International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 6 June 2023, pp: 728-737 www.ijaem.net ISSN: 2395-5252

Use of Waste Tire rubber as Sustainable Construction Material to Improve Solid Waste Management in India

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Date of Submission: 14-06-2023 Date of Acceptance: 24-06-2023

ABSTRACT

The amount of concrete used for infrastructural development is the second most utilized material on our planet, resulting in a scarcity of natural resources for ingredients used in concrete like sand and coarse aggregates. As industrialization is boosted rapidly in the past five decades, its effect on the environment is very drastic and the management of solid wastes become a challenge for engineers and society. To overcome this problem the incorporation of wastes generated from the industry in construction materials can be a viable solution. The current study includes the utilization of waste generated through the automobile industry from discarded tires. Recycledrubber fiber (RF)and crumb rubber (CR) werewell mixed for better gradation and usedas a volumetric fractional swap of fine aggregates from 0% to 20%. The results showed that the exchange of sand with well-graded rubber particles (RP) enhanced the properties of rubberized concrete (RC) up to a certain limit. RC with a 10% volume exchange of sand with RPpretreated using NaOH expressed good performance in comparison to the normal concrete.

Keywords: Waste Tires, Crumb Rubber, Pre-treatment of Crumb Rubber, Rubberized Concrete,

I. INTRODUCTION

The construction industry is one of the instant rising industries contributing around 10% to the GDP of the world. Manufacturing of concrete includes the usage of ingredients extracted from natural resources like sand from rivers, lime required for cement production, and the production of coarse aggregates through stone crushing and water used in concrete. As the upsurge in construction is observed the scarcity of these ingredients is also faced by society, which ultimately resulted in a hike in construction costs. On the other side of the coin, industrial and infrastructural development come out with the generation of waste in large amounts, which is merely not possible to manage with this urbanization and industrialization. The effect of the infrastructuralactivities on the environment is always witnessed as the production of concrete generates several problems for the environment, as its constituents are extracted from natural resources, and the main binder material used in concrete, cement emits an equal amount of carbon dioxide (CO_2) **(Cachim et al., 2014)**. The mining of sand from river banks damages aquatic life and the ecological balance. Similarly, the automobile industry also generates a large amount of discarded tires. According to **(Sofi, 2018)** around 1000 million tires are discarded every year and 90% of them are just stockpiled and used for incineration, which again reflects in land and air pollution. As a very less quantity of discarded tires is recycled, it is the need of automobile and civil engineers to get solutions for this environmental problem by incorporating rubber particles in concrete as complete or partial switching of aggregates. So many researchers have tried to include rubber particles in concrete and they provided a better solution and raised new questions to work out in further research works on RC with good mechanical qualities. A detailed review of RC is conducted in this study relevant to the problem statement. **(Yang et al., 2018)**studiedhigh strain rate behavior of RC using dynamic compressive and cracking tensile characteristics of concrete containing recycled tire rubber, and fine aggregate replacement is being done in increments of 5% from 5% to 20%. The impact toughness for RC with 15% replacement is the highest in this research. Another research on RC is performed by

