International Journal of
Science and Engineering Investigations vol. 7, issue 78, July 2018
ISSN: 2251-8843

Analysis of Mechanical Behavior of Reinforced Concrete with Steel Tire Fiber

Marco Antônio Guimarães dos Santos[1], Robson Pereira de Lima[2], Lorena Alves da Silva Machado[3], Jaqueline do Carmo Lima Carvalho[4]
[1]Federal University of Minas Gerais
[2,3,4]Estadual University of Minas Gerais
([1]marco.gsantos@hotmail.com, [2]robson.lima@uemg.br, [3]lorenaalves.machado@hotmail.com, [4]jaqueline.z.lima @gmail.com)

Abstract- Steel Fibre Reinforced Concrete (SFRC) is a composite that can be used as an alternative to the use of reinforced concrete for continuous and precast structures. These SFRC applications are associated with infrastructure works with great social demand, such as basic sanitation and transport, involving pavements and tunnels. Currently, there is a greater concern with the environment and its conservation, regarding the inappropriate disposal of tires, so this work has the objective of studying reinforced concrete with recycled steel fibres of discarded tires (RSFRC), emphasizing the study of properties mechanics of this concrete, based on scientific technical productions on the use of fibres. The need to compensate for the clear deficiency that the concrete presents with its brittle behavior and its low capacity of deformation is the main reason why it was indispensable to the incorporation of reinforcements. One of the most promising solutions to improve poor traction performance is the addition of fresh mixed fibers with a random distribution throughout the volume, making it possible to obtain a composite with more isotropic properties, as well as promoting effects positive, such as the gain of resistance to rupture, reduction of deformations, control of the cracking process in different size levels in different zones of the concrete and, consequently, the increase of the durability of the structure. The results follow the procedure foreseen for the investigation of the incorporation of recycled steel fibres - with a total volume of 30 kg / m³ (1,2%) in relation to concrete (2500 kg / m³) - comparing the performance of the resulting composites, relative to the simple concrete whose nominal compressive strength (*fc* 28) is 30 MPa. The particularities of the blends in the fresh and hardened state were evaluated. Finally, a technical feasibility analysis was carried out and the results showed that the contribution of the metallic fibers contributed positively to the performance of the SFRC, where the gain in the resistance to simple axial compression assumed a value close to 17%.

Keywords- *Fibre Reinforced Concrete, Recycled Steel Fibre Reinforced Concrete, Fissures, Composite Materials*

I. INTRODUCTION

Since the beginning of automobile industrialization, tires, as indispensable elements of the whole process, have assumed great importance in the transport of goods and people. However, after exhausting their useful life, they need to be discarded, which makes unserviceable tires a global problem.

Ref. [21], states that tires have begun to play a prominent role in the discussion of impacts on soil, air and water. Throughout its life causes impact, when used releases fragments to the air provoking allergic reactions to the people, at the end of its useful life, they become structures difficult to be eliminated, since they are produced with the objective of having long life beyond the difficulty of being stored depending on their size.

Faced with the current reality of waste tires, measures that attenuate the effects of environmental impact are welcome for the improvement and preservation of the environment and quality of life. Such as the use of steel fibers contained in these tires, previously discarded and now with potential use as cementitious composites.

Due to the great variety of fibers with potential for reinforcement of composites used in the production of mortars and concretes for civil construction, it is essential to know the potential of these materials through their characterization to better apply them [26].

The steel fibers exist in abundance in materials of industrial production and have their reutilization motivated in means differentiated by environmental questions, where the disposal of the same is extremely unviable to the environment. Due to its availability at low cost if taken from the correct source, which in the case would be unusable tires resulting from the final disposal where there is no possibility of reuse, the use of its fibers tends to reduce the dispersion of this material in nature and create a means of exploitation and application of what could subsequently create environmental problems thus reducing the waste environment and enabling the production of composites also economically viable.

The steel fibers, due to their high modulus of elasticity, when added to the concrete make it difficult to propagate cracks [17, 18, 19, 20]. Because of the post-fissuring capacity of the composite, the fibers allow a redistribution of stresses in the material even when added in small quantities to the concrete [22].

