Effect of Temperature on the Mechanical Behavior of Bituminous Mixture with Waste Oil and Tire Rubber

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Abstract

The bituminous mixture of flexible pavement subjected to complex stresses such as traffic load and climatic conditions due to daily and seasonal variations causes damage to the surface course. On the other hand, the incorporation of several alternative materials, such as waste cooking oil (WCO), waste engine oil (WEO), and crumb tire rubber (CTR), into bituminous mixtures to improve their performance. This research aims to study the effect of temperature on the mechanical behavior of bituminous mixtures with WEO or WCO combined with reacted and activated rubber (RAR) using the Fénix test at different temperatures (0, 5, 10, and 25°C). The results showed that the bituminous mixture with (AB-WRCO) has higher maximum strength (RT) values than the bituminous mixture with (AB-WREO) at all temperatures tested. While the fracture energy was higher at 5 and 10 °C for AB-WRCO and AB-WREO, respectively, Furthermore, these alternative solutions involve attaining economic benefits and preparing an eco-friendly asphalt pavement.

Keywords: Aged bitumen (AB); waste oil; Reacted and activated rubber (RAR); Fénix test; Fracture energy.

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1. Introduction

Reclaimed asphalt pavement (RAP) has recently become more widely used in the manufacture of bituminous mixtures and less expensive option for construction and rehabilitation pavement [1]. On the other hand, it is considered beneficial from technical, economic, and environmental aspects [2]. The lifespan of bituminous mixture typically ranges between 7 and 15 years, and after less than a decade of construction, numerous asphalt pavements require various types of rehabilitation due to the different damages sustained during their service life [3, 4]. As a result, a large amount of RAP materials were produced, which leads to environmental pollution due to improper disposal [5]. Thus, one of the solutions that are becoming more and more appealing from the perspective of energy and environmental protection is the recycling technology of waste asphalt pavement [6-7]. The key to recycling RAP is reusing the aged bitumen [8]. Aging affects bitumen performance and becomes one of the major costs of pavement performance deterioration [9].

Recently, the incorporation of several waste materials such as waste cooking oil (WCO), waste engine oil (WEO), and crumb tire rubber (CTR) into bituminous mixtures to improve their performance has already been studied, furthermore, achieving environmental and economic benefits. Many studies have been conducted on the use of waste engine oil (WEO) and waste cooking oil (WCO) with bitumen, which are two main types of bitumen rejuvenators with good regeneration effects [10-11], Such as El-Shorbagy et al. [12] have used WEO and WCO as rejuvenators to ameliorate the performance of aged bitumen. Al Qurashi et al. [13] found that the addition of waste motor oil improved the physical properties (reduced viscosity and softening point values) of aged bitumen.

On the contrary, the addition of these materials can lead to some defects in the performance of the bituminous mixture, namely lower elastic recovery and rutting resistance due to poor adherence [14], for this reason, rejuvenated bitumen requires certain additives to improve it, the investigation by Ren et al. [2] demonstrated that using crumb tire rubber enhances the properties of the rejuvenated bitumen. Yi et al. [15] studied the development of new rejuvenator bitumen composed by WCO and CTR. Based on the previous studies mentioned above, this research aims to study the effect of temperature on the mechanical behavior of bituminous mixtures with waste engine oil (WEO) or waste cooking oil (WCO) combined with reacted and activated rubber (RAR) using the Fénix test.

II. Materials and methods

II.1. Materials

Aggregates and limestone filler used in this study are illustrated in Figure.1, aged bitumen (AB) with a softening point of 58◦C, penetration of 30 dm at 25 ◦C, were the materials chosen for the production of the bituminous mixtures.

Another replacing materials used in this study were WCO and WEO which collected from restaurants and auto repair shops, respectively. With respect to reacted and activated rubber (RAR) used as a rubber modifier (Figure.2)

Figure.1. Aggregates used in this study.

Figure.2. Waste oil (WREO, WRCO), and reacted and activated rubber (RAR).

