Construction and Building Materials 156 (2017) 621–631

Contents lists available at ScienceDirect

Construction and Building Materials

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

Structural analysis of polymer modified bituminous materials in the rehabilitation of light-medium traffic volume roads

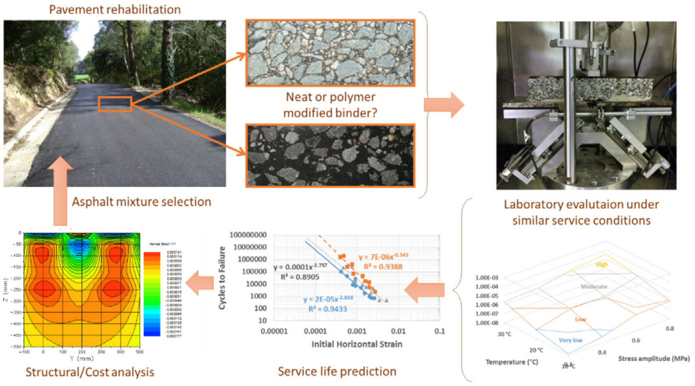
F. Moreno-Navarro *, M. Sol-Sánchez, M.C. Rubio-Gámez

Construction Engineering Laboratory of the University of Granada (LabIC.UGR), Severo Ochoa s/n, 18071 Granada, Spain

HIGHLIGHTS

- Innovative methods are applied to structural analysis polymer-modified bituminous materials (PMBM).
- Empirical results used in layered elastic software to assess PMBM pavements.
- PMBM resulted a solution to rehabilitate light-medium traffic volume roads.
- Results proved that PMBM allows for a reduction of roads overlay thickness.
- PMBM provided more durable structures and rehabilitation solutions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 22 March 2017
Received in revised form 28 August 2017
Accepted 1 September 2017

Keywords:
Fatigue
Bituminous mixtures
Pavement design
Asphalt
Roads
Structure

ABSTRACT

The long-term advantages of using of polymer-modified binders are not commonly observable in traditional tests or pavement design methods. Because of this fact and for economic reasons, their application is limited to high traffic volume roads. This paper examined the structural behaviour of bituminous mixtures used in road surface layers (considering costs and performance), and analysed the viability of using these materials for the rehabilitation of light-medium traffic volume roads. The results demonstrate that polymer-modified materials could be more structurally and economically efficient than unmodified materials, offering a solution to designers for the rehabilitating of light-medium traffic volume roads.

1. Introduction

In recent decades, considerable efforts have been undertaken to develop new asphalt materials that could enhance the performance of road pavements [1–6]. One type of material that has emerged in this regard is polymer-modified binder, which can offer stronger resistance against fatigue cracking, rutting, or thermal effects [7–10]. Nonetheless, their real application is rare, since designers tend to favour the use of traditional asphalt mixtures (manufactured with neat bitumens) when designing the pavement structure.

Many design catalogues or empirical methods have been developed on the basis of experimental observations that are several decades old, and they fail to consider the potential advantages of using polymer modified binders in terms of rutting and fatigue

---

* Corresponding authors.

E-mail addresses: fmoreno@ugr.es (F. Moreno-Navarro), msol@ugr.es (M. Sol-Sánchez), mcrubio@ugr.es (M.C. Rubio-Gámez).

http://dx.doi.org/10.1016/j.conbuildmat.2017.09.006

resistance or thermal susceptibility [11–14]. Moreover, Mechanistic-Empirical (ME) design methods [15,16] could show significant differences between the stress and strain conditions calculated and those actually observed in the field. This discrepancy could lie in the fact that these tests are commonly based on linear elastic mechanic parameters, whilst bituminous materials generally behave in a non-linear and non-elastic manner, as well as in damage initiation and propagation (damage is determined by stress or strain induced at specific locations in the pavement structure, and the majority of ME methods do not provide information on how damage is accumulated) [17,18]. Because of these facts, the reliability of these methods could be restricted to certain conditions such as when designing layers of limited thickness manufactured with polymer modified binders (which have a low elastic modulus), since ME methods would provide optimal structural solutions with a greater thickness than in the case of other mixtures that offer lower performance but higher modulus. Thus, from the designing stage, the use of bituminous mixtures manufactured with polymer modified binders is limited (as their production costs cannot be compensated by reducing the thickness of the layers), and their application has traditionally been restricted to the construction of high volume traffic roads.

In the last years, road pavement maintenance has emerged as an important issue for road administrators, since the profitability of the investments in these infrastructures is directly related to the success of the rehabilitation program. It is worth noting that the road network in developed countries is primarily composed of light-medium traffic volume roads (secondary or regional roads). To illustrate, in 2011 these roads represented around 94% of the paved roads in France, 77% in Germany, 84% in Italy, 89% in Spain, and 70% in the UK (the countries with the most extensive road networks in Europe) [19]. Thus, effective strategies for the rehabilitation of these types of roads will be of critical importance in the coming years. In this regard, the use of polymer modified bituminous materials is an alternative that should be considered, since the latter could help to maximize the service life of the existing structure whilst also using a layer of reduced thickness.

