Gamma Radiation Doses Effects on Mechanical Properties and Microwave Absorption Capacity of Rubber Doped Concrete

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ABSTRACT

The main raw material for the construction industry is concrete; whose fundamental components are the fine and coarse aggregates, water and cement. For the obtaining of these materials are necessary activities that generate environmental deterioration, since the aggregates are extracted from quarries or river banks and for each ton made of cement is emitted into the atmosphere a great lot of carbon dioxide. In this way, the present work is developed with the purpose of contributing to the research that can help the conservation of basic natural resources through the use of waste polymers such as waste tire rubber, in the production of concrete, hoping to reduce its harmful environmental impact. This work focuses on the one hand, in the study of the effects of the incorporation to the concrete, of different proportions of scratched rubber coming from waste tires, on its mechanical properties and on its capacity for microwaves absorption. On the other hand, it is also studied the effect of aging by applying different doses of gamma radiation on the before mentioned properties, seeking with this the possibility that it can be used in the construction industry either as structural material or as a coating. Replacements were made between 5% and 25% of rubber in order to do not significantly affecting the mechanical properties of the concrete. The results of the mechanical and microwave tests performed on the different samples with different gamma radiation doses were compared and it was found that open the possibility of research with great benefits such as the use of waste tires in the designing of concrete mixtures and the improvement of its properties. It is considered important to point out the economic benefit in the context of sustainable development, which involves solving the problem of environmental pollution caused by waste tires, to achieve the welfare of the population by improving their quality of life.

1. Introduction

1.1 Pollution by Concrete Production and Waste Rubber Tires

Concrete is one of the most important materials within the construction industry, this is due not only to its relatively low cost but also to the properties it shows such as easy placement before setting, resistance to weathering, durability, among others. For this reason, it is widely used around the world; however it has a great impact on the environment since it requires a lot of natural resources for its manufacture (sand, gravel and water). Besides, Portland cement production generates carbon dioxide that is released into the atmosphere, it is estimated that the cement industry is the responsible for the emission of one tone of CO_2 per year worldwide [9].

In the same way, the use of rubber tires and their subsequent disposal as waste rubber tires or recycling is a serious problem for the environment. While European countries such as Germany, France, Austria recycle up to 60% of their used tires, in Mexico there is practically no such recycling, due to low environmental awareness and a non-existent control system. In fact, it is estimated that more than 30 million tires are discarded annually and only 10% is recycled and the remaining 90% end up in vacant lots, rivers and roads. Tire trailers are not only unsightly and fire risk sites, but also represent a health risk as breeding grounds for harmful fauna such as rats, cockroaches, flies and mosquitoes, which can transmit diseases. Some of these fires can last for months and even years [1, 2], so the disposal of tires in landfills is often prohibited. As a result, the number of illegal trailers has increased with the consequent environmental and health problems, since in case of fire, the

air becomes highly toxic and contaminates the subsurface freezing mantles; Likewise, these sites become breeding grounds for harmful fauna such as rodents, cockroaches, snakes, spiders, scorpions, mosquitoes, etc., carriers of diseases or that represent a danger to human beings, and contribute to the deterioration of the urban image.

Currently, the renewal industry has made significant progress in the tire recycling process, achieving the separation of the three basic components: Textile fiber, steel and elastomeric. Probably the most used method for recycling tires is the reuse of these after undercutting (elimination of steel wires) [3, 4]. For example using it in bituminous mixtures in hot powder or edge for the modification of binders in asphalt pavements [6, 7, and 8]. On the other hand, the main method to eliminate waste tires is to burn them to produce steam, electricity or heat that is, using them as an alternative fuel such as in cement kilns. This is a widespread practice in the United States and Europe [5] and is very beneficial for the industry since the cost as a fuel is considerably lower than the original material. However, several studies have shown that the burning of tires releases substances of maximum danger to humans, such as carbon monoxide, furans, toluene, benzene and lead oxide [10].

