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# EVALUATION OF TIRE RUBBER DISPOSAL IN CONCRETE FOR PAVEMENTS

Rosa Cristina Cecche Lintz[1] and Maria Rachel Russo Seydell[1*]

[1]*Center for Exact Sciences, Environmental and Technology, Civil and Environmental Engineering, Pontifical Catholic University of Campinas, São Paulo, Brazil*

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**Abstract:** The production of waste by the tire industry has been a growing problem, indicating the need for its reuse. More than thirty million tires are discharged per year in Brazil, where regulation for the environment states that for each four new tires, five unusable ones must be adequately disposed by manufacturers and importers. Paving consumes an extremely large quantity of materials, which can be the source of rational application of waste and rejected materials. Research shows that tire rubber can be added to asphalt, which increases its durability and improves pavement quality and safety conditions by absorbing the rubber elastic properties, and also be used for architectural applications, among others. This study deals with the addition of rubber fibers from tire crushing in concrete for roadway pavements in order to provide proper indication about the alternative material disposal through an evaluation of the mechanical behavior of the modified concrete. Different concrete mixes were produced, within which, part of fine aggregates were substituted by tire rubber and mechanical experiment tests were performed, which show that, due to great resistance losses, the disposal of this alternative material in concrete should be considered for light traffic pavements, with the addition of rubber ranging up to 10% in mass.

**Keywords:** Reuse; tire rubber; pavements; concrete; mechanical behavior



[*] Correspondence to: Maria Rachel Russo Seydell, Tel.: +55 19 3343 7370, E-mail: mrachel@puc-campinas.edu.br

## INTRODUCTION

More than thirty million tires are discharged per year in Brazil. It is very important that researchers indicate solutions for the adequate disposition of this alternative material. They have discovered that tire rubber can actually be used in roadway pavements.

Paving consumes an extremely large amount of materials, being a source of rational application of waste and rejected materials, either natural, altered, processed or modified.

The addition of tires in asphalt helps to preserve the environment and to improve the quality of flexible pavements. Studies have shown that asphalt with rubber improves safety conditions by absorbing the rubber elastic properties (Oda & Fernandes Jr., 2001).

Rubber pasture can be used in industrial floors, railing rubber, traffic obstacles and shoe soles. Research is being conducted to find out how to use the whole rubber waste material, whether for the contention of river margins to avoid landslides, for the construction of artificial reefs for fish raising, moles, or equipment for children playgrounds. The Penn State Institute of the Environment at Penn State University is presently studying the use of whole tires in pavement sub-base.

In Brazil, the regulation for final destination of this material was published by the Brazilian National Council of the Environment – CONAMA, in its Resolution 258/1999. According to the resolution, for each four new tires, manufacture and import companies must give final destination to five unusable tires.

The construction segment has been able to absorb industrial waste materials, therefore helping to reduce the exploitation of non renewable natural aggregates and the incorrect destination of unusable materials.

According to Topçu (1995), the properties of concrete with rubber are influenced by rubber granulometry. Rubber course aggregates affect concrete properties more negatively than rubber fine aggregates. The author also verifies that rubber concrete has good properties for architectural applications, road constructions where high strengths are not required, wall panels which require low unit weight, construction elements and barriers subjected to impact.

Hernandéz-Olivares *et al.* (2002) indicate that the difficulties for concrete application are the rigid behavior of concrete and its easy-to-crack characteristic at early ages, due to plastic shrinkage. However, according to Albuquerque *et al.* (2002), the addition of rubber can improve some concrete characteristics, such as flexibility, elasticity and capacity to absorb energy and impact.

Xi *et al*. (2004) concludes that in order to reuse solid wastes, such as rubber particles from waste tires, extensive experimental studies were performed for developing a different type of concrete – a rubber modified concrete. His experimental results show that this type of concrete has some unique properties, with potentials to be used in various applications.

Traffic noise, within a frequency ratio of 250 to 4,000 Hz, has grown in metropolitan areas and sound barriers are being added to roads to minimize the problem. Zhu *et al*. (2008) show, through acoustic absorption coefficient measurements, that crushed rubber may represent a viable alternative for concrete barriers in roadways.

For the dimensioning of concrete pavements, according to Rodrigues & Montardo (2002) and Massucato *et al.* (2005), it is recommended that the flexural strength, within the period of 28 days should be greater than 4.2 MPa, compression strength should not be less than 30 MPa and the slump test for fresh concrete should be of 80 to 100 mm for a cement consumption of 350 to 450 kg/m$^3$.

