Properties of different types of concrete containing waste tires rubber- a review

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Abstract. According to Rubber Manufacturer's Association, about 270 million waste tires are produced in United States each year. Also about 300 million scrap tires are stockpiled at the United States. Significant development in transportation and an enormous increment in the quantity of vehicles create various issues, for example, environmental contamination. Many research studies utilized scrap tires rubber in different types of concrete mixes such as normal concrete and self-compacting concrete to produce rubberized concrete and self-compacting rubberized concrete.

This review paper presents important results and conclusions that obtained from previous studies which used waste tires rubber as aggregates (fine and coarse aggregates). The results showed that the mechanical properties (compressive strength, splitting tensile strength, and flexural strength) decreased by adding rubber particles. Also the fresh properties negatively affected as rubber contain was increased but stay in the acceptable limits. The failure mode of concrete change from brittle to ductile by incorporating scrap tires rubber in concrete.

1. Introduction

The scrap tires rubber non-degradable by nature, so they are left as stockpiles. These stockpiles of tires rubber causing a great health and environmental risk worldwide. Tire fires can happen easily, burning for a long time (months) and creating contamination in the air and ground. Recycling helps to reduce the number of tires in storage. So many researches focused on the use of tires rubber as aggregates to produce sustainable concrete [1]. The use of rubber aggregates in different shapes and sizes saves natural resources, helps to maintain a clean environment, reduces unite weight of concrete, changes behavior of concrete from brittle to ductile, enhances the absorption of energy, and increases resilience [2]. Scrap tires can be used for manufacturing of Portland cement (used as a fuel). In addition, it can be used to produce crumb rubber modifier- recycled asphalt pavement (CRM-RAP) [3, 4]. Fine and coarse aggregate is replaced by waste tires rubber. Waste tires rubber is the main waste materials used to obtain rubberized concrete.

2. Classification of waste tires rubber

The cracker mill process tears apart or reduces the size of waste tires rubber by passing the tires between rotating corrugated steel drums. By using this process, particles in different shapes and sizes are produced. Table 1 and figure 1 show the types of waste tires rubber [5].
Rubberized concrete (RC)

It is a new structural materials using recycled tires rubber as partial replacement for aggregates (fine and coarse aggregates) in a Portland cement concrete. The percentages of rubber replacement usually ranges from 5% to 25% by weight or volume of aggregates and sometimes reach to 50% and 75%. The percentages more than 25% lead to more negative effect on properties of concrete [6, 7].

3.1. Fresh and hardened properties

Güneyisi et al. (2004), [8] two types of waste tires rubber (chip and crumb rubber) were used instead of coarse and fine aggregates, respectively. The percentages of rubber ranging from 2.5% to 50% by volume of total aggregates. Silica fume was used instead of cement with percentages varying from 5% to 20%. The results showed that the strength decreased as rubber content increased. This reduction in strength can be eliminated by adding silica fume.

Ghaly and Cahill (2005), [9] in their studies fine aggregate (sand) was replaced by crumb rubber. The percentage of crumb rubber was 5%, 10%, and 15% by volume of mixture with water cement ratio 0.47. The test of compressive strength was carried out in 7 and 28 days. The results showed that the compressive strength decreased about 18.9%, 26.1%, and 56.8% in 7 days and about 25.9%, 47.5%, and 59.1% in 28 days when the rubber replacement was 5%, 10%, and 15%, respectively.
Aiello and Leuzzi (2010), [10] used chip tire rubber to replace coarse aggregates with size from 10mm to 25mm and plasticizer about 1% by weight of cement. The percentage of chip rubber was 25.5%, 50.5%, and 75.5% by volume of coarse aggregate. They observed that the workability increased as a chip tire content increased. The results also showed that the compressive strength decreased as rubber percentage increased. The diminution in compressive strength was 47.8%, 54.4, and 62.3% when the rubber replacement was 25.5%, 50.5%, and 75.5%, respectively.

