce electricity through steam generation and resulting ash is used as a value added product in making high strength concrete (HSC). Table-1 gives the physical properties of the rice-husk.

Table 1: Physical Properties of Rice Husk

Parameter	Nature Value
Colour	Golden
Length	4.5mm (average)
Hardness	6 Mohr's Scale
Density(Bulk)	96-160 Kg/m ³
Thermal Conductivity	3.3 K Cal-cm/g m ² /°C
Angle of repose	35° (ungrounded)
Fuel value	2800-3700 K-Cal/kg

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III. EXPERIMENTAL PROGRAMME

3.1. Selection of materials

Coarse aggregate (20mm, 10mm), sand, ordinary Portland cement (grade-43), amorphous Rice husk ash (RHA), normal tap water and superplasticizer were selected to produce the required high strength cementitious composites.

3.1.1. Coarse aggregates

Locally available coarse aggregate in the form of a blend of crushed and round aggregates was used in the work.

3.1.2. Fine aggregate (Sand)

Locally available sand in the form of Badarpur sand is used as fine aggregate (F.A).

3.1.3. Ordinary Portland cement

Normal Portland cement manufactured by J.K. cement was used as the main cementing material. It complied with the requirements of IS 12269. The cement was tested for standard consistency, setting time, and compressive strength (of mortar and cement-concrete).

3.1.4. Amorphous rice husk ash

Amorphous (non-crystalline) RHA was used as a supplementary cementing material (SCM). It was produced in very fine powder form with a whitish graycolor.



Fig. 1: Setup for burning Rice husk

3.1.5. Water

The water used for mixing and curing was clean and free from injurious amount of oils, acids, alkalis, salts, sugar, organic materials or other substances. Normal tap water was used as the mixing water for preparing the concrete and mortar specimens.

3.1.6. Superplasticizer

A poly-carboxylate-based HRWR, commercially known as **AT-CARPOL 401**, was used to assist production concrete of the required strength and flowability. The HRWR was available in the form of a brown liquid, and is manufactured by Ado additives Technologies Private Limited.

3.2. Cement Consistency test

The standard consistency of a cement paste is defined as that consistency which will permit the Vicat plunger having 10mm diameter and 50mm length to penetrate to a point 5 to 7mm from the bottom of the Vicatmold when the cement paste is tested.

3.2.1. Apparatus:

Table 2: Apparatus Specifications

Name	Capacity/size	Accuracy/Least count
Vicat apparatus	Should be made as per IS:5513	-
Balance	1000 g	1 g
Measuring cylinder	100 ml	1 ml

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3.2.2. Test results:

Table 3: Consistency and setting time results

S.No.	Cement property	Reading obtained
1	Normal consistency	33%
2	Initial setting time	100 minutes
3	Final setting time	560 minutes

3.3. Compressive strength test on mortar cubes

The following materials were used in the preparation of cement mortar specimens: Local Badarpur natural sand sieved with 425 micron sieve; OPC 43 grade cement marketed by JK Cement; and homogeneous rice husk ash produced by special arrangement; normal potable water conforming to IS 4031 (Part IV).

Mortar cubes of size 70.1 mm are formed. Three cubes were made for each batch for each age of testing. Hence, a total number of 36 cement mortar cubes were prepared whose specifications are depicted in the table, 9 samples corresponding to control specimen; and 9 each for cubes containing 5%, 10% and 15% of RHA. The ratio of cement to sand was kept constant as 1:3 with RHA as an additive binder material.

Table 4: Results for compressive strength of mortar

RHA Content	Average Compressive Strength (N/mm ²)		
	7 day	28 day	90 day
0%	18.86	29.10	31.10
5%	29.07	36.01	38.25
10%	21.50	29.30	30.11
15%	20.50	28.28	28.69

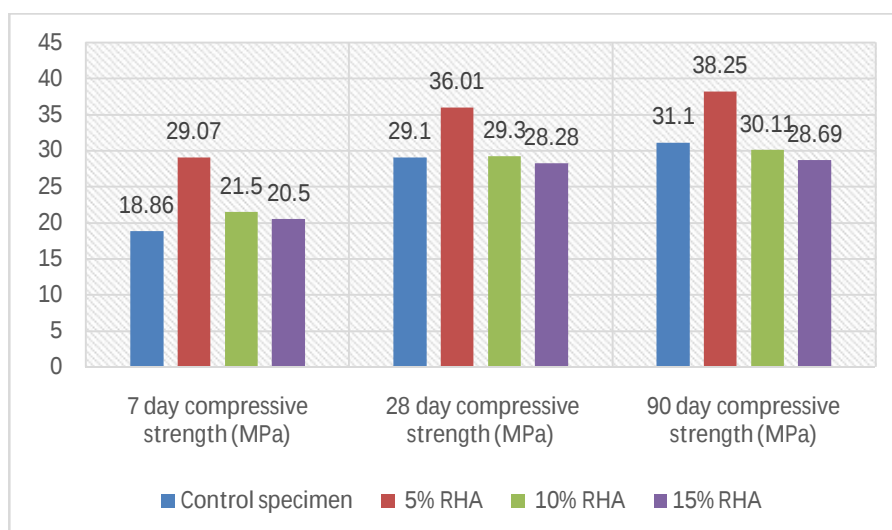


Fig. 2. Graphical comparison of compressive strength of mortar cubes

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Fig. 3: Mortar test specimen under UTM

