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Asphalt mixtures modified with basalt fibres for surface courses

C. Celauro [a,*], F.G. Praticò [b]

[a] Department of Civil, Environmental, Aerospace, Materials Engineering (DICAM), University of Palermo, Italy
[b] DIIES Department, University Mediterranea of Reggio Calabria, Italy

HIGHLIGHTS

- The benefit of introducing basalt fibres in surface course is investigated.
- Basalt fibres proved to satisfy specific needs in road technique.
- Use of fibres or waste materials is a good solution to face environmental issues.
- This widens maintenance and rehabilitation options for urban pavement management.

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ABSTRACT

This paper shows the results of an experimental study concerning the effect of introduction of basalt fibres in asphalt mixtures for surface course, mainly with regard to those to be used in urban areas, for dedicated bus lanes. Surface layers, where tire-pavement interactions occur, have to provide different properties such as high friction (very important for users' safety), stability, resistance to meteorological agents, and contribution to the overall pavement performances. Considering that basalt fibres provide considerable physical and mechanical properties and above all high abrasion resistance, scope of the study is to evaluate the effects of these fibres on mixtures properties, especially in terms of friction and rutting behaviour.

For this purpose, after setting up a model to estimate the impact of fibres on asphalt film thickness and richness modulus, the mixtures produced were subjected to laboratory tests for performance evaluation in terms of rutting resistance and the surface texture.

The test results allow drawing some important conclusions about basalt fibre-modified asphalt mixtures: in particular, these mixtures show better performance with reference to permanent deformation resistance when compared with the traditional mixture; moreover, the introduction of basalt fibres involves a "flattening" of the profile texture and a lower macrotexture. Interestingly, fibres addition is likely to slightly increase the micro-texture. This point calls for further study.

1. Introduction

The modern road pavements must meet many performance requirements in order to satisfy the current needs of the transport: not only due to the increasing traffic load that requires high mechanical performance; they must also ensure the movement of vehicles securely, smooth, safe and comfortable surfaces according to qualitative levels that depend on the category of road and the expected traffic.

Road safety is related to the quality of the surface layer of the pavement. In particular, adequate friction, in tire – road interaction, must be guaranteed in all situations, to allow the vehicle to maintain the chosen trajectory and efficient braking, especially in curve.

Another functional characteristic of the surface layers - the user's comfort - involves a series of factors related to surface characteristics of the road and in particular to the absence of irregularities, such as waves and degradations of any kind [1].

Nowadays, for sustainable development, research focuses on developing new technologies for asphalt mixtures production in order to improve mechanical and functional performances and assure the same performances specified by the current Technical Specification, also thanks to the use of specific additives for achieving improved performances. Furthermore the use of specific additives such as fibres or scrap materials is considered as an interesting and effective solution to face environmental issues linked to

* Corresponding author.
E-mail addresses: clara.celauro@unipa.it (C. Celauro), filippo.pratico@unirc.it (F.G. Praticò).

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reusing waste materials and to satisfy particular needs in road technique [2].

At present, there are two research orientations to improve pavement performance of asphalt mixture: one is to better asphalt non-deformability at high temperature, via improving aggregate gradation, which is based on asphalt structure type and design procedures; the other is to better asphalt mechanical performance and decrease temperature susceptibility, via improving asphalt property and quality [3]. For the past few years, more and more new materials have been introduced into the technology field of bituminous pavements. Thus, the third orientation to improve its performance is formed, that is to add specific additives - fibres amongst these - to asphalt to improve its physical and mechanical property.

At the moment, there mainly are three types of fibres applied in pavement project: cellulose fibres, polyester fibres and mineral fibres [4]. Taking asphalt regeneration into consideration, mineral fibres have been familiar to people, with better mechanical performance and higher work temperature [5].

Basalt fibres (especially those obtained from scoria or vesicular basalt that cannot be directly used as a construction material) can be considered environmentally friendly and non-hazardous materials. It is not a new material, but its applications are surely innovative in many industrial and economic fields, from building and construction to energy efficiency, from automotive to aeronautic, thanks to its good mechanical, chemical and thermal performances. Hence, basalt fibre has gained increasing attention as a reinforcing material especially if compared to traditional glass fibres.

The production process, even if it is very similar to the glass fibres one, does not require additives and a lower amount of energy is needed with benefits in terms of environmental impact, economics and plants' maintenance. The base cost of basalt fibres depends on the quality and the chemical composition of the raw material and this leads to have several kind of fibres with different thermal, chemical and mechanical properties [6]. Indeed, the final cost of the fibres depends, at a large scale, not only on the specific production process for the needed type of fibre, but also on the total quantities to be produced. Many scientific studies confirm the growing interest on this type of fibres [6–9].

