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Research Note

Influence of waste tyre fibers on strength, abrasion resistance and carbonation of concrete

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Abstract. Waste tire is increasingly becoming an environmental, health, and aesthetic problem. Used tires are of category of waste whose recycling is extensively difficult because of highly complex structure, the diverse composition of the raw material. Concrete is a versatile construction material due to easy fabrication, locally available material, and high mechanical strength. The use of waste tires as a concrete additive is a possible disposal solution. Rubberized concrete may thus contribute in sustainable construction by use of industrial waste, minimizing the natural resources and producing a more efficient material. In this paper experimental investigation is carried out to evaluate the flexural strength, compressive strength, abrasion resistance and carbonation of concrete containing waste rubber tire fibers as partial replacement of fine aggregates. Fibers from mechanical grinding of used rubber tire have been incorporated with three water-binder ratio and six levels of rubber fibers contents (0-25%). It has also been shown that with increasing replacement level of rubber fibers, flexural strength and abrasion resistance is increased. Further, it has been also observed that compressive strength (up to 90 days) and carbonation depth change with the increasing of the replacement level of waste rubber content.

1. Introduction

Large quantities of waste rubber tire are produced every year. Disposal of waste tire is generally carried out by two methods: stockpiling and land filling. Stockpiles are unsightly and also dangerous from the point of fire hazard. Landfilling of waste tires causes problems due to their uneven settlement and tendency to raise the surface. Recycling of waste tire is another option of disposal and is extensively difficult because of high complex configuration of the ingredient materials.

In the present era, concrete is a versatile construction material due to easy fabrication, locally available material and high mechanical strength. Waste can be used as admixtures in the concrete, so that natural sources are saved and simultaneously the environment is protected from waste deposits [1,2]. Therefore, waste rubber concrete can contribute in sustainable construction by use of industrial waste minimizing the natural resources and production of a more efficient material.

Workability of concrete is influenced by the inclusion of crumb rubber aggregates. Olivares and Barluenga [1] has shown that workability of fresh concretes with crumb rubber fibers decreases gradually with increasing crumb rubber percentage as partial replacement of aggregates. Similar observations of decrease in workability have been reported in the liter-

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ature [2-5]. However, Aiello and Leuzzi [6] and Wang et al. [7] reported that workability of fresh concrete could slightly be improved by the use of waste rubber tire particles as the partial substitution of aggregate.

Systematic reduction in compressive strength has been observed with the increase in rubber content [3,5,8-12]. Sohrabi and Karbalaie [13] carried out an experimental study using rubberized concrete with consideration of silica fume also. It has been shown that addition of silica fume increases the compressive strength of the rubberized concrete.

Systematic studies have also been carried out at the varied replacement levels by Al-Tayeb et al. [14], Yung et al. [15] and Wang et al. [7]. These studies have been carried out at constant w/c ratio and it was shown that compressive strength decreases as the amount of rubber particle replacement increases. Experimental studies carried out by Xue and Shinozuka [16], Li et al. [17] and Pacheco-Torgal et al. [18] show that compressive strength of the rubberized concrete is decreased when the amount of the rubber crumb is increased as coarse aggregate.

It has been reported in the literature that flexural strength is increased with the increase of crumb rubber content [11,19,20-22]. However, few studies [6,12,23] show that there is a reduction in flexural strength with increase of the replacement level of rubber content.

Deterioration of concrete may take place due to abrasion caused by various exposures (skidding, rubbing or sliding of object) on the concrete surface. Sukontasukkul and Chaikaew [24] carried out a study on abrasion resistance of concrete block containing crumb rubber. It was reported that the rubber crumb concrete block exhibited less abrasion resistance than the reference concrete block. Ozbay et al. [5] also carried out an experimental study and reported that the depth of wear and mass loss increased with an increase in rubber particles.

The study carried out by Bravo and Brito [25] on carbonation resistance of waste rubber tyre concrete indicated that carbonation resistance is significantly affected by the incorporation of waste rubber particles in concrete. In this study, the effect of w/c ratio on carbonation resistance has not been considered.

In the above studies, the effect of inclusion of waste rubber tire was not evaluated with varying w/c ratios. Few studies are also available about rubber fibers as a partial replacement of fine aggregates. Therefore, there is a need to carry out systematic experimental study to evaluate various properties of concrete incorporating rubber fibers with varying w/c ratios and different replacement level of fine aggregate by waste rubber fibers.