The production of waste materials by the tire industry has been an increasing worldwide problem, indicating the need for its reuse, although not with acceptance of lower quality.

In this context, this study deals with the evaluation of the mechanical behavior of concrete, modified by the addition of rubber fibers resulted from tire crushing, to be used in roadway pavements. The study of a concrete trace used in roadway pavements for the reference mixture is proposed, from which substitutions of sand aggregate by rubber residues in growing percentages are performed. Flexural and compression resistance are evaluated and, based in the literature review, the technical viability for the dimensioning of concrete pavements in Brazil is verified.

## EXPERIMENT PROGRAM

The influence of the addition of rubber fibers in concrete was studied from static tests performed in cylindrical specimens. Different concrete traces were produced, within which, part of the fine aggregates were substituted by tire rubber in 0, 10, 20, 30 and 40% in mass.

Material characterization and static experiment tests were performed, such as compression, flexural and tensile strength by diameter compression during the periods of 7 and 28 days.

The concrete traces were sampled with the use of two fractions of rubber with maximum characteristic dimensions of 4.8 and 2.4 mm.

For all mixtures, compression strength (NBR 5739), tensile strength by diametric compression (NBR 7222) and flexural strength (NBR 12142) static tests were performed.

The concretes were mixed in the inclined axle intermittent rotating canister (NBR 5738). The materials addition was performed in the following order: coarse aggregates, part of the water (with additives), cement, sand, rubber and the rest of the water.

**Table 1.** Concrete composition with and without rubber

| MATERIALS | CONSUMPTION (kg/m$^3$) |
|---|---|
| Reference concrete $C_R$ | |
| Cement | 443 |
| Fine aggregate – artificial sand | 212 |
| Fine aggregate – natural sand | 314 |
| Coarse aggregate – $B_0$ | 638 |
| Coarse aggregate – $B_1$ | 638 |
| Rubber fibers (0%) | 0 |
| Water | 179 |
| Polyfunctional admixture | 1.772 |
| Air-entraining admixture | 0.08 |
| Concrete $C_1$ | |
| Cement | 443 |
| Fine aggregate – artificial sand | 212 |
| Fine aggregate – natural sand | 283 |
| Coarse aggregate – $B_0$ | 638 |
| Coarse aggregate – $B_1$ | 638 |
| Rubber fibers (10%) | 31 |
| Water | 179 |
| Polyfunctional admixture | 1.772 |
| Air-entraining admixture | 0.08 |
| Concrete $C_2$ | |
| Cement | 443 |
| Fine aggregate – artificial sand | 212 |
| Fine aggregate – natural sand | 251 |
| Coarse aggregate – $B_0$ | 638 |
| Coarse aggregate – $B_1$ | 638 |
| Rubber fibers (20%) | 63 |
| Water | 179 |
| Polyfunctional admixture | 1.772 |
| Air-entraining admixture | 0.08 |
| Concrete $C_3$ | |
| Cement | 443 |
| Fine aggregate – artificial sand | 212 |
| Fine aggregate – natural sand | 220 |
| Coarse aggregate – $B_0$ | 638 |
| Coarse aggregate – $B_1$ | 638 |
| Rubber fibers (30%) | 94 |
| Water | 179 |
| Polyfunctional admixture | 1.772 |
| Air-entraining admixture | 0.08 |
| Concrete $C_4$ | |
| Cement | 443 |
| Fine aggregate – artificial sand | 212 |
| Fine aggregate – natural sand | 189 |
| Coarse aggregate – $B_0$ | 638 |
| Coarse aggregate – $B_1$ | 638 |
| Rubber fibers (40%) | 125 |
| Water | 179 |
| Polyfunctional admixture | 1.772 |
| Air-entraining admixture | 0.08 |

The consumption of cement is of 443 kg/m³ and the water/cement text is maintained constant. The concrete composition is shown in **Table 1**.

The cylindrical specimens (10×20 cm) were molded on vibratory table at the average temperature of 23 ± 2°C and relative air humidity between 49.5 and 62% and were cured submersed in water tank saturated with lime, for 28 days, in accordance to NBR 5738. After the cure process, the specimens were remolded, recapped and sent for laboratory tests.

**Table 2.** Physical characteristics of CP III 40 RS type cement

| Setting time initial (min) | 203 |
|---|---|
| Setting time final (min) | 273 |
| Residue in sieve 325 (%) | 2.5 |
| Residue in sieve 400 (%) | 5.3 |
| Blaine specific surface (cm$^2$/g) | 4443 |
| Water for normal consistency a/c (%) | 30 |
| Compressive strength (MPa) | |
| 1 day | 12.2 |
| 3 days | 30.3 |
| 7 days | 41.2 |
| 28 days | 53.2 |
| Loss in fire (%) | 2.31 |
| Insoluble residue (%) | 0.85 |
| $SO_3$ (%) | 2.08 |

## MATERIALS

The CP III 40 RS Portland cement characteristics are shown in **Table 2**.

