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Fatigue performance of bituminous mixtures made with recycled concrete aggregates and waste tire rubber

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HIGHLIGHTS

- Fatigue performance of hot-mix asphalt (HMA) for binder course has been studied.
- 0%, 35% and 42% of recycled concrete aggregate (RCA) were incorporated to HMA.
- B35/50 and crumb rubber modified bitumen BC35/50 were used.
- As RCA percentage increases, the fatigue resistance of HMA also increases.
- Crumb rubber improves fatigue life of HMA made with RCA in medium traffic roads.

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ABSTRACT

Fatigue cracking is one of the main hot-mix asphalt (HMA) failure modes. The current laboratory investigation analyses the fatigue performance of HMA made with recycled concrete aggregates (RCA). An HMA type AC 22 bin S made with 0%, 35% and 42% of RCA was tested in the indirect tensile fatigue test (ITFT) device. Three constant stress levels, ranging from 150 kPa to 350 kPa were used. Mixtures were manufactured at the optimum bitumen content using two types of bitumen: a B35/50 penetration grade bitumen and a 10% waste tire rubber modified bitumen, BC35/50. This investigation demonstrates the beneficial effect on fatigue life of the incorporation of RCA. Additionally, the use of crumb rubber could lead to RCA bituminous mixtures with higher fatigue life in medium traffic roads.

1. Introduction

Hot-mix asphalt (HMA) is a widely used road pavement material. Of the more than 5.2 million km of the European road and highway network, it is estimated that over 90% are paved with HMA or other bituminous materials [1]. Similarly, more than 92% of the more than 4 million km of U.S. highways and roads are paved with asphalt [1].

Transport infrastructures enhance the economic and social development of a region, increase accessibility and help to mitigate territorial imbalances. For all of these reasons, the quality and durability of highways and road networks must be ensured. It is very important to analyse HMA properties and weaknesses carefully.

Fatigue cracking is one of the main HMA failure modes along with rutting and low temperature cracking [2]. Fatigue cracking results in the shortening of pavement life [3] and is directly related to the quality of road asphalt pavements [4]. Fatigue cracking occurs when the asphalt pavement is subjected to repeated traffic loading [5], as a consequence of the passage of vehicle wheels with a loading level lower than the tensile strength of the material [4]. Despite this low loading level, the cumulative effect of repeated traffic loading over time leads to the appearance of fissures. This phenomenon usually occurs in two stages. In the first stage, called "initiation phase," the appearance of micro-cracks (not visible to the naked eye) that reduce the stiffness of the HMA occurs [6]. Later, in a second stage called "propagation," as traffic loads continue, the coalescence of micro-cracks gives way to the formation and growth of macro-cracks [7]. The growth of these macro-cracks begins with stable crack growth and continues with unstable crack growth [8] that finally, at the end of the second phase, leads to the structural failure of the mixture.

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It is necessary to take into account that other mechanisms, such as self-heating or bitumen tixotropy, which are acting in parallel to cause fatigue, can reduce stiffness [6]. These mechanisms are predominant at the beginning of the "initiation" phase [6].

The fatigue structural failure manifests itself at the flexible pavement surface in two main cracking forms:

- When the bituminous layer is thin or medium, the highest tensile stress is at the bottom of the HMA as a result of bending of the bituminous layer when vehicles pass. In this case, fatigue cracking is usually visible as interconnected cracks, known as "alligator" cracking [9] because of the appearance (Fig. 1a). These cracks may allow water infiltration to reach the base course or the subgrade [4] and lead to the subsequent appearance of other pavement distress, such as potholes. When "alligator" cracking occurs, the classical fatigue approach, that is, bottom-up fatigue cracking, is prevalent: as a consequence of the horizontal tensile strains or stresses induced by the traffic at the bottom of HMA layers, cracks are originated and propagate upward to the surface course [10]. As a result, the loss of stiffness originated by the appearance of cracks finally leads to increased tensile strains at the bottom of the asphalt layers and increased surface deflections [11].
- When the thickness of the bituminous layer is sufficiently high, the most prejudicial stresses are shear stresses originating at the top of the HMA, which are the consequence of the complex contact pressure distribution under the vehicle tire [11]. This causes fatigue of HMA in the form of longitudinal cracking along the wheel path [10] together with small transverse cracks [11] (Fig. 1b). In this case, the prevalent fatigue mechanism is top-down fatigue cracking: cracks initiate at the HMA surface and progress downwards through the bituminous layer. Environmental factors, such as thermal stresses and the existence of damage zones, may accelerate top-down fatigue cracking [12].

