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Influence of the Incorporation of Rubber Fibers on The Properties of Concrete Reinforced with Steel Fibers

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The use of steel fibers in concrete affects its rheological properties in the fresh state and increases its energy absorption capacity in the hardened state. Rubber fibers come from tires and when incorporated into concrete, they promote an improvement in its damping factor. This work aimed to evaluate the use of rubber fibers on the mechanical properties of concrete reinforced with steel fibers. The evaluated properties were: compressive strength, tensile strength, static and dynamic modulus of elasticity and damping. The mixes of the tested concretes varied the consumption of steel and rubber fibers. From the results found, it can be seen that the rubber associated with steel fibers within the concrete mixtures improves the damping rates of the material.

Keywords: *Concrete with steel fibers, waste rubber, alternative materials.*

1. Introduction

The civil construction industry in the last few years has to be more open to reusing solid residues, and in Brazil have been boosted by the creation of the National Politics of Solid Residues, instituted by the law project nº 12.305[1], which directs the management of the residues, since the production, reduction, reuse, recycling, and treatments of these residues, such as the property Ambiental final disposal of the rejects. This law has as an instrument the selective collection of the residues, the reverse logistics, and other tools relative to the imputation of shared responsibility by the life cycle.

The incorporation of tire rubber waste in the production of composites, as recycled aggregate, has been motivated by the Resolution of the National Council for the Environment (CONAMA) nº 258[2], amended by Resolutions nº 301[3] and nº 416[4], which establishes that the Companies that sell tires are required to collect and dispose of unusable tires in the national territory in an environmentally appropriate manner. Resolution nº 416[4] considers that improperly disposed of tires constitute an environmental liability, which can result in a serious risk to the environment and public health. This Resolution resolves that, for each new tire sold, companies must properly dispose of an unusable tire.

The exploitation of natural, non-renewable deposits is another factor that represents a great impact on the environment and is directly linked to the production of concrete. In this way, several studies have been carried out on the technical feasibility of incorporating mineral additions, replacing part of the cement, and recycled aggregates and/or waste, in total or partial replacement of the natural aggregates present in concrete[5,6].

The use of waste rubber in the composition of composites as an aggregate recycled has been studied by several researchers[7,8]. Rubber when used in the composition of concrete and mortar decreases its specific mass and mechanical resistance[9,10]. On the other hand, increases the energy absorption capacity of the material and improves the acoustic properties of the material[11,12]. In work developed by Gomes et al.[13] it was possible to verify that rubber, when incorporated into mortars, reduces thermal conductivity improving the thermal insulation of the material.

Another material used in concrete to improve its properties is steel fibers. Reinforcing concrete with steel fibers improves the performance of the material, increasing its capacity to absorb energy, toughness, ductility, and resistance to impact and abrasion[14]. Fibers create barriers within the material preventing increased cracking[15,16].

Several are the benefits from the incorporation of steel fibers and rubber residues to concrete, in terms of energy absorption. In this research, the properties of four concrete mixtures are analyzed, aiming to investigate the behavior of concrete containing steel fibers and rubber associated in its composition. The technological contribution is in the proposition of a structural concrete mix, with a minimum compressive strength of 20 MPa, applied to concrete pieces that require higher damping rates.

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2. Materials and Methods

To develop this study the following materials were selected: Portland CPV cement, silica fume with characteristics presented in Table 1, quartz sand for fine aggregate (density of 2.66 kg/dm^3), basalt gravel for coarse aggregate (density of 2.65 kg/dm^3), hooked end steel fibers (65/35) showed in Figure 1a, waste rubber from tires (#1,2mm - #0,6mm) with density of 1.16 kg/dm^3, used in substitution of the natural fine aggregate, showed in Figure 1b, water, superplasticizer (density of 1.12 kg/dm^3).

The consumption of steel fibers used in the C-0.5SF-0R and C-0.5SF-10R mixes was 40 kg/m^3. Each batch of concrete produced corresponds to a volume of 0.08 m^3 of concrete. The amount of material used in each concrete batch is indicated in Table 2.

