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A study on mechanical properties of concrete including activated recycled plastic waste

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Abstract. This paper describes the experimental studies carried out to determine the properties of fresh and hardened concrete with Recycled Plastic Waste (RPW) as a partial replacement material for fine aggregates. In the experimental study, RPW was used for replacing river sand and manufactured sand (M sand) aggregates in concrete. The replacement level of fine aggregates was ranging from 5% to 20% by volume with an increment of 5%. M40 grade of concrete with water cement ratio of 0.40 was used in this study. Two different types of RPW were used, and they are (i) un-activated RPW and (ii) activated RPW. The activated RPW was obtained by alkali activation of un-activated RPW using NaOH solution. The hardened properties of the concrete determined were dry density, compressive strength, split tensile strength, flexural strength and ultrasonic pulse velocity (UPV). The properties of the concrete with river sand, M sand, activated RPW and un-activated RPW were compared and inferences were drawn. The effect of activation using NaOH solution was investigated using FT-IR study. The micro structural examination of hardened concrete was carried out using Scanning Electron Microscopy (SEM). The test results show that the strength of concrete with activated RPW was more than that of un-activated RPW. From the results, it is evident that it is feasible to use 5% un-activated RPW and 15% activated RPW as fine aggregates for making concrete without affecting the strength properties.

Keywords: concrete; recycled plastic waste; river sand; manufactured sand; strength

1. Introduction

In recent days, use of plastic carry bags has been increased in day-to-day life. Plastic carry bags have become one of the essential materials in our life for purchasing daily household items and packaged food items. These plastic bags after usage bags are often not properly disposed. The used plastic bags are thrown out in vacant land which in due course, gets into the earth causing land pollution. There is also possibility of these plastic bags blocking infiltration of storm water in to the ground and hence affects the recharging ability of the aquifer. It has been reported (Darrin Qualman 2018) that only 18 percent of the plastic used in automobiles and buildings is recycled. Therefore, it is important to find a suitable solution for disposing used plastic carry bags.

In the construction industry, use of concrete is inevitable. Concrete requires large volumes of fine and coarse aggregates for its production and for obtaining fine and coarse aggregates, natural resources are being depleted. Research studies are available in the literature that use copper slag, silica fume, waste foundry sand, and fly ash as replacement material for fine and coarse aggregates used in concrete.

In this study, it is proposed to use recycled carrier bag plastic waste as one of the materials for replacing fine aggregates in the manufacturing of concrete. Ismail *et al.* (2008) have investigated the effects of using plastic waste as a partial replacement for fine aggregates on the properties of concrete. The authors have observed that the workability of the concrete decreased with increase in the quantity of plastic waste in concrete. The compressive strength of concrete containing plastic waste was less than that of the control mix for all curing period considered. Karanth *et al.* (2017) have studied the use of waste plastic fibres with different percentages of volume fraction and various aspect ratios in concrete. The author concluded that 1.25% of waste plastic fibres are increasing the shear strength and impact strength of concrete. Liu *et al.* (2013) studied the static and dynamic mechanical properties of concrete consisting of plastic particles as a partial replacement material for conventional river sand. Test results have shown that the energy absorption capacity and impact resistance of concrete containing plastic were superior to that of reference concrete. The dynamic compressive strength of the concrete containing plastic decreased with the increase in plastic content. Coarser plastic particles affected the properties of concrete more adversely than finer particles (Hama *et al.* 2017). Research study has indicated that in places where moderate strength

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(a) River sand (b) Manufactured sand

