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PRELIMINARY STUDIES TO USE TEXTILE FIBERS OBTAINED FROM RECYCLED TIRES TO REINFORCE ASPHALT MIXTURES

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Abstract

The use of crumb rubber in the modification of asphalt has occurred because of the problems related to disposal of scrap tires. However, the use of scrap tires in asphalt pavements, known as asphalt rubber pavements, can minimize environmental impacts and maximize conservation of natural resources. The textile fibers from recycled tires are typically disposed of in landfills or used in energetic valorization, but similar to other fibers, they can be used as a valuable resource in the reinforcement of engineering materials such as asphalt mixtures. Thus, this work aims at studying the use of textile fibers recycled from ground tires in the reinforcement of conventional asphalt mixtures. The application of textile fibers from ground tires was evaluated through laboratory tests on specimens extracted from slabs produced in the laboratory. Indirect tensile tests were performed on a series of nine asphalt mixtures with different fiber and asphalt contents and compared with a conventional mixture. The results obtained from a 50/70 pen asphalt were used to define three asphalt mixture configurations to be used with 35/50 pen asphalt. The results indicate that the textile fibers recycled from used tires can be a valuable resource in the reinforcement of asphalt mixtures.

Keywords: Asphalt mixtures, Tire fibers, Recycling, Indirect tensile strength

1. INTRODUCTION

The asphalt layers of road pavements are composed of asphalt mixture, a mixture of asphalt and aggregates, combined in various proportions to maximize its strength. However, due to increasing traffic, asphalt mixtures have been subjected to more severe loads that require a higher level of performance. Asphalt modification is one approach taken to improve pavement performance (Amorim et al., 2015; Brovelli et al., 2013; Brovelli et al., 2015).

Recently, crumb rubber recycled from used tires has been used in the modification of asphalt and has improved asphalt mixture performance (Neto et al., 2006; Thives et al., 2013; Lo Presti, 2013; Lo Presti and Airey, 2013). This use is typically carried out by applying crumb rubber from tire grindings to modify the asphalt used in asphalt mixtures or to replace part of the aggregates in asphalt mixtures (Peralta et al., 2010; Lo Presti et al., 2014). The other components of recycled tires (fibers and metals) are not used in the asphalt mixtures and are discarded. The fibers are typically disposed of in landfills or used in energetic valorization, but similar to other fibers, they can be used as a valuable resource in the reinforcement of engineering materials such as asphalt mixtures (Chowdhury et al., 2006).

Different types of fibers are currently employed to reinforce asphalt mixtures, including polypropylene, polyester, asbestos, cellulose, carbon, glass and nylon (Abtahi et al., 2010).

Based on the success using of different types of fibers in asphalt mixtures, this work aims at studying the use of textile fibers recycled from ground tires in the reinforcement of conventional asphalt mixtures.

The application of textile fibers from ground tires was evaluated through indirect tensile tests on specimens extracted from slabs produced in the laboratory using 1.5% of fiber content. Two type of asphaltswere used namely a 35/50 pen asphalt and a 50/70 pen asphalt. For each type of asphalt, three different asphalt content were used. Conventional dense asphalt mixtures were used as reference. The results indicate that the textile fibers recycled from used cars can be a valuable resource in the reinforcement of asphalt mixtures.

2. MATERIALS AND METHODS

2.1. Materials used

Despite the influence of the aggregate gradation on the asphalt mixtures behavior (Sousa et al., 1998) the study developed in this work was based on an AC14 asphalt mixture (14 mm maximum aggregate size) produced with two conventional asphalt binders with an optimum binder content of 5.0%. The mineral aggregates used in this work were obtained from a local quarry and are of granitic origin. The filler is from a limestone source. The aggregate gradation is presented in Figure 1, as well as the limits proposed in the European standard.

