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Effect of the recycling process and binder type on bituminous mixtures with 100% reclaimed asphalt pavement

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HIGHLIGHTS

- Three different recycling temperatures were compared in terms of cracking resistance.
- Fénix test was used at different temperatures to evaluate the cracking resistance.
- Hot and Half-warm recycled mixtures showed similar stiffness and ductility.
- The ductility of hot and half-warm recycled mixtures was critical below 12 °C.
- Cold recycled mixtures had the highest ductility and the lowest stiffness.

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ABSTRACT

There is a great interest in increasing the amount of recycled material used in asphalt mixes because of the beneficial impact on the environment. This is leading to the development of different recycling procedures, from cold in-situ to hot in-plant recycling. The objective of the study presented in this paper is to evaluate cracking resistance of recycled mixes manufactured by three types of processes, i.e., cold with emulsion, hot with high penetration bitumens and hot with emulsion (half-warm mixture), using 100% of reclaimed asphalt pavement (RAP) at different temperatures. Differences in their workability and ease of use are also analysed by gyratory compaction.

1. Introduction

The recycling of bituminous layers is a highly valued alternative for road pavement rehabilitation from the economic and environmental perspectives because it leads to savings in energy and natural resources. This technique can even bring additional advantages compared to overlaying, such as maintaining section geometry and reducing the duration of traffic disruption.

Different types of recycling processes of bituminous layers are currently used. Some consist of techniques which are consolidated and familiar because they are the oldest ones, namely hot and cold recycling of asphalt mixes. Specifications regarding these can be found in many countries [5]. Other processes are newer techniques that produce warm and half-warm recycled mixtures about which much research is being conducted to verify the properties of the resulting mixture [25,7,6,10–12,24,29,22].

Hot recycling of an asphalt mix is the manufacture of a bituminous mixture using conventional materials (aggregates, bitumen and filler) but replacing a portion of these by material from milling of a deteriorated and aged pavement (commonly called RAP). The purpose is to achieve a mixture with similar characteristics to those of a conventional hot bituminous mix. However, the presence of RAP gives the mixture certain particular characteristics; the aged bitumen in the RAP is distinguished by its low penetration and high softening point, meaning that its cohesive properties are usually lower than those of a new bitumen. To compensate for this degree of ageing, a very soft new bitumen and even rejuvenating agents are often added, resulting in a blend of binders with acceptable properties [30].

Another property to be analysed is gradation. The addition of new aggregates corrects the gradation of the aggregates of the RAP in order to achieve the particle size distribution and void con-

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tent specified for a hot asphalt mixture. Mixtures made with this RAP have no problems of plastic deformation [17]; on the contrary, the main risk of these mixtures is excessive stiffness and very low ductility. It is therefore important to evaluate the behaviour of hot recycled mixtures at low temperatures by analysing their cracking resistance [28,2,31].

As far as mixing and compaction temperature is concerned, cold recycling with emulsion is at the other end of the recycling techniques. Mixtures are manufactured from material obtained from milled bituminous layers combined with a bitumen emulsion at room temperature. From the environmental perspective, these are the most sustainable mixtures since no virgin aggregates or heating of materials are needed [26]. On the other hand, from the technical point of view, there are some disadvantages compared with hot recycled mixes, and these are a barrier to their use. During the manufacturing stage, the layer of mixtures recycled with emulsion requires very high compaction energy to densify and the water in the emulsion a long curing time to evaporate. These two requirements mean a longer construction time, and therefore a lower performance during construction [3,27,9]. As to quality, significant differences are also found between these mixtures and hot recycled mixtures: mixtures recycled with emulsion have the advantage of being flexible, and can therefore be spread in very thin layers without cracking, but their stiffness modulus is usually very low, resulting in low resistance to traffic loads or to the action of water. For this reason, in some countries, the use of mixtures recycled with emulsion is restricted to the pavement base and binder layers of roads subjected to low intensity traffic [8].

New recycling techniques have been developed in recent years to improve the performance of cold recycled mixtures with emulsion by reducing the use of bitumens or excessive heating of materials. One of these techniques involves half-warm recycled mixtures, which are obtained by heating the RAP to a temperature not exceeding 100 °C and mixing it with a bitumen emulsion [16]. In this process, the manufacturing and laying temperature is lower, thereby reducing fuel consumption and greenhouse gas emissions. Additionally, the highest possible rate of recycled material is used.