(c) Recycled plastic waste (d) Coarse aggregate

Fig. 1 Aggregates used in this study

and ductility are sufficient, manufactured plastic aggregates could be used up for replacing conventional raw materials up to 25% (Alqahtani *et al.* 2017). Increasing the amount of coarser, flakier and irregular-shaped plastic aggregates in concrete resulted in lower durability performance as compared to the concrete containing finer, smoother and irregular shaped plastic aggregates (Silva *et al.* 2013). Gesoglu *et al.* (2017) observed that the tensile strength of concrete with plastic was low and hence resulted in rapid spread of micro cracks under the applied load. The reason for this observation was due to that fact that the plastic aggregates had a broad surface area and hence caused weaker bond between plastic aggregates and cement paste (Nursyamsi *et al.* 2017). The use of plastic in concrete has been found to increase its thermal insulation performance compared to conventional concrete (Ruiz-Herrero *et al.* 2016). Paliwal and Maru (2017) used shredded plastic waste in concrete together with fly ash as partially replacement material for cement. The weight of the plastic waste considered was 0.6% of the total weight of concrete. The authors concluded that the mechanical and durability properties are improved with 10% of fly ash and 0.6% of plastic waste fibres. Sabau and Vargas (2018) have investigated that the e-plastic waste as a partial replacement material for coarse aggregate. The reduction in compressive strength was observed to be 44% for 60% of replacement. The author concluded that 15% of cost reduced compared to the conventional concrete. 10% of the E-plastic content concrete mix yielded stability and very good strength (Ashwini Manjunath 2016). Bhogayata *et al.* (2018) studied the impact strength and durability properties of concrete containing metalized plastic waste fibers from food packaging plastics. Test results showed that these fibers effectively refilled the pore spaces around the aggregate-hydrated cement paste transition zone and reduced the voids inside the concrete. The compressive, flexural and splitting tensile strength value was found to be decreasing with increase in the percentage of plastic. Also, it was observed that the ductility of polymer concrete increased with increase in the percentage use of plastic (Bulut *et al.* 2017). Toghroli *et al.* (2018) have reviewed the available research studies in the literature on pavement porous concrete using recycled waste materials such as plastic waste, glass waste, recycled crushed glass, steel slag, steel fibre, tires waste etc., and concluded that the cost of concrete production could be reduced due to the utilization of waste materials. The authors have also mentioned that using waste materials in concrete has beneficial effects despite few defects. Chemical activations with different types of plastic waste are studied to improve the adhesion properties of the cementitious matrix (Thorneycroft *et al.* 2018, Naik *et al.* 1996). Chemical activation could be done by stirring the plastic waste in sodium hydroxide solution or sodium hypochlorite solution. Due to chemical activation, the adhesion property of the plastic waste was modified. The authors have observed that due to improved adhesion properties of plastic waste with the cementitious matrix, the hardened properties of concrete increased. However, Literature review indicated that only limited number of studies is available on the use of activated RPW as a partial replacement for fine aggregates in concrete. In this paper, experimental studies were carried out to determine the properties of concrete containing un-activated and activated RPW used as a partial replacement for fine aggregates.

2. Experimental details

2.1 Materials

2.1.1 Ordinary Portland cement (OPC)

OPC from UltraTech cement manufacturer, India, with a specific gravity of 3.13, consistency of 32%, initial setting time of 45 minutes and final setting time of 250 minutes conforming to IS 12269:2013 was used throughout this study.

2.1.2 Fine aggregate

Locally available fine aggregates (river sand and manufactured sand) conforming to IS 383-1970 were used in this study for casting control concrete specimens. River sand was extracted from the river beds and it is available in the local market. Manufactured sand was procured from the local market. Manufactured sand was obtained by crushing of coarser gravel in order to achieve desired size that can be used as fine aggregates in concrete. Specific gravity and fineness modulus for river sand used is 2.77 and 2.98, respectively. Similarly, specific gravity and fineness modulus for manufactured sand used is 2.65 and 2.76, respectively.

2.1.3 Coarse aggregate

Coarse aggregate used in this study is locally available crushed stone aggregate with a maximum size of 20 mm, having a specific gravity of 2.71 and fineness modulus of 4.76.

2.1.4 Recycled plastic waste

The source of plastics used in this study is a commercially available carrier bag plastic waste. Recycled plastic wastes were collected from waste processing plant near Karaikudi, Tamilnadu, India. The photographic image of all aggregates used in this study is shown in Fig. 1. RPW was obtained by applying thermal process to the collected and shredded carrier bag plastic waste. RPW used in this study is low-density polyethylene. Particle size distribution of river sand, manufactured sand and RPW is shown in Fig. 2.

2.2 Activation of recycled plastic waste

The main reason for the decrease in concrete strength is poor bond between the plastic waste and cementitious matrix. To achieve a better bond between the plastic waste and cementitious matrix, plastic wastes are activated by alkali 4% (wt.) sodium hydroxide solution. Recycled plastic wastes are mixed with a prepared solution in a beaker and stirred using a mechanical stirrer for 24 hours. Fig. 3 shows the activation method for the RPW using a mechanical stirrer.

2.3 Parameters and mix identification

The effect of RPW on the fresh and hardened concrete properties was investigated in this study. Two types of recycled plastic waste, namely activated recycled plastic waste and un-activated recycled plastic waste were used. Both river sand and manufactured sand were partially replaced with RPW (5%, 10%, 15% and 20%) in concrete and the studies were carried out. Casting process of concrete specimens involved the following. First, cement and fine aggregates were mixed thoroughly without adding water. After preparation of cement-fine aggregates dry mix, coarse aggregates were added. Water was then added slowly until all the ingredients of mixture were uniformly distributed. Approximate time of mixing after addition of water was 2 min.