In order to reduce the ecological impact that this entails, efforts have been made to reduce the consumption of non-renewable natural resources in the manufacture of concrete. A viable option for the solution to the problem caused by scrap tires is the reuse of the tire elastomeric in the concrete as a substitute for the fine or coarse aggregate, procuring the quality of the product and, if possible, seeking the increase in desirable properties such as strength, the elasticity module and the durability. In this sense, concrete is the mixture of fine and coarse aggregates with a cementing paste composed of Portland cement and water, which, once set, forms a monolithic mass similar to rock. The paste hardens due to the chemical reaction between water and Portland cement, generating hydration products. The fine aggregates are natural or synthetic sands with maximum sizes of up to 10 mm and the coarse aggregates are rocks or gravels with maximum sizes of up to 152 mm. Both aggregates constitute between 60 and 75% of the total volume of the mixture, so they can limit the properties of the concrete and influence its performance. However, these properties depend mainly on the quality of the paste formed by water and cement, as well as the affinity they have with the aggregates and their ability to work together.

1.2 Gamma Radiation Effects

Gamma radiation (γ) is a type of high-energy electromagnetic radiation formed by photons and generally produced by radioactive elements or subatomic processes such as the annihilation of a positron-electron pair. This type of ionizing radiation of such magnitude is capable of penetrating matter more deeply than alpha or beta radiation [12]. When a polymeric material is subjected to ionizing radiation, physical and chemical effects are produced which are a function of the nature of the polymers, as well as the radiation dose. The advantage of working with this type of macromolecules is the great sensitivity to changes in the chemical bonds, obtaining different properties in terms of crystalline, density, coefficient of thermal expansion, modulus of elasticity, permeability, as well as in the resistance to corrosion, abrasion and solvents.

With gamma radiation it is possible to modify the chemical structure of the particles or polymeric fibers through three processes: splitting or scission of chains (cross-linking) and grafting (graphing). These mechanisms contribute, to a greater or lesser extent, to modifying the mechanical behavior of polymers. The influence of each process depends on the amount of energy absorbed per unit mass (dose), the concentration, the dispersion, the atmosphere (inert or air) and the temperature at which the irradiation is carried out, as well as the post-treatment [13]. It is reported that physical and chemical effects can be expected when a polymeric material is subjected to ionizing radiation. The polymeric macromolecules are very sensitive to changes in its chemical bonds which can result in different properties in terms of crystalline, density, coefficient of thermal expansion, modulus of elasticity, permeability, as well as corrosion resistance, abrasion and solvents. Such effects depend on the nature of the polymers as well as the dose of the radiation. Based on the aforementioned, the objective of this research work is the study of the effects of the incorporation to the concrete, of different proportions of scratched rubber coming from waste tires as the effect of aging by applying different doses of gamma radiation on its mechanical properties and on its capacity for microwaves absorption.

2. Experimental Setup

Five batches named B0, B1, B2, B3 and B4, each batch of 6 specimens of concrete blocks mixed with rubber scratches of waste recycle tires were prepared according to the compositions shown in Table 1. The specimens obtained were 30 continuous square section bars of 5 cm of side by 30 cm of length, see figure 1. After the irradiation doses, the six bars of each batch were sectioned to obtain cubes of 75 cm^3 and square slices 1 cm thick. All of the samples were wrapped in blotting paper to isolate them from the environment, see figure 2.

Table 1. Amounts of concrete + rubber used in the study. The cement used was Portland CPC 30 type.

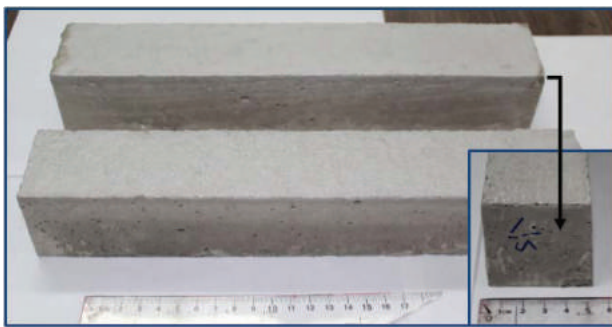| Batch 0, 1, 2, 3, 4	Rubber content (Vol. %)	Concrete (Vol. %)
M0	0	100
M5	5	95
M10	10	90
M15	15	85
M20	20	80
M25	25	75

Figure 1. Concrete continuous bars of 5 cm × 5 cm × 30 cm length obtained after 24 hours from the casting. The box shows the cross section of the bar.