There are so far few studies about the use of basalt fibres in the road pavement, all confirming their good properties in terms of Marshall stability, rutting stability, water stability [5,10,11], the possibility to have better low temperature performance, and the anti-fatigue property. Besides, at high temperatures, the stiffness of asphalt mixture can be increased and permanent deformation can be reduced [11,12]. Thus, it is of interest to evaluate the benefit of introducing basalt fibres in surface course for urban applications, in order to offer effective maintenance and rehabilitation options for urban pavement management, as a valuable alternative to the use of polymer modified bituminous mixtures.

2. Objectives and main phases of the study

The object of this research work is to evaluate the effect of the introduction of basalt fibres in asphalt mixtures for surface courses, in terms of surface texture and permanent deformation resistance, especially for use in urban areas, for dedicated bus lanes, where vertical stresses and strain level are more severe [13], due to frequent stopping and restarting manoeuvres, both at bus stops and at traffic lights [14].

The study is organized into the following main sections: modelling, design of experiments, material characterisation and mix design, results and discussions.

A model to consider the impact of fibres on asphalt film thickness and richness modulus is set up. The consequent effect in determining the optimum binder content, as related to the binder film thickness, is then derived. The factorial plan of experiments is shortly summarized in the Design of experiments paragraph, while the Material characterization and mix design section fully provides the characterization of the materials used in this study. In the Results analysis and conclusions section key conclusions are drawn and main contributions are pointed out.

3. Modelling

In the pursuit of the above objectives, if analytical methods are used to estimate the specific surface area of aggregates [15], it is relevant to model the impact of fibres on two conceptually similar approaches to determine the optimum binder content: the asphalt film thickness (according to the Standard STP 204-19 [16]) and the richness modulus [17], fundamental to ensure mixture durability.

If the aggregates are modelled in terms of spheres (where D_A is the diameter, m) and the fibres are modelled in terms of cylinders (diameter: D_F, m, height L, m, $L/D_F \cong 800$), the specific surfaces, (SS_A, SS_F, respectively, m^2/kg), are approximated as follows:

$$SS_A = \frac{6}{D_A \cdot G_{seA}} \tag{1}$$

$$SS_F = \frac{4}{D_F \cdot G_{seF}}. \tag{2}$$

where G_{se} refers to the effective specific gravity of aggregates/fibres.

Let the thickness (z, m) of the asphalt binder on the single particle be the function given by:

$$z = \frac{\alpha^* \cdot D^{0.8}}{G_{se}^{0.2}} \tag{3}$$

It follows:

$$z_A = \frac{\alpha_A^* \cdot D_A^{0.8}}{G_{seA}^{0.2}} = \frac{\alpha_A^*}{G_{seA}} \cdot \left(\frac{6}{SS_A}\right)^{0.8} \tag{4}$$

And

$$z_F = \frac{\alpha_F^* \cdot D_F^{0.8}}{G_{seF}^{0.2}} = \frac{\alpha_F^*}{G_{seF}} \cdot \left(\frac{4}{SS_F}\right)^{0.8} \tag{5}$$

If K_D is the richness modulus of the bituminous mixture, as *per* Duriez formula [17], the percentages of bitumen (by weight of aggregates) are given by:

$$b_A = \frac{\alpha_A^*}{G_{seA}} \cdot \left(\frac{6}{SS_A}\right)^{0.8} \cdot SS_A = \frac{\alpha_A^* \cdot 6^{0.8}}{G_{seD}} \cdot \frac{G_{seD}}{G_{seA}} \cdot SS_A^{0.2} = K_{DA} \cdot \alpha_A \cdot SS_F^{0.2} \tag{6}$$

$$b_F = \frac{\alpha_F^*}{G_{seF}} \cdot \left(\frac{4}{SS_F}\right)^{0.8} \cdot SS_F = \frac{\alpha_F^* \cdot 6^{0.8}}{G_{seD}} \cdot \frac{G_{seD}}{G_{seF}} \cdot \left(\frac{4}{6}\right)^{0.8} \cdot SS_F^{0.2} = K_{DF} \cdot \alpha_F \cdot \beta_F \cdot SS_F^{0.2} \tag{7}$$

where α is the well-known coefficient that takes into account the specific Gse, while β (which pertains to the shape effects on the theoretical framework of Duriez and Arambide [17]) is herein defined based on the equations above.

It turns out that if A% and F% are the percentages of aggregates and fibres (by total weight of non-binder components) respectively (e.g., F = 0.2%, A = 99.8% [5,10,18]), the corresponding asphalt binder percentage of the mixture (B, by total weight of aggregates/fibres) is the following:

$$B = \frac{b_A \cdot A\% + b_F \cdot F\%}{A\% + F\%}. \tag{8}$$