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ASSESSMENT OF THE BRITTLENESS INDEX OF RUBBERIZED CONCRETES

İlker Bekir Topçu
Osmangazi University, Civil Eng. Dept., Eskişehir, Türkiye

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ABSTRACT

Many properties of concrete can be changed by adding industrial waste materials in it. In this study, the effect of different amount of rubber chips on the brittleness of rubberized concretes were investigated. These kinds of concretes are used especially in structures which are exposed to crashing effects. The laboratory tests were conducted by using 15, 30 and 45% by weight two different sized coarse aggregate. On the prepared cylindrical specimens loading, unloading and reloading tests were carried out for 7 and 28-day, and σ–ε hysteresis loops were also drawn. Then the brittleness index values of these series were determined. The variation of brittleness index values were evaluated for different amount of rubber chips, compressive strength and toughness values. Finally, it was observed that concretes which contain 15% rubber chips gave the highest brittleness index values with low compressive strength and toughness values. © *1997 Elsevier Science Ltd*

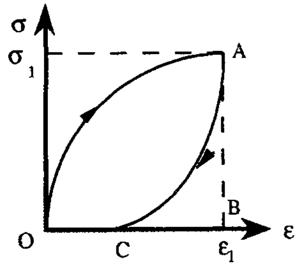
Introduction

In some applications of concrete, it is desired that concrete should have low unit weight, high strength, toughness and impact resistance. Although concrete is the most commonly used construction material, it does not always fulfill these requirements. One of these applications is the use of waste automobile tire chips for this purpose. In order to improve these properties, the use of some industrial waste materials in concrete has been investigated during the past few years. To achieve this goal, waste automobile tire chips were added into concrete.

It is pointed out that the resilience and toughness properties are increased in rubberized concretes (1, 2, 3). One of the first studies about this kind of concrete were made by Rad (4). At the end of his study, it was seen that the compressive strength of the rubberized concrete was nearly 35% of normal concrete compressive strength, and such concretes could be used where the structural properties are not important. Topçu and Özçelikörs (5) searched in their studies for the physical and mechanical properties of the concretes which they added 10 and 30% rubber chips into them. The result of these studies showed that 10% rubber chips addition increased the toughness by 23%. They also suggested that these type of concretes would be useful in places where the load-carrying is not necessary and the sound isolation is necessary. Eser (6) added 10, 20 and 30% rubber chips into the normal C 16 concrete and examined the physical and mechanical properties of this concrete. He concluded that by adding 10% rubber chips the increase at the toughness of the concrete was 23% compared to that of the concrete. For the 28-day concretes, he found out that the reductions in the compressive strength were 94% and 65% for 30% and 10% rubber chips replacements, respectively. Eldin and Senouci (1) used two types of tire chips as coarse aggregate while producing the concrete of the compressive strength 35 MPa and obtained different compound concretes. In the first type of the rubber, they used 25% replaced by rubber chips instead of coarse aggregate which was used in normal concrete. For the second type they used ground rubber instead of sand. It was seen that there were reductions of up to 85% of the compressive strength and up to 50% of the tensile strength after replacing the aggregate and sand by rubber chips. Also it was seen that there was 65% reduction in compressive strength by using the ground rubber instead of the sand. The reason for the strength reduction could be attributed both to a reduction of the quantity of the solid load-carrying material and to stress concentrations in the paste at the boundaries of the rubber aggregate. Since the rubbers absorb more energy the plastic deformation at the time of fracture increases by the rubber replacement. The most important characteristics is σ–ε curves that show the behavior of the concrete under compression. It is explained that the whole energy that is necessary for the fracture of a material is toughness. The area under the curve gives total fracture energy and it's the measure of material toughness.The test results show that concrete specimens containing rubber chips possess high toughness since most of the total energy generated upon fracture is plastic.

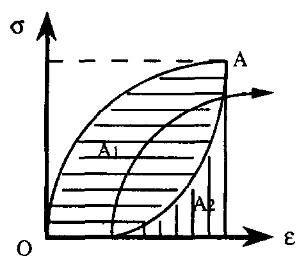
Brittleness of Concrete

Concrete is quite brittle and it is broken easily under very small deformation when it is pressed. For a tough material, most of the total energy generated upon fracture is plastic, while for a brittle material, most of the total energy generated upon fracture is elastic. The energy that material absorbs until it is broken is plastic energy. That's why we are trying to reduce the brittleness of the concrete, briefly, by increasing the plastic energy. It is desired from concrete to have more ductility instead of brittleness. Ductile fracture occures after plastic deformation and contraction. One will be able to know the cause of fracture and so some precautions can be taken before fracture occurs. Here, an attempt was made to give the concrete such a ductile property by adding different materials.