In the present study, workability, compressive strength, flexural strength and water absorption of rubber fiber concrete are evaluated for varying w/c ratio and percentage of partial replacement of fine aggregates by rubber fibers. Eighteen different concrete mixes are cast with varied percentages of rubber fibers for 0.35, 0.45 and 0.55 w/c ratios. In this study, partial replacement of fine aggregate by rubber fibers ranges from 0% to 25% in the increment of 5%. Workability, compressive strength, flexural strength water absorption, abrasion and carbonation of these specimens are tested as per codal guidelines. This systematic study will show the feasibility of rubber fibers to be used in concrete.

2. Experimental studies

Details of the carried out experimental studies are divided in three parts, namely: material, mix proportions and test methods.

2.1. Material

Ordinary Portland cement was used for the concrete mixes in this study. Rubber fibres in the mixes were used as a partial replacement of fine aggregates. The rubber fibres (2 to 5 mm wide) maximum 20 mm in length (aspect ratios of 4 to 10) were used. Fine aggregates (natural sand) of fineness modulus 2.84 and coarse aggregates (crushed gravel) of maximum size of 12 mm were used in this work. Physical properties of various materials are shown in Table 1. High Range Water Reducer (HRWR) "Glanium Sky 777" of BASF was used as admixture to obtain the desired workability.

2.2. Mix proportions

Eighteen concrete mixes were prepared using water cement ratio of 0.35, 0.45 and 0.55 with the partial replacement of fine aggregate by rubber fiber ranging from 0% to 25% in the increment of 5%. These mixes were first dry-mixed for 2-3 minutes in the mixer. To maintain the workability and the uniformity of the mixes, the amount of super-plasticizer (HRWR) used varies percentage by the weight of the cement. When

Table 1. Physical properties of cement, aggregates and rubber powder.

Properties	Ordinary Portland cement	Coarse aggregate	Fine aggregates	Rubber fibers
Specific gravity	3.12	2.59	2.56	1.07
Water absorption	-	0.5%	0.5%	-

Table 2. Concrete mix proportion (per Cum) with rubber fibers.

Mix no.	Cement (kg)	Fine aggregate (kg)	10 mm coarse aggregate (kg)	20 mm coarse aggregate (kg)	Rubber fibers* (kg)	Water (kg)	HRWR (%)	Compaction factor	Slump (mm)
R1	364	764	562.18	562.18	0	127.4	2.1%	0.9	72
R2	364	726	562.18	562.18	15.87	127.4	2.0%	0.91	74
R3	364	688	562.18	562.18	31.59	127.4	2.0%	0.91	74
R4	364	649.74	562.18	562.18	47.46	127.4	2.1%	0.91	73
R5	364	611.52	562.18	562.18	63.48	127.4	2.2%	0.91	74
R6	364	573.3	562.18	562.18	80.08	127.4	2.4%	0.91	72
R7	364	764	562.18	562.18	0	163.8	0.5%	0.92	76
R8	364	726	562.18	562.18	15.87	163.8	0.6%	0.92	75
R9	364	688	562.18	562.18	31.59	163.8	0.6%	0.92	77
R10	364	649.74	562.18	562.18	47.46	163.8	0.6%	0.92	76
R11	364	611.52	562.18	562.18	63.48	163.8	0.6%	0.92	75
R12	364	573.3	562.18	562.18	80.08	163.8	0.6%	0.92	75
R13	364	764	562.18	562.18	0	200.2	0%	0.92	79
R14	364	726	562.18	562.18	15.87	200.2	0%	0.92	79
R15	364	688	562.18	562.18	31.59	200.2	0%	0.92	78
R16	364	649.74	562.18	562.18	47.46	200.2	0%	0.92	79
R17	364	611.52	562.18	562.18	63.48	200.2	0%	0.92	77
R18	364	573.3	562.18	562.18	80.08	200.2	0%	0.92	78

* Rubber fibers were replaced in the increment of 5%.

the mix showed desired workability and viscosity for uniform fiber distribution, the mixture was placed in a mould and vibrated on table vibrator. The specimen was covered with plastic sheets and stored at room temperature for 24 h prior to de-moulding. The details of concrete mix with observed workability in term of compaction factor are shown in Table 2.

