A Review of the Hardened Properties of Eco-Friendly Concrete Containing Rice Husk Ash

Rajashree Baruah[1], Rajat Saxena[2], Dr. Trilok Gupta[3], Dr. Ravi Sharma[4]

[1]*M. Tech student, Department of Civil Engineering, College of Technology and Engineering, MPUAT, Udaipur, Rajasthan, India.*
[2]*Research Scholar, Department of Civil Engineering, College of Technology and Engineering, MPUAT, Udaipur, Rajasthan, India.*
[3]*Assistant Professor, Department of Civil Engineering, College of Technology and Engineering, MPUAT, Udaipur, Rajasthan, India.*
[4]*Professor, Department of Civil Engineering, College of Technology and Engineering, MPUAT, Udaipur, Rajasthan, India.*

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Abstract -*Cement manufacture depletes environmental resources, requires large energy usage, and emits large quantities of green house gases. Roughly one tonne of carbon dioxide is released by ordinary Portland cement accounts for approximately 7% of global carbon dioxide emissions. Governments and ecologists also reported severe ecological problems (pollution and health issues) related to the cement and construction sectors.*

Rice husk ash (agricultural waste) is produced as rice husk has irregular abrasive surface and high silica composition which cannot be naturally degraded and because of the poor nutritional values, it cannot be used as food for livestock. When discarded as a landfill, they will take up a lot of land and become a big environmental threat. The ashes will spread to the surrounding areas, produce pollution, and ruin natural beauty if they are disposed by burning. One of the potential options for rice husk disposal is to turn it into rice husk ash and introduce it into materials based on cement. The utilization of rice husk ash (RHA) as a cement substitute is found to be eco-friendly, and economically viable. This paper presents an overview of the published results on the successful utilization of rice husk ash as supplementary cementitious material and the properties of such concrete at fresh and hardened stages. The findings of this study show that in regular, high strength and self-compacting concrete, there is a promising future for the use of rice husk ash as it demonstrates high strength, low shrinkage, and permeability, high resistance to carbonation, chloride, sulphate, and acidic environments.

Keywords -Properties of concrete, Rice hush ash, Splitting tensile strength, Carbonation, Durability.

1. INTRODUCTION

In developing countries like India, concrete is widely used as a building material and 12 billion tonnes of concrete are manufactured every year [1,2]. It is projected that this product will be 18 million tonnes by 2050 [3]. One of the main concrete components is cement, which binds coarse and fine aggregates together. In the current scenario, the production of cement is expected to be 4,100,000 thousand metric tonnes, producing CO_2 on a large scale, resulting in global warming [4]. Cementative fillers are powdered materials which do not have cementitious property, but they form compounds with the cementitious property when moisture is present [5]. A large quantity of 150 billion of rice is grown worldwide and an immense amount of waste is generated that pollutes the atmosphere. Rice hush ash (RHA) is produced from agricultural waste and can be used effectively in concrete to replace cement due to its binding properties that can yield economic and environmental benefits [6]. Waste materials should be used in concrete in order to conserve the natural resources and simultaneously the ecosystem is secured from the deposition of waste materials. Therefore, the use of RHA waste in concrete could be one of the best options for the disposal of this waste as it saves natural resources and provides a more efficient material. [7]. Waste rubber concrete can thus contribute in sustainable construction. RHA has pozzolanic properties and increases strength and resistance to corrosion along with a major increase in workability [8]. In Contrary to this, some researchers found a small improvement in strength with decreased workability due to the use of RHA in concrete [9]. However, due to accelerated pozzolanic reactions, some authors found an increase in the strength of concrete mixtures from 5-20 percent cement substitution with RHA [9]. The optimum percent of RHA with its effect of different properties is given in Table 1.

Table 1 Properties of RHA used by different authors

Cement replacement material	% replacement	Trends in properties	Sources
RHA	15	Increase in compressive strength	[11]
RHA	10,15,20	Increase in compressive strength	[12]
RHA + Metakaolin	15 and more	The decrease in compressive strength	[13]
RHA + C-S-H	2.5 and 15	Increase in compressive strength	[14]
RHA	5	Increase in compressive strength	[15]
RHA	5	Increase in compressive strength	[16]
RHA	20	Increase in compressive strength	[17]
RHA	0-20	Increase in compressive strength and reduction in chloride penetration	[18-19]
RHA	10	Increase in compressive strength and low porosity	[20]
RHA	10	Increase in compressive strength	[21-23]
RHA + Silica fumes	30,20	Increase in compressive strength and flexural strength	[24]
RHA + Metakaolin	40	Increase in compressive strength	[25]
RHA + Metakaolin + Polypropylene	10	Improved mechanical properties	[26]
RHA	5	Improved mechanical properties	[27]
RHA	15	Increase in compressive strength	[28-29]
RHA	20	Improved mechanical properties	[30]
RHA	10	Improvement in performance and durability	[31-32]
RHA	10	Increase in compressive strength	[33]
RHA + Silica fume + Admixture	10	Improved mechanical properties	[34]

The study on chemical research, as performed by [35], reveals that RHA is chemically similar to OPC. RHA has a silica content of 85%, known as non-crystalline silica, which should be used as a partial substitute for cement [36-40]. RHA is measured as an extremely pozzolanic substance which can be used to mitigate the pollution crisis as an added material in concrete [41-46].

