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Preliminary Mechanical Characterization of HMA Mixtures with a High Content of Recycled Materials †

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Abstract: The use of recycled materials is necessary to realize the green transition towards carbon neutrality. Several waste products are highly valued materials that cannot be landfilled without exploiting their full potential. Promoting the circular economy concept, this study aims to produce more sustainable paving materials using selected recycled products in binders and asphalt mixes. Rubber (R) from End-of-Life Tyres (ELTs) and Re-refined Engine Oil Bottom (REOB), i.e., the by-product of waste lubricants refining, were employed to produce extended bitumens (25%wt. bitumen replacement) trying to solve the ELTs and REOBs large production, thus disposal, worldwide. In addition, recycled aggregates from various urban and industrial sources were used to halve the quantity of virgin mineral aggregates in the developed asphalt mixtures. Considering two different types of REOBs, two mass proportions of R and REOB and two production temperatures of extended bitumens, eight asphalt mixes containing about 50%wt. of recycled materials were manufactured and underwent to preliminary mechanical tests. The stiffness, tensile and moisture resistances of the greener asphalt concretes were evaluated and compared to two reference mixes: one mainly consisted of virgin materials, and another contained 50%wt. of recycled aggregates and neat bitumen. The eight greener mixes exhibited promising responses in terms of stiffness and tensile strength, showing better intermediate values than the reference ones, but more water susceptibility.

Keywords: rubber-REOB extenders; recycled aggregates; HMA; mechanical characterization

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1. Introduction

More than 90% of the European road network consists of asphalt mixtures [1], i.e., petroleum bitumen and virgin mineral aggregates. Hence, the asphalt industry needs to be restructured in order to substitute the conventional road products that come from non-renewable resources with suitable innovative materials. Pavement engineers have focused on eco-friendly road construction materials, encouraging the use of recycled raw materials to achieve the progressive, yet irreversible, green transition. In particular, recycled materials can be used as constituents of sustainable paving materials to partially or totally replace the bitumen and aggregates present in traditional asphalt concrete.

At the binder level, specific recycled products, such as waste polymers, resins and engine or bio-oils, can be used either as modifiers/additives for improving the performances of the final bituminous material, or as replacements for the virgin constituents themselves. The latter option represents the current trend of paving materials technology, which aims to produce extended bitumens or alternative binders, in which bitumen is replaced at a minimum percentage equal to 25% or 75%, respectively [2–4]. Among available recycled materials, this study employs rubber (R) from End-of-Life Tyres (ELTs) and Re-Refined Engine Oil Bottom (REOB), which is the by-product of the exhausted engine oils refinery process for producing second-hand lubricants, as constituents of extended bitumens. The recycling of these two wastes may help in reducing the disposal concerns related to their large-scale production worldwide. Only in Italy, the collection of ELTs exceeded 210,000 tons in 2019 [5]; while ≥180,000 tons of waste engine oils were collected in 2018 [6]. Recent studies have investigated the possibility of combining the use of waste polymers and oils to produce sustainable extended bitumen, increasing the recycling rate of bitumen. Their combination could exploit the positive effects of both recycled materials, while mitigating their drawbacks. In fact, the softening effect of REOB can represent a key factor to compensate for the increased stiffness of R-modified bitumens [7,8]. Moreover, R can improve the performance of the final binder at high temperatures and REOB at low temperatures [8–10]. At the asphalt mix level, the use of recycled aggregates can help the paving industry to achieve the sustainability goals due to the high energy demand of aggregates' production and greenhouse gas emissions [11]. Reclaimed asphalt pavement (RAP), construction and demolition (C&D) and various urban and industrial wastes are the main sources of recycled aggregates. These materials can substitute virgin materials, contributing to the circular economy [12]. In this research, the recycled aggregates from RAP, urban and industrial wastes are used to replace 50%wt. of the virgin ones.

The authors aim to evaluate and, eventually, assess the feasibility of using high contents of recycled materials at the binder and the asphalt mix levels for the production of greener paving materials, satisfying the specifications of traditional road products.

