ELSEVIER

PII:S0958-9465(95)00010-8

Cement & Concrete Composites 18 (1996) 135–139

0958-9465/96/$15.00

The Use of Rubber Tire Particles in Concrete to Replace Mineral Aggregates

H. A. Toutanji

Department of Civil Engineering, University of Puerto Rico, Mayaguez, Puerto Rico 00681-5000

(Received 25 October 1995; accepted 23 January 1996)

Abstract

The effect of the replacement of mineral coarse aggregate by rubber tire aggregate is investigated in this paper. Four different volume contents of rubber tire chips were used: 25, 50, 75 and 100%. The incorporation of these rubber tire chips in concrete exhibited a reduction in compressive and flexural strengths, the reduction in compressive strength was approximately twice the reduction of the flexural strength. The specimens which contained rubber tire aggregate exhibited ductile failure and underwent significant displacement before fracture. The toughness of flexural specimens was evaluated for plain and rubber tire concrete specimens. The test revealed that high toughness was displayed by specimens containing rubber tire chips as compared to control specimens. Copight © 1996 Elsevier Science Ltd.

Key words: Concrete, rubber tire aggregate, load-deflection, post failure, compression, flexure, toughness.

INTRODUCTION

A wide variety of waste materials has been suggested as viable, or even beneficial, additives to concrete. These waste materials include cellulose, wood lignin, bottom ash, fly ash and silica fume. Rubber from scrap tires is one of the most recent waste materials investigated for its potential use in the construction field.

It is estimated that 285 million tires are discarded annually in the United States, and only 34% (97 million) are currently being used or recycled.[1] The remaining 66% (188 million) contribute to the already alarming environmental solid waste problem. The accumulations of discarded tires provoke fire and health hazards.[2,3] Tires are often shredded to be used as landfills or for producing tire chips and crumb rubber. Most tire shredding equipment is mobile and can be easily moved from one scrap tire stockpile or landfill to another. The shredding process reduces the tire to pieces that are 6 in^2 or smaller.

There are a number of applications of scrap tires,[4–6] including use in reefs and breakwaters, playground equipment, erosion control, highway crash barriers, guard rail posts, noise barriers. They are also used in asphalt pavement mixtures and as fuel in cement kilns and pulp and paper plants.[7–9] At the beginning of 1991, 44 states in the United States of America had passed legislation or regulations addressing scrap tires.[10,11] These regulations are funding the cleanup of tire piles, regulating tire storage and management, and in many cases, providing market incentives for tire recycling and the use of tires for energy.

The objective of this research is to investigate the possibility of using rubber tire chips and particles as a replacement for the mineral aggregates in Portland-cement concrete. In this study the compressive and flexural strengths of rubber tire concrete are evaluated, and the effect of the volume contents of the rubber tire chips on these strengths is also examined.

EXPERIMENTAL PROCEDURE

Materials

The average standard 28-day cylinder compressive strength of the concrete was $f'_c = 31{\cdot}9$ MPa

Table 1. Control mix proportion and strengths

Cement (kg/m³)	*Water (kg/m³)*	*Sand (kg/m³)*	*Crushed stone (kg/m³)*	*Compressive strength (MPa)*	*Flexural strength (MPa)*
365	183	73	1096	31·9	3·8

(4,623 psi) and flexural strength was $f'_c = 3{\cdot}8$ MPa (537 psi), with mix ratio of cement: sand:gravel:water = 1:2:3:0·5 by weight. Table 1 shows the proportions for 1 m³. ASTM Type II portland cement was used. The aggregate consisted of crushed stone coarse aggregate of a maximum size of 19 mm (3/4 in) with a specific gravity of 2·65, and concrete sand with a maximum size of 4·76 mm (3/16 in). The specific gravity of the regular concrete sand was 2·68 and the fineness modulus was 2·56. The water to cement ratio was 0·5.

