Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1806-2563
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v35i1.11283

Mechanical properties of structural concrete with partial replacement of fine aggregate by tire rubber

Laura Granzotto[1*] and Rafael Alves de Souza[2]

*[1]Programa de Pós-graduação em Engenharia Urbana, Universidade Estadual de Maringá, Av. Colombo, 5790, 87020-900, Maringá, Paraná, Brazil. [2]Departamento de Engenharia Civil, Universidade Estadual de Maringá, Maringá, Paraná, Brazil. *Author for correspondence. E-mail: rsouza@uem.br*

ABSTRACT. The urbanization of big cities, the reduced number and size of landfills, the population growth rate, and the increased use of disposables have generated an expressive volume of waste in the environment. Some waste materials have been reused in recent years, as for example, those generated by the civil construction. However, other types of waste are not experiencing the same situation, such as tire rubbers. One alternative for the reutilization of this material consists of using their powder to replace the fine aggregate in the composition of concrete. This study presents experiments on normal strength concrete mixed with different rates of rubber powder. Results reveal the possibility of obtaining an optimum rate of powder incorporation without harming the compressive and tensile strength of concrete.

Keywords: residue, alternative materials, sustainability, civil construction.

Propriedades mecânicas do concreto estrutural com substituição parcial da areia por borracha de pneu

RESUMO. O processo de urbanização nas grandes cidades, a diminuição da quantidade e tamanho dos aterros, o crescimento populacional e a maior utilização de materiais descartáveis geram um expressivo aumento do número de resíduos gerados no meio ambiente. Nas últimas décadas, tem-se observado o reaproveitamento de alguns tipos de resíduos, como por exemplo, aqueles produzidos pela construção civil. Porém, a mesma situação não ocorre para outros tipos de resíduos, como por exemplo, a borracha dos pneus de automóveis. Uma alternativa para o reaproveitamento de pneus inservíveis consiste na utilização do pó de borracha como material de substituição parcial do agregado miúdo na composição do concreto. Dessa maneira, o presente trabalho apresenta experimentos com concretos de resistência normal com diferentes taxas de adição de pó de borracha. Os resultados obtidos revelam que é possível se obter uma taxa ótima de adição sem que ocorram perdas significativas para a resistência à compressão e à tração do concreto com adições.

Palavras-chave: resíduo, materiais alternativo, sustentabilidade, construção civil.

Introduction

The world population has focused on the concepts of sustainability and several segments related to science and technology are proposing alternatives to control or minimize damages caused by the indiscriminate consumption of raw materials and by the large volume of waste produced. The recycling of waste is a viable alternative and civil construction is a promising sector to absorb these materials.

The construction industry has been contributing for some damages to nature, mainly due to the high volume of debris generated. As solution for this problem, the debris generated in constructions as well waste materials from other industries such as tires, plastics, glass and shoe soles could be used as aggregates in the composition of concretes and mortars.

Tire is an example of the richness of urban garbage and it is easily found in landfills, dumps, open stockpiles, roadsides and rivers. Besides representing a waste, it can cause serious problems such as soil contamination, rivers pollution, in addition to being a refuge for disease vectors, such as dengue.

The Brazilian National Association of Tire Industry (http://www.anip.com.br) states that the chemical composition of tire rubber is usually 20% carbon, 7% hydrogen, 1.2% zinc oxide, 1.3% sulfur, 15% iron and 5.5% other components. These components form a structure hard to be naturally eliminated, with a long term degradation, around 400 to 800 years, becoming a huge problem to the environment. A recent study from the mentioned organization revealed that of the 22 million tires annually exchanged in Brazil, 53.2% are useless (can no longer run on automotive vehicles) and 46.8% are possible to be reformed under evaluation.

The rubber from tires or the material itself are attractive for using as a by-product, once the carcass obtained from recycling is easy to transport. Besides that, the carcass obtained from tires offers no major risks, has standardized geometrical sizes and also has high resistance to weathering and aging. In accordance with NBR 10004 (ABNT, 2004a), NBR 10005 (ABNT, 2004b) and NBR 10006 (ABNT, 2004c), any waste tire from retreading or shredding can be considered as a suitable waste for utilization in the composition of concrete or mortar in civil constructions.