Figure 2. After the cutting, the cubes as the slices obtained were wrapped in blotting paper to isolate them from the environment.

The obtained samples, Radiated (R) and the No Radiated (SR) were mechanically characterized by performing compression tests in an Instron universal machine for mechanical tests, model 4206 of 150 kN of capacity, using a deformation speed of 0.5 mm per minute. There exist several different criteria and proposals for the calculation of the modulus of elasticity of the concrete [3, 4, and 5], however, in the present work, the modulus of elasticity was calculated by the equation 1 according to the established criterion By the American Concrete Institute (ACI).

$$E_0 = 4700\sqrt{f_c'} \qquad (1)$$

where:

E_0 = Modulus of Elasticity (Mpa)
f_c' = Stress Strength of concrete (Mpa)

In the same way, the fracture stress was determined using a strain criterion of 0.01 %. In order to determine changes in the microwave isolation capacity of the samples due to the gamma radiation doses, studies of microwave penetration were carried out on the different samples. A microwave guide consisting of a T-shaped guide, two square waveguides, a klystron microwave generator JAN-CRP 2K25 and at the opposite end, an HP X-424A PIN diode detector for the detection of the microwave signal was used.

3. Results

3.1 Mechanical Properties

The results of the mechanical tests are showed in figure 3 as stress vs. strain curves of the samples at its different compositions. As reported in a previous work, it is observed the presence of two slopes in all of the samples. The first slope corresponds to the "elastic" behavior of the material in which the linearity of the deformation regarding the stress is suddenly interrupted showing a maximum value followed by a small drop. Such interruption is due to the micro-cracking of the sample, which in the present work is considered as the failure of the same. It is important to mention that the appearance of an internal micro crack is presumed since in the visual inspection of the surface of the sample the presence of cracks was not observed.

After the first change of the slope, the fracture stress value increases again as the deformation does too, forming the second slope that exhibits a "semi-linear" behavior corresponding to the "quasi-elastic" behavior of the cracked material. The stress value observed when the crack appears corresponds to the Fracture stress of the material and it was determined from the graphs of figure 3 using the 0.01 % criterion described in the experimental procedure. Fracture Stress vs Rubber Content values are showed in the bar graphic of figure 4. As expected, the sample without rubber additions, exhibits the highest fracture stress of approximately 4.8 MPa, followed by the sample with rubber content of

5 Vol.% and a fracture stress of 2.25 MPa. After that, the fracture stress decreases to the values of 1.0 Mpa, 1.3 Mpa and 0.2 Mpa values corresponding to the samples with 15 vol. %, 20 Vol. % and 25 vol. % of rubber content respectively.
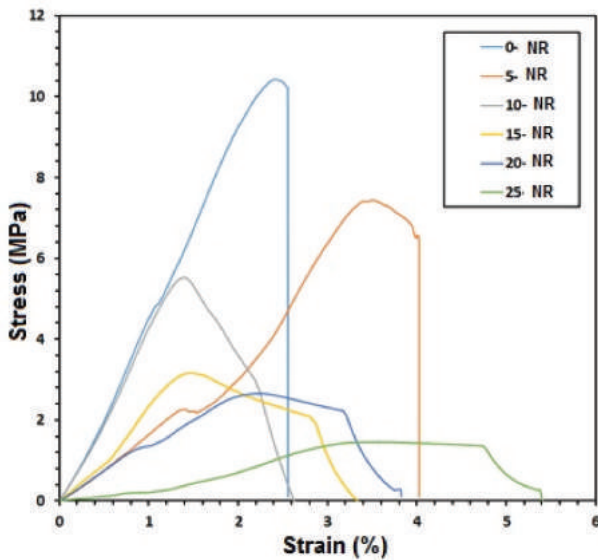