Shredded rubber tires, produced by Envirocrete 2000®, with a maximum size of 12·7 mm (1/2 in) and a specific gravity of about 0·61, were used. The rubber tire chips were free of steel wires. The particle-size distributions of all aggregates were graded and the particle-size grading of each was within the limits of ASTM C 33. Four different contents of rubber aggregate were used to replace the mineral aggregate, 25, 50, 75 and 100% by volume. No mineral or chemical admixtures were added. In general all mixes, control and rubber tire mixes, exhibited acceptable workability with respect to handling, placement, and finishing. The control mix exhibited a slump of about 76 mm (3 in) and with 100% replacement of the coarse aggregate with rubber particles the slump was decreased by about half to 38 mm (11/2 in). The slump of the rest of the mixes was between 75 and 40 mm. Nevertheless, with the reduction of the slump due the incorporation of rubber aggregate in concrete, the mixes exhibited an acceptable workability with no difficulties in casting and finishing the specimens.

Test specimens

Cylindrical compressive specimens, measuring 100 mm in diameter and 200 mm in height (4 × 8 in) were prepared. All specimens were moist cured for 28 days at a temperature of 29 °C (85 °F) and at a relative humidity in excess of 95%. A total of 50 specimens was made, 25 for compression and 25 for flexure. The strengths were determined in accordance with ASTM C 39, using 300-Kip-capacity universal testing machine. The flexural tensile specimens, measuring 100 × 100 × 350 mm (4 × 4 × 14 in) were prepared. The specimens were tested in accordance with ASTM C 78, the outer and inner spans each being 100 mm, as may be seen in Fig. 1. The four-point bend tests were conducted using an Instron® testing machine. The specimens were loaded at a cross-head speed of 0·5 mm/min. Load and displacement were digitally recorded at a rate of 10 data points per second.

TEST RESULTS

The results of the average compressive strength and flexural tensile strength for control and rubber tire concrete specimens are shown in Table 2. Each of these values represents the average of five specimens.

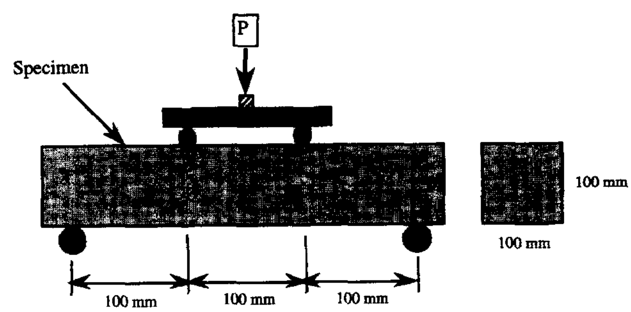

Fig. 1. Four-point bend test.

Table 2. Strength values

Volume of chip rubber aggregate (%)	*Compressive strength MPa (psi)*	*Flexural strength MPa (psi)*
0	31·9 (4,623)	3·8 (548)
25	19·6 (2,846)	3·5 (506)
50	13·8 (1,997)	3·1 (455)
75	9·9 (1,429)	2·8 (411)
100	7·5 (1,094)	2·4 (354)

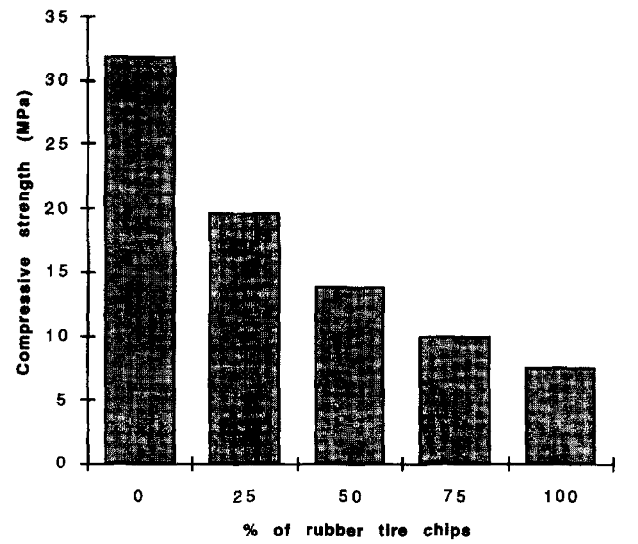

Fig. 2. Compressive strength as a function of percentage of rubber tire chips.

