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Bond performance of rubber particles in the self-compacting concrete

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ABSTRACT: Generating more ductile concrete elements by using waste tire rubbers have been studied for thirty years. Researchers have been produced a lot of rubberized concrete from low strength structure applications to self-compacting concretes having high strength and durability. It is possible to have more flexible concrete while using the fiber shaped waste tire rubbers. Critical problem of use of these rubbers is poor adherence between rubbers and cement paste interface. It is assumed that use of pozzolans with the Portland cement will fix this adherence problem. Therefore, waste tire rubbers have been studied in the self-compacting concrete in order to enhance the problem. Portland cement, grand granulated furnace slag and pozzolanic cement were used together for preparing the self-compacting concretes. Bonding performances of waste tire rubbers and reinforced bars in the self-compacting rubberized concrete were investigated experimentally in this study.

1 INTRODUCTION

There are two types of rubber, natural or synthetic. Natural and synthetic rubbers are mainly consisting of isoprene polymer and styrene-butadiene-copolymer respectively. The waste rubber contains carbon, zinc oxide, iron sulfide, antimony, sulfur and chlorine other than main component. The waste rubber is used in the same manner as waste tires (Chandra 1997). Over the years, disposal of tires has become one of the serious environmental problems. Landfilling is becoming unacceptable because of the rapid depletion of available sites for waste disposal. Large quantities of waste tires are generated each year throughout the world. These stockpiles are dangerous not only due to potential environmental threat, but also from fire hazards and provide breeding grounds for rats, mice, vermines and mosquitoes (Chandra 1997; Siddique 2008).

Reuse the waste vehicle tires becomes increasingly important environmental problem. Use of these wastes in construction sector which is one of the most consumed of the raw materials is very important in terms of environmental protection, sustainability and economic gains (Emiroğlu & Yıldız 2010; Koçak & Alpaslan 2011). The issue of using waste tire rubbers in concrete production has become popular recent years, because of the dream of obtaining more ductile concrete and contributing to the waste recycling. Many studies were performed on the basis of recycling of tires in the pavement and concrete until now. Most of the researchers have been reported that, while economy is major problem for rubber included asphalt pavement, poor bonding between the rubber particles and cement paste is the other problem for rubber included concretes (Rubberized Concrete) (Eldin & Senouci 1993; Khatib & Bayomy 1999, Güneyisi et al. 2004).

2 USE OF TIRE RUBBER AS AGGREGATE REPLACEMENT

The pioneering works on rubberized concretes are Eldin and Senouci (1992) & Khatib and Bayomy (1999). In their studies, fiber or chip shaped waste rubber particles were substituted with the fine or coarse aggregate by volume. They are individually reported that there was systematic reduction in compressive strength while rubber content is increased (Eldin & Senouci 1993; Khatib & Bayomy 1999).

Many of laboratory and researchers investigated physical and mechanical properties of rubberized concretesince two decade. The common view of most of the researchers that, despite the decline occurring in the strength, with the production of rubberized concrete, it can be achieved a composite material that absorbing more energy and obtaining lighter structural element. Besides, some of the studies examine the sound and heat insulation properties of rubberized concrete. They have suggested that heat and sound insulation of rubberized concrete is better than those of plain concrete. A brief summary of literature about the subject is below.