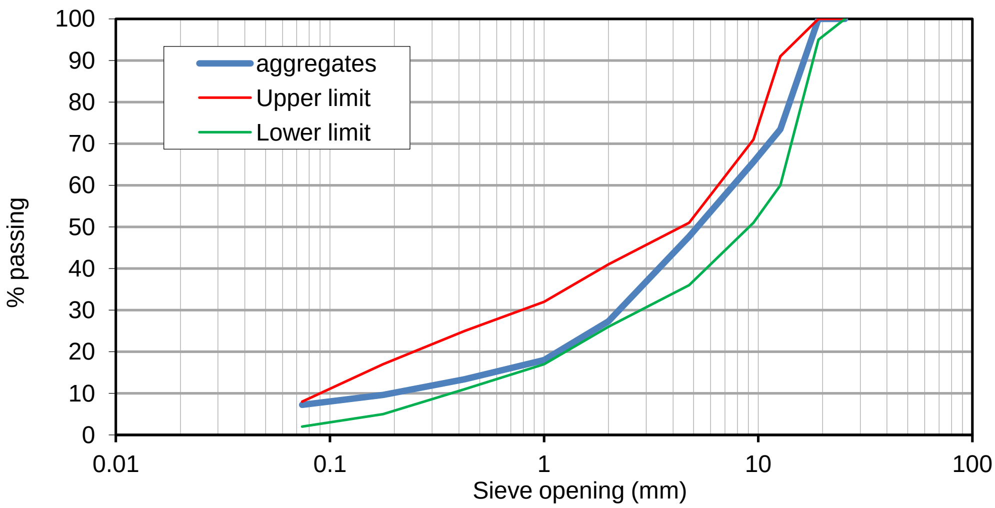

Figure 1. Aggregate gradation used for the asphalt mixtures

Two asphalts were used in this work: a 50/70 pen asphalt and a 35/50 pen asphalt. They correspond to a relatively soft asphalt (50/70) and a relatively hard asphalt (35/50) for warm climatic conditions, characterized by an average Shell design air temperature of 16 ºC, for which the pavement design temperature is approximately 23 ºC for a pavement with 15 cm of asphalt layers.

The asphalts were characterized in terms of penetration, softening point and viscosity. The results of the asphalt characterization are presented in Table 1, where it can be observed that the 35/50 asphalt has a penetration of 46 mm/10 and the 50/70 asphalt has a penetration of 67 mm/10. These different values allow the study of the influence of asphalt stiffness on asphalt mixture behavior. As expected, the viscosity of the 50/70 asphalt is lower than that of the 35/50 asphalt, which is beneficial for asphalt mixture production and compaction. The softening point is within the recommended values for the climatic conditions of this study.

Table 1. Properties of asphalt binders

Properties	Standard	35/50	50/70
Penetration 25 ºC, 100 g, 5 s (0.1 mm)	ASTM D5	46	67
Softening point (ºC)	ASTM D36	60	52
Viscosity (cP) a 175 ºC	ASTM D2196	180	114

The fibers used in this work to reinforce the asphalt mixtures were obtained from the grinding of used truck and car tires. The primary purpose of grinding of used tires is obtaining crumb rubber to modify asphalt binders and for use in playground pavements. However, the grinding process produces by-products such as steel, which is used in the siderurgy, and textile, which is usually sent to landfills or used in energetic valorization.

The rubber usually passes through the mills/screens to achieve various particle size reductions and during this process, the steel is removed using magnets while the textile fibers are removed using a suction system.

The physical aspect of the textile fibers obtained from the grinding of used tires is presented in Figure 2. The characterization of the fibers is extremely complex because they are relatively short and they are completely interlaced. As observed in Figure 2, the textile fibers have a small amount of crumb rubber that is benefic for the performance of the asphalt mixture (Brovelli et al., 2014).

Figure 2. Aspect of the fibers used in the asphalt mixtures

2.2. Mixture designs

This work was developed based on a conventional AC14 asphalt mixture (14 mm maximum aggregate size) produced with two conventional asphalt binders (50/70 and 35/50 pen asphalt) with an optimum binder content of 5.0%. The addition of the fibers to the asphalt mixtures was studied through the use of 6 different asphalt mixtures with 1.5% fiber content and different asphalt binder contents for both asphalt binders used (35/50 and 50/70). The different compositions are presented in Table 2. The Conventional (50/70) and Conventional (35/50) mixtures are the reference mixtures produced with the 50/70 and 35/50 binders and with 5% of asphalt content. The other asphalt mixtures are referenced as 'A' for the asphalt binder content and 'F' represent the fiber content and the asphalt type is indicated between the parentheses.