Ganjian et al. (2012), [5] in their studies coarse aggregate was replaced by chip rubber with percentage 5%, 7.5%, and 10% by weight of coarse aggregate. The results displayed that the compressive strength, splitting tensile strength, and modulus of elasticity decreased with increased chip rubber content. The diminution in compressive was about 10% and 23% when the replacement of rubber was 7.5% and 10%. The reduction in modulus of elasticity and splitting tensile strength was about 17%, 24%, and 25% and about 30%, 40%, and 60%, respectively, when the rubber replacement was 5%, 7.5%, and 10%.

Antil (2014), [6] investigated the effects of utilizing crumb rubber as sand in various percentages of replacement (0%, 5%, 10%, 15% and 20%) (by volume). They observed that concrete containing higher proportion of tiers rubber has high toughness. The slump value of concrete increased about 1.08%, with the crumb rubber replacement of 10%. The results also showed the splitting tensile strength, compressive strength, and modulus of rupture of the concrete decreased about 30%, 37%, and 31%, respectively, when 20% fine aggregate was replaced by rubber (crumb rubber).

Ali and Saravanan (2015), [7] in their studies sand (fine aggregate) was replaced by a single gradation of crumb rubber (0.9 mm) varying from 5% to 20% by weight of fine aggregate. The test results demonstrated that the value of slump decreased with the increase in rubber content. The test results also showed that the addition of rubber aggregate led to a decrease in compressive strength and splitting tensile strength of concrete when compared with the reference mix. The reduction in compressive and splitting tensile strength were 29.5% and 60.8% respectively at 28 days of curing (20% replacement by weight of fine aggregate). The increasing in modulus of rupture (flexural strength) was obtained with rubber replaces 10% of the fine aggregate.

Khorami and Ganjian (2015), [11] studied the mechanical properties such as flexural strength, compressive strength, and splitting tensile strength by replacing coarse aggregate with chip rubber (0, 5, 7 and 9%) by weight of gravel. The results displayed that the values of compressive strength increased about 5% with percentage of rubber 5%. The compressive strength values decreased about 10% and 23% with rubber replacement 7% and 9% when compared with the control mix. The reduction in tensile strength was observed up to 7% replacement. Flexural strength did not significantly affect with the rubber percentage of 5%.

Bhatt et al. (2017), [12] used crumb rubber as a sand replacement with percentage 0%, 2.5%, 5%, 7.5% and 10% by weight of fine aggregate. They observed that the percentage of crumb rubber about 10% exhibited a linear response between the crumb rubber increasing and the compressive strength. The flexural strength comes optimum when 5% of crumb rubber replaced by fine aggregate.

4. Self-compacting rubberized concrete (SCRC)
Self-compacting concrete (SCC) differs from the ordinary concrete that the fresh properties (flow ability, ability of passing, and resistance to segregation) must be checked to be classified as a self-compacting concrete. The hardened properties are similar. European guideline (EFNARC 2005) [13] has developed several different tests to obtain the three fresh properties of self-compacting concrete. The tests of SCC according to EFNARC 2005 are listed in table 2.
Self-Compacting Rubberized Concrete (SCRC) is a kind of self-compacting concrete (SCC) with the partial substitution of aggregates (fine and coarse aggregates) by rubber particles made from the scrap tires rubber. The studies about SCRC still limited because adding waste tires rubber to the concrete mixtures exhibits a decrease in strength. On the other hand, SCRC possesses several benefits such as the ability to absorb plastic energy, change failure mode from brittle to ductile, vibration absorption, and acceptable workability. SCRC considered eco-friendly and cheap concrete [14].

4.1. Fresh and hardened properties
Bignozzi and Sandrolini (2006), [15] investigated the properties of self-compacting concrete (SCC) containing ground rubber instead of fine aggregate. The rubber percentages was 0%, 22.2%, and 33.3% by volume of fine aggregate. They observed that the value of slump flow did not affect by adding rubber particles for both percentages. The value of J ring test also did not effected when the rubber percentages was 22.2% but increased with the 33.3%. The results also showed that the compressive strength decreased as rubber contain increased.

Topçu and Bilir (2009), [16] in their studies the aggregates was replaced by rubber particles with rubber contents of 180, 160, and 120 kg/m³ by weight in self-compacting concrete. The results showed that the slump flow value slightly increased as rubber content increased by adding chemical admixtures. The value of slump flow ranging from 680mm to 800mm. The value of V-funnel falls above or under acceptance criteria of European guideline. The time of V-funnel test ranging from 4.4 to 15.3 sec. The compressive strength decreased by adding rubber particles.