If the rice husk is turned to ash at a temperature below 500 °C, due to the presence of unburnt fuel, the combustion is not complete and the pozzolanic effect of the ash was reduced. The silica content was converted to non-crystalline or amorphous silica (the silica content is approximately 90 percent) when the ash was formed at a controlled temperature of 550-700 °C and is highly suitable for use as pozzolana [28, 47-48]. Rice husk ash (RHA) produces a greater proportion of silica as compared with all other agricultural waste materials. Kamia et al. (2000) noted that ortho silicic acid is absorbed by rice plants from groundwater and then polymerized to form amorphous silica on the husks. The RHA thus formed by controlled combustion, in the presence of water resulting in cement compounds, react with the calcium hydroxide present in cement [50-52]. A lot of studies have been conducted on the use of RHA in cement concrete as a partial substitution for ordinary Portland cement or fine aggregates since the end of the 1960s, and several papers and patents have been published [53-56].

Mehta started a study on RHA on cement materials based on the impact of pyro-processing on RHA pozzolanic reactivity. Another analysis was carried out by Pitt (patent 1976) who developed a fluidized bed furnace for the controlled combustion of rice husk based on the work of Mehta. When the burning temperature and the residence time of rice husk inside the furnace were controlled highly pozzolanic RHA could be produced [55]. Since then, a lot of analysis has been conducted across the globe on the implementation of RHA. The world's forecasted production of rice paddy, potential husk and ash production for 2016 is shown in Table 2.

Table 2 The world's forecasted production of rice paddy, potential husk and ash production for 2016 [56]

Country	Rice paddy production in million tons	Husk produced (20% of rice paddy)	Potential ash (18-20% of the husk)
China	211.2	42.24	7.6
India	158.4	31.68	5.70
Indonesia	71.9	14.38	2.59
Bangladesh	52.9	10.58	1.90
Vietnam	44.5	8.90	1.60
Thailand	30.3	6.06	1.09
Africa	29.1	5.82	1.05
Myanmar	28	5.60	1.01
South America	23.7	4.74	0.85
Philippines	18.7	3.74	0.67
Japan	10.6	2.12	0.38
North America	10.4	2.08	0.37
Pakistan	9.9	1.98	0.36
Others	32.3	6.46	1.16

1.1 Properties of rice husk ash (RHA)

Rice husk ash is a fine pozzolan which depends on the source of raw material. Due to the combustion, time period and temperature of burning, the color vary from white grey to black. James and Rao [57] have observed that isothermal heating of at least 402 °C is necessary for the release of silica after the destruction of organic matter from the rice husk. 500 °C combustion was done with the most reactive silica [57, 50]. Bie et al. [58] studied the influence of burning conditions on the mechanical actions of cement (RHA in a muffle furnace) and concluded that at 600 °C the rice husk burns than at elevated temperatures. K_2O was able to decompose and produce more carbon in RHA when the temperature was raised. RHA is categorized as type N pozzolan, as per the ASTM C618 code. The cumulative quantity of silicon dioxide, iron oxide, and aluminum oxide could not be less than 70 percent of the overall mass and up to 10 percent of the total ignition loss [59]. Salas et al. [54] stated the specific surface area of treated RHA was 10 times that of silica fume (274,000 m^2 / kg).

2. PROPERTIES OF HARDENED CONCRETE

Different hardened properties of RHA concrete such as compressive strength, tensile strength, flexure strength has been reviewed in this paper.

2.1 Compressive strength

Compressive strength is the property of concrete without any cracking or deflection to bear the load on its surface. On a compression testing machine (CTM) with a load-carrying capacity of 5000 KN, the compressive strength of the concrete is determined and provides the full load the concrete sample takes at the time of failure.

Singh et al. [60] performed an investigation in which cubes were cast to be checked for each mix for 7 days and 28 days of curing, except for a concrete mix containing carbon nanotubes. After 28 days of curing, nine different numbers of concrete cubes were cast and tested.

At 5% replacement of RHA gave the maximum compressive strength which is 36.7 MPa at 7 days and 49.1 MPa at 28 days. While minimum compressive strength was observed at 25% replacement of RHA which is 21.1 MPa at 7 days and 27.4 MPa at 28 days (Fig. 1).

