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The Effects of Engineering Properties of Waste Tires into Self Compacting Concretes

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ABSTRACT: There have been more than 10 million waste tires in the world and it reaches about 300 thousand tons for our country. Degradation of waste tires in nature take very long time and leaving this waste into the landfills poses serious health hazards for both human health and the our habitat. Therefore, waste management for waste tires is necessary. Reuse of waste tires in the concrete production process is one of the recycling methods used. This method contributes to have lighter concrete materials and higher toughness and also contributes to elimination of waste. In this study, mechanically cut waste tires having 25, 50 and 75 mm in length were evaluated by replacing the volume of coarse aggregate in Self-Compacting Concrete (SCC). On the concrete specimens, having 5%, 10% and15% (by volume of coarse aggregate) of waste tires, unit weight, slump, 28 day compressive strength, experiments were performed. SEM (Electron Microscope) and EDS (Energy Dispersive Spectroscopy) analyzes of the samples were also investigated. At the end of the study, it was observed that 10% waste tire replacement increased the 28 day compressive strength values of the specimens.

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. 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 previously conducted studies, it is indicated that generally waste tyre rubber usage decreases the durability of the concrete but makes the concrete gain elasticity and toughness (Öztürk 2016).

By using several cutting methods, waste tyres are used in the form of rubber particles, chips and fibres. 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 (Lie et al (1998), Topçu (2008)). The rubber ratio in the concrete has generally replaced between 0-100% according to the aggregate volume but after 20% to 25%, there is observed a systematic decrease in compressive and axial tensile strength of the concrete (Mindness and Young (1981), Neville (2002), Erdoğan (2007)). Due to 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, elasticity module and fracture toughness were studied, however there are not sufficient studies on its positive effects on fracture mechanism of the concrete (Emiroğlu (2012), Khatib and Bayomy, (1999)).

In this study, the rubbers were smoothly cut and the contact surfaces of rubber with cement paste were tried to be controlled and the effect of self-compacted concrete on main characteristics such as unit weight, slump, 28 day compressive strength experiments were investigated.

2 MATERIAL AND METHOD

2.1 Material

Aggregate: Limestone aggregates obtained from Düzce district were used and two different sizes of aggregates as fine (0-5 mm) and coarse (5-12 mm) aggregates were preferred in the study.

Cement: CEM I 42.5R type Portland cement obtained from OYAK Bolu Cement Factory Inc. was used in the study and chemical analysis, physical and mechanical characteristics of the cement is given in Table 1.

Table 1. Physical and mechanical characteristics, and chemical analysis 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	2^{nd} day	31.0
Cl^-	0.0226	7^{th} day	39.7
Loss on Ignition (%)	4.23	28^{th} day	55.4
Undissolved residue	0.73	**Flexural strength (MPa)**	
S.CaO (%)	1.40	28^{th} day	8.4
Mineralogical composition			
C_3S (%)	72.66	C_3A	4.69
C_2S	-	$2Ca_3A+C_3AF$	11.84

Rubber Aggregate (RA): As rubber aggregate, the material called as bladder which applies pressure to the walls of mould during tyre production and is similar to tyre chemistry in a large extent and becomes waste after about 200 use was used. 1.a). Rubber aggregate was prepared by cutting mechanically by guillotine in 3 different lengths as 25 mm, 50 mm and 75 mm and in 5x5 mm cross section 1.b).

Figure 1.a.Bladder

Figure1.b.Rubber Aggregate (25 mm).

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.

Table 2. BFS physical and chemical analysis.

