Properties of high-strength concrete containing well graded rubber particles

A Habib*, U Yildirim, O Eren
Civil Engineering Department, Eastern Mediterranean University, Famagusta. North Cyprus

*E-mail: ahed.habib@gmail.com

Abstract. Discarding of old rubber tires is indeed a very serious environmental problem all over the world represented by a high risk for uncontrolled fires and other environmental and health hazards. It was estimated that every year about one billion tires get to the end of their life span. Recently, the construction industry has taken up the challenge to incorporate recycled materials in concrete mixtures by means aggregate replacement. Nowadays, many researches are focused on investigating rubberized concrete as a structural material due to its enhanced properties such as ductility, energy dissipation and damping ratio. Previous studies have suggested the use of fine rubber particles rather than coarse ones when high strength concrete is targeted despite the fact that using coarse ones provide enhanced energy dissipation, damping ratio and vibration behavior. This study is intended to address the effects of utilizing significant amount of well graded fine and coarse rubber aggregates on the properties of high strength concrete. On the basis of the investigations some mechanical, durability and dynamic tests will be conducted on concrete with different rubber replacement percentages. The results of the experimental works have shown that it is possible to develop high strength concrete when well graded fine and coarse rubber particles is used to replace 25% percent of the natural aggregates. Furthermore, the vibration behavior of the concrete mixture was improved considerably when high content of rubber aggregates was added into concrete.

1. Introduction
Disposal of old rubber tires causes very serious environmental problems every year [1, 2, 3]. Nowadays, studies on the application of non-biodegradable wastes as aggregates replacement in concrete are becoming very common all over the world aiming to incorporate the principles of sustainability in the construction activities [4]. Recently, many investigations on the use of recycled rubber particle in concrete by means of aggregate replacement were conducted trying to develop what so-called ‘rubberized concrete (RBC)’ [5, 6, 7].

Previous investigations on RBC have confirmed a significant reduction in the strength capacity of concrete as the rubber content is increasing [8, 9, 10, 11]. Nevertheless, developing of high strength rubberized concrete using fine rubber particles was reported to be possible when up to 12.5% of the fine aggregate is replaced [4]. Furthermore, the resistance of RBC against water permeability is decreased due to its increased porosity [12]. On the other hand, adding rubber to concrete improves its ability to highly dissipates energy which when used in structural members can positively influence the vibration behavior of the building [13].
This study is intended to take the research in the field of the RBC one step further by studying the effects of replacing natural aggregates by well graded fine and coarse rubber particles on the behavior of concrete. As a part of the study some of the mechanical, durability and dynamic characteristics of RBC mixtures will be reported at two rubber replacement percentages.

2. Materials and Methods

2.1. Materials Properties

In order to produce a concrete that has the characteristics of high-strength concrete the materials with the properties shown in Table 1 were used.

| Material       | Properties                                                                 | Standard       |
|----------------|-----------------------------------------------------------------------------|----------------|
| Cement         | Blast-furnace Slag Cement CEM II/B-S 42.5 N with a specific gravity of 3.15 | ASTM C595      |
| Silica Fume    | It has a 95 % SiO₂ content                                                   | ASTM C1240     |
| Water          | Tap water free from contamination                                           | ASTM C1602     |
| Admixtures     | High range water reducer Polycarboxylic ether-based superplasticizer GLENIUM 27 with specific gravity of 1.026 and brown color | ASTM C494      |
| Steel Fiber    | Hooked end steel fiber with a length of 50 mm, slenderness of 80 and tensile strength of 1225 MPa | ASTM A820      |
| Fine Aggregate | Crushed stones with a maximum particle size of 5 mm distribution as shown in Figure 1. | ASTM C33       |
| Coarse Aggregate | Crushed limestone rock with a nominal maximum size of 10 mm and distribution as shown in Figure 1. | ASTM C33       |
| Rubber         | A mix of fine and coarse rubber particles from old car tires with a specific gravity of 1.06 and particle size distribution as shown in Figure 1. | ASTM C330      |

![Figure 1. Aggregate particle size distribution.](image-url)
2.2. Rubber Pre-Treatment Using NaOH Solution
The aim of this treatment is to enhance the surface roughness of each rubber particle which will result in improved concrete properties. In fact, the process was started by washing the rubber aggregates in tap water to remove any impurities and dust, soaking them in the 10% NaOH solution for half an hour, then the rubber were washed by water until their pH became 7 (to prevent any possible negative impact on the concrete durability), finally, they were left away to get air-dried.