Compressive strength

The effect of the replacement of the coarse mineral aggregate with rubber aggregate on the compressive strength is shown in Fig. 2. Losses in compressive strength were up to 75%, depending on the volume percentage of rubber chips. The specimens containing rubber exhibited post failure compression loads and underwent significant displacement before failure as shown in Fig. 3. Although, the specimens are highly cracked, they were able to withstand some of the ultimate load. This finding is consistent with what was observed by Eldin and Senouci;[12] however, in their work they used a different size of rubber aggregate and their rubber aggregate contained steel wires. The large displacement and deformation which were observed are due to the fact that rubber aggregate has the ability to withstand large deformations. Rubber aggregate particles seem to act as springs and cause a delay in widening the cracks and preventing the catastrophic failure which is usually experienced in plain concrete specimens.

Flexural strength and toughness

A significantly smaller reduction in flexural strength was observed as compared to compressive strength with increases in the tire chip contents. The flexural strength specimens lost up to 35% of their flexural strength, as shown in Fig. 4. Load–deflections of the flexural beam specimens were continuously recorded digitally using a personal computer and a load frame manufacturer's software. Load–deflection curves for specimens containing 0, 50 and 100% rubber aggregate are shown in Fig. 5. As may be seen in Fig. 5, the failure of specimens containing rubber tire chips exhibited a ductile mode of failure as compared to the control specimens. The specimens exhibited a higher capacity to absorb energy. The specimens were capable of withstanding measurable post failure loads and undergoing significant displacement. This was due to the ability of the rubber aggregate to undergo large elastic deformation before the failure of the specimen took place. The failure was initiated in the extreme fiber of

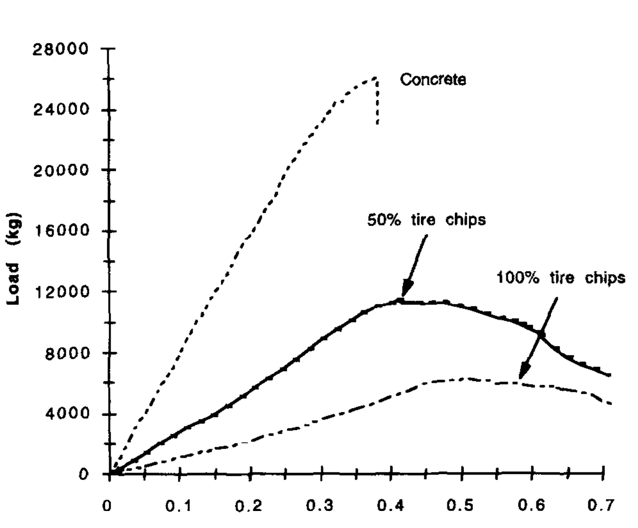

Fig. 3. Load–deflection curves for plain and rubber tire concrete cylinders.

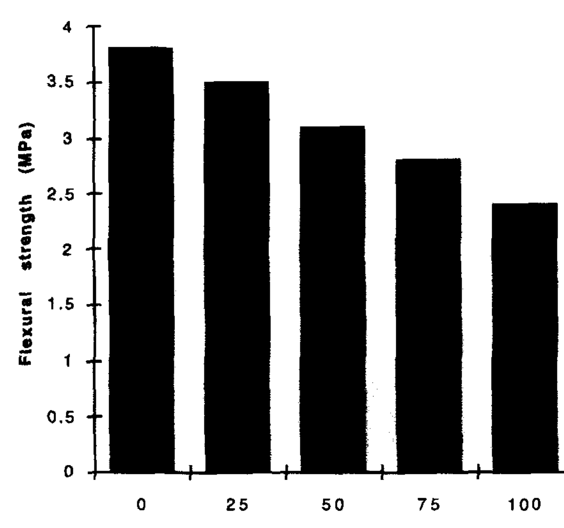

Fig. 4. Flexural strength as a function of percentage of rubber tire chips.