Olivares et al. (2007) represent the results of fatigue behavior of rubberized concrete prismatic specimens. They have used %0, %3.5 and %5 volumetric fractions of rubbers. The prismatic samples were exposed to natural weathering for one year, and then three point bending fatigue tests were performed. As a result, it is presented that the feasibility of using rubberized cement based composite material as a rigid pavement for roads on elastic subgrade (Olivares et al. 2007). Hernandez-Olivares et al. (2002) used crumbed waste tire fibers (average length 12.5 mm) and short polypropylene (PP) fibers (length from 12 to 19 mm) to modify concrete. They concluded that the static strength and stiffness of the modified concrete were not reduced significantly (Olivares et al. 2002). Li et al. (1998) studied the properties of concrete incorporating scrap rubber tire particles and reported that the concrete samples incorporating scrap tire particles set out a ductile failure. In addition, rubberized concrete absorbed a large amount of energy under compressive and flexural loads and ensured good vibration isolation (Li et al. 1998). Kaloush et al. (2006) reported that the high rubber content mixes had a lower flexural strength than plain concrete. But the rubberized concrete mixes had more ductility and comparable toughness values to the plain concrete. Rubberized concretes are more resistant to thermal changes and in all failure tests, the rubberized concrete specimens stayed intact indicating that the rubber particles may be absorbing forces acting upon it (Kaloush et al. 2006). Turgut and Yeşilata (2008), have used the rubber particles for the production of brick. They found that rubber added bricks composites would be a low cost, lightweight and good thermal resistance (Turgut & Yeşilata 2008). Consequently, in many studies, it is reported that rubberized concrete mixes exhibit more ductile properties, but a reduction ofthe mechanical strength is inevitable (Khaloo et al. 2008).

Results of various studies indicate that the mechanical strength of rubberized concrete mixtures is greatly affected by size, proportion, and surface texture of rubber particles, and the type of cement used in such mixtures (Nehdi & Khan 2001). Güneyisi et al. (2004) have used silica fume for improving the bond performance of rubberized concretes. Crumb rubbers and tire chips were used as two types of tire rubber in the mixtures. They have reported that there was a large reduction in the strength and elastic modulus values with the increase in rubber content. However, the silica fume improved the bond performance of matrix (Güneyisi et al. 2004). Segre and Joekes (2000) embedded waste tire rubber powders with NaOH solution and the results showed that NaOH surface treatment increased rubber/cement paste interfacial bonding strength and improved strength and toughness in waste tire powder modified cement mortar (Segre & Joekes 2000). Tantala et al. (1996) tried to pre-treatment on waste rubbers in order to increase the adhesion between the tires and cement paste. They notified that the addition of untreated rubber reduces the compressive strength of concrete, because (without modification) there is little mechanical or chemical adhesion between the rubber and the concrete. The compressive strength of a composite material is typically dictated by the properties of the weakest interfacial link in the material. But, merely washing the rubber particles and letting them dry does slightly increases the strength of rubberized concrete (Tantala et al. 1996).

While the study about rubberized concrete is continuing, since the mid-1980s new developments in concrete technology is provided. Having high fluidity, denser mortar phase, and high viscosity concretes also called self-compacting concrete (SCC) is developed (Bignozzi & Sandrolini 2006). SCC is an engineered material consisting of cement, aggregates, water and admixtures with one or more mineral admixture such as pozzolanic materials, fly ash, granulated blast furnace slag (GGBS), microsilica, metakaolin, and chemical admixtures to take care of specific requirements, such as, high-flowability, compressive strength, high workability, enhanced resistances to chemical or mechanical stresses, lower permeability, durability, resistance against segregation, and passibility under dense reinforcement conditions (Kumar 2006).

In this study, bonding performance of waste tires and reinforced bars were investigated on the rubberized self-compacting concrete (R-SCC) mixtures.

3 MATERIAL AND METHOD

3.1 *Materials and concrete mix design*

Cem I 42,5 R, Cem IV/B (P) 32,5 R, GGBFS, fine and coarse natural aggregates (0-4.75 mm and 4.75-12.5 mm), waste tire rubbers, superplasticizer (SP), air entraining agent (EA), and water were used as raw materials. Tire rubber aggregates (TRA) were prepared by mechanical cutting process, and then fine materials were removed by sieving the TRA on 4.75 mm sieve. TRA used in this study obtained in a fiber shaped form, based on the cutting method. Figure 1 shows the fiber shaped view and rough surface of TRA used in the study. Specific gravities of natural fine, coarse aggregate and the TRA were 2.75, 2.79 and 0.91 respectively.

Mix design compositions of SCC with and without TRA were listed in Table 1.

