Jordan Journal of Civil Engineering, Volume **12**, No. **4**, **2018**

Strength and Durability Characteristics of Rice Husk Ash Concrete Reinforced with Polypropylene Fibres

Rizwan Ahmad Khan [1] ***and Rahul Sharma*** [2]

[1] Associate Professor, Aligarh Muslim University, Aligarh, India. E-Mail: rizwankhan1@gmail.com
[2] Research Scholar, Dr. B.R. Ambedkar National Institute of Technology, Jalandhar, India.
E-Mail: Khanar@nitj.ac.in

ABSTRACT

This study was conducted to investigate the strength and water permeation properties of Rice Husk Ash (RHA) concrete reinforced with polypropylene fibres (PP). The properties evaluated include compressive strength, splitting tensile strength, flexural strength, initial surface absorption test (ISAT) and capillary suction test (sorptivity). An experimental program was planned, in which thirteen concrete mixes were prepared. Ordinary Portland Cement (OPC) was partially replaced by RHA at 10%, 15% and 20% with addition of PP at 0.5%, 0.75% and 1% by weight of binder. The water/binder (w/b) ratio was kept constant at 0.38. Super-plasticizer was varied from 0.3% to 0.7% by weight of binder for different concrete mixes. The use of RHA in concrete mixes was found to increase the compressive strength at later ages and inclusion of higher amount of PP decreases compressive strength. The splitting tensile strength was found to increase with RHA as well as PP for all concrete mixes. There was significant enhancement in flexural strength with increase in PP content, especially at later ages. Initial surface absorption test and capillary suction test showed that as the replacement of cement by RHA in concrete mixes increases, water absorption in concrete mixes was found to decrease compared to control mix. Addition of PP also decreases ISAT-10 and initial rate of absorption (IRA) values, but RHA has more effect on the reduction of absorption characteristics than PP.

KEYWORDS: Rice husk ash (RHA), Polypropylene fibres (PP), Hardened and durability properties.

INTRODUCTION

The microstructure of cement paste in the interfacial transition zone (ITZ) can be significantly improved by adding (super) fine materials, such as Fly Ash (FA), Silica Fume (SF) , Metakaolin (MK) and Rice Husk Ash (RHA). India is the second largest producer of rice in the world. Rice husk is obtained from the outer covering part of the rice grains which consists of two interlocking halves (Xu et al., 2011). It is estimated that 1,000 kg of rice grains produce 200 kg of rice husk. After rice husk is burnt, about 40 kg would become RHA. It contains about 80-85% silica, which is highly reactive depending upon the temperature of incineration. It also improves the properties of fresh concrete, reduces heat evolution, reduces permeability and increases strength at later ages (Kishore et al., 2011; Ganesan et al., 2007; De Sensale et al., 2006; Sharma, 2013). RHA is a highly reactive pozzolanic material produced by controlled burning of rice husk. The utilization of RHA as a pozzolanic material in cement and concrete provides several advantages, such as improved strength and durability properties, reduced material costs due to cement savings and environmental benefits related to disposal of waste materials and to reduced carbon dioxide emissions (Khan

---

Received on 20/3/2017.
Accepted for Publication on 19/7/2018.

et al., 2002). RHA concrete showed lower strength at early ages, although attaining strength of about 96% at 90 days and 98% at 180 days of control concrete (Madandoust et al., 2011; Khan et al., 2012). Binary blend of 25% RHA as partial replacement of cement was found to have the same or better strength than control concrete (Khan et al., 2012). SSC concrete exhibited lower workability with increase in RHA content (Singh et al., 2013).

Durability of concrete is influenced by both physical and chemical properties of concrete. Deterioration is caused by the ingress of deleterious agents and the reaction of these agents with either the cement paste, the aggregate or the reinforcing steel. Most of these deteriorations are due to ingress of water and aggressive agents into the concrete. Three transport modes can occur in structures: diffusion (due to concentration gradient), permeability (due to pressure gradient) and capillarity suction (due to capillarity effects) (Desmettre et al., 2012). Permeability and sorptivity are major factors affecting the durability of concrete, because aggressive agents penetrate through porous concrete more rapidly (Song et al., 2007). Available pore space and connectivity of pores govern the ingress and transport of gases and liquids into porous materials and, consequently, the durability of these materials. The pore volume is characterized by porosity and connectivity of pores by permeability. These two properties together govern the durability of porous materials such as concrete (Bosnjak et al., 2013). The economic impact of the durability problem has led to extensive research for over two decades and has initiated the way to the production of better and durable concrete or reinforced concrete structures (Basheer et al., 2001). The use of blended cements or supplementary cementing materials decreases permeability, thereby increasing the resistance of concrete to deterioration by aggressive chemicals (Malhotra et al., 1996; FIP Report, 1988). Therefore, the incorporation of pozzolanic materials, such as FA, SF and RHA, has become an increasingly accepted practice in concrete structures exposed to harsh environments (Bui et al., 2005).

Concrete is a tension-weak building material, which is often ridden with cracks related to factors, such as plastic and hardened states as well as drying shrinkage. To overcome these problems, incorporation of fibres will enhance ductile behavior of the concrete matrix. In the development of concrete-like materials, reinforcement with dispersed fibres plays an important role to overcome crack-related problems (Nili et al., 2010). Use of polypropylene fibres in concrete has attracted attention among researchers because of their low cost, outstanding toughness and enhanced shrinkage cracking resistance in concrete. It was found that inclusion of PP enhanced durability of concrete sleepers, but reduced compressive strength, whereas it increased tensile and flexural strengths (Ramezanianpour et al., 2013). Self-compacting concrete containing different volumes of PP had insignificant effects on compressive strength and elastic modulus, though tensile and flexural strengths increased for maximum percentage of fibres (Mazaheripour et al., 2011). It was observed that inclusion of PP in lower amounts had no significant effect on mechanical properties of natural pozzolan cement concrete, although it improved early age cracking control ability of concrete (Medina et al., 2014). Oil palm shell light-weight concrete, reinforced with different types of PP at volume fractions of 0.25- 0.5%, increased compressive strength from 42 to 47 MPa in comparison to plain concrete of 41MPa at 28 days of curing. It was also found that fibres were more effective in enhancing flexural strength compared to splitting tensile strength at low volume fractions (Yew et al., 2015). It was reported that performance of PP was superior to that of brass-coated steel fibres in terms of cost and content (Haddad et al., 2004). Higher percentage of fibres in concrete may lead to decrease strength due to improper mixing of fibre units. Combination of steel and polypropylene fibres had better performance than monofibre system if proper percentage is used (Cengiz et al., 2004). Concrete containing hybrid fibres in combination with steel and PP in the range of 0.85% and 0.15%, respectively, improved mechanical properties, whereas further increase in percentage of polypropylene in hybrid fibres decreased strength properties (Afroughsabet et al., 2015). In this paper, the aim of investigation is to study strength and water permeation properties and relationship between them using RHA as partial replacement of OPC reinforced with polypropylene fibres. In order to assess the application of RHA in durability, initial surface absorption test (ISAT) and capillary suction test (CST) were performed.