Table 2. Asphalt and fiber content of the asphalt mixtures

Asphalt mixtures	Asphalt content (%)	Fiber content (%)	Asphalt type
Conventional (50/70)	5.0	0.0	50/70
A6.0 F1.5 (50/70)	6.0	1.5	50/70
A6.5 F1.5 (50/70)	6.5	1.5	50/70
A7.0 F1.5 (50/70)	7.0	1.5	50/70
Conventional (35/50)	5.0	0.0	35/50
A6.0 F1.5 (35/50)	6.0	1.5	35/50
A6.5 F1.5 (35/50)	6.5	1.5	35/50
A7.0 F1.5 (35/50)	7.0	1.5	35/50

Asphalt mixtures for this work were produced in the laboratory. Each batch of aggregate was maintained at a temperature of 180°C, comprising three different aggregate gradations (0/5 mm, 5/10mm and 10/15 mm). Then, about 50 seconds before adding the asphalt binder at 150 ºC, the amount of fibers, at ambient temperature, was introduced into the mixer. After a thorough mixing, the asphalt mixtures were compacted at a temperature of 140 ºC. A vibrating steel roller was used to compact the asphalt mixtures into slabs (Figure 3). Cylindrical specimens of 101.6 mm diameter and 63.4 mm thick were cored from the slabs for indirect tensile strength tests as shown in Figure 4.

Figure 3. Asphalt mixture compacted in a slab mold using a steel roller compactor

Figure 4. Cylindrical specimens used in the indirect tensile strength tests

The cylindrical specimens were characterized in terms of void content, as indicated in Table 3, after being subjected to air conditioning (room temperature of 20 ºC) and water conditioning (at 40 ºC for 68 hours). The conventional mixtures presented a typical void content (between 3.2% and 5.2%); the void content of the mixtures with fibers was influenced by the binder and fiber contents and ranged between 0.8% and 5.6%. The increase in binder content decreased the voids in the asphalt mixtures, whereas the presence of the fibers allowed a reduction in the void content, mainly due to the lubricant effect during the compaction process. The void contents obtained result from using the same compaction energy, and the difference is only due to the presence of fiber and binder contents in the asphalt mixture.

Table 3. Density and void content of the asphalt mixtures

Asphalt mixture	After air conditioning		After water conditioning	
	Density (g/cm3)	Voids (%)	Density (g/cm3)	Voids (%)
Conventional (50/70)	2.37	5.18	2.38	5.03
A6.0 F1.5 (50/70)	2.36	0.80	2.36	0.97
A6.5 F1.5 (50/70)	2.29	5.57	2.30	5.46
A7.0 F1.5 (50/70)	2.39	2.50	2.39	2.50
Conventional (35/50)	2.48	3.30	2.48	3.20
A6.0 F1.5 (35/50)	2.35	2.51	2.35	2.53
A6.5 F1.5 (35/50)	2.34	1.92	2.34	1.98
A7.0 F1.5 (35/50)	2.34	1.33	2.34	1.13

2.3. Performance test

Indirect tensile strength tests were carried out on the cylindrical specimens to determine the performance of the asphalt mixtures.

The indirect tensile strength tests were carried out using the device presented in Figure 5, by applying a load diametrically along the direction of the cylindrical specimen axis with a constant speed of displacement until failure. The indirect tensile strength is defined as:

$$ITS = \frac{2P}{\pi DH} \tag{1}$$

where ITS is the indirect tensile strength, P is the peak load, D is the diameter of the specimen, and H is the height of the specimen, as expressed in EN12697-23 (2003).

Figure 5. Indirect tensile strength test apparatus

A typical plot of the results of the indirect tensile strength test is presented in Figure 6 and is characterized by the evolution of the applied deformation of the specimen (50 mm/min) against the measured load (strength). From this test, the tensile strength is obtained as the peak of the load-deformation curve, and the failure deformation is obtained as the deformation at the peak load. Three other values were extracted from the indirect tensile strength tests: the “ascending slope,” defined as the slope of the initial phase of the load-deformation curve, which gives an indication of the stiffness of the asphalt mixture, and the “descending slope,” defined as the slope of the final phase of the load-deformation curve, which gives an indication of the recovery of the asphalt mixture.The other value is the energy of deformation, defined as the area under the load-deformation curve, after the extrapolation of the final part of the curve down to the horizontal axis. This parameter has been used by Lee et al. (2005) to evaluate the fatigue cracking resistance of fiber-reinforced asphalt concrete, even as Vasconcelos et al. (2012).

