AN INVESTIGATION ON ITZ MICROSTRUCTURE OF THE CONCRETE CONTAINING WASTE VEHICLE TIRE

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ABSTRACT

Interfacial transition zone (ITZ) microstructure of rubber reinforced concrete has been examined by using Scanning Electron Microscopy (SEM). The rubber reinforced concrete has been prepared in the form consisting of various proportions of waste vehicle tires. The effect of the rubber on interfacial transition zone which exists between tire rubber and cement paste has been investigated. A total of 9 batches of concretes has been prepared. Each batches consists of six cylinders which makes totally fifty four samples of Φ150x300 mm. Compressive strength, split tensile strength, unit weight tests and SEM analysis were conducted on the prepared samples. In this particular study, bonding characteristic and fracture analysis between rubber tires and cement paste have been investigated. Although adhesion between the rubber and cement paste was weak, roughening interface is formed and it constructed a mechanical interlock.

Keywords*:* Rubber reinforced concrete; Scanning electron microscopy (SEM); Interfacial transition zone (ITZ).

1. INTRODUCTION

Management of solid wastes is one of the most important issues around the World. Waste vehicle tires are one of these solid wastes. The disposal of waste tires represents a major issue in the solid waste dilemma because there are more than 242,000,000 scrap tires, approximately one tire per person, generated each year in the United States [1]. It was predicted that approximately 120 000 ton waste vehicle tires were generated in Turkey by the year 2000 [2]. These stockpiles are dangerous not only because they pose a potential environmental threat, but also are fire hazards and provide breeding grounds for mosquitoes [3]. Innovative solutions to cope with the tire disposal problem have long been in development. Among the most promising alternatives are: reuse of ground tire rubber in a variety of rubber and plastic products, thermal incineration of worn-out tires for the production of steam or electricity, and use of tire rubber in asphalt mixes [4].Celik [5] has used recycled tire rubber in asphalt concrete to determine characterization of the fatigue behaviour of rubberized asphaltic concrete and assesses the effect of waste shredded rubber on its fatigue properties. The addition of the rubber is highly significant on the fatigue life of asphaltic concrete. Early studies on the use of worn-out tires in asphalt mixes were very promising. After the experimental studies it is seen that rubberized asphalt had better skid resistance, reduced fatigue cracking, and achieved longer pavement life than conventional asphalt. However, the initial cost of rubberized asphalt is 40 to 100% higher than that of conventional asphalt, and its long-term benefits are uncertain. Likewise, the asphalt industry can currently absorb only 30 to 40% of the scrap tires generated. Moreover, when pavements incorporating these materials are themselves recycled, disposal of the embedded rubber could itself become a serious environmental hazard [4].

Because of these problems more and more attention has been paid to use waste vehicle tires in Portland cement concrete as waste aggregate. This method has low cost with a portion of aggregates replaced by waste tire aggregates and called rubberized concrete. Besides, rubberized concrete results show less unit weight, high toughness despite compressive, split tensile and bending strength reductions. Topcu [6] investigated the effect of particle size and content of tire rubbers on the mechanical properties of concrete. He found that, although the strength was reduced, the plastic capacity was enhanced significantly. Khatib and Bayomy [7] used fine crumb rubber and tire chips to replace a portion of fine or coarse aggregates. They found that the rubber-filled concrete showed a systematic reduction in strength, while its toughness was enhanced. They also proposed a regression equation to estimate the strength of rubber-filled concrete. Güneyisi et al. carried out to develop information about the mechanical properties of rubberized concretes with and without silica fume. They were used crumb rubber and tire chips as fine and coarse aggregate. Test results indicated that there was a large reduction in the strength and modulus values with the increase in rubber content. However, the addition of silica fume into the matris improved the mechanical properties of the rubberized concretes and diminished the rate of strength loss [8]. Segre and Joekes [9] used saturated NaOH solution to treat waste tire rubber powders. They found that NaOH surface treatment increased rubber/cement paste interfacial bonding strength and resulted in an improvement in strength and toughness in waste tire powder modified cement mortar. Hernandez-Olivares et al. [10] used crumbed waste tire fibers (average length 12.5 mm) and short polypropylene (PP) fibers (length from 12 to 19 mm) to modify concrete. Based on the picture they provided, it is estimated that the tire fiber thickness was about 0.5 mm. They concluded that the static strength and stiffness of the modified concrete were not reduced significantly.

The scanning electron microscope (SEM) is one of the most important instruments available for the examination and analysis of microstructural characteristics of materials. The primary reason for the SEM's advantage is the high resolution that can be obtained when they are examined. The electron microscope has been a powerful tool in the examination of cement and concrete since the early development of them. Microscope was particularly first used to study the hydration process of concrete [11]. Then, researchers used the SEM to observe the crack growth and fracture surfaces on the loaded or fractured concrete samples [12, 13].