MATERIALS AND EXPERIMENTAL METHODS

a) Materials

Cement: 43 grade Ordinary Portland Cement (OPC) from a single lot was used throughout the course of the investigation. The physical properties of the 43 grade cement as determined from various tests conforming to Indian Standard IS: 8112-1989 (Part-1) (Indian Standard 8112, 1989) are listed in Table 1. Chemical compositions of OPC and RHA are shown in Table 2. All the tests were carried out as per the recommendations of IS: 4031-1988 (Indian Standard 4031, 2002). Cement was carefully stored to prevent deterioration in its properties due to contact with moisture.

Rice Husk Ash (RHA): RHA is an agro-based material. RHA utilized was of grey colour and light in weight. Specific gravity of RHA was 1.96.

Aggregates: Crushed stone sand was used as fine aggregate. Fineness modulus, specific gravity and bulk density were 2.74, 2.65 and 1675 kg/m^3, respectively. Locally available crushed stone aggregate of 12.5 mm nominal size was used as coarse aggregate with fineness modulus, specific gravity and bulk density of 7.54, 2.69 and 1690 kg/m^3, respectively.

Fibres: Monofilament shape polypropylene fibres (PP) of ENDURO® HPP45 with a length of 45 mm were used in the concrete mix. The added fibres comply with ASTM C 1116 Type 111 4.1.3. These are non-corrosive in nature.

Table 1. Physical properties of 43 grade OPC

Characteristic Properties	Observed Value	Codal Requirements (IS:8112-1989)
Fineness (m^2/kg)	300	225 Minimum
Standard consistency (%)	32	……………
Initial setting time (minutes)	62	30 Minimum
Final Setting time (minutes)	270	600 Maximum
Specific gravity	3.15	……………
Soundness by Le-Chat expansion (mm)	1.0	10.0 Maximum
Compressive strength (MPa)		
3 days	24.6	23 Minimum
7 days	34.3	33 Minimum
28 days	45.2	43 Minimum

Table 2. Chemical composition of OPC and RHA

Oxide composition	Cement	RHA
SiO_2	21.39	90.87
Al_2O_3	6.08	0.19
Fe_2O_3	3.78	0.96
CaO	65.7	0.58
Na_2O	0.21	0.39
K_2O	0.74	2.8
LOI	1.68	3.76

Super-plasticizer: The super-plasticizer used in the study was Glenium SKY777. Glenium SKY777 is based on second generation polycarboxylic ether polymers and supplied as a light, brown liquid instantly dispersible in water. Relative density of super-plasticizer is 1.10 ± 0.01 at 25°C with a PH value greater than 6 and Chloride ion content less than 0.2%. Glenium SKY777 complies with IS: 9103:1999 (Indian Standard 9103, 1999). Glenium SKY777 conforms to ASTM-C-494 Type 'F' and Type 'G' (American Society for Testing and Materials C 494/C494M -12, 2013) depending on the dosage used. The dosages of super-plasticizer were different for different concrete mixes to obtain a constant slump value of 100 ± 10 mm. Super-plasticizer was added into concrete mix after 50% to 70% of the mixing water has been added. Dosage of super-plasticizer varied from 0.3% to 0.7% by weight of binder.

b) Mix Proportioning

Thirteen concrete mixes were prepared. M1 was the control mix and M2 to M13 were mixes with different percentages of RHA with different volume fractions of PP as shown in Table 3. OPC was replaced by RHA at 0%, 10%, 15% and 20%. PP was added to all concrete mixes at 0%, 0.5%, 0.75% and 1%, except to the control mix, by weight of binder. Water to binder ratio was kept constant for all concrete mixes; i.e., 0.38. Mix proportions of fibre-reinforced RHA concrete are shown in Table 4.

c) Preparation of Test Specimens

Casting of specimens was carried out under laboratory conditions using tilting type rotary drum mixer. Each mix consisted of 15 standard cubes for the determination of 7-, 14-, 28-, 56- and 90-day compressive strengths.

Table 3. Binders used for investigation

Mix	OPC (%)	RHA (%)	PP (%)
M1	100	0	0
M2	90	10	0
M3	85	15	0
M4	80	20	0
M5	90	10	0.50
M6	90	10	0.75
M7	90	10	1
M8	85	15	0.50
M9	85	15	0.75
M10	85	15	1
M11	80	20	0.50
M12	80	20	0.75
M13	80	20	1

Six cylinders of 100 mm diameter and 200 mm depth were used for splitting tensile strength determination at 28, 56 and 90 days, two standard cubes for ISAT and two cylinders of 100 mm diameter and 200 mm depth for CST at 28 and 56 days.

Table 4. Mix proportions of fibre-reinforced RHA concrete

Mix	Cement (kg/m^3)	RHA (kg/m^3)	W/B	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	PP (%)	Water (l/m^3)	Super-plasticizer (%)
M 1	447.37	-	0.38	866.582	968.368	-	170	0.30
M 2	402.63	44.737	0.38	853.97	954.27	-	170	0.40
M 3	380.26	67.106	0.38	848.92	948.64	-	170	0.50
M 4	357.896	89.474	0.38	842.62	941.59	-	170	0.60
M 5	402.63	44.737	0.38	853.97	954.27	0.5	170	0.45
M 6	380.26	67.106	0.38	848.92	948.64	0.75	170	0.475
M 7	357.896	89.474	0.38	842.62	941.59	1	170	0.50
M 8	402.63	44.737	0.38	853.97	954.27	0.5	170	0.55
M 9	380.26	67.106	0.38	848.92	948.64	0.75	170	0.575
M10	357.896	89.474	0.38	842.62	941.59	1	170	0.60
M 11	402.63	44.737	0.38	853.97	954.27	0.5	170	0.65
M 12	380.26	67.106	0.38	848.92	948.64	0.75	170	0.675
M 13	357.896	89.474	0.38	842.62	941.59	1	170	0.70

For each batch of concrete mixed, the quantities of various ingredients; i.e., cementitious content, fine aggregate, coarse aggregate, fibres, water and super-plasticizer, were kept ready in the required proportions.