(Elchalakani et al., 2016), the flexural, compressive, and tangential elastic modulus is reduced with the incorporation of rubber particles (RP) in concrete. 10% to 40% replacement by weight of fine aggregates has been opted in this research. The 17% substitution of aggregates is recommended by the authors. **(Zheng et al., 2008)**in addition to comparing the static and dynamic elasticity moduli, the author presented a study on determining the concrete's damping ratio.When compared to a normal mix, the dynamic modulus of elasticity is determined to be less than 37.4%, however the damping ratios have increased by over 144%. Another study performed by **(Issa & Salem, 2013)** carried 15% to 100% replacement and conclude that the mechanical qualities of RC decreased linearly with an increase in amount of rubber. The ductility of RC is enhanced and suggested to be useful in the construction of roadside barriers. **(Mendis et al., 2017)** demonstrated the application ofCR and experiments conducted by them showed that the use of varying sizes in the RC has similar compressive strength as that of control concrete. Another research conducted by **(Agrawal et al., 2023)** commented that the pre-treated RP in RC has better strengths than untreated RP. The scanning electron microscopy (SEM) performed in this study showed that the bonding between RP and cement can be improved using pretreatment methods. The studies **(Gupta et al., 2016; Youssf et al., 2016)** showed that the dynamic behavior of RC is significantly improved than the control concrete. They also concluded that the chloride ion penetration is negligible for the replacement of sand by RP in concrete. The slump of RC is improved by 22% using sodium hydroxide (NaOH) pretreated CR in concrete. The study performed on geo-polymer concrete (GPC) by **(Luhar et al., 2019)**hypothesised that rubberized GPC has greater flexural strength than the typical mix. The modulus of elasticity of rubberized GPC is lessenedby 36.34% for 30% switch of sand, which imparts flexibility to the concrete. Research carried by **(Emiro et al., 2012)** stated that the use use of RP along with high volume of finer materials can impart strength to the RC. The performance of RC for the acid attack is observed better than the control mix as the strength reduction is lesser for RC **(Thomas et al., 2015)**. The research performed by **(Gupta et al., 2015)**proved that the RF added to concrete has been shown to increase the impact resistance of RC, as well as its ability to absorb energy.Some of the research studies evaluated in this study show an improvement in the performance of RC when taking into account its dynamic features. In addition to this,a wide variation is observed for compressive strengths and other mechanical properties as the RC showed biased conclusions for the inclusion of RP in concrete. Therefore the reviewed literature comes out with the conclusion to work on improving the mechanical and durability properties of RC using the pretreatment methods to achieve the desired strength.

II. MATERIALS & METHODOLOGY

1.1 Materials

The mix design for concrete was carried out referring to Indian Standard IS 10262 **(BIS 10262, 2019)**. Five different mixes were prepared using partial substitution of fine aggregates by RP with an increment of 5% up to 20%. The pretreatment of RP was adopted by using NaOH.

Ordinary Portland cement (OPC) 53 grade is the cement that is utilized; it has a specific gravity of 3.15 and was chosen because it has the qualities that were evaluated beforethe mix design. of IS12269 **(BIS 12269, 1992)**. According to IS 2386 **(BS 2386 Part 3, 2016)** sand was used in this research with a specific gravity of 2.65 and water absorption of 1%. The fineness modulus of sand was 2.40 Coarse aggregates incorporated in the study conform to IS 383 **(BIS 383, 2016)**the nominal maximum size of the aggregates was 10 mm, and they had a specific gravity of 2.84. The impact value and crushing strengths were 4.02% and 19.36%, respectively, and they fell within acceptable ranges as defined by IS 383; coarse aggregates absorbed 0.5% of water. The RP used in the mixing of an equal amount of RF and CR has a size of 0.8 – 2.36 mm for CR and 2 – 5 mm and with lengths, up to 15 mm, the aspect ratio of RP was around (6-9) are shown in fig. 1. Mixing of RF and CR was done to get the proper gradation of RP equivalent to sand. The specific gravity of RP was calculated as 0.85. silica fume and fly ash having the same specific gravity as 2.2 were added as the cementitious materials to limit the cement content up to 450 kg as per the IS 10262 and accordingly the water-cementitious material ratio was determined. The particle size distribution for sand and RP was performed by sieve analysis and it is shown in fig.2.

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Fig. 1: Types RF and CR used in the study