Figure 3. Fracture Stress as a function of the samples at its different compositions. The box indicates the rubber content and NR means without radiation.
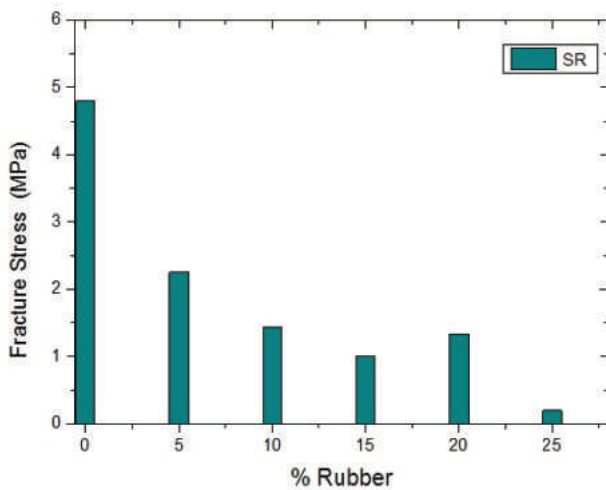

Figure 4. Fracture Stress values observed as a function of the rubber content in the specimens under study.

When comparing the mechanical properties of the samples without radiation with the samples with different gamma radiation doses, it was observed that the radiation apparently has a beneficial effect on the mechanical resistance of some of the samples. Figure 5 show the results of concrete irradiated at 0, 70, 140 and 210 kGy made with auto tire particles. From figure 5, it can be appreciated that, apparently the increment of gamma radiation dose affects mainly to the samples without rubber (black bars) and the sample with 5 vol. % rubber (red bars) because they show the highest fracture stress values. In these samples the fracture stress decrease from approximately 4.8 MPa to 2.4 MPa when a 35 kGy dose of gamma radiation is applied in the sample with no rubber, but such value increases again to 5.8 MPa staying this rate almost constant when doses of 140 kGy and 210 kGy are applied. On the other hand, the sample with 5 vol. % rubber shows an increase in the Fracture Stress from 3.0 MPa corresponding to the sample without radiation, to 4.5 MPa corresponding to the sample with 70 kGy dose of Gamma Radiation. Subsequently to these values, a great decrement is observed. The samples with higher rubber contents also showed increments and decrements in their Fracture Stress values according to the gamma radiation doses applied but such values were very low.
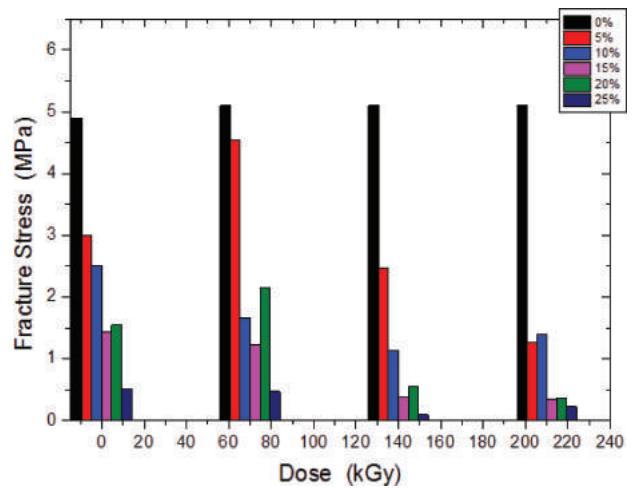

Figure 5. Effect of the Gamma radiation doses on the fracture stress of the samples at its different compositions.

In concrete, an alternative that has proven to be efficient to increase resistance values, is the use of gamma radiation through two methods:
- Modification of the structural properties of the reinforcements and their subsequent
  Incorporation into concrete mixtures.
- Direct irradiation of the concrete with the reinforcements included.