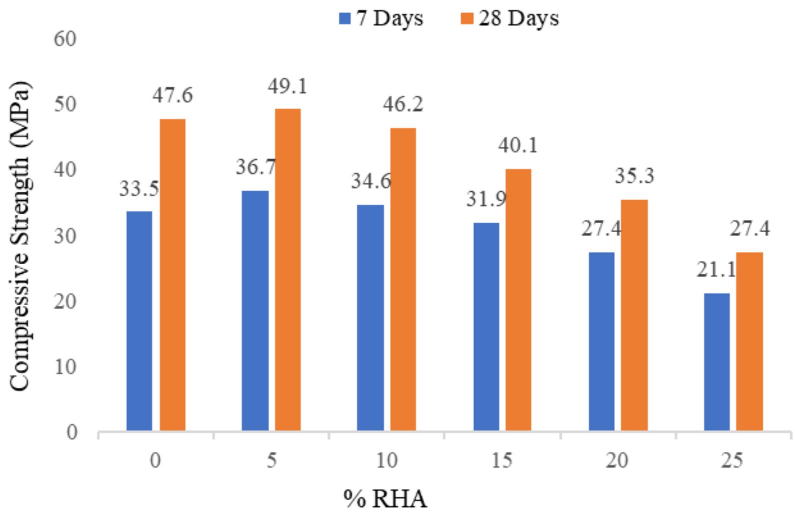

Fig. 1 Compressive strength test results [60]

The compressive strength of the RHA concrete was investigated by Bheel et al. [61] as per the ASTM C39 standard test technique. The experimental results indicated that with curing ages, the compressive strength of plain and blended concrete increases, i.e. a maximum of 36.4 MPa and 41.68 MPa at 56 days and a minimum of 23.6 MPa and 24.54 MPa at 7 days respectively, at a ratio of 0.45 w/c. Generally, the strength appears to decrease as the water content in concrete was increased, but with increased curing age, with 10 percent RHA, it increases in plain as well as concrete. Maximum compressive strength is reported at a ratio of 0.45 w/c and a curing duration of 56 days and a minimum of 0.60 w/c and a curing age of 7 days (Fig. 2). It is further noted that, relative to normal concrete, the cubical compressive strength reaches a limit of 14.51 percent.

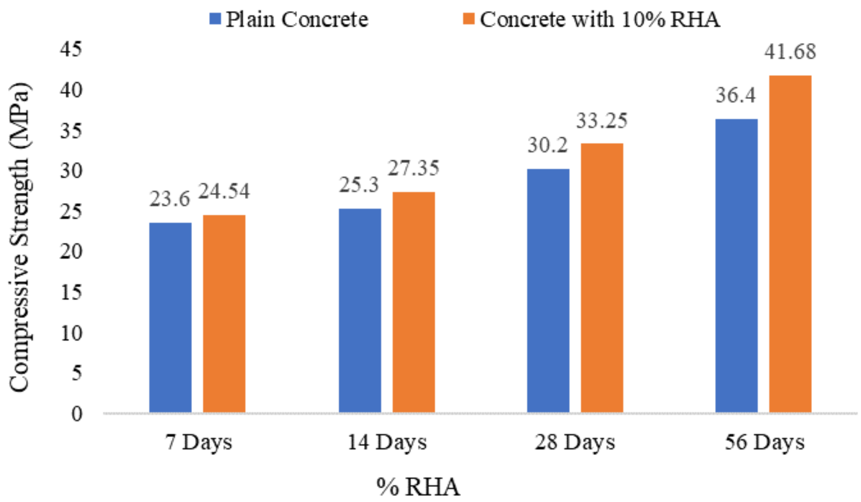

Fig. 2 Compressive strength test results of Plain concrete and 10% RHA [61]

Bheel et al. [62] performed a compressive strength test on cubes (100 mm to 100 mm) using various percentages of RHA. For each proportion, three specimens were cast and, finally, the mean value of these three concrete specimens was taken as the final result. The compressive strength was at most 10% of the RHA used in concrete as cement substituent material and at least 20% of the RHA, at 7, 14, and 28 days (Fig. 3):

