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Use of Rubber as Aggregate in Concrete: A Review

ISHTIAQ ALAM, UMER AMMAR MAHMOOD, NOUMAN KHATTAK
Department of Civil Engineering, University of Engineering and Technology Peshawar Pakistan
Email: ishtiaqalamkk@yahoo.com

Abstract: Rubber is produced excessively worldwide every year. It cannot be discharge off easily in the environment as its decomposition takes much time and also produces environmental pollution. In such a case the reuse of rubber would be a better choice. In order to reuse rubber wastes, it was added to concrete as coarse aggregate and its different properties like compressive strength, Tensile strength, ductility etc. were investigated and compared with ordinary concrete. As a result it was found that rubberized concrete is durable, less ductile, has greater crack resistance but has a low compressive strength when compared with ordinary concrete. The compressive strength of rubberized concrete can be increased by adding some amount of silica to it.

Keywords: *Compressive strength, Silica, Rubberized concrete, Flexural strength, Compressive strength*

Introduction:

A large variety of waste materials are considered feasible and even much valuable additives for concrete. Some of these materials include cellulose, fly ash, silica fumes and wood particles. Rubber obtained from scrapped tyres is considered as the most recent waste materials that have been examined because of its vital use in the construction field [1].

Worldwide, the production of rubber increases every year. Different countries of the world has different rate of producing rubber, for instance United States produces 3.6 million tons of rubber per year [2]. Iran produces 100,000 tons of rubber per year [3]; similarly Malaysia produces 200,000 tons of rubber per year [4]. These numbers increases with the increase in the production of vehicles.

Investigations have shown that scrapped rubber tyres contain materials that do not decompose under environmental conditions and cause serious problems. One choice of decomposition is burning, but that would also results in harmful pollutions. Based on these problems, tyres can be used as aggregates in concrete [2].

It is very difficult to manage the waste produced by the rubber-tyre industry and to handle the waste. It is not easily biodegradable waste form. According to Guneyisi et al. 2004 [[5]] the rubber waste is not easily biodegradable even after a long span passes after the landfill treatment. Siddique and Naik, 2004 [[6]]stated that the rubber tyre waste has been utilized as fuel for the kilns, as a form of feed for the carbon black and it is also found that the environmental hazardous pollution caused by the combustion of rubber tyre in the kilns is greatly reduced as compared to the carbon black fuel.

Toutanji, 1996 [1] stated that the utility of rubber tyre in concrete industry i.e. noise barriers, electricity posts, and in the mixture plants of asphalt pavements. Eldin and Senouci, 1993, [7] Toutanji, 1996 [1], Khatib and Bayomy, 1999 [8], Siddique and Naik, 2004 [6], Batayneh et al , 2008 [9], Aiello and Leuzzi, 2010 [11], and Najim and Hall, 2010 [12] commented that the recycled rubber tyre waste is a promising material in the construction industry and the sole reason for this is the lightweight of the resulting concrete when the rubber tyre is incorporated in it as an aggregate replacement (partial or complete). The elasticity, energy absorption capacity of concrete after the addition of rubber tyre as replacement of coarse aggregate in concrete has been showing some promising results as stated by Eldin and Senouci, 1993 [7], Toutanji, 1996 [1], Khatib and Bayomy, 1999 [8], Siddique and Naik, 2004 [6], Batayneh et al, 2008 [9], Aiello and Leuzzi, 2010 [11], and Najim and Hall, 2010 [12].

Aiello, M. A., and Leuzzi, F. 2010 [11], commented that the utilization of waste products in concrete has an attractive advantage and attention all around the globe and the reason for this is the awareness among the researchers in the form of environmental consciousness.

Batayneh, M. K., Marie, I., and Asi, I. 2008 [10] stated that the accumulations of stockpiles of the rubber tyres are very dangerous to the society as they pose a great environmental concern, hazard due to fire and provision of breeding grounds for various insects like mosquitoes which may carry very diseases from this source.

