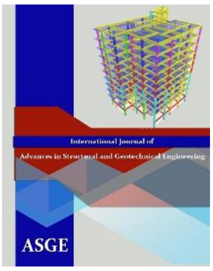

International Journal of Advances in Structural and Geotechnical Engineering

https://asge.journals.ekb.eg/

Print ISSN 2785-9509 Online ISSN 2812-5142

Special Issue for ICASGE'19

Performance of High Strength Concrete Containing Recycled Rubber

Ayman Abdelmonem, Muhammad S. El-Feky, Mohamed Kohail, Elsayed A.R.Nasr

ASGE Vol. 03 (03), pp. 106-116, 2019

PERFORMANCE OF HIGH STRENGTH CONCRETE CONTAINING RECYCLED RUBBER

Ayman Abdelmonem[1], Muhammad S. El-Feky[2], Mohamed Kohail[3], Elsayed A.R.Nasr[4]

[1]*Postgraduate Student, Faculty of Engineering, Ain Shams University, Egypt*
E-mail: ayman.abdelmonem1@gmail.com
[2]*PhD, Civil Engineering Department, National Research Centre, Egypt*
E-mail: msaelfeky@yahoo.com
[3]*Assistant Professor, Faculty of Engineering, Ain Shams University, Egypt*
E-mail: m.kohail@eng.asu.edu.eg
[4]*Associate Professor, Faculty of Engineering, Ain Shams University, Egypt*
E-mail: mosyn1950@gmail.com

ABSTRACT

Recycling of materials has become a major interest for engineers as a part of their collective efforts in finding and developing environmentally friendly solutions towards a more sustainable future. Inadequate disposal of the huge numbers of tires generated every year after they reach their service life and become waste has become one of the most challenging problems that can create health and safety risks. One of the promising solutions is utilizing waste rubber in civil engineering applications as partial replacement of natural aggregate in conventional concrete. This paper aims to investigate the performance of high strength concrete containing recycled rubber as partial replacement of fine aggregate. Four different mixes were produced in which crumb rubber partially replaced fine aggregate by 0%, 10%, 20%, and 30% of volume. Slump, density, compressive strength, tensile strength, flexural strength, and water absorption were evaluated. The rubberized concrete mixes showed good workability and slightly lower density compared to the control mix. A systematic reduction in compressive, tensile, and flexural strength was observed with increasing the rubber content. Rubberized concrete mixes showed higher water absorption compared to the control mix. The results of this study provide an insight on the effect of rubber particles on high strength concrete.

Keywords: High strength concrete, Rubberized concrete, Crumb rubber, Waste tires

INTRODUCTION

Recycling of materials has become a major interest for engineers as a part of their collective efforts in finding and developing environmentally friendly solutions towards a more sustainable future. World demand for tires is projected to rise every year, as the rising incomes in developing regions will spur growth in the number of vehicles in use, fueling demand for tires. According to the U.S. tire manufacturers association, in 2017 almost 287.3 million of scrap tires were produced in the United States and about 60 million tires was stockpiled [1]. With these huge numbers of tires generated every year around the world, the inadequate disposal of these tires after they reach their service life and become waste has become one of the most challenging problems that can create health and safety risks. Disposal of these tires in landfills is problematic as they provide a breeding ground for mosquitoes, vermin, and snakes that may carry diseases. Accidental fires can occur easily, and the tires can burn for months creating substantial pollution. The natural decomposition process of waste tires is also very slow [2], [3]. Thus legislations have been introduced by some countries to ban the disposal of tires in landfills and encourage the reuse of waste tires [2], [4], [5]. Such regulations led to increasing the efforts to using waste rubber in other applications. Since concrete is one of the dominated materials in the construction field and green construction recently has been an essential aspect in the production of concrete, therefore utilizing waste rubber to partially replace natural aggregate in conventional concrete can be considered as a one step forward towards sustainable construction as it reduces the amount of rubber entering landfills and conserves the natural resources. Several studies have been conducted in the past two decades investigating the reuse of recycled tire rubber as replacement of fractions of mineral aggregate [6–13].

Many studies have been conducted to evaluate the effect of inclusion of waste rubber as aggregate in concrete. Taha et al. [14] stated that the increase in the rubber content has a negative effect on the workability of fresh rubberized concrete which can be shown in the substantial loss in the slump of the rubberized concrete. The reduction in slump seems to be increased in case of using the relatively larger tire chips compared to using the smaller crumbed rubber particles. It was also observed that the reduction increases at high replacement levels of rubber particles which might be attributed to the roughness of the rubber particles and might result to an increase in friction between the ingredients of the fresh concrete. Moustafa and ElGawady [15] reported that replacement of fine aggregate with rubber up to 10% did not have a severe effect on the slump of the concrete mixes. Increasing the replacement level above 10% had a severe effect on the workability. Mixture with 30% replacement made the concrete almost not workable, so mechanical vibration was needed due to the loss of workability.