2. Materials

A 50/70 penetration grade bitumen (coded as B) was used for producing extended bitumens and greener asphalt mixes, and it is the reference material of the study. Powdered rubber (R) from ELTs and two Re-refined Engine Oil Bottoms (REOBs) from two distinct refining plants, namely O1 and O2, were used to replace 25%wt. of bitumen, producing extended bitumens. The size distribution of R varies between 0 and 0.42 mm. The two REOBs have similar density, about 1.0 g/cm^3, but O1 is less viscous than O2.

A total of eight R-REOB extenders were produced by varying the type of REOB (O1 and O2), the R-REOB mass proportion and the production temperature. In detail, R-REOB mass proportions equal to 1:1 and 1:2 (coded R and R2, respectively) were selected based on a preliminary study that can be found elsewhere [10]. The production temperatures were 160 °C and 180 °C. Pre-heated R and REOBs at each production temperature were mixed at a rate of 800 rpm for 1 h. REOBs were warmed up in oven for at least 1 h 30′, while R for 15′. While mixing, all blends were continuously heated by a heating plate. Once prepared, each R-REOB blend was incorporated into B by replacing its 25%wt. for producing extended bitumens. The B and extenders were preliminary heated in oven at either 160 °C or 180 °C for ≥1 h 30′ and 15′, respectively, keeping apart before combining them. Then, the blend was heated again for 15′ prior mixing at 800 rpm for 1 h.

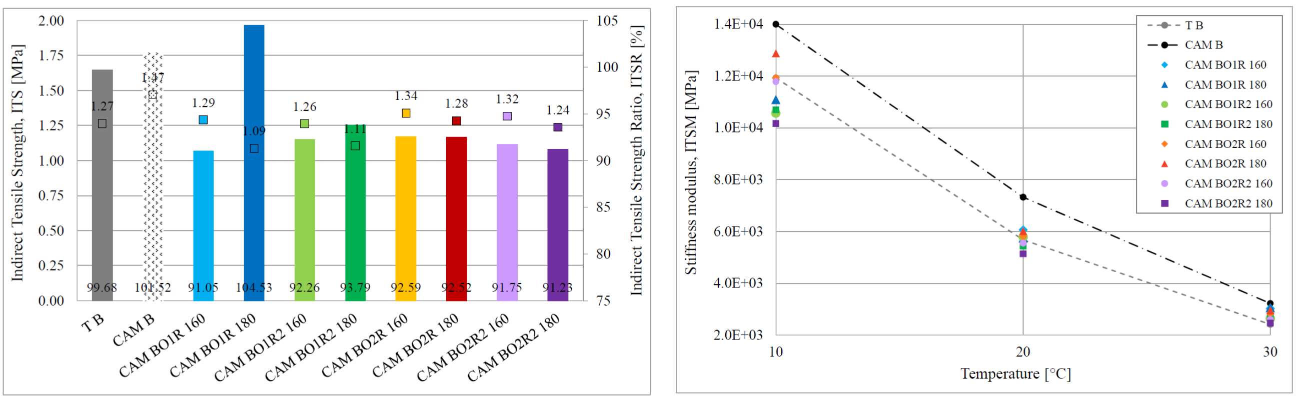
The mix design of Hot Mix Asphalt (HMA) mixes for wearing course layers in compliant with Italian specifications was adopted. Eight greener HMA mixes and a control mixture containing 50%wt. of recycled aggregates (8% incinerated urban wastes, 22% industrial wastes and 20% RAP) and an optimum binder content of 5.7% on the weight of aggregates were produced using either the developed extended bitumens and the Pen 50/70. These mixes with 50% of recycled aggregates were coded as CAM (i.e., Minimum Environmental Criteria), followed by the name of the extended or neat bitumen used. Moreover, the CAM mixes were compared with a traditional HMA that mainly contains virgin materials (T 50/70). Its optimum binder content was 5.6%. Four samples per each mix were manufactured by using the gyratory compactor (EN 12697-31, 120 gyrations).