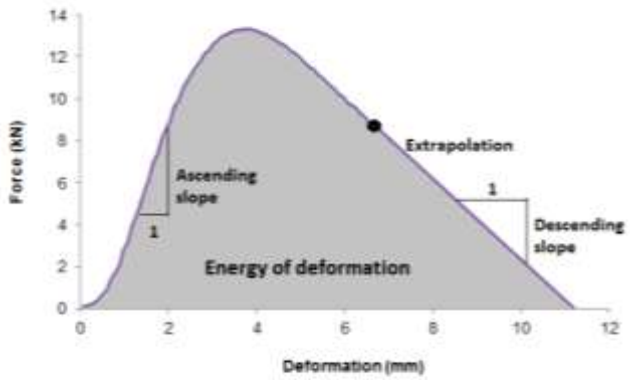

Figure 6. Typical plot of indirect tensile strength test results

The indirect tensile strength tests were carried out at the temperature of 20 ºC after specimens were conditioned for two hours in a climatic chamber, as recommended in Minhoto et al. (2005) and Minhoto et al. (2008). However, to study the influence of water on the asphalt mixture behavior, a set of specimens were tested at 40 ºC after being subjected to water conditioning at 40 ºC for 68 hours, as defined in EN 12697-12 (2009). For each asphalt mixture, 6 specimens were tested: 3 specimens at 20 ºC without water conditioning and 3 specimens at 20 ºC after water conditioning.

The indirect tensile strength ratio is defined as the quotient of the average indirect tensile strength for the specimens subjected to water conditioning and the average indirect tensile strength for the specimens without water conditioning (air conditioning).

$$ITSR = 100 \times \frac{ITS_w}{ITS_d} \qquad (2)$$

where ITSR is the indirect tensile strength ratio (%), ITS_w is the indirect tensile strength of the wet group, and ITS_d is the indirect tensile strength of the dry group, as expressed in EN12697-23 (2003).

3. RESULTS AND DISCUSSION

The testing program carried out with the asphalt mixtures studied in this work was based on the indirect tensile strength tests on specimens subjected to air and water conditioning conducted at 20 ºC. All results presented in this analysis are the average of the three specimens tested.

The load-deformation curves for all mixtures subjected to air conditioning are presented in Figure 7. A clear difference can be observed between the mixtures produced with the 35/50 pen asphalt (4 lines at the top of the figure) and the mixtures produced with the 50/70 pen asphalt (other lines). These differences are observedin terms of maximum tensile strength and slope of the ascending and descending part of the load-deformation curve. Asphalt mixtures with 35/50 pen asphalt present the highest tensile strength compared to the mixtures with 50/70 pen asphalt. The deformation at failure is also dependent of the type of asphalt used in the mixtures. The conventional mixtures produced with both asphalts and used as a reference present behavior within the asphalt type group.

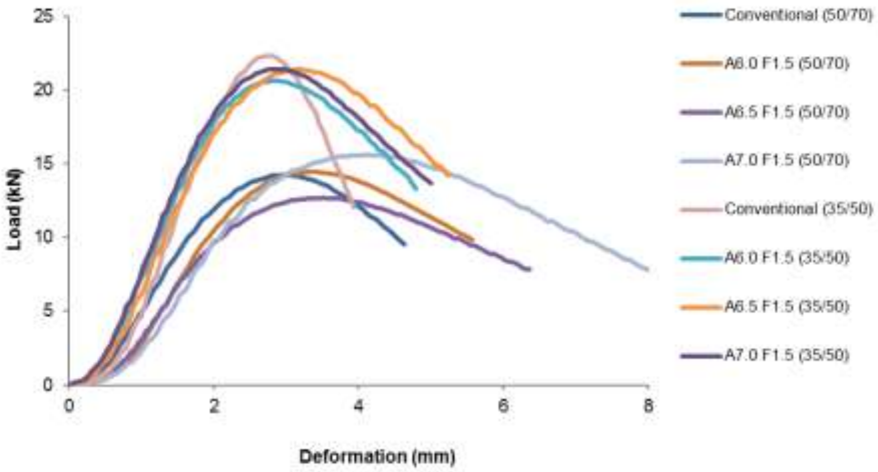

Figure 7. Load-deformation curves for asphalt mixtures subjected to air conditioning