Given this possibility, the main aim of the work presented in the current paper is to compare polymer modified bituminous asphalt layers with traditional materials in terms of both structural resistance and long-term performance. For this purpose, the structural behaviour of some of the most common bituminous mixtures used in road surface layers worldwide has been studied (comparing their results in terms of economy and performance). Their mechanical response was evaluated in the laboratory using the UGR-FACT method [20], and the information obtained was then used to assess the impact of the thickness of the layers on their structural behaviour using two layered elastic computer programs.

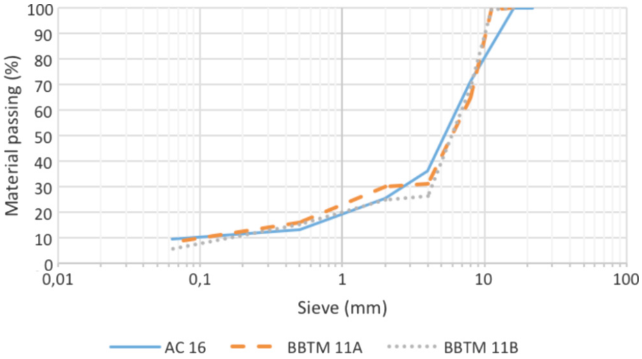


Fig. 1. Grain size curves of the mineral skeletons used in the manufacture of the mixtures.

Table 1
Properties of the binders used in the manufacture of the mixtures.

Property	Bituminous binders		
	B1	PMB-1	PMB-2
Type of modifier	–	SBS	SBS
Softening Point (°C, EN 1427 [23])	53.2	61.2	68.4
Penetration at 25 °C (mm/10, EN 1426 [24])	57	55	62
Elastic recovery (%, EN 13398 [25])	9	83	91

2. Methodology

2.1. Materials

Three different asphalt mixtures for surface layer were used during this study. One of them, the AC 16 mixture [21], was considered as the reference material, since it is traditionally used worldwide as a surface layer in the rehabilitation of light-medium traffic volume roads. This mixture has a continuous graded mineral skeleton (Fig. 1). The aggregates used for the manufacture of the AC 16 mixture were ophite in the coarse fractions (12/18 mm and 6/12 mm), limestone in the fine fraction (0/6 mm), and calcium carbonate in the filler fraction. The bituminous binder used for the manufacture of this mixture was a conventional binder B1, whose main characteristics are summarised in Table 1. Based on the Spanish requirements for the design of these materials [22], the optimal bitumen content selected was 5% over the total weight of the mixture. The main properties of the mixture AC 16 are shown in Table 2.

In order to compare the mechanical behaviour of the traditional surface layer AC 16, two mixtures manufactured with polymer modified binders were studied: BBTM 11A and BBTM 11B [32]. Both mixtures have a gap-graded mineral skeleton (Fig. 1), and they are commonly used in surface layers of high volume traffic roads and highways. The main differences between them is that the BBTM 11B has a slightly lower content of fine fractions (sand and filler) in order to provide a better macro-texture (to ensure better adherence with the tyre [33]) and a higher air void content (to improve the permeability of the layer, and to remove rainwater from the surface layer). The nature of the aggregates used for the manufacture of the BBTM mixtures was the same as that used for the AC 16 mixture (in order to minimise the impact of variables that could affect the outcome of the study). The mixtures were manufactured with two different polymer modified bitumens (PMB-1 for the BBTM 11A and PMB-2 for the BBTM 11B, Table 1). The optimal bitumen content selected for these after the study of several job mix formulas was 5.5% for the BBTM 11A and 5% for

Table 2
Properties of the mixtures studied.

Properties	AC 16	BBTM 11A	BBTM 11B
Type of Bitumen	B1	PMB-1	PMB-2
Bitumen Content (% over the total weight of the mixture)	5.0	5.5	5.0
Bulk Density (g/cm^3, EN 12697-6 [26])	2.392	2.395	2.112
Air Voids (%,EN 12697-8 [27]))	4.3	4.1	16.5
Indirect Tensile Strength at 15 °C (kPa, EN 12697-23 [28])	2158	1769	1392
Indirect Tensile Strength Ratio (%, EN 12697-12 [29])	93	92	91
Wheel Tracking Slope at 60 °C (mm/10^3 load cycles, EN 12697-22 [30])	0.10	0.03	0.06
Stiffness at 20 °C, rise time value 124 ± 4 ms (MPa, EN 12697-26, C [31])	6249	4284	2421