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Mechanical performance of mechanomutable asphalt binders under cyclic creep and recovery loads

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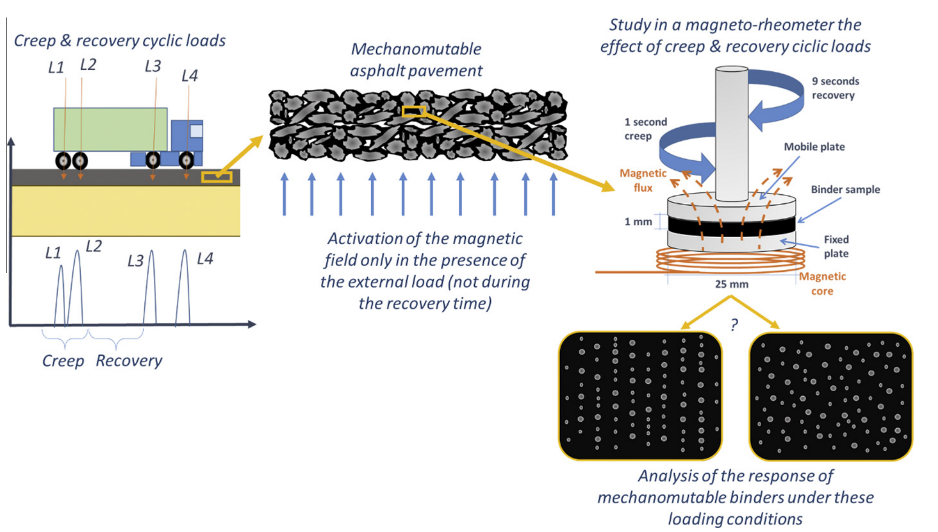
HIGHLIGHTS

- MAB modify their mechanical behavior when they are activated by a magnetic field.
- MAB behave as smart materials offering a wide range of engineering applications.
- MAB improve their resistant against plastic deformations.
- An increase in the magnetic particle content improve its mechanical behavior.

GRAPHICAL ABSTRACT



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ABSTRACT

Mechanomutable asphalt binders are able to modify their mechanical behavior when they are activated by a magnetic field. Under the effect of the magnetic field, these binders can increase their stiffness and perform elastically, and once the magnetic field is removed, the material recovers its original visco-elastic properties. Because of this fact, these smart materials could offer a wide range of interesting engineering applications. One such use could be its incorporation into structures that are required to support cyclic loading, such as asphalt pavements, as they can be punctually activated to minimize the impact of traffic loads. Based on these considerations, this paper studies the mechanical performance of mechanomutable asphalt binders under cyclic loads similar to those occurring in real pavements during their service life. For this purpose, a magneto-rheometer has been used to carry out different multiple stress creep and recovery tests under different magnetic field strength. The results obtained show that, in spite of the fact that these binders do not have a significant recovery capacity, they can reduce the cumulative permanent deformations produced in them due to the effect of cyclic loads when they are under the effect of a magnetic field.

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1. Introduction

In recent years, pavement engineering research has focused on the development of new smart materials that could render the road a more efficient infrastructure [1–4], and which could increase its functionality [5–10]. In this respect, a new pavement material (mechanomutable asphalt binders, MAB) has been recently developed [11] and it could provide an interesting tool for improving the mechanical performance of the main civil engineering infrastructures (roads, highways, airports, ports, etc.). These binders (MAB) are able to adapt their mechanical response to the stresses that they are required to support, and they could provide pavements that are sufficiently rigid to reduce the appearance of plastic deformations, whilst flexible enough to avoid the formation of cracks.

MAB are based on similar concepts to those used in the development of magnetorheological (MR) fluids or elastomers [12–15]. These binders are composed of a bituminous matrix that has been modified with magnetic particles that are homogeneously dispersed over it. When these particles are activated by an external magnetic field, the binder can considerably increase its stiffness, and when the magnetic field is removed, its initial rheological properties are restored [11]. The results obtained in previous research have shown that the type of bituminous matrix (harder or softer) used in the manufacturing of the binders has an impact on the degree to which they can modify their mechanical properties. In addition, as the strength of the magnetic field applied or the concentration of the magnetic particles increases, the degree of change produced in the properties of the binders also increases.