3. Mechanical Characterizations

Static and dynamic characterizations of all HMA mixes were performed. Two static mechanical tests were used to measure the Indirect Tensile Strength (ITS) and the Indirect Tensile Strength Ratio (ITSR) of mixes in compliance with EN 12697-23 and EN 12697-12 standards, respectively. The tensile strength of asphalt concretes was determined by applying a compression load at a constant speed rate of 51 mm/min. The ITS test was performed at 25 °C. The ITSR ratio measures the durability of the samples as it determines the effect of saturation and accelerated water conditioning. This investigation quantifies the ratio between the ITS values of an asphalt mix after water conditioning to that of a dry specimen. All mixes were conditioned in water bath according to Method A of the standard. Then, the samples were removed, dried and conditioned at 25 °C in a climate chamber before undergoing to ITS test. During these characterizations, the load was applied until a failure occurred; hence, the set of four specimens per each HMA mix were halved to perform the ITS test on dry and wet samples. Regarding dynamic characterization, all HMA mixes were subjected to the Indirect Tensile Stiffness Modulus (ITSM) test by using a servo-pneumatic testing machine. The stiffness modulus was established according to EN 12697-26 standard in the IT-CY configuration. Pulse loading was applied with a 124 ms rise time to generate a horizontal deformation of 5 ± 2 μm. As it is a non-destructive test, it was replicated at three different test temperatures, namely 10, 20 and 30 °C. Before being tested, all samples were conditioned at the test temperature for at least 4 h.

4. Results and Discussion

The preliminary mechanical responses of the innovative CAM mixes and the two control mixtures are reported in Figure 1. In general, the ITS test highlighted the intermediate response of the CAM mixes manufactured using the developed extended bitumens from the two control ones, i.e., T B and CAM B. Only the CAM BO1R 180 and CAM BO1R2 180 mixes showed less strength than T B. Nonetheless, all mixes met the Italian specification that requires an ITS value higher than 0.7 MPa. Regarding the water susceptibility, both control mixes exhibited a very low level of water susceptibility. Despite all HMA mixtures exceeded the minimum ITSR value requested by the Italian specification, that is usually equal to 90%, the CAM mixes produced using the eight extended bitumens were more susceptible to water damage than the control ones. The ITSM results showed that the CAM mixes with extended bitumens behaved similarly to T B, especially at 20 °C. At 10 °C, the CAM mixes with R-REOB-modified bitumens generally showed a similar or lower levels of stiffness than T B, which can be related to the softening effect caused by REOBs. The opposite results were obtained at 30 °C. The presence of R stiffened the final paving mixes. The T B and the CAM mixes with extended bitumens were less stiff than CAM B at all test temperatures. This trend can be related to the presence of recycled aggregates and, especially, RAP. A general increase in ITS, ITSR and ITSM values was observed when enhancing the content of R. On the other hand, the effects of the production temperature and the type of REOB were not clear.



(**a**) (**b**)

Figure 1. Results of HMA mixes under mechanical analysis: (**a**) ITS and ITSR tests; (**b**) ITSM test.

5. Conclusions

The preliminary mechanical characterization of greener paving materials was conducted to evaluate and, eventually, assess the feasibility of the use up to about 50%wt. of recycled materials in HMA mixes for wearing course layers. Thanks to static and dynamic mechanical tests, eight CAM mixes containing the developed extended bitumens were analysed. The proposed greener HMA mixes achieved intermediate values between the control mixtures (T B and CAM B), highlighting similar behaviour of traditional road construction materials. This means that the use of R-REOB-modified bitumens can mitigate the increased stiffness caused by the use of recycled aggregates, especially RAP. The ITSM values confirmed the stiffening effect of R and its influence at high temperatures and the softening effect of REOB. Water conditioning has a negative effect on CAM mixtures. Albeit all mixes meet the Italian specification, the use of recycled materials seems to increase the water susceptibility of the final asphalt materials, which needs further investigations.

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