Cube specimens of size 100 mm×100 mm×100 mm (width×depth×length), cylinder specimens of size 100 mm×200 mm (diameter×length) and prism specimens of size 100 mm×100 mm×500 mm (width×depth×length) were used to measure the compressive strength, split tensile strength and flexural strength, respectively. Total of 360 specimens were cast, and average of three specimens was reported. The specimens were cured for 7 and 28 days. The mix identification "RS" shows the River Sand, "MS" shows the Manufactured Sand, "A" shows the Activated, "UA" shows the Un-Activated and "RPW" shows the Recycled Plastic Waste. For example, RS-UA-5RPW identification

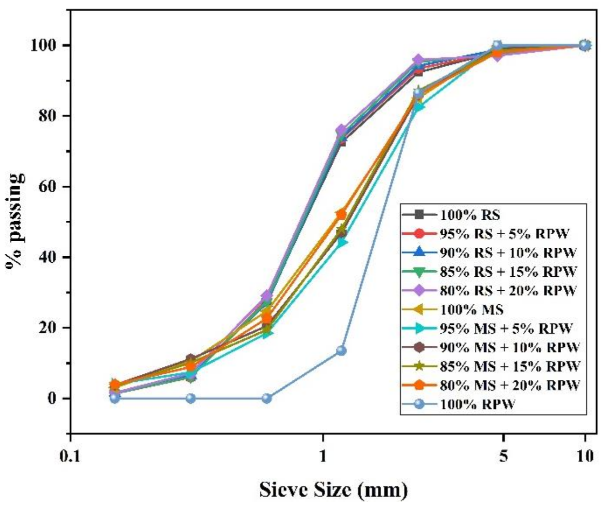

Fig. 2 Particle size distribution curves for various types of fine aggregates used in this study

Fig. 3 Recycled plastic waste treated with sodium hydroxide using mechanical stirrer

Table 1 Mix details for concrete with un-activated and activated RPW fine aggregates

Mix	Mix proportions (kg/m^3)				
	Cement	Fine aggregates	Coarse aggregates	RPW aggregates	Water
RS 0RPW	440	663	1153	0	176
RS 5RPW		630		11	
RS 10RPW		597		23	
RS 15RPW		563		34	
RS 20RPW		530		46	
MS 0RPW		634		0	
MS 5RPW		602		12	
MS 10RPW		571		23	
MS 15RPW		539		34	
MS 20RPW		507		46	

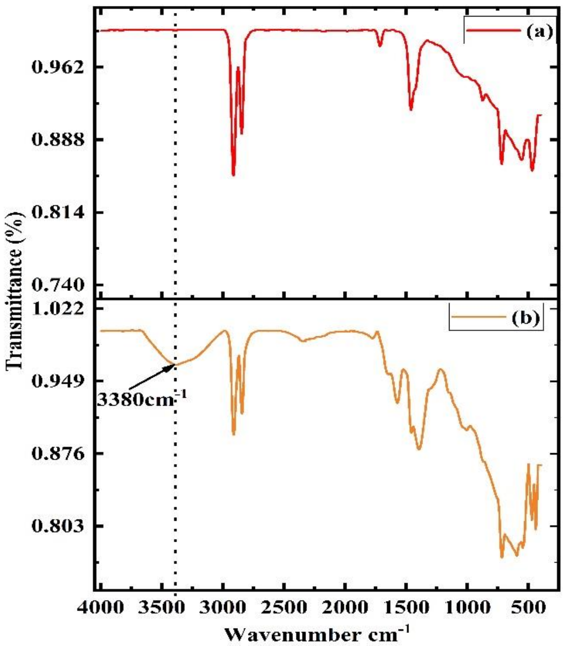

Fig. 4 IR spectra (a) un-activated recycled plastic waste, (b) activated recycled plastic waste

shows the concrete prepared with 5% of un-activated RPW replaced with river sand. The mix proportions used for concrete production are given in Table 1.

3. Results and discussions

3.1 Fourier-transform infrared spectroscopy (FT-IR)

Figs. 4(a)-(b) show the FT-IR spectra for un-activated and activated RPW. The FT-IR results shown in this study were obtained using a Bruker Tensor 27 FT-IR model. It was equipped with Deuterated Triglycine Sulphate (DTGS) detector, mid-IR source (4000 to 400 cm^{-1}) and controlled by OPUS software. The Attenuated Total Reflection (ATR) mode was used in this study. The sampling area was approximately 1mm^2. The band at 3380 cm^{-1} is addressed to stretching vibrations of OH from sodium hydroxide, whereas no peak in the region of 3200-3600 cm^{-1} is addressed to un-activated RPW (IR Frequencies, 2018). Hence, RPW activated by sodium hydroxide is confirmed through FT-IR analysis.