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. With regard 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 [14].

In some applications of concrete, it is demanded that concrete should have low unit weight, high strength, high toughness and high impact resistance. Although concrete is the most commonly used construction material, it does not always fulfill these requirements. One of the ways to improve these properties might be the addition of the rubber into concrete as an aggregate. For this purpose, the usage of some industrial waste materials in concrete has been investigated during the past few years [15-17].

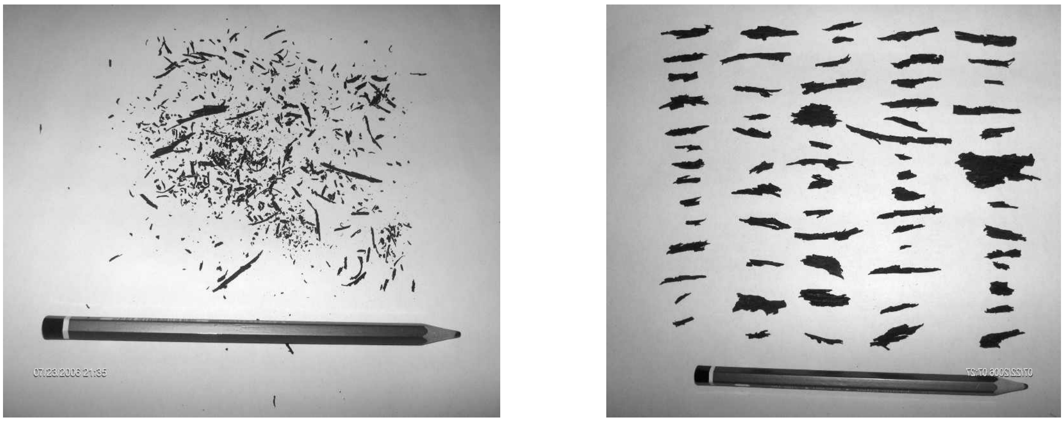
The objectives of this study are to evaluate morphologies of the crack surface and characteristics of rubberized concrete of ITZ between rubber tires and cement paste and traditional aggregate and therefore, to obtain a preliminary understanding of the interfacial bond between them.

2. EXPERIMENTAL PROCEDURE

Type I Portland cement, gravel, natural sand and water were used to prepare control concrete. The control concrete mix designed according to ACI Standard 211.1. Cement content, water/cement ratio and aggregate volume were kept constant in all mixtures.

Fiber shaped waste tire rubbers were produced by mechanical cutting. Cutting machine and shape of waste tire fibers are shown in Fig. 1. Waste tire fibers were divided in two groups by sieving. After the cutting processing, the waste tire fibers were sieved as 0-4 mm and 4-8 mm. Two groups of rubberized concrete mix were prepared.

1. ILB: In this group 0-4 mm sieved tire fibers were replaced with 0-4 mm sieved normal aggregate in the range of 0-20% by the total aggregate volume.
2. KLB: In this group 4-8 mm sieved tire fibers were replaced with 4-8 mm sieved normal aggregate in the range of 0-20% by the total aggregate volume.



a) Tire fiber (0-4 mm) **b)** Tire fiber (4-8 mm)

Figure 1. Waste tire fibers used in this study.

Mix designs of concrete and specific gravities of mix materials are shown in Table 1 and Table 2.

Table 1. Mix designs of concrete (1 m^3 of concrete)

Content	Plain Concrete
Cement (Type I)	418
Coarse aggregate	535
Fine Aggregate	993
Water	230

Table 2. Specific gravities of aggregate and tire rubber.

	Fine Aggregate	Coarse Aggregate	Fine Tire Rubber	Coarse Tire Rubber	Cement
Specific Gravity (gr/cm^3)	2.56	2.56	0.95	0.91	3.02

Water/Binder ratio (0.55) and cement content (418 kg/m^3) were kept constant in all samples. Four designated rubber contents were selected 5%, 10%, 15% and 20% by volume of total aggregate. To unify the rubber content, the range of rubber content was selected as total aggregate volume of plain concrete. Total 54 cube test specimens, *Φ*150x300 mm, were prepared for compressive strength, split tensile strength and unit weight tests.

Some of the test results such as compressive strength, split tensile strength and unit weight of plain and rubberized concretes are listed in Table 3.