Ganjian, E., Khorami, M., and Maghsoudi, A. A. 2009 [13] stated that the tyre pile fires have been remaining a greater environmental problem as the fires caught by tyres are very hazardous and that the fires can burn for months, sending up an acrid black plume that is visible from various mile away. It is a matter of great concern that the acrid plums contain various amounts of toxic chemical and the air pollutants in it is causing a serious threat to the environment and its inhabitants.

Siddique and Naik, 2004 [6] stated that it has been a growing practice among the researchers to use the deformed shapes of rubber tyres while incorporating into the concrete mixture. The rubber tyres shows

better performance in concrete when they are cut in the form of normally sized coarse aggregate to take the full advantage of the shape factor of the aggregate. Due to this fact, the compressive strength of the concrete can be made more or less stronger as compared to the aggregate sizes which are not in the proper shape to be incorporated in the concrete.

Methodology:

1. Recycled scrap tyres materials:

Siddique and Naik (2004) [6], commented from their research on the use of recycled tyres as materials to be used in the concrete as partial or complete replacement of aggregate that there are four types of scrap tyre particles available which are classified in accordance to their particle size and the texture. These types consist of slit tyre particles in the form of slits which are halved in two halves. Apart from the slit tyre particles, there are shredded tyre particles which are also utilized in concrete as a replacement of aggregate in the concrete. The particle size varies from 300 to 400 millimeters long and 100-200 millimeters wide. There is also ground type of rubber tyre available for the utility in research work which is cut in the sizes of 19mm to 0.15 mm. The crumb rubber used in the concrete has to be having a nominal size equal to the standard sieve dimension of 4.75 mm.

Ganjian, E., Khorami, M., and Maghsoudi, A. A. (2009) [13], commented as part of their research work in which he used crumb rubber as partial and complete replacement fine aggregate in concrete and reported the various performance levels of concrete subject to the different phenomenon like shrinkage, segregation, workability, flexural bending stresses, shear bending stresses, normal consistency of cement paste and the initial and final setting times determination.

Fattuhi N, Clark L. 1996, reported that the use of crumb tyre particles as the partial replacement sand in the concrete has better performance levels as compared to the full or complete replacement of sand in the concrete with the crumb tyre particles. The partial replacement of sand with crumb tyre particles are imparting better performance levels to the concrete at various serviceability levels as compared to the complete replacement of crumb aggregate with the sand. The sand in the concrete along with the crumb tyre particles are imparting better shear capacity, fire resistance and resistance to spalling due to various environmental hazards like, fire, rainwater and collective segregation in concrete.

2. Specimen preparation and testing:

Siddique, R. and Naik, T. R. (2004) [6] propose various arrangements and sequences for the preparation of samples for testing in laboratory for determination of various parameters of structural and material importance. The most common methodology as adopted by R. Naik. 2004, was to prepare 100x100x100 mm cubes for each mix in the aggregate replacement strategy. However cylinders of 150mm x 300mm height are also a better option for determining of performance levels in concrete.

Ganjian, E., Khorami, M., and Maghsoudi, A. A. (2009) [13], presented the comparison of various ASTM procedures available for the determination of performance levels when the crumb or crushed rubber aggregate is used in concrete as partial replacement of sand.

Eldin, N. N., and Senouci, A. B. (1993) [7], narrated that the testing of small beams when crumb particles of tyres are used as replacement of sand. He prepared specimen which were fabricated like small beams and then cured in water for 28 days in accordance to American Standard of Testing and Materials. For each concrete mix, the routine experimental procedures of determination of slump of hydraulic cement concrete, split tensile strength, flexural strength of concrete and the determination of compressive strength after 28 days moist curing were performed in accordance to the ASTM procedures.

Hernandez-Olivares, F., Barluenga, G., 2004, conducted an extensive study on the fire resistance of concrete prepared in crumb tyre aggregates. He had adopted the methodology of specimen preparation in which he used a variable amount of replacement of crushed tyre aggregate in 20%, 40%, 60% and 80%.