Initially, sand and cement were mixed thoroughly to get a uniform mix in dry condition indicated by the uniform colour and the absence of concentration of either material. Then, coarse aggregate was added to this dry mix and turned over twice or three times in dry state in a tilting type rotary drum for one minute. Then, water was added to the mix up to 30 % and fibres were uniformly distributed into the mix. Thereafter, again 40% water was added to the mix and the remaining 30% water was mixed with super-plasticizer to get a uniform mix of required slump. Mixing was continued for about one minute to get a uniform mix.

The moulds for casting the specimens were cleaned, brushed and oiled and placed on a vibrating table with a speed range of 12000 ± 400 r.p.m. and an amplitude of 0.055 mm. The homogenous concrete mix already prepared was placed in the specimen moulds in two layers and each layer was vibrated properly. After filling the composite mix in moulds, the surface was finished by a trowel. The specimens were marked with their respective designations after 3 hours of setting and were allowed to set in the moulds for 24 hours. Subsequently, the specimens were demoulded and immersed in a temperature-controlled curing tank.

d) Compressive Strength

This test was conducted according to IS 516-1959 (Indian Standard 516-2002). The test was conducted on cubes of size 100mm x 100mm x 100mm. Specimens were taken out of the curing tank at the age of 7, 14, 28, 56 and 90 days of water curing. Surface water was then allowed to drip down. Specimens were then tested on a 200-ton capacity Compression Testing Machine (CTM). The average of three samples was taken as the representative value of compression strength for each batch of concrete.

e) Splitting Tensile Strength

This test was conducted on cylinders of 100mm diameter and 200 mm length. Splitting tensile strength test was conducted according to IS 5816-1999 (Indian Standard 5816, 1999). Specimens were taken out of the curing tank at the age of 28, 56 and 90 days of water curing. Surface water was then allowed to drip down. Specimens were then tested on a 200-ton capacity Compression Testing Machine (CTM).

f) Flexural Strength

Flexural tests were conducted on concrete beams of size 100mm x 100mm x 500mm casted for concrete of each series. This test was conducted according to IS 516-1959 (Indian Standard 516, 2002). Flexural strength tests were conducted on a 100 kN MTS make Close Loop Actuator System, as shown in Figure 1. The supports and other parts of the supporting and loading unit were cleaned and the test specimen was placed on the supports such that the load was applied to the faces other than the cast faces of the specimen. The third-point loading method was used to carry out the test. Effective span of 450 mm is maintained between the supports. The complete load-deflection curve was recorded for each specimen using the data acquisition system of the machine. Two specimens were tested for each mix. The flexural strength test was determined by using the following formula:

$$f=P*L/bd^2$$

f = strength in MPa, P = load in N, L = span length in mm, b = average width of the specimen at fracture, as oriented for testing, in mm, d = average depth of the specimen at fracture, as oriented for testing, in mm.

Figure (1): Flexural strength test

g) Initial Surface Absorption Test (ISAT)

This test method provides data for assessing the uniaxial water penetration characteristics of a concrete surface. This test was conducted as per BS 1881-208

(1996) (British Standard Institution 1881-208, 1996). For this test, cubes of size 150mm x 150mm x 150mm were prepared. Cubes were tested after a curing age of 28 and 56 days. Prior to testing, conditioning of specimens was carried out.

Cubes were kept in oven for drying at (105 ± 5) °C until constant mass was achieved; i.e., not more than 0.1% weight changed over any 24 h drying period. After that, cubes were placed in the dessicator to cool down. The temperature in the cabinet was allowed to fall to within 2 °C of that of the room. Silica gel was kept in the dessicator in powdered form to absorb any moisture. Specimens were kept in the cabinet until required for testing. After conditioning of cubes, these were tested for Initial Surface Absorption. The test assembly is shown in Fig. 2.

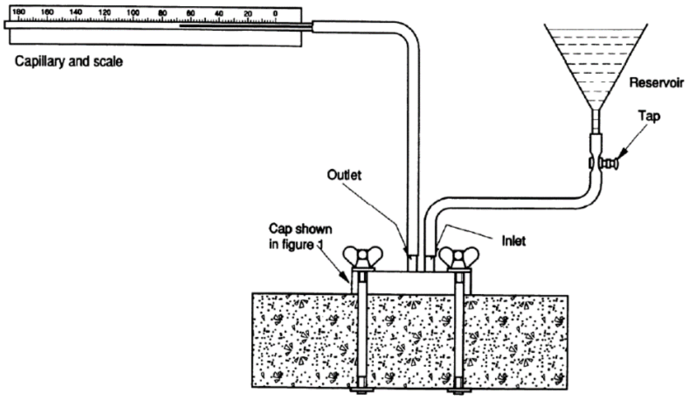

Figure (2): Assembly of typical absorption apparatus

h) Capillary Suction Test

This test method is used to determine the rate of absorption (sorptivity) of water by hydraulic cement concrete. Absorption was tested by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water.

This test is carried out as per ASTM standard C 1585–04 (American Society for Testing and Materials C 1585-04, 2007) and the test specimen was a 100 ± 6 mm diameter disc with a length of 50 ± 3 mm. Schematic of the CST test is shown in Fig. 3. Specimens were obtained by cutting cylinders of 100 mm diameter and 200 mm length with the help of a specimen cutting machine with water-cooled blade. Three specimens were cut for each mix at each age of testing. Conditioning of specimens was carried out by the same procedure adopted for ISAT.

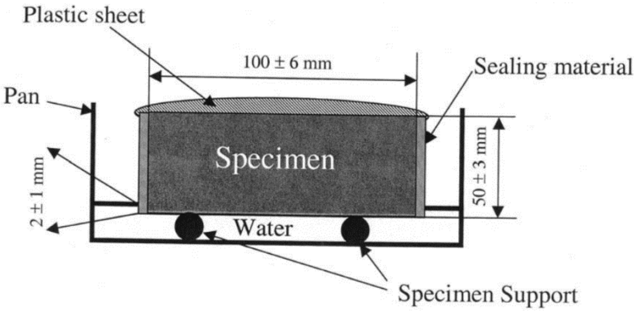

Figure (3): Schematic of the CST procedure

RESULTS AND DISCUSSION

a) Workability

Workability of concrete mixes was determined by using slump cone test. Inclusion of RHA as partial substitute for cement increases water demand for required workability. This may be attributed to large surface area and porous structure of RHA particles. With increase in the percentage of RHA and PP, workability decreased. PP decreases flowability of concrete mixes as PP increases from 0.5% to 1%, which is due to the increase in fibre units, resulting in an increase in the viscosity of concrete. Super-plasticizer was varied from 0.3% to 0.7% by weight of binder to achieve a slump of 100 ±20mm for all concrete mixes. All concrete mixes had slump values between 90 mm and 120 mm. The highest slump was obtained for control concrete, whereas concrete containing 80%OPC, 20% RHA and 1% PP had the lowest slump.

b) Compressive Strength

Compressive strength results of all mixes are shown in Fig. 4 to Fig. 7. The use of RHA from 10% to 20% as partial replacement of OPC shows an increase in the later-age compressive strength of the mixes though early -age compressive strength of the mixes shows slight decrease. This may be due to slow pozzolanic reaction of RHA.