Table 1. Chemical and physical properties of cement and silica fume.

Test		Results	
		Cement	Silica Fume
SiO_2		-	> 90%
Specific surface area (m^2/kg)		-	19.000
Specific mass (kg/dm^3)		3.10	2.20
Setting time (min)	Initial setting	130	-
	Final setting	210	-

Table 3 shows the number of specimens produced in this study and used in each test.

The mixtures were produced in a concrete mixer with an inclined axis and the cylindrical specimens with dimensions of 100x200mm received a small layer of release agent and the concrete was disposed in two distinct layers. After 24 hours, these were removed from the molds and submerged in a water tank until they reached an age of 7 to 28 days.

2.1. *Experimental tests*

For all tests performed, cylindrical specimens of 100 × 200 mm were used.

For the determination of water absorption, void ratio and mass density[17], was followed. To determine the compressive strength[18], tensile strength[19] and static modulus of elasticity[20], was used a universal testing machine, electromechanical, microprocessed, with a capacity of 600 kN.

To determine the static modulus of elasticity[20], was adopted. The method consists of applying 30% of maximum stress to the specimen at three different times during the test, and a final one with the maximum tension until the specimen ruptures and measuring the deformation of the specimen.

ASTM E1876[21] and ASTM C215[22] were used to determine the dynamic elasticity module and the damping rate, by the impulse excitation technique using the Sonelastic® equipment[23], as shown in Figure 2.

3. Results

For fresh concrete, the slump test was performed to obtain concrete consistency results, as shown in Table 4.

Table 2. Consumption of materials used in the production of 0.08 m^3 of concrete.

Materials	Mixes			
	C-0SF-0R	C-0,5SF-0R	C-0SF-10R	C-0,5SF-10R
Cement (kg)	29.1	29.1	29.1	29.1
Silica Fume (kg)	2.91	2.91	2.91	2.91
Fine Aggregate (kg)	72.17	72.17	64.95	64.95
Coarse Aggregate (kg)	72.75	72.75	72.75	72.75
Rubber (kg)	0	0	3.15	3.15
SP (kg)	0	0.087	0.087	0.116
Water (kg)	14.55	14.55	14.55	14.55

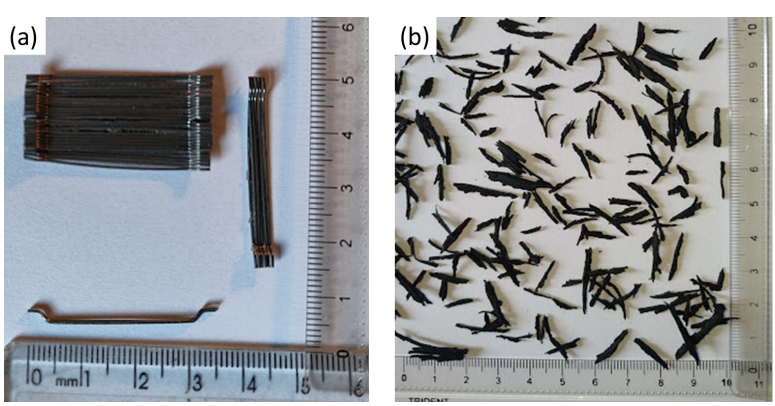

Figure 1. (a) Hooked end steel fiber and (b) waste rubber.

Table 3. Number of specimens produced for testing in the fresh and hardened states of the concretes.

	Mixes							
	C-0SF-0R		C-0,5SF-0R		C-0SF-10R		C-0,5SF-10R	
Age (days)	7	28	7	28	7	28	7	28
Water absorption	-	3	-	3	-	3	-	3
Compressive strength	6	6	6	6	6	6	6	6
Tensile strength	3	3	3	3	3	3	3	3
Static modulus of elasticity	-	3	-	3	-	3	-	3
Dynamic modulus of elasticity	-	6	-	6	-	6	-	6

Table 4. Results of the tests in the fresh and hardened states of the studied concretes.