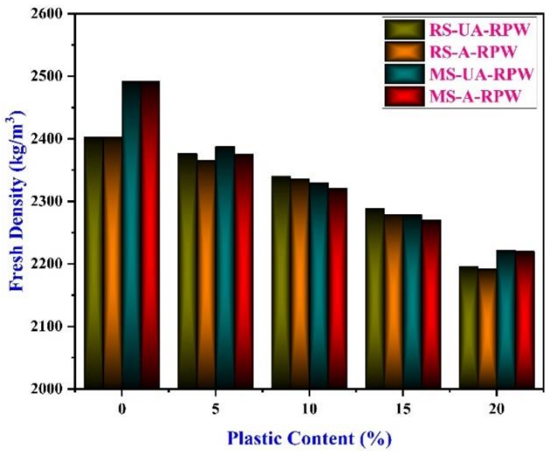

Fig. 5 Variation of fresh density with plastic contents

3.2 Fresh density

Fig. 5 shows the fresh density of concrete containing RPW as a partial replacement for both river sand and manufactured sand. The test results showed that inclusion of RPW as a partial replacement for fine aggregates decreased the fresh density of the concrete as compared to the control concrete. The reason for this observation could be attributed due to the lighter weight of the recycled plastic waste aggregate. Control mix using river sand and manufactured sand had a fresh density of 2402.9 kg/m^3 and 2491.6 kg/m^3, respectively. The results indicated that the fresh density of concrete containing 5%, 10%, 15% and 20% of un-activated RPW aggregates as a partial replacement of river sand tends to decrease by 1.10%, 2.61%, 4.76% and 8.60%, respectively, compared to the control mix. Similarly, for both activated and un-activated RPW replaced concrete, fresh densities are less compared to the control mix concrete.

3.3 Dry density

Fig. 6 presents the dry density of the concrete with various replacement levels of RPW with both river sand and manufactured sand. Control mix with river sand and manufactured sand had a dry density of 2388.7 kg/m^3 and 2461.2 kg/m^3, respectively. When 20% of the river sand was replaced by the un-activated RPW, the density decreased up to 8.98%. The use of RPW in concrete could result in structure with reduced dead load and hence it would attract less amount of earthquake forces.

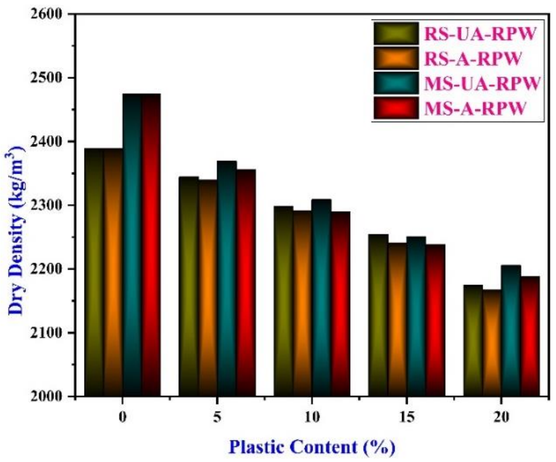

Fig. 6 Variation of dry density with plastic contents

Table 2 Compressive strength of concrete

Mix	Compressive strength (N/mm^2)			
	With un-activated RPW		With activated RPW	
	7 day	28 day	7 day	28 day
RS 0RPW	37.95	50.23	37.95	50.23
RS 5RPW	33.01	44.70	35.81	47.15
RS 10RPW	28.90	39.25	33.01	44.25
RS 15RPW	25.25	34.78	30.95	41.78
RS 20RPW	21.75	29.15	28.45	37.95
MS 0RPW	37.02	49.75	37.02	49.75
MS 5RPW	32.15	43.71	34.44	46.21
MS 10RPW	28.21	38.22	32.81	43.05
MS 15RPW	24.15	32.31	29.95	40.04
MS 20RPW	19.98	26.29	26.45	35.95

3.4 Compressive strength

The compressive strength of the tested specimens is given in Table 2.

The compressive strength of the concrete with RPW aggregates as a partial replacement for river sand and manufactured sand is shown in Figs. 7 and 8, respectively. The 28th day compressive strength of river sand and manufactured sand concrete was 50.23 MPa and 49.75 MPa, respectively. The un-activated RPW aggregates content of river sand concrete mixes had a reduction in compressive strength of 11%, 22%, 31% and 42% for a replacement level of 5%, 10%, 15% and 20%, respectively. Similarly, the activated plastic content of concrete mixtures had a reduction in compressive strength of 6%, 12%, 17% and 24% for a replacement level of 5%, 10%, 15% and 20%, respectively. Similarly, manufactured sand concrete mix with un-activated RPW had a reduction in compressive strength ranged from 12% to 47% as the replacement level increased from 5% to 20%. On the other hand, compressive strength for the activated RPW decreased slightly from 7% to 28% as the replacement level increased from 5% to 20%. This might be due to reduction in bond strength between the surface of the RPW and the cementitious materials.