Gupta et al. [16] used admixtures to maintain compaction factor of 0.9 for mixes with rubber ash and different w/c ratios, it was noticed that the amount of admixtures increased with increasing the rubber ash content which was similar to that observed by Bisht and Ramana [17]. Raffoul et al. [5] mentioned that the fresh flowability of the rubberized concrete is affected more by fine aggregate replacement than that of coarse aggregate replacement, especially when reaching rubber contents more than 20 % of the total aggregate. On the contrary, Aiello and Leuzzi [18] pointed out that there was a slight increase in the slump when using rubber shreds as a partial substitution of coarse or fine aggregates.

Gupta et al. [16] showed that increasing the percentage of rubber ash in concrete leads to the reduction of the density of concrete for w/c ratio 0.35, 0.45 and 0.55. Xue and Shinozuka [19] reported that density decreased from 2475 kg/m^3 to 2069 kg/m^3 with 20% rubber replacement ratio and nearly the same result was obtained when replacing 7% of cement with silica fume. The gradual reduction in the density of the rubberized concrete was reported by several authors and was attributed to the low specific gravity of rubber compared to that of natural aggregates [14], [17], [20–22].

Taha et al. [14] used chipped tire and crumbed rubber to replace coarse and fine aggregate with different replacement level and reported a reduction in the compressive strength in both cases, however, the reduction in compressive strength was more pronounced in the case of replacing the coarse aggregate. Atahan and Yücel [7] mentioned that replacement of 100% of both fine and coarse aggregate with rubber has led to a reduction of 93% and 96% of compressive strength and modulus of elasticity, respectively. Significant reduction in compressive strength, splitting tensile strength and flexural strength of rubberized lightweight concrete was noted by Lv et al. [23] with the most reduction in strength occurring for replacement ratios below 50%. Gupta et al. [20] investigated the effect of rubber fiber as a replacement of fine aggregate with three w/c ratios (0.35, 0.45 and 0.55) and three levels of silica fume replacement of cement (0%, 5% and 10%). They concluded that with increasing the rubber content, the compressive strength decreases for all w/c ratios. However, the addition of silica fume reduces the loss in the compressive strength. Holmes et al. [24] stated that to avoid substantial loss in strength, crumb rubber replacement should not exceed 20% of the aggregate content, similar observation was also stated by Issa and Salem [25] as they reported that at replacement levels below 25%, good compressive strength results were recorded which encourage the use of that concrete mix in non-structural applications. However, with replacement levels beyond 25%, compressive strength drastically decreased which prevents the use of the rubberized concrete in structural or non-structural applications.

Khalil et al. [26] studied the impact resistance of self-compacting concrete where crumb rubber replaced the sand by volume with ratios from 0% to 40%. The results showed that the impact resistance increased with increasing the rubber up to 30% replacement level, and then it decreased for the 40% replacement level. According to Khalil et al. [26] this means that replacing sand with rubber beyond 30% adversely affect the interlocking between aggregates leading to a loss in the mechanical properties which affects the development in impact resistance. It was obvious that the 30% rubber mix demonstrated to have better impact resistance than the other mixes with three times impact resistance over the control mix and with 40% decrease in the compressive strength. A significant increase in energy dissipation was recorded by Atahan and Yücel [7] with increasing the rubber content as the 100% rubber replacement of both coarse and fine aggregate achieved an increase of 160.8% in the energy dissipated compared to that of the control mix. It was also observed that mixes with 20% and 40% rubber reduced impact severity while maintaining much strength and resistance to fracture upon impact.

MATERIALS AND EXPERIMENTAL PROCEDURE

Materials

In this study Portland cement type I (CEM I 52,5R) in accordance with ASTM C150 [27] was used to produce the rubberized concrete mixes. Silica fume was used as a partial replacement of cement by weight. Clean crushed dolomite of maximum size of 12 mm and specific gravity of 2.96 was used as coarse aggregate. Natural available clean sand with particles size smaller than 0.5 mm and specific gravity of 2.65 and fineness modulus of 2.25 was used as fine aggregate. Crumb rubber from waste tires with a specific gravity of 0.45 was obtained from a local company and was produced using mechanical shredding, the steel fibers were separated from rubber after the used tires were shredded and ground. The crumb rubber was available in two sizes (1-4 mm and powder form of 0-1 mm commercially known as mesh 40). The two sizes were mixed with percentages of 70% of mesh 40 and 30% of 1-4 mm to achieve similar grading to that of sand. The sieve analysis for sand and rubber is shown in Fig. 1. Sika ViscoCrete 3425 with a specific gravity of 1.08 was used as a super plasticizer.