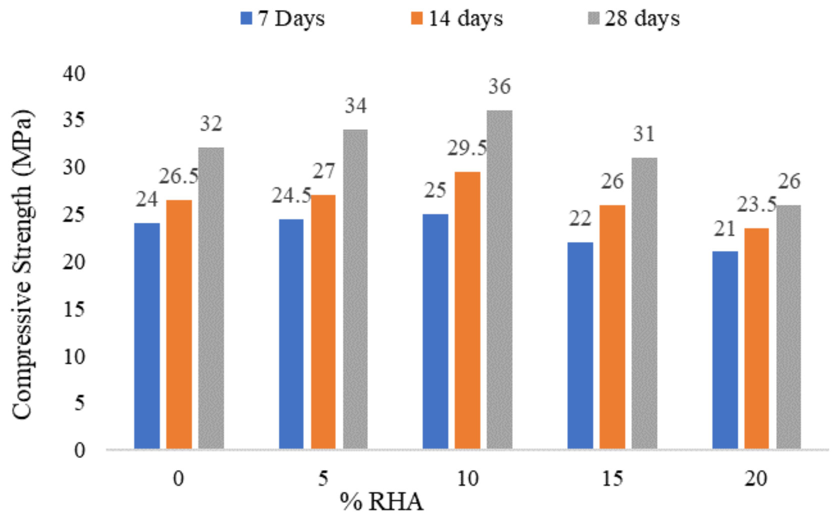

Fig. 3 Compressive strength test results at 7,14 and 28 days [62]

Huang et al. [63] conducted compressive strength tests with various RHA replacement ratios at 3, 28, and 120 days on high-performance concrete. Compared with SF, it can be found that RHA increases the compressive strength of ultra-high performance concrete (UHPC).

The compressive strength of the sample with replacement ratio 66% RHA was 137.2 MPa at 28 Days. The compressive strength of 66% RHA sample was 9.76%,14.5% and 10.02% higher than that of control sample at 3, 28 and 120 days respectively. In addition to the filling effect, RHA's pozzolanic reactivity and internal curing effect make an outstanding contribution to compressive strength growth. It is suspected that the rise in the amount of trapped air may harm the improvement in compressive strength. Therefore, by changing the trapped air material, UHPC can achieve an extended growth in compressive strength.

Gastaldini et al. [64] suggested that the compressive strength of the concrete containing 20% RHA with a water to cement ratio of 0.35 showed a strength of 75.2 MPa at 28 days. The concrete containing 20 percent RHA and 1 percent K_2SO_4 (by cement weight, as a chemical activator) showed 9 percent, 33 percent, and 43 percent improvement in compressive strength (compared to control concrete) for the mixture with water to cement ratios of 0.35, 0.50 and 0.65 at 91 days of age, respectively.

Chindaprasirt et al. [65] proposed that 20 percent could be the optimum cement replacement with RHA. Salas et al. [67] noted that the use of 5-10% RHA substantially improved the concrete strength and was equivalent to that of concrete containing the same quantity of silica fume.

By replacing 20 percent of cement with RHA, Madandoust et al. [66] conducted studies and noted that the short-term strength improvement of RHA concrete is lower than normal concrete. The strength of RHA concrete was 65 percent of standard control concrete at 3 days of age. At 90 days, 98 percent at 180 days, equal strength at 270 days, and 102 percent (means 2 percent higher strength) at 360 days, it increased to 96 percent. Because of the higher pozzolanic operation in RHA concrete, due to the reduced production of strength at an early age, it may be inappropriate in fast track construction projects.

Suaiam et al. [67] substituted rise husk ash to find out the change properties of concrete. With increase in replacement percentage, the compressive strength decreased. Antiohos et al. [68] tested the compressive strength, RHA mortar specimens with Blaine fineness 4000 and 7000 cm^2/g. The samples containing RHA of 7000 cm^2/g fineness had higher strength. The strength of concrete with RHA with 10 percent was comparable to that of control concrete and the strength decreased upon further replacement.

The combination of RHA and metakaolin for the development of self-compacting concrete with greater cement replacement of up to 40 percent were recommended by Kannan and Ganesan [69]. There was an improvement of up to 30 percent in SCC compressive intensity when 20 percent RHA and 20 percent metakaolin were used. It was pointed out by Bie et al. [58] that the use of 10% RHA can be the optimum proportion to enhance the strength of cement mortar.

Zahedi et al. [70] claimed that it would be advantageous to use RHA with nano-silica since nano-silica can lead to high early strength, whereas RHA can boost long-term strength and durability.

The properties of RHA concrete were investigated by Siddique et al. [71]. The compressive strength of 10 percent RHA concrete improved by 8.7 percent, 10 percent, and 13.4 percent at 7, 28, and 56 days as compared to the control concrete. The formation of calcite within the cement-sand pore structure will contribute to this increase in strength.