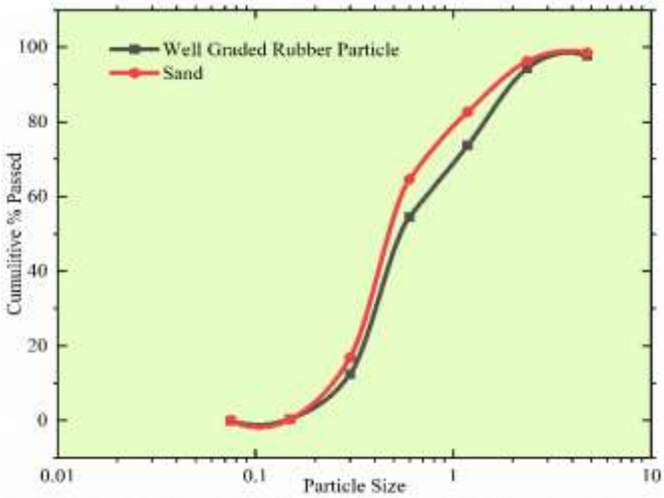

Fig. 2: Particle Size Distribution for Sand and RP

1.2 Experimental Methodology

This study was conducted on 60 MPa high-strength concrete and by substituting fine aggregates from 5% to 20% by its volume using RP pretreated with NaOH. The workability, density, compressive strength and flexural and splitting tensile strengths, water absorption tests, and impact resistance tests were conducted on modified RC mixes and they were compared with the strengths of controlled concrete with 0% substitution of sand by RP. The super-plasticizers used in this study were VISCOFLUX 5507 procured from Apple Chemie IndustriesPvt. Ltd. Nagpur from the Nagpur region and used as a high-range water reducer. In every mix, the superplasticizer was maintained at 1% by weight of cement.The mix design was processed for the desired slump of 120 mm. The quantity of constituents for 1 m^3concrete was determined and mentioned in table 1.

Table II.1: Mix Proportions for Concrete Mixes for 1m^3 concrete in kg.

SN	Mix ID	Cement	Fly Ash	Silica Fume	Water	Coarse Aggregate	Fine Aggregate	Rubbe r Fiber	Super-plastici zer
1	CC	443.00	83.00	28.00	141.00	1197.00	572.00	0.00	5.54
2	RC5	443.00	83.00	28.00	141.00	1197.00	544.00	9.00	5.54

3	RC10	443.00	83.00	28.00	141.00	1197.00	515.00	18.00	5.54
4	RC15	443.00	83.00	28.00	141.00	1197.00	487.00	28.00	5.54
5	RC20	443.00	83.00	28.00	141.00	1197.00	458.00	37.00	5.54

The workability in form of slump and density was determined by following IS 1199 Part 3 and ASTM C138 **(ASTM: C138/C138M-13, 2013; BIS 1199, 1959)**. A slump cone test was used to determine the workability, with top and bottom diameters of 20 and 10 cm and a height of 30 cm.Fresh concrete was placed in the slump cone and the slump value was measured in mm as subsidence of specimen. The 30 cm high cylinder of 15 cm diameter with its known volume was used to determine the fresh density of concrete. The density of the cylinder was computed using the difference in mass and volume of the cylinder between its weight when filled with concrete and when empty.

A 15 cm concrete cube was used to measure each specimen's compressive strength as the mean of three specimens of a mix. The curing for 28 days was done before testing the specimens. The rectangular beam of dimensions 10 x 10 x 50 cm was used to calculate the flexural strength of concrete mixtures, and cylindrical specimens with a diameter of 15 cm and a height of 30 cm were used to calculate the splitting tensile strength. The 28 days of curing were allowed before testing the specimens all these mechanical properties were assessed conforming to IS 516, IS 5816,andIS 1199 **(BIS 1199 Part 5, 2018; BIS 516, 2021; BIS 5816-1999, 1999)**.

The water absorption of concrete is performed according to BS1881 **(BS1881-122, 2011)**, this test was carried out to see what impact adding RP would have on how long concrete will last. Specimens that had been curing for 28 days and measured 75 mm in diameter and 75 mm in height were oven dried for 72 hours at 1060 C before being allowed to cool for 24 h. The weight of specimens was taken and then they are immersed in water for 30 minutes longitudinally then again the weight was recorded and using this record of weights water absorption was determined. If the height of specimens is varying with 75 mm diameterthen it was suggested by BS 1881 to use a correction factor for the particular height to get accurate results. In this study, the correction factor applied is 1 as the size of specimens used is according to the standards.

