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Effects of polymer additives on bituminous mixtures

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HIGHLIGHTS

- Constructability and volumetric characteristics are not affected by polymers.
- Polymers are analogous (or better) to modified bitumen, in terms of modulus.
- Polymers reduce temperature and frequency susceptibility of bituminous mixtures.
- Bituminous mixtures fatigue life is improved by using polymer additives.
- The addition of polymers improves the rutting resistance of bituminous mixtures.

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ABSTRACT

The laboratory investigation described in this paper focuses on the effects of polymers as additives for bituminous mixtures. Three dosages (3%, 6% and 9% by weight of bitumen) of EVA and LDPE polymers were used. The investigation was divided into two main phases. The first one focused on a comparison between mixtures to which polymers were added and a modified bitumen-bound mixture. The comparison was performed by observing constructability, volumetric and mechanical performances (e.g. dynamic moduli). The second phase aimed at evaluating the effects of such polymers on the performance of the corresponding mixtures at in