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Unveiling the Benefits of Engineered Crumb Rubber for Asphalt Mixtures via Performance-Related Characterization: Rutting Behavior †

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Abstract: Even though alternative paving materials, like rubberized asphalt, are sometimes present in specifications, these are still not widely adopted from road agencies mainly due to a lack of experience, reticence in changing work habits and, often, a lack of evidence of real gains in the change. Authors believe that performance-based laboratory characterization is a solution to highlight differences with conventional asphalt mixtures. Hence, this research wants to highlight the differences between designing asphalt mixtures modified with engineered crumb rubber (ECR) on the basis of conventional indirect tensile testing (ITS), as prescribed by Italian specifications, and by means of performance-related characterization. ECR allows to asphalt mixtures to be modified through a dry process without inconveniences such as uncontrolled swelling and the generation of fumes; on the other hand, performance-related characterization focuses on highlighting rutting behavior by using a basic approach, still based on ITS, and a more advanced viscoplastic methodology using the asphalt mixture performance tester (AMPT). As a result, performance-related characterization is necessary to highlight clear gains in the rutting behavior of the asphalt mixtures modified with ECR. Advanced methodology by means of AMPT provides a fine-tuned characterization; however, the basic approach by means of ITS already highlights the differences in performance. ECR could be widely used to improve the properties of dense mixtures for roads with low traffic; in fact, it solves many of the practical issues of adding crumb rubber through a dry process and greatly improves paving material properties compared to conventional asphalt mixtures, with an increase in cost of only 10%.

Keywords: rutting; permanent deformation; performance-related properties; tire rubber; modified asphalt mixtures; AMPT; ITS

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1. Introduction

In recent years, the pavement industries have shown great interest in improving pavement construction practices, with the aim of increasing the service life and minimizing the efforts required for pavement maintenance and rehabilitation. Several research studies have investigated various ways of predicting the basic failure mechanisms for flexible pavements, such as rutting. [1]. In order to improve the rutting behavior, nowadays, technology developers are currently incorporating synthetic and/or recycled polymers into the conventional asphalt mixture since it has been proven to improve resistance to damage phenomena, including rutting. Despite having this specific advantage, together with other positive features, rubberized asphalt is still not fully implemented worldwide, including networks managed by Italian road authorities. Nevertheless, it has to be underlined that since 2021, Italian specification (ANAS, 2021) has included the use of rubber powder within their specifications; however, the required mechanical characterization of the mixes is still related to conventional parameters such as the indirect tensile strength test (ITS) at 25 °C [2]. It does not include any characterization related to assessing resistance to permanent deformation.

This study proposes a new approach for the performance-related characterization of asphalt mixtures complying with Italian specifications, which is key to discriminating the rutting behavior of a conventional asphalt mixture and a relative modified mixture with engineered crumb rubber (ECR). Along these lines, the experimental program used a multi-level approach, based on basic level testing, i.e., the high-temperature indirect tensile strength test (HT-ITS) at 54 °C and performance-based viscoplastic characterization based on advanced-level testing using an asphalt mixture performance tester (AMPT) was intended to be used [3]. For performance-based permanent deformation, a Stress Sweep Rutting (SSR) test was conducted. Based on the SSR test, the Rutting Strain Index (RSI) was calculated for climatic conditions in the Sicily region, Italy.

2. Methodology

2.1. Conventional Characterization

Conventional characterization included the indirect tensile strength (ITS). The ITS test was performed according to UNI EN 12697-23 at 25 °C on three replicates for each mixture investigated. Therefore, specimens did not need further temperature conditioning after curing. The indirect tensile strength is the maximum tensile stress calculated from the peak load applied at break specimen and the dimensions of the specimen, using Equation (1):

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

where P is maximum load, H is the height of the specimen and D is the specimen diameter.

2.2. Performance-Related Characterization—Basic Level

Like conventional testing at 25 °C, the basic level of the performance-related test was carried out through a high-temperature ITS test. The specimens were conditioned at the test temperature, 10 °C below the average as the 7-day maximum pavement temperature, 20 mm below the pavement surface at 50% reliability. The test was performed at 54 °C [4].