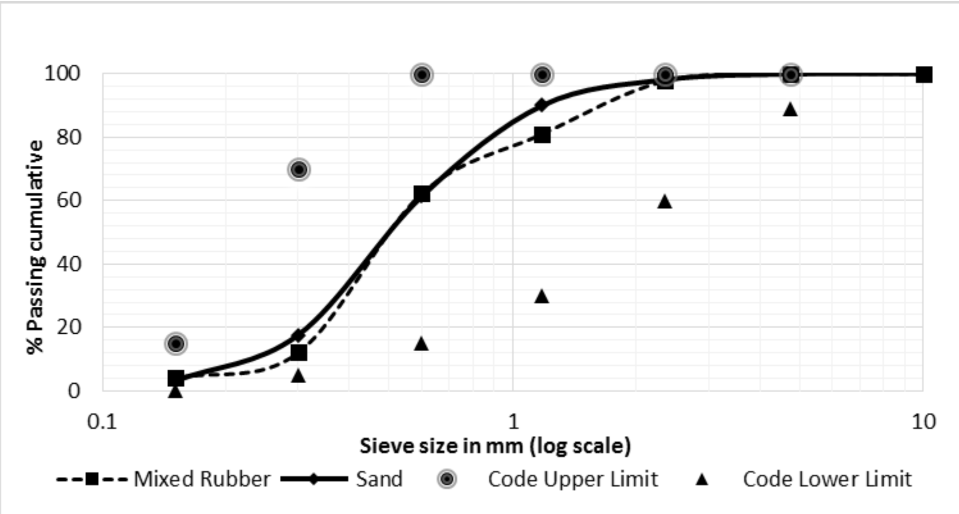

Fig. 1: Sieve analysis for rubber and sand used.

Mixtures Proportions

An overall of four series of mixtures were prepared in the laboratory. The control mix (R0) was made of natural aggregates, cement, silica fume, water, and super plasticizers. Rubberized concrete mixes were made by partially replacing the fine aggregate with rubber. The rubber replacement ratios used were 10% (R10), 20% (R20), and 30% (R30) of the volume of sand.
All the mixtures were prepared with silica fume replacement ratios 15% by weight of cement. The super plasticizer was used with a ratio of 1.5% by weight of cement. The water to cement ratio for all mixtures was 0.3. Table 1 shows the constituents of each mix.

Table 1: Mixtures constituents (kg/m³)

Mix ID	Cement	Silica Fume	Water	Coarse aggregate	Fine aggregate	Rubber mesh 40	Rubber 1-4 mm	Super plasticizer
R0	382.5	67.5	135	1000	820	0	0	6.75
R10	382.5	67.5	135	1000	738	9.75	4.2	6.75
R20	382.5	67.5	135	1000	656	19.5	8.4	6.75
R30	382.5	67.5	135	1000	574	29.3	12.5	6.75

Mixing Procedure and Curing

All mixtures were prepared by mixing the coarse aggregates, fine aggregates, and rubber in a laboratory concrete drum mixer. They were mixed in dry condition for 1 min, then adding the cement and silica fume and continue the dry mixing for another 1 min. Finally, adding the super-plasticizers to the mixing water and was gradually added to the mix and continue the mixing for about 3 minutes.
All samples were compacted on a vibrating table in two and three layers respectively, each layer was vibrated for 10 seconds. After one day of casting at 20°C and 55% RH, the specimens were de-molded and submerged into a water tank to be cured at a temperature of 20°C until the day of testing.

Testing Procedures

Slump test was conducted according to ASTM C143 [28] to evaluate the workability of the rubberized concrete. Cubes of 100 mm x100 mm x100 mm were cast for compressive strength test, the strength was determined at 7 and 28 days as per BS EN 12390-3 [29]. Splitting tensile strength was performed at 28 days on cylinders of 100 mm diameter and 200 mm height as per ASTM C496 [30]. Flexural tensile strength was performed at 28 days on prisms of 200 mm x 50 mm x 50 mm as per ASTM C293 [31]. Universal Testing Machine SHIMADZU 1000 KN was used to conduct the tests. Water absorption was conducted on cubes of 100 mm x100 mm x100 mm at 28 days as per ASTM C 642 [32].

RESULTS AND DISCUSSION

Slump Test

Slump test results are presented in Fig. 2. The results show that all mixes have good workability with slump values over 200 mm. the loss in the slump is less than 10% for all rubber replacement levels. The R0 and R10 mix almost achieved the same slump with 235 mm and 240 mm respectively, then the slump slightly decreased to 215 mm and 220 mm for the R20 and R30 mixes with a maximum loss in slump of 8.5 %. This indicates that rubber replacements of up to 30 % did not have severe effects on the workability of the fresh rubberized concrete. The reason for the good workability is attributed to the use of super plasticizers as advised by previous authors as it decreases the negative effects of rubber on the workability of fresh concrete [33].

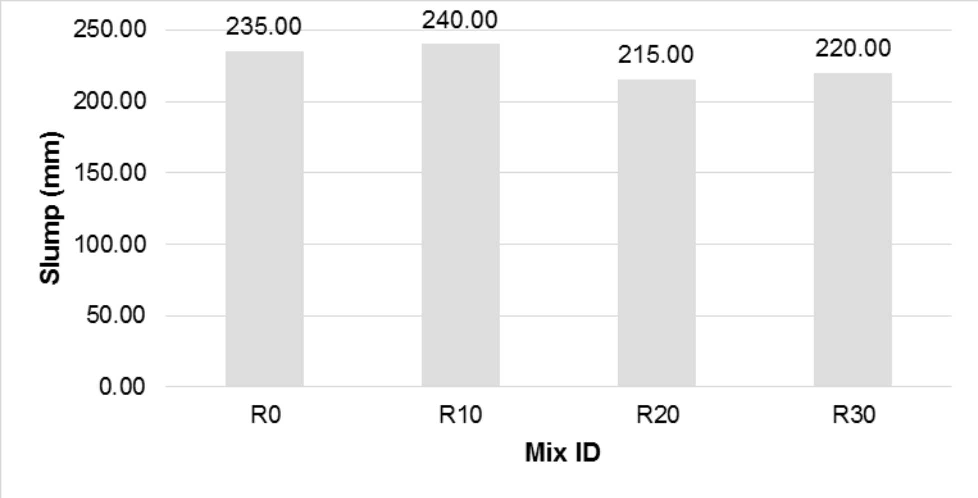

Fig. 2: Slump of all mixes.