This concrete can be used for various purposes such as application to industrial floors, tunnels and places that receive impact loads. Even in works that are closely linked to dynamic efforts such as structures built in regions subject to seismic shocks or even subject to cyclic stress fatigue, it is feasible to use fiber reinforced concretes to minimize the damage caused by these efforts and minimize cracking of the structure ensuring a longer life for the material.

Steel fiber reinforced concrete (SFRC) lowers the potential for cracking of cementitious dies and becomes an excellent choice for application in various civil construction systems. Ref. [1], SFRC is a composite formed from a cementitious matrix, containing hydraulic cement, large and small aggregates, reinforced with natural, synthetic or metallic fibers.

As for the cracking effect, it can be affirmed that the reinforcement with discontinuous and randomly distributed fibers plays an important role in the control of crack propagation, thus altering the mechanical behavior of the composite after the rupture of the matrix, increasing its tenacity, ie, their capacity to absorb energy (12, 24). Ref. [12], the incorporation of fibers into brittle cementitious matrix has the function of increasing the composite's toughness through the process of controlling the propagation of the resulting cracks and the increase of the tensile and flexural strengths.

In addition to the recycled polymer materials, researchers are developing products with added metal residues. Ref. [27], developed his research on the use of recycled steel fibers from the disposal of used tires. Ref. [24], studied the hybridization of steel fibers and recycled steel fibers, illustrating that the relationship between these materials can be made for mechanical and environmental gains.

Ref. [14] emphasizes that the applicability of steel fibers is immeasurable when compared to the applicability of polymeric and natural fibers. Consequently, with higher demand, more generation of metal fiber waste occurs. Ref. [23], explain a number of advantages for fiber insertion in concretes, which can be applied in civil construction, nautical and aerospace industries. With this, it is not by chance that the metallic filaments are the most used reinforcements for matrices, at the moment, in the whole world.

In this way, we intend to study in this work the interaction and technical viability of the cementitious matrix with the recycled steel fibers of discarded tires as reinforcement material, considering its potential crack propagation controller and its high tensile strength. In order to do so, it was necessary to carry out an extensive bibliographical study on the use of several fibers in concrete and their post-cracking behavior, as well as to perform comparative qualitative-quantitative tests of the mechanical properties of RSFRC for different fiber contents, regarding the resistance to simple axial compression and flexural traction, and finally, it was necessary to collect and analyze the data to compose the study of technical feasibility.

II. MATERIALS AND METHODS

A. *Methodology*

Two methodological phases were determined, as follows, preliminary or exploratory phase, to define the basic parameters for the generation of a composite with the incorporation of the recycled steel fiber. For that, cylindrical specimens were prepared for the compression tests, with different fiber contents. The results of the preliminary phase were used to subsidize the next phase.

The second phase, of evaluation, sought to analyze the effectiveness of high levels of recycled steel fiber. Defined a recommended reference content for fiber use. In all the tests a concrete without fiber addition was adopted as a reference parameter, with a mean compressive strength of 30 MPa.

The characterization of the recycled steel fiber was taken with reference to the data pre-established by steel manufacturers.

For the comparative analysis of the two types of concrete, conventional materials such as crushed stone, cement, sand and water [11], and subject to varying curing times of 7, 14, 21 and 28 days that at the same time will offer different resistances. After the preparation of the concrete trait, the trunk abatement test was performed [5], which is responsible for verifying the workability, consistency and mortar content of the concrete having as unit of measurement the centimeter (cm).

The other standards adopted in this work were: basic characterization of the small aggregate - grain size composition [6], swelling coefficient [9], specific mass [3, 6], unit mass and volume of voids [2], specific mass, apparent and water absorption [4], procedure for molding and curing of specimens [7].

The definition of the trait adopted in this research was taken from the characterization of the materials involved and their consumption rates, in a way that adjusts to the increase of different fiber contents, according to the method of characterization of the Brazilian Portland Cement Association (ABCP). Following the test, the concreting of at least 3 cylindrical specimens of the conventional way of dimensions 10x20 cm was carried out when their resistance to compression was tested, for ages of 7, 14, 21 and 28 days. As a way of analyzing the mechanical properties provided by the steel fiber to the concrete, two different levels of steel fiber were applied to the concrete, and also a reference concrete was made, without the addition of fiber, so that the mechanical properties could be compared and evaluated.