In Brazil, procedures on how to use waste tires is a issue of great discussion in the scientific field. Discussions regarding what to do with thousands of tires disposed inappropriately and not attending the current regulations in the country is gradually taking place. According to the Brazilian National Environment Council - Conama (2009) the Resolution 416 aims to regulate the management of waste tires, considering that tires inadequately disposed are environmental liabilities, and may result in serious risks to the environment and public health.

In this way, it is necessary to ensure that this liability is allocated in an environmentally appropriate and safe way. In the Article 1, the Resolution 416 determines that manufacturers and importers of new tires, each weighing more than 2.0 kg, are obliged to collect and properly dispose the waste tires in the national territory, in proportions defined by the mentioned Resolution.

According to the Resolution No. 416 of Conama (2009), the environmentally suitable disposal of waste tires are based on technical procedures in which tires are uncharacterized to their previous form and their constituent elements are reused, recycled or processed by techniques permitted by the environmental authorities. These techniques must follow the current legislation and specific operational standards to prevent damage or risks to public health and safety as well as to minimize environmental impacts.

Taking into account this context, this paper aims at presenting the behavior of concrete produced with different proportions of fine aggregate of waste tire rubber. The influence of different levels of replacement of natural fine aggregate by recycled materials have been investigated and the properties of fresh concrete (workability and mass density) and hardened concrete (compressive strength and tensile strength) were analyzed.

The results obtained in this research have confirmed previous experimental results published before in the literature. In general way, there is a decrease in the tensile and compressive strength due to the lack of bonding between rubber and Portland cement and this decrease is proportional to the quantity of rubber content (ELDIN; SENOUCI, 1993; FATTUHI; CLARK, 1996; SUKONTASUKKUL; CHAIKAEW, 2006; CANOVA et al., 2007; FIORITI et al., 2010). Workability and elastic modulus is also found to decrease as the percentage of rubber increases (ELDIN; SENOUCI, 1993).

The conclusions evaluated in this study take into account the use of materials with specific characteristics of the region. In this way, would be interesting to conduct new researches using similar methodology in other regions, in order to confirm the quality of the results obtained herein.

Material and methods

Representative samples of tire aggregates were collected from the tire processing company Resibras, located at Apucarana, Paraná State. In the mentioned company, the tires collected undergo the process of separation, shredding and sieving, where the rubber is separated from the other components of tires. In a final process, the material is classified according to its width. Based on this initial classification performed by the company, the waste collected has an average thickness of 2 mm.

In laboratory the material undergoes further analyses before its utilization as fine aggregate, such as: aggregates particle size distribution (or gradation), weight density and mass density. The particle size distribution of the tire aggregates was performed following the rules contained in NBR 7211 (ABNT, 2009a) and the results obtained are listed in the Table 1.

Table 1. Particle size distribution.

Property	Sand	Rubber	Gravel
Maximum diameter	1.2 mm	1.2 mm	19 mm
Fineness modulus	2.87	3.85	8.91
Classification (NBR 7211:2009)	Medium	Medium	Gravel #1

According to NBR 7211 (ABNT, 2009a) the rubber used can be classified as fine aggregate, once its particle size distribution was close to the limits imposed by the standard and within the characterization recommended by NBR NM ISO 3310-1 (ABNT, 2010). This last code classifies as fine aggregate, the material whose 95% of its content can pass through a 4.8 mm-sieve.

The rubber waste is made up by several types of particles with different shapes and sizes. The highest percentage was retained in the 1.2 mm-sieve and the predominant shape is constituted by grains with some small fiber particles. The residue retained on the bottom of the sieves was not discarded and were also incorporated in the constitution of the concrete, in order to simulate a real situation.

The mass density of the aggregates has been obtained through the tests described in NBR NM 45 (ABNT, 2006). By another hand, the weight density of the aggregates has been obtained by using the tests described in the NBR NM 52 (ABNT, 2009b). Table 2 illustrates the obtained results for the mass and weight density of the aggregates.