2.3. Mix Proportioning
The concrete mix proportion shown in Table 2 was designed to achieve high-strength concrete after adding the rubber aggregates. Thus, based on the findings of the previous investigations over 50% reduction was expected when 25% of the aggregates will be replaced by recycled rubber particles. Therefore, to overcome this reduction in the strengths of concrete both silica fume and steel fiber were incorporated in the mixture.

The rubber replacement percentages in this study were selected as 15% and 25% which were based on the results of old researches that recommended high content of rubber aggregate.

In fact, the process of concrete production was handled in controlled laboratory conditions. Due to the high amount of binding materials required to produce high-performance concrete that includes significant amount of rubber aggregate the production stage followed the requirements of ultra-high-performance concrete standard ACI 239-18 in terms of mixing duration. As a result, concrete mixing procedure took in total 20 minutes. Thereafter, ASTM C1758 standard practice was followed for making and curing of the concrete samples.

| Material             | Control Mix (ZRBC) | 15% Rubberized Mix (15RBC) | 25% Rubberized Mix (25RBC) |
|----------------------|--------------------|----------------------------|----------------------------|
| Cement (kg)          | 1000               | 1000                       | 1000                       |
| Water (kg)           | 180                | 180                        | 180                        |
| Fine Aggregate (kg)  | 448                | 381                        | 336                        |
| Coarse Aggregate (kg)| 672                | 571                        | 504                        |
| Rubber Aggregate (kg)| 0                  | 70                         | 117                        |
| Admixture (kg)       | 50                 | 50                         | 50                         |
| Silica Fume (kg)     | 300                | 300                        | 300                        |
| Steel Fiber (kg)     | 78                 | 78                         | 78                         |

2.4. Experimental Program
As part of this study, experimental tests will be conducted to evaluate the effects of adding fine and coarse rubber aggregates on the mechanical, durability and dynamic behavior concrete.

In general, the guidelines shown in Table 3 were used to carry the mechanical and durability tests on concrete specimens.

On the other hand, to obtain the dynamic characteristics of each mixture a free vibration test was performed with the acceleration values being recorded using an accelerometer sensor with a range of ±2g and a sampling frequency of 200 Hz. Generally, the procedure of testing each cantilever beam as shown in Figure 2 was started by applying the supporting conditions, setting up the sensor location and imposing vibration on the specimen by impact loading. Then, the recorded data were undergoing a pre-processing stage to reduce the noise emerged from the surrounding environment and improve their reliability. The followed method is called moving average filter [14]. Thereafter, Excel 2016 and SeismoSignal software package [15] were used to produce the fast Fourier transform (FFT) that converted the recorded data from the time domain to the frequency domain and to calculate the natural frequency of each specimen. Finally, the expressions below were used to calculate the dynamic modulus of elasticity of each sample.
\[ f_n = \frac{1}{2\pi} \sqrt{\frac{k}{M}} \]  
\[ \Rightarrow E = \frac{4\pi^2 f_n^2 qL^4}{12I} \]  

Table 3. Standards to be followed in this research.

| Test                           | Specimen Size in (mm) | Remarks         |
|--------------------------------|-----------------------|-----------------|
| Density of Hardened Concrete   | 150*150*150           | ASTM C642       |
| Compressive Strength           | 150*150*150           | ASTM C39        |
| Splitting Tensile Strength     | 150*150*150           | ASTM C496       |
| Static Modulus of Elasticity   | 200*100               | ASTM C469       |
| Water Penetration              | 150*150*150           | DIN 1048        |