The quantities of 30 kilograms of steel fiber were added to $1m^3$ of concrete, so the respective legends of F30 will be adopted to differentiate the traces of fiber with reference concrete denominated REF.

The mixing was carried out mechanically with the aid of a free-fall concrete mixer that produces a movement where the inner blades of the tank take the material to the top and from there they fall by gravity or free fall, the materials were mixed gradually, ensuring homogeneity.

The axial compression test is considered the main test of characterization of concrete. It is widely used in the civil construction sector, since from this one obtains the Characteristic Strength of Concrete to Compression (fck), being this parameter used as reference for the calculations and dimensioning of the constructive elements. Thus, in total, 24 test specimens were used to determine this test.

B. Materials

1) Cement

The cement type CP IV-32 RS Pozolánico was used as the bonding material, which is marketed in the region. It was developed to meet situations where the risk of fissures caused by the heat of hydration is high. Its content of pozzolanic additions ensures that the heat released by the cement clinker hydration is lower, avoiding the risk of cracking. The pozzolanic addition will provide greater durability to the structure and higher strengths compared to the cements of its category. It is especially indicated in situations where the application environment is chemically aggressive. When the application does not require the immediate use of the structure or a deformation at more advanced ages.

2) Fine Aggregate

The fine aggregate used in the trials of this research is the same sand commonly used in the civil construction works of the region, classified as average sand.

The sand was characterized as follows, the aggregate is washed and air-dried for removal of impurities prior to storage. The granulometric distribution and quality indices of this small aggregate were determined [10].

3) Coarse Aggregate

The coarse aggregate used for the preparation of the concrete specimens was gravel 1 of basaltic origin with the characterized granulometric distribution. This choice was due to the fact that a better distributed mixture was obtained, in order to reduce voids with the addition of fibers.

4) Additive

The addition of plasticizer additive in all concrete traces with the addition of recycled steel fiber was chosen due to the possibility that the addition of fiber could compromise the workability and affect the strength of the specimens. The additive used was the Erca Group Plastofluid RMX 179 in the ratio of 0.7% in grams, of the total kilos of cement.

5) Fibers

The theme of this study is reinforced concrete with recycled steel fibers. Thus, knowledge of the geometric characteristics, the production process and the physical, chemical and mechanical properties of steel fibers is of great importance. Such steel fibers are discontinuous elements produced with variations of shapes, sizes and types of steel. The steel fibers used in the concrete matrix for the development of this work were extracted from the discarded tires and passed through standardization of the measurements, being approximately equal to 60 mm in length and 0.75 mm in diameter.

The specifications of the steel fibers relate to the fabrications of SAE 1070 and 1080 steels which are commonly used in radial tires for passenger cars. These steels have the following characteristics, as shown in the tab 1.

TABLE I. MECHANICAL PROPERTIES OF STEEL

Properties	AISI 1070	AISI 1080
Modulus of elasticity	190-210 (GPa)	190-210 (GPa)
Poisson Coefficient	0.27-0.30	0.27-0.30
Tensile Strength	640-760 (MPa)	965 (MPa)

III. RESULTS AND ANALYSIS

A. Characterization of the materials and composition of the mix ratio

1) Granulometric composition

This test was conducted according to [6]. First the mass retained in each sieve was recorded, then the accumulated percentage was calculated and finally the graph of the granulometric curve of the sand and the gravel 1 was made. Subsequently, the maximum size of the aggregate and the fineness modulus. Considering that for the analyzed sand, fineness modulus was obtained equal to 2.7, in this case it is characterized as average sand. The maximum sand size (mm) was 4.75, indicating its small aggregate state. For the analyzed gravel, a maximum diameter of 19.00 mm was obtained, characterized as a large aggregate.