2.3. Test methods

Properties of a hardened concretes were measured by conducting compression strength, flexural strength water absorption, abrasion and carbonation tests. Compressive strength of the rubber fiber concrete were performed on a hydraulic compression testing machine at 7 days, 28 days and 90 days as shown in Figure 1.

Flexural strength was determined for three specimens of each mix. The flexural strength test was performed with four point loading configuration on the universal testing machine of 200 kN capacity at 7 and 28 days as shown in Figure 2.

Water absorption test was performed as per BIS: 1124 [26] and BS 1881-122 [27]. Three oven drying specimens were placed for 24 hours in water bath. The initial weight and final weight were recorded and the percentage of water absorption was determined as per the guidelines of the codes.

Accelerated carbonation test was conducted on 28-day cured concrete prisms (50×50×100 mm). Specimens were dried in an oven at 60°C for 14 days until constant weight was achieved. Two coats of epoxy based paint were applied on the longitudinal sides of the prism to ensure uni-axial CO_2 penetration from the top and bottom face only. The specimens were then kept in carbonation chamber (Figure 3) at 5% controlled CO_2 concentration with preset relative

Figure 1. Compression test.

humidity (50±5%) and temperature (27±1°C). After desired CO_2 exposure (14, 21, 28, 35, 42, 56 and 90 days), three prisms from each representative concrete mix were taken out. The depth of carbonation was measured after splitting the specimens (Figure 4), as per RILEM guidelines [28], and spraying phenolphthalein indicator (1% phenolphthalein in solution of 70% ethyl alcohol). The depths of carbonation at the top and bottom face of the specimen were recorded for each of three specimens.

Figure 2. Flexural test.

Figure 3. Carbonation chamber.

Figure 4. Splitting of specimens.

3. Results and discussion

3.1. Workability

Workability of the concrete is the main factor for acceptance of any waste material of its possible use in the concrete. In this study, a suitable percentage of admixture HRWR was used to obtain a compaction factor of 0.9 or more for the concrete mixes with rubber powder or rubber fibers contents. Measured compaction factor and percentage HRWR used for each mix are shown in Table 2.

It can be seen from Table 2 that for each w/c ratio, requirement of percentage of HRWR does not vary significantly. At any w/c ratio, the insignificant increase in percentage of HRWR shows that the workability of concrete is not affected by adding rubber fibers.

3.2. Compressive strength

The compressive strength of the waste rubber tire fiber concrete at 7 days for three w/c ratios has been shown in Figure 5. It is seen from the figure that compressive strength decreased with the increase of the replacement level. Figures 6 and 7 show the compressive strength of rubber fiber concrete at 28 and 90 days. It can be seen that reduction in compressive strength is also observed for three w/c ratios as in the case of 7 days. The reduction in compressive strength may be due to the lower strength of the substitute material as compared to original material. Similar reduction has been observed by Guneyisi et al. [8], Taha et al. [9], Khaloo et al. [10], Yilmaz et al. [11] and Ganjian et al. [12]. Compressive strength of rubber fiber concrete (28 days) is 23.6 N/mm^2 for 25% replacement level at 0.45 w/c ratio whereas for the same w/c

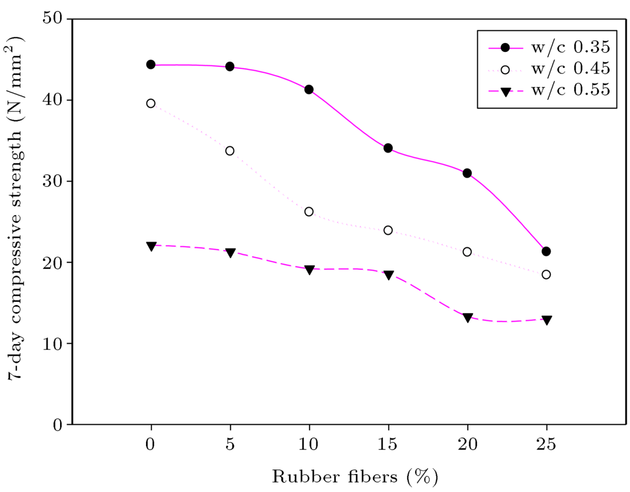

Figure 5. 7-day compressive strength of rubber fibers.