2.2 Tensile strength

This property for concrete relates to its tensile strength. This is obtained by performing a split tensile test on a concrete specimen. The concrete specimen in this test is taken as cylindrical. Tensile strength for the concrete specimen is defined as the tensile stresses developed due to the application of the compressive load at which the concrete specimen may crack. Singh et al. [60] performed a split tensile strength test in which six cubes of 100 mm X100 mm X 500 mm was cast, for concrete, should be measured at 7 and 28 days of curing for each mixture. After 28 days, nine separate numbers of concrete cubes were cast and tested. In Fig. 4 it can be seen that at 5% replacement of RHA gives the maximum tensile strength which is 2.36 MPa at 7 days and 3.178 MPa at 28 days. While minimum tensile strength was observed at 25% replacement of RHA which is 1.443 MPa at 7 days and 2.041 MPa at 28 days

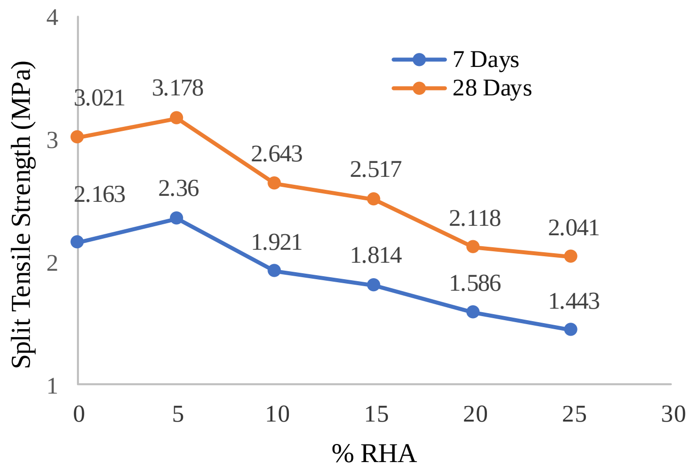

Fig. 4 Split tensile strength [60]

Bheel et al. [60] conducted ASTM C496 splitting tensile strength testing technique is followed to determine concrete's tensile behavior. In this report, UTM cast and tested a total of 72 cylinders of plain and concrete with 10 percent RHA. Similarly, this measure is also measured at 0.45, 0.50, and 0.60 w/c ratios and 7, 14, 28, and 56 days of recovery time for compressive power. Overall, experimental results show that at 0.45 w/c ratio and 56 days of curing duration, the splitting tensile strength of plain and blended concrete reaches a limit of 4.65 MPa and 4.2 MPa respectively. At a ratio of 0.45 w/c and a curing age of 56 days, this concrete value with 10 percent RHA is 10.71 percent greater than plain concrete (Fig.5). Lower early strength may be due to the evaporation of less hydration heat due to the presence of calcium silicate, which induced strength gain with extended curing age at the latter point.

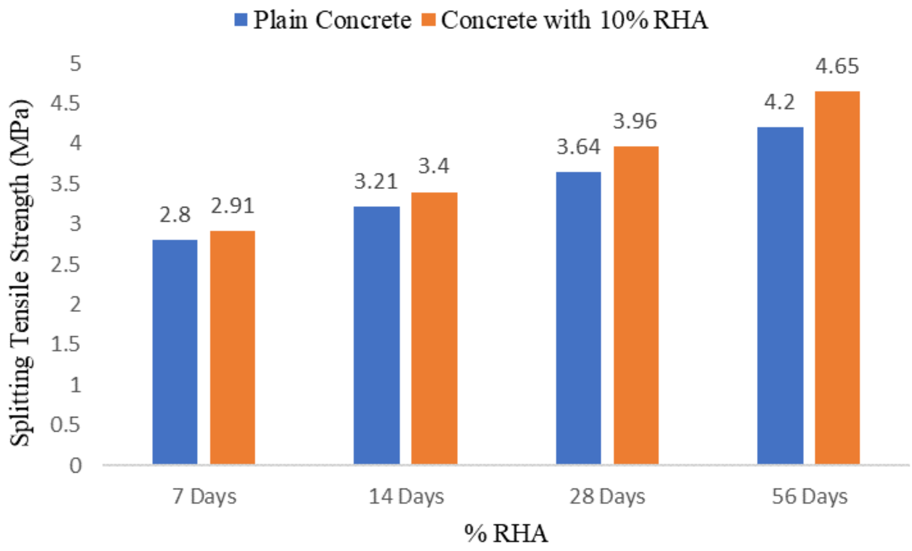

Fig. 5 Split tensile strength of plain concrete and RHA concrete [61]

Splitting tensile strength tests on cylinders (200 mm to 100 mm) of different percentages of RHA that were cured at 7, 14, and 28 days were performed by Bheel et al. [62]. For each proportion, three concrete samples were cast and an average was taken as the final product. At 10 percent RHA specimens, the maximum splitting tensile strength of concrete was noted and at 20 percent, the minimum splitting strength of concrete was reported. The cylinders have been tested using UTM. Fig. 6 indicates the experimental work outcomes.