The concrete's impact resistance was tested using ACI 544 **(ACI 544.2R, 1988)**criteria to measure the material's energy absorption. For all concrete mixes, specimens measuring 15 cm in diameter and 6.35 cm in height were prepared for 28 days of curing. The specimen was fastened into the lugs, and a 4.5 kg hammer ball with a 6.35 cm diameter was dropped on it from a height of 450 mm. The no. of blows required for the levels of distress like generation of the initial and final crack was noted and then by multiplying the potential energy with the no. of blows required the impact energy for the initial and final crack was obtained. The proportion of the final impact energy to the initial impact energy was used to compare how much energy was absorbed by RC and control concrete.

III. RESULTS AND DISCUSSIONS

After completion of casting and curing, specimens were tested using various Indian Standards, and results were interpreted.

1.3 Fresh Density and Workability

As per ASTM C138 **(ASTM: C138/C138M-13, 2013)** the fresh density is calculated. The fresh density of control concrete is found to be highest than other concrete mixes and the density declined with increment in the rubber content the fresh density for RC20 decreased by 7.97%. the reason behind this decrease is that the specific gravity of RP is less than that of sand and the insertion of RP forms voids which in turn reduces the density of concrete. The declined trend of density is described in fig. 3.

The workability of concrete mixes is determined using slump cone apparatus conforming to IS 1199 **(BIS 1199, 1959)**. The results obtained in this research showed that the slump value goes on lessening with the risein RP in concrete. As the dosage of superplasticizer is kept constant at 1%, it can be clearly stated that the inclusion of RP in concrete shows a water requirement as it absorbs the water and hence the slump is reduced. Fig. 2 demonstrates the variation in workability for all concrete mixes. The maximum decrease is seen for the RC20 mix with a slump value of 92.40 mm.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 6 June 2023, pp: 728-737 www.ijaem.net ISSN: 2395-5252

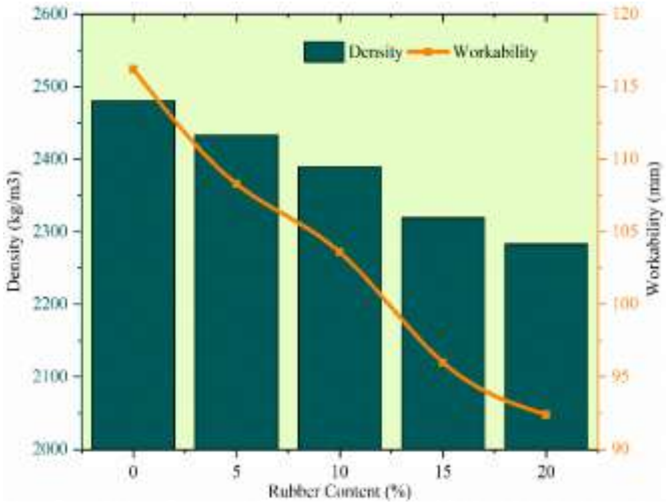

Fig. 3: Variation of Density and Workability with varying Rubber Content in RC

1.4 Compressive Strength

Using a 2000 kN compression testing machine, the 28-day compressive strength of all concrete mixtures is calculated. All specimens' compressive strengths were based on the assumption that they were three specimens on average. The control mix's compressive strength was 62.38 MPa, but when RP was added up to 10% of the mix, the strength reached 60.63 MPa and, correspondingly, 59.64 MPa, which is a respectable result. The further upsurge in the quantity of RP showed a declined trend of RC15 the obtained strength was 54.46 MPa, while the 20% RP gives a strength of 49.93 MPa. Almost a 19.93% decrease is observed with the incorporation of 20% RP in concrete. The earlier studies revealed that the use of untreated RP is more susceptible to strength loss than treated RP**(Agrawal et al., 2023; Battal et al., 2013; Copetti et al., 2020)**. The results obtained in this study proved that the loss in compressive strength is curtailed due to the pretreatment method adopted for RP and the gradation of rubber before its utilization. The compressive strength results are depicted in Fig. 4.