After the irradiation, the structural changes of the reinforcements are related to the mechanical properties of the concrete, including the resistance to stress, to compression, to impact, as well as the deformations in the point of yield and to the rupture. It is important to mention

that, as reported in a previous work, the sample without rubber additions offers the best compressive strength but also the most fragile behavior since, once the crack initiates, it moves quickly, fragmenting the sample and collapsing it. In the present work, the "elastic" deformation showed by the sample without rubber additions was approximately 0.05 mm of maximum deformation before it cracks and the resulting fragments get separated, see figure 6 a). At the end of the test, once the sample is removed from the testing machine, it collapsed and the fragments were completely separated, see figure 6 b).
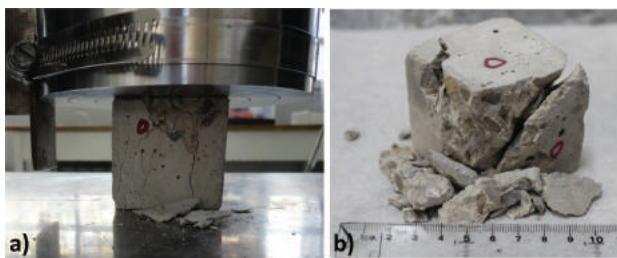

Figure 6. Representative photograph of the sample with no rubber additions fragmented and collapsed during the compressive test.
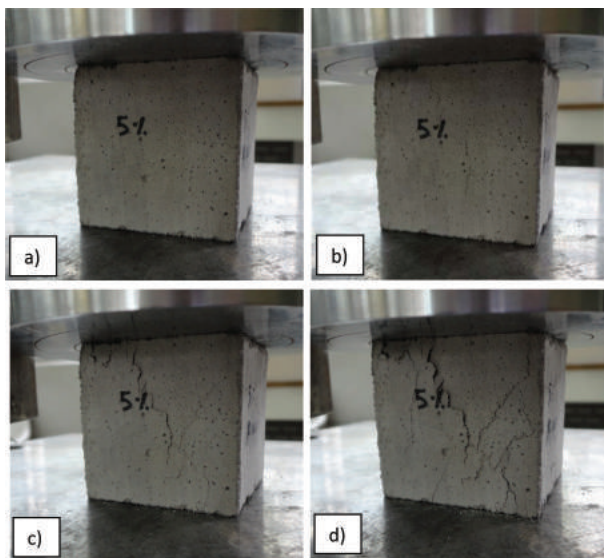

Figure 7. Compressive test and evolution of the cracking as a function of the crosshead and the deformation. a) Start of the test and 0 mm deformation; b) 0.5 mm deformation; c) 1.0 mm deformation; c) 1.5 mm deformation

Otherwise, the samples with rubber additions shows a barely "ductile" behavior since in these samples, once the crack initiates it does not moves quickly but a little slow without observing the collapse seen in the sample with no rubber additions, for example, the specimen with 5 % rubber, exhibited 0.07 mm of maximum deformation

before the raising of the crack. Comparing the 0.07 mm of maximum deformation of the sample with rubber additions against the 0.05 mm of the samples without rubber, it results in an increment of approximately 22 %. In order to observe the behavior under compression of the samples with rubber additions, the compression platen was allowed to advance up to 2 mm of deformation. The results are showed in figure 7. It can be see that the sample is complete and cracking free, see figure 7 a). The figure 7 b) shows the same sample but with 0.5 mm of deformation and the appearance of a crack visible to the eye. In this point, it is important to mention that the crack corresponding to the 0.07 mm of maximum deformation mentioned above was microscopic and invisible to the human eye; however, it is assumed the existence of such microcrack due to the sudden stress decrease registered during the compressive test. Once the crack appears, it begins to advance and to expand, while the appearance and widening of additional cracks are observed, se figure 7 b, c. Once the test was finished, the sample was removed from the plate and although fractured, it was complete as it can be seen in figure 8.
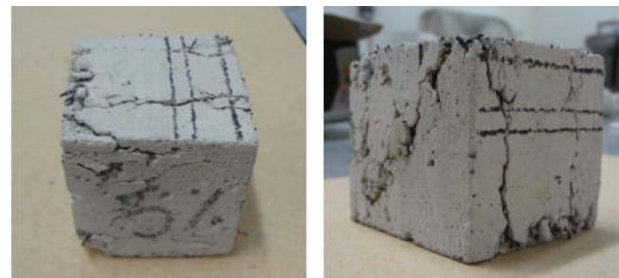

Figure 8. Specimen of 5 vol. % rubber after the compressive test. The total displacement of the head was 2 mm.