Chemical composition		Physical composition	
SiO_2 (%)	41.00	Start of Setting (hr/min)	02:00
Al_2O_3 (%)	13.32	End of Setting (hr/min)	02:25
Fe_2O_3 (%)	1.11	Specific Weight	2.78
CaO (%)	34.17	Humidity (%)	0.07
MgO (%)	7.29	Specific Surface (cm^2/g)	5048
SO_3 (%)	0.11	Sieve residue (45μ)	0.90
$S^=$	0.72		
Na_2O (%)	0.44		
K_2O (%)	0.96		
TiO_2	0.87		
Mn_2O_3	0.76		
Loss on Ignition (%)	0.14		
Cl^-	0.0158		
(CaO+MgO=/$SiO_{2)}$	1.01		
CaO+MgO+ SiO_2	82.46		
Vitreous Phase	100.00		

Notched Beam Mould: In the study, mould in 240x50x50 mm sample size was used and 10 mm of notch opening was selected. Used notches were produced with 3 mm thick metal pieces.

2.2 Method

In the design of self-compacting concretes, rubber aggregates with 0% (LA0 control), 5% (LA25-5, LA50-5, LA75-5), 10% (LA25-10, LA50-10, LA75-10) and 15% (LA25-15, LA50-15, LA75-15) ratios and with 3 different lengths (25,50 and 75 mm) were used instead of aggregates. Totally 10 series of concrete casting were performed. For each of the series 3 cubic samples with 150 x 150 x 150 mm size and 3 notched beam samples with 240 x 50 x 50 mm size were poured. CEM I 42,5R cement with 3.15 g/cm³ specific weight was used in the mixtures and concretes with 550 kg/m^3 dose were produced.

Sieve analyses as per TS 3530 EN 933-1 standard were made on aggregates. Aggregate granulometry was mixed according to TS 706 EN 12620 standard and mixture granulometry curve was obtained (Figure 2).

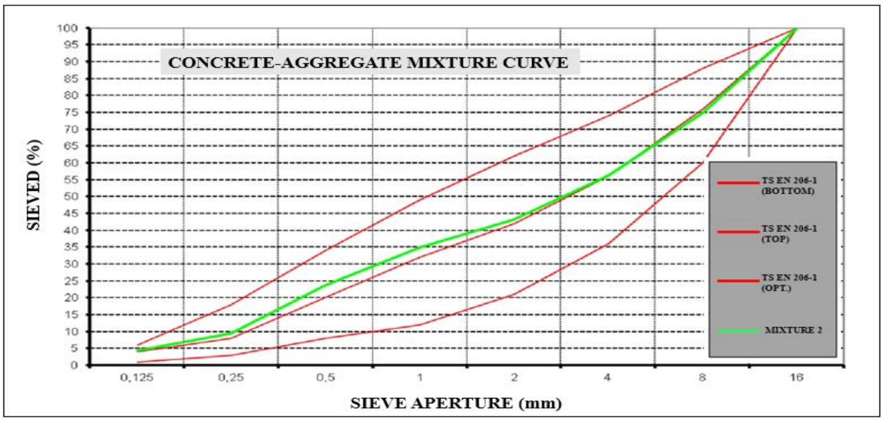

Figure 2. Mixture granulometry curve

Unit Weight Test: Samples placed in a container without any rodding or shaking process for which the volume and tare weight was known were weighed with the container. By subtracting the tare weight from the gross weight, net weight of the concrete was obtained (Wn). Results of unit weight test that was conducted as per TS EN 12350-6 are calculated according to Eq. 1.

$$B = Wn / Vn \ (kg/m^3) \quad (1)$$

B: Unit weight of fresh concrete (kg/m^3)
Wn: Net weight of the concrete in measurement container (kg)
Vn: Calibrated volume of the measurement container (m^3)

Slump-Flow Test: Flow test was performed to determine the plasticity of the fresh concrete by using conventional slump funnel. The surface of the flow plate, which was placed on a completely smooth surface, was wetted and slump funnel was placed on its centre. It was filled with concrete in a single time without making any pressing and the funnel was pulled upwards perpendicular to the table. After the final flow was ended, the diameter of the flowed concrete was measured from two points perpendicular to each other and the arithmetic mean of both diameters was obtained.