II.2. Experimental methods

II.2.1. Sample Preparation:

The bituminous mixtures composition and their particle size distribution are presented in Figure. 3. According to the Marshall test (EN 12697-34), the best properties for the reference mixture were with the bitumen content equal to 6.2%. Following that, to prepare modified bitumen mixtures, there are two basic methods: wet and dry processes. In this study, the wet process was used to obtain renewable bitumen. Regarding the percentage of modifiers, 15% of RAR and 5% of waste oil were selected depending on the weight of the aged bitumen. Finally, different types of bituminous mixtures with different types of bitumen (AB-WRCO and AB-WREO) were available to be tested later at different temperatures using the Fénix test.

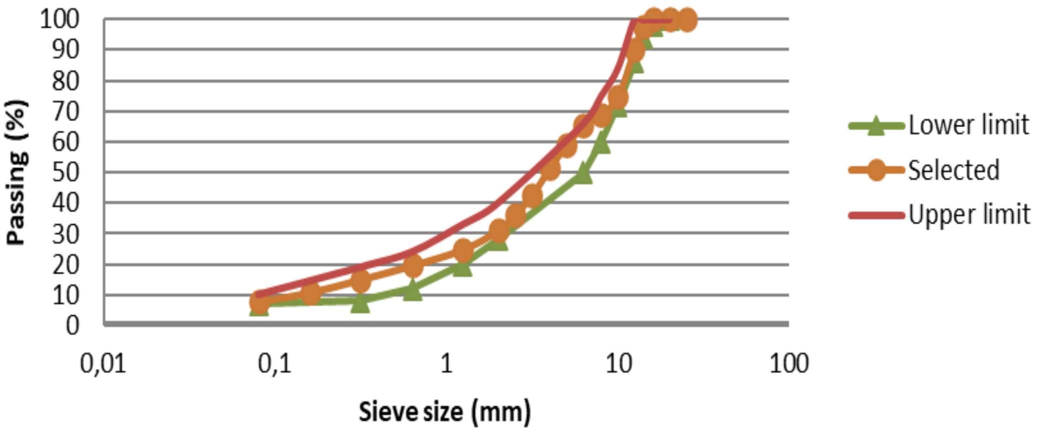

Figure.3. Particle size distribution.

II.2.2. Fénix test:

The road research laboratory at Universitat Politècnica de Catalunya in Barcelona, Spain, developed a new experimental test. It was used in this research to evaluate the effect of reacted and activated rubber (RAR) combined with waste oils (WCO and WEO) on the cracking resistance of the bituminous mixture [16]. The Fénix test illustrated in Figure 4.

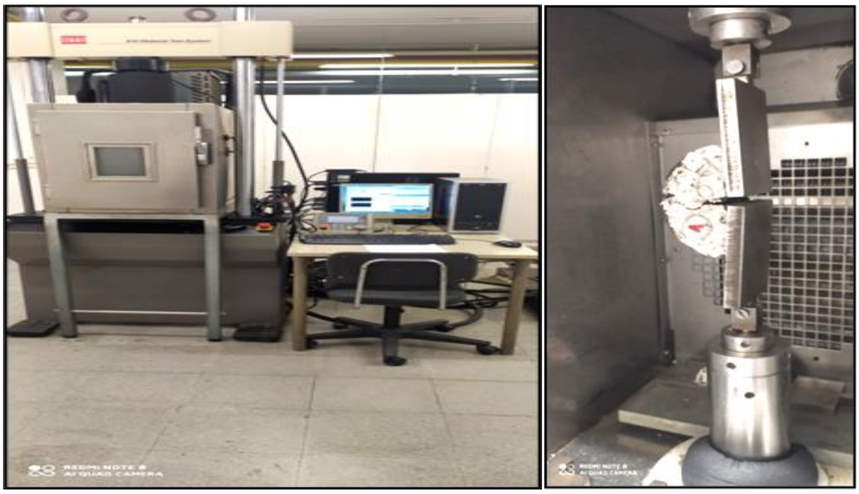

Figure.4. Fénix test used in the road research laboratory at Universitat Politècnica de Catalunya in Barcelona, Spain.

This test is based on subjecting a semi-cylindrical sample of Marshall to a constant displacement of 1 mm/min and at a specific temperature. Different temperatures (0, 5, 10, and 25 °C) were used in this research, as shown in Figure 5.