Table 2. Mass density and weight density of the aggregates.

Material	Mass density (kg m^{-3})	Weight density (kg m^{-3})
Sand	1,557	2,654
Tire rubber	468	570
Gravel #1	1,680	1,784

Considering the purpose of this study of building pavements using waste tire as fine aggregate, it has been selected the variables that mechanically characterize concrete: compressive strength and tensile strength. For evaluating the mentioned parameters it has been used waste tires defined in proportions relative to sand in weight of 5, 10 and 15%.

In agreement with Helene and Terzian (2001), one of the most important parameters related to the dosage is the water/cement ratio and the definition of employed materials. With all previous data of the materials, it was determined the initial mix proportioning of 1:2:3 (cement:sand:gravel). The percentages of rubber were replaced relative to the sand weight, and the amount of water necessary has presented little variations for obtain a homogeneous concrete.

After defined the intervals of some parameters (amount of water and percentage of waste tire), it has been defined the parameters that should be held constant during the experimental program:

a) Type of materials: cement and gravel used in the study was CP II-Z-32 and Gravel #1, respectively;
b) Concrete age: ages of 7 and 28 days have been selected as the standard ages for testing compressive strength and tensile strength (diametral compression);
c) Curing type: specimens have experienced a curing cycle of 24 hours in normal conditions. Later, the specimens were introduced in a moist chamber up to the age of 7 and 28 days for the tests;
d) Slump: the workability determined by the slump-test was set between 50 and 70 mm.

In order to keep the same slump and verify the variations especially presented on the compressive strength, the mix design presented different levels of water in order to obtain a homogeneous mass. In this way, it was carried out the mix design for the standard concrete and for the concrete with waste tire, besides of a previous definition of water/cement ratio. Based on this procedure, the experiment program conducted to 8 types of concrete dosages. For each dosage presented in Table 3, groups of 18 specimens have been tested to axial compression and diametral compression, producing results for 144 specimens.

Table 3. Mixture proportions for concrete with waste tire replacing sand.

Concrete		Mixture proportioning 1:2:3 (cement: fine aggregate: coarse aggregate)				
		Cement	Sand	Rubber	Gravel	w/c
C20	Standard	1	2	0	3	0.63
	5%	1	1.9	0.1	3	0.58
	10%	1	1.8	0.2	3	0.55
	15%	1	1.7	0.3	3	0.55
C25	Standard	1	2	0	3	0.54
	5%	1	1.9	0.1	3	0.58
	10%	1	1.8	0.2	3	0.58
	15%	1	1.7	0.3	3	0.57

Results and discussion

The concrete workability is affected by the aggregate properties. Rheological properties related to the shape and particle size of aggregates and consumption of water necessary to achieve a certain workability (property related to shape, texture and absorption of the aggregate) are the major parameters related to the aggregates.

The average weigh density of the fresh concrete was measured following the prescriptions of the NBR 9833 (ABNT, 2008) and results are presented in Table 4. By another hand, NBR 5738 (ABNT, 2003) guided the procedures for molding and curing the specimens. The mixture was placed in cylindrical molds, with 0.10 m of diameter and 0.20 m height, greased with mineral oil to ease the removal after drying (period of 24 hours).

Considering the workability, the slump of the standard concrete reached the goal. However, with the incorporation of waste rubber aggregate, a decrease in most cases has been observed. In that way, the addition of different percentages of water was necessary in order to maintain the same slump obtained in the standard concrete (0.065 m).

Table 4. Average weight density for fresh concrete.

Material	Weight density (kg m^{-3})
Concrete C20	2430
Concrete C20 + 5%	2364
Concrete C20 + 10%	2259
Concrete C20 + 15%	2188
Concrete C25	2420
Concrete C25 + 5%	2344
Concrete C25 + 10%	2298
Concrete C25 + 15%	2239

Metha and Monteiro (1994) reported that the shape and texture of aggregate particles may affect the mixture workability. By analyzing the waste rubber used, it was observed an uneven granular format and small portion of fibers, which may explain the reduced concrete workability, once the shape and texture in this case may have hindered the packaging of particles.