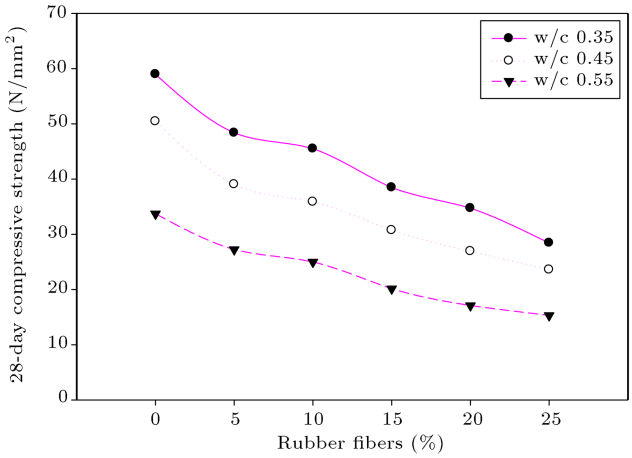

Figure 6. 28-day compressive strength of rubber fibers.

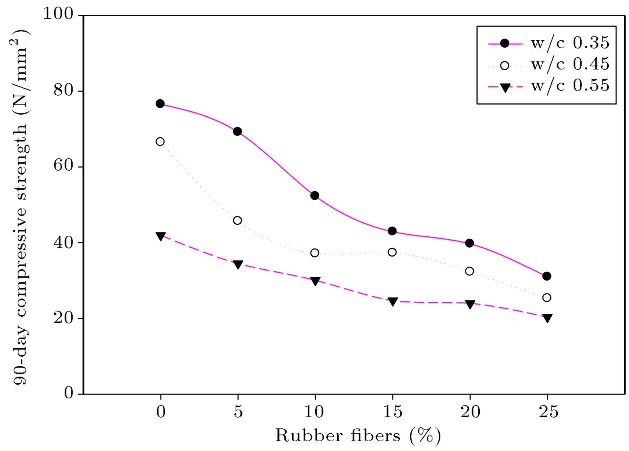

Figure 7. 90-day compressive strength of rubber fibers.

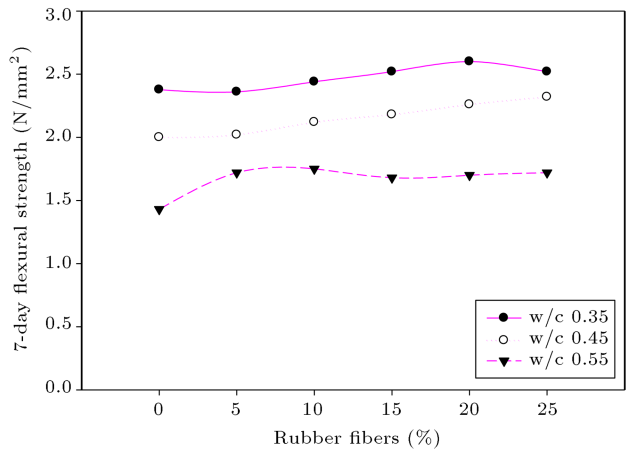

Figure 8. 7-day flexural strength of rubber fibers.

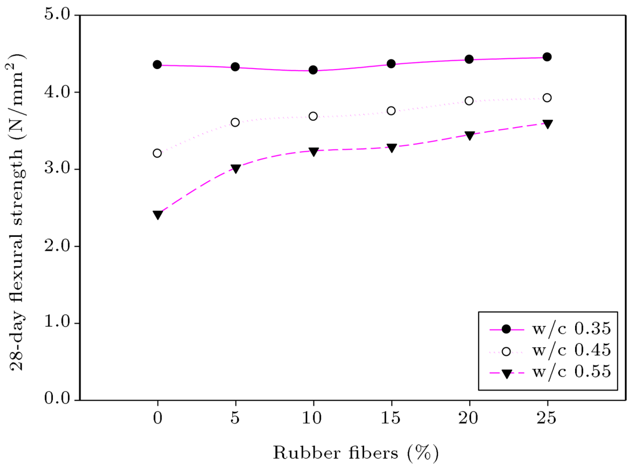

Figure 9. 28-day flexural strength of rubber fiber concrete.

ratio, the compressive strength is 50.4 N/mm^2 for 0% replacement level.