Moreover, plastic is considered to be a hydrophobic material, which had slow down the cement hydration by not

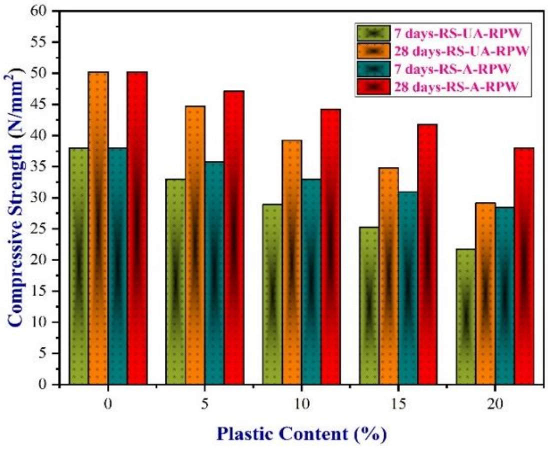

Fig. 7 Variation of compressive strength with plastic content for river sand concrete

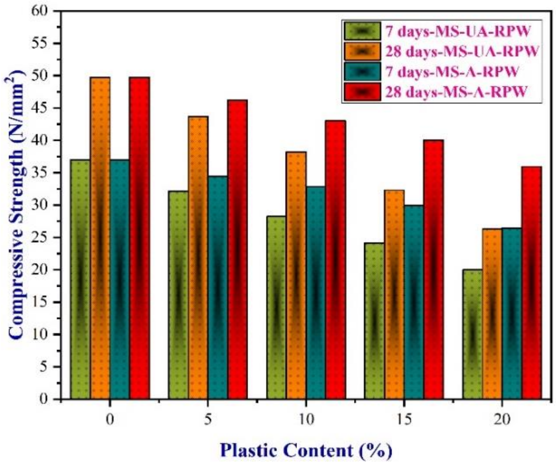

Fig. 8 Variation of compressive strength with plastic content for manufactured sand concrete

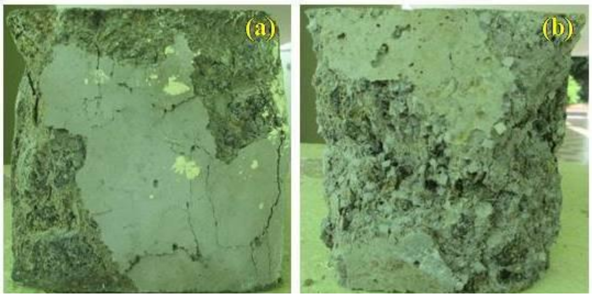

Fig. 9 Failure modes of compressive strength test cubes, (a) Control specimen, (b) Plastic content concrete specimen

allowing the water to enter through the pores of the concrete during the curing period (Ismail *et al*., 2008). The activated RPW content of the concrete mix had less reduction in compressive strength compared to the un-activated plastic content. M40 grade of concrete requires the minimum compressive strength of 40 MPa. In this case, it is feasible to use the structural grade concrete mixes with 5% fine aggregates replacement with un-activated RPW and 15% fine aggregates replacement with activated RPW.

The failure mode of compressive strength test cube is shown in Figs. 9(a)-(b). It was observed from the Figs. 9(a).

Table 3 Split tensile strength of concrete

Mix	Split tensile strength (N/mm^2)			
	With un-activated RPW		With activated RPW	
	7 day	28 day	7 day	28 day
RS 0RPW	3.15	4.23	3.15	4.23
RS 5RPW	2.95	3.98	3.13	4.10
RS 10RPW	2.80	3.71	3.00	3.92
RS 15RPW	2.66	3.53	2.90	3.78
RS 20RPW	2.50	3.31	2.77	3.65
MS 0RPW	3.10	4.16	3.10	4.16
MS 5RPW	2.90	3.85	3.03	4.01
MS 10RPW	2.68	3.60	2.87	3.82
MS 15RPW	2.54	3.35	2.75	3.68
MS 20RPW	2.40	3.18	2.69	3.54

Table 4 Flexural strength of concrete

Mix	Flexural strength (N/mm^2)			
	With un-activated RPW		With activated RPW	
	7 day	28 day	7 day	28 day
RS 0RPW	3.70	4.96	3.70	4.96
RS 5RPW	3.52	4.67	3.58	4.78
RS 10RPW	3.32	4.39	3.45	4.56
RS 15RPW	3.15	4.15	3.30	4.42
RS 20RPW	2.95	3.95	3.22	4.28
MS 0RPW	3.72	4.94	3.72	4.94
MS 5RPW	3.49	4.63	3.55	4.70
MS 10RPW	3.23	4.33	3.33	4.48
MS 15RPW	2.95	3.98	3.25	4.30
MS 20RPW	2.78	3.64	3.11	4.10