2) Determination of moisture content

The result of the moisture content test for sand according to the requirements of [15], was equal to 1,52%. By means of the analysis of the moisture content it is possible to measure the percentage of water that was present in the empty spaces of the analysis materials. This study becomes important in the determination, because the more water present in the aggregates the less water addition should be added to the trace.

3) Especific mass

The results of the specific sand mass were obtained by means of the arithmetic mean of the three analyzed samples of the material. The procedure followed the instructions of [16]. The results of the mass-specific test of the large aggregates followed the pycnometer method, where the average between the samples and the specific masses calculated was also performed, according to tab. 2:

TABLE II. SPECIFIC MASS OF AGGREGATES

Materials	Especific mass (kg/dm^3)
Sand	2,60
Gravel 1	2,72

The results of the specific masses of sand and gravel 1 analyzed were close to 2.60 and 2.72 kg / dm^3, respectively. Ref. [25], the specific mass has a range of variation from 2.6 to 2.7 g / cm3. The values found then are close to this margin.

For aggregates of natural origin used in the manufacture of concrete of normal density, most of the time they are dense and resistant, being, therefore, hardly limiting factors of the resistance and also of the elastic properties of the concrete [25].

4) Unit mass

The tests were based on the basis of the instructions of [2]. The volume used for data accumulation was 0.01475 m³. Tab. 3 represents a unit mass of the analyzed materials.

TABLE III. AGGREGATE UNIT MASS

Aggregates	Unit mass (kg/dm³)
Loose Sand	2,60
Loose Gravel 1	2,72

It was experimentally confirmed that the unit mass of the sand is larger than that of the aggregate. This phenomenon occurs because, in the large aggregate, the unit of apparent volume does not cause swelling.

With the unit mass, it is possible to determine the volume occupied by a given mass of aggregate. This value influences the choice of the type of aggregate and the quantity that will be used in the concrete recipe [25].

5) Characterization of recycled steel fibers

The metal fibers used were extracted and supplied by RACRI Comércio e Transportes LTDA, which manufactures rubber from discarded tires, the steel from which these tires are classified as SAE 1070 and SAE 1080 in general.

Among the fibers received, they were separated from the impurities, selected and standardized, whose shape factor is 80, since it has a length equal to 60 mm and 0.75 mm in diameter, as can be seen in fig. 1.

Figure 1. Uniformisation of the fibers used

The fibers had no anchorage length, such as those made on the market, their mixture was not fast and their distribution was not perfectly homogeneous without the formation of "balls" or "hedgehogs", which compromised in parts the results of the work. In fig. 2 it is possible to see the degree of impurity found in the tangle of fibers.

Figure 2. Sample of collected fibers

After adjusting the trace, with 1: 1.26: 2.18 ratio, and depending on the desired strength class (fc> 30 MPa), the water-cement ratio was determined to be 0.34, obeying the requirement of a workability of 75 to 125 mm.

B. Results of the Simple Compression Test

It is known that the presence of the fibers improves little or even damages the values of compressive strength of the composites. As observed in Fig. 3, the incorporation of fibers caused a small increase of resistance in relation to the reference (REF), for the content of 30 kg / m³. This behavior may be related to the molding process of the CPs, which occurred in conventional metallic molds with dimensions of 100 x 200 mm. The values with fiber content represented an increase of 16.76% on average, compared to the fiber-free trait.

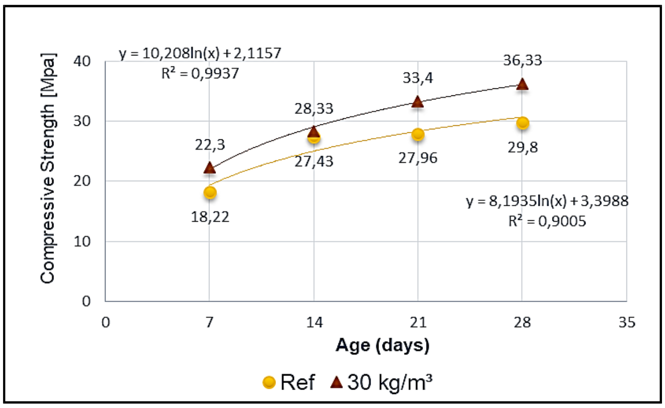

Figure 3. Simple compression strength for 30 kg / m³ content.