Density

Using waste rubber to replace sand appears to have a slight effect on the density of the concrete. It is observed that the density of the rubberized concrete slightly decreases with increasing the rubber content, which appears to be as a result of the low specific gravity of waste rubber compared to that of natural aggregate [16], [23]. The R30 mix had approximately 8.2% reduction in density compared to the R0 mix which is consistent with Moustafa and ElGawady [15] as they reported 6% reduction in the density of rubberized concrete when replacing 30% of sand with rubber. Fig. 3 shows the density of each concrete mixture.

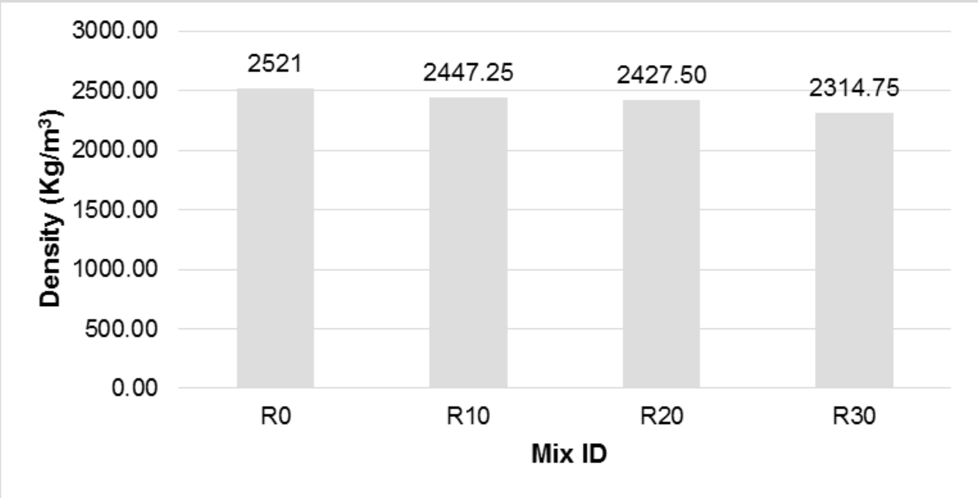

Fig. 3: Density of all mixes.

Compressive Strength

Fig. 4 shows the results of the 7 and 28 days compressive strength with respect to the rubber content. The results show that there is a gradual decrease in the compressive strength of the rubberized concrete with increasing the rubber content for both 7 and 28 days. Using replacement levels of 10%, 20%, and 30% resulted in a reduction of the 7 days compressive strength by 3%, 18%, and 27%, respectively. The maximum compressive strength recorded was for the control mix (R0) with 39.2 MPa, while the lowest value was obtained for the 30% replacement level (R30) with 28.6 MPa. The results for the 28 days compressive strength followed the same trend as the control mix (R0) reached a compressive strength of 62.6 MPa while the R30 mix reached a compressive strength of 35.0 MPa. The reduction in the

compressive strength observed was 25.7%, 39.4%, and 44% for the replacement levels of 10%, 20%, and 30% respectively compared to mix R0 (control mix). Similar reductions in compressive strength were obtained by Feng et al. [34]. Several reasons might be the cause of the reduction in compressive strength as reported by many authors. One of the possible reasons is that the rubber particles are elastically deformable which makes them softer than the surrounding cement paste, so during loading cracks starts to form quickly around the rubber particles, which can cause quick failure. The decrease in compressive strength can also be due to the weak bonding between rubber particles and the cement paste compared to the good bonding between the natural aggregate and the cement paste, which might lead to the formation of cracks. The replacement of the natural aggregate which is the solid load carrying material with the rubber which is soft material would certainly cause a reduction in strength [23], [35–37].
Comparing the compressive strength results of the 7 days and 28 days it was observed that the rate of reduction of strength at 7 days was less than that of 28 days which is explicable that at the early age, the aggregate strength had not been entirely developed. In addition, the rate of development in strength was high in the control mix and then dropped with the addition of rubber, which is clear in Fig. 5.

