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Recycled asphalt mixtures produced with high percentage of different waste materials

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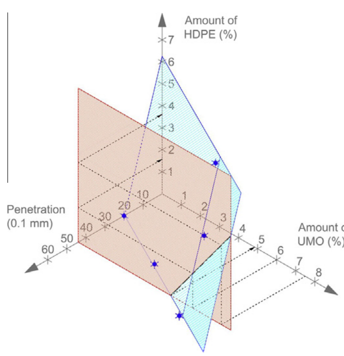
HIGHLIGHTS

- This work studies the use of RA and other waste materials in recycled asphalts.
- Used motor oil was tested as a binder rejuvenating agent.
- Waste high-density polyethylene (HDPE) was used as a mixture stabilizer.
- Penetration tests were used to obtain the optimum combination of both additives.
- The blend of the selected waste materials improved the performance of the mixtures.

GRAPHICAL ABSTRACT



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ABSTRACT

The use of sustainable solutions in construction is not just an option, but is increasingly becoming a need of the Society. Thus, nowadays the recycling of waste materials is a growing technology that needs to be continuously improved, namely by researching new solutions for waste valorisation and by increasing the amount of wastes reused. In the paving industry, the reuse of reclaimed asphalt (RA) is becoming common practice, but needs further research work. Thus, this study aims to increase the incorporation of RA and other waste materials in the production of recycled asphalt mixtures in order to improve their mechanical, environmental and economic performance. Recycled mixtures with 50% RA were analyzed in this study, including: (i) RA selection, preparation and characterization; (ii) incorporation of other waste materials as binder additives or modifiers, like used motor oil (UMO) and waste high-density polyethylene (HDPE); (iii) production of different mixtures (without additives; with UMO; with UMO and HDPE) and comparison of their performance in order to assess the main advantages of each solution. With this study it was concluded that up to 7.5% of UMO and 4.0% of HDPE can be used in a new modified binder for asphalt mixtures with 50% of RA, which have excellent properties concerning the rutting with WTS = 0.02 mm/10^3 cycles, the fatigue resistance with ε_6 = 160.4, and water sensitivity with an ITSR of 81.9%.

1. Introduction

A common issue in which the Society is focused nowadays is the recycling of used materials, based on their economic and environmental value. The constant population growth and of the higher standard of living cause an increase on the production of

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waste. Therefore, developed countries have taken conscience that waste management is a fundamental key to solve this emergent and serious problem. Not only urban waste, as bottles, paper, organic waste, but also industrial waste and construction and demolition waste must be carefully processed in order to reduce their environmental impact and maximize their valorisation. The specific area of road paving industry is also addressing that topic, where recycling of reclaimed asphalt (RA) materials [1] and the incorporation of other wastes and by-products [2] in road pavements have been tested and applied in recent years.

In fact, a large number of studies are presently concentrated on the use of RA. Several techniques are amply developed to incorporate this type of materials and their selection depends on the country and on the materials and methods available [3–6]. The technological evolution observed in the last years has resulted in an increase of the amount of RA incorporated in the production of new/recycled asphalt mixtures, being possible to include RA percentages in the order of 50% [7–9]. Other studies [10,11] also assessed the possibility of incorporating 100% of RA in "new" totally recycled mixtures, which were able to show characteristics similar to those of a conventional asphalt mixture.

The incorporation of RA in new mixtures is a way to reuse materials, decrease the quantity of waste placed in landfills and decrease the need of new materials, preserving the natural resources. The bitumen of RA materials is normally aged, and thus it is necessary to add some sort of rejuvenating agent to improve the workability and flexibility of the recycled mixtures incorporating RA materials. The use of commercial rejuvenators is a way to solve the problem, but it increases the cost of the final mixture [12,13]. Despite the cost of the rejuvenators, their influence on the properties of the final mixtures is usually enough to justify their use. However, in order to reduce the cost of the rejuvenator and incorporate higher amounts of waste in new asphalt mixtures, a previous study [10] tried to apply used motor oil (UMO) as a different type of bitumen rejuvenator. The results obtained in that study were very promising, since UMO effect on aged bitumen was similar to that of a commercial rejuvenator.