Compressive strength of rubber fiber concrete is also affected by water cement ratio as in the normal concrete. It can be seen from Figure 6 that compressive strength of waste rubber tire fiber concrete (28 days) is 20.1 N/mm^2 at 0.55 w/c for 15% replacement level ratio, whereas at the same replacement level, the compressive strength is 38.5 N/mm^2 for 0.35 w/c ratio.

3.3. Flexural strength

Flexural strength of waste rubber fiber concrete at 7 and 28 days for varying w/c ratio has been presented in Figures 8 and 9. It is seen that the flexural strength of rubber fibers concrete is increased with the increment of rubber fiber content. Increase in flexural strength was dependent on the shape of rubber fibers. Since long fibers of 20 mm were used in the present work, it resulted in increase of pulling resistance. Similar observations have been reported earlier by Segre et al. [17], Wu et al. [18], Al-Akhras et al. [19] and Ganesan et al. [20]. Flexural strength of rubber fiber concrete (28 days) is 3.92 N/mm^2 for 25% replacement level at 0.45 w/c ratio whereas for the same w/c ratio, the flexural strength is 3.2 N/mm^2 for 0% replacement level.

Flexural strength of rubber fiber concrete is also affected by water cement ratio as in the normal concrete. It can be seen from Figure 9 that flexural strength of waste rubber tire fiber concrete (28 days) is 3.29 N/mm^2 at 0.55 w/c for 15% replacement level ratio, whereas at the same replacement level, the flexural strength is 4.36 N/mm^2 for 0.35 w/c ratio.

3.4. Water absorption

Figure 10 shows the water absorption of rubber fibers concrete for w/c ratios of 0.35, 0.45 and 0.55. It is observed that the percentage of water absorption of rubber fibers concrete increases with the incremental percentage of rubber fiber for 0.35 and 0.45 w/c ratios up to 15% replacement, whereas for the 0.55 w/c ratios, reduction in water absorption is observed. Water absorption of rubber fiber concrete (28 days) is 1.07 for 25% replacement level at 0.45 w/c ratio, whereas

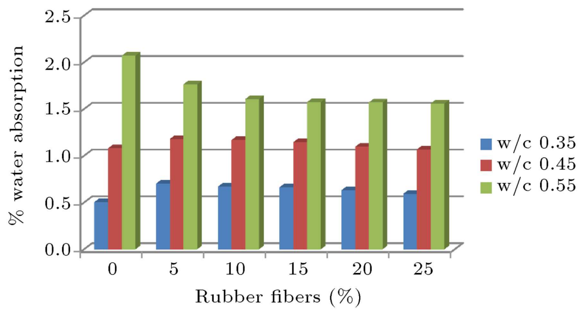

Figure 10. Water absorption of rubber fiber concrete.

for the same w/c ratio, the water absorption is 1.08 for 0% replacement level.

For low w/c ratio mixes (w/c of 0.35 and 0.45), the porosity due to gap between rubber aggregate and cement matrix, may be responsible for slightly higher water absorption in rubber concrete as compared to normal concrete. However, in the case of higher w/c ratio mixes (w/c of 0.55), the reduction of gaps between rubber aggregate and cement matrix might be leading to lower water absorption in rubber fiber concrete as compared to the normal concrete.

Water absorption of rubber fiber concrete is also affected by water cement ratio as in the normal concrete. It can be seen from Figure 10 that water absorption of waste rubber tire fiber concrete (28 days) is 1.57% at 0.55 w/c for 15% replacement level ratio, whereas at the same replacement level, the water absorption is 0.66% for 0.35 w/c ratio.

3.5. Abrasion

The variation in abrasion resistance of rubber fibers concrete in term of depth of wear (mm) is shown in Figure 11 for w/c ratio 0.35, 0.45 and 0.55. It is observed that the depth of wear of rubber fibers concrete decreases with the increase of percentage of rubber fibers. The increase in wear resistance may be due to (i) smooth surface achieved in rubber concrete, (ii) presence of silica as filler in rubber tyres, which is responsible to increase abrasion resistance. Depth of wear is 1.17 mm for control mix with w/c ratio of 0.45 whereas depth of wear reduces to 0.72 mm even for higher replacement level of rubber fibers (25%) mix at the same w/c ratio.