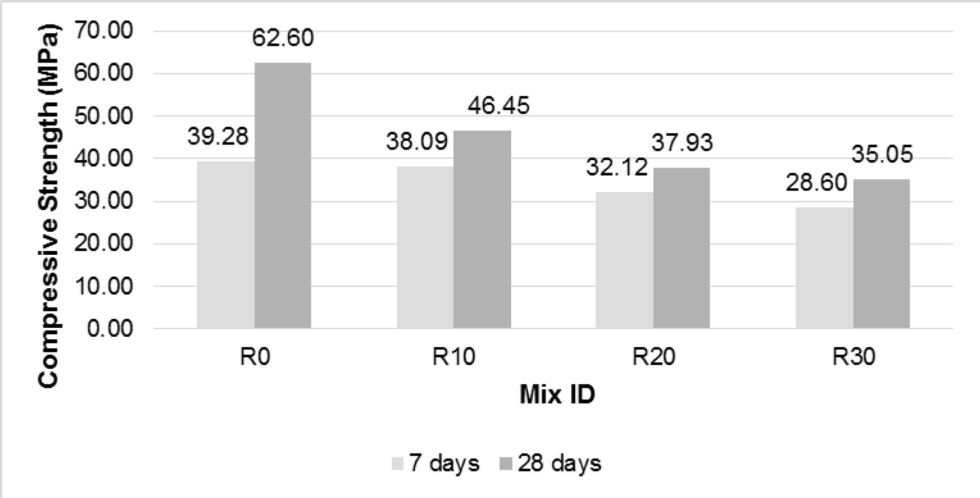

Fig. 4: Compressive strength at 7 and 28 days.

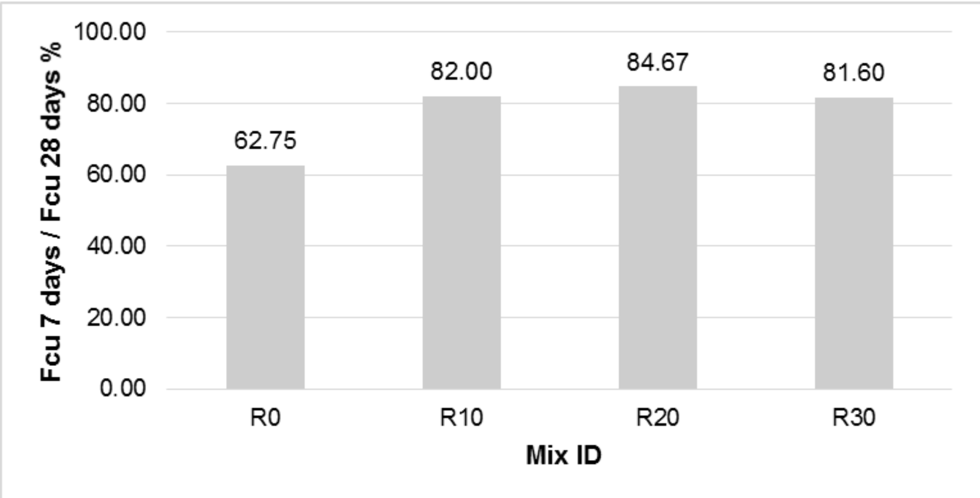

Fig. 5: % Compressive strength at 7 days / Compressive strength at 28 days.

Indirect Tensile Strength

Fig. 6 presents the results of indirect tensile strength with respect to rubber content. It can be shown that the behavior of splitting tensile strength showed a similar trend to that of compressive strength where a reduction in splitting tensile strength occurs with increasing the rubber content. The splitting tensile strength decreased by 44.15%, 62.26%, and 64.28% when rubber replaced sand with 10%, 20%, and 30% respectively. The maximum tensile strength obtained was 6.33 MPa for R0 mix, while the lowest value recorded was 2.26 MPa for R30 mix. This reduction in strength may be attributed to the same reasons affecting the compressive strength as The interface zone between rubber and cement may act as a micro-crack due to weak bonding between the two materials; the weak interface zone accelerates concrete breakdown [38]. The splitting tensile to compressive strength ratios computed were 10.11%, 7.61%, 6.30%, and 6.45% for R0, R10, R20, and R30 mixes respectively. The ratio seems to be decreasing with increasing the rubber content.

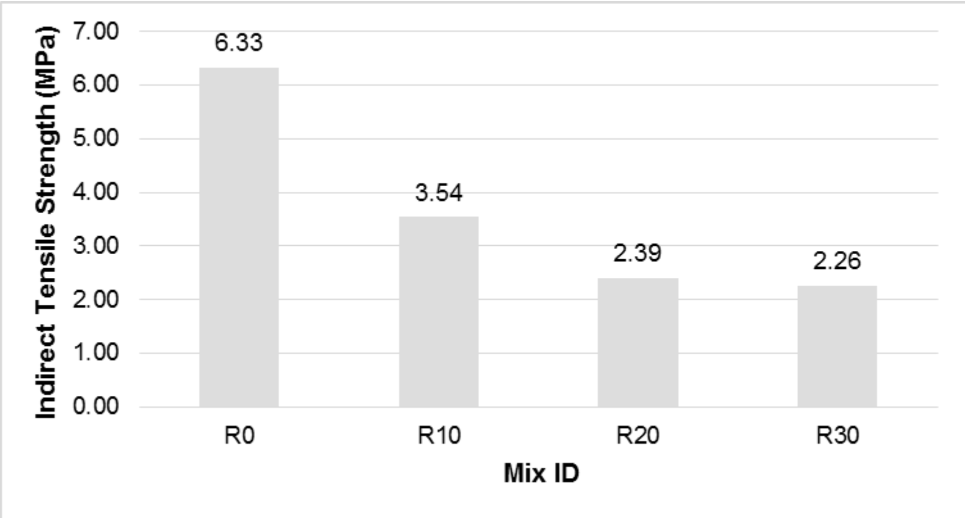

Fig. 6: Indirect tensile strength at 28 days.