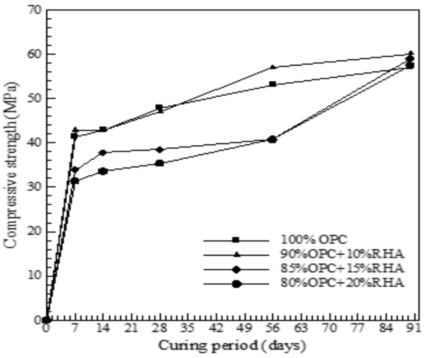

Figure (4): Compressive strength of concrete mixes at different replacement by RHA without PP fibres

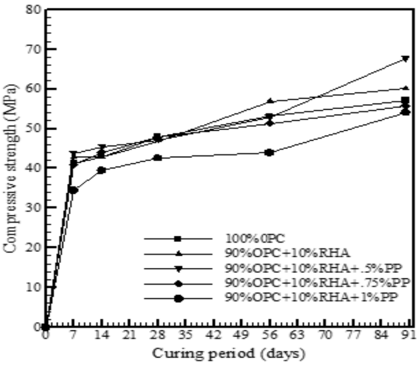

Figure (5): Compressive strength of concrete mixes at 10% replacement by RHA with different fraction of PP fibres

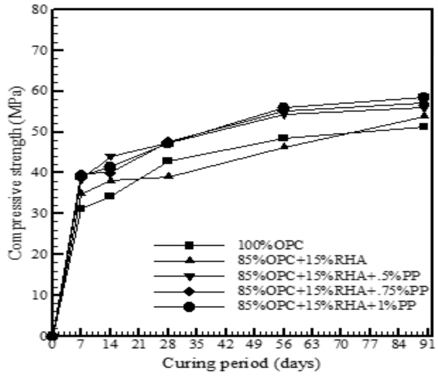

Figure (6): Compressive strength of concrete mixes at 15% replacement by RHA with different fraction of PP fibres

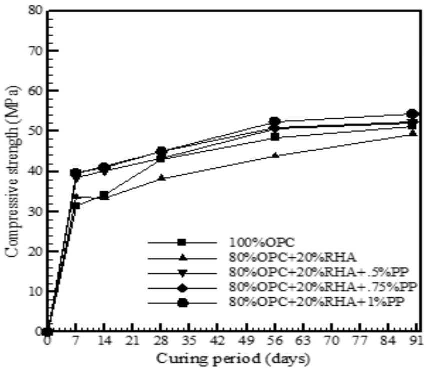

Figure (7): Compressive strength of concrete mixes at 20% replacement by RHA with different fraction of PP fibres

The maximum compressive strength was obtained for a mix containing OPC replacement by 10% RHA with 0.5% volume fraction of fibres by weight of binder. The increase in strength was found to be 5.99%, 5.87% and 18.54% for 7, 14 and 90 days of curing, respectively, compared to control mix. It was observed that concrete with OPC replacement by 10% RHA performed better than concretes with 15% and 20% RHA replacements. By inclusion of 10% RHA without PP, compressive strength increases approximately at all curing periods, whereas at 15% and 20% RHA without PP, there was a decrease in compressive strength expect for 90 days of curing compared to control mix. This may be due to the fact that the quantity of RHA in the mix is higher than the amount required to combine with the liberated lime during the hydration process, thus leading to excess silica leaching out, causing a deficiency in strength, as it replaces part of the cementitious material but does not contribute to strength. The addition of PP increases compressive strength at 0.5% volume fraction for 10% RHA, but further addition of PP at 0.75% and 1% decreases compressive strength. This may be attributed to the redistribution of void structure due to the increases in PP content and the presence of weak interfacial bonds between the PP and cement RHA grains. At 15% and 20% RHA, addition of PP decreases compressive strength expect for 90 days of curing for 0.5% volume fraction of PP. The results indicate that RHA was found to be more effective in enhancing the compressive strength than PP for the long term.

c) Splitting Tensile Strength

The results of splitting tensile strength for all mixes are shown in Fig.8 to Fig. 11. The splitting tensile strength test results of fibre-reinforced RHA concrete show that in general there is an increase in splitting tensile strength ranging from 2% to 92%.

It was noticed that both RHA and PP increase the splitting tensile strength. Inclusion of PP from 0.5% to 1% in the mixes increases splitting tensile strength and 1% volume fraction of PP gives maximum increase in strength for concrete mixes. This may be due to the increase in the number of PP fibres in the concrete mixes, which prevents propagation of cracks, resulting in an increase in splitting tensile strength. Enhancement in splitting tensile strength of concrete containing RHA was due to the filling of pores between cement particles. The maximum value of splitting tensile strength obtained is 6.81 MPa, for a mix with 10% RHA as replacement of OPC and 1% PP content by weight of binder at 90 days of curing age. The splitting tensile strength for 10% OPC replacement by RHA with 1% PP increased by 6.76%, 41.89% and 92.52% for 28, 56 and 90 days of curing, respectively, compared to control mix. This increase is attributed to the bridging effect of fibres, making concrete specimens bear more load even when cracks appear till crushing. At 15% OPC replacement by RHA with 1% PP, the splitting tensile strength was increased by 58.36%, 55.74% and 59.19% for 28, 56 and 90 days of curing, respectively. Similarly, for 20% OPC replacement by RHA with 1% PP, the splitting tensile strength increased by 1.77%, 25% and 52.02% for 28, 56 and 90 days of curing, respectively.

d) Flexural Strength

The flexural strength results of all mixes are shown in Table 5. It was noticed that flexural strength increases with higher amount of PP and curing age, especially at 90 days of curing. Use of 10% RHA as cement replacement was observed to increase the flexural strength at all curing periods compared to control mix. This may be due to the filling effect of RHA at early age and secondary reaction of RHA at later age. Further increase in replacement level of cement by RHA at 15% and 20% reduced flexural strength, which may be due to less cementitious properties exhibited by RHA with the increase in its content.

