Construction and Building Materials 178 (2018) 183–194

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# Improvement of high modulus asphalt mixtures with average quality aggregate and bitumen by application of polymeric additives

M. Ranieri, C. Celauro *

*DICAM – Dipartimento di Ingegneria Civile, Ambientale, Aerospaziale, dei Materiali, University of Palermo, 90128 Palermo, Italy*

## HIGHLIGHTS

- The need for higher performances requires improved asphalt concrete for pavement.
- Mix design of improved mixtures with average quality components was carried out.
- Dry addition of commercial and waste polymers was carried out into the mixes.
- Polymeric additives are proved to improve mechanical performances.
- Saving of high quality and not-renewable resources is a beneficial consequence.

## ARTICLE INFO

*Article history:*
Received 2 January 2018
Received in revised form 11 April 2018
Accepted 12 May 2018

*Keywords:*
High modulus mixtures
Bituminous mixtures
Polymers
Waste plastics

## ABSTRACT

The paper deals with the development of asphalt mixtures for high performing binder and base courses, modified with both commercial and waste polymeric additives, via dry process. The focus was on the mix design of high performing mixtures making use of average quality aggregate and average penetration grade bitumen (as locally available) instead of the usually required high quality components, manly very hard bitumen, thus aiming to improve the reference mixture as made possible by suitable polymers. Mixtures were subjected not only to conventional tests for mix design purposes, but also to advanced tests for performance evaluation such as rutting resistance and fatigue resistance. The dynamic modulus was also evaluated by means of modulus tests in triaxial cell.

The test results provided useful information about the use of studied additives for bituminous mixtures. In details, when selecting a High Modulus Base aggregate gradation, the addition of polymeric additives is proved to improve mechanical performances such as modulus and permanent deformation resistance even when using average quality aggregate and less hard bitumen (more easily available in Southern Italy) than those typically used for these special formulations, with beneficial environmental consequences (saving of high quality, not-renewable resources).



## 1. Introduction

Increased heavy vehicle traffic, geometric and weight changes in load transfer systems on the road pavement, together with the widespread tendency to traffic overloaded, have created problems in most existing road pavements. Today the growing demand for performance and the need to protect the ecosystem lead engineers/designers to develop new manufacturing and monitoring technologies, and to experiment the use of new materials, and to improve analysis models as well as design methods of pavements and mixtures. The criterion followed is to promote more rational use of available resources and low environmental impact techniques [1].

For economic and technical reasons, we are currently witnessing a phenomenon of expansion on the market of additives used in the technology of asphalt mixtures. These products are used in order to improve performance and reduce the costs for asphalt pavement production and execution. In general, meeting all these goals with a single product is difficult, because higher quality requires higher costs. The latest researches in this area have resulted in products whose quality increases performance at minimal cost [2].

The incorporation of waste materials and other industrial products as construction materials is also discussed, as being one of the main solutions used by practitioners to respond to society's current sustainability issues. In particular, the introduction of plastic waste

* Corresponding author.
*E-mail addresses:* mauro.ranieri@unipa.it (M. Ranieri), clara.celauro@unipa.it (C. Celauro).

https://doi.org/10.1016/j.conbuildmat.2018.05.126
0950-0618/

in asphalt binders and mixtures is an excellent alternative to landfill disposal [3], because asphalt modification by polymer incorporation can significantly improve the performance of road pavements [4–9].

The demand for superior performance compared to those of traditional asphalt mixtures, the recovery and recycling of existing pavements, the use of new materials combined with new production technologies have given rise to so-called special pavements. These have particular characteristics regarding particle size fractions and high quality materials. This category includes, for example, asphalt mixtures with additives and high modulus asphalt mixtures.

High modulus asphalt mixtures for base (and binder) layers, better known as Enrobé à Module Élevé (EME), were introduced in France in the 1980s with the purpose of maximizing stiffness and fatigue resistance, whilst ensuring that rutting and durability (particularly moisture resistance) requirements were still being met. One of the fastest growing offsets of EME has been urban roads, based on the ability to reduce overall layer thickness as a result of the substantially higher stiffness of the material, while still being able to maintain the same level of performance. This has translated into direct savings in road construction material usage and construction costs. The superior structural properties of high modulus material justify thickness reductions of 25 to 40% compared with conventional French materials [10–12].

The main characteristic of these mixtures is high stiffness, obtained by using specific gradations, hard or very hard bitumens and quite high bitumen content. Due to a limited workability of the mixtures, their use was mostly to be considered in case of very high traffic or when mechanical stability of the bituminous mix is of primarily importance [13,14] (airports, mainly, for strengthening of taxiways and runways).