Mixture	Slump (mm)	Water absorption (%)	Void index (%)	Specific mass (kg/l)
C-0SF-0R	75	4.00	9.43	2.60
C-0,5SF-0R	76	4.14	9.89	2.65
C-0SF-10R	50	4.74	10.84	2.56
C-0,5SF-10R	70	4.63	10.83	2.62

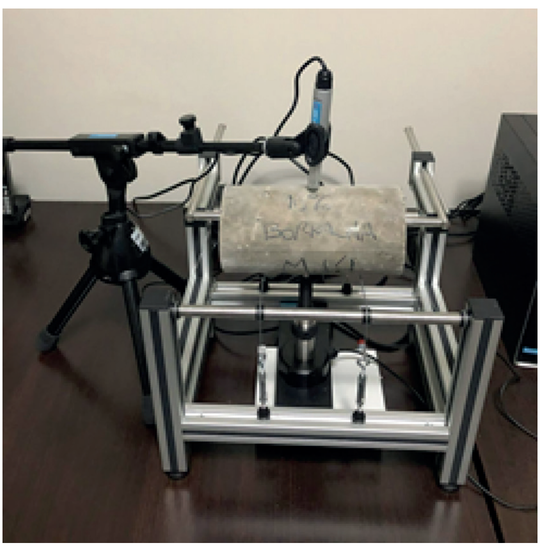

Figure 2. Test setup for the impulse excitation technique.

Initially, the specimens were placed in an oven at a temperature of (105±5)°C for a period of 72 hours and the dry mass value was recorded. Then, the specimens were immersed in water at a temperature of (23±2)°C for a period of 72 hours. Then, they were boiled for a period of 5 hours. After the water had cooled to a temperature of (23±2)°C, the immersed mass was recorded using a hydrostatic balance. The specimens were removed from the water, dried with a cloth and the saturated mass was recorded.

As can be noticed the water absorption increased by 18.50% with the waste rubber incorporation, this tendency can be associated with the hydrophobic behavior of the rubber witch during the mixing process adsorbed water in the specific surface of the material and create a bigger ITZ between the rubber particle and the cement paste. The same tendency can be reported to the void index that increased by 14.95% related to the increase of ITZ in the cement paste.

The incorporation of steel fibers in the control mix causes an increase of 1.92% of the specific mass, related to the specific mass of the fibers added in the mix, and for the rubber, the effect is from a decrease of 1,53% also associate with the lower specific mass of the rubber in comparative with the quartz sand.

This tendency also is noticed by Thomas and Gupta[24] and reported, by Nematzadeh et al.[15]. Meyyappan et al.[25] found that the increase in porosity in concretes containing 5%, 10%, 15%, and 20% rubber was 7.23%, 8.79%, 10.54% and 13.38% respectively.

3.1. Compressive strength

The compressive strength results are obtained after the specimens are ground. Figure 3 shows that adding waste rubber to concrete caused a decrease in the compressive strength of the concrete, 29.44% for C-0SF-10R compared to the control mixture. The steel fiber also caused a small reduction, around 5% to 9% in both mixtures with the material compared to similar mixtures without steel fibers. This trend was also observed by Silva et al.[7], who used rubber tires to produce high-performance concrete, and by Gomes et al.[12] who used recycled rubber aggregate for self-compacting concrete and reported a 3.9% reduction with a 1% increase in rubber.

He et al.[26] showed that by treating the rubber surface with NaOH solutions, the loss of compressive strength was reduced.

The concrete is classified by ABNT NBR 8953[27] as structural when it has a minimum compressive strength of 20 MPa. In this research all the studied mixtures were classified as structural.

3.2. Tensile strength

As with compressive strength, for tensile strength, the results shown in Figure 4 report a decrease of 24.89% for C-0SF-10R compared to C-0SF-0R.

But when the steel fibers are incorporated into the concrete, it was noticed that the tensile strength increased by 24.47% for the C-0.5SF-0R mixture in relation to the C-0SF-0R.