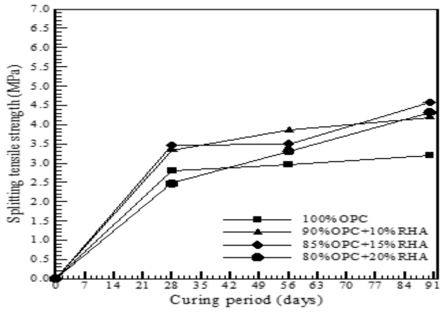

Figure (8): Splitting tensile strength of concrete mixes by different RHA replacements with different curing periods

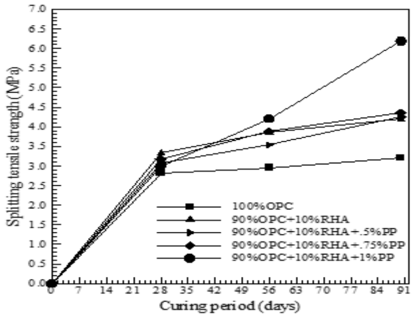

Figure (9): Splitting tensile strength of concrete mixes by 10% RHA replacement with different fractions of PP fibres

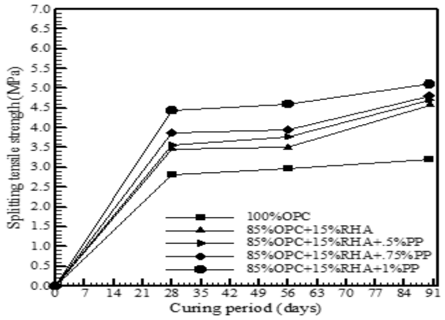

Figure (10): Splitting tensile strength of concrete mixes by 15% RHA replacement with different fractions of PP fibres

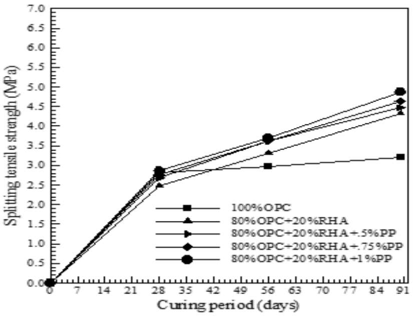

Figure (11): Splitting tensile strength of concrete mixes by 20% RHA replacement with different fractions of PP fibres

Table 5. Flexural strength of all mixes at different curing ages

Mix no.	Description	Flexural strength (MPa)		
		28 days	56 days	90 days
1	100%OPC	3.96	5.69	6.04
2	90%OPC+10%RHA	4.26	5.80	6.51
3	85%OPC+ 15%RHA	3.75	4.84	5.29
4	80%OPC+20%RHA	3.56	4.43	4.99
5	90%OPC+10%RHA + 0.5%PP	4.18	5.08	5.6
6	90%OPC+10%RHA + 0.75%PP	4.05	5.18	6.28
7	90%OPC+10%RHA + 1%PP	2.59	3.73	5.12
8	85%OPC+ 15%RHA + 0.5%PP	2.64	4.66	5.85
9	85%OPC+15%RHA + 0.75%PP	4.10	5.39	5.80
10	85%OPC+ 15%RHA + 1%PP	3.69	4.40	5.51
11	80%OPC+20%RHA+0.5%PP	3.14	5.28	5.99
12	80%OPC+20%RHA + 0.75%PP	4.12	4.88	5.83
13	80%OPC+20%RHA + 1%PP	4.74	5.22	6.26

The inclusion of PP in concrete mixes increases flexural strength and prevents propagation of cracks. At 28 days of curing, maximum flexural strength was obtained for a mix containing OPC replacement by 20% RHA with 1% volume fraction of PP. This may be attributed to the bridging effect provided by the PP. The concrete mix containing 10% RHA and 0.75% PP showed maximum resistance to deflection, which was about 10 mm at 90 days of curing. The resistance to deflection was more offered at 90 days of curing for all concrete mixes as shown in Fig. 12 to Fig. 16. The addition of fibres into concrete mix helps in resisting deflection and cracking at later age. It was observed that replacement of 10% RHA with different fractions of PP shows better resistance to cracking and deflection than 15% and 20% RHA. Plain concrete mix was found to have lower resistance to deflection compared to mixes reinforced with PP.

e) Initial Surface Absorption Test (ISAT)

The initial surface absorption values (ISAT-10) of various mixes at 26 and 56 days of curing are shown in Table 6. For a particular curing age, absorption was measured at 3 different time periods; i.e., 10, 30 and 60 minutes. The absorption of water or flow of water decreased with time.

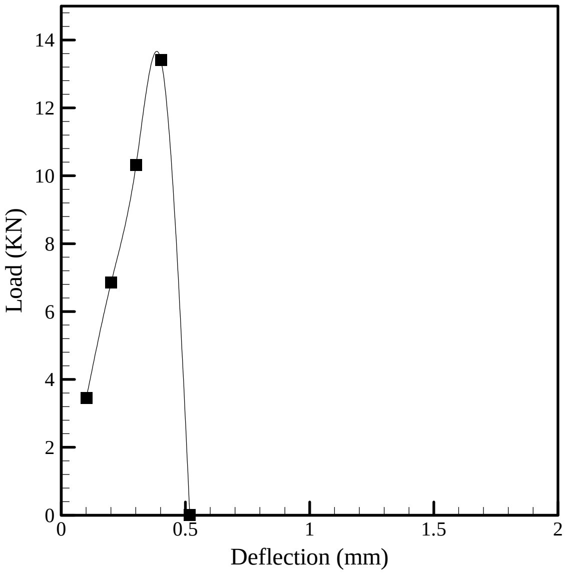

Figure (12): Load-deflection curve for 100% OPC at 90 days

Table 6. Initial surface absorption values of various mixes

Mix no.	Description	Initial Surface Absorption [ml/(m^2.Sec)] at 10 min.	
		28 days	**56 days**
1	100%PC	0.419	0.341
2	90%PC+10%RHA	0.393	0.317
3	85%PC+ 15%RHA	0.351	0.288
4	80%PC+20%RHA	0.338	0.270
5	90%PC+10%RHA+0.5%PP	0.377	0.312
6	90%PC+10%RHA+0.75%PP	0.383	0.338
7	90%PC+10%RHA+1%PP	0.393	0.346
8	85%PC+ 15%RHA+0.5%PP	0.367	0.320
9	85%PC+15%RHA+0.75%PP	0.380	0.330
10	85%PC+ 15%RHA+1%PP	0.397	0.335
11	80%PC+20%RHA+0.5%PP	0.427	0.377
12	80%PC+20%RHA+0.75%PP	0.438	0.388
13	80%PC+20%RHA+1%PP	0.496	0.406