Depth of wear is decreased as w/c ratio reduces from 0.55 to 0.35 for the varying replacement level of rubber fibers (0% to 25%). For 15% replacement level, depth of wear is 1.15 mm for 0.55 w/c ratio whereas depth of wear is decreased to 0.92 mm for 0.35 w/c ratio. It can also be seen from the results for varied w/c ratio and replacement level that the maximum depth of wear observed is less than permissible limits [29].

3.6. Carbonation

The influence of rubber fibers on carbonation of concrete mixes with varied w/c and percentage of rubber fibers has been studied. The depth of carbonation for a concrete mix with 0.35 w/c ratio and varied rubber fibers ratios are shown in Figure 12 for CO_2 exposure duration of 14, 21, 28, 35, 42, 56 and 90 days. Similarly Figures 13 and 14 show depth of carbonation for a concrete mix with 0.45 and 0.55 w/c ratios, respectively.

It can be seen from the figures that the carbonation depth for chosen replacement level increases for 0.35, 0.45 and 0.55 w/c ratios. It can also be observed that carbonation depth increases with the increase of CO_2 exposure duration. The increase in carbonation depth may be due to increase in permeability. The increase in permeability may be due to reduction in bonding between particles in the concrete mixture as reported by Ganjian et al. [12]. The carbonation depth of 8.35 mm has been observed for 0.35 w/c ratio with 25% replacement level whereas at the same replacement level, carbonation depth of 11.92 mm was observed for 0.55 w/c ratio. The carried out experimental studies

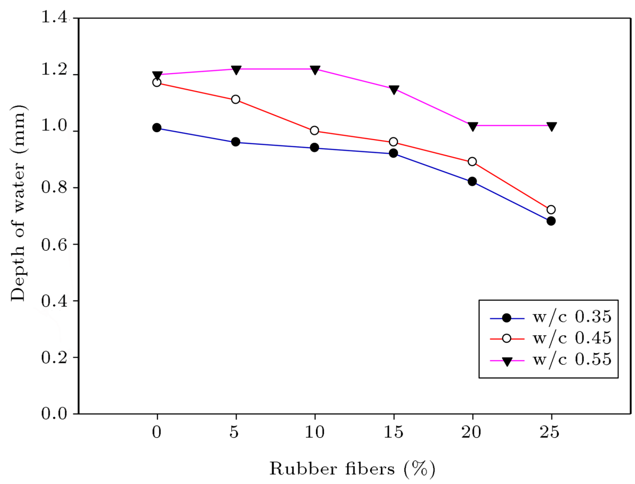

Figure 11. Depth of wear of the rubber fiber concrete.

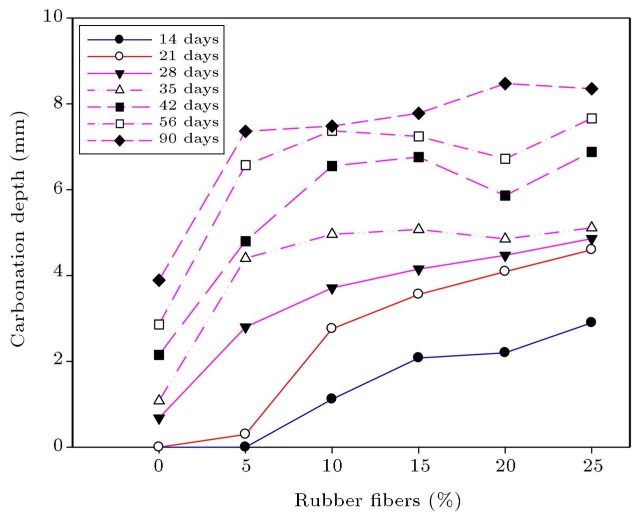

Figure 12. Carbonation depth for w/c ratio of 0.35.

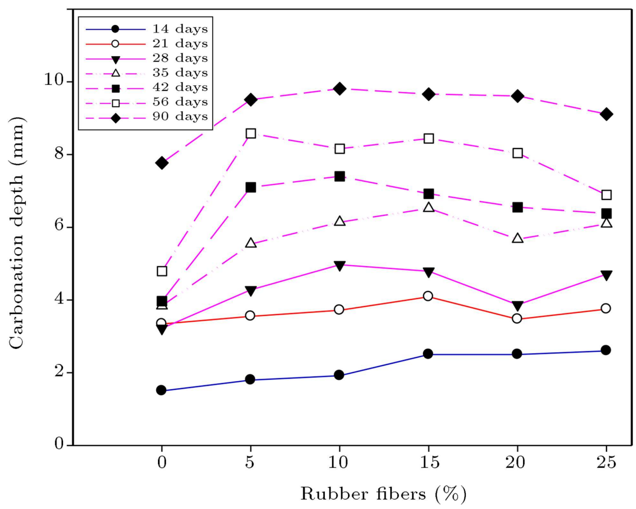

Figure 13. Carbonation depth for w/c ratio of 0.45.

