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Micromechanical contribution for the prediction of the viscoelastic properties of high rate recycled asphalt and influence of the level blending

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ABSTRACT

This research deals with an experimental and micromechanical study of high rate recycled asphalt with 70% of RAP. Rheological measurements of shear complex modulus of virgin, RAP and blended binders were performed at different temperatures and frequencies. Then, a micromechanical model based on the generalized self-consistent scheme (GSCS) was suggested for the prediction of the effective mechanical properties of the recycled asphalt. The GSCS-based approach aims to homogenize the heterogeneous material taking into account the intergranular porosity, on the one hand, and the possible interactions between its phases on the other one. The suggested method was compared to a step-by-step (successive) homogenization approach and literature data in elastic case were used for this purpose. The results have shown that the GSCS-based approach presents a good agreement with the data especially for higher volume fractions of aggregates. Furthermore, the significant influence of the blend homogeneity level on the estimation of the effective mechanical properties of the recycled asphalt was highlighted.

1. Introduction

Pavement recycling has been increasingly gaining a great attention in the asphalt industry. In addition to the ecological benefits and the natural resources preservation, recycling allows also the reduction of energy consumption resulting therefore in a more cost-effective production and considerable economical gains [1,2]. In France, since the oil crisis of 1973, the bituminous materials have been more and more recovered for recycling and competitive efforts are made to involve high amounts of RAP (reclaimed asphalt pavement). Nowadays, RAP rates up to 30% are commonly used in the road construction and rehabilitation projects making thereby necessary to control the properties of the final recycled product [3].

In this context, some research works have focused on the investigation of the viscoelastic properties of the recycled asphalt from different point of views. Eddhahak-Ouni et al. [4,5] have presented an experimental laboratory protocol based on a progressive extraction combined with a FTIR spectroscopy analysis in order to highlight the relationship

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between the manufacture recycling process on the one hand and the level of homogeneity of the blended binder on the other one. They concluded that the temperature and the time mixing parameters involved in the asphalt manufacture shall be well calibrated in order to reach the wished blending level of the final binder and to control thereby the mechanical performances of the recycled asphalt. Other research works suggested empirical and analytical predictive models for the prediction of the viscoelastic properties of the asphaltic concrete based upon the rheological information of its bituminous binder and mix design [6–9]. Some of these models have shown some limitations for specific solicitation frequency and temperature ranges [10] and others often require complementary experimental tests on the asphaltic concrete [11].

Although they are reliable, the experimental-based approaches are sometimes very long and cumbersome to perform. Furthermore, experiences can be costly and too much time and energy-consuming especially when dealing with the investigation of the material responses under different mechanical scenarios. For these reasons, innovative approaches based on the rational mechanics have been adopted in opposition of the so-called empiric school. The micromechanics which has been developed for decades is a complementary approach whose purpose is to provide efficient deductive tools for the prediction of the effective properties of the heterogeneous material based on the knowledge of the properties of its constituents. It was highlighted with the help of the extensive literature that micromechanics can be used to understand the mechanical behavior of the bituminous materials. Buttlar et al. [12] used the generalized self-consistent scheme (GSCS) model [13,14] in order to investigate the asphalt mastic behavior. Later, Shashidar and Shenoy [15] suggested a modified form of Buttlar solution involving the use of an order of magnitude analysis for simplification of the complex sets of the GSCS equations. The research of Lachihab [16] considered the asphalt as a biphase composite including spherical inclusions coated by a bitumen film and embedded in the infinite equivalent medium. Nevertheless, the intergranular porosity was not taken into account in his work. More recently, Alam and Hammoum [17] presented a micromechanical analysis based on a successive homogenization process in which the self-consistent model was considered in three multiscale steps for the prediction of the viscoelastic properties of HMA mixes. However, errors up to 50% were recorded in some cases for the prediction of the mechanical behavior of the asphalt. From the above studies, the suitability of the generalized self-consistent model was shown and its reliability to provide good predictions of the equivalent properties of the composite [18], but further work is still needed for a better prediction of the asphalt properties.

In this framework, the objectives of the present work are:

(i) To present a novel micromechanical approach based on the GSCS model and illustrated on a laboratory case of a high rate recycled HMA including 70% of RAP. The intergranular porosity of the composite is taken into account in the modeling.
(ii) To investigate the level of blending of the final binder and its influence in the prediction of the viscoelastic properties of the high rate recycled HMA.

2. Theoretical development

The recycled asphalt is a heterogeneous material composed of typically 95% (by mass) of aggregates and 5% of bituminous binder. Thus, this composite can be assumed as a multiphase material reinforced by elastic inclusions (aggregates "a") which are surrounded by a viscoelastic matrix (mastic "m") and weakened by the porosity phase (air voids "p") (Fig. 1). Accordingly, the micromechanical model which will be considered here is based on the generalized self-consistent scheme (GSCS) [16]. This model was initially formulated by Christensen and Lo [13] for two-phase materials through a 3-phase scheme by considering a composite spherical inclusion coated by a matrix shell which is embedded in an equivalent homogeneous infinite medium (EHM). Unlike the classic self-consistent scheme, the GSCS is an implicit model since the final solution is expressed as a function of the properties of the EHM which is unknown in itself. For further information on this micromechanical scheme, the reader could consult the detailed work of Hervé and Zaoui [14].

In addition, for a better and more accurate definition of the multiphase composite, conclusions have been drawn from the previous research of Navaro [19] through which it was highlighted that in the case of a good blending of the virgin binder into the RAP-binder, the aggregate is surrounded by just one homogeneous binder layer (Fig. 2a). Accordingly, in the case of a "good" blending configuration, one can suppose a monolayer spherical inclusion of a $(2 + 1)$-phase micromechanical model [20]. Whereas, in the case of a "bad" blending of virgin and RAP binders, a 2-layered inclusion is considered. The first layer close to the aggregate corresponds to the RAP binder and the second layer is relative to the virgin binder (Fig. 2b). Accordingly, a $(3 + 1)$-phase model will be adopted for the description of this configuration. In the following, the micromechanical development based on the $(n + 1)$-phase model ($n = 2, 3$) is presented in order to appreciate the effective homogeneous mechanical properties of the recycled asphalt composite in both configurations (good and bad blending levels). For the sake of simplicity, the problem will be first tractable in the case of linear elasticity and the solution is then extended to the viscoelasticity.

2.1. The GSCS-based approach (elasticity case)

In this section, we will assume that the heterogeneous material is composed with purely elastic phases; thereby the associated representative volume element (RVE), denoted as "Ω", is described by a first elastic spherical inclusion (corresponding to the aggregates) coated by an elastic phase and a second spherical inclusion (corresponding to the

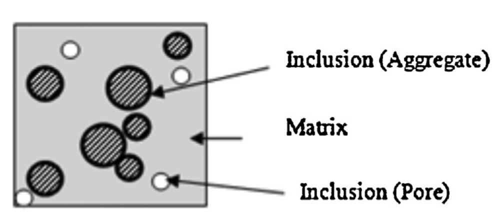

Fig. 1 – Schematic modeling of the asphaltic concrete.