The load-deformation curves for all mixtures subjected to water conditioning are presented in Figure 8, in which it can be observed that the separation between the asphalt mixtures produced with the different asphalt types is not so clear as observed for the air-conditioned mixtures. Furthermore, within a given type of asphalt, the dispersion of the results is extremely high compared to that of the results observed for the mixtures subjected to air conditioning. This phenomenon is due to the different void contents of the mixtures, which allow water intrusion and thus affect the asphalt-aggregate interaction, mainly reducing the maximum tensile strength. In terms of the slope of the load-deformation curves, the ascending part of the curve does not present a unique slope, whereas the descending part clearly presents two distinct slopes.

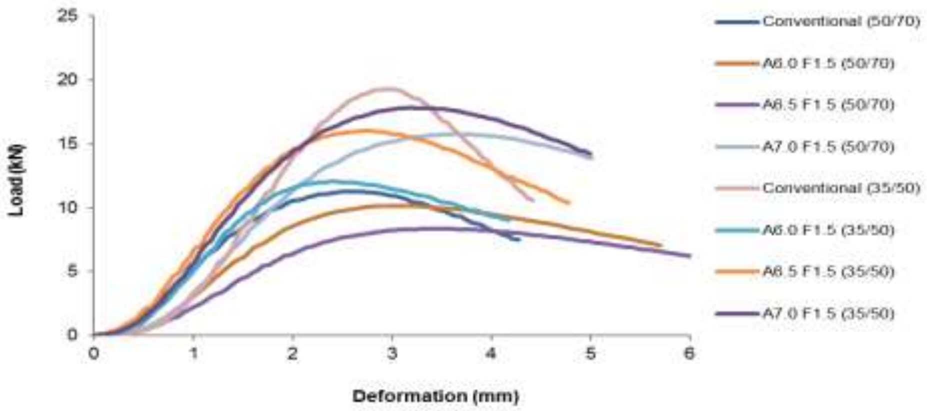

Figure 8. Load-deformation curves for asphalt mixtures subjected to water conditioning

The Indirect Tensile Strength (ITS), defined as the strength at the peak of the load-deformation curve, is presented in Figure 9 for both air and water conditioning. For the mixtures subjected to air conditioning, the presence of fibers does not increase the tensile strength of the mixtures compared to the reference mixture. This means that the fibers are not working as reinforcement in the mixtures, as it was assumed they would. This is most likely due to the short length of the fibers, which does not provide enough binding length, and thus, the tensile strength of the mastic does not increase. Water conditioning produces a significant reduction in the tensile strength. The increase in the void content allows water intrusion that reduces the interaction between the asphalt and the aggregates and thus the indirect tensile strength. However, the tensile strength follows the same trend as the one observed for air conditioning. The comparison between both asphalt binders used in this work shows a significant reduction of the ITS when using a soft asphalt as the 50/70 as compared with the 35/50 pen asphalt.