The compressive strength of the specimens has been measured as recommended by NBR 5739 (ABNT, 2007). As one can observe in Figures 1 and 2, with the replacement of sand particles by rubber the average concrete compressive strength has decreased.

Figure 1 shows that concrete C20 with replacements of 5 to 10% of sand by rubber presents a small reduction in the compressive strength for the age of 7 days. For the age of 28 days the losses are higher for levels above 5% of substitution. Figure 2 shows almost the same trend for concrete C25 except by the fact that for the age of 7 days, substitutions above 5% will generate more losses.

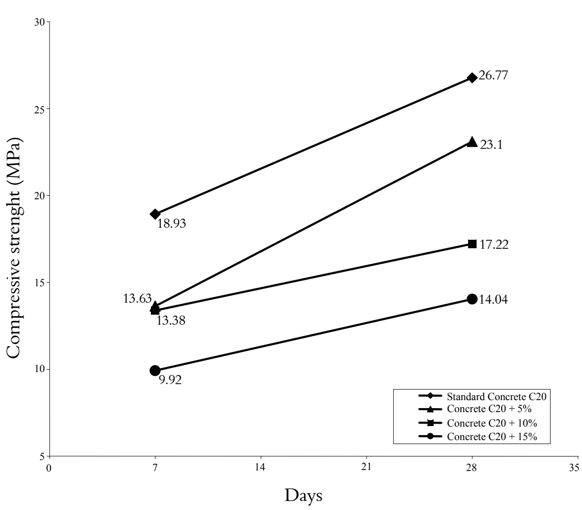

Figure 1. Compressive strength for standard concrete C20 with waste tires.

Testes have been conducted for measuring tensile strength by means of diametral compression ("Brazilian Test") were developed according to NBR 7222 (ABNT, 2011) and the average results are shown in Figures 3 and 4.

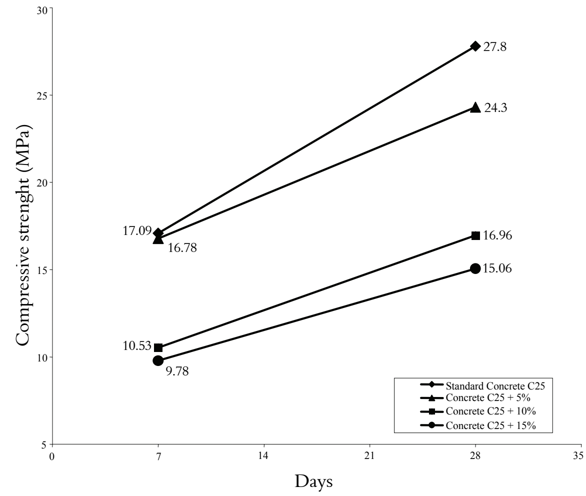

Figure 2. Compressive strength for standard concrete C25 with waste tires.

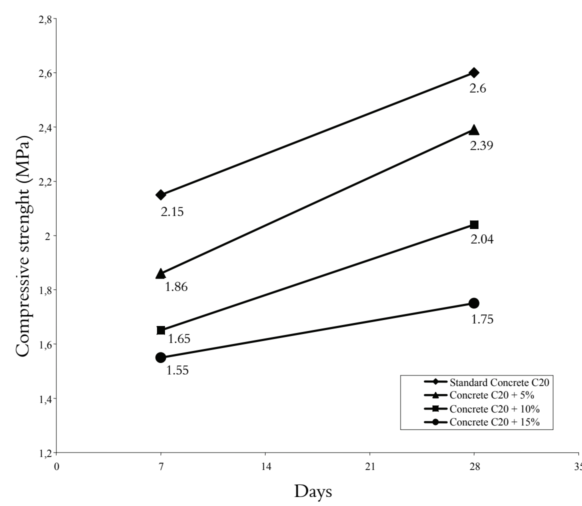

Figure 3. Tensile strength for standard concrete C20 with waste tires.