Figure 2. Setup of the free vibration test

3. Results and Discussions

3.1. Bulk Density
The bulk density for each concrete mix was obtained using the method provided in ASTM C642 by taking the mass of the specimen (in kg) divided by its volume (in m\(^3\)). Thereafter, the average of six different specimens were found as shown in Table 4. In fact, it was observed that concrete faces a decrease in its density related directly to the increase in rubber content, this change is attributed to the significant difference between the specific gravity of rubber and natural stone particles.

3.2. Compressive Strength
The average 28 days compressive strength of each mixture is shown in Table 4. In general, the results indicated a significant reduction in the strength corresponds to 29% and 43% for 15RBC and 25RBC respectively. This drop is attributed to many reasons including replacing higher strength and load-carrying capacity aggregate by lower one [13] and the weaker bond between the rubber aggregates and cement past in comparison to the natural aggregate one which lead to rapid rupture of concrete [16].

3.3. Splitting Tensile Strength
Similar to compressive strength the 28 days splitting tensile strength of concrete, Table 4, was affected by the rubber replacement, in which the observed reduction were 4% and 17% for 15RBC and 25RBC respectively.
3.4. Static Modulus of Elasticity

The variation in the static elastic modulus of RBC with respect to the control mixture is shown in Table 4. This difference is due to the reduction in the compressive strength of the RBC specimens.

3.5. Depth of Water Penetration

This test was conducted to examine the durability behavior of RBC in comparison to the control mixture. In general, the depth of water penetration, Table 4, was very small in all cases (below 5 mm) due to using high amount of silica fume while the pattern of variation showed an increase in the depth as more rubber particles are being added to the concrete.

| Test                              | ZRBC | 15RBC | 25RBC |
|-----------------------------------|------|-------|-------|
| Bulk Density (kg/m³)              | 2312 | 2191  | 2139  |
| Compressive Strength (MPa)        | 96.77| 68.5  | 55.07 |
| Splitting Tensile Strength (MPa)  | 5.32 | 5.1   | 4.39  |
| Static modulus of elasticity (GPa)| 53.6 | 38.2  | 36.6  |
| Depth of water penetration (mm)   | 1.25 | 3.5   | 4.5   |
| Dynamic Modulus of Elasticity (GPa) | 60.06 | 44.66 | 42.93 |

3.6. Dynamic Modulus of Elasticity

Figure 3 shows the results of the Fast Fourier transform (FFT) of each concrete mix. As can be seen there, the frequency of concrete decreased as the rubber replacement percentage is increasing. This reduction is mainly attributed to the drop in the specimen’s modulus of elasticity.

The dynamic modulus of elasticity for each specimen was calculated using the formula mentioned previously chapter and the results are shown in Table 4. Moreover, the pattern of reduction in the dynamic modulus of elasticity is very close the one for static modulus of elasticity as shown in Figure 4 due to their direct relation.

![Figure 3](image_url)

**Figure 3.** Fast Fourier transform graph of (a) ZRBC, (b) 15RBC and (c) 25RBC.
4. Conclusion
This study has focused on the properties of high-strength rubberized concrete. As a part of this study, experimental tests were conducted to comprehensively examine the effect of using well graded fine and coarse rubber particles as aggregates replacement on the some of the mechanical, durability and dynamic properties of high-strength concrete. On the basis of the above statements the following conclusions are drawn:

- Adding rubber to concrete significantly reduces its mechanical properties in comparison to conventional concrete.
- Using rubber aggregates in concrete reduces its bulk density considerably.
- Replacing 25% of the natural aggregates by well graded fine and coarse rubber particles reduced its compressive strength by almost 40%.
- Incorporating rubber in a concrete mix reduces its resistance to water absorption in comparison to the normal one.
- Both static and dynamic modulus of elasticity are reducing as the rubber content in concrete is being increased.