3.4. Compressive strength test on concrete cubes

The acceptance criterion of quality of concrete is laid down in IS: 456-2000. The criterion is mandatory and various provisions of the code have to be complied before the quality of concrete is accepted. In all the cases, the 28-days compressive strength shall alone be the criterion for acceptance or rejection of the concrete. In order to get a relatively quicker idea of the quality of concrete, optional test for 7 days compressive strength of concrete be carried out. The compressive strength of concrete cubes is shown in Table 4.

The cube moulds of required size (150 mm for nominal size of aggregate not exceeding 38 mm) shall be made in such a manner as to facilitate their separation into two parts. Cube moulds shall be provided with a base plate and they shall be as per IS: 10086-1982. The dimensions, tolerance and materials of cube moulds shall be as given in table 5.

Table 5: Dimensions, material and tolerance of moulds

S. No.	Description	Requirements
1	Distance between opposite faces, mm	150 ± 0.2
2	Height of mould, mm	150 ± 0.2
3	Thickness of wall plate, mm	8
4	Angle between adjacent interior faces and between interior faces and top and bottom plates of mould.	$90 \pm 0.5^\circ$
5	Length of base plate, mm	280
6	Width of base plate, mm	215
7	Thickness of base plate, mm	8
8	Permissible variation in the planeness of interior faces: for new moulds, mm for moulds in use, mm	0.03 0.05
9	Permissible variation in the planeness of base plate, mm	0.03
10	Materials a) Side plate b) Base plate	Cast iron Cast iron

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Fig. 4: A universal testing machine (Earthquake Lab, Civil Dept. DTU)



Fig. 5: UTM digital output device

Table 6: Compressive strength of concrete cubes

Specimen specification	7 day compressive strength	28 day compressive strength
Control specimen	16.23 MPa	33.15 MPa
5% RHA	19.80 MPa	35.02 MPa
10% RHA	19.00 MPa	33.71 MPa
15% RHA	15.53 MPa	31.80 MPa

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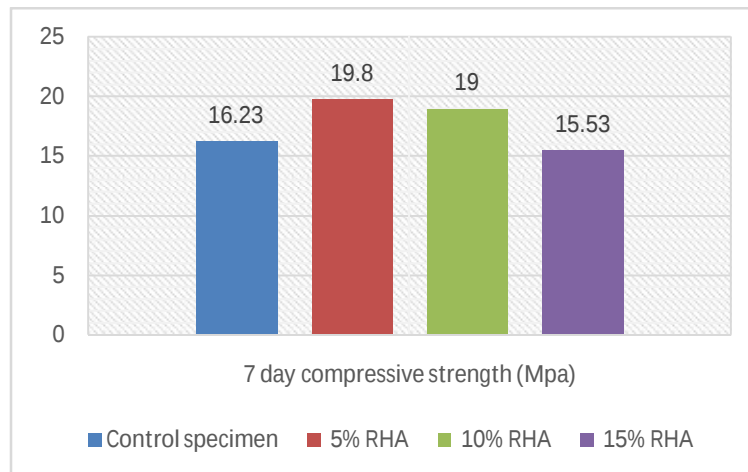


Fig. 6: Graphical comparison of 7 day strength of concrete cubes

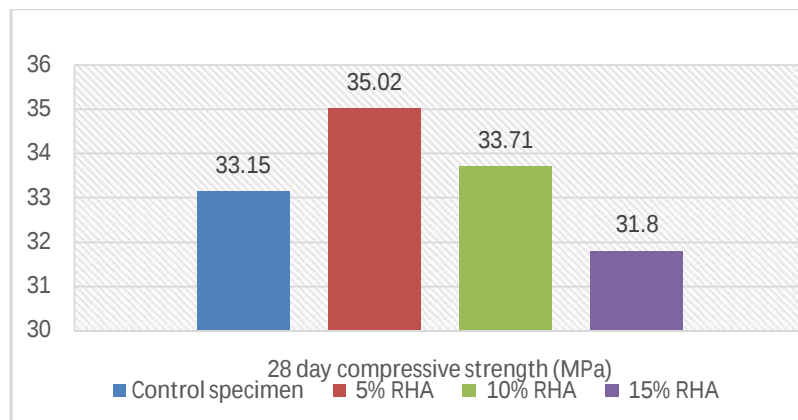


Fig. 7: Graphical comparison of 28 day strength of concrete cubes

3.5. Test for flexural strength of concrete beams

Beam moulds of size 100 x 100 x 500 mm are used in the project. The specimen is placed in the machine in such a manner that the load shall be applied to the uppermost surface as cast in the mould, along two lines placed 14cm apart. The maximum load applied to the specimen during the test is recorded. The flexure test results are given in table 7 and figure 9 respectively.