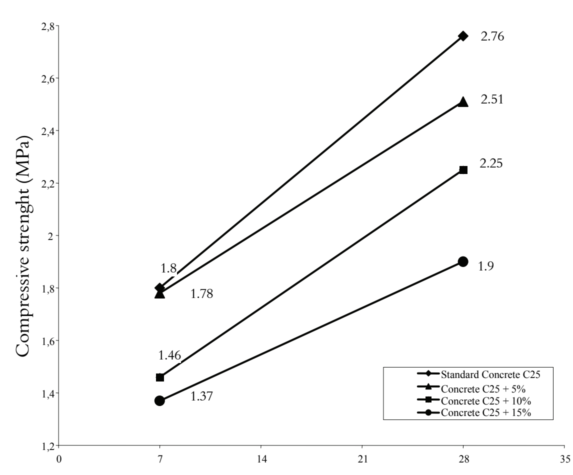

Figure 4. Tensile strength for standard concrete C25 with waste tires.

For concretes with partial replacement of sand by rubber, the losses in the tensile strength regarding the standard concrete were small only for additions up to 10%. For additions above 10% a more significant reduction in the tensile strength can be observed.

Figures 2 and 4 shows that for early ages (7 days) and concrete C25, an addition of rubber of 5% will not produce impact in the compressive and tensile strength results regarding the standard concrete without rubber addition. By another hand, Figures 1 and 3 shows that for concrete C20, small additions of rubber will affect the compressive and tensile strength for ages of 7 days and 28 days almost in the same way.

As the slump was the target of the experimental program, the reductions observed in the compressive and tensile strengths could be explained based on the final consumptions of cement presented in Table 5. As one can observe, dosages with more cement usually conduct to higher values of strength.

Table 5. Cement consumption.

Concrete type		Cement consumption (kg m^{-3})
C20	Standard	373
	5 %	360
	10 %	347
	15 %	331
C25	Standard	386
	5 %	360
	10 %	343
	15 %	330

Regarding the variations between compressive strength and tensile strength, it can be observed that the losses in the tensile strength are proportionally lower than the losses observed in the compressive strength. The ratios between tensile strength and compressive strengths are better illustrated in Tables 6 and 7. As one can observe, the ratio between tensile strength and compressive strength increases as the rubber amount also increases.

In general, the studied material has a reduction in strength values due two main factors: the incorporation of water and rubber and the drop in consumption of cement. Another factor with possible interference is the air incorporated into the mass due to the incorporation of rubber.

Conclusion

The utilization of tire rubber as fine aggregate in concrete is perfectly feasible taking into account the mechanical properties obtained. Experimental results revealed that additions of rubber up to 5% in substitution to sand may produce concretes with average compressive and tensile strength similar to that one obtained for normal strength concrete.

For substitutions above 5% a more significant impact may be observed in the compressive and tensile strength. Also, the workability and elastic modulus are downgraded as the percentage of rubber increases.

The obtained results shows that this material may be used in structures as sidewalks, pavers, curbs, paths of bike lanes, walls and prefabricated ornaments. However, future research is needed in order to evaluate the effect of the different size particles of tires, shrinkage and creep, durability, resistance under fire, shock wave absorption, resistance to acid attack, level of heat conductivity and noise level absorption.

Table 6. Ratios between tensile strength and compressive strengths for 7 days.

Concrete	Concrete C20			Concrete C25		
	Tensile strenght (MPa)	Compressive strength (MPa)	Ratio %	Tensile strength (MPa)	Compressive strength (MPa)	Ratio %
	7 days			7 days		
Standard	2.15	18.93	11.35%	1.80	17.09	10.53%
5%	1.86	13.63	13.64%	1.78	16.78	10.60%
10%	1.65	13.38	12.33%	1.46	10.53	13.86%
15%	1.55	9.92	15.62%	1.37	9.78	14.00%

Table 7. Ratios between tensile strength and compressive strengths for 28 days.