Najim and Hall (2012), [17] investigated the fresh and hardened properties of SCC by utilizing crumb rubber (2mm-6mm size) instead of fine aggregate, coarse aggregate, and both them. The rubber replacement was 15, 10, and 5% by weight. They observed that the best results of compressive strength can be obtained from FCR (fine and coarse aggregates replacement). The flexural strength decreased about 12% by utilizing 5% waste tires rubber (for all types of mixes). The reduction in flexural strength was 40% by using 15% waste tires rubber (for all types of mixes). For splitting tensile strength, the results observed that the splitting tensile strength by using rubber instead of coarse aggregates gives higher splitting tensile strength than other mixes with rubber replacement 5%.

| Table 2. Tests of SCC |
|-----------------------|
| Characteristic        | Test Method   | Measured value |
| Flowability/filling ability | Slump flow | Total spread |
|                       | Kajima box   | Visual filling |
| Viscosity/flowability | T₅₀₀         | Flow time |
|                       | V-funnel     | Flow time |
|                       | O-funnel     | Flow time |
|                       | Orimet       | Flow time |
| Passing ability       | L-box        | Passing ratio |
|                       | U-box        | Height difference |
|                       | J-ring       | Step height, total flow |
|                       | Kajima box   | Visual passing ability |
| Segregation resistance| Penetration  | Depth |
|                       | Sieve segregation | Percent laitance |
|                       | Settlement column | Segregation |
Ismail and Hassan (2015), [18] used crumb rubber as a fine aggregate. The rubber replacement was 0, 5, 10, and 15% by weight of fine aggregate. The results showed that the slump flow diameter decreased from 700mm for SCC to 675mm for SCC containing 15% rubber particles. L-box ratio decreased from 0.89 to 0.75 and time of V-funnel increased from 6.39sec to 8.75sec. The results also showed that the compressive strength and splitting tensile strength decreased about 30%, 16%, and 14% and about 31%, 24%, and 16% respectively by utilizing 15%, 10%, and 5% rubber replacement.

Güneyisi et al. (2016), [19] utilized crumb rubber and chips rubber instead of fine aggregate and coarse aggregate in self-compacting concrete. The rubber replacement was 5, 10, 15, 20, and 25% by weight of aggregates. The tests results showed that the diameter of slump flow ranging from 680mm to 750mm and from 560mm to 710mm in the mixes containing crumb rubber and chips rubber, respectively. The compressive strength decreased by adding rubber particles but when the rubber replacement was 25% the compressive strength more than 31MPa can be achieved with cement content about 364 kg/m³.

Padhi and Panda (2016), [20] prepared SCC mixes containing waste tires rubber by weight of fine aggregate. The rubber replacement was 5, 10, and 15% by weight of fine aggregate. The size of rubber particles passing through 4.75 mm sieve. Fresh and hardened tests were performed at 28 days of curing. The results showed that the workability of self-compacting rubberized concrete (SCRC) decreased by using scrap tires rubber. The compressive strength and splitting tensile strength decrease from 45MPa to 27MPa and from 4Mpa to 2.2Mpa, respectively, for SCC and SCC containing 15% of rubber particles. The modulus of rupture increased when the percentage of crumb rubber was 5%.

Hilal (2017), [21] in her study two size of rubber particles was used, the first one passing from 1mm sieve (No.18) and the second passing from 4mm sieve (No.5). The rubber percentages was 5, 10, 15, 20, and 25% by weight of fine aggregate. The reduction in compressive strength was 31% and 46% by using No.18 and No.5 crumb rubber, respectively. The splitting tensile strength decreased about 45% and 48% by using No.18 and No.5 crumb rubber, respectively. The results also showed that the flexural strength decrease from 5.6MPa to 3.3MPa by utilizing No.18 crumb rubber, and from 5.6Mpa to 3.1Mpa by utilizing No.5 crumb rubber.

5. Water absorption

Bignozzi and Sandrolini (2006), [15] investigated the properties of self-compacting concrete (SCC) containing ground rubber instead of fine aggregate. The rubber percentages was 0%, 22.2%, and 33.3% by volume of fine aggregate. The test results showed that the water absorption increased about 0.8% when the rubber replacement 33.3%.