3. Results and discussions

a. Effect on workability:

Figure 1 Crumb rubber used in experiments

Khatib and Bayomy [8] noted that by increasing the rubber content in concrete the slump as well as the unit weight decreases. But it still gave a workable mix despite of adding rubber to it when compared with ordinary concrete.

b. Effect on Unit weight :

The density of rubberized concrete was found comparatively less than ordinary concrete. With the increase in the percentage of rubber in concrete the density of it decreases [14]. The density of concrete greatly depends upon the amount of air entrained or air entrapped, water-cement ratio, which in turn depends upon the size of aggregates. The increase in rubber content in concrete increases the air content which decreases the density (unit weight) of concrete. At about 25% of the content of rubber in concrete,

the density decreases to about 90% of the ordinary concrete. However this decrease is very less when rubber content is less than 10-15% of the total aggregate volume [15].

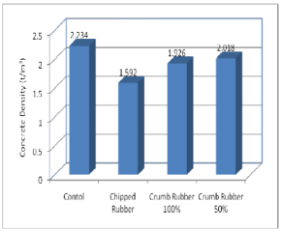

Figure 2 Effect of the waste tire rubber on the concrete density (after A. K. Abdel-Gawad; Y. El-Sherbini, and A. Shalaby)

c. Effect on Compressive Strength

Compressive tests are considered as the most convenient test for evaluating the quality of the Concrete. Kumaran S.G. et al [16] conducted various tests on rubberized concrete, having tyre articles and crumb rubber of sizes 36, 24 and 18 mm and found that there is a reduction of 85% in compressive strength and about 50% of reduction in split tensile strength but showed large absorption of energy.

Kaloush K.E. et al investigated that increase in rubber content in concrete decreased the compressive strength. This reduction was due to the presence of entrapped air. Experiments have showed that compressive strength can be increased by adding some de-airing agents into rubberized concrete [17].

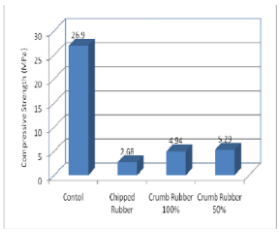

Figure 3 Effect of waste tire rubber on the compressive strength of concrete

Ling T.C. and Hasanan M.N, investigated that there was a organized decline in the compressive strength with the increase in rubber content from 0 % to 40% [15]. Felipe J.A. and Jeannette Santos found that strength reduction of 50% was celebrated for a mix with 14% replacement in their studies [18].Hanson achieved higher compressive strength in crumbrubber concrete by dropping trapped air in the mix [19].

Neville A. M. studied, a reduction in compressive strength with the adding up of rubber aggregate in the concrete mix but there is still a possibility of increasing the compressive strength by using de-airing agents [20].

d. Effect on Tensile Strength:

Michelle Danko, Edgar Cano and Jose Pena examined that the tensile strength of rubberized concrete is mostly affected by the size, shape, and textures of the aggregate and the strength of concretes decreases as the volume of rubber aggregate increases [14].The tensile strength of rubberized conctere decreases but the strain at failure increases correspondingly. Higher tensile strain at failure is indicative of more energy absorbent mixes [17]. Tests conducted on the behavior f rubberized concrete containing tyre chips and crumb rubber as a replacement of aggregates having sizes 38, 24 and 19 mm showed reduction in tensile strength by almost 50% but also showed maximum energy absorption during tensile loading [16].

e. Effect on Impact Strength and other mechanical properties:

From previous tests it is obvious that the toughness, impact resistance and plasticity of concrete increases by adding some amount of rubber into concrete. The lower the toughness of concrete means the higher strength. For achieving high strength and toughness, the concrete should be modified. Test have shown that adding rubber to concrete can only increases the toughness value of it [15].