Table 2. Numerical results of the mechanical tests performed on the R and SR samples at its different rubber contents.

Sample	Compressive Strength (Mpa)		Strain (%)		Modulus of Elasticity	
	SR	R	SR	R	E0	E0R
M1	3.00	2.41	0.61	0.18	8141.32	7293.33
M2	1.86	2.02	0.31	0.25	6409.34	6679.74
M3	1.54	0.52	0.95	0.52	5836.00	3381.77
M4	0.52	0.48	0.75	1.80	3377.25	3253.00

An important point to note is that the modification of the concrete with rubber scratches produces changes on its deformation capacity as it can be seen in figure 9. It can be appreciated that non radiated samples (SR) exhibits an oscillatory behavior of the deformation at its

different compositions, however, an increase tendency in the deformation as a function of the rubber content in the sample can be assumed. It is important to mention that such values corresponds to the "elastic zone "of the Stress vs. Strain curve where the specimen has no any cracks and it is considered as an integral element.
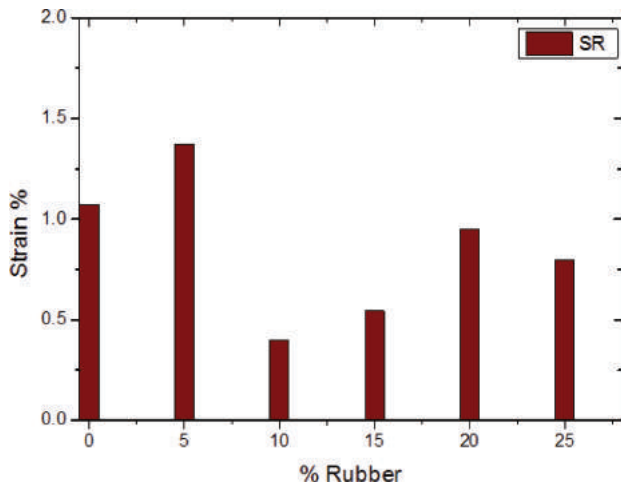

Figure 9. % Strain values registered during the compressive test of the samples at its different compositions.

3.2 Structural Characterization

In an attempt to give a possible explanation to the "elastic" behavior of the samples modified with rubber, several photographs were taken in the fracture of the samples and in the cracks of the same. Figure 10 shows the images obtained. From figure 10a, it can appreciate that there is a uniform distribution of the rubber scratches inside the block. No gaps are observed which suggest the existence of a good adhesion with the cement and sand mixture, see the box. Figure 10b shows a closer observation of the fracture focusing in the rubber scratches. It can be seen that the rubber scratches are not smooth on their surface but have a certain roughness which allows and promotes an adequate adhesion of the same with the cement and sand mixture since the presence of remnants of mixture on the surface of the scratches is observed. In addition, it was found the presence of internal cracks, most of them wide, which once formed, were propagated through the matrix of cement and fine aggregate (sand) and even through the coarse aggregate separating them completely and giving rise to the disintegration and collapse of the material in the samples with no rubber additions. On the other hand, in the rubber-modified samples narrow cracks were observed which do not seem to evolve or widening or even growing as fast as those of the samples without rubber. The "elastic" behavior observed in the samples with rubber additions is presumably due to the fact that long rubber scratches, acts like "anchors"