The flexural strength of the specimen is expressed as the modulus of rupture f_b which, if 'a' equals the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen, in cm

$$f_b = 3pa/bd^2$$

Where,

a = 14cm

b = measured width in cm of the specimen

d = measured depth in cm of the specimen at the point of failure

p = maximum load in kg applied to the specimen

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Point bend Test: This is a compression test where you support a length of material by spanning it across two supports on each end. There is nothing supporting the middle portion underneath of it. Then you press down from above directly in the middle of the span of material until the supported material breaks or reaches a specific distance. This test measures how strong the material in flexure (flexural strength).



Fig. 8: Three point load test using UTM

Table 7: 28 day Flexural strength of concrete beams

Specimen specification	28 day flexure strength
Control specimen	14.28
5% RHA	13.43
10% RHA	12.02
15% RHA	11.50

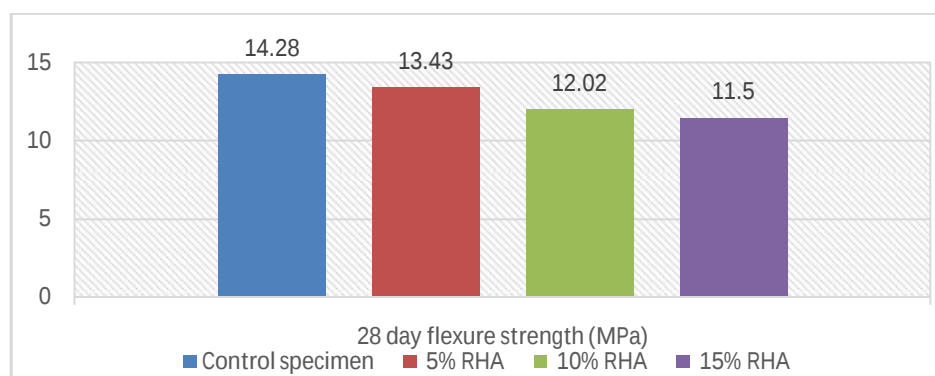


Fig. 9: Graphical comparison of 28 day flexural strength

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IV. DISCUSSIONS ON TEST RESULTS

4.1. Discussion on compressive strength of mortar

The results of compressive strength test for mortar cube are shown in table V and in figure III. The mortar cubes are formed by adding 5, 10, 15 % RHA in cement mortar. At 7 days the mortar cubes with RHA shows slight increase in compressive strength in comparison to control specimen and the strength of mortar cube is higher in the specimens having lesser RHA content. It shows that the RHA has low early strength gain mechanism in comparison to cement. At 28 days the mortar cubes with 5% RHA shows maximum strength as compared to other specimens and the overall strength of specimens with RHA has increased significantly. At 90 days mortar cubes with 5% RHA shows compressive strength of 38.25 MPa against 31.1 MPa of control specimen at same age. As the age of mortar cubes is increasing the strength is also increasing and mortar with 5% RHA gives the optimum result. However the largest strength development happened between 7 and 28 days as can be seen from the graph.

4.2. Discussion on compressive strength of concrete

The detailed results for compressive strength are given in table VII and its graph is also shown in figures VII and VIII. The addition of RHA in proportion of 5 and 10% of cement resulted in higher compressive strength of concrete as compared to control for 7 days and 28 days of curing. At 7 day the strength of concrete having 15 % RHA is lesser in comparison to the strength of plain concrete. At 28 days the compressive strength of concrete having 5% RHA is 35.02 MPa as compared to 33.15 MPa of control specimen. For all curing durations the RHA content of 5% shows the maximum gain in compressive strength. It shows that the concrete with RHA takes more time to gain strength as compared to plain concrete. The addition of RHA has been found to increase compressive strength due to the pozzolanic effect.

4.3. Discussion on flexural strength of concrete

The results of flexure test on beams of 0, 5, 10 and 15% of RHA are shown in table VIII and its graph is also depicted in figure X. The beam was tested after 28 days of curing and the flexural strength of beam having RHA was not positive. The maximum flexural strength obtained is 34.08 MPa as shown in the table and the flexural strength decreases as the RHA content increases. This shows that the development of strength due to RHA requires sufficient duration of curing. RHA being a pozzolanic material is expected to gain strength after 56 days and 90 days, due to which in 28 days testing the result of flexural strength test is not positive.

V. CONCLUSION

1. Rice Husk Ash used in the study containing maximum possible amount of amorphous silica content, produced by complete combustion of the rice husk shows satisfactory results.
2. The test sample prepared with addition of 5% RHA content shows the best gain in compressive strength for curing duration of 7 and 28 days.
3. The flexure test for beams shows that there is no positive gain in strength by addition of RHA in any proportion for the curing duration of 28 days.
4. The reason behind the strength gain mechanism for flexural strength of beams is the pozzolanic nature of RHA due to which the samples are expected to obtain maximum gains in strength after 56 and 90 days of curing, as is seen in the strength gain results for mortar sample test for curing duration of 90 days.

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