Reclaimed Asphalt Pavement

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The incorporation of reclaimed asphalt pavement (RAP) in new asphalt mixtures is one of the most applied recycling techniques in pavement construction and maintenance. This technique uses additives to rejuvenate the aged bitumen in RAP. Full recycling of RAP rejuvenated with waste cooking oil (WCO) seems promising regarding the observed mechanical behaviour, except for rutting resistance. The incorporation of low-density polyethylene (LDPE) from urban waste as a low-cost polymer is promising to improve rutting resistance. Considering the adequate performance of this type of asphalt mixtures, there are good expectations about the future use of these solutions in real pavements, particularly for low and intermediate traffic levels. The findings obtained so far also show that full recycling of asphalt concrete with WCO and LDPE is a feasible and economic paving technology.

Keywords: circular economy ; low density polyethylene ; reclaimed asphalt pavement ; sustainability ; waste cooking oil

1. Introduction

Over the last decades, with the growing environmental concerns, several sectors of society and industry are changing their behaviour in terms of consumption resources, waste management, and efficiency of goods and services production. Recycling and reusing of non-renewable materials are becoming increasingly imperative in order to move towards a circular and sustainable economy as well as a sustainable use of resources. In particular, the industry of construction and maintenance of transport infrastructures is gradually applying environmentally friendly solutions, aiming to reduce its ecological footprint.

The incorporation of reclaimed asphalt pavement (RAP) in new asphalt mixtures is one of the most applied recycling techniques in pavement construction and maintenance by applying different production processes, such as hot-, warm-, half-warm- and cold-mix asphalt ,[[1],[2],[3],[4],[5],[6]. Apart from reducing the use of new non-renewable raw materials, the use of RAP may also contribute to reduce energy consumption and emissions, as well as to decrease disposal of that demolition waste in landfills[7] .

Nevertheless, the use of RAP as a constituent of new asphalt mixtures, particularly when recycling incorporates high percentages of RAP, involves some challenges related to the capability of RAP's aged bitumen to act as a binder. As reported in the literature[8] , it is usually recognised that bitumen suffers short- and long-term ageing, which involves different origins and mechanisms, such as oxidation and volatilisation of constituents [9]. These phenomena happen during manufacturing and construction activities of asphalt mixtures as well as throughout the pavement lifespan. An aged bitumen presents changes in its molecular groups, generally with increased amounts of stiffer fractions, which result in higher binder viscosity [10]. The ratio asphaltenes/maltenes, for instance, generally increases with ageing, resulting in a harder and brittle bitumen, with worse adhesion to aggregates and less coating properties [11].

Restoring the properties of an aged binder to a satisfactory level may be achieved by adding a considerable amount of virgin bitumen to the asphalt mixture and/or by applying appropriate rejuvenators. The rejuvenator ability to reactivate the aged binder is of major importance to achieve adequate performance of the asphalt mixture. The diffusion of rejuvenator into the asphalt binder is crucial to achieve adequate rejuvenation of the asphalt binder [12]. The temperature has been reported as the parameter with the highest influence on the diffusion rate [13]. Indeed, the literature reports that part of the RAP's aged bitumen—the "black rock"—does not blend with the rejuvenator, preventing bitumen from being reactivated as a binder [1],[14]. The use of chemical rejuvenators, specifically developed to rejuvenate aged bitumen, is a costly part of RAP recycling[15]. Therefore, reusing some by-products as alternative rejuvenators can bring some advantages to paving technology, namely, by reducing costs.

2. Using Waste Cooking Oil (WCO) as an Alternative Rejuvenator for Asphalt Binders

Several studies carried out over the last years have aimed at using waste cooking oil (WCO) as an alternative rejuvenator for asphalt binders [12].[15].[16][17][18][19]. Although the worldwide production of WCO is not known with accuracy (Azahar et al. [20]stated a production of about 10 million tonnes per year), we know that a great part of WCO is landfilled or thrown into the sewers, losing its potential value and creating a significant negative environmental impact. For instance, according to the APA—the Portuguese Environmental Agency—WCO production in Portugal in 2018 was 74,351.9 tonnes, which represents a rise of about 280% in comparison to 2017. However, the available data for 2018 show that the recorded WCO is just 50% of new cooking oil production.

According to Zhang et al.[19].a better quality WCO to rejuvenate bitumen should have low acid value (i.e., mass of potassium hydroxide (KOH) in milligrams that is required to neutralize one gram of WCO). The higher the amount of free fatty acids (FFAs) in the WCO, the higher the acid value. FFAs of WCO increase with the applied heat, time of use, and the quantity of water resulting from frying activities [21]. Zhang et al. [19].concluded in a specific research project that WCO acid values in the range of 0.4 to 3.2 mg KOH/g are preferable regarding high-temperature rheology of rejuvenated bitumen. They also verified that WCOs with acid values between 0.4 and 0.7 mg KOH/g generally meet all the needed requirements for bitumen rejuvenation. Although samples of WCOs were obtained in controlled and undemanding conditions, this material may have acid values as low as 0.38 mg KOH/g [19], where commonly available WCOs have acid values from 1.32 to 3.6 mg KOH/g [21].