Gesoğlu and Güneyisi (2011), [22] examined the water absorption capacity of SCC containing crumb rubber instead of fine aggregate. The replacement was 0, 5, 15, and 25% by volume of fine aggregate. The test results observed that the water absorption increased as rubber content increased. The water absorption ranging from 2.8% to 4.3% and from 2.6% to 4.0% at 28 and 90 days, respectively.

Padhi and Panda (2016), [20] used crumb rubber in NC and SCC passing through 4.75mm with rubber replacement 5, 10, and 15% by weight of fine aggregate. The results showed that the water absorption increased from 0.35 to 0.59 for NC and increased from 0.25 to 0.92 for SCC.

Bhatt et al. (2017), [12] used crumb rubber as a sand replacement with percentage 0%, 2.5%, 5%, 7.5% and 10 % by weight of fine aggregate. The results showed that the water absorption increases as crumb rubber proportion increases as shown in figure 2.
6. **Stress-strain relationship for RC**

The addition of waste tire rubbers improved the post-cracking resistance of concrete by absorbing energy. This type of concrete can be used for applications where impact or blast resistance was needed, such as bunkers and jersey barriers, or where vibration damping is required such as foundation pads in railway stations. Due to the positive action of rubber particles [23], Benazzouk et al. (2003), [24] showed that the ductility in the stress-strain relation increased by adding rubber particles and increasing size of particles. The BI (brittleness index) was computed to evaluate the ductility of concrete as shown in figure 3. The peak value was obtained when the percentage of rubber was 10%. After this percentage, the failure mode change from brittle to ductile. The decline in brittleness index values with rubber percentage more than 10% lead to increase plastic energy.
Batayneh et al. (2007), [1] studied the behavior of the stress-strain curve for rubberized concrete. Fine aggregate was replaced by rubber (0.075-4.75 mm). The stress–strain behavior of the mix still brittle with rubber percentage 40% similar to that of the reference specimen, but with rubber percentage 60% and 80% stress-strain curve behavior transition from brittle to ductile failure mode as shown in figure 4.

Aiello and Leuzzi (2010), [6] an enhancement in the post-cracking resistance of concrete was achieved by adding waste tires rubber aggregates. Coarse aggregate was replaced by chip rubber with rubber proportion, 50% and 75% by volume of gravel (coarse aggregate). Toughness indices and residual strength factors increased with rubber content increased. The toughness indices and residual strength factors are presented in table 3. Residual strength factors, which are derived directly from toughness indices. It means the level of strength retained after first crack.

| Amount of rubber content % | Toughness indices | Residual strength factor | Toughness |
|----------------------------|-------------------|--------------------------|-----------|
|                            | I5, I10, I20      | R5,10, R10,20            |           |
| 50                         | 4.06, 8.72, 14.4  | 93.2, 56.8               | 113       |
| 75                         | 4.96, 9.92, 17.8  | 99.2, 78.8               | 196       |

Antil (2014), [7] investigated the behavior of concrete containing 10%, 15%, and 20% tires rubber. The stress–strain behaviors of the mix with rubber percentage 10% behave in a similar to the reference mix (brittle material). Nonlinear behavior was observed with the other two mixes containing 15% and 20% rubber. When the peak stress was reached, the specimen continued to yield (tough material) as shown in figure 5. The mix with a higher proportion of waste tires rubber has a high toughness.
7. Conclusions

From the previous studies that mentioned above, concluded the following points:

- Scrap tires rubber can be used in normal concrete and self-compacting concrete.
- The workability decreased by using waste tires rubber.
- The compressive strength decreased as rubber content increased. Also the splitting tensile strength and flexural strength decreased by utilizing rubber particles.
- In some studies can be noticed the increment in flexural strength when the rubber replacement was 10% by weight of fine aggregate. The flexural strength comes optimum when 5% of crumb rubber replaced by fine aggregate.
- The incorporating rubber particles in concrete lead to convert the failure mode of concrete from brittle to ductile. Also the absorption energy (post-crack resistance) increased by adding scrap tires rubber.

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