A logarithmic linear regression analysis was performed to model the experiment and the equation 1 below was obtained, which has R^2 coefficient = 99.37%, where the predicted behavior curve is presented. This modeling cannot predict the resistance drop for the given fiber content, on the contrary, it shows that the higher its age the greater its resistance.

$$f_c^{RSFRC}\,[\text{Mpa}] = 10{,}208\ln(\text{days}) + 2{,}1157 \quad (1)$$

IV. FINAL CONSIDERATIONS

The steel fibers are difficult to manually extract the discarded tires, resulting in a long and arduous work. Therefore, the fibers were obtained through a tire rubber processing company (RACRI Comércio e Transportes LTDA), however care was not taken on the collection of the raw material, which resulted in a 5 kg entanglement between fibers and impurities.

After receiving, as one of the objectives of this work, the characterization of the material was performed, seeking to standardize the form factor for 80, being 60 mm in length and 0.75 mm in diameter, given its importance in maintaining a more homogeneous mixture without great variations in order not to impair RSFRC's behavior regarding its post-cracking resistance. However, in making this standardization, the maximum amount of fibers available did not exceed 300 grams, which would make the research impossible, given the need for a large amount of raw material, but because it was a preliminary study, work continued. Even with these caveats, satisfactory results can be obtained.

Another important aspect to be mentioned, the microscopic study of the structure of the post-fissured material with the aid of a scanning electron microscope (SEM), was not performed, which makes it impossible to analyze the behavior on a large scale of the fiber-cement-matrix interaction.

V. CONCLUSION

The data collected indicated discrete gains in this property with fiber insertion. The gains in compressive strength, for the 30 kg / m³ content, were on average 16.76% in relation to the reference, for 28 days.

Although this resistance increase in structural calculation should not be considered for safety reasons, it may represent an important reserve of resistance in structural parts. It is believed that this effect is due to the fact that the presence of the fibers reduces transverse deformation during the simple compression test, delaying the rupture of the specimen.

REFERENCES

[1] AMERICAN CONCRETE INSTITUTE. ACI 544.1R-96 Report on Fiber Reinforced Concrete. ACI Committee 544 (Reaproved 2009), Detroit, USA, 1996

[2] Associação Brasileira de Normas Técnicas – ABNT NBRNM 45 - Agregados - Determinação da massa unitária e do volume de vazios. Rio de Janeiro: 2006.

[3] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – ABNT NBRNM52 - Agregado miúdo - Determinação da massa específica e massa específica aparente, Rio de Janeiro, 2009.

[4] Associação Brasileira de Normas Técnicas – ABNT NBRNM 53 - Agregado graúdo - Determinação da massa específica, massa específica aparente e absorção de água. Rio de Janeiro: 2009.

[5] Associação Brasileira de Normas Técnicas – ABNT NBRNM 67 – Concreto - Determinação da consistência pelo abatimento do tronco de cone. Rio de Janeiro: 1998.

[6] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – ABNT, NBR NM248 - Agregados - Determinação da composição granulométrica, Rio de Janeiro, 2003.

[7] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – ABNT. NBR 5738 - Concreto – procedimento para moldagem e cura de corpos de prova. Rio de Janeiro, 2015.

[8] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – ABNT NBR 6457 - Amostras de solo - Preparação para ensaios de compactação e ensaios de caracterização. Rio de Janeiro, 2016.

[9] Associação Brasileira de Normas Técnicas – ABNT NBR 6467 - Agregados – Determinação do inchamento de agregado miúdo - Método de ensaio. Rio de Janeiro: 2006.

[10] Associação Brasileira de Normas Técnicas – ABNT NBR 7211 – Agregados para concreto - Especificações. Rio de Janeiro: 2009.

[11] Associação Brasileira de Normas Técnicas – ABNT NBR 12655 - Concreto de cimento Por tland — Preparo, controle, recebimento e aceitação — Procedimento. Rio de Janeiro: 2015.