Table 3. Mechanical properties of rubberized concrete (28 days)

Properites	Concrete without rubber	5%		10%		15%		20%	
		ILB	KLB	ILB	KLB	ILB	KLB	ILB	KLB
Compressive Strength (MPa)	45.69	41.71	42.49	33.69	37.30	24.75	26.96	22.14	23.91
Split Tensile Strength (MPa)	4.191	3.087	3.741	2.928	3.141	2.622	2.676	2.346	2.238
Unit Weight (kg/m^3)	2258	2190	2190	2120	2120	2050	2050	1980	1980

SEM analysis was carried out in this study to examine the fracture and bond characteristics of rubber reinforced concrete. The SEM samples were collected from the fracture areas after the compressive strength tests. All samples chosen for the SEM analysis were coated with silver/gold for electrical conduction.

2. EXPERIMENTAL RESULTS AND DISCUSSION

The rubberized concrete has to confirm certain requirements for mechanical properties. They are particularly compressive and split tensile strengths. Although these values are considerably decrease with the addition of waste tire pieces as seen in Table 3, their values are still in reasonable range. After the concrete samples were selected for SEM studies, images were taken from each sample. A total of four samples taken from center and edge of the concrete cylinders in axial direction were studied. Fig. 2 shows the SEM image of normal concrete. It is clear that morphology of C-S-H gel appears as type III (denser-almost sphere) in the conventional concrete.

In the rubberized concrete, 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 3. Without an interface bonding, stress transfer between fibers and cement paste is possible owing to a mechanical interlocking. Seperation or breaking of the rubber was not oftenly observed on the fracture surface and generally the rubber appeared on the fracture surface was in the pulled out form. 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 4 shows an example of pulled out a piece of rubber tire. As the rubber tires were being mixed, the hard particles of mix impacted and abraded the rubber surface as well as chopping procedure, causing deformation and so intrusions and extrusions. Grooves and pits also on the surface of the rubber tire fibers, due to its chopped form, the paste and rubber tightly matched. Therefore, strong mechanical interlocking has been established and no dramatic drop on the bending strength is recorded for a certain volume fraction of rubber tire.

Interface structure of three components, cement paste and aggregate and rubber tire, is shown in Figure 5. A strong interface bonding between cement paste and aggregate is established but weak interface bonding between rubber tire and aggregate and cement paste is obvious from the picture.

The SEM images of rubberized concrete showed that cracks generated from voids between rubber tire and cement paste in the concrete. Fig. 6 and Fig 7 show some micrograph of microcracks generated from ITZ between rubber tires and cement paste. It was found that these cracks usually start from ITZ between rubber tires and cement paste because of poor bonding characteristic around rubber tires and cement paste. There are a lot of microcracks near ITZ in rubberized concrete. These microcracks seem clearly in Fig 6.

In rubberized concrete, crack formation is different from plain concrete because bond strength between rubber and cement paste is poor than that of between aggregate and cement paste. Therefore initial cracks were formed around rubber tires and cement paste in rubberized concrete.

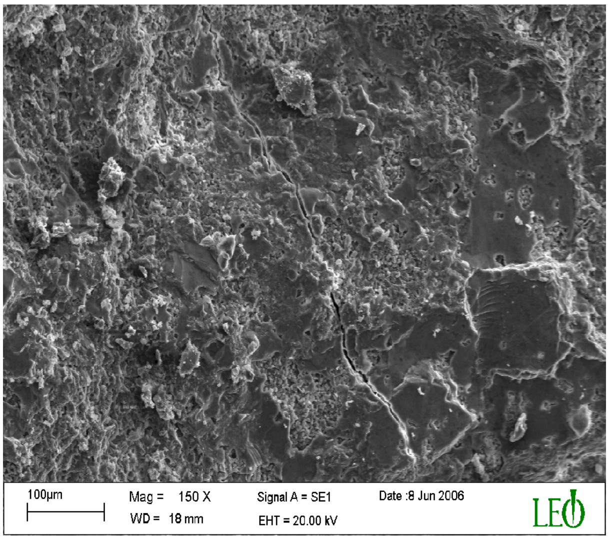


Figure 2. A SEM picture of fractured surface of control specimen.