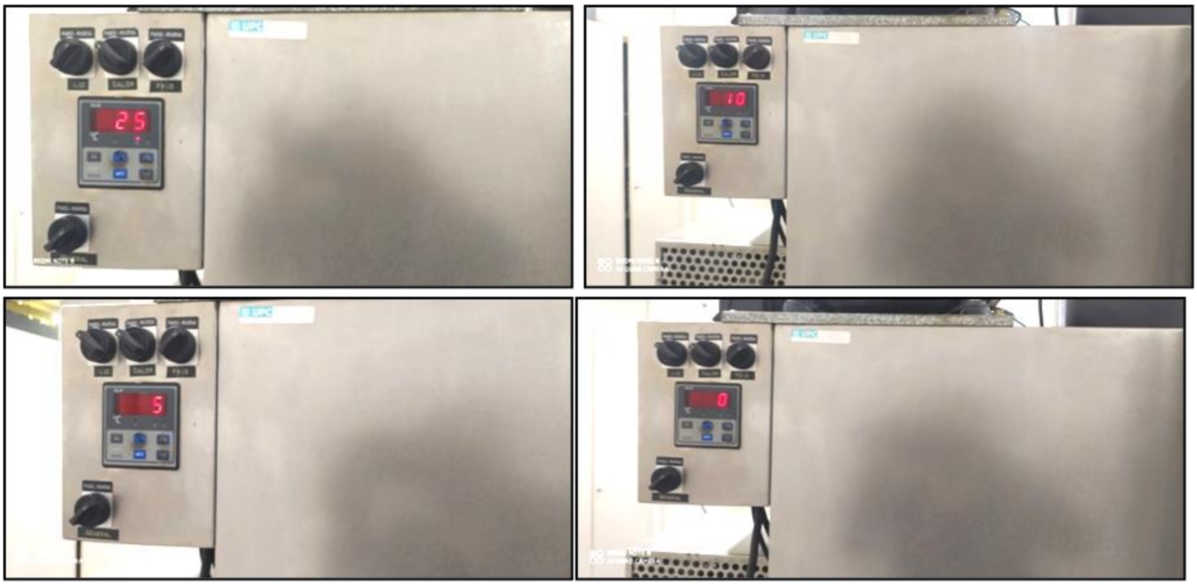

Figure.5. Temperatures used in the Fénix test (0, 5, 10 and 25°c).

To evaluate the effect of temperature on the bituminous mixture, we kept the samples for 48 hours at a specified temperature before testing. Throughout the test, as shown in Figure 6, load and displacement data are obtained to calculate the parameters related to the breaking process [17].

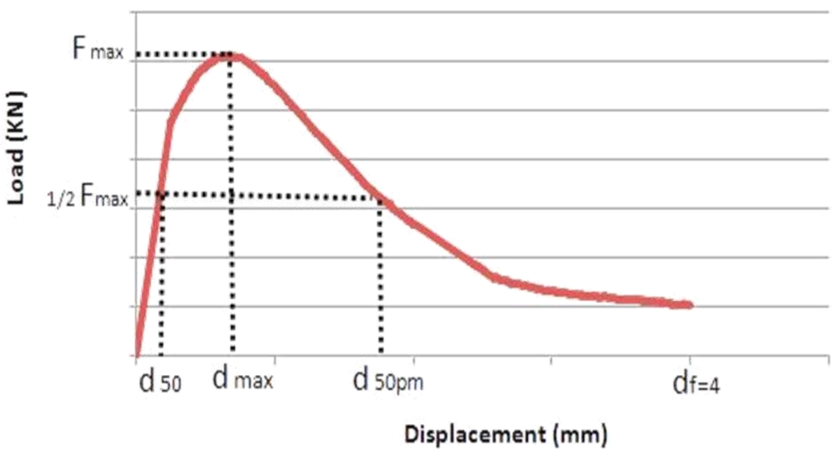

Figure.6. Stress-displacement curve [18].

The three parameters that are considered to be most indicative of the mixtures' strength, toughness displacement, and fracture energy are analyzed in this work [19].