[12] BEAUDOIN, James Jim. Handbook of fiber reinforced concrete – principles, properties, developments and applications. Noyes Publications, USA., 1990, p. 332.

[13] BENTUR, Arnon; MINDESS, Sidney. Fibre reinforced cementitious composites. United Kingdom. Barking, Elsevier. 1990.

[14] BERNARDI, Stefania Tesi. Avaliação do comportamento de materiais compósitos de matrizes cimentícias reforçadas com fibra de Aramida Kevlar. Dissertação (Mestrado em Engenharia) – Programa de Pós-Graduação em Engenharia Civil, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2003.

[15] DEPARTAMENTO NACIONAL DE ESTRADAS DE RODAGEM – DNER-ME 052/94 – Solos e agregados miúdos – determinação da umidade com emprego do "Speedy". Rio de Janeiro, 1994.

[16] DEPARTAMENTO NACIONAL DE ESTRADAS DE RODAGEM – DNER-ME 194/98 – Agregados – determinação da massa específica de agregados miúdos por meio do frasco Chapman. Rio de Janeiro, 1998.

[17] FIGUEIREDO, Antônio Domingues; CECCATO, Marcos Roberto e TORNERI, Paola. Influência do comprimento da fibra no desempenho do concreto reforçado com fibras de aço. 39ª REIBRAC. Instituto Brasileiro do Concreto. São Paulo. 1997. 10p.

[18] FIGUEIREDO, Antônio Domingues. CONCRETO COM FIBRAS DE AÇO. In: Isaia, Geraldo Cechella. (Org.) Concreto. Ensino, Pesquisa e Realizações. São Paulo: IBRACON, 2005. v.2, capitulo 39, p.1195-1225. 2005a.

[19] FIGUEIREDO, Antônio Domingues. Parâmetros de Controle e Dosagem do Concreto Projetado com Fibras de aço. São Paulo, 1997. 342p. Tese (Doutorado). Escola Politécnica, Universidade de São Paulo.

[20] FIGUEIREDO, Antônio Domingues; HELENE, Paulo. O ensaio de punção de placas para o controle da tenacidade no concreto com fibras de aço. In. IV Congresso Iberoamericano de Patologia das Construções e VI Congresso de Controle da Qualidade - CONPAT 97. Porto Alegre, Brasil. 21 a 24 de Outubro de 1997. Volume II. Anais. p.469-76.

[21] GOLDENSTEIN, Marcelo. Panorama Da Indústria De Pneus No Brasil: Ciclo De Investimento, Novos Competidores E A Questão Do Descarte De Pneus Inservíveis. BNDES Setorial, Rio de Janeiro, n.25, p. 107-130, mar.2007.

[22] GOMES, Ítalo Alexandre; LIMA, Robson Pereira de; SILVA, Maike da. Desenvolvimento de concreto enriquecido com fibras de aço. Revista Engenharia de Interesse Social, João Monlevade, v. 1, n. 2, p. 59-69, 2017. ISSN 2525-6041.

[23] MARTINEAU, P. AGOPYAN, V. Conferência Magna I – Compósitos: material inovador. In: Arquimacom' 2002. São Paulo, 2002.

[24] MARTINELLI, E. CAGGIANO, Antônio. XARGAY, H. An experimental study on the post-cracking behavior of hybrid industrial/recycled steel fiber-reinforced concrete. Construction and Building Materials (2015) 290 – 298.

[25] MEHTA, P. K. e MONTEIRO, P. J. M. Concreto: Estrutura, propriedades e materiais. São Paulo. PINI, 1994. 573p.

[26] SILVA, Everton; MARQUES, Maria; FORNARI JR, Celso. APLICAÇÃO DE FIBRA DE COCO EM MATRIZES CIMENTÍCIAS. Elet. em Gestão, Educação e Tecnologia Ambiental, v(8), nº 8, p. 1555-1561, SET-DEZ, 2012. Rev. (e-ISSN: 2236-1170)

[27] ZAMANZADEH, Z. LOURENÇO, L. BARROS, J. Recycled steel fiber reinforced concrete failing in bending and in shear. Construction and Building Materials (2015).