Compressive Strength Test: If compressive strength of concrete is known, it is possible to have information about the size of other kinds of strengths. Knowing compressive strength provides qualitative information about other properties of concrete. Compressive strength test was carried out as per TS EN 12390–3 "Determination of compressive strength in hardened concrete samples" standard. For each test series, totally 30 cubic samples of 150x150x150 mm were produced for test in order to break them after 28 days of cure period. Hydraulic press, having 300 tones of capacity with one axis was used in the test and compressive strengths of concrete samples were calculated according to Eq. 4.

$$F_c = F / A_c \tag{4}$$

Fc: Compressive strength (MPa)
F: Maximum load achieved at time of fracture (N)
Ac: Cross sectional area of sample (mm^2)

Scanning Electron Microscope (SEM) and Energy Distribution Spectrometer (EDS): After 28 days of water cure of rubber aggregated concretes having different lengths and replacement percentages, about 150 grams of sample from one batch of concrete mixture (LA25-10) was taken. The surfaces of concrete samples, adherence of them with rubber aggregate and their micro structures were examined by secondary electron imaging method with different zoom ratios by Scanning Electron Microscope /SEM), (Quanta FEG). Concrete samples obtained by SBR were exposed to water cure (28 days) and 150 grams of sample was taken from one batch and EDS analysis were performed on EDASDD Apollo 40 instrument.

3 CONCRETE MIXTURE DESIGN

In the study, SCC samples obtained with the ratios in Table 3 were produced by vertical axis mixer with 100 dm^3 capacity. Firstly, fine, coarse and rubber aggregates were placed into the mixer and mixed for 1 minute; then cement and BFS were added to this mixture and mixed for 2 minutes more. While mixing process continues, 3/4 of concrete mixing water was added and mixing was continued for 1 minute more. 1/4 of the remaining mixing water was added to the mixture with hyperplasticiser and air entrainer and mixed for 3 minutes more. SCC fresh concrete tests were started. Fresh concrete tests were performed in order to determine parameters of SCC mixtures such as processability, passing ability and resistance against segregation. Samples were hold for one day to complete the setting and then placed in a cure bath for which the water temperature was 20±2 ºC for 28 days of cure period.

Table 3. Concrete Mixture Ratios ($1m^3$)

<table>
<tr><th rowspan="2">Ingredients (kg/m³)</th><th colspan="10">Sample Code and Rubber Aggregate Ratios</th></tr>
<tr><th>LA0 (control)</th><th>LA25</th><th>LA25-10</th><th>LA25-15</th><th>LA50-5</th><th>LA50-10</th><th>LA50-15</th><th>LA75-5</th><th>LA75-10</th><th>LA75-15</th></tr>
<tr><td>Cement (CEM I 42.5R)</td><td>375</td><td colspan="3">375</td><td colspan="3">375</td><td colspan="3">375</td></tr>
<tr><td>Blast Furnace Stag</td><td>175</td><td colspan="3">175</td><td colspan="3">175</td><td colspan="3">175</td></tr>
<tr><td>Total Filler</td><td>550</td><td colspan="3">550</td><td colspan="3">550</td><td colspan="3">550</td></tr>
<tr><td>Water</td><td>192.5</td><td colspan="3">192.5</td><td colspan="3">192.5</td><td colspan="3">192.5</td></tr>
<tr><td>Water/Filler</td><td>0.35</td><td colspan="3">0.35</td><td colspan="3">0.35</td><td colspan="3">0.35</td></tr>
<tr><td>Water/Cement</td><td>0.5</td><td colspan="3">0.5</td><td colspan="3">0.5</td><td colspan="3">0.5</td></tr>
<tr><td>Hyperplasticiser (1.46%)</td><td>8</td><td colspan="3">8</td><td colspan="3">8</td><td colspan="3">8</td></tr>
<tr><td>Air entrainer (0.2%)</td><td>1</td><td colspan="3">1</td><td colspan="3">1</td><td colspan="3">1</td></tr>
<tr><td>Thin aggregate (0-5 mm)</td><td>1168</td><td colspan="3">1168</td><td colspan="3">1168</td><td colspan="3">1168</td></tr>
<tr><td>Coarse aggregate (5-12 mm)</td><td>500</td><td colspan="3">475</td><td colspan="3">450</td><td colspan="3">425</td></tr>
<tr><td>Rubber aggregate (5-15 mm)</td><td>-</td><td colspan="3">10.1</td><td colspan="3">20.5</td><td colspan="3">30.4</td></tr>
</table>