The natural aggregate was used as follows:

(a) Natural fine aggregate of quartz origin and artificial fine aggregate of basaltic origin. The natural sand presented maximum characteristic dimension of 1.2 mm and the artificial fine aggregate presented maximum characteristic dimension of 4.8 mm (NBR 7211).

(b) Coarse aggregate of basaltic origin. Two types of grinded aggregate were used: grinded 0 (maximum characteristic dimension of 9.5 mm) and grinded 1 (maximum characteristic dimension of 12.5 mm).

(c) Vulcanized rubber fibers were obtained from light truck refurbish tires with maximum characteristic dimension of 4.8 mm and 2.4 mm (**Fig. 1**).


**Fig. 1** Rubber maximum characteristic dimension 4.8 mm.

**Table 3.** Specific mass of the materials

| Materials | Apparent specific mass (kg/L) | Absolute specific mass (kg/L) |
|---|---|---|
| Fine aggregate – artificial sand | - | 3.06 |
| Fine aggregate – natural sand | 1.54 | 2.63 |
| Coarse aggregate – $B_0$ | 1.56 | 2.93 |
| Coarse aggregate – $B_1$ | - | 3.04 |
| Rubber (4.8 mm) | 0.39 | 0.88 |
| Rubber (2.4 mm) | 0.24 | 0.90 |

### Physical Characterization of the Materials

The Chapman bottle was used for rubber absolute specific mass test, in accordance with NBR NM 52, in which water was substituted by ethyl alcohol.

The absolute specific mass of the mineral aggregate was determined according to NBR NM 52 for the sand and to NBR NM 53 for the grinded aggregate. The aggregate in loose state had their unit mass determined in accordance with NBR 7251 requirements.

For aggregate characterization and classification related to granulometry, mechanical straining was performed following the requirements of NBR 7211.

**Table 3** presents the physical characteristics of the materials used in the mixtures.

## LABORATORY TESTS

### Compression Strength Test

The compression strength test was performed using 10 × 20 cm cylindrical specimens, tested at the age of 7 and 28 days. The load was applied continuously, without shock, with constant growing tension until specimen rupture (NBR 5739).

### Tensile Strength Test

For the tensile strength by diametric compression test, 10 × 20 cm cylindrical specimens were tested at the ages of 7 and 28 days, fractured in a universal press, under constant loading speed (NBR 7222).

### Flexural Strength Test

For the flexural strength test, 75 × 15 × 15 cm prismatic specimens (**Fig. 2**) were subjected to rupture at the ages of 7 and 28 days (NBR 12142). Rupture occurred at the third average distance between the support elements, and the flexural strength was calculated by the **Eq. (1)**:

**Fig. 2** Flexural strength test.

$$f_{ctm} = \frac{pl}{bd^2} \tag{1}$$

where $f_{ctm}$ = flexural strength (MPa); $P$ = rupture load (N); $l$ = distance between the support bars (mm); $b$ = specimen average width at the rupture section (mm); $d$ = specimen average height at the rupture section (mm).

### Slump Test

The workability of the concrete was measured by the slump test for each mixture (NBR NM67).

## ANALYSIS OF THE TEST RESULTS

**Table 4** presents the results obtained from the mechanical tests, in accordance with the percentages of rejected materials that were incorporated to the mixtures. **Table 5** presents the resistance losses compared to the reference concrete.

By analyzing the average compression strength, tensile strength by diametric compression and flexural strength presented in **Table 5**, after 7 days, we find that the mixtures $C_1$, $C_2$, $C_3$ and $C_4$ presented average compression strength corresponding respectively to 51.7, 35.4, 31.7 and 9.5% of the value obtained for this property compared to the reference concrete. One can verify that the values of compression strength for the mixtures $C_2$ and $C_3$ are close and, also, for substitutions over 30%, the loss of strength increases, as shown by the mixture $C_4$.