Concrete	Concrete C20 (MPa)			Concrete C25 (MPa)		
	Tensile strenght (MPa)	Compressive strength (MPa)	Ratio %	Tensile strenght (MPa)	Compressive strength (MPa)	Ratio %
	28 days			28 days		
Standard	2.60	26.77	9.71%	2.76	27.80	9.92%
5%	2.39	23.10	10.34%	2.51	24.30	10.32%
10%	2.04	17.22	11.84%	2.25	16.96	13.26%
15%	1.75	14.04	12.46%	1.90	15.06	12.61%

References

ABNT-Associação Brasileira de Normas Técnicas. **NBR 10004**: resíduos sólidos - classificação. Rio de Janeiro, 2004a.

ABNT-Associação Brasileira de Normas Técnicas. **NBR 10005**: procedimento para obtenção de extrato lixiviado de resíduos sólido. Rio de Janeiro, 2004b.

ABNT-Associação Brasileira de Normas Técnicas. **NBR 10006**: procedimento para obtenção de extrato solubilizado de resíduos. Rio de Janeiro, 2004c.

ABNT-Associação Brasileira de Normas Técnicas. **NBR 7211**: agregado para concreto – especificação. Rio de Janeiro, 2009a.

ABNT-Associação Brasileira de Normas Técnicas. **NBR NM 52**: agregado miúdo - determinação da massa específica e massa específica aparente. Rio de Janeiro, 2009b.

ABNT-Associação Brasileira de Normas Técnicas. **NBR NM 45**: agregados - determinação da massa unitária e do volume de vazios. Rio de Janeiro, 2006.

ABNT-Associação Brasileira de Normas Técnicas. **NBR NM ISO 3310-1**: peneiras de ensaio - requisitos técnicos e verificação – parte 1: peneiras de ensaio com tela de tecido metálico. Rio de Janeiro, 2010.

ABNT-Associação Brasileira de Normas Técnicas. **NBR 5738**: moldagem e cura de corpos-de-prova de concreto, cilíndricos ou prismáticos - procedimento. Rio de Janeiro, 2003.

ABNT-Associação Brasileira de Normas Técnicas. **NBR 5739**: concreto - ensaios de compressão de corpos-de-prova cilíndricos. Rio de Janeiro, 2007.

ABNT-Associação Brasileira de Normas Técnicas. **NBR 7222**: concreto e argamassa - determinação da resistência à tração por compressão diametral de corpos de prova cilíndricos. Rio de Janeiro, 2011.

ABNT-Associação Brasileira de Normas Técnicas. **NBR 9833**: concreto fresco - determinação da massa específica, do rendimento e do teor de ar pelo método gravimétrico. Rio de Janeiro, 2008.

CANOVA, J. A.; BERGAMASCO, R.; DE ANGELIS NETO, G. A utilização de resíduos de pneus inservíveis em argamassa de revestimento. **Acta Scientiarum. Technology**, v. 29, n. 2, p. 141-149, 2007.

CONAMA-Conselho Nacional de Meio Ambiente. **Resolução CONAMA nº 416/2009**. Brasília: Ministério do Meio Ambiente, 2009

ELDIN, N. N.; SENOUCI, A. B. Rubber-tire particles as concrete aggregates. **ASCE Journal of Materials in Civil Engineering**, v. 5, n. 4, p. 478-496, 1993.

FATTUHI, N. I.; CLARK, N. A. Cement-based materials containing tire rubber. **Journal of Construction and Building Materials**, v. 10, n. 4, p. 229-236, 1996.

FIORITI, C. F.; INO, A.; AKASAKI, J. L. Análise experimental de blocos intertravados de concreto com adição de resíduos de processo de recauchutagem de pneus. **Acta Scientiarum. Technology**, v. 32, n. 3, p. 237-244, 2010.

HELENE, P.; TERZIAN, P. **Manual de dosagem e controle do concreto**. São Paulo: Pini, 2001.

METHA, K.; MONTEIRO, P. J. M. **Concreto, estrutura, propriedades e materiais**. 1. ed. São Paulo: Pini, 1994.

SUKONTASUKKUL, P.; CHAIKAEW, C. Properties of concrete pedestrian block mixed with crumb rubber. **Construction and Building Materials**, v. 20, n. 7, p. 450-457, 2006.

Received on September 27, 2010.
Accepted on August 1, 2011.