which keeps together the fragmented pieces and offering an additional resistance to the collapse of the sample and still charging.
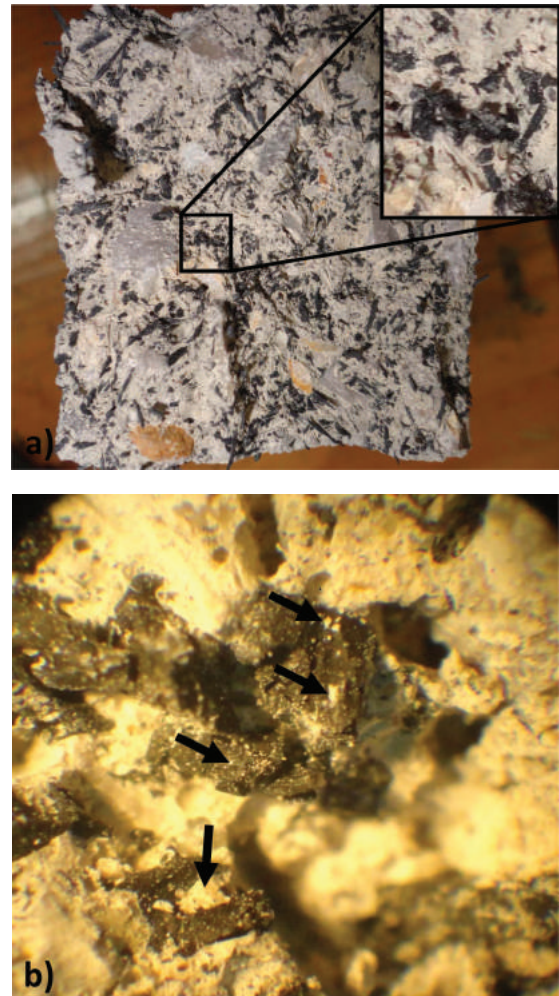

Figure 10. a) Macro-photograph of the fractured surface of a sample with rubber additions. b) Close up of a zone containing rubber scratches.

3.3 Microwaves

Starting from the base that waves are a means of transporting energy or information; electromagnetic waves can be guided or unguided waves, the first case refers to structures that guide the wave and the second refers to free propagation of the waves. In addition, these types of waves have three fundamental characteristics; they move at great speed, adopt properties of the waves and radiate outward from a source without the aid of any discernible physical vehicle, whose energy is transported by an electric field or magnetic field, associated with the wave. Different materials behave

differently in the presence of microwaves. The behavior is described in terms of the dielectric constant. If the polarization is very low (real part of the dielectric constant), the process only produces a difference in charge without heating the material, but if it is high, the product heats up quickly. This process is expressed as the imaginary part of the dielectric constant referred to as the dielectric loss factor.

These properties are known in many materials and can be found with relative ease, except in the case of active ingredients. The conversion of electromagnetic energy into thermal energy is carried out by the electromagnetic characteristics of the material. Generally, when a frequency is used for the heating process and the characteristics of temperature dependence are not known, it can be obtained based on the behavior of the material itself. For water, its relaxation frequency is greater than the frequency of microwaves, as the temperature increases, it moves further away from the frequency of the microwaves, resulting in less absorption of microwave energy. On the other hand, for large molecules at low temperatures, their relaxation frequency is lower than the frequency of the microwaves, but as their temperature increases, their frequency increases and they approach the microwaves, so that their absorption of microwave energy increases, resulting in a greater heating.
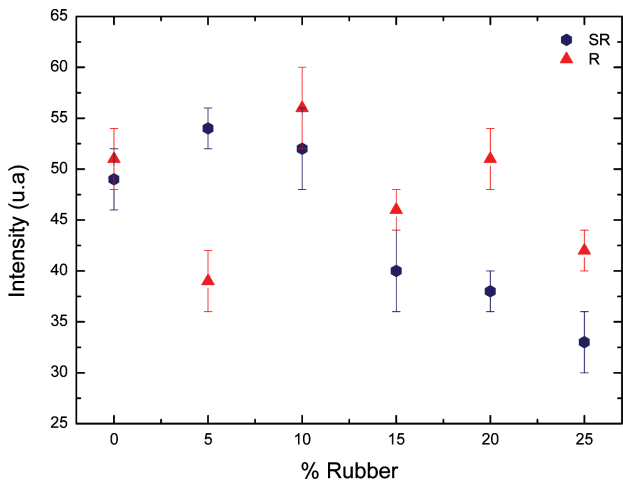

Figure 11. Intensity of the microwaves that pass through the samples with different percentages of rubber, both for the radiated and non-radiated samples.