BC : Elastic Deformation
CO : Plastic Deformation

FIG. 1.
Elastic and plastic deformations.



Brittleness Index (BI)=A2/A1

FIG. 2.
Definition of brittleness index.

As seen in Fig.1, ε_1 strain is obtained by applying σ_1 stress to the specimen.This position is shown as OB line. BC line is obtained where the stress is zero. Finally, the total deformation will be the total of elastic and plastic deformation. $\sigma-\varepsilon$ curves are established for repeated loading which is applied by loading, unloading and reloading phases (7, 8). When loading reaches a maximum value which is the concrete carrying capacity or a previously defined value then the loading will be stopped.

Brittleness Index (BI). Toughness values which are measured from the areas under $\sigma-\varepsilon$ curves were examined in two different ways as being plastic and elastic. Irreversible plastic energy that was lost during fracture is shown by A1. Recovering deformation energy that was obtained by unloading just before the fracture is shown by A2 (9, 10). These facts were shown in Fig. 2. BI of a concrete specimen in compression is defined as the ratio of 80-100% of the elastic deformation energy to irreversible deformation energy corresponding to the pre peak point of the stress-strain curve (9). Briefly, BI as seen in Fig. 2, is the ratio of A2 elastic deformation energy to A1 plastic deformation energy. When the ratio A2/A1 approaches to zero, all energies become irreversible, when the ratio A2/A1 goes to infinite all energies become reversible. For the brittle materials such as concrete which has the bigger elastic energy capacity than the plastic energy capacity, brittleness index value will be bigger than the ductile materials. In other words, there's a transition in the material from brittleness to ductility by increasing its brittleness index value (9).

Experiments

In the preparation of all the specimens, ordinary Portland cement containing pozzolan (28-day com pressive strength 32.5 MPa) and 0-4 mm natural sand were used. The unit weight of the sand is 1640 kg/m^3, specific gravity is 2640 kg/m^3, absorption in 30 minutes is 1%, fineness modulus is 2.00. C 16 quality concrete was produced by using blue calcer crushed stone as coarse aggregate. This aggregate has the dimension of 1-16 mm (fine, FC) and 1-31.5 mm (coarse, CC), 1425 and 1400 kg/m^3 unit weight, 2720 and 2700 kg/m^3 specific gravity. The dimension of rubber chip obtained by the mechanical grinding of discarded tires is 0-1 mm, unit weight 427.5 kg/m^3 and specific gravity 650 kg/m^3. Also modulus of elasticity is 5-15 MPa and fineness modulus 1.91. In the experimental studies, three each series of coarse and fine crushed stones with 0-1 mm rubber and two each series C 16 quality concrete without rubber were produced. During these studies two different series of concrete were produced. In the first series d_{max} (maximum size of coarse aggregate) was 16 mm and on the second 31.5 mm. From each series one normal concrete and three rubberized batches

TABLE 1

Mix Proportions of Concrete Series

Mixture		Cement	Sand 0-4	Crushed Stone 4-8	Crushed Stone 8-16	Crushed Stone 16-31.5	Water	Air
d_{max} = 16 mm	kg	347	707	722	364	---	216	0.00
	dm^3	110	268	268	134	---	216	5.00
d_{max} = 31.5mm	kg	307	560	534	423	389	191	0.00
	dm^3	97	212	198	155	141	191	5.00

containing 0-1 mm rubber chips at the ratios of 15, 30 and 45% by weight of aggregate that was replaced. The mixtures belong to C 16 quality concrete were shown in Table 1.

The fracture load of specimens with 30 cm height and 15 cm diameter was determined by loading them under compression. After determining the fracture load, compressive strength was found by dividing the fracture load to the area. The reloading maximum value was found by taking the 80% of the compressive strength and multiplying it with the area. Loading and unloading tests were made in order to define BI. Strains were calculated by dividing the longitudinal deformations to the first length of the specimen. Loading and unloading curves were drawn by σ and ε. Finally, the areas under the loading curves were evaluated and brittleness index values were calculated (11).