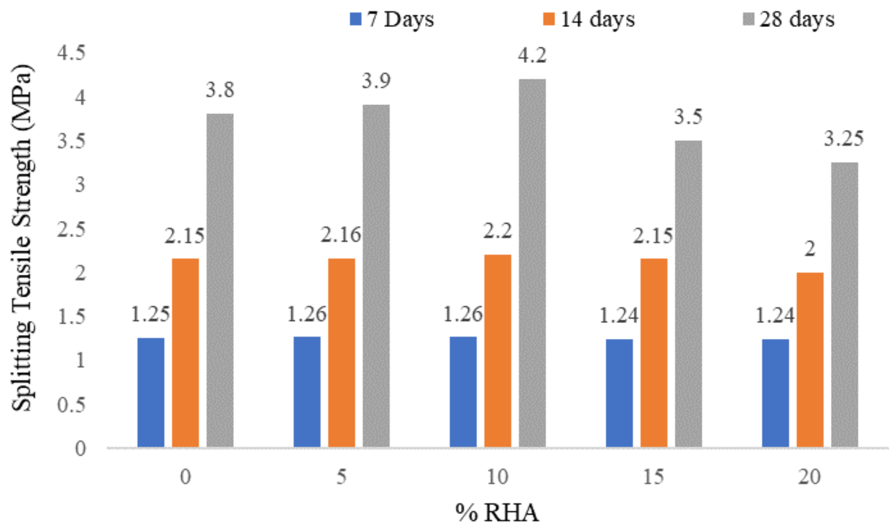

Fig. 6 Split tensile strength at 7,14 and 28 days [62]

Salas et al. [54] have found that the flexural tensile strength (rupture module) of concrete samples containing ordinary RHA is comparable to that of the control mix samples, whereas the strength is much higher for concrete containing treated RHA.

Giaccio et al. [72] studied the failure mechanism of RHA concrete and stated that as the stresses at which the cracks form and spread are higher in RHA concrete compared to control concrete, there is a potential for brittle failure.

Wei and Meyer [73] noted that partial RHA replacement increases the bending properties and resilience of the fiber-reinforced concrete composites during wetting and drying cycles.

Mohseni et al. [74] observed a 28-day flexural strength decreased by 2%, 11%, and 14% when RHA was substituted for 10 %, 20%, and 30% of cement. At 90 days of age, the flexural intensity of the specimens containing 30 percent RHA increased. When 3% nano-Al_2O_3 was applied to the 10% RHA samples by cement weight, there was a 34% and 41% improvement in flexural strength at the ages of 28 days and 90 days, respectively. The 28 day and 90-day flexural strength improved by 18.6 percent and 23.1 percent respectively when 0.3 percent polypropylene fiber was applied to the concrete containing 10 percent RHA and 1 percent nano-Al_2O_3.

Using cylindrical specimens of 150 mm in diameter and 300 mm in height, Saraswathy and Song [75] performed the splitting tensile strength as per ASTM C496-90. With the growing amount of RHA, from 5 percent to 15 percent of replacement, the intensity was found to increase gradually. The control concrete strength was 4.49 N/mm^2 and for the specimens containing 15 percent RHA, it was 4.92 N/mm2. The intensity decreased to 4.60 N/mm^2 and 4.58 N/mm^2 respectively, still higher than the control mix values when the substitution was 20-25 percent. At 30 percent replacement, the intensity experienced a major decrease, hitting 3.67 N/mm^2.

Madandoust and Ghavidel [76] claimed that the initial splitting tensile strength of the control concrete was higher than that of the 10% glass powder and 5% RHA cement-weight blended concrete. As it was 71 percent of the control concrete at the age of 7 days, the strength of the blended concrete increased with age and it increased to 97 percent at the age of 90 days.

Venkatanarayanan and Rangaraju [77] noticed an improvement in strength compared to control concrete when 7.5 percent and 15 percent were the levels of rice husk ash. When unground rice husk ash was used, it was 16 percent and 4 percent, while the rise was 21 percent and 15 percent when ground RHA was used.

2.3 Flexural strength

A flexural test is done to find out the tensile strength of the concrete. It tests the ability of an unreinforced concrete beam to withstand failure in loading. The results of the flexural strength test are expressed as modulus of rupture in MPa.

Singh et al. [60] performed a flexural strength test for concrete at 28 days of curing for each mixture. In Fig. 7 it can be seen that at 5% replacement of RHA gives the maximum tensile strength which is 3.35 MPa at 28 days. While minimum tensile strength was observed at 25% replacement of RHA which is 1.975 MPa at 28 days.