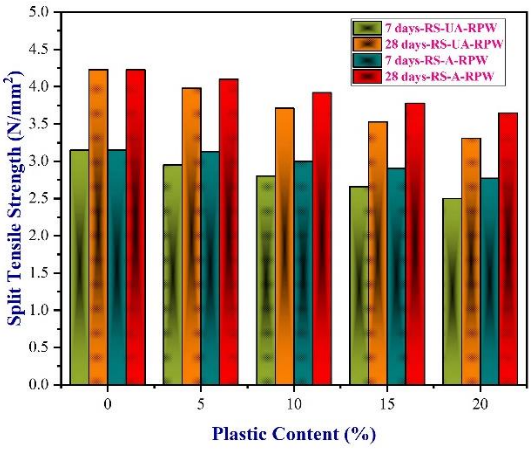

Fig. 10 Variation of split tensile strength with plastic content for river sand concrete

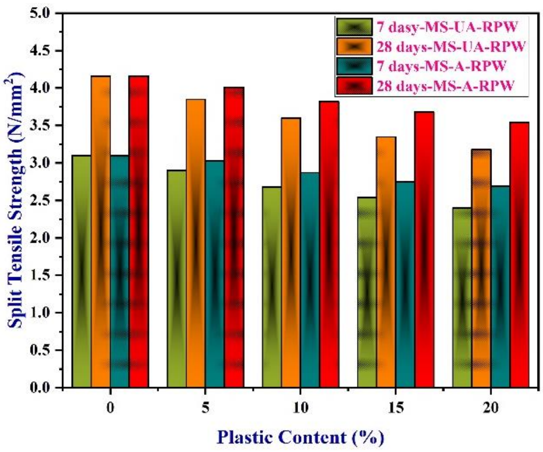

Fig. 11 Variation of split tensile strength with plastic content for manufactured sand concrete

and 9(b). that the failure modes of the control specimen and plastic content concrete are similar. Concrete specimens failed by cone type failure. It is observed that during the compressive strength test, when applying a load, the initial crack was started very early in the RPW content concrete compared to the control mix concrete. And also the spalling of concrete in cube specimen was high compared to the control mix concrete specimen.

3.5 Split tensile strength

The split tensile strength of the tested specimens is given in Table 3.

The relationship of split tensile strength and RPW aggregates content concrete for both river sand and manufactured sand is shown in Figs. 10 and 11. The decrease in the split tensile strength of the RS-UA-RPW mix as compared to control mix is 6%, 12%, 17% and 22% for a replacement level of 5%, 10%, 15% and 20%, respectively. Similarly, for RS-A-RPW mix, the reduction in split tensile strength was found to be 3%, 7%, 11% and 14% for a replacement level of 5%, 10%, 15% and 20%, respectively. Similar to the case of MS-UA-RPW mix, as compared to control mix has a reduction in split tensile strength of 7%, 13%, 19% and 24% for a replacement level of 5%, 10%, 15% and 20%, respectively. Similarly, for MS-A-RPW mix, the reduction in split tensile strength is 4%, 8%, 12% and 15% for a replacement level of 5%, 10%, 15% and 20%, respectively. Split tensile strength also decreases due to the increase in the percentage of RPW. Similar to the case of compressive strength, the decrease in split tensile strength may be explained by the weak adhesion between the RPW and cement matrix, and also the hydrophobic nature of the RPW. In the case of split tensile strength also, activated RPW replaced concrete had more strength compared to the un-activated RPW replaced concrete.

3.6 Flexural strength

The flexural strength of the tested specimens is given in Table 4.

Figs. 12 and 13 show that the flexural strength of concrete containing river sand and manufactured sand with RPW aggregates replacement. The reduction in the flexural strength of RS-UA-RPW concrete mix compared with the control mix ranged from 6% to 20% as the replacement level was increased from 5% to 20%. Similarly, for RS-A-RPW mix, the reduction in flexural strength ranged from 4% to 14% as the replacement level was increased from 5% to 20%. Similar to the case of MS-UA-RPW mix there is a reduction in flexural strength ranged from 6% to 26% as the

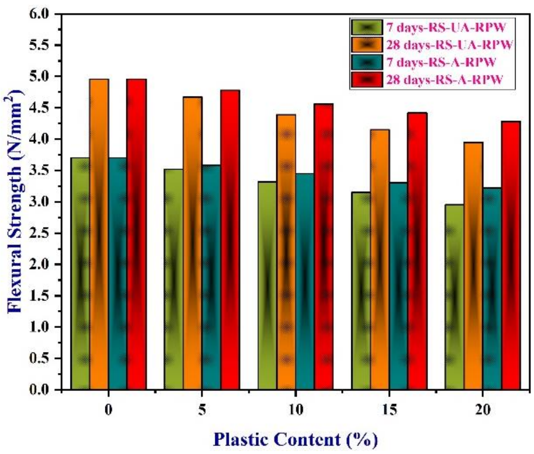

Fig. 12 Variation of flexural strength with plastic content for river sand concrete