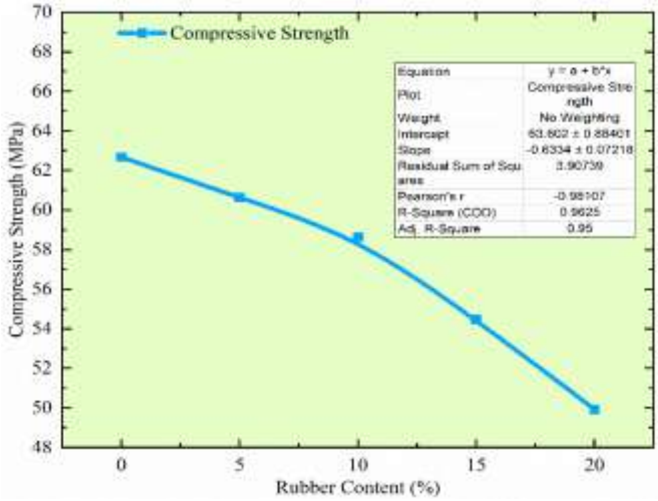

Fig. 4 Variation in Compressive Strength with Rubber Content

1.5 Splitting Tensile and Flexural Strength

When calculating the splitting tensile strength of a concrete mix, 300 mm cylinders are used, and the average of three specimens is taken into account.Gradation and pretreatment both had positive effects on splitting tensile and flexural strength, which were reduced as a result of the presence of RP in concrete.Using IS 516 **(BIS 516, 2021)**as a guide, the flexural strength was calculated. 6.02 MPa is the measured flexural strength for control concrete, whereas flexural strengths for RC5, RC10, and RC15 are stronger than the flexural value recommended by IS 456**(IS 456, 2000)**. In comparison to control concrete, the

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flexural strength of RC20 was found to be 20.83% lower at 4.77 MPa. The test equipment for split tensile and flexural strength is shown in Fig. 5. Up to 10% RP substitution in place of sand, concrete's splitting tensile strength was also at a reasonable level. The results for splitting tensile strength and flexural strength are displayed in Fig. 6.

Fig. 5 Test Setup for Flexural and Splitting Tensile Strength

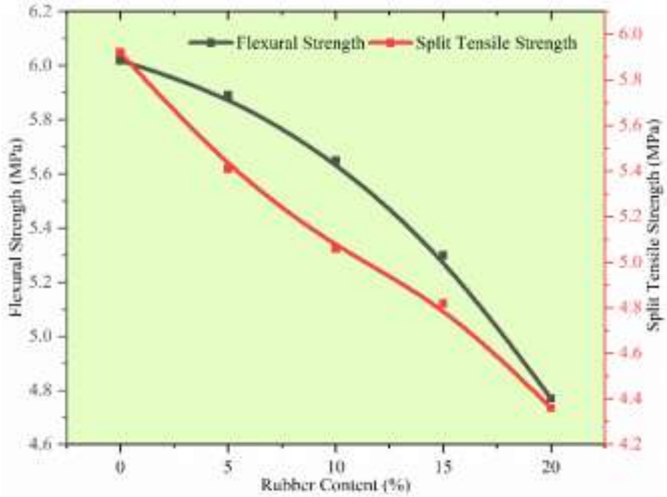

Fig. 6 Flexural and Splitting Tensile Strengths for Concrete Mixes

1.6 Water Absorption

The tendency of RC to absorb water should be examined concerning the durability of concrete since void formation is a possibility because of the weak bonding between the cement paste and RP, which is a component of concrete. The method explained in BS1881 **(BS1881-122, 2011)** was followed and the results were obtained. The water absorption for RC is increased in linear relation to the rubber content. For RC20 the water absorption is 4.68% almost 2.38 times higher than control concrete. Water absorption for all concrete mixes is depicted in fig. 7.