The first parameter is the maximum strength (RT), which is determined by Equation (1):

$$RT = F_{max}/S \quad (1)$$

The second parameter is the toughness displacement (DT) calculated by Equation (2):

$$DT = d_{50pm} - d_{max} \quad (2)$$

The third is fracture energy (GD) which is a combination of all the energies produced during the Fénix test, calculated by Equation (3):

$$GD = \frac{\int_0^{df} F(x)dx}{S} \times 10^6 \qquad (3)$$

Where RT is the maximum strength (MPa), Fmax is the maximum tensile load (N) and DT is The toughness displacement(mm), d50pm is the displacement at 50% of the peak load (mm), d max is the maximum fracture load(mm), GD is the fracture energy (J/m²), F is the tensile load (N), x is displacement (m), S is surface fracture (mm²), and df is displacement at the end of the test (m).

III. Results and discussion

The bituminous mixture made with the AB-WREO binder has lower bulk density values than those obtained with the mixture (AB-WRCO), table 1. This seems to indicate that the AB-WREO binder gives the mixture higher compaction to the mixture.

Table.1. bulk density of bituminous mixture with AB-WRCO and AB-WREO

Bulk density (g/cm³)				
Bituminous mixture	0°C	5°C	10°C	25°C
AB-WRCO	2,375	2,395	2,399	2,393
AB-WREO	2,366	2,387	2,332	2,380

The Fénix diagram is shown in Figure 7, which allows for analyzing the variation in the strength and ductility of the bituminous mixture at different temperatures. Thus, the average toughness displacement (DT) values on the X-axis and the average maximum strength (RT) values on the Y-axis are plotted for two types of bituminous mixtures with two types of bitumen, as well as at testing temperatures of 0, 5, 10, and 25°C. This graph reveals the limits determined through the authors' experience with the testing method [20], Classify the behavior of the bituminous mixture in this graph into fragile, ductile, or high ductile, as well as low-strength mixtures, into vertical lines and a horizontal line, respectively. Furthermore, iso-toughness curves are shown as long as the result of RT*DT continues constant.

Firstly, a bituminous mixture with aged bitumen (reference) was tested at 25°C, and the results were 0.08 MPa, 1.25 mm, and 124 J/m² of maximum strength (RT), toughness displacement (DT), and fracture energy (GD) respectively.

The figure shows that all mixtures have brittle behavior at 0, 5, and 10°C, but the bituminous mixture with (AB-WREO) has ductile behavior when tested at a temperature of 25°C, while the bituminous mixture with (AB-WRCO) has a high ductile behavior. In general, a decrease in average maximum strength (RT) values and an increase in average toughness displacement (DT) values are observed for both bitumen mixtures due to the addition of waste oil and reacted and activated rubber (RAR) to the aged bitumen. Comparing these results, the bituminous mixture with (AB-WRCO) shows higher maximum strength (RT) values than the bituminous mixture with (AB-WREO) at all temperatures tested.

Regarding the toughness displacement (DT) values for both bituminous mixtures, the same values are shown at 0 and 5°C, but at 10 °C, the bituminous mixture with AB-WRCO are lower, unlike at 25 °C, where are slightly higher.