Substitution of waste rubber by volume with the natural aggregate is a popular method for the production of rubberized concrete and it was used in the study (Khatib & Bayomy 1999; Güneyisi et al. 2004; Emiroğlu et al. 2008; Topçu 1995). A plain (without

TRA) SCC and four different R-SCC mixtures having 15%, 30%, 45% and 60% TRA replacement were produced. Slump-flow and fresh concrete unit weight tests were performed on the concrete specimens.

Figure 1. Tire rubber aggregates used in the study.

Table 1. SCC mix design (1 m^3).

Constituents	SCC Codes-TRA Ratios				
	R0	R15	R30	R45	R60
	0	15	30	45	60
Cem I (kg/m^3)	300	300	300	300	300
Cem IV/B (P) (kg/m^3)	165	165	165	165	165
GGBFS (kg/m^3)	135	135	135	135	135
Total Filler (kg/m^3)	600	600	600	600	600
Water (kg/m^3)	170	170	170	170	170
Water/Filler (kg/m^3)	0,28	0,28	0,28	0,28	0,28
SP (% 1,5) (kg/m^3)	9,00	9,00	9,00	9,00	9,00
EA (% 0,5) (kg/m^3)	3,00	3,00	3,00	3,00	3,00
Fine Natural Aggregate (0-5 mm) (kg/m^3)	1192	1192	1192	1192	1192
Coarse Natural Aggregate (5-12 mm) (kg/m^3)	521	443	364	286	208
TRA (5-12 mm) (kg/m^3)	-	26,6	53,2	79,9	106,5

The specimens were demoulded in a day following casting and then placed in water tank for curing purpose and stayed there until the tests were done. For hardened concrete, all mixes were tested for compressive and bonding strengths at the ages of 7 and 28 days. For the compressive strength tests, 100-mm cube specimens were cast from each batch without compacting or vibrating (TS EN 12390-3, 2003). Bond strength test specimen was a prism with a cross-section of 100 x 100 mm and a length of 150 mm. Each specimen had horizontally bonded reinforcing bars of 14 mm in diameter and 450 mm in length. A rigid plastic sheathing was tightly attached to the loaded end of each bar to limit the bond between the bar and concrete to the remaining portion of the bar. The anchorage length was 100 mm for all bars. The bonded length of each bar was properly cleaned to ensure an adequate bond within the concrete. A schematic picture of the mold for the bonding test is depicted in Figure 2. Three specimens were cast for each mix to check the repeatability ofresults.

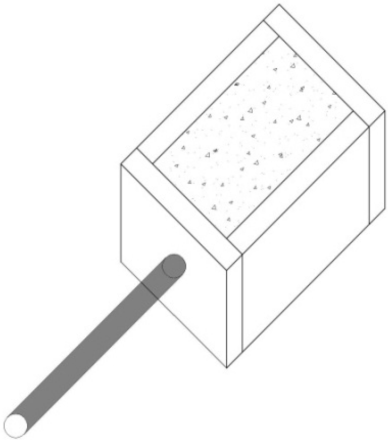

Figure 2. A schematic picture of the bonding test mold.

3.2 *Test method*

The pull-out load is applied progressively up to the bond failure. Figure 3 demonstrates the experimental setup of pull-out tests.

Figure 3. Test setup of pull-out.

The specimens were placed on the universal tensile test machine having a capacity of 50 ton and then pull-out tests were performed with a constant displacement rate of 0,030 mm/s. The test was terminated when pull-out failure occurred; the reinforced steel began to yield, or the surrounding concrete cover failed in split. Bond strength values of the specimens were calculated by using Equation 1.

$$\tau=\frac{P_{max}}{\pi\times l\times\phi}\left(\frac{N}{mm^2}\right) \qquad (1)$$

where τ = bond strength (MPa); Pmax = maximum load (N); l = anchorage length (mm); and Ø = bar diameter (mm).

4 EXPERIMENTAL RESULTS

4.1 *Fresh and Hardened Concrete Properties of R-SCC*

Fresh concrete unit weight, slump-flow, and compressive strength test results of R-SCCare given in Table 2.