Flexural Strength

The variations in flexural strength results obtained at 28 days are shown in Fig. 7. Flexural strength values between 13.05 and 9.45 MPa were obtained. The maximum value 13.05 MPa was observed for the R0 mix, while the minimum value obtained was 9.45 MPa for the R30 mix. The behavior of reduction in strength was similar to that of compressive and indirect tensile strengths but with a lower rate of strength reduction than both of them as the flexural strength decreased with 3.45%, 27.59%, and 27.59% for R10, R20, and R30 mixes respectively. The obtained results are similar to what reported by Thomas and Chandra Gupta [39]. The reduction in strength with increasing the rubber content was expected and in agreement with several studies and might be due to the weak bonding between cement paste and rubber particles [17], [38], [40]. However, some other few studies reported that the flexural strength increase with the increase in the amount of rubber [41–43].

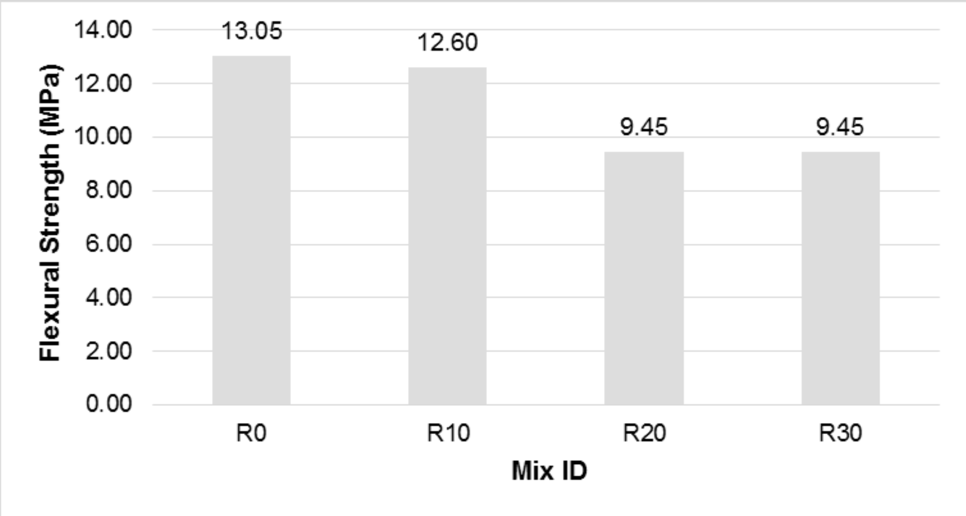

Fig. 7: Flexural strength at 28 days.

Water Absorption

The addition of rubber in concrete influences the water absorption of concrete mixes as shown in Fig. 8. A gradual increase in water absorption is observed with increasing the rubber content. Water absorption for 28 days cured specimens is 1.47% for R30 mix while that for R0 mix is 1.00%. The water absorption increased by 27%, 30%, and 46% for R10, R20, and R30 mixes respectively. Several studies also reported an increase in water absorption with increasing the rubber content [16], [17], [36], [44].

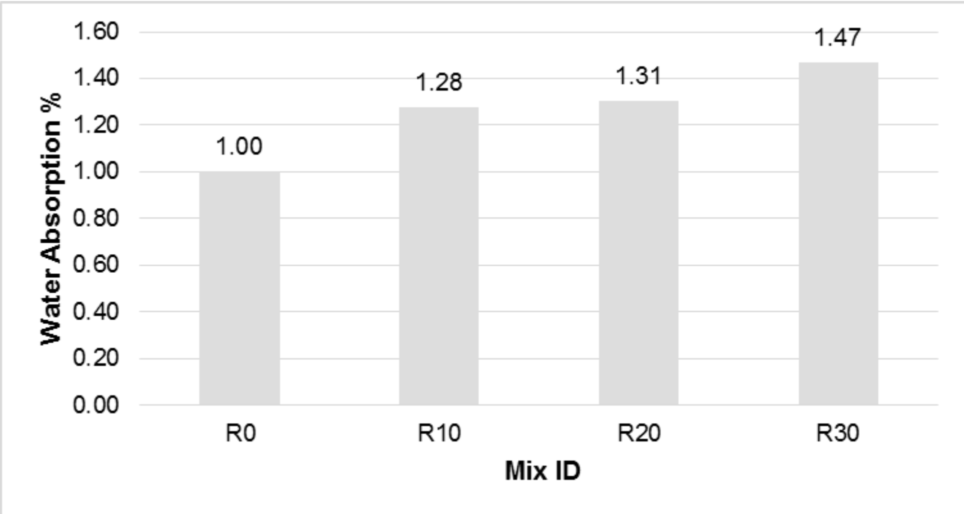

Fig. 8: Water absorption at 28 days.