In essence, EME is hot-mix asphalt consisting of hard bitumen blended at high binder content with good quality, fully crushed aggregates in order to produce a (relatively) fine-graded mix with low air void content. EME is designed to combine good mechanical performance with durability and impermeability when well compacted [10]. It is designed in the laboratory to yield high elastic stiffness, high permanent deformation resistance and high fatigue resistance, whilst also offering good moisture resistance and good workability, which are the four key parameters for long-life pavements. To achieve the required performance, i.e. high stiffness, fatigue resistance, high rutting resistance, resistance to brittle thermal cracking, ageing resistance and workability, appropriate asphalt mix designs were found which resulted in the first set of performance-based specifications NF P 98-140 published by AFNOR in 1992 [15]. Among the key components were the hard special bitumen grades, mostly 10/20 and 15/25 penetration, with characteristics that resulted in compromises between optimized thermal susceptibility and ageing resistance [12].

According to a research project [10] developed in 2007 by the CRR (Centre de Recherches Routieres in Belgium), which takes as its primary reference the French standard NF P 98-140 [15], these mixtures were considered as a possible solution to contrast rutting in Belgium, due to increased heavy traffic. The primary objective of this study was to assess the technological feasibility, in terms of mix design, production and application of these mixtures very well-known abroad, especially in France, the country of origin, and still little used in Belgium. In other words, the aim was to provide the necessary knowledge in the study of the mix design of EME and the correct requirements to be included in the specifications by verifying that it was possible to produce this mixture with the materials commonly used in Belgium [10].

There is doubtless similar interest in application of these mixtures in Southern Italy [16] and in Sicily in particular, where there is not only heavy traffic, but also and above all a warm Mediterranean climate, which is more penalizing – as far as rutting resistance, mainly – than the French and Belgian continental climate. Indeed, the use of EME would be particularly advantageous in warm climates [17].

Although for several years these mixtures have been used in many applications such as highways, urban roads and airport runways, Italian current technical standards does not yet cover the high modulus asphalt. These mixtures are also of particular interest in other countries [11,18–21] such as Australia, United Kingdom, South Africa, Spain, Poland, Morocco and Mauritius.

The aim of this study primarily is to evaluate the feasibility of producing "EME" mixtures not necessarily by using high-performance materials, but – in accordance to environmental and economic sustainability issues- by preferring the use of locally available stone aggregate and bitumen, thanks to proper addition of suitable polymers.

In order accomplish with the above aim, the study is organized into the following main sections: materials, methods, results and discussion and, lastly, conclusions. The materials' section fully provides the characterization of the base materials used in this study. The methods, results and discussion section shortly summarizes the experimental plan, then the experimental results are detailed and discussed, with respect to the objectives of the paper. In the conclusion section, key conclusions are drawn and main contributions are pointed out.

## 2. Materials

The special asphalt mixtures that are the object of this study are known in the technical literature as EME that is, as already mentioned above, high-modulus asphalt mixtures, with good performance both in terms of stability and durability. The materials used to produce these mixtures will detailed in what follows.

### *2.1. Bitumens*

The binders used in this study were a standard neat bitumen (penetration grade 50/70), very commonly available in contexts such as in Southern Italy, and a harder neat bitumen (penetration grade 35/50) in the range of the high modulus bitumen: their characteristics are reported in Table 1. The reason for choosing the 35/50 pen grade bitumen was primarily due to its availability on the local market, compared to even harder pen grade bitumens.

A dynamic mechanical analysis of these binders was conducted with a dynamic shear rheometer (DSR), making it possible to obtain the rheological properties in terms of complex modulus $|G^*|$ and phase angle $\delta$ for a reference temperature of 30 °C, as shown in Fig. 1. These were obtained by frequency sweep tests, in the frequency range between 0.10 and 10 Hz, carried out in strain-controlled mode over a wide range of temperatures, according to the EN 14,770 standard. The tests were carried out using parallel plate geometry, by applying strain amplitudes carefully checked to be within the LVE response of the material, in order to ensure applicability of the time-temperature superposition principle. The testing temperature ranged from −10 °C to 80 °C, while the testing frequency ranged from 0.1 to 10 Hz.

The plate geometries adopted were 8 mm with a 2 mm gap, in the range of testing temperature between −10 and 30 °C, and 25 mm with a 1 mm gap, in the range of testing temperature between 30 and 80 °C.

As expected (see Fig. 1), in the low frequency range 35/50 pen grade bitumen is stiffer and more elastic when compared to the 50/70 pen grade bitumen. At high frequency, the complex modulus master curves coincide, but the phase angle master curves still prove the beneficial contribution of an higher elastic component in the case of the 35/50 pen grade bitumen. This behaviour, in the whole range of service temperature, is the basic reason for preferring the use of low penetration grade binders for production of high-modulus asphalt mixtures, for pavement application when complex modulus is of primary interest and stress relaxation (at low temperatures) is not of concern [22].

### *2.2. Polymeric additives*

The additives used in the study were two commercial products - a polymeric compound of selected polymers (SP) and a polyfunctional polymeric system (PPS) - and a waste plastic (P) recovered after recycling of greenhouse films.

SP is a compound of different polymers having low molecular weight and medium melting point, commercially provided in semi-soft and flexible granules. Approximately, a dosage of 4–8% on weight of bitumen is recommended. PPS is a