Non-polar materials (e.g., air, Teflon, quartz, glass) cannot convert microwave energy into heat. Microwaves pass through these materials and do not weaken. However, there is literature that supports that a large number of plastics including PVC, rayon, nylon, polyester, polyethylene and PTFE can absorb microwaves. In the figures 11 and 12 we see how the different samples behave, in the presence of microwaves. It is observed that as the percentage of material

of the car rim increases, the passage of the microwaves increases to a certain point and then decreases according to the law of Lambert's [17, and 18]:

$$P(z) = P_0 \exp(-2\beta z) \qquad (2)$$

P (z) is the energy absorbed by the material as a function of the penetration distance z from the surface. P_0 is the radiation intensity at the surface of the material and β is the so-called attenuation factor, this indicates the distribution of energy within the material and is a measure of the decay of the energy absorbed. All this as a function of the percentage of rubber. For the radiated sample, the microwaves have a behavior of descents and rises but tending towards a certain value. It is observed that the percentage of rubber in the sample increases that the intensity of the microwave passing through it decreases.
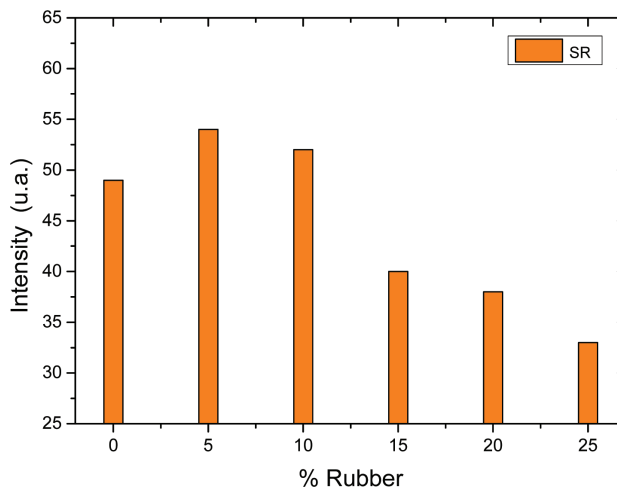

Figure 12. Intensity of the microwaves that pass through the samples with different percentages of rubber, for the samples not radiated.

4. Conclusions

Great efforts have been made in environmental matters to reduce pollution, such as the present investigation, which contemplates the use of scrap tires as reinforcement material for concrete. In general improvements are observed in the mechanical properties of the concrete when the tire recycling is added, something desired for the concrete; however, the treatment based on Gamma rays allows observing the passage of time in the material and the properties within the mixture, with results superior to the concrete witnesses. This represents a solution to the drawbacks of using these materials within the construction industry. Finally, the

combination of the low cost of the waste material and the increase in the mechanical properties of the concrete, make this an attractive product with not only economic benefits, but environmental ones.

The stress vs. strain curves of the samples at its different rubber content shows two slopes where the first one corresponds to the "elastic" behavior previous to the micro-cracking which is observed as a change in the slope of the line. Samples with no rubber additions exhibits a fragile behavior since once the crack appears, a rapid fragmentation and collapsing of the material is observed. Samples with rubber additions exhibits an "elastic" behavior since once the crack appears, a slow fragmentation and slow collapsing of the material is observed. This is presumably due to the long rubber scratches, acts like "anchors" maintaining together the fragmented pieces and offering an additional resistance to the collapse of the sample and still charging. It is assumed that gamma radiation dose affects the mechanical properties of the samples being such effect major in the samples without rubber and in the sample with 5 vol. % rubbers because they show the highest fracture stress values. The microwaves in the non-radiated samples behave according to Lambert's law, where the energy absorbed by the material is a function of the penetration distance and an attenuation factor. All this as a function of the percentage of rubber. The radiated samples have an ups and downs behavior for the different percentages of rubber in the sample.

Acknowledgement

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