CONCLUSIONS

This paper presents results of an experimental investigation carried out for evaluating the properties of high strength concrete containing recycled rubber as partial replacement of fine aggregate where crumb rubber was used to partially replace the fine aggregate by 0%, 10%, 20%, and 30% of volume. On the basis of the performed tests, the following conclusions can be drawn:

1. Rubber replacement of up to 10% did not have an effect on slump, however slight reduction in slump of maximum 8.5% was observed for rubber content beyond 10%.
2. The density of rubberized concrete decreased slightly with increasing the rubber content. Mix with 30% rubber replacement decreased by 8.2% compared to the control mix.
3. Compressive strength was found to be decreased with increasing the rubber content at 7 and 28 days. The compressive strength at 28 days for 30% rubber replacement decreased by 44% reaching a compressive strength of 35 Mpa, which opens the possibilities of using rubberized concrete with replacement levels up to 30% in structural elements.
4. Reductions in splitting tensile and flexural strengths were recorded with increasing the rubber content. The losses in tensile and flexural strength were 64.28% and 27.59% respectively for the 30% rubber replacement mix.
5. Water absorption increased with increasing the rubber content with a maximum increase up to 46% for 30% rubber replacement.

FUTURE SCOPE

Studying the Impact resistance, abrasion resistance and the effect of seawater on the properties of rubberized concrete is currently being undertaken by the authors.

REFERENCES

[1] U . S . Tire Manufacturers Association (2018), "2017 U . S . Scrap Tire Management Summary", *https://www.ustires.org*.

[2] Milanez, B. and Bu, T. (2009), "Extended producer responsibility in Brazil : the case of tyre waste", Vol. 17, pp. 608–615.

[3] Pelisser, F., Zavarise, N., Longo, T. A., and Bernardin, A. M. (2011), "Concrete made with recycled tire rubber: Effect of alkaline activation and silica fume addition", *Journal of Cleaner Production*, Vol. 19, no. 6–7, pp. 757–763.

[4] Siddique, R. and Naik, T. R. (2004), "Properties of concrete containing scrap-tire rubber – an overview", Vol. 24, pp. 563–569.

[5] Raffoul, S., Garcia, R., Pilakoutas, K., Guadagnini, M., and Medina, N. F. (2016), "Optimisation of rubberised concrete with high rubber content: An experimental investigation", *Construction and Building Materials*, Vol. 124, pp. 391–404.

[6] Al-Tayeb, M. M., Abu Bakar, B. H., Ismail, H., and Akil, H. M. (2013), "Effect of partial replacement of sand by recycled fine crumb rubber on the performance of hybrid rubberized-normal concrete under impact load: Experiment and simulation", *Journal of Cleaner Production*, Vol. 59, pp. 284–289.

[7] Atahan, A. O. and Yücel, A. Ö. (2012), "Crumb rubber in concrete: Static and dynamic evaluation", *Construction and Building Materials*, Vol. 36, pp. 617–622.

[8] Cheng, Z. and Shi, Z. (2014), "Vibration attenuation properties of periodic rubber concrete panels", *Construction and Building Materials*, Vol. 50, pp. 257–265.

[9] Mohammed, B. S. (2010), "Structural behavior and m – k value of composite slab utilizing concrete containing crumb rubber", *Construction and Building Materials*, Vol. 24, no. 7, pp. 1214–1221.

[10] Mohammed, B. S., Anwar, K. M., Ting, J., Swee, E., Wong, G., and Abdullahi, M. (2012), "Properties of crumb rubber hollow concrete block", *Journal of Cleaner Production*, Vol. 23, no. 1, pp. 57–67.

[11] Montella, G., Calabrese, A., and Serino, G. (2014), "Mechanical characterization of a Tire Derived Material : Experiments , hyperelastic modeling and numerical validation", *Construction and Building Materials*, Vol. 66, pp. 336–347.

[12] Najim, K. B. and Hall, M. R. (2010), "A review of the fresh / hardened properties and applications for plain- (PRC) and self-compacting rubberised concrete (SCRC)", *Construction and Building Materials*, Vol. 24, no. 11, pp. 2043–2051.

[13] Toumi, A., Nguyen, T., and Turatsinze, A. (2013), "Materia ls and Design Debonding of a thin rubberised and fibre-reinforced cement-based repairs : Analytical and experimental study", *Materials and Design*, Vol. 49, pp. 90–95.

[14] Taha, M. M. R., Asce, M., and El-wahab, M. A. A. (2009), "Mechanical , Fracture , and Microstructural Investigations", Vol. 20, no. 10, pp. 640–649.

[15] Moustafa, A. and ElGawady, M. A. (2015), "Mechanical properties of high strength concrete with scrap tire rubber", *Construction and Building Materials*, Vol. 93, pp. 249–256.

[16] Gupta, T., Chaudhary, S., and Sharma, R. K. (2014), "Assessment of mechanical and durability properties of concrete containing waste rubber tire as fine aggregate", *Construction and Building Materials*, Vol. 73, pp. 562–574.

[17] Bisht, K. and Ramana, P. V. (2017), "Evaluation of mechanical and durability properties of crumb rubber concrete", *Construction and Building Materials*, Vol. 155, pp. 811–817.