4 FINDINGS AND DISCUSSION

4.1 Unit weight and Slump-Flow Tests

Results of unit weight and slump-flow tests for fresh concretes are given in Table 4.

Table 4. Flow and weight for unit volume results of fresh concrete samples

Samples	Weight for Unit Volume (kg/m^3)	Flow (mm)
LA0 (control)	2409	723
LA25-5	2099	740
LA25-10	1953	690
LA25-15	1987	619
LA50-5	2020	756
LA50-10	2095	740
LA50-15	1970	694
LA75-5	2045	772
LA75-10	2153	723
LA75-15	1949	643

When control sample was compared with SCCs replaced with RA, it was observed that replacement with RA decreased the unit weight of fresh concrete. When flow result of mixtures were examined, in all series with 15% RA content and in samples of LA25-10, the flow was not at desired level whereas it was determined to be 70 cm and above for other groups.

4.2 Compressive Strength

Totally 30 cubic concrete samples in 150 x 150 x 150 mm size which consists three samples for each test series were manufactured and their compressive strength for 28 days were examined. Obtained compressive strength values are given in Figure 3.

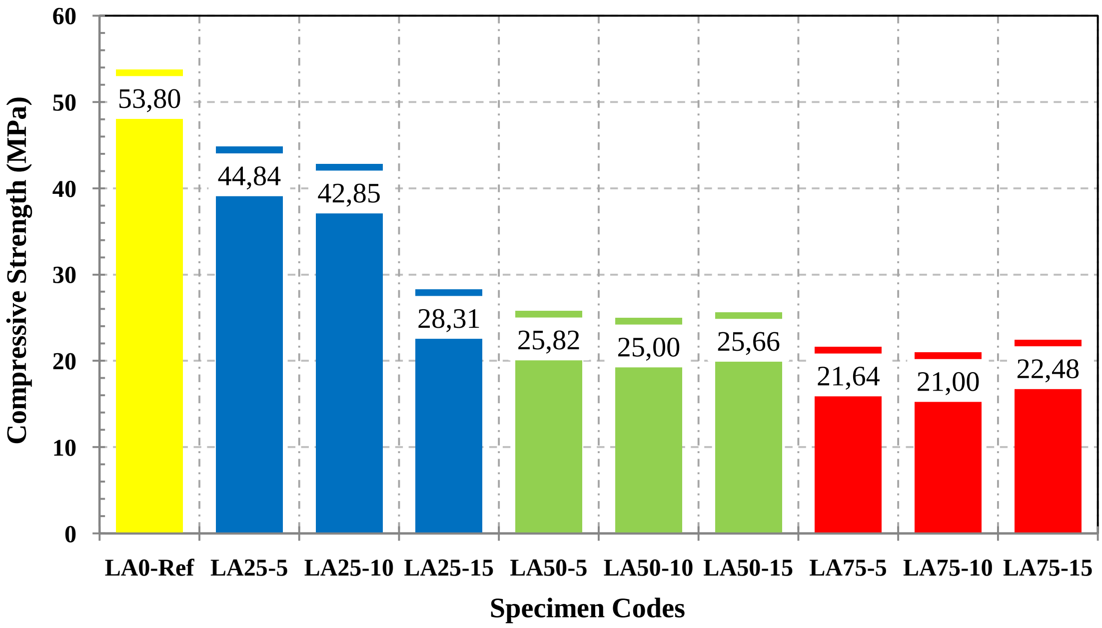

Figure 3. Compressive strength of SCC samples (MPa)