2.3. Performance-Related Characterization—Advanced Level

The performance-related characterization at the advanced level considered the study of rutting resistance using an Asphalt Mixture Performance Tester (AMPT) in accordance with AASHTO TP 79-13. The resistance to permanent deformation was evaluated with a Stress Sweep Rutting test (AASHTO TP 134-19), in which three cylindrical specimens were tested for each mixture.

Stress Sweep Rutting (SSR) tests at two temperatures (high TH: 54 °C; and low TL: 20 °C) were considered, and for each temperature, a vertical load was applied for 600 cycles at three deviatoric stress levels (200 loading blocks for each segment). Confining stress of 69 KPa was applied with a loading pulse of 0.4 s, followed by a rest time of 3.6 s for TH and 1.6 s for TL. The SSR test allowed us to determine the shift model for permanent strain using FlexMATTM rutting [4].

3. Results and Discussions

3.1. Conventional Characterization

Figure 1 represents the results obtained from the ITS test for the investigated mixtures. It can be observed that the examined mixtures have a similar ITS value with a percentage difference of 7%. Both mixtures fully meet the Italian road authority requirements [3].

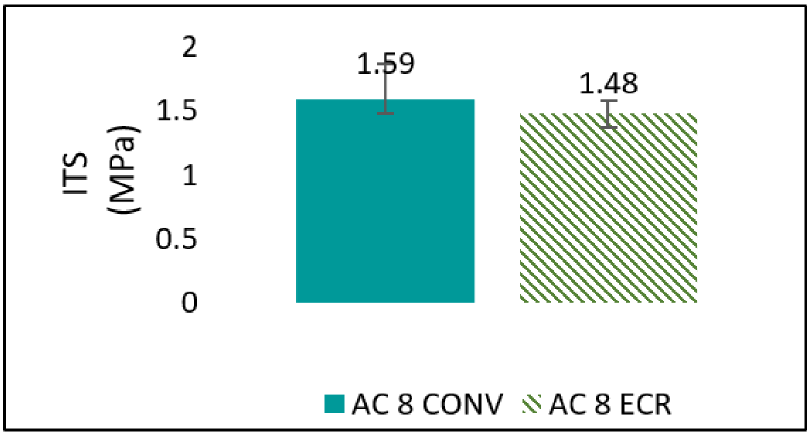

Figure 1. Indirect tensile strength test results.

3.2. Performance-Related Characterization—Basic Level

Figure 2 indicates the results of HT-ITS, and it can be observed that mix AC 8 ECR had the highest strength values with an average of 0.42 MPa, i.e., 420 KPa. Mix AC 8 was in the "Poor" rutting resistance tier, as shown in Figure 2, while AC 8 ECR was in the "Excellent" category. This difference between the two mixtures, in terms of percentage, is equal to 172%.