Considering the fresh concrete unit weight test results demonstrated in Table 1,a decrease occurs with the increase in the percentage of rubber content because of lower specific gravity of TRA.

When we examine the Table 2, slump-flow values for all the mixtures are between the limits proposed by Efnarc (2005) (Table 3). However, it is clear that when the rubber content increased, the slump flow spread gradually decreases. It is mentioned earlier by Taha et al. (2003) and Turatsinze and Garros (2008) that the reduction on slump flow spread can be attributed to the rough surface of the rubber particles, Figure 1, resulting from a high friction between the TRA and the cement paste (Taha et al. 2003; Turatsinze & Garros 2008). Besides, it is supposed that the fiber shaped dimensions (Fig. 1) of the TRA used in the study affect the slump flow diameter.

Table 2. Fresh and hardened properties of R-SCC.

Experiment/TRA Replacement		SCC Codes-TRA Ratios				
		R0	R15	R30	R45	R60
		0	15	30	45	60
Fresh Concrete Unit Weight (kg/m^3)		2442	2319	2213	2066	1952
Slump-Flow Diameter (mm)		840	775	725	643	615
Compressive Strength (f_c) (MPa)	7^{day}	66.2	62.3	41.4	31.4	27.1
	28^{day}	71.6	63.7	47.2	32.9	25.2

Table 3. Slump-flow classes (Efnarc, 2005).

Class	Slump-Flow Diameter (mm)
SF1	550-650
SF2	660-750
SF3	760-850

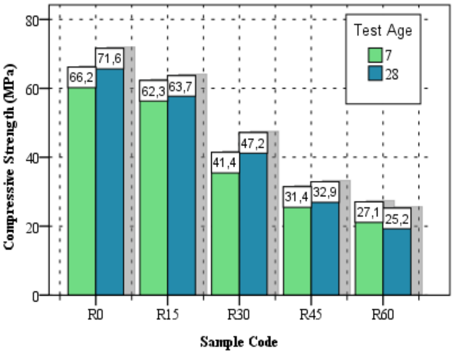

Figure 4. Compressive strength test results of R-SCC.

When compressive strength test results are examined, a decrease of the compressive strength when increasing the rubber content is obtained both at 7 and 28 days tests. Compressive strength test results are presented in Figure 4 in order to clearly demonstrate the systematic reduction in the strength.

Compressive strength test results confirm previous research works performed by different researchers up to now. The authors have also reported that shape and size distribution of rubber aggregates affects some of the concrete properties in terms of fresh and hardened stage (Khatib and Bayomy 1999; Topçu, 1995; Aiello and Leuzzi 2010; Emiroğlu et al. 2008).

4.2 *Bond Performance of Rubber Particle, Reinforced Bar and Cement Paste*

Test results of the bonding strength of all designated R-SCC specimens by the pull-out test are shown in Figure 5.

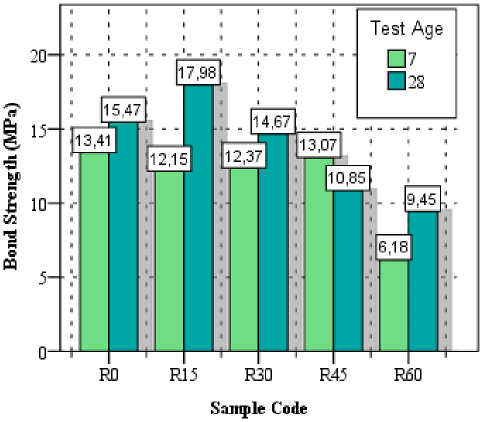

Figure 5. Bond strength test results of R-SCC.

ACI 318 proposes that the bond strength is linearly proportional to the square root of the compressive strength, the values of bond strength are thus normalized bond strength, and the effect of variations in compressive strength eliminated (ACI 318 2005; Zhu et al. 2004; Lachemi et al. 2009). The normalized bond strength ratios of the mixes are shown in Table 4.

Table 4. Normalized bond strength of R-SCC mixtures.