A similar behavior was reported by Guo et al.[10] who reported a 30% decrease in strength when 20% rubber was incorporated into the concrete.

Figure 4 shows that for the mixture containing associated steel fibers and rubber (C-0.5SF-10R) the reduction in tensile strength is minimized.

3.3. Elastic modulus

As shown by the results obtained for the modulus of elasticity in Figure 5, it appears that: the addition of steel fibers (C-0.5SF-0R) decreased the static modulus by 4.96% and the dynamic modulus by 1.43%. The replacement of 10% of the natural aggregate by the waste rubber (C-0SF-10R) reduced the static elastic modulus by 8.56% and the dynamic modulus by 13,67%.

A similar behavior was reported by Zhuang et al.[28] that when the rubber index is lower than 10% in substitution of the natural aggregate, the increase of the dynamic properties of the concrete is about 15-25%.

The main reasons for the decrease of the elastic modulus in the concrete with rubber are three: the weakness in the concrete matrix occasioned by the increase of ITZ by the rubber, the high-stress concentration and crack propagation due the lower elastic modulus of soft rubber, and the non-uniform distribution of the rubber inside the concrete matrix[29]. Concrete has a high energy absorption capacity compared to ordinary concrete, due to increased energy absorption.

3.4. Damping ratio

The damping property of concrete is related to the ability to dissipate energy in the internal structure of the material[12]. The results of the damping ratio are showed in Figure 6.

As the results shows the damping ratio increase with the insert of the steel fiber, and the waste rubber to the concrete. To the C-0,5SF-0R mix, the increase was of 1,99% from the control mix (C-0SF-0R), the C-0SF-10R mix presents an increase of 17,66% from the control mix, and the C-0,5SF-10R present an increase of 16,93% from the control mix. A similar behavior was reported by Li et al.[12] who studied rubber aggregate in self-compacting concrete and notice a linear increase of the damping ratio with increase of the rubber with different granulometry.

Figure 6 shows the advantage of using rubber and steel fibers incorporated together in concrete.

3.5. Scanning electron microscopy (SEM)

The scanning electron microscopy (SEM) test of the concretes studied in this research was performed in the Multiuser Laboratory of Electronic Microscopy at the UNICAMP School of Technology, in the SEM equipment TESCAN Vega 3, configured with a beam energy of 10 kV, a beam current between 500 pA and a working distance of 10 mm.

Two samples were used for each concrete mix, thus ensuring the generation of complete images of the

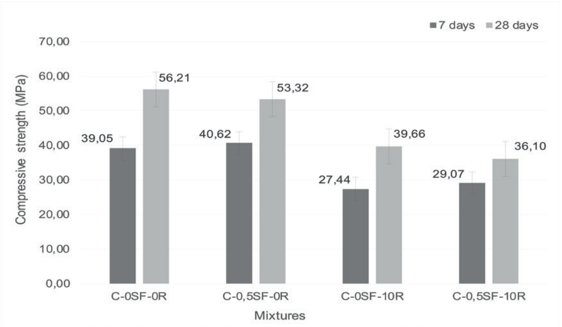

Figure 3. Results of compressive strength tests on concrete specimens tested at 7 and 28 days.

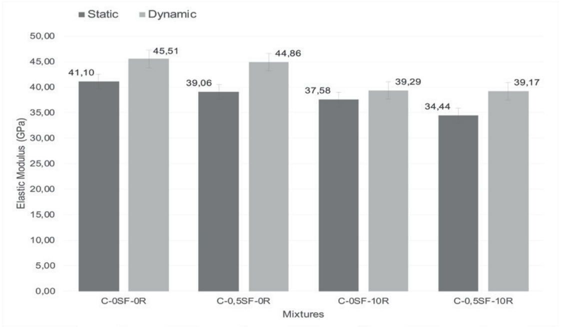

Figure 5. Results of modulus of elasticity tests on concrete specimens tested at 28 days.