During the service life of a real pavement, a given zone is only under mechanical loading when the wheel of a vehicle passes over it – for the remainder of the time this zone is free of mechanical loads. These mechanical loadings L1, L2, etc., and the lag time t1, t2, etc., are shown in Fig. 1. The load supported at a specific point "A" is plotted as a function of time in the lower graphs, where the rest periods and the mechanical loading can be seen in detail.

Thus, for the effective application of these types of binders (MAB), the magnetic field should only be applied during the instant that this zone is altered by the presence of the wheel, and then switched off until a new wheel is detected. Studies carried out with MR fluids have demonstrated that the changes produced in their rheological behavior occur in a drastic, reversible, and rapid way, typically with an order of magnitude of a millisecond [16–18]. Nonetheless, there is still little information available regarding the mechanical performance of MAB under cyclic loads – which combine stress periods and rest periods, where the magnetic field is only activated under the presence of the load and switched off during the rest period.

This paper constitutes an evaluation of the mechanical behavior of MAB under loads comparable to those that would occur during the real application of these materials in a road pavement. For this purpose, several MAB (manufactured with different bituminous matrix and particle concentrations) have been tested using a magneto-rheometer (which can apply a magnetic field over the sample). The main objective of this research was to assess the mechanical response of the MABs once the load and the magnetic field are removed.

2. Methodology

2.1. Materials

Based on the results obtained from previous research [11], two different neat binders, named B 20/30 and B 50/70, and two different magnetic particle concentrations with 1% w/w and 10% w/w (% concentration over the weight of the binder) were selected to manufacture representative MABs. In order to compare the performance of these smart binders, a high-performance commercial binder (commonly used in the construction of long-life pavements) composed of Styrene-Butadiene-Styrene polymer modified bitumen (PMB) was also tested. The characteristics of the neat bituminous matrix used for the manufacture of the MABs, as well as the characteristics of the high-performance polymer modified bitumen (PMB) used to compare the results obtained, are summarized in Table 1. Spherical HQ carbonyl iron powder was used as magnetic particles to manufacture the MABs. These particles have a median particle size of d_{50} = 2.3 μm (particle diameter ranges from 0.5 μm to 3 μm) and an iron content of 97% (density = 7.5 g/cm^3).

The manufacture of the MABs was conducted at a constant temperature of 120 °C, where the iron powder particles and the neat binders were mixed using an agitator at 200 rpm for 10 min. Based on these circumstances, four different MABs were manufactured: B 20/30-1% (composed of a B 20/30 matrix and 1% over the weight of the binder of iron powder particles); B 20/30-10% (composed of a B 20/30 matrix and 10% over the weight of the binder of iron powder particles); B 50/70-1% (composed of a B 50/70 matrix and 1% over the weight of the binder of iron powder particles); and B 50/70-10% (composed of a B 50/70 matrix and 10% over the weight of

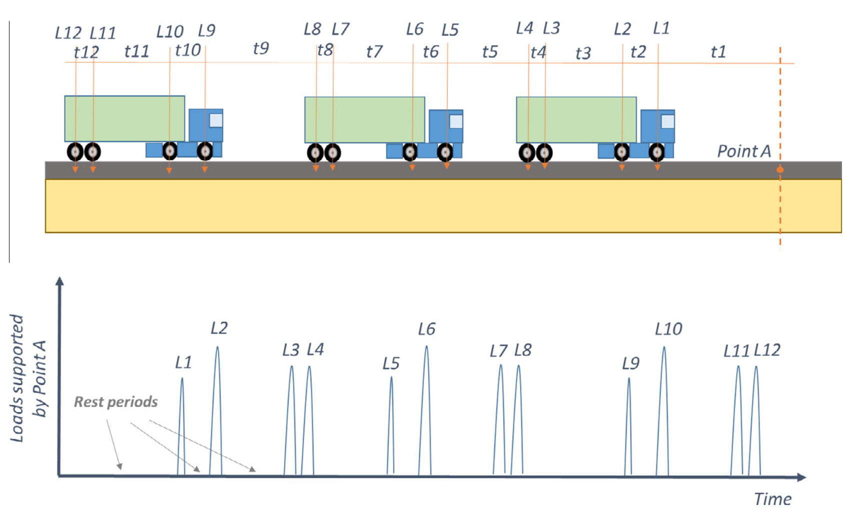

Fig. 1. Sketch of the mechanical loads suffered by a given point in the pavement.