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Fracture energy and mechanical characteristics of self-compacting concretes including waste bladder tyre

Alper Bideci [a,*], Hakan Öztürk [b], Özlem Salli Bideci [a], Mehmet Emiroğlu [c]

[a] Düzce University, Art, Design and Architecture Faculty, Department of Architecture, 81600 Düzce, Turkey
[b] Düzce University, Kaynaşlı Vocational College, Department of Architecture, 81600 Düzce, Turkey
[c] Düzce University, Faculty of Technology, Department of Civil Engineering, 81600 Düzce, Turkey

HIGHLIGHTS

- Waste rubber bladders were evaluated as fibre shaped rubber aggregate in SCCs.
- Different rubber lengths and volumetric fractions were used to produce rubber incorporated SCCs.
- Performance of waste rubber incorporated SCCs were analyzed by physical, mechanical and fracture energy test results.
- 25 mm rubber length with 10% volumetric fraction gave the best results in terms of overall examination of the results.

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ABSTRACT

Management of solid wastes is one of the most important environmental problems in the world. Waste tyres are also one of these solid wastes. The growing number of waste tyres that are stocked every year brings problems in respect of human health, environmental pollution, and also causes esthetical problems. The main purpose of this study is to investigate the effect of waste tyre addition on self-compacting concretes' mechanical characteristics and fracture properties under bending. In this study, waste bladder tyres (RA) mechanically cut in 25, 50 and 75 mm lengths were used by volumetric replacement of coarse aggregates in self-compacting concretes (SCC). Unit weight, flow, J-ring, column segregation, water absorption, 28 days of compressive strength, ultrasound pulse velocity and fracture energy tests were applied on concretes obtained by replacement of coarse aggregates in 5%, 10% and 15% ratios by volume. Also, Scanning Electronic Microscope (SEM) and Energy Distribution Spectroscopy (EDS) analyses of the samples were examined. In the study, it was determined that RA replacement decreases unit weight of fresh concrete; when RA length ratio increases, it becomes difficult for the concrete to pass through reinforcement openings; in hardened concrete samples dry unit weight decreases; 10% fibre addition increases compressive strength values; after the ultrasonic pulse velocity measurement, the concretes are included in "good" quality concrete classifications. As a conclusion, it was determined that 25 mm long 10% rubber aggregate replacement to self-compacting concretes can give optimum results.

1. Introduction

The most common solutions for waste tyres are reusage of them in plastic products, heat and electricity production by burning waste tyres (cement factories etc.) and using them as aggregates in concrete or asphalt concrete. Studies on using waste tyres as aggregates in concretes are currently very limited compared with the studies on their utilization in asphalt coatings. Several studies were performed on using waste tyre rubbers as concrete aggregates. However, it is necessary to make more research before recommending them in constructional applications. In previous studies, it is indicated that waste tyre rubber usage decreases the durability of the concrete, but makes the concrete gain elasticity and toughness [1,2].

By using several cutting methods, waste tyres are used in the form of rubber particles, chips and fibers. Also the tyres are burned and their ashes are used in the concrete. While these rubber aggregates are used in concrete, fine aggregates are replaced partially with fine aggregates and coarse aggregates are replaced partially with coarse aggregates. The rubber ratio in the concrete has generally replaced between 0% and 100% according to the aggregate volume but after 20%–25%, there is observed a systematic decrease in compressive and axial tensile strength of the concrete. Due to

* Corresponding author.
E-mail address: alperbideci@duzce.edu.tr (A. Bideci).

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this fact, it is required to make a limitation in the waste rubber content in the concrete. In the studies performed up to date, generally the effect of waste tyre on fresh concrete characteristics and on determinative characteristics of hardened concretes such as compression, axial tensile, modulus of elasticity and fracture toughness were studied, however there are not sufficient studies on its positive effects on fracture mechanism of the concrete [1,3–7].

In most of the studies up to date, rubber aggregates were used either in the form of finely grounded powder or in the form of chopped chips. In the performed studies, it is reported that rubbers with fibre shape have better performance than those with chip shaped. But it is known that length/diameter ratio should not be very high, otherwise fibre shaped rubbers have the risk of winding to each other during mixing [1,8].