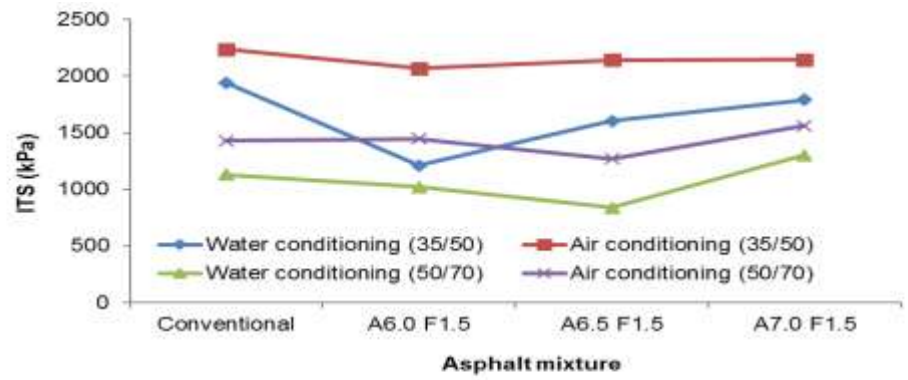

Figure 9. Indirect tensile strength

The effect of moisture on the asphalt mixtures was evaluated through the Indirect Tensile Strength Ratio (ITSR) and the results are presented in Figure 10. The conventional mixtures, without fibers, presents the greatest ITSR, indicating that the presence of fibers increases the water sensitivity. This is most likely because the fibers allow water intrusion, reducing the adhesion between the asphalt and the aggregate. The exception are the mixtures with 7.0% of asphalt because the large amount of asphalt in the mixtures allows a complete sealing of the mixture avoiding the water entrance.

Most of the standards recommend that the ITSR should be greater than 70% to avoid the disaggregation of the mixture in the presence of water in the pavement.

The results obtained for the 50/70 asphalt indicate that only A7.0 F1.5 have sufficient water resistance. This fact can be explained because the stiffness of the asphalt does not allow a complete involvement of the fibers and thus allows the entrance of water, reducing the moisture resistance. The results for the 35/50 asphalt indicate that for 1.5% fibers, the asphalt content must be at least 6.5%. The mixture with 6.0% asphalt content has a significantly decreased ITSR compared to the other mixtures and compared with the same mixture but with the 50/70 asphalt. However, the mixtures with the 35/50 asphalt exhibit better water sensibility behavior than the mixtures with the 50/70 asphalt.

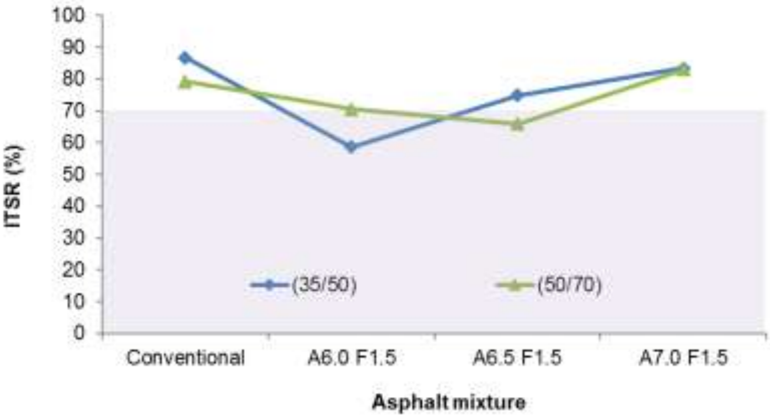

Figure 10. Indirect tensile strength ratio

Figure 11 shows the ascending slopes of the load-deformation curves that can be correlated to the stiffness of the asphalt mixtures. Observation from this figure showed that water conditioning reduces the slope which in turn reduces the asphalt mixture stiffness. It can be explained that the presence of fibers allows ingress of water which reduces the asphalt-aggregate interaction thus decreasing the asphalt mixture stiffness.

For mixtures with 50/70 asphalt the ascending slope decreases when the asphalt content increases and the opposite occurs for 35/50 asphalt. It is clear that the use of higher penetration asphalt binder increases the asphalt stiffness and consequently the ascending slope obtained in the indirect tensile strength test. It is not evident what the effect of the binder content on the ascending slopes for the air conditioning asphalt mixtures is. However, for asphalt mixtures subjected to water conditioning, a slight increase in the ascending slope is observed for the asphalt mixture produced with 6.5% asphalt content, but a decrease is observed for 7.0% of asphalt content.