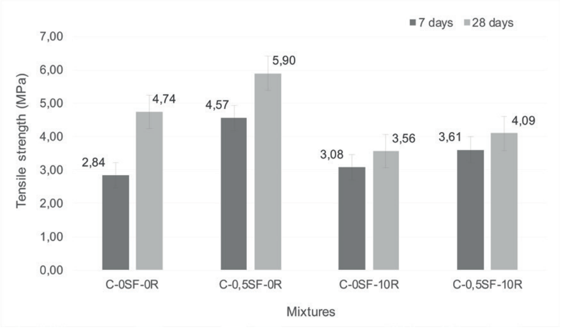

Figure 4. Results of tensile strength tests on concrete specimens tested at 7 and 28 days.

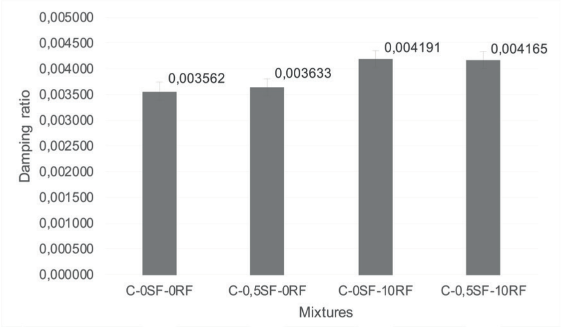

Figure 6. Results from damping ratio tests of concrete specimens tested at 28 days.

microstructure of the proposed material. As the samples in this work are classified as non-metallic, all samples were metalized to improve their electronic conduction and thus generate images more accurately and precisely.

The concrete samples were fractured into portions that contained all the materials used in the mix composition, as shown in Figure 7 for better visualization of characteristics such as pores and quality of the interaction between paste and aggregates, called Interface Transition Zone.

The analysis of the samples using scanning electron microscopy made it possible to evaluate the microstructure of the studied concrete mixes with waste rubber and steel fibers. Traces C-0SF-0R, C-0SF-10R, and C-0,5SF-10R were analyzed.

In the analysis of the microstructure of the concrete, it is possible to visualize in the SEM images of the C-0SF-0R a dense and compact structure, but with heterogeneous formation, with feel pores, which corroborates with the mechanical results for compressive strength. Figure 8 shows the reference concrete's microstructure, without replacing the fine aggregate with waste rubber or adding steel fiber, in the 50μm and 200μm scales.

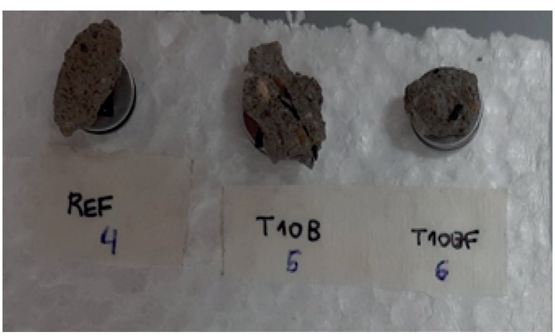

Figure 7. Samples of concrete used for SEM.

Figure 9 shows the microscopy of C-0SF-10R concretes, with 10% replacement of the fine aggregate by rubber in the 50μm and 200μm scales. There is an increase in the quantity and dimensions of pores formed by air bubbles, the presence of voids and microcracks compared to the reference trace, and the interface between the rubber and the cementitious matrix is quite evident at the 50μm scale. This happens due to the hydrophobic characteristic of rubber, which forms a film of water around it during the concrete curing process; and after hardening, this characteristic results in a well-defined and spaced transition zone of the cementitious matrix, which causes loss of mechanical resistance. But the addition of waste rubber to the concrete is beneficial since the acoustic characteristics and resistance to deformations by impacts are increased[8].

Figure 10 shows the microscopy of the concretes with the same 10% replacement of the fine aggregate by rubber with the addition of steel fiber on it, C-0,5SF-10R, in the 50μm and 200μm scales. There is an increase in the amount and dimensions of pores formed by air bubbles, the presence of voids and microcracks when compared to the reference trace, and the interface between the rubber and the cement matrix is quite evident at the 50μm scale. It is also noted that the rubber is involved by the hydrated products of the cement paste.