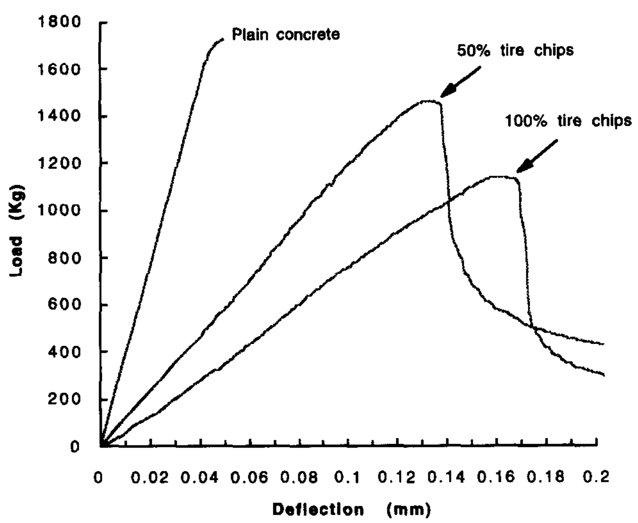

Fig. 5. Load–deflection curves for plain and rubber tire concrete beams.

the tension region of the beam specimens in which cracks propagated in the mortar until they reached the rubber aggregate. When cracks reached the rubber particles and, because of their elastic properties and low modulus of elasticity, the rubber particles prolonged and sustained a portion of the applied load, which leads to an increase in the area of the failure surface.

Figure 6 shows that the reduction in compressive and flexural strengths is due to the incorporation of rubber tire aggregate in concrete. The reduction in compressive strength was significantly higher than that in flexural strength, and the relationship between the rubber aggregate content in concrete and percent of reduction in strength were not linear in either measures of strengths, as may be seen in Fig. 6.

To study the toughness of the flexural specimens, toughness tests based on the area under the load–deflection curve at a flexural load equal to 85% of P_{max}. The toughness value was calculated as a ratio between the area under the load–deflection up to 85% of P_{max} and the area under the load–deflection corresponding to an approximation of the limit of elastic behavior. Figure 7 illustrates how each of the areas were determined. A best-fit line to linear portion of the load–deflection graph for each specimen was obtained by linear regression analysis. This line was then extrapolated to intersect with the maximum load sustained by the beam. The area under the load–deflection corresponding to this intersection is referred to as A_1. The area under the load–deflection up to 85% of the load is referred to as A_2. It should be noted that the 85% factor of P_{max} was only selected for the purpose of comparison, other values can also be used. Thus, the toughness value (T_n) can be expressed as follows:

$$T_n = A_2/A_1$$

In the case of the control specimens, Δ_1, was about the same as Δ_2. The toughness was almost the same for specimens containing 50 and 100% tire chips, which was equal to 1·21. For the concrete specimens (0% tire chips), T_n was equal to one. Thus, specimens with rubber tire aggregate exhibited greater toughness as compared to the control specimens; however,

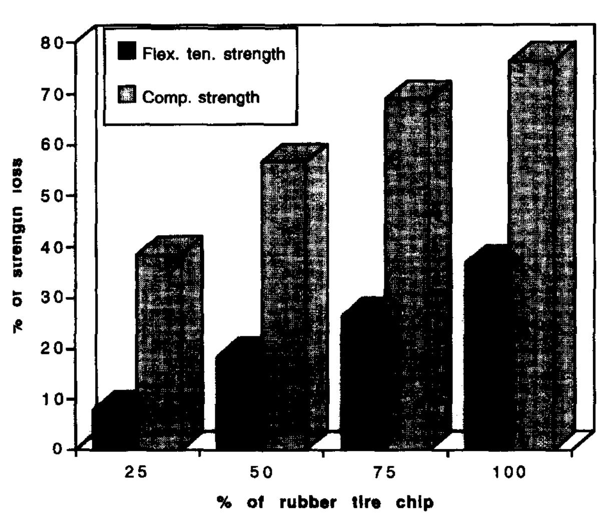

Fig. 6. Loss of strength due to the replacement of the coarse mineral aggregate by tire chip aggregate.