When 28 days of compressive strength of concrete samples were examined to the control sample, in samples with LA25 replacement, for the ones with 5% and 10% replacement it increased by 25% and 30% respectively whereas it decreased by 21% for the ones with 15% replacement. In samples with LA50 replacement, for the ones with 5% and 15% replacement a compressive strength decrease by 28% were observed whereas 14% increase was observed for the sample with 10% replacement. In concrete samples with LA75 replacement, for the sample with 5% and 15% replacement it decreased by 40% and 38%, respectively whereas it increased by 34% for the sample with 10% replacement.

The maximum compressive strength was recorded for control sample (53.8 MPa) and miminum compressive strength was recorded for LA75-10 coded sample (21.0 MPa) in the study. Also, it was determined that 5% and 10% RA replacement in 25 mm length had positive contributions to compressive strength.

4.3 SEM – EDS Analysis

SEM image showing mineralogical structures of concrete samples and EDS analysis are shown in Figure 4. It was observed that there were hydrated phases and non-hydrated cement particles within the structure of the samples.

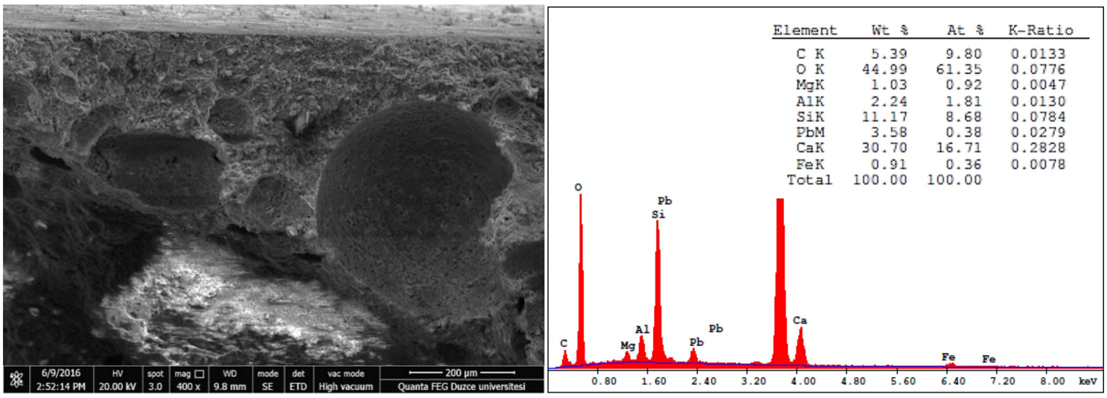

Figure 4. SEM and EDS analyses of samples

5 CONCLUSIONS

Results of tests applied on self compacting concretes prepared with rubber aggregate (RA) (in 25 mm, 50 mm and 75 mm length, 5x5 mm section) addition (in each size separately by 0%, 5%, 10%, 15%) by volumetric replacement of coarse aggregates are listed below.

- When control sample and SCCs with RA replacement were compared, RA replacement was observed to decrease unit weight of fresh concrete.
- When flow result of mixtures were examined, in all series with 15% RA content and in samples coded with LA25-10, the flow was not at desired level, whereas it was determined to be 70 cm and above for other groups.
- In the study, the maximum compressive strength was recorded for control sample

(53.8 MPa) and the minimum compressive strength was recorded for LA75-10 coded sample (21.0 MPa). Also, it was determined that 5% and 10% RA replacement in 25 mm length had positive contributions to compressive strength.

- When SEM and EDS images of samples were examined, it was observed that there were hydrated phase sand non-hydrated cement particles within the structure of the samples.

As a result of the study, it is determined that 25 mm long 10% rubber aggregate replacement to self-compacting concretes can give optimum results in terms of overall examination of the physical and mechanical test results.

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