[18] Aiello, M. A. and Leuzzi, F. (2010), "Waste tyre rubberized concrete: Properties at fresh and hardened state", *Waste Management*, Vol. 30, no. 8–9, pp. 1696–1704.

[19] Xue, J. and Shinozuka, M. (2013), "Rubberized concrete: A green structural material with enhanced energy-dissipation capability", *Construction and Building Materials*, Vol. 42, pp. 196–204.

[20] Gupta, T., Chaudhary, S., and Sharma, R. K. *Mechanical and durability properties of waste rubber fiber concrete with and without silica fume*, Vol. 112. Elsevier Ltd, 2016.

[21] Li, L. J., Tu, G. R., Lan, C., and Liu, F. (2016), "Mechanical characterization of waste-rubber-modified recycled-aggregate concrete", *Journal of Cleaner Production*, Vol. 124, pp. 325–338.

[22] Noaman, A. T., Abu Bakar, B. H., and Akil, H. M. (2016), "Experimental investigation on compression toughness of rubberized steel fibre concrete", *Construction and Building Materials*, Vol. 115, pp. 163–170.

[23] Lv, J., Zhou, T., Du, Q., and Wu, H. (2015), "Effects of rubber particles on mechanical properties of lightweight aggregate concrete", *Construction and Building Materials*, Vol. 91, pp. 145–149.

[24] Holmes, N., Browne, A., and Montague, C. (2014), "Acoustic properties of concrete panels with crumb rubber as a fine aggregate replacement", *Construction and Building Materials*, Vol. 73, pp. 195–204.

[25] Issa, C. A. and Salem, G. (2013), "Utilization of recycled crumb rubber as fine aggregates in concrete mix design", *Construction and Building Materials*, Vol. 42, pp. 48–52.

[26] Khalil, E., Abd-Elmohsen, M., and Anwar, A. M. (2015), "Impact Resistance of Rubberized Self-Compacting Concrete", *Water Science*, Vol. 29, no. 1, pp. 45–53.

[27] ASTM C150 (2002), "Standard Specification for Portland Cement", *Annual Book of ASTM Standards*.

[28] ASTM C143 / C143M (2001), "Standard Test Method for Slump of Hydraulic-Cement Concrete", *Annual Book of ASTM Standards*.

[29] BS EN 12390-3 "Testing hardened concrete. Compressive strength of test". 2009.

[30] ASTM C496 / C496M "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens", *Annual Book of ASTM Standards*.

[31] ASTM C293 / C293M "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Piont Loading)", *Annual Book of ASTM Standards*.

[32] ASTM C642-97 (1997), "Standard Test Method for Density , Absorption , and Voids in Hardened Concrete", *Annual Book of ASTM Standards*.

[33] Youssf, O., Elgawady, M. A., Mills, J. E., and Ma, X. (2014), "An experimental

investigation of crumb rubber concrete confined by fibre reinforced polymer tubes", *Construction and Building Materials*, Vol. 53, pp. 522–532.

[34] Feng, W., Liu, F., Yang, F., Li, L., and Jing, L. (2018), "Experimental study on dynamic split tensile properties of rubber concrete", *Construction and Building Materials*, Vol. 165, pp. 675–687.

[35] Khatib, Z. K. and Bayomy, F. M. (1999), "Rubberized Portland Cement Concrete", *Journal of Materials in Civil Engineering*, Vol. 11, no. 03, pp. 206–213.

[36] Ganjian, E., Khorami, M., and Maghsoudi, A. A. (2009), "Scrap-tyre-rubber replacement for aggregate and filler in concrete", *Construction and Building Materials*, Vol. 23, no. 5, pp. 1828–1836.

[37] Girskas, G. and Nagrockienė, D. (2017), "Crushed rubber waste impact of concrete basic properties", *Construction and Building Materials*, Vol. 140, pp. 36–42.

[38] Sofi, A. (2017), "Effect of waste tyre rubber on mechanical and durability properties of concrete - A review", *Ain Shams Engineering Journal*, pp. 1–10.

[39] Thomas, B. S. and Chandra Gupta, R. (2016), "Properties of high strength concrete containing scrap tire rubber", *Journal of Cleaner Production*, Vol. 113, pp. 86–92.

[40] Hilal, N. N. (2017), "Hardened properties of self-compacting concrete with different crumb rubber size and content", *International Journal of Sustainable Built Environment*, Vol. 6, no. 1, pp. 191–206.

[41] Al-Akhras, N. M. and Smadi, M. M. (2004), "Properties of tire rubber ash mortar", *Cement and Concrete Composites*, Vol. 26, no. 7, pp. 821–826.

[42] Segre, N. and Joekes, I. (2000), "Use of tire rubber particles as addition to cement paste", *Cement and Concrete Research*, Vol. 30, no. 9, pp. 1421–1425.

[43] Ganesan, N., Bharati Raj, J., and Shashikala, A. P. (2013), "Flexural fatigue behavior of self compacting rubberized concrete", *Construction and Building Materials*, Vol. 44, pp. 7–14.

[44] Onuaguluchi, O. and Panesar, D. K. (2014), "Hardened properties of concrete mixtures containing pre-coated crumb rubber and silica fume", *Journal of Cleaner Production*, Vol. 82, pp. 125–131.