Sample Code	Normalized Bond Strength $(\tau / \sqrt{f_c})$	
	7 Day	28 Day
R0	1,648	1,828
R15	1,539	2,253
R30	1,923	2,135
R45	2,332	1,892
R60	1,187	1,882

As it is reported earlier, the workability properties and compressive strength of concrete play a major role in the pullout bond strength (Lachemi et al. 2009). Depending on the rubber content workability and compressive strength of R-SCC mixtures are gradually affected. For 7 day curing condition, the maximum bond strength values are obtained from 0% TRA included R-SCC mix at the value of 13.41 MPa, while the minimum value obtained from 60% TRA included mix at the value of 6.18 MPa. For 28 day curing condition, the maximum bond strength values are obtained from 15% TRA included R-SCC mix at the value of 17.98 MPa, while the minimum value obtained from %60 TRA included mix at the value of 9.45 MPa.

Concrete is a heterogeneous multiphase material. On a macroscopic scale, it is a mixture of cement paste and fine and coarse aggregates, with a range of sizes and shapes. Regarding to its mechanical behavior, concrete is often considered to be a three-phase composite structure, consisting of aggregate particles, the cement paste matrix in which they are dispersed, and the interfacial transition zone (ITZ) around the aggregate particles and cement paste (Nemati 1997). For the sake of comparison of normal vibrated rubberized concrete (R-NVC) and R-SCC mixes, Scanning Electron Microscopy (SEM) and Optical Microscopy images were mutually evaluated in the study.

In the R-NVC, it is obvious that no interface bonding between cement paste and rubber tire has been maintained. An example of poor adhesion between them is shown in Figure 6 (Emiroğlu et al. 2008).

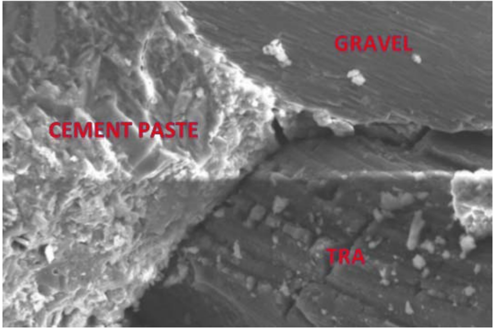

Figure 6. ITZ between TRA and cement paste(Emiroğlu et al. 2008).

Without an interface bonding, stress transfer between fibers and cement paste is possible owing to a mechanical interlocking. No transition layer, or even trace of patch of tire material adhering to the interface, was observed. This suggests that the interfacial bonding strength is weak. Figure 7 shows an example of poor adherence between rubber tire and cement paste. As the rubber tires were being mixed and vibrated, the hard particles of mix impacted and abraded the rubber surface as well as chopping procedure, causing deformation and so intrusions and extrusions (Emiroğlu et al. 2008).

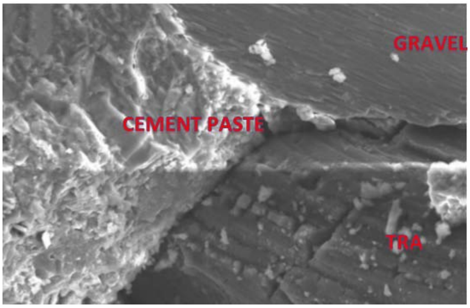

Figure 7. An image of ITZ between rubber tire, aggregate and cement paste (Emiroğlu et al. 2008).

Figure 8 and Figure 9 demonstrate the optical microscopy images of R-SCC mixtures. Based on the 0% TRA included concrete image (Fig. 8) there was a good bonding between natural aggregate (gravel) and cement paste interface.

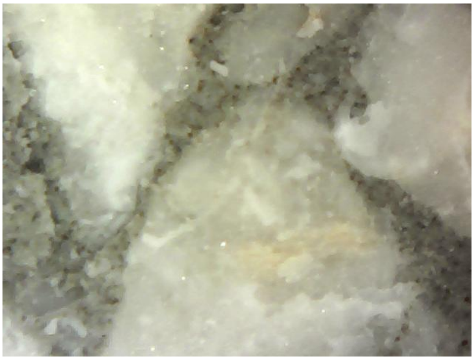

Figure 8. Optical microscopy image of 0% TRA included R-SCC.