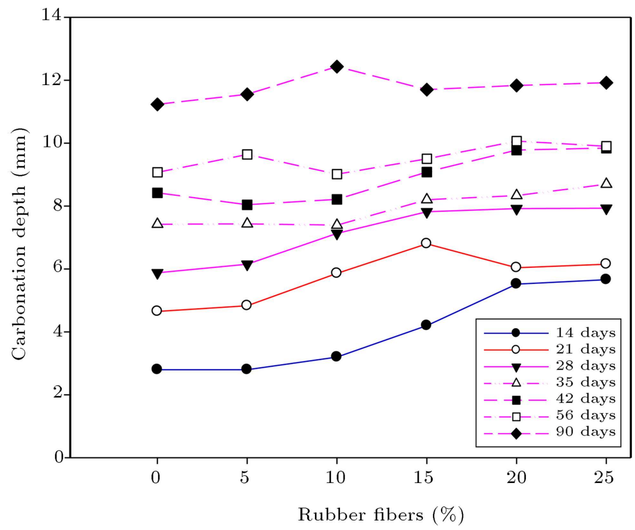

Figure 14. Carbonation depth for w/c ratio of 0.55.

show that the carbonation depth observed is less than minimum cover required (15 mm) for large replacement level (25%) and high CO_2 concentration (5% for 90 days).

4. Conclusions

The objective of this study was to demonstrate the suitability of waste rubber fibers in concrete through experimental investigation. In the present study, rubber tire particles in form of rubber fibers were used to partially replace fine aggregate by rubber fibers. Based on the test result and discussions, the following conclusions are drawn:

1. Workability of rubber fiber concrete is not affected by the addition of rubber fibers.
2. Compressive strength (up to 90 days) of waste rubber tire fiber concrete is decreased with the increase of the replacement level. At 25% replacement level, the compressive strength of rubber fiber concrete (28 days) is 23.6 N/mm^2 at 0.45 w/c ratio whereas for the same w/c ratio, the compressive strength is 50.4 N/mm^2 for 0% replacement level.
3. Flexural strength of rubber fibers concrete is increased with the increment of rubber fiber content. At 25% replacement level, the flexural strength of rubber fiber concrete is (28 days) 3.92 N/mm^2 at 0.45 w/c ratio whereas for the same w/c ratio, the flexural strength is 3.2 N/mm^2 for 0% replacement level.
4. Percentage of water absorption of rubber fiber concrete increases with the incremental percentage of rubber powder for 0.35 and 0.45 w/c ratios up to 15% replacement, whereas for the 0.55 w/c ratio, reduction in water absorption is observed.
5. Water absorption of waste rubber tire fiber concrete (28 days) is increased by 0.9% when w/c ratio is increased from 0.35 to 0.55 for 15% replacement level ratio.
6. The depth of wear of rubber fibers concrete decreases with the increase of percentage of rubber fibers. Though, depth of wear is decreased as w/c ratio reduces for the varying replacement level of rubber fibers, even for higher replacement level and maximum w/c ratio, the depth of wear is less than permissible limit.
7. Carbonation depth increases with the increase of CO_2 exposure duration. It is also clear from the studies carried out that the maximum observed carbonation depth is less than minimum cover required (15 mm) for large replacement level (25%) and high CO_2 concentration (5% for 90 days).

Compressive strength (up to 90 days) is decreased, while water absorption and carbonation depth are increased with the increase in replacement level; this may be attributed to weak bond between rubber particles and cement paste. Flexural strength and abrasion resistance is increased with the increase in replacement level and it may be due to long fibers.

Although, the outcome of the study has established the scope for utilization of waste rubber tyre as fine aggregate in concrete, toughness of the rubberized concrete may be considered for future investigations.

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