The amount of rejuvenator to be included in a recycled asphalt mixture is limited in order to avoid rutting problems, but the use of polymers can be a solution for this restriction. In fact, polymers have been traditionally used as additives to modify the properties of asphalt binders, in order to improve the mechanical properties of the asphalt mixtures. Virgin elastomers and plastomers have been successfully studied and used as asphalt modifiers. The most commonly used are the styrene–butadiene–styrene (SBS) block copolymers [14], although other polymer types have also been tested. Al-Hadidy and Yi-qiu [15] have also used low density polyethylene (LDPE), with very positive results. Polacco et al. [16] also obtained positive results, especially with linear low-density polyethylene (LLDPE). Other polyethylene-based polymers were tested in that study, but in all cases the obtained polymer-modified asphalt had a heterogeneous structure and showed storage instability. High-density polyethylene (HDPE) was also studied as asphalt modifier [17], and it was possible to observe that more economic pavements with higher performance and durability can be obtained by using 5% HDPE for bitumen modification. The good results obtained in these studies led to more recent studies with waste plastics (polymers) for bitumen modification [18]. In this context, plastic package waste [19] and plastic bottles waste [20] were both used in asphalt mixtures with encouraging results, allowing to conclude that the use of new or recycled polymers could ultimately give similar results, highlighting the more efficient use of waste plastic in environmental terms.

Taking the abovementioned into account, the main aim of the present study is to use higher amounts of different reclaimed materials in the production of new asphalt mixtures with a performance at least as good as that of conventional mixtures. The maximum percentage of RA incorporation is usually imposed by technical limitations of the asphalt plants. In this study, a percentage of 50% RA incorporation was defined, since that recycling rate can presently be used in some asphalt plants without significantly compromising their production rates. In order to increase the use of reclaimed materials in the asphalt mixtures, a recycled rejuvenator (UMO) and a recycled bitumen modifier (waste HDPE) were also used to improve the properties of the final binder, thus assuring an adequate performance of the new asphalt mixture.

2. Materials and methods

2.1. Materials

The present study has been carried out using a series of different materials. Taking into account the objective of maximizing the recycling rate, 50% of reclaimed asphalt (RA) was added to the final mixture, reducing the use of raw materials to less than 50%. In order to improve the properties of the final mixture, other waste materials were also used, which were chosen with the objective of increasing the amount of reclaimed materials incorporated in the mixture. Thus, used motor oil (UMO) and waste high-density polyethylene (HDPE) have been used for bitumen modification.

In order to fulfill the European specification requirements (EN 13108-1 and 13108-8), the final mixture must present adequate characteristics in terms of aggregates particle size distribution, binder content, air voids content and mechanical properties. Thus, it was necessary to characterize the individual materials used prior to the production of the mixture, as described in the following subsections.

2.1.1. Reclaimed asphalt material

The RA used in this study was obtained from a motorway pavement in Portugal, by milling the thickness of the pavement corresponding to a single layer (surface course) in order to obtain a homogeneous material. After fifteen years in service, the pavement presented fatigue cracking, and thus the RA binder would be expected to be very hard after being exposed to such long term aging.

2.1.2. Waste materials used for bitumen rejuvenation/modification

Regarding the wastes used as additives to modify the bitumen, used motor oil and HDPE, these have different functions. The UMO was used to rejuvenate the aged bitumen of the RA. Actually, the addition of UMO to the aged bitumen is expect to increase its penetration grade and decrease its softening point [21].

The use of waste plastics/polymers to modify the binder is actually a current practice in scientific studies and most of these conclude that the use of these materials improve the performance of the asphalt mixtures [19,20]. Based on the number of studies in this area, on the quantity of plastic wastes generated and collected, and on the alternative processes for their reuse, a waste HDPE was selected as being the option with higher potential of valorisation. This material has been obtained from a company that collects and treats waste polymers in the North of Portugal. After collection, the polymers undergo a visual separation process and a mechanical treatment to reduce the size of the particles for dimensions smaller than 4 mm. The HDPE used in this study was mainly obtained from waste plastic packaging.

2.1.3. New materials

With respect to the virgin aggregates used to fulfill the grading curve of the mixture, they are granite igneous rocks and the filler is limestone. These types of aggregates were chosen based on their availability in the region, and on the type of layer where they are expected to be used (surface course). Table 1 shows the main properties of the natural aggregates used in the study.

Taking into consideration a previous study carried out with the chosen RA [10], it was possible to conclude that the fine particles of that RA are excessive. For this reason, a maximum value for the percentage of fines to be introduced in the new mixture was imposed.

Table 1
Main properties of the natural aggregates.

Property	6/14 mm agg.	4/6 mm agg.	0/4 mm agg.
Density (EN 1097-6) (Mg/m^3)	2.66	2.65	2.66
Water absorption (EN 1097-6) (%)	<1	<1	<1
LA Abrasion Coef. (EN1097-2) (%)	28	28	28