It is possible to verify that, with increasing levels of rubber incorporation in the mixtures, there is an increase in pores and microcracks, resulting in a less compact structure with a pronounced transition zone. It is also noted that the transition zone between the cementitious matrix and rubber is increased due to its water-repellent characteristics. This evidence justifies the decrease in compressive and tensile strengths in bending when comparing the reference (C-0SF-0R) to those with the replacement of fine aggregate by rubber and steel fibers.

Sidhu and Siddique[30] verified the influence of the thickness of the ITZ and noticed that for concretes without rubber the ITZ has a thickness below 1 μm and for concretes

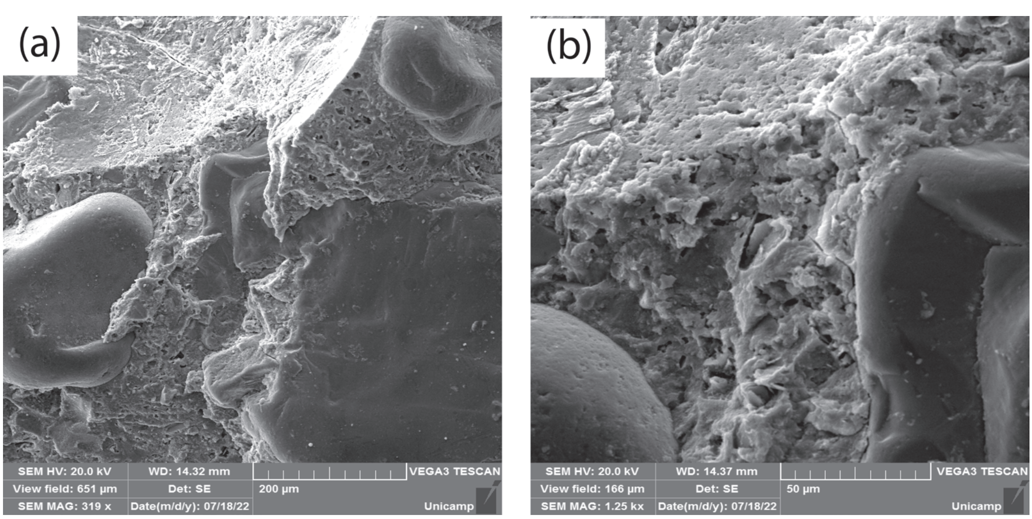

Figure 8. Microscopy of the C-0SF-0R. (a) 200 μm (b) 50 μm.

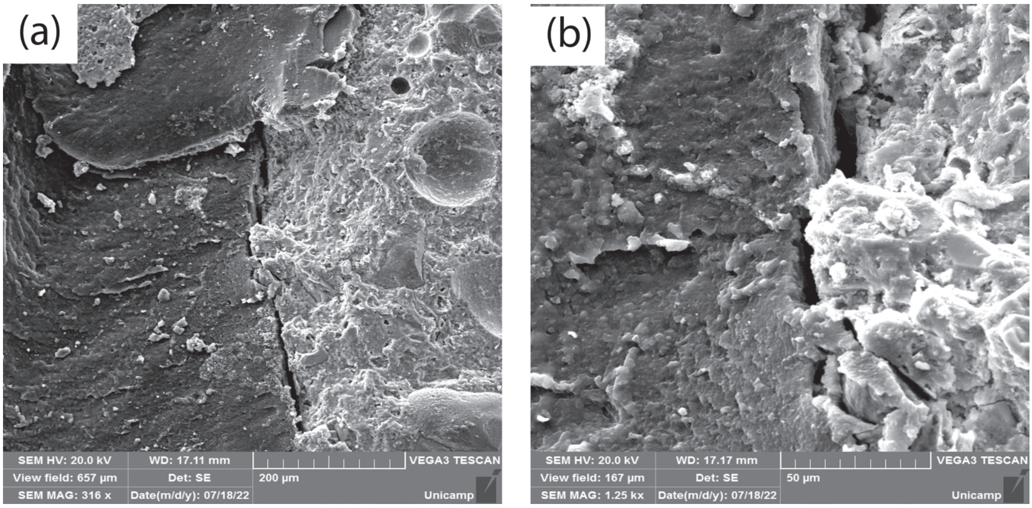

Figure 9. Microscopy of the C-0SF-10R. (a) 200 µm (b) 50 µm.