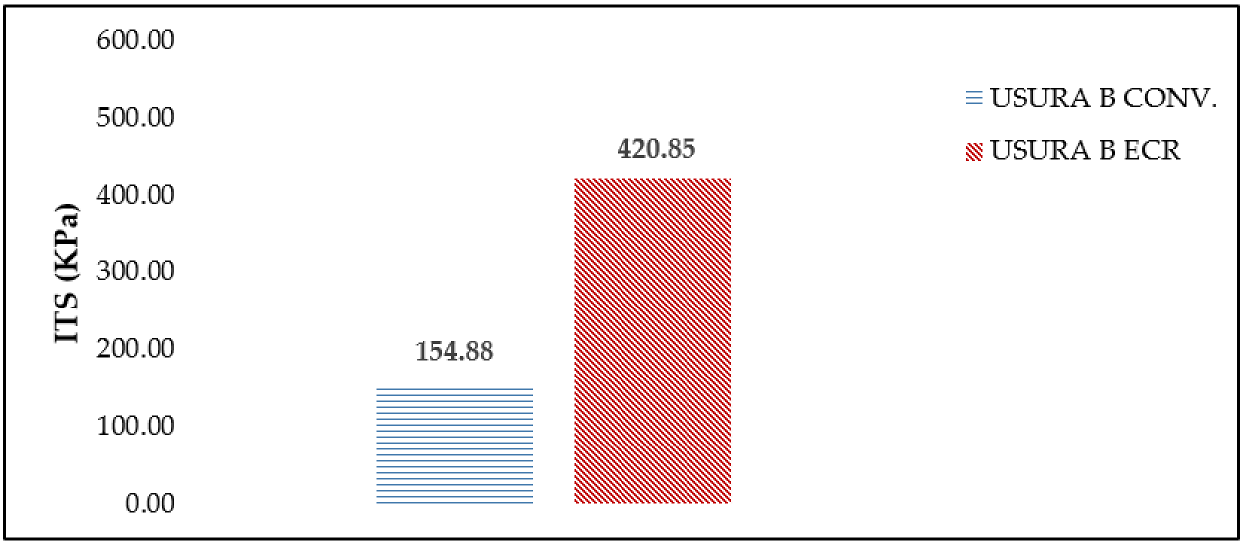

Figure 2. High-temperature indirect tensile strength test results with HT-ITS requirements.

3.3. Performance-Related Characterization—Advanced Level

The average SSR test results for 20 °C and 54 °C are illustrated in Figure 3a,b. The trend was permanent deformation accumulation with an increasing number of cycles [4]. At the high temperature of 54 °C, the AC 8 ECR mixture displayed a minimum achievement of 19,434 με in the permanent strain. This confirms that the modified asphalt mixtures were less susceptible to rutting, with an average percentage difference of 50% as compared to the conventional AC 8 mix.

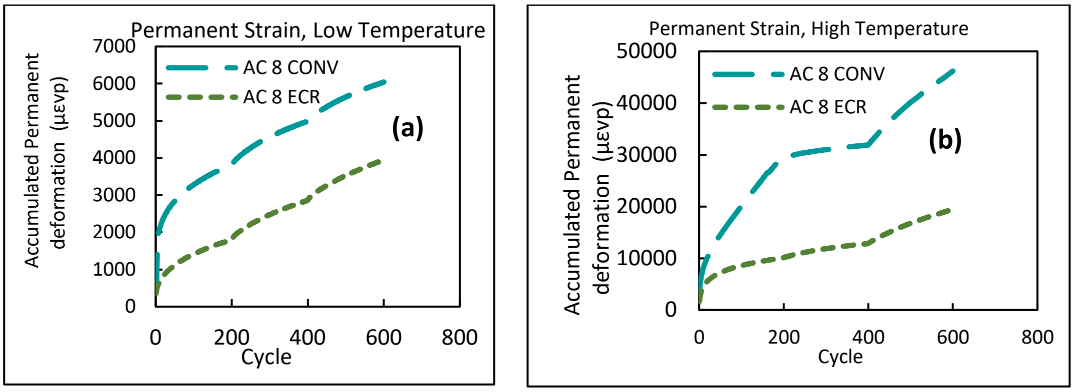

Figure 3. SSR test results (**a**) at 20 °C and (**b**) at 54 °C.

In addition, the micro strain obtained at 600 cycles for AC 8 was 43.185 µε, and for AC 8 ECR, it was 25.387 µε, showing better resistance as compared to conventional mixtures. In order to have a clearer understanding of permanent strain developed under the climate conditions of the Sicily region in Italy, the advanced level was extended to calculate the RSI.

The obtained RSI values for AC 8 and AC 8 ECR were compared with the standard specifications [4]. For conventional mixtures, the RSI value obtained was 71.52%, which is not recommended for any surface course, and the AC 8 ECR mixture value was approximately around 3.89%, which is recommended for heavy traffic on a surface course.

4. Summary and Conclusions

This research evaluated the prediction of permanent deformation using conventional and ECR mixtures. It was also intended to compare the methodology of basic and advanced-level testing performed on permanent deformation.

In summary, the research suggested that modifying conventional asphalt mixtures for wearing courses by adding ECR led to an improvement in terms of permanent deformation. Performance-related characterization is necessary to highlight differences due to modifications. Although advanced-level characterization for rutting resistance by means of AMPT is probably accurate and allows for further pavement design exercises, the basic approach by means of ITS already highlights the differences in rutting behavior.

As final recommendations for practitioners, the authors believe that ECR could be widely used to improve the properties of dense mixtures for urban and secondary roads; in fact, it solves many of the practical issues of adding crumb rubber through a dry process and greatly improves paving material properties compared to conventional asphalt mixtures, with an increase in cost of only 10%.

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