Figure 9. Optical microscopy image of R-SCC mixture.

It is clear from Figure 9 that there is no crack formation on the ITZ between rubber particles and cement paste. Emiroğlu et al. (2008) declared that micro-cracks were generated between tire rubber and cement paste in the R-NVC. These cracks usually start at the ITZ, between rubber tires and cement paste, because of poor bonding characteristic around rubber tires and cement paste. There are a lot of micro-cracks near the ITZ in the rubberized concrete (Fig. 7) (Emiroğlu et al. 2008).

It is considered that the use of high volume of finer materials such as GGBFS and other cementitious materials may improve ITZ between TRA and cement paste. In addition, it is assumed that casting process of the fresh concrete can play important role on ITZ performance of R-NVC and R-SCC mixtures. The vibration process of the mortar during casting the R-NVC mixes, most probably, causes air voids and microcracks at the ITZ between TRA and cement paste. For this reason bond performance of R-SCC is better than that of R-NVC concrete mixtures.

5 CONCLUSIONS

Based on the study, the following conclusions can be said;

It is possible to produce R-SCC mixtures between the limit proposed by Efnarc (2005) based on the slump-flow diameter. The slump-flow diameter of R-SCC mixtures is dependent on the rubber content in the mix.

A gradual decrease is occurred in strength value of R-SCC similarly as it is reported earlier by Turatsinze and Garros (2008); Bignozzi and Sandrolini (2006); Topçu and Bilir (2009); Aiello and Leuzzi 2010.

The lowest compressive and bond strength values have been measured on the 60% R-SCC mixture at the end of 7 or 28 days.

The highest compressive strength value has been measured on the 0% R-SCC mixture at the end of 28 day, however the highest bond strength values has been measured on the 15% R-SCC mixture.

It can be possible to obtain a structural grade of R-SCC mixture without compromising more strength. It is possible to obtain minimum 40 MPa compressive strength value while using %30 coarse aggregate replacement with the rubber aggregate.

REFERENCES

ACI Committee 318 2005. Building code requirements for structural concrete (ACI 318-05) and commentary (ACI 318R-05), American Concrete Institute, Farmington Hills, Michigan.

Aiello, M. A., Leuzzi, F. 2010. Waste Tyre Rubberized Concrete: Properties at Fresh and Hardened State, *Waste Management*, 30: 1696-1704.

Bignozzi, M.C. & Sandrolini, F. 2006. Tyre Rubber recycling in Self-compacting Concrete, *Cement and Concrete Research* 36: 735-739.

Chandra, S. 1997. *Waste Materials used in Concrete Manufacturing*. New Jersey: Noyes Publications.

Efnarc 2005. The European Guidelines for Self-compacting Concrete: Specification, Production and Use, The European Federation of Specialist Construction Chemicals and Concrete Systems.

Eldin, N.N. & Senouci, A.B. 1993. Rubber-tire particles as concrete aggregate, *Journal of Materials in Civil Engineering, ASCE* 5 (4): 478-496.

Emiroğlu M. Yıldız, S. Keleştemur, M. H. 2008. An Investigation on ITZ Microstructure of the Concrete Containing Waste Vehicle Tire, *Computers and Concrete* 5 (5): 503-508.

Emiroğlu, M. & Yıldız, S. 2010. The Evaluation of Waste Tyres in Construction Sector, In Arzuhan Burcu Gültekin (Ed.), *International Sustainable Buildings Symposium (ISBS),May 2010,*Ankara, Türkiye, 837-839.

Güneyisi, E. Gesoğlu, M. & Özturan, T. 2004. Properties of Rubberized Concretes containing Silica Fume, *Cement and Concrete Research* 34: 2309-2317.

Kaloush, K.E. Way, G.B. & Zhu, H. 2006. Properties of Crumb Rubber Concrete, *Transportation Research Record: Journal of the Transportation research Board*1914/2005: 8-14.