Sakalakale et al (2014) recorded an improvement in the flexural intensity of 25 percent and 13.13 percent [78]. The

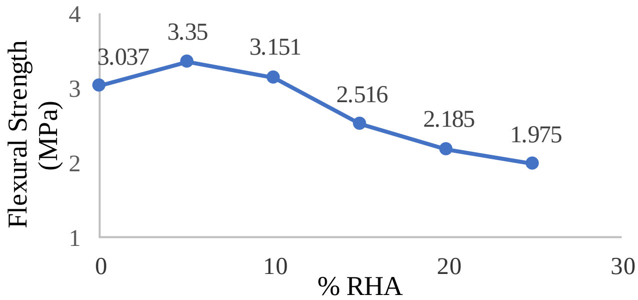

Fig. 7 Flexural strength results at 28 days [60]

inclusion of hooked steel fibers raises the average flexural strength of mixtures with 1.5 percent addition of steel fibers by 35 percent. Compared to the reference combination, the concrete with 15% RHA shows a maximum flexural strength increase of 78.4 percent of control mix. The aspect ratio and tensile strength of fibers can be attributed to this increase in flexural strength. In regions of the crack edge, the use of hooked steel fibers strengthens the fibro matrix bond and releases fracture energy, and the tensile stress is subsequently transferred to the fibers that avoid the spread of macro cracks [79]. The flexural strength increased with the percentage of steel and could be due to a random distribution of fibers that mitigated crack prorogation [80].

The rise in steel fibers from 0.5 percent to 1 percent raises the flexural strength by 100 percent, was observed by Oliveira et al (2013) [81]. This percentage decreases, however, to 26 percent when the percentage of fiber is increased to 1.5 percent.

3. DURABILITY PROPERTIES

The ability of concrete to resist various chemical attacks, abrasion, weathering actions are defined as the durability of concrete. Chloride penetration, abrasion resistance, carbonation and electrical resistivity were reviewed from various research work.

3.1 Chloride penetration

Chloride penetration, test methods are needed to allow the determination of representative values in a reasonable time. There are different driving forces for chloride penetration in concrete: surface tension (absorption), pressure (permeation) and diffusion (movement of ions under a concentration gradient).

A major reduction in the overall charge passed by 65 percent, 68 percent, and 59 percent at the water to cement ratios of 0.35, 0.50, and 0.65 respectively (at 20 percent RHA) was noted by Gastaldini et al. [63]. When the concrete containing 20% RHA was chemically activated by 1% K_2SO_4 by cement weight, the cumulative charges were decreased by 75 percent, 74 percent, and 71 percent. The overall charges were decreased by 74 percent, 73 percent, and 75 percent at water-to-cement ratios of 0.35, 0.50, and 0.65 respectively when the concrete blends were triggered by 1 percent Na_2SiO_3.
The rapid chloride permeability test (ASTM C1202) was performed by Salas et al. [54] to measure the electrical conductivity of concrete. As the presence of rice husk ash helped to densify the pore structure of the concrete, it was observed that the transferred charge was very low in RHA concrete. The mercury intrusion porosimetry (MIP) technique verified the pore refinement, confirming the average diameter of 0.041 µm for the control cement paste and 0.021-0.023 µm for the RHA-containing concrete.

De Sensale [47] indicated that by replacing 15 percent of Portland cement with RHA, the best resistance to chloride ion penetration was achieved.

Madandoust et al. [66] tested chloride ion penetration on specimens containing 20 percent RHA in compliance with ASTM C1152. Samples were exposed to 5 percent NaCl during eleven months of wet and dry cycling. Following dry drilling, the powder was taken from the samples (0-10 mm, 10-20 mm, 20-30 mm, and 30-40 mm). It was seen from the chemical analysis that with the higher amount of RHA in concrete, there was lower chloride concentration and the penetration decreases with concrete depth.

Siddique et al. [79] found that as compared to control concrete, the charge passed by the 10 percent RHA concrete decreased by 52.6 percent at 56 days of curing. As compared to bacterial control concrete, it decreased by 48.4 percent at 56 days in the case of bacterial concrete. In the case of RHA-containing bacterial concrete, the permeability level for RHA concrete was from 'medium' to 'moderate' whereas it was from 'very low' to 'moderate'.

3.2 Abrasion resistance

It is possible to characterize the abrasion resistance of concrete as its ability to resist being worn away by rubbing. If the depth of abrasion is decreased, this suggests that the concrete is more resistant to abrasion. More abrasion-resistant concrete may be applied to pavements, floors, and concrete sidewalks, to hydraulic structures such as tunnels and dam spillways, or to other surfaces to which abrasive forces are applied during operation between surfaces and moving objects [78].

Siddique et al. [79] calculated the abrasion resistance of concrete as per BIS 1237. The abrasion depth was 0.831, 0.585, and 0.491 mm at 7, 28, and 56 days for 10 percent RHA concrete, while the wear depth was just 0.752, 0.501, and 0.400 mm at 7, 28, and 56 days for concrete containing 10 percent RHA and bacteria.

The optimum replacement level of RHA was described by Jamil et al. [80] as 14.3 percent for ASTM type-1 cement with 55 percent C3S and 19 percent C2S.