Self-compacting concretes (SCCs) have flowability characteristics and ability to self-leveling, and does not need vibration while placing the formwork. SCCs are flowable and resistant to segregation, has higher homogeneity and lower porosity [9].

To know formation (initiation) and propagation of the crack in concrete based on the nonlinear fracture mechanisms is getting more important. Fictitious crack approach and effective-elastic crack approach are used to examine crack propagation in quasi-brittle materials such as concrete based on different energy dissipation mechanisms. Based on the fictitious crack model first proposed by Hillerborg et al. fracture energy of concrete are measured the area under the entire stress-elongation curve [10,11].

It is known that the main problem that revealed during usage of rubber aggregates in concrete is the poor adherence between rubber and cement paste. Therefore in this study, it was aimed to control the contact surfaces of rubber with cement paste especially by cutting the rubbers properly, and the effect of self-compacted concrete on main characteristics such as compressive strength and fracture surface energy were investigated.

2. Material and method

2.1. Material

2.1.1. Aggregate

Limestone aggregates were used and two different sizes of aggregates as fine (0–5 mm) and coarse (5–12 mm) aggregates were preferred in the study.

2.1.2. Cement

CEM I 42.5R type Portland cement was used in the study. Chemical compositions, physical and mechanical characteristics of the cement are given in Table 1.

2.1.3. Rubber aggregate (RA)

As rubber aggregate, the material called as bladder which applies pressure to the walls of the mould during tyre production and is similar to tyre chemistry in a large extent and becomes waste after about 200 use was used (Fig. 1a). Rubber aggregate was prepared by cutting mechanically by guillotine in 3 different lengths as 25 mm, 50 mm and 75 mm and in 5 × 5 mm cross section (Fig. 1b).

Table 1
Chemical composition, physical and mechanical characteristics of cement.

Chemical composition		Physical characteristics	
SiO_2 (%)	18.37	Start of setting (h/min)	02:00
Al_2O_3 (%)	4.26	End of setting (h/min)	03:55
Fe_2O_3 (%)	3.89	Volume constancy (mm Total)	1.30
CaO (%)	64.04	Specific Weight	3.18
MgO (%)	1.52	Specific Surface (cm^2/g)	4209
SO_3 (%)	3.01	Sieve residue (45μ)	3.65
Na_2O (%)	0.12	**Mechanical characteristics**	
K_2O (%)	0.72	**Compressive strength (MPa)**	
Total alkali	0.59	2nd day	31.0
Cl^-	0.0226	7th day	39.7
Loss on Ignition (%)	4.23	28th day	55.4
Undissolved residue	0.73	**Flexural strength (MPa)**	
S.CaO (%)	1.40	28th day	8.4

2.1.4. Blast Furnace Slag

Blast Furnace Slag (BFS) was obtained from OYAK Bolu Cement Ereğli Grinding and Packaging Facilities and its physical and chemical characteristics are given in Table 2.

2.1.5. Water

In the study, tap water supply that complies with TS EN 1008 standard [12] was used.

2.1.6. Plasticiser and air entrainer

In the study, hyperplasticiser modified polycarboxylate based polymer additive and air entrained substance obtained from Sika Construction Chemicals Inc. was used. Product information is given in Table 3.

Fig. 1a. Bladder.

Fig. 1b. Rubber aggregate (25 mm).

Table 2
BFS physical and chemical analysis.

Chemical composition		Physical composition	
SiO_2 (%)	41.00	Initial time (hr/min)	02:00
Al_2O_3 (%)	13.32		
Fe_2O_3 (%)	1.11		
CaO (%)	34.17	Finally time (hr/min)	02:25
MgO (%)	7.29		
SO_3 (%)	0.11		
$S^=$	0.72	Specific gravity (g/cm^3)	2.78
Na_2O (%)	0.44		
K_2O (%)	0.96		
TiO_2	0.87	Humidity (%)	0.07
Mn_2O_3	0.76		
Loss on ignition (%)	0.14		
Cl^-	0.0158	Specific surface (cm^2/g)	5048
(CaO + MgO = /SiO_2)	1.01		
CaO + MgO + SiO_2	82.46		
Vitreous phase	100.00		