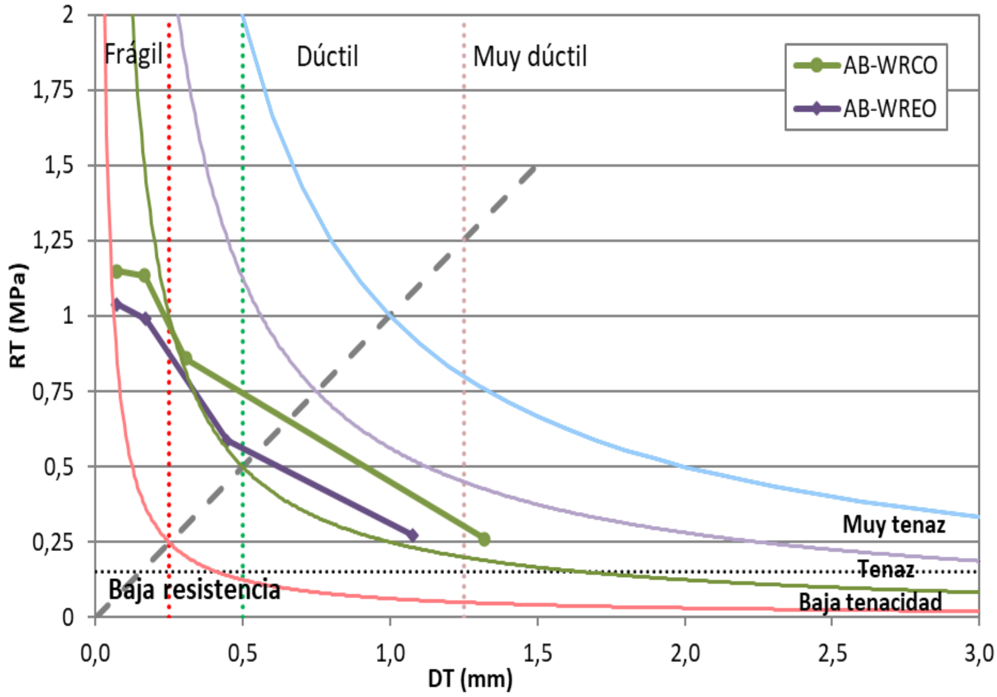

Figure.7. Fénix diagram of bituminous mixture manufactured with AB-WRCO and AB-WREO.

Variation of the fracture energy of bituminous mixtures with AB-WRCO are shown in Figure 8, the values showed an obvious increase in the response to cracking from 0 °C to 10 °C, then the fracture energy decreased at the temperature of 25 °C. As for the bituminous mixture with AB-WREO, the values were higher at a temperature of 5°C. By comparing the results, the bituminous mixture with AB-WRCO illustrated higher values of fracture energy at 5, 10, and 25°C. The evaluation of this energy is a useful method for determining bituminous mixtures' resistance to breaking. These fracture energy results are consistent with previous results for the maximum strength (RT) and toughness displacement (DT) values.

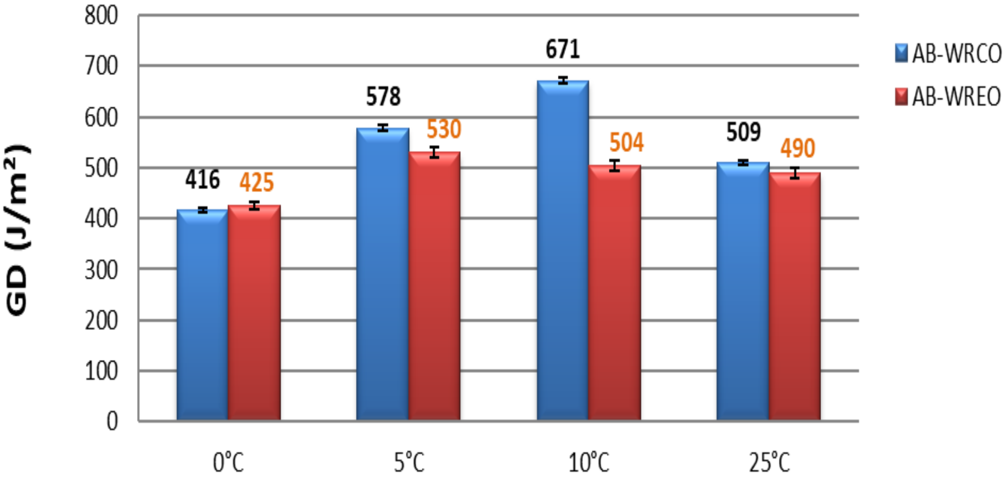

Figure.8. Average values of the fracture energy.

IV. Conclusion

In this study, the effects of temperatures on the mechanical behavior of bituminous mixtures with AB-WREO and AB-WRCO were investigated. The following conclusions can be drawn:

- The bituminous mixture with (AB-WRCO) has a higher maximum strength (RT) at all temperatures tested.
- All the mixtures have brittle behavior at 0, 5, and 10°C.
- At a test temperature of 25°C, the bituminous mixture with (AB-WREO) has a ductile behavior, and the mixture with (AB-WRCO) has a high ductility behavior.
- The fracture energy (GD) of the bituminous mixture with AB-WRCO showed higher values at 5, 10, and 25°C.
- Finally, the use of waste cooking oil, waste engine oil, and crumb tire rubber as replacement additives in aged bitumen is encouraged not only as an effective method of improving the properties of bituminous mixtures, especially in high-temperature zones but also to attain environmental protection and economic benefits.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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