Khaloo, A.R. Dehestani, M. & Rahmatabadi, P. 2008. Mechanical properties of concrete containing a high volume of tire-rubber particles, *Waste Management* 28 (12): 2472-2482.

Khatib Z.K. & Bayomy F.M. 1999. Rubberized Portland cement concrete, *J. Mater. Civ. Eng.* 11 (3): 206-213.

Koçak, Y. & Alpaslan, L. 2011. Potential Use of Waste Tires in Cement and Concrete Industry, In Ilhami Demir (Ed.) *6th International Advanced Technologies Symposium (IATS'11),* Ankara, 118-122.

Kumar, P. 2006 Self-compacting Concrete: Methods of Testing and Design, *Journal of the Institution of Engineers (INDIA)* 86 (February 2006): 145-150.

Lachemi, M. Bae, S. Hossain, K.M.A. & Sahmaran, M., 2009. Steel-concrete Bond Strength of Lightweight Self-consolidating Concrete, *Material and Structures* 42: 1015-1023.

Nehdi, M. & Khan, A. 2001. Cementitious Composites Containing Recycled Tire Rubber: An Overview of Engineering Properties and Potential Applications, *Cement, Concrete, and Aggregates, CCAGDP* 23 (1): 3-10.

Nemati, K.M. 1997. Fracture analysis of concrete using scanning electron microscopy, *Scanning* 19 (6): 426-430.

Olivares, F.H. Barluenga, G. Bollati, M. & Witoszek, B. 2002. Static and dynamic behaviour of recycled tyre rubber-filled concrete, *Cem. Concr. Res.* 32 (10): 1587-1596.

Olivares, F.H. Barluenga, G. Landa, B.P. Bollati, M. & Witoszek, B. 2007. Fatigue behavior of recycled tire rubber-filled concrete and its implications in the design of rigid pavements, *Construction and Building Material* 21: 1918-1927.

Segre N. & Joekes I. 2000. Use of tire rubber particles as addition to concrete paste*, Cem. Concr. Res*. 30: 1421–1425.

Siddique, R. 2008. *Waste Materials and By-Products in Concrete.* Springer.

Taha, R.M.M. El-Dieb A.S. & Abd El-Wahab M.M. 2003. Fracture toughness of concrete incorporating rubber tire particles. In: El-Dieb A, Reda Taha MM, Lissel SL, (Ed.). *Int. Conf. on Performance of Construction Materials*.

Tantala, M. W. Lepore, J. A. & Zandi, I. 1996. Quasi-Elastic Behavior of Rubber Included Concrete, In Ronald Mersky (Ed.), *12th International Conference on Solid Waste Technology and ManagementPA., 1996*. Philadelphia,.

Topçu, I.B. & Bilir, T. 2009. Experimental Investigation of Some Fresh and Hardened Properties of Rubberized Self-Compacting Concrete, *Materials and Design* 30: 3056-3065.

Topçu, İ.B. 1995. The Properties of Rubberized Concretes, *Cement and Concrete Research* 34: 304-310.

TS EN 12390-3, 2003. Testing hardened concrete-Part 3: Compressive strength of test specimens, Ankara, Turkey.

Turatsinze, A. & Garros, M. 2008. On the Modulus of Elasticity and Strain Capacity of Self-Compacting Concrete Incorporating Rubber Aggregates, *Resources, Conservation and Recycling* 52: 1209-1215.

Turgut P. Yeşilata, B. 2008. Physico-mechanical and thermal performance of newly developed rubber-added bricks, *Energy and Buildings* 40 (5): 679-688.

Z. Li F. Li & J.S.L. Li. 1998. Properties of concrete incorporating rubber tyre particles, *Magazine of Concrete Research* 50: 297-304.

Zhu, W. Sonebi, M. & Bartos, P.J.M. 2004. Bond and Interfacial Properties of Reinforcement in Self-compacting Concrete, *Material and Structures* 37: 442-448.