Half-warm recycled mixtures have certain advantages over cold recycled mixtures because RAP temperature favours coating and increases initial cohesion of the mixture (curing time is decreased). As a result, these mixtures have better mechanical characteristics, keep similar flexibility and can be laid in thin layers.

In summary, recycled mixture design must pay attention to mixture workability to facilitate laying and compaction, and to stiffness and ductility because of their influence on in-service behaviour of pavements.

The following study compares the above properties in recycled mixtures manufactured by the three recycling processes: hot, half-warm and cold. The mixtures were prepared with the same type of RAP without the contribution of virgin aggregates, thereby ensuring the formation of similar granular structures and keeping constant residual bitumen content.

To evaluate workability of mixtures, all specimens were manufactured using the gyratory compactor and applying the same number of gyrations and the same conditions of vertical pressure and gyration angle, and volumetric variation and shear stress were recorded during the compaction process [13]. To analyse the mechanical properties, Fénix test was applied at different temperatures to determine the number of parameters related to stiffness and ductility of mixtures [21,15]. This test was also used to assess cracking resistance since cracking is a typical distress associated with high RAP content mixtures, as stated by many researchers [14,32,18].

1.1. Methodology and experimental plan

The study consisted in manufacturing four recycled bituminous mixes using the same type of milled bituminous material, reclaimed asphalt pavement (RAP), without contribution of virgin aggregates, i.e., adding 100% RAP, with bituminous binders and by different processes. Table 1 shows the experimental plan.

The RAP contained 4.06% of bitumen. The solid line in Fig. 1 shows the RAP gradation used to manufacture the specimens. The dashed line corresponds to the gradation of aggregates after the extraction test. This figure shows how the fines are bonded by the mastic and that the RAP particles are coarser.

Two of the mixtures were hot-recycled with different penetration bitumens, 70/100 and 160/220, and manufactured at 145 °C. Since the function of these bitumens is to restore the lost properties of the aged bitumen of the RAP, i.e., penetration and viscosity, the degree of influence of this variable (bitumen type) on the properties to be analysed was also determined.

The other two mixtures were prepared with cationic emulsions. One was cold-recycled with C60B5 emulsion (58–62% bitumen content and breaking index 5); the other was half-warm by heating the RAP at 100 °C and mixing it with C67B3 emulsion (65–69% bitumen content and breaking index 3). The latter emulsion has higher residual bitumen content and lower water content.

The penetration index of the recovered binder from the RAP was 16 tenths of millimetres (0.1 mm) and the softening point, 84 °C. Residual bitumen content was kept constant in all cases, i.e., 5.5% by weight of mixture (5.8% by weight of RAP), to determine the percentages of bitumen and emulsion to be incorporated in each type of mixture.

With regard to manufacturing conditions, 100 gyrations of the gyratory compactor, a piston vertical pressure of 0.6 MPa and a gyration angle of 0.82° were applied following the standard test UNE-EN 12697-31. Six replicates were manufactured for each type of mixture.

Mixtures prepared with emulsions were compacted using slotted moulds to allow drainage of water released during compaction, Fig. 2.

In the case of mixtures with emulsion, coating water content was 1%, obtained from Proctor compaction test (standard UNE 103501) and curing conditions were three days at 50 °C according to the Spanish Technical Specifications for Roads Rehabilitation [23].

The parameters recorded during the compaction test were the evolution of density and shear stress. At the end of the compaction process, and the curing time in the case of specimens made with emulsion, bulk density was determined by the hydrostatic method according to standard UNE-EN 12697-6.

Cracking resistance of all specimens was evaluated by Fénix test. This test determines the effort required to crack a semi-cylindrical specimen by applying a tensile stress along the diametrical plane through two metal plates glued to the specimen in the diametrical plane and subjected to the anchors of the press. The test is performed at a constant displacement speed of the piston of 1 mm/min. The specimen has a small notch between the two plates, as shown in Fig. 3, which induces cracking of the specimen. The load applied and piston displacement are recorded throughout the test to determine tensile stiffness index (IRT), fracture energy (G_D), toughness index (IT) and displacement at 50% of post-peak maximum load ($d_{0.5\ PostFmax}$).

A stiffness parameter (tensile stiffness index) is defined as the slope of the load-displacement curve between 25 and 50% of maximum load reached during the pre-peak portion of the test:

$$IRT = \frac{0.5F_{\max} - 0.25F_{\max}}{(d_{0.5}F_{\max} - d_{025}F_{\max})},$$