References
[1] Pelisser, F., Zavarise, N., Longo, T., & Bernardin, A. (2011). Concrete made with recycled tire rubber: Effect of alkaline activation and silica fume addition. Journal of Cleaner Production.
[2] Yung, W., Yung, L., & Hua, L. (2013). A study of the durability properties of waste tire rubber applied to self-compacting concrete. Construction and Building Materials.
[3] Aslani, F. (2015, 9 18). Mechanical Properties of Waste Tire Rubber Concrete. Journal of Materials in Civil Engineering, 28(3), 04015152.
[4] Thomas, B., & Chandra Gupta, R. (2016). Properties of high strength concrete containing scrap tire rubber. Journal of Cleaner Production.
[5] Eldin, N., & Senouci, A. (1993). Rubber-Tire Particles as Concrete Aggregate. Journal of Materials in Civil Engineering.
[6] Eldin, N., & Senouci, A. (1994). Measurement and prediction of the strength of rubberized concrete. Cement and Concrete Composites.
[7] Topçu, B. (1995). The Properties Of Rubberized Concretes. Cement and concrete research, 25(2), 304-310.
[8] Eldin, N., & Senouci, A. (1992). Engineering properties of rubberized concrete. *Canadian Journal of Civil Engineering*.

[9] Fattuhi, N., & Clark, L. (1996). Cement-based materials containing shredded scrap truck tyre rubber. *Construction and Building Materials*.

[10] Khatib, Z., & Bayomy, F. (1999). Rubberized Portland Cement Concrete. *Journal of Materials in Civil Engineering*.

[11] Zheng, L., Huo, X., & Yuan, Y. (2008). Strength, Modulus of Elasticity, and Brittleness Index of Rubberized Concrete. *Journal of Materials in Civil Engineering*.

[12] Su, H., Yang, J., Ling, T., Ghataora, G., & Dirar, S. (2015). Properties of concrete prepared with waste tyre rubber particles of uniform and varying sizes. *Journal of Cleaner Production*.

[13] Xue, J., & Shinozuka, M. (2013). Rubberized concrete: A green structural material with enhanced energy-dissipation capability. *Construction and Building Materials*.

[14] Smith, S. W. (1997). *The scientist and engineer's guide to digital signal processing*.

[15] Antoniou, S., Pinho, R., & Bianchi, F. (2018). SeismoSignal. Seismosoft.

[16] Bisht, K., & Ramana, P. (2017). Evaluation of mechanical and durability properties of crumb rubber concrete. *Construction and Building Materials*.

[17] ASTM. (2013). ASTM C642 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete.

[18] ASTM. (2019). ASTM C595 Standard Specification for Blended Hydraulic Cements.

[19] ASTM. (2017). ASTM C496 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.

[20] ASTM. (2017). ASTM C494 Standard Specification for Chemical Admixtures for Concrete.

[21] ASTM. (2014). ASTM C469 Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression.

[22] ASTM. (2018). ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

[23] ASTM. (2017). ASTM C330 Standard Specification for Lightweight Aggregates for Structural Concrete.

[24] ASTM. (2018). ASTM C33 Standard Specification for Concrete Aggregates.

[25] ASTM. (2015). ASTM C1758 Standard Practice for Fabricating Test Specimens with Self-Consolidating Concrete.

[26] ASTM. (2018). ASTM C1602 Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete.

[27] ASTM. (2015). ASTM C1240 Standard Specification for Silica Fume Used in Cementitious Mixtures.

[28] ASTM. (2016). ASTM A820 Standard Specification for Steel Fibers for Fiber-Reinforced Concrete.

[29] DIN. (1975). DIN 1048-5: Testing concrete, testing of hardened concrete (specimens prepared in mould).

[30] ACI. (2018). *ACI 239R-18: Ultra-High Performance Concrete: An Emerging Technology Report*. USA: Farmington Hills.