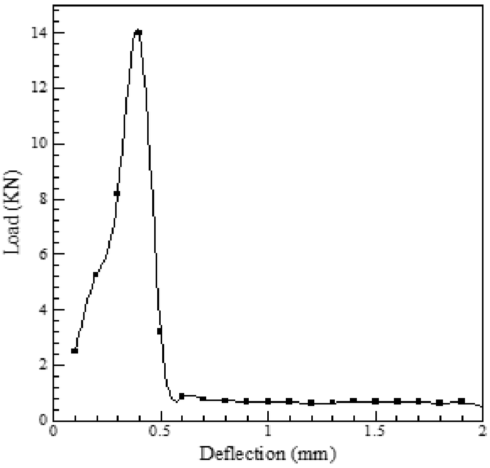

Figure (13): Load-deflection curve for 90%OPC +10%RHA+0.75%PP at 90 days

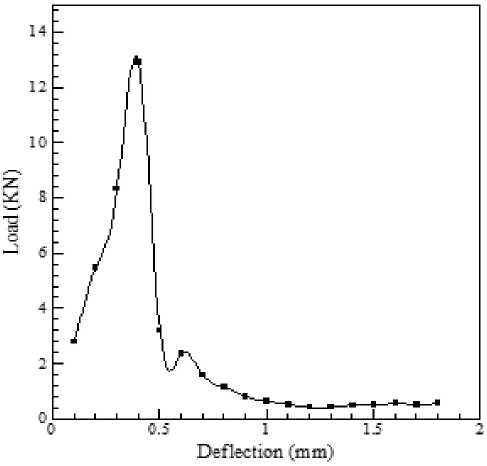

Figure (14): Load-deflection curve for 85%OPC +15%RHA+0.75%PP at 90 days

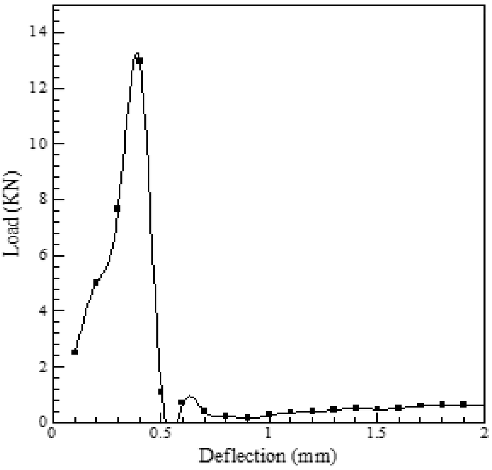

Figure (15): Load-deflection curve for 80%OPC +20%RHA+0.75%PP at 90 days

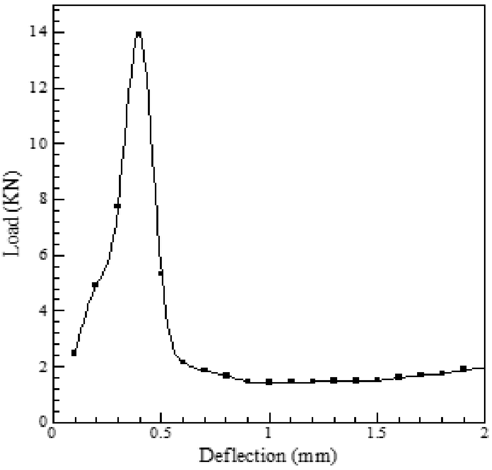

Figure (16): Load-deflection curve for 80% OPC + 20%RHA+1%PP at 90 days

This was due to the rate of water absorption becoming less as time increases when the outer zone of the surface is saturated and it is more difficult for water to be absorbed by the inner pores. It was found that the flow data at 10 min. interval gives a more representative trend of the surface absorption characteristics. Flow rate at less than 10 minutes might not represent a stable and constant flow of water into the concrete and flow rates at 30 and 60 min. intervals would not be suitable, since the concrete surface would already be in a saturated state and the data obtained will not be suitable for comparative purposes. The absorption of the concrete decreases as the replacement of OPC by RHA increases. The lowest value of ISAT-10 was found for concrete mix containing 80%OPC and 20% RHA, which is approximately 19.33% and 20.82% less than those of control mix at 28 and 56 days of curing, respectively. This may be attributed to pore refinement through filling and secondary hydration reaction of RHA. Absorption was found to increase as PP content increases from 0% to 1%, but it was less than for the control mix as well as for 10% and 15% RHA at 28 and 56 days of curing (except for 20% OPC replacement by RHA).

Mixes containing 20% RHA with different fractions of PP were observed to have an increase in absorption characteristics compared to control mix. Absorption was increased by 1.90% and 10.55% at 0.5% PP content, by 4.53% and 13.78% at 0.75%PP content and by 18.77% and 19.06% at 1%PP content for 28 and 56 days, respectively. This may be due to the increase in PP content, which makes concrete less homogenous, resulting in an increase in the pores.

f) Capillary Suction Test (Sorptivity)

Variations in average initial rate of absorption (IRA) value of concrete mixes at different curing ages are shown in Fig. 17 to Fig. 20. The results clearly show that sorptivity decreases with the increase in curing time. The average IRA value decreases with the increase in the replacement level of OPC by RHA at 28 and 56 days of curing. The addition of PP in concrete mixes at 0.5% PP increases average IRA value which decreases at 0.75% PP content then again increases at 1% for all concrete mixes for 28 and 56 days of curing. Mixes containing 20% RHA with different PP contents have more average IRA values than these containing 10% and 15% RHA as cement replacement. It was observed that mix M9 showed the lowest IRA value, followed by mix M4, with values approximately 40% and 35% less than those of the control mix at 28 days of curing, whereas mix M1 showed the highest IRA value. At 56 days, the concrete mix containing 80%OPC and 20% RHA showed the lowest IRA value of 0.010mm/(sec$^{1/2}$), which is less by about 23.07% compared to that of the control mix, whereas mix M7 showed an IRA value of 0.015 mm/(sec$^{1/2}$), which is approximately 17.69% higher than that of the control mix. RHA was found to be more significant in the reduction of absorption than PP in concrete mixes.