Evaluation of Test Results

Hysteresis loops are given for two different types of concrete. Fig.3 is given for normal concrete without rubber chips, and Fig.4 is given for concrete containing 45% rubber chips in it with coarse aggregate concrete (CC). These loops were obtained by loading and reloading tests on specimens. Hysteresis loops for 15 and 30% rubber chips added concretes were found to be between the normal concrete and 45% chips added concrete. Hysteresis loops for fine aggregate with and without rubber chips in them were found to be similar to that obtained with coarse aggregate. When examining these eight different hysteresis loops, it has been found that the slope of normal concretes is steeper than that of the rubber added concretes. The toughness and brittleness index values were determined by examining the areas below the loops as explained above (under the topic of brittleness index).

Evaluation of the Brittleness Index Results. BI of the concretes are obtained from hysteresis loops. BI was calculated as the ratio of 78-84% of the reversible deformation energy to the irreversible deformation energy. In this experiment both FC and CC concretes were studied for obtaining the brittleness index values when the rubber quantity is increased.

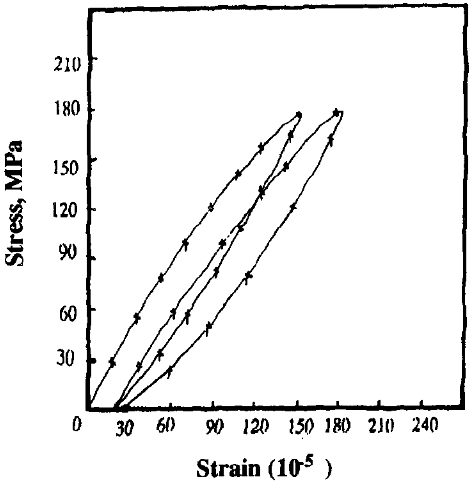


FIG. 3.
Hysteresis loops normal concretes.

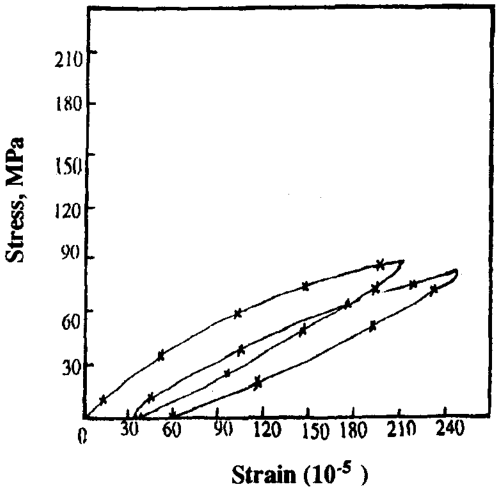


FIG. 4.
Hysteresis loops in concretes contain rubber 45%.

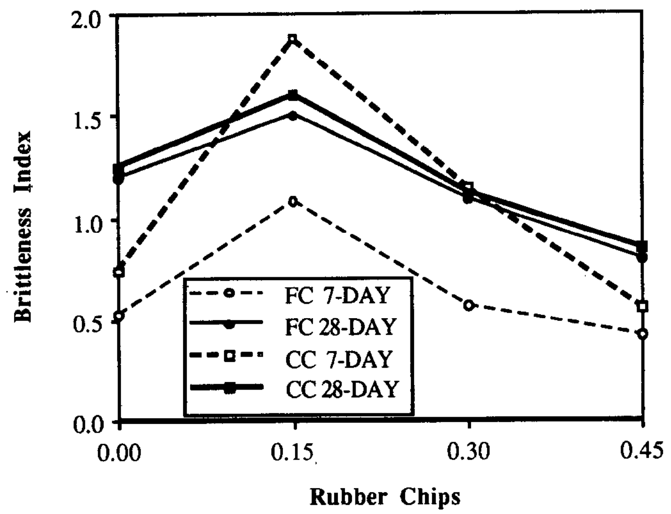


FIG. 5.
Brittleness index values versus amount of rubber chips.

As seen in Fig. 5, the highest BI values were obtained at 15% rubber addition. In the experiments on 7-day specimens, for the normal concrete BI are 0.53 and 0.74, with the addition of 15% rubber chips they are 1.08 and 1.60. For the 28-day normal concrete specimens the BI values are 1.20 and 1.25, with rubber addition they are 1.50 and 1.88. The decreasings of the BI values with rubber additions after 15% show that there is a transition from the brittle material to the ductile material. This is good for concrete. For 15% rubber chips addition, average BI value increasings are 103% for 7-day FC, and 116% for CC and 25% for 28-day FC, and 50% for CC concretes. But for the normal concrete there's a decrease between normal and rubberized concrete containing 45% rubber chips. This decrease