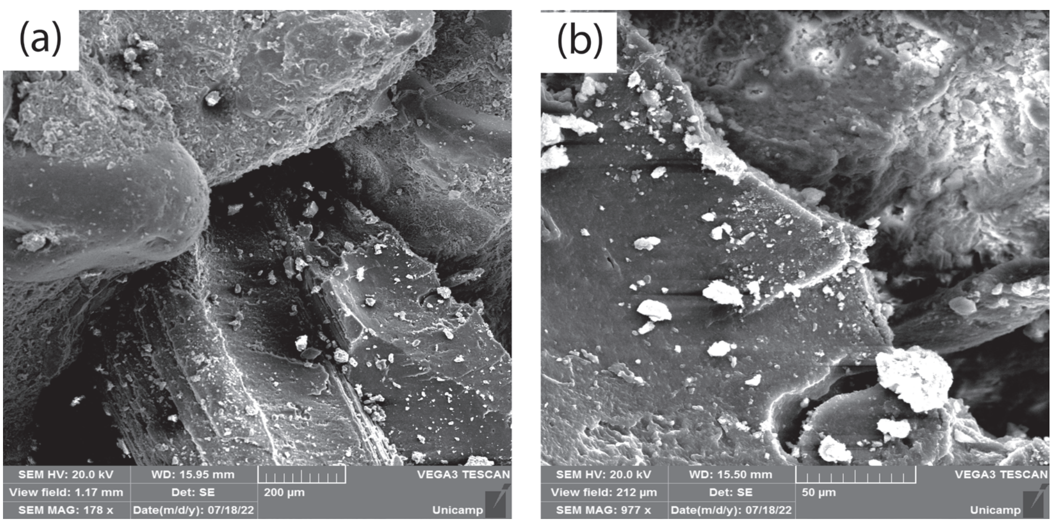

Figure 10. Microscopy of the C-0,5SF-10R. (a) 200 µm (b) 50 µm.

with 15 and 30% of rubber the thickness of the ITZ is in the range of 1.6 to 3.0 µm.

4. Conclusions

This study investigated the differences in the physical and mechanical properties of concretes with waste rubber fibers and steel fibers, and from the data obtained it can be concluded that:

- In the fresh state, the percentage of superplasticizer had to be increased to maintain workability.
- The incorporation of steel fibers increased by 1.90% in the concrete density, and rubber fiber caused a decrease of 1.53%. This fact is associated with the different specific weights of these two materials.
- The void index for the mix with rubber fiber incorporated had a 15% increase, and this can be associated with the ITZ between the cement matrix and the rubber face, noticed in the SEM test.
- The incorporation of rubber fiber as a substitution of the fine aggregate in the mix C-0SF-10R caused a compressive strength to decrease of 30% in comparison with the C-0SF-0R. However, all the concretes studied in this research were classified as structural.
- The tensile strength followed the comprehensive strength and decreased by 25% with the incorporation of the rubber fiber in the C-0SF-10RF when compared with the C-0SF-0R. But the steel fiber increased by around 25% when incorporated in the mixes C-0,50SF-0R.
- The dynamic modulus of elasticity is greater than the static one in the range of 10 to 15%.
- The damping rate increased by around 17% when rubber was added to concrete. This may be associated with the increase in voids that the rubber caused in the concrete.
- The joint use of steel fibers and rubber in the concrete for the studied composition classifies the

concrete as structural, indicated for the construction of structural parts that require higher damping rates than conventional concrete.

5. Acknowledgments

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