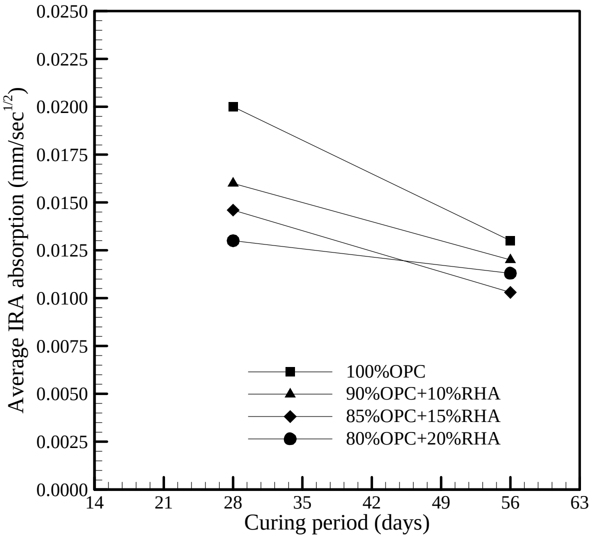

Figure (17): Variation in average IRA values of concrete mixes by different RHA replacements without fibre content

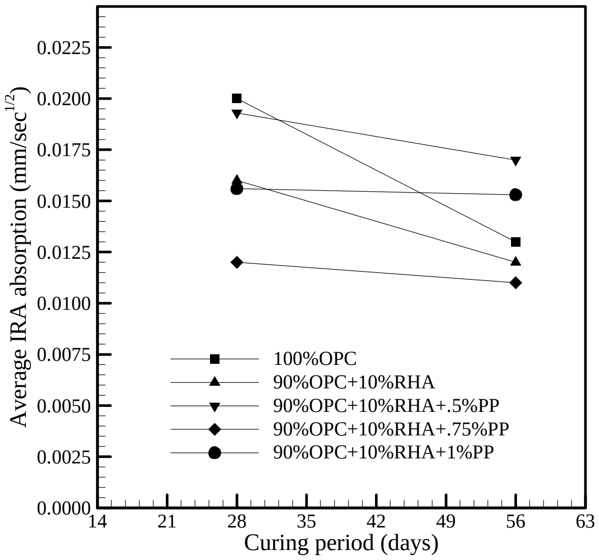

Figure (18): Variation in average IRA values of concrete mixes by 10% RHA replacement with different PP fibre contents

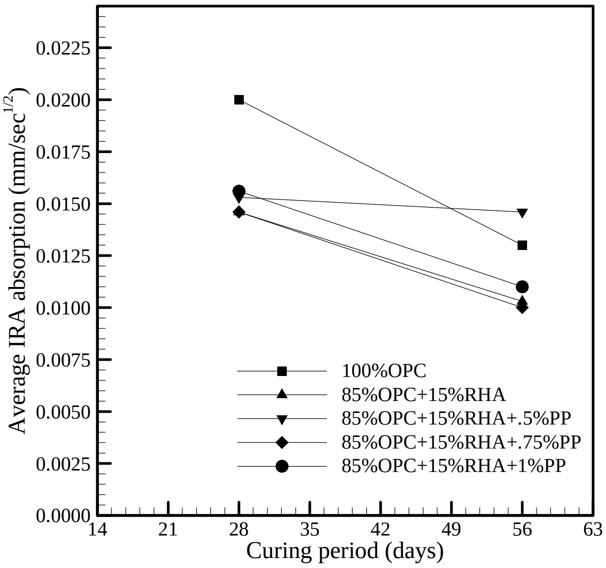

Figure (19): Variation in average IRA values of concrete mixes by 15% RHA replacement with different PP fibre contents

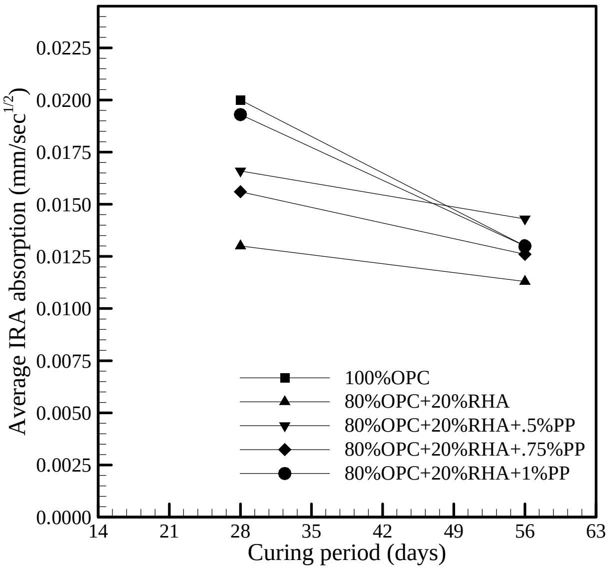

Figure (20): Variation in average IRA values of concrete mixes by 20% RHA replacement with different PP fibre contents

CONCLUSIONS

The following conclusion are drawn from this investigation.

1. Addition of RHA in concrete mixes was found to increase compressive strength at 10% replacement as compared to the control mix, whereas further addition of RHA at 15% and 20% decreases compressive strength. Inclusion of PP into concrete mixes increases compressive strength at 0.5% fibre content as compared to the control mix, whereas further addition of fibres at 0.75% and 1% with RHA decreases compressive strength for all mixes.
2. Inclusion of RHA into concrete mixes led to increase the long-term compressive strength for plain mixes as well as those reinforced with 0.5% volume fraction of PP.
3. Incorporation of RHA in concrete mixes was found to increase splitting tensile strength at 10% and 15% replacement, whereas it slightly decreased at 20% replacement, but was higher than that of the control mix. Addition of PP into concrete mixes also increased splitting tensile strength and achieved maximum strength at 1% fibre content for different RHA replacements.
4. Use of 10% RHA as cement replacement was observed to increase flexural strength at all curing periods compared to the control mix, whereas further addition of RHA at 15% and 20% decreases flexural strength. Incorporation of PP in concrete mixes increases flexural strength, prevents propagation of cracks and offers a significant resistance to deflection of about 10 mm at later ages.
5. As the replacement of cement by RHA in concrete mixes increases, absorption was found to decrease as compared to the control mix. Inclusion of PP in concrete mixes was found to increase ISAT-10 values, which were however less than for the control mix as well as for 10% and 15% RHA replacements with different PP contents, whereas 20% RHA as cement replacement with fibres yields higher ISAT-10 value than that of the control mix.