1.7 Impact Resistance

It is vital to assess the impact resistance of modified concrete because the addition of RP to concrete revealed a decrease in the material's brittleness and an improvement in its flexibility.The procedure outlined in ACI Committee 544-2R **(ACI 544.2R, 1988)** is adopted to determine the impact resistance test using no.of blows required for distress in RC specimensto inform of initial and final crack. A certain concrete mix's ability to absorb energy is proved by comparing the final impact energy to the initial impact energy after determining the impact energy for the initial and final cracks. Figures 8 and 9 show the test setup for impact resistance using the drop weight test and energy absorption for all concrete mixtures, respectively. It can be observed that as the rubber content increases, more hits are needed to generate the early and ultimate cracks. In comparison to control concrete, the RC20 mix's energy absorption is 8.85% higher. The number of blows necessary for crack development for each concrete mix is listed in Table 2. Compared to control concrete, the number of blows for the ultimate crack increased by about 264.47%.

Table II: Impact Resistance for concrete mixes

Rubber Content	No. of Blows for Initial Crack	No. of Blows for Final Crack	Difference	Initial Impact Energy	Final Impact Energy	N2/N1	Average Energy Absorption
0	65	76	11	1291.24	1509.76	1.17	
0	68	74	6	1350.84	1470.03	1.09	1.13
0	63	72	9	1251.51	1430.3	1.14	
5	87	101	14	1728.28	2006.39	1.16	
5	86	98	12	1708.41	1946.79	1.14	1.17
5	92	110	18	1827.6	2185.18	1.20	
10	116	144	28	2304.37	2860.6	1.24	
10	126	152	26	2503.02	3019.52	1.21	1.20
10	123	143	20	2443.43	2840.73	1.16	
15	168	206	38	3337.36	4092.24	1.23	
15	186	211	25	3694.94	4191.57	1.13	1.21
15	192	243	51	3814.13	4827.26	1.27	
20	213	267	54	4231.3	5304.02	1.25	
20	226	277	51	4489.55	5502.67	1.23	1.23
20	221	268	47	4390.22	5323.89	1.21	

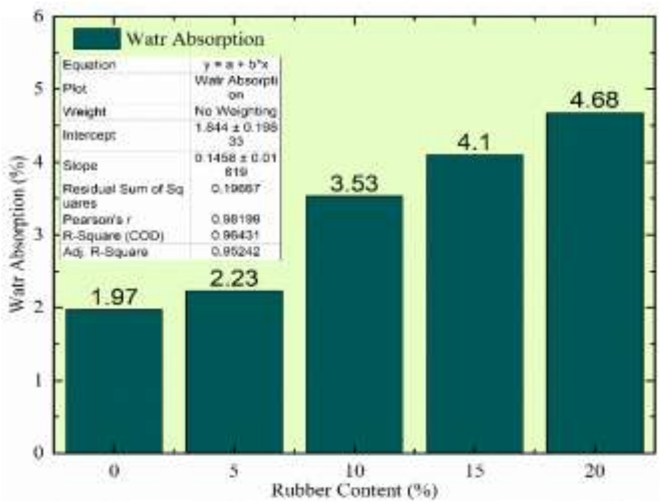

Fig. 7 Water Absorption for Concrete

Fig. 8 Test Setup for Impact Resistance Test

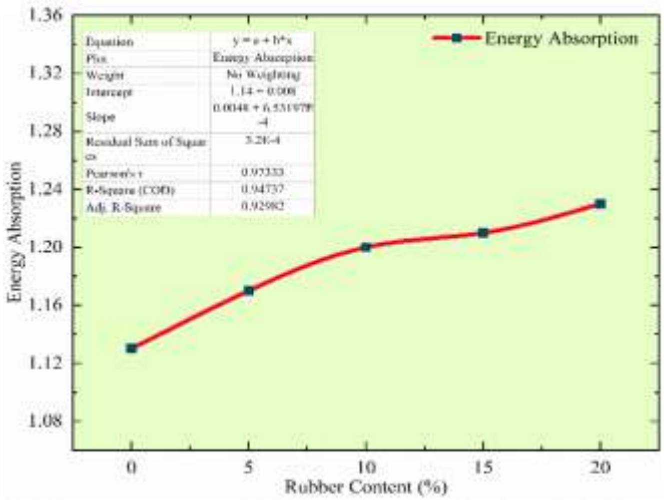

Fig. 9 Energy Absorption of Concrete Mixes

IV. CONCLUSIONS

The investigation of RC for mechanical and durability tests was performed in this research by substituting the sand fractionally by well graded and pretreated RP. The research work was concluded as below.