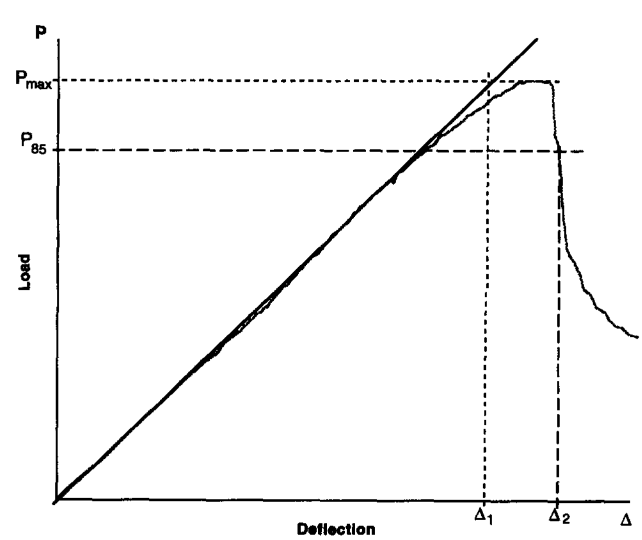

Fig. 7. Determination of areas to calculate beam toughness.

toughness did not increase with an increase in the rubber content volume from 50 to 100% in the concrete specimens. The ratio of the elastic region to that of plastic of specimens for 50 and 100% rubber tire chip specimens was about the same.

CONCLUSIONS

The replacement of mineral coarse aggregate by shredded rubber tire chips causes a reduction in both compressive and flexural strengths. The reduction in compressive strength was greater than for the flexural strength. The reduction in both strengths increased with increasing the rubber aggregate volume content. The relationship between the reduction in strength and volume of rubber aggregate in concrete is not linear.

The toughness increased when rubber tire is incorporated into concrete. Specimens with 50 and 100% rubber tire aggregate exhibit equal toughness values.

Although more research is needed to study the properties of rubber tire concrete, the reduction in strength due to the incorporation of rubber tire chips in concrete makes this composite less attractive in the construction field at this time, particularly in the design of structural elements. More research should be focused on maximizing the mix design and the incorporation of mineral admixtures to improve strength.

At present, it is suggested that rubber tire concrete be used in crash barriers on roads and highways, in applications such as sound barriers and vibration absorbency, and in agricultural purposes as fences and poles.

ACKNOWLEDGEMENT

The author would like to acknowledge the financial support of the National Science Foundation CAREER Grant CMS-9501541.

REFERENCES

1. Franklin Associates, Ltd. and Hershey, R. L., *Markets for Scrap Tires*. Report No. EPA/530-SW 90-074A, Environmental Protection Agency, Office of Solid Waste, October 1991.
2. Guidelines for using recycled tire carcasses in highway maintenance. Report Prepared by the California Department of Transportation, Office of Transportation Laboratory, Sacramento, 1987.
3. Statewide market study for used tires. Report Prepared by Resource Conservative Consultants, Michigan DNR.
4. Pilisbury, H., Markets for scrap tires: An EPA Assessment. *Resource Recycling*, (1991) 19–24.
5. Farcasiu, M., Another use for old tires. *Chemtech*, (1993) 22–4.
6. Perma-Post: Guideline and applications of the use of shredded rubber tire. Report produced by Envirocrete 2000 Inc., Bellingham, WA, 1992.
7. Shuler, T. S., Pavlovich, R. D., Epps, J. A. & Adams, C. K., Investigation of materials and structural properties of asphalt–rubber paving mixture. Report No. FHWA/RD-861027, FHWA, US Department of Transportation, September 1986.
8. Sladek, T., *Disposal Techniques with Energy Recovery for Scrapped Vehicle Tires*. City and County of Denver, Colorado, 1987.
9. Tarricone, P., Recycled roads. *Civil Engineering*, **63** (1993) 46–9.
10. Silkora, M., Third annual legislative update. *Scrap Tire News*, **5** (1991) 14.
11. Heitzman, M. A., Design & construction of asphalt paving materials with crumb rubber modifier. *Recycled Tire Rubber in Asphalt Pavements*, Transportation Research Board Report, TRP no. 1339, Washington DC 1992.
12. Eldin, N. N. and Senouci, A. B., Rubber-tire particles as concrete aggregate. *Journal of Materials in Civil Engineering*, **5** (1993) 478–96.