Modarres and Hosseini [81] found that, after 120 days of curing, the addition of 3% RHA decreased concrete porosity and thus improved fatigue resistance and energy absorption of the material, while the addition of 5% RHA resulted in higher porosity and lower concrete fatigue life.

3.3 Carbonation

The surface of the concrete can be penetrated by carbon dioxide and react with the alkaline elements, primarily $Ca(OH)_2$ of the cement paste. The pH value of the pore solution can be reduced to less than 9 by this reaction (carbonation). Protection of reinforced steel from corrosion would be at risk when the alkalinity of the pore solution is lost. Carbonation can also affect the properties of concrete, such as strength, permeability, shrinkage, and resistance to chemical & physical attacks [82].

The carbonation of chemically activated RHA concrete was studied by Gastaldini et al. [83] using specimens of 100 X 100 mm in scale, as per RILEM TC 116-PCD and CPC 18, RILEM. Within a controlled chamber maintained at 23 ± 1 ° C and 65 ± 1 percent relative humidity, the prepared specimens were exposed to 5 percent carbon dioxide. The depth of penetration of carbon dioxide was measured using the process of phenolphthalein spray testing. It was found that when 20 percent RHA was used, the carbonation depth decreased. When 1 percent K2SO4 was used as a chemical activator along with 20 percent RHA, the carbonation further declined. In the water-to-cement ratio of 0.5 specimens, carbonation decreased from 7.50 to 4.69 mm and in the water-to-cement ratio of 0.65 specimens, it decreased from 14.14 to 10.68 mm.

The depth of carbonation of concrete containing 20 percent and 40 percent black rice husk ash was investigated by Chatveera and Lertwattanaruk [84]. The carbonation depth of 20 percent black rice husk ash containing concrete was higher than that of the control concrete. The carbonation depth was further increased by raising the amount of ash from 20 percent to 40 percent and improving the water to cement ratio. The increase in carbonation is due to the rise in porosity and the lower cement concentration.

3.4 Electrical resistivity

Electrical resistivity is a technique that is used by calculating the diffusion of ions in the concrete through the pore solution for the quality control and performance-based assessment of concrete.

The electrical resistivity of concrete was described by Layssi et al. [85] as the ability of concrete to withstand the transfer of ions subjected to an electric field. It is influenced by the distribution and interconnection of the pore size, pore fluid conductivity, degree of saturation, and temperature. Electrical resistivity is determined by the uniaxial method of two points and the method of four points (Wenner probe).

A rise in electrical resistivity was reported by Gastaldini et al. [86], as the curing time increased from 3 to 91 days. As the percentage of RHA in concrete rose from 10 percent to 20 percent, the electrical conductivity doubled (w / b ratios 0.35, 0.50, and 0.65) and at 30 percent RHA, relative to the reference samples, the resistivity was 340 percent, 442 percent, and 404 percent respectively for the w / b ratios 0.35, 0.50 and 0.65. Ω

For all the concrete specimens containing 0-20 percent RHA, Safiuddin Md. and Soudki [87] observed true electrical resistivity (between 5 and 10 k Ω -cm). With a growing amount of RHA, the resistivity improved and it was 52 percent higher than the control concrete specimens at a content of 20 percent.

Chao-Lung et al. [88] noted a sharp increase in the electrical resistivity of soil-containing RHA concrete after 14 days of age (due to the pozzolanic reaction solidification of the pores).

Zahedi et al. [70] studied the electrical resistivity of control mortar specimens, RHA-containing specimens, and both RHA-containing and nano silica-containing specimens. The electrical resistivity of RHA concrete was found to be decreasing at 7 days of age (due to low early pozzolanic activity) and the resistance increased compared to the control mix at 28 and 90 days of age. In specimens containing nano-silica and 10 percent RHA at 28 and 90 days of age, the highest electrical resistivity (improvement of 328.6 percent compared with the control mix) was observed.

4. CONCLUSIONS

From the above literature studies, the following conclusions can be drawn:

- Concrete strength improved with increasing quantities of up to 20 percent of the RHA. It is suggested to use RHA for long-term strength and durability.
- The mechanical properties (splitting tensile strength, flexure strength) of concrete increases up to 5-15 percent replacement of cement. After that brittle failure occurs which forms the cracks in concrete.
- With an increase in the volume of RHA, from 5 percent to 15 percent of replacement, the resistance to abrasion concrete was found to increase slightly.
- The rise of 15-20 percent in the amount of RHA in concrete decreases the potential for carbonation and penetration of chloride
- The electrical resistivity of RHA containing concrete was greater than that of the control concrete samples due to the pozzolanic reaction solidification of the pores which in turns increases the durability of concrete.

From the above study it can be suggested that RHA can be utilized effectively in sustainable concrete to decrease the accumulation of RHA. With the use of RHA in concrete cement content can be reduced which turns into a Eco-friendly solution.

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