**Table 4.** Mechanical test results

| Concrete | Compression strength (MPa) | | Tensile strength (MPa) | | Flexural Strength (MPa) | |
|---|---|---|---|---|---|---|
| | 7 days | 28 days | 7 days | 28 days | 7 days | 28 days |
| $C_R$ (0%) | 51.70 | 54.20 | 3.30 | 4.60 | 6.45 | 7.07 |
| $C_1$ (10%) | 26.72 | 31.80 | 2.54 | 3.39 | 5.10 | 5.15 |
| $C_2$ (20%) | 18.30 | 23.10 | 2.05 | 2.11 | 3.37 | 3.40 |
| $C_3$ (30%) | 16.40 | 21.20 | 1.54 | 2.10 | 3.07 | 3.10 |
| $C_4$ (40%) | 4.90 | 5.97 | 1.00 | 1.22 | 1.61 | 1.64 |

**Table 5.** Percentage of resistance in relation to the reference concrete

| Concrete | Compression strength (%) | | Tensile strength (%) | | Flexural Strength (%) | |
|---|---|---|---|---|---|---|
| | 7 days | 28 days | 7 days | 28 days | 7 days | 28 days |
| $C_1$ (10%) | 51.7 | 58.6 | 76.9 | 73.7 | 79.0 | 72.8 |
| $C_2$ (20%) | 35.4 | 42.6 | 62.1 | 45.8 | 52.2 | 48.0 |
| $C_3$ (30%) | 31.7 | 39.1 | 46.6 | 45.6 | 47.6 | 43.8 |
| $C_4$ (40%) | 9.5 | 11.0 | 30.3 | 26.5 | 24.9 | 23.2 |

There was a tendency of reduction of the compression strength with the increased amount of substitution of sand by rubber. However, the reduction has not occurred in a linear form. A tendency of 48% reduction of the compression strength was observed for the substitution of 10% of sand by tire rubber and more than 65% reduction for the other mixtures.

Comparing the values of tensile strength, we observe that the mixtures $C_1$, $C_2$, $C_3$ and $C_4$ presented a lower decrease in the flexural strength values in relation to the reference mixture ($C_R$) than in the tensile strength by diametrical compression.

At 28 days of age, the gain of compression strength of the concrete mixtures is higher for the mixtures containing rubber than for the reference mixture. On the other hand, for the tensile strength the gain for the concrete with rubber is of approximately 33% and, for the flexural strength, it was shown that the gain for this mixture is less meaningful.

At this age, it was observed a compression strength reduction of 42, 58 and 60% for the 10, 20 and 30% mixtures, respectively, in relation of the reference concrete. For the tensile strength the reduction is less meaningful for the 10% mixture.

The mixture with 10% of rubber substitution presents the mechanical properties related to tensile and compression strength required for the dimensioning of pavements in Brazil (Rodrigues & Montardo, 2002; Massucato *et al.*, 2005).

The effect of the increasing substitution of sand by rubber in concrete has affected the consistence of the mixture in the fresh state. The workability of the concrete was measured by the slump test and the consistence index obtained for each mixture were 92 mm for the reference concrete $C_R$, 89 mm for $C_1$, 86 mm for $C_2$, 83 mm for $C_3$ and 80 mm for $C_4$.

Considering that rubber can improve some concrete characteristics as flexibility, elasticity and capacity to absorb energy and impact (Hernandéz-Olivares *et al.*, 2002), future research should be conducted to determine fracture tenacity and rupture of rubber concrete aiming its application in the manufacturing of pre-moulded elements to be used as contention and sound roadway barriers.

## CONCLUSIONS

Based on the concrete mechanical properties studied, with and without rubber, the results obtained from the tests were relevant.

Results show that the composites containing rubber had a considerable loss in compression strength when compared to the reference concrete (without rubber). Mixtures with 20 and 30% of waste material presented similar average compression strength, indicating that, for percentages over 30%, the loss of strength reaches 90% in comparison with the mixture without rubber.

For the tensile strength, the substitution of 30% of the aggregates by rubber presented loss in tensile strength by diametric compression, as well as in flexural strength, of approximately 55% compared to the reference mixture.

Due to the resistance losses verified, in order to maintain flexural strength up to 4.2 MPa and compression strength up to 30 MPa at the age of 28 days, the addition of rubber to concrete should not exceed 10%.

The study of the literature and the great resistance losses verified in this study experiment program show that concrete pavement must not be used for greater amounts of rubber residue disposals, which can be properly used in other pavement layers providing more efficiency and better technical conditions.

For future research, considering that rubber can improve some concrete characteristics such as its flexibility, elasticity and capacity to absorb energy and impact (Hernandéz-Olivares *et al.*, 2002), further studies to determine fracture tenacity and rupture of rubber concrete, aiming its application in the manufacturing pre-molded elements to be used as contention and sound roadway barriers are recommended.

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