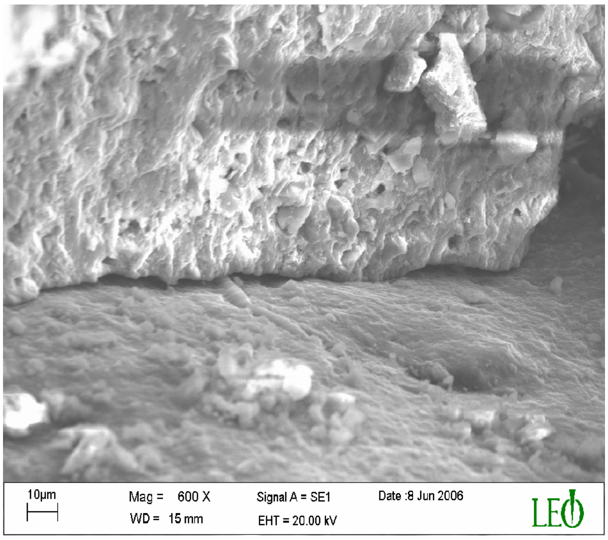


Figure 3. ITZ between rubber and cement

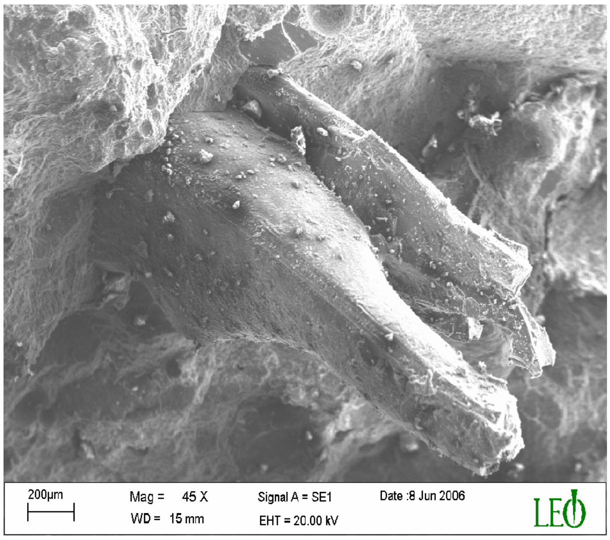


Figure 4. SEM image of pulled out rubber tire

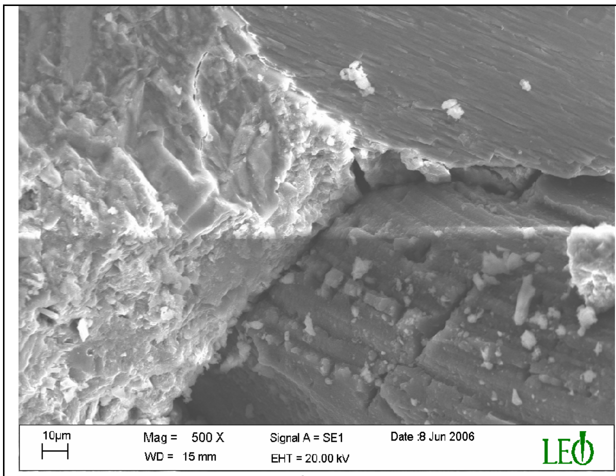


Figure 5. An image of ITZ between rubber tire, aggregate and cement paste

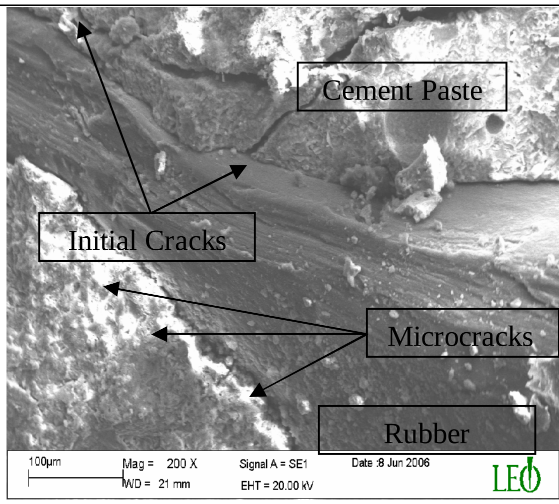


Figure 6. Scanning electron microscopy picture of rubberized concrete

3. CONCLUSIONS

An experimental procedure was conducted which enabled the preservation of the compressive stress-induced microcracks and bonding characteristic in ITZ of rubberized concrete under applied load. Compressive strength and split tensile strength of the rubberized concrete is lower than traditional concrete because bond strength between cement paste and rubber tire particles is poor. Besides, pore structures in rubberized concretes are much more than traditional concrete.

Based on this study, the following conclusions can be said.

1. The ITZ characteristic of rubberized concrete is poor than the traditional concrete. Additionally, strength of a tire rubber is lower than that of traditional aggregate Due to these facts, compressive strength and split tensile strength of rubberized concrete is less than plain concrete.
2. There is systematic reduction in strength data with the increasing of the rubber content in traditional concrete. These reductions are related with the poor bonding characteristic between rubbers and cement paste around the ITZ of rubberized concrete.

3. Although adhesion between the rubber and cement paste was weak, roughening interface is formed and it constructed a mechanical interlock which resisted relative movement of fibers immediately after cracks initiated.
4. C-S-H morphologies of normal and rubberized concrete are same. From the SEM images, the addition of waste tire rubber in normal concrete has not any harmful effect on the C-S-H formation in concrete.

ACKNOWLEDGMENTS

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