6. Addition of RHA and PP into concrete mixes decreases the average IRA values as compared to the control mix, but RHA in concrete mixes has a more significant effect in decreasing average IRA value in comparison to PP.

REFERENCES

Afroughsabet, V., and Ozbakkaloglu, T. (2015). "Mechanical and durability properties of high-strength concrete containing steel and polypropylene fibres". Construction and Building Materials, 94, 73-82.

American Society for Testing and Materials C 1585-04. (2007). "Standard test method for measurement of rate of absorption of water by hydraulic-cement concretes". American Society for Testing and Materials, West Conshohocken, United States.

American Society for Testing and Materials C 494/C494M -12. (2013). "Standard specification for chemical admixtures for concrete". American Society for Testing and Materials, West Conshohocken, United States.

Basheer, L., Kropp, J., and Cleland, D.J. (2001). "Assessment of the durability of concrete from its permeation properties: a review." Construction and Building Materials, 15, 93-103.

Bosnjak, J., Ozbolt, J., and Hahn, R. (2013). "Permeability measurement on high-strength concrete without and with polypropylene fibres at elevated temperatures using a new test setup." Cement Concrete Research, 53, 104-111.

British Standard Institution 1881-208. (1996). "Testing concrete — part 208: Recommendations for the determination of the initial surface absorption of concrete". British Standard Institution, 389 Chiswick High Road, London.

Bui, D.D., Hum, J., and Stroeven, P. (2005). "Particle size effect on the strength of rice husk ash blended gap-graded Portland cement concrete." Cement and Concrete Composites, 27,357–366.

Cengiz, O., and Turanli, L. (2004). "Comparative evaluation of steel mesh, steel fibre and high-performance polypropylene fibre-reinforced shotcrete in panel test". Cement Concrete Research, 34, 1357-1364.

De Sensale, G.R. (2006). "Strength development of concrete with rice husk ash." Cement and Concrete Composites, 28, 158-160.

Desmettre, C., and Charron, J.P. (2012). "Water permeability of reinforced concrete with and without fiber subjected to static and constant tensile loading". Cement Concrete Research, 42, 945-952.

FIP Report. (1988). "Condensed silica fume in concrete." FIP State-of-Art Report, FIP Commission of Concrete, Thomas Telford House, United Kingdom.

Ganesan, K., Rajagopal, K., and Thangavel, K. (2007). "Rice husk ash blended cement: assessment of optimal level of replacement for strength and permeability properties of concrete." Construction and Building Materials, 22, 1675-1683.

Haddad, R.H., and Smadi, M.M. (2004). "Role of fibres in controlling unrestrained expansion and arresting cracking in Portland cement concrete undergoing alkali-silica reaction." Cement Concrete Research, 34, 103-108.

Indian Standard 4031. (2002). "Methods of physical tests for hydraulic cement". Bureau of India Standards, New Delhi, India.

Indian Standard 516. (2002). "Methods of tests for strength of concrete". Bureau of India Standards, New Delhi, India.

Indian Standard 5816. (1999). "Splitting tensile strength of concrete- method of test". Bureau of India Standards, New Delhi, India.

Indian Standard 8112. (1990). "43 grade ordinary Portland cement – specification". Bureau of India Standards, New Delhi, India.

Indian Standard 9103. (1999). "Concrete admixtures – specification". Bureau of India Standards, New Delhi, India.

Khan, M.I., and Lynsdal, C.J. (2002). "Strength, permeability and carbonation of high-performance concrete." Cement Concrete Research, 32, 123-131.

Khan, R., Jabbar, A., Ahmad, I., Khan, W., Khan, A.N., and Mirza, J. (2012). “Reduction in environmental problems using rice-husk ash in concrete.” Construction and Building Materials, 30, 360-365.

Kishore, R., Bhikshma, V., and Prakash, P.J. (2011). “Study on strength characteristics of high-strength rice husk ash concrete.” Procedia Engineering, 14, 2666-2672.

Madandoust, R., Ranjbar, M.M., Moghadamb, H.A., and Mousavi, S.Y. (2011). “Mechanical properties and durability assessment of rice husk ash concrete.” Bio-Eng., 110,144 -152.

Malhotra, V.M., and Mehta, P.K. (1996). “Pozzolanic and cementitious materials— advances in concrete technology". Vol. I, Gordon and Breach, Netherlands, 189 pp.

Mazaheripour, H., Ghanbarpour, S., Mirmoradi, S.H., and Hosseinpour, I. (2011). “The effect of polypropylene fibres on the properties of fresh and hardened light-weight self-compacting concrete”. Construction and Building Materials, 25, 351-358.

Medina, N.F., Barluenga, G., and Olivares, F.H. (2014). “Enhancement of durability of concrete composites containing natural pozzolan blended cement through the use of polypropylene fibres”. Composites-Part B, 61, 214-221.

Nili, M., and Afroughsabet, V. (2010). “The effects of silica fume and polypropylene fibres on the impact resistance and mechanical properties of concrete.” Construction and Building Materials, 24, 927-933.

Ramezanianpour, A.A., Esmaeili, M., Ghahari, S.A., and Najafi, M.H. (2013). “Laboratory study on the effect of polypropylene fibre on durability and physical and mechanical characteristics of concrete for application in sleepers.” Construction and Building Materials, 44, 411-418.

Sharma, R. (2013). “An experimental investigation on strength and water permeation properties of rice husk ash concrete reinforced with polypropylene fibres”. Dissertation, Dr. B.R. Ambedkar National Institute of Technology, Jalandhar, Punjab, India.

Singh, D., Singh, S.P., Khan, R., and Kumar, S. (2013). “Workability of self-compacting concrete containing rice husk ash.” Proceedings of the 2013 UKIERI Concrete Congress-Innovations in Concrete Constructions-International Conference, March 5th-8th, 196-200, Dr. B.R. Ambedkar National Institute of Technology, Jalandhar, India. Edited by Dhir, R. K., Emeritius Professor, University of Dundee.

Song, H.W., and Kwon, S.J. (2007). “Permeability characteristics of carbonated concrete considering capillary pore structure.” Cement Concrete Research, 37, 909-915.

Xu, W., Tommy, Y.L., and Memon, S.A. (2011). “Microstructure and reactivity of rice husk ash.” Construction and Building Materials, 29, 541–547.

Yew, M.K., Mahmud, H.B., Ang, B.C., and Yew, M.C. (2015). “Influence of different types of polypropylene fibre on the mechanical properties of high-strength oil palm shell light-weight concrete”. Construction and Building Materials, 90, 36-43.