The literature states that blending WCO with bitumen has a considerable influence on the aged asphalt binder properties, showing a realistic potential of WCO as a bitumen rejuvenator. The observed trend among the studies was as follows: penetration considerably increases, softening point and kinematic viscosity (@135 °C) decrease [15].[18] and the ratio of asphaltenes to maltenes decreases as a result of the growth in the ratio of lower molecular weight oily medium [15]. Despite these changes of properties, it has not been possible to improve the binder workability (based on viscosity) to the level of virgin (not aged) bitumen [12],[15]. Regarding rheology performance, aged bitumen and WCO blends perform better than the aged binder at low temperature (based on PI—penetration index evaluation) as well as when the material is subjected to load repetition at higher strain levels at 25 °C (fatigue parameter) in a DSR—dynamic shear rheometer [12]. The higher the WCO percentage in the binder blend (acid value of 1.65 mg KOH/g), the lower the rutting resistance is (based on $G^*/\sin\delta$—the rutting resistance parameter). Although the trend was similar, the experimental rutting resistance was considerably better in a similar binder blend with treated WCO (acid value of 0.54 mg KOH/g) [18].

The effect of adding WCO into asphalt mixtures is not widely disseminated yet. Although adding WCO to aged bitumen considerably rejuvenates its properties, regarding asphalt concrete (AC) with a high RAP percentage, the resulting characteristics depend considerably on the rejuvenator diffusion level within the blend.

Zaumanis et al.[12] studied the performance of a 9.5 mm Superpave mixture with 100% recycled asphalt, using 12% of WCO (by mass of binder). According to the results, the AC clearly passed the defined requirements for maximum rut depth (Hamburg wheel-tracking test). Also, gyratory compactor tests revealed better workability in comparison with that of a RAP mix without WCO. Regarding low-temperature cracking (based on indirect tension configuration to evaluate creep compliance and tensile strength results at −10 °C), an asphalt mixture with WCO performed better than a RAP mix without rejuvenator in terms of creep compliance and slightly below for tensile strength. Fatigue resistance estimated through fracture work density results (based on indirect test configuration at 19 °C) did not improve in comparison with that of a RAP mix without WCO.

Bitumen rejuvenation with WCO was applied by the authors' research team within an ongoing project dealing with full recycling of RAP aimed at manufacturing a low-cost and eco-efficient AC for pavements with low to medium traffic levels, ensuring adequate durability. To achieve that goal, the raw material processing was as minimal as possible. Since the needed performance of AC was achieved, taking the in-service conditions into account, some of the empirical requirements usually followed may have been overlooked.

Preliminary studies carried out by the authors' research team [22] considering full incorporation of RAP and WCO as rejuvenators revealed the need to improve permanent deformation resistance of the resulting asphalt concrete. Therefore, the authors decided to add a low-cost polymer—low density polyethylene (LDPE)—collected from urban waste containers as a binder modifier, trying to improve the aforesaid potential mechanical weakness of the resulting asphalt concrete. Indeed, the use of different plastic wastes as additives for asphalt concrete has been considered in several studies, generally with positive contributions to the mechanical performance of asphalt mixtures [23][24][25].

Moreover, the authors have already done some work in using flakes of LDPE collected from urban waste [26], with promising results in terms of permanent deformation resistance of asphalt concrete. That paper also summarized some issues related to the availability of plastic waste and its inadequate deposition in nature as well as the need of increasing its recycling level in order to reduce the environmental damage.

The laboratory results presented in this paper showed that full recycling of RAP is feasible by using WCO as binder rejuvenator and LDPE as binder modifier. The LDPE incorporation improved the resistance of the obtained asphalt concrete against permanent deformation, while keeping good performance related to fatigue cracking. This process required additional control of the manufacturing procedure, particularly with regard to homogeneity of mix composition from one production batch to the other.

3. Conclusion

A global analysis on the performance of the asphalt mixtures with WCO and LDPE, carried out by using calculated performance indicators (stiffness, phase angle, permanent resistance resistance, water sensitivity anf fatigue cracking resistance), showed that those blends performed better than a conventional mixture used as reference. In addition, the incorporation of 6% of LDPE (by mass of bitumen) had a favourable effect on the permanent deformation resistance, while keeping a very good performance in terms of resistance to fatigue cracking.

Full recycling of RAP, rejuvenated with WCO and LDPE flakes as a bitumen modifier, is feasible and has a great potential as a paving material, particularly for low and intermediate traffic roads. Furthermore, this type of material can contribute to reducing inadequate deposition of WCO and waste of LDPE in nature, as well as to reducing energy consumption and CO_2 emissions. The studies on this type of asphalt mixture must continue to fully understand its long-term behaviour, especially after aging, and the life cycle analysis.

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