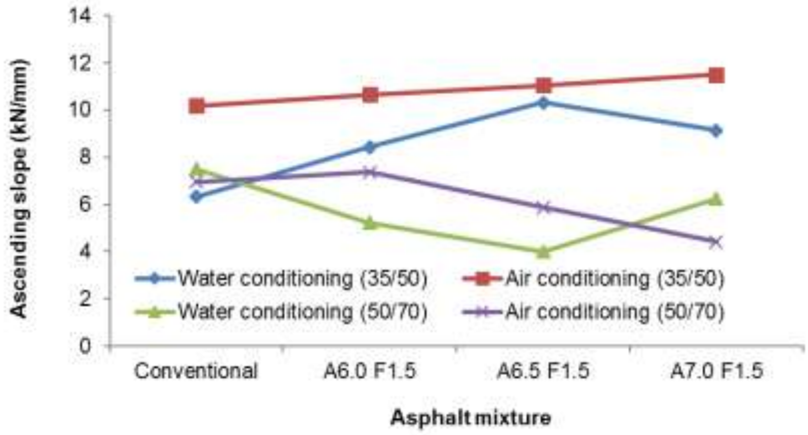

Figure 11. Ascending slopes of the load-deformation curve

The descending slopes of the load-deformation curves, which give an indication of the resistance of the asphalt mixture after cracking, are represented in Figure 12. Lower descending slopes correspond to greater cracking propagation resistance. As expected, the results demonstrated that the descending slope is reduced due to the presence of the fibers. This is because after the failure of the asphalt mixture, the tensile strain within the mixture is supported by the fibers and observed as a lower descending slope. The water conditioning considerably reduces the descending slope.

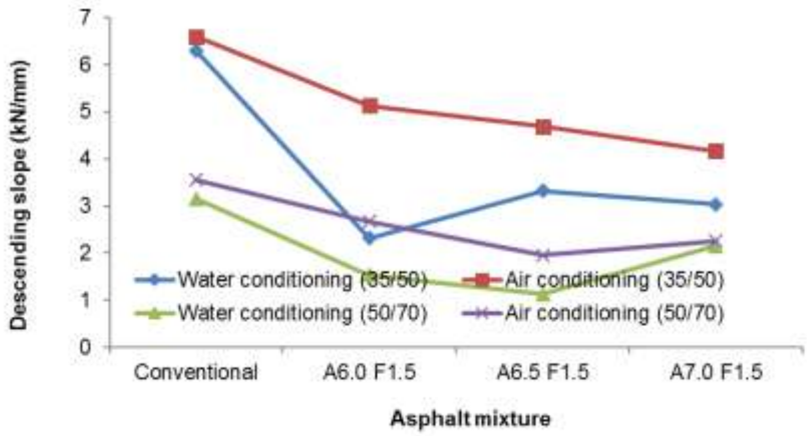

Figure 12. Descending slopes for the asphalt mixtures with 50/70 asphalt

The deformation energy measured in the indirect tensile strength test is represented in Figure 13. This energy gives an indication of the total cracking resistance of the asphalt mixtures. The greater the deformation energy, the greater the cracking resistance of the asphalt mixture. Thus, the increase in the fiber content and the asphalt content produced asphalt mixtures with more cracking resistance. Under water conditioning, all mixtures are subjected to a significant reduction in cracking. The mixture containing 7.0% asphalt was not influenced by water conditioning, most likely due to its very high asphalt content.

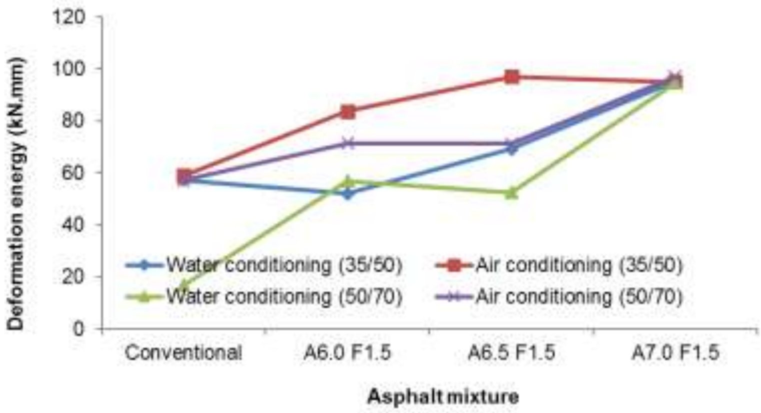

Figure 13. Deformation energy

The results of the deformation at failure are represented in Figure 14. The obtained values, approximately 3 mm, are extremely low, showing the good behavior of these mixtures. There is no clear evidence of the influence of the asphalt content or of the fiber content in the deformation at failure of the studied asphalt mixtures. The results are within the same range, and the values are slightly higher than those obtained for the conventional mixture. The mixtures subjected to water conditioning experienced less deformation at failure, most likely due to the aging of the asphalt during conditioning. This result is supported by the fact that the deformation behavior results are different from those regarding other variables that are related to the stiffness of the material.