HMA is typically composed of approximately 95 percent mineral aggregates mixed with 5 percent of bituminous binder [1]. In some cases, the addition of small amounts of other materials such as fibres, may improve some of the bituminous mixture's properties [10].

In view of these percentages, it is clear that the substitution of virgin mineral aggregates with recycled aggregates will have economic and environmental advantages. For these reasons, the use of residues and industrial by-products as recycled aggregates has been an excellent choice over the last few decades. Some of these residues are still being studied. This is the case with recycled concrete aggregates (RCA) from construction and demolition waste (C&DW).

Some authors have investigated the use of RCA on HMA, with encouraging results [13]. The fatigue resistance of HMA made with RCA is one of the less studied properties. In this regard Chen et al. [14] followed the AASHTO T-321 to analyse the four-point bending fatigue life, concluding that the use of RCA as mineral filler in HMA produced mixtures with higher fatigue resistance. Pérez et al. [15,16] followed Spanish NLT-350 standard to analyse the three-points bending fatigue life of HMA made with RCA up to 60%, concluding that these mixtures behave similar to conventional ones. Arabani and Azarhoosh [17] used the Nottingham Asphalt Tester to analyse the fatigue life of mixtures made with RCA. They concluded that when RCA is used in the fine fraction, the fatigue life of the mixtures increases, while when RCA is used in the coarse fraction, the fatigue life decreases. Moghadas Nejad et al. [18] used the indirect tensile fatigue test and concluded that the use of up to 100% RCA improved the fatigue life of the bituminous mixtures. Pasandín and Pérez [19] concluded that mixtures up to 20% of RCA perform similar to conventional ones, while higher percentages of RCA lead to mixtures with poor fatigue life. Also Pasandín and Pérez [20] stated that mixtures made with RCA coated with bitumen emulsion perform similar to conventional mixtures in terms of fatigue life.

The aim of this investigation is

- Determine whether the use of RCA affects the fatigue resistance of HMA.
- Evaluate whether there is any trend in fatigue life as the RCA percentage in HMA is increased.
- Reach a better understanding of the performance of HMA made with RCA.

To fulfil these objectives, an experimental laboratory investigation was conducted that focused on the fatigue resistance of HMA made with RCA. In the study, an AC 22 bin S made with 0%, 35% and 42% RCA was tested in the indirect tensile fatigue test (ITFT) device at a constant temperature of 20° C at the optimum bitumen content with two types of bitumen: B35/50, penetration grade bitumen, and BC35/50, a waste tire rubber modified bitumen.

2. Materials and methods

2.1. Basic materials

2.1.1. Aggregates

Two aggregates were used in this investigation: natural aggregates and recycled concrete aggregates (RCA) from construction and demolition waste (C&DW).

The natural aggregates were crushed limestone from a local quarry in Madrid (Spain). RCA were obtained from the demolition of residential buildings and were supplied by a C&DW recycling plant in Madrid (Spain).

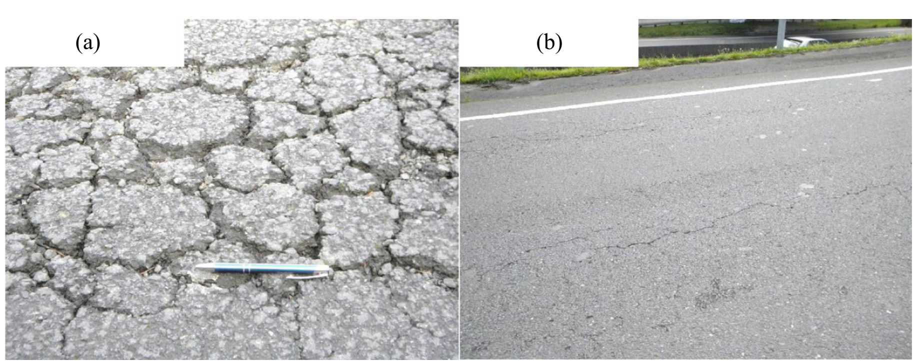

Fig. 1. Cracking due to HMA fatigue: a) "Alligator" cracking and b) Longitudinal cracks along the wheel pad.