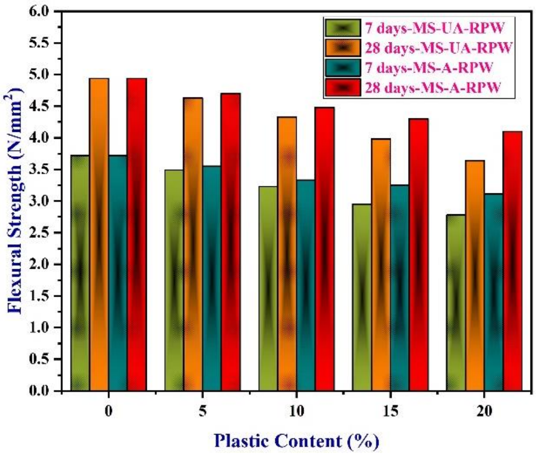

Fig. 13 Variation of flexural strength with plastic content for manufactured sand concrete

replacement level was increased from 5% to 20%. Similarly, for MS-A-RPW mix, the reduction in flexural strength is 5% to 17% as the replacement level was increased from 5% to 20%. Flexural strength also decreases with an increase in the RPW content in concrete mixes. Similar to the explanation given for the reduction in compressive strength and split tensile strengths, the flexural strength of the plastic content mix is reduced due to the weak bond strength and also it is related to the natural fine aggregates replaced by low-density aggregates. It is observed that during the flexural strength test, the deformation capacity is increased when compared to the control mix specimens. This might be due to the ductile nature of the plastics.

3.7 Ultrasonic pulse velocity (UPV)

The influence of RPW in concrete was evaluated using the ultrasonic pulse velocity test. The test was carried out at the age of 28 days. Table 5 shows the characteristic quality of concrete in terms of the ultrasonic pulse velocity as per IS 13311 (Part 1):1992. As per the standard, the quality of the control mix concrete containing both the river sand and manufactured sand is showing excellent quality.

Table 5 Velocity criterion for concrete quality grading

S.No	Pulse velocity by No. cross probing (km/sec)	Concrete quality grading
1.	Above 4.5	Excellent
2.	3.5 to 4.5	Good
3.	3.0 to 3.5	Medium
4.	Below 3.0	Doubtful

*Note - In case of “doubtful’’ quality it may be necessary to carry out further tests.

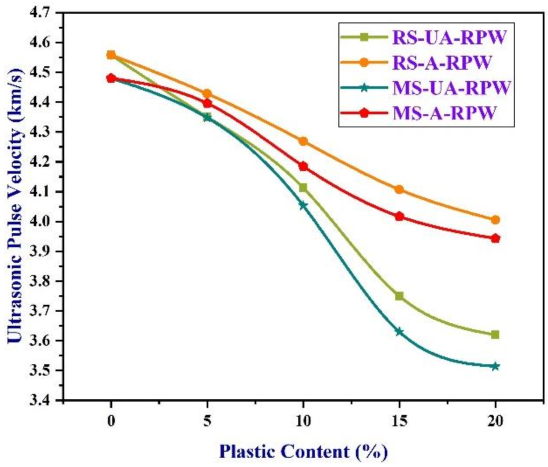

Fig. 14 Ultrasonic pulse velocity versus plastic content

Incorporation of RPW content has a significant effect on the UPV values and the value becomes less for a higher percentage of plastic content in concrete. This might be the increasing RPW content causes an increase in the pore size of the concrete and reduce the capability of transmit the ultrasonic pulse waves in concrete during the ultrasonic pulse velocity test. This trend is confirmed by the scanning electron microscopy analysis. Fig. 14 also shows that the activated RPW content concrete has higher UPV values than the un-activated RPW content concrete. This is likely because the activated RPW binds with the cementitious materials. However, the influence of plastic content on UPV decreases with the increase in RPW content percentage.

3.8 Scanning Electron Microscopy (SEM)

Figs. 15(a)-(d) show that the SEM image of control mix river sand concrete, control mix manufactured sand concrete, activated RPW content concrete and un-activated RPW content concrete, respectively. These test samples were taken from the cube compressive strength specimens. A small thin section of samples were prepared for microstructure analysis. It was observed from the Figs. 15(a)-(b) that, there is no delamination observed in the microstructure of the control mix concrete. Fig. 15(c). shows that, the major cracks and voids are very much reduced as compared to the un-activated RPW content concrete. In the case of un-activated RPW content concrete, major crack formation in microstructure could be attributed due to the weak adhesion between the surface of the plastic and cement matrix (Fig. 15(d)). Similar observations have also been made in earlier research study reported (Yang *et*

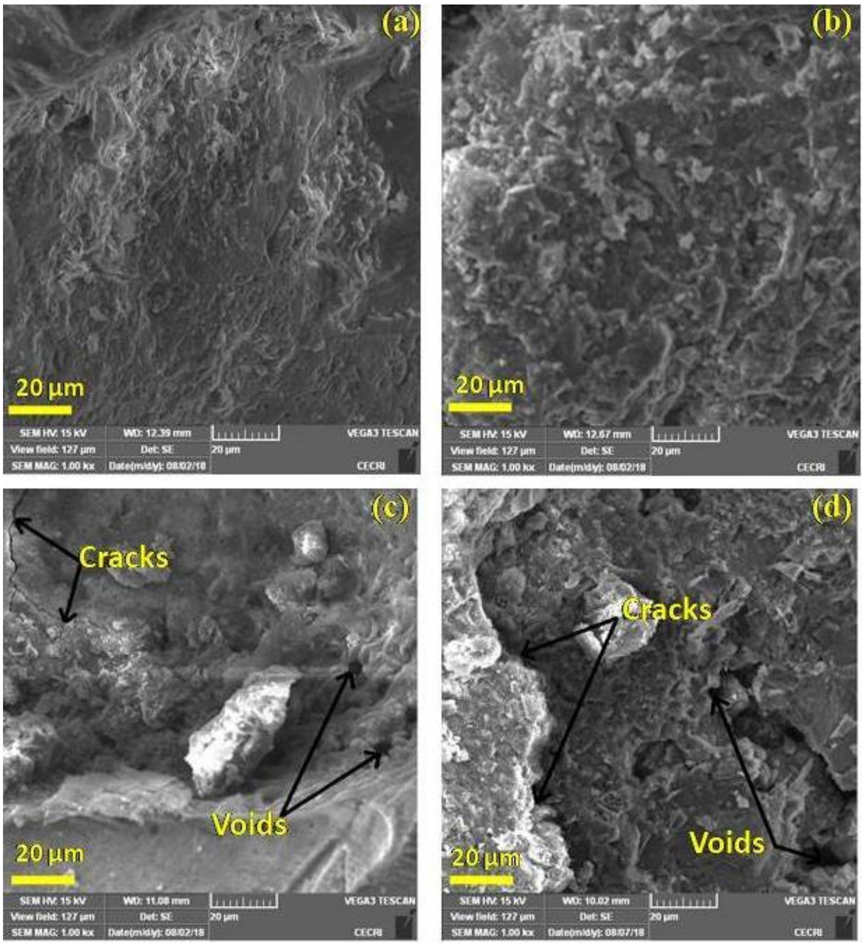

Fig. 15 SEM image of concrete mixes, (a) River sand control mix concrete, (b) Manufactured sand control mix concrete, (c) Activated plastic content concrete, (d) Un-activated plastic content concrete

al. 2015) with 30% use of RPW fine aggregates. Due to this weak adhesion, early cracking and spalling of concrete occurred during load application. This might be the reason for the strength deterioration of the RPW content concrete mix.

4. Conclusions

This paper examines the influence of RPW aggregates on the fresh, hardened and microstructure properties of the concrete mixes. The following main conclusions are made based on the test results of the presented work.

• Fresh and dry density decreases with increasing the percentage of RPW content in concrete. Reduction in fresh density of concrete for 20% replacement in the river sand concrete mixture for un-activated and activated RPW is 8.60% and 8.79%, respectively when compared to the control mix concrete.

• The reduction in dry density for 20% replacement in the river sand concrete mixture for un-activated and activated RPW concrete is 8.98% and 9.27%, respectively compared to the control mix concrete. Reduction in fresh and dry density is due to the low density of RPW aggregates as compared to the river sand and manufactured sand.

• The reduction in compressive, split tensile and flexural strength of river sand concrete with un-activated RPW is 31%, 17% and 16% respectively for 15% replacement level. Similarly for river sand concrete with activated RPW is 17%, 11% and 11% respectively for 15% replacement level. The concrete with manufactured sand also showing decreases in strength with the increase of RPW content.

• Micro structural studies confirm the cause for the reduction in strength of RPW content concrete due to the delamination in concrete.

• Ultrasonic pulse velocity test shows the good quality of concrete. But the increase of RPW content in concrete reduces the quality of concrete when compared to the control mix concrete.

• The use of un-activated RPW for river sand is feasible up to 5% and activated RPW is up to 15%. Almost similar results were achieved for manufactured sand concrete.

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