Two types of arrangements were made by using 15% of rubber tyre in equal amount of coarse aggregate. The first one was tyre rubber and second as chips dispersed. As a result increase in toughness was observed. But the stiffness as well as strength was considerably decreased. After applying peak load on concrete it was observed that the ordinary concrete was dispersed while the rubberized concrete had much deformation before failure. The rubber chip modified concrete takes fewer loads than fiber modified concrete before the failure of concrete mix [16]

Figure 4 A Concrete sample arranged for Impact resistance test

Modulus of elasticity was found less when rubber was used as aggregates on concrete mix. The compressive strength of concrete and elastic properties of concrete greatly depends upon the modulus of elasticity. The more rubber added to concrete the lesser is the modulus of elasticity [21]. It has been investigated that a distribution of mini expansion joints was occurred when crumb rubber was used as aggregate to concrete. This means that concrete is good in controlling cracks. In January 2003 a slab was tested having 25% of crumb rubber as a replacement of coarse aggregate in concrete. After performing tests, results showed that no visual cracks were produced and the ductility and toughness had increased [17].

Tests on tension, Fatigue and ultrasound velocity test showed that high energy dissipation capabilities were found for rubberized concrete, which intern results in

high toughness and high ductility. Various failure patterns showed that concrete made by adding rubber to it can have large deformations and maintain their integrity [22].

Michelle Danko, Edgar Cano and Jose Pena investigated from all failure tests that concrete made of rubber absorbed much force and specimens did not disintegrate when load is applied on it [14].

f. Effect on Flexural Strength:

Kaloush K.E, George B. W. and Han Z [17] investigated that the flexure strength of concrete having rubber decreases by increasing the content of rubber in concrete. On the other hand Kang Jingfu, Han Chuncui and Zhang Zhenli further investigated that the flexural strength was increased by adding rubber in roller compacted concrete. By increasing the content of rubber into concrete the flexural strength and ultimate tension elongation increases when the compressive strebgth was kept constants for roller compacted concrete [23].

Table: 1 Effect of crumb rubber content on various strength results After Malek K. Batayneh et al [10]

Crumb rubber Content (%)	Flexural strength (MPa)	Splitting tensile strength, ft (MPa)	Compressive strength, fc (MPa)
0	3.68	2.820	25.330
20	2.550	1.840	18.960
40	2.040	1.470	12.270
60	1.380	0.940	8.070
80	0.770	0.533	4.470
100	0.640	0.220	2.500

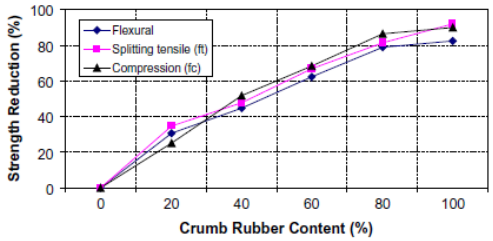

Figure 5. Comparison between strength reduction and rubber content.After Malek K. Batayneh et al [10]

g. Stress–strain relationship:

The relationship between stress and strain is shown in Fig. 5 for the different rubber contents that have been used as aggregates in concrete mix. The stress–strain behaviors of the specimens containing rubber of up to 40% having a smaller peak is same as that of ordinary concrete mix. A linear behavior was shown for rubber content up to 40% while for rubber content 60 and 805 non-linear behavior was observed.

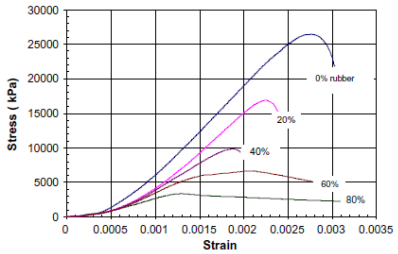

Figure 6 Relationship between stress and strain for different rubber contents. after Malek K. Batayneh et al [10]

Conclusions:

The following conclusions have been drawn from research on using rubber as aggregate in concrete

- When rubber was used instead of aggregates in concrete it shows less compressive strength when compared with ordinary concrete. But it also shows some ductile behavior before failure.
- Rubberized concrete shows reduction in density of concrete when compared with control concrete specimen.
- Concrete made of crumb rubber as fine aggregate shows much strength when compared with concrete made of chipped rubber as coarse aggregate.
- No appreciable increment in the compressive strength of concrete density by using different percentage of rubber as fine aggregates in concrete.
- It is recommended to use silica fume in rubberized concrete to increase its compressive strength.
- It is recommended to use rubberized concrete small structures like road curbs and non-bearing walls etc.

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