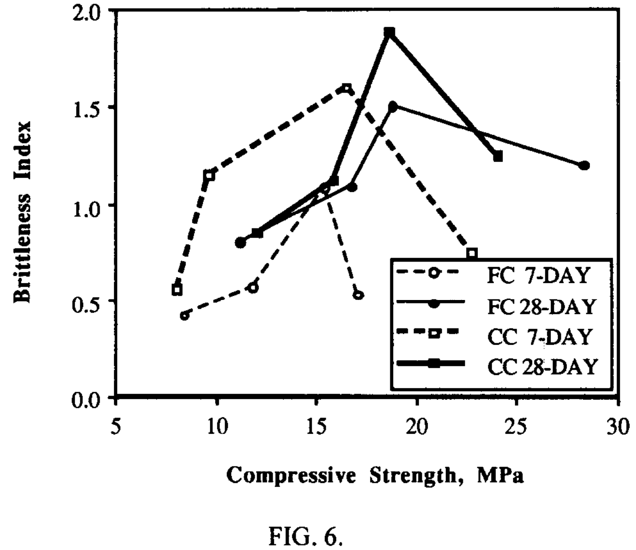


FIG. 6.
Brittleness index values versus compressive strengths.

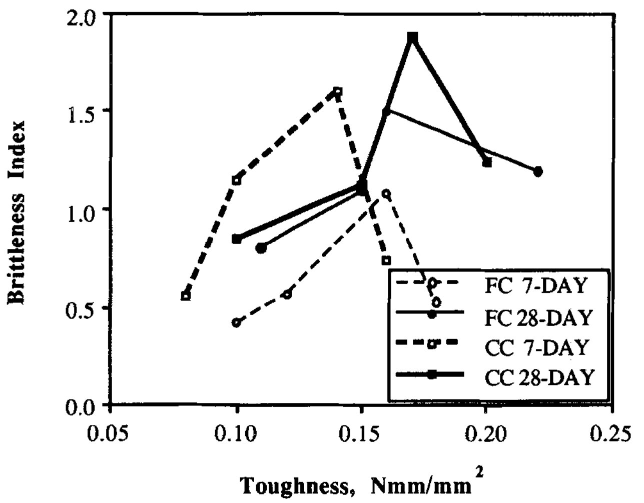


FIG. 7.
Brittleness index values versus toughness values.

is 22% for the FC and 29% for CC concrete. These values are for 7 and 28-day. The variation of the brittleness index values with compressive strengths are given in Fig. 6. All the plots of compressive strength versus BI values have a peak point at the 15% rubber chips addition. Low brittleness index values were obtained for all the rubberized and normal concrete series except 15% series.

The variations of the brittleness index values with the toughness values are given in Fig. 7. There are the same changes as explained above. The peak values are obtained for 15% addition then as the addition ratio is more than 15%, then the BI and compressive strength values are decreased.

After examining the Figs. 5, 6 and 7, it can be said that the highest BI values are obtained for 15% rubber chips addition. More additions of chips change the properties of concrete in the desired way, because lower BI values mean the ductile type behavior. The decreasing on the BI values were provided by lower rubber chips additions than this point. As seen Fig. 6 the BI values of C 16 are between 1.0 and 1.1 for FC and CC. BI value is 1.8 and compressive strength is 18 MPa for 15% rubber chips addition. The BI values of normal concretes is about 1.2 for FC and CC, and lower BI values can be obtained by adding 25% rubber chips addition. BI values are equal for normal concrete and 25% rubber chips added concrete. BI value is 0.8 when the rubber chips addition is 45%. As seen from Fig.6, although there is a difference between the FC and CC concrete BI values for 7-day, but the variations in lines in Fig.6 are similar and there is no big difference for 28-day. As seen in Fig.7, the variation of toughness values versus BI values give similar change as mentioned above. The highest toughness values were obtained when the BI values are 1.5 (CC) and 1.0 (FC) for 7-day, and 1.5 (FC) and 1.8 (CC) for 28-day. There is a peak point in all the variations.

Conclusion

In concretes obtained by adding rubber tire chips from 15% to 45%, compressive strength and toughness values decreased while BI values increased. The highest BI values were obtained at 15% rubber chips addition. Lower BI values were obtained for all the other series. It was also observed that for 7-day, the percent increase in BI values both for FC and CC were the same, which was about 100%. For the 28-day, the BI values increased by 25% for FC and 50% for CC concretes. Finally, it can be said that coarser aggregate concretes should be expected to give higher BI values than the finer ones, for 15% rubber chips addition.

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