The obtained values are identical for all mixtures with fibers and are identical to those for conventional mixture. This reduced difference between mixtures is most likely due to the stiffness of the asphalt. The good behavior of these mixtures is also observedwith regard to the effect of water conditioning.

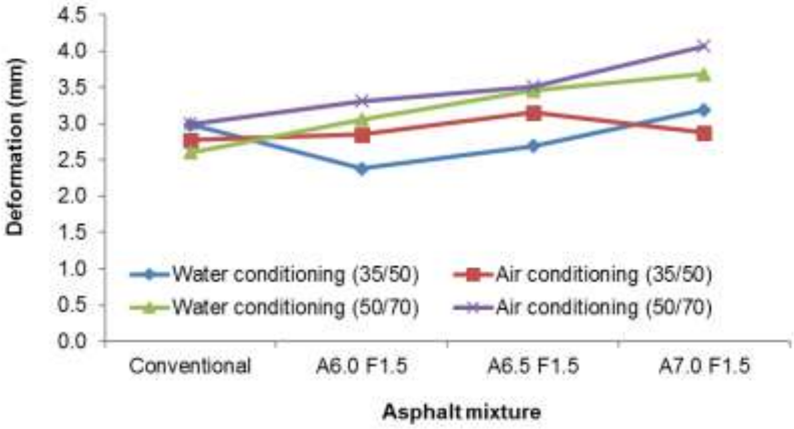

Figure 14. Deformation at failure

4. CONCLUSIONS AND FURTHER INVESTIGATIONS

The present work studied the behavior of asphalt mixtures with textile fibers recycled from used tires. Two asphalt types were considered, namely a 50/70 and a 35/50 pen asphalt. Various combinations of asphalt content for 1.5% of fiber content were considered through the production of 6 asphalt mixtures that were compacted in slabs to obtain cylindrical specimens for indirect tensile strength tests. Comparisons were carried out with conventional asphalt mixtures. Indirect tensile strength, indirect tensile strength ratio, ascending slope and descending slope of the load-deformation curve, deformation energy and deformation at failure were considered in the analysis of the laboratory results.
The following conclusions can be drawn from this study:

- The load-deformation curves obtained from the indirect tensile strength tests are dependent on the type of asphalt used in the asphalt mixtures. This dependence was observed for both air and water conditioning mixtures.

- The presence of tire fibers does not increase the indirect tensile strength of the mixtures compared to the mixture without fibers.
- The water sensibility expressed as the indirect tensile strength ratio indicates that significant reductions in the indirect tensile strength occur due to the presence of the fibers. This effect is minimized for high asphalt contents.
- The ascending slope of the load-deformation curves from the indirect tensile strength tests indicates that the presence of fibers reduces this parameter, mainly for mixtures subjected to water conditioning.
- The descending slope is clearly reduced due to the fibers, which indicates the fibers' ability to slow cracking propagation.
- The deformation energy is significantly increased for asphalt mixtures with fibers produced with 35/50 pen asphalt.
- The deformation at failure is dependent of the type of asphalt used in the mixtures.

Based on the results of this work, there is great potential for the use of textile fibers recycled from used tires that are incorporated in asphalt mixtures. However, more research must be undertaken to confirm the potential of this type of fiber for application in asphalt mixtures. The next step in this research must be the confirmation of these results using specimens compacted with traditional equipment such as a Marshall or gyratory compactor which are used as standard for the evaluation of water sensitivity analysis. Also, mechanical behavior, in terms of stiffness, fatigue resistance and permanent deformation, must be analyzed in comparison to conventional asphalt mixtures. Due to the presence of fibers, the compactability of these mixtures must be evaluated.

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