- Rubber has a low specific gravity, which decreased RC's density, the modified RC can be used as lightweight concrete as for RC20 the density decreased to 2282.93 kg/m^3 from 2480.83 kg/m^3 of normal mix.
- The workability of RC raised concern as the incorporation of Rp reduced the slump value by 20.48% for 20% replacement of sand. The desired slump can be achieved with the increase of superplasticizers with the amount of rubber waste included.
- The compressive strength of up to 10% replacement of sand using well-graded and pretreated RP showed better performance while the further increment in rubber content reduces the compressive strength drastically.
- The split tensile and flexural strengths of RC showed good performance up to 15% substitution of sand as the strengths received up to 15% replacement is more than the limit specified in Indian standards.
- As RC's water absorption rate rises along with its rubber content, this is a serious hazard. For 10% exchange of sand with RP showed 3.53% water absorption, beyond 10% replacement the water absorption is almost 2 times the water absorption on the control mix.
- When compared to the control mix, RC's impact resistance was improved by its increased flexibility.With a nearly threefold increase in rubber content compared to control concrete, the number of impacts necessary for ultimate fracture development rises.

The study performed on RC concluded that the incorporation of Rp in concrete can be a viable solution for solid waste management and for avoiding the scarcity of sand throughout the world. It is recommended that the 10% replacement of sand by RP is possible in view of the mechanical and durability properties of concrete.

REFERENCES

[1]. ACI 544.2R. (1988). Measurement of properties of fiber reinforced concrete. ACI Materials Journal, 85(6), 583–593. https://doi.org/10.14359/2355

[2]. Agrawal, D., Waghe, U., Ansari, K., Dighade, R., Amran, M., Qader, D. N., & Fediuk, R. (2023). Experimental effect of pre-treatment of rubber fibers on mechanical properties of rubberized concrete. Journal of Materials Research and Technology, 23, 791–807. https://doi.org/10.1016/j.jmrt.2023.01.027

[3]. ASTM: C138/C138M-13. (2013). Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric). ASTM International, i, 23–26. https://doi.org/10.1520/C0138

[4]. Battal, K., Matthew, N., & Hall, R. (2013). Crumb rubber aggregate coatings / pre-treatments and their effects on interfacial bonding , air entrapment and fracture toughness in self-compacting rubberised concrete (SCRC). mm. https://doi.org/10.1617/s11527-013-0034-4

[5]. BIS 10262. (2019). Concrete Mix Proportioning Guidelines. IS 10262-2019, New Delhi, India.

[6]. BIS 1199. (1959). Methods of sampling and analysis of concrete. IS 1199, 1–49.

[7]. BIS 1199 Part 5. (2018). Fresh Concrete-Methods of Sampling, Testing and Analysis Part 5 Making and Curing of Test Specimens (First Revision). IS 1199 Part 5-2018, New Delhi, India, 1199(December). www.standardsbis.in

[8]. BIS 12269. (1992). IS (Indian Standard). 2013. Ordinary Portland Cement, 53 Grade — Specification. IS 12269-13. IS 12269, 6(2), 141-142+144.

[9]. BIS 383. (2016). Coarse and fine aggregate for concrete - Specification. Bureau of Indian Standards IS 383 -2016, New Delhi, India, January, 1–18.

[10]. BIS 516. (2021). Hardened concrete - Methods of test. IS 516-2021, New Delhi, India, 54(August), 1–20. www.standardsbis.in

[11]. BIS 5816-1999. (1999). Specification for splitting tensile strength of concrete - Method of Test. IS 5816-1999, New Delhi, India, 1–8.

[12]. BS 2386 Part 3. (2016). Methods Of Test For Aggregates For Concrete Specific Gravity, Density, Voids, Absorption And Bulking. IS 2386 Part 3-2016, New Delhi, India, 2386 Part(October 1963), 1–19.

[13]. BS1881-122. (2011). BSI Standards Publication Testing concrete Part 122 : Method for determination of water absorption. BSI Standards, 1–8.

[14]. Cachim, P., Velosa, A. L., & Ferraz, E. (2014). Substitution materials for sustainable concrete production in Portugal. KSCE Journal of Civil Engineering, 18(1), 60–66. https://doi.org/10.1007/s12205-014-0201-3

[15]. Copetti, C. M., Borges, P. M., Squiavon, J. Z., da Silva, S. R., & de Oliveira Andrade, J. J. (2020). Evaluation of tire rubber surface pre-treatment and silica fume on physical-mechanical behavior and microstructural properties of concrete. Journal of Cleaner Production, 256. https://doi.org/10.1016/j.jclepro.2020.120670

[16]. Elchalakani, M., Aly, T., & Abu-Aisheh, E. (2016). Mechanical properties of rubberised concrete for road side barriers. Australian Journal of Civil Engineering, 14(1), 1–12. https://doi.org/10.1080/14488353.2015.1092631

[17]. Emiro, M., Y, S., Kele, O., & Kele, M. H. (2012). Bond performance of rubber particles in the self-compacting concrete. 779–786.

[18]. Gupta, T., Chaudhary, S., & Sharma, R. K. (2016). Mechanical and durability properties of waste rubber fiber concrete with and without silica fume. Journal of Cleaner Production, 112, 702–711. https://doi.org/10.1016/j.jclepro.2015.07.081

[19]. Gupta, T., Sharma, R. K., & Chaudhary, S. (2015). Impact resistance of concrete containing waste rubber fi ber and silica fume. International Journal of Impact Engineering, 83, 76–87. https://doi.org/10.1016/j.ijimpeng.2015.05.002

[20]. IS 456. (2000). Plain and Reinforced Concrete - Code Of Practice. IS 456-2000, New Delhi, India, July, 1–106.

[21]. Issa, C. A., & Salem, G. (2013). Utilization of recycled crumb rubber as fine aggregates in concrete mix design. Construction and Building Materials, 42, 48–52. https://doi.org/10.1016/j.conbuildmat.2012.12.054

[22]. Luhar, S., Chaudhary, S., & Luhar, I. (2019). Development of rubberized geopolymer concrete: Strength and durability studies. Construction and Building Materials, 204, 740–753. https://doi.org/10.1016/j.conbuildmat.2019.01.185

[23]. Mendis, A. S. M., Al-Deen, S., & Ashraf, M. (2017). Behaviour of similar strength crumbed rubber concrete (CRC) mixes with different mix proportions. Construction and Building Materials, 137, 354–366. https://doi.org/10.1016/j.conbuildmat.2017.01.125

[24]. Sofi, A. (2018). Effect of waste tyre rubber on mechanical and durability properties of concrete – A review. Ain Shams Engineering Journal, 9(4), 2691–2700. https://doi.org/10.1016/j.asej.2017.08.007

[25]. Thomas, B. S., Gupta, R. C., Mehra, P., & Kumar, S. (2015). Performance of high strength rubberized concrete in aggressive environment. Construction and Building Materials, 83, 320–326. https://doi.org/10.1016/j.conbuildmat.2015.03.012

[26]. Yang, G., Chen, X., Xuan, W., & Chen, Y. (2018). Dynamic compressive and splitting tensile properties of concrete containing recycled tyre rubber under high strain rates. Sadhana - Academy Proceedings in Engineering Sciences, 43(11), 1–13. https://doi.org/10.1007/s12046-018-0944-5

[27]. Youssf, O., Mills, J. E., & Hassanli, R. (2016). Assessment of the mechanical performance of crumb rubber concrete. Construction and Building Materials, 125, 175–183. https://doi.org/10.1016/j.conbuildmat.2016.08.040

[28]. Zheng, L., Huo, X. S., & Yuan, Y. (2008). Experimental investigation on dynamic properties of rubberized concrete. 22, 939–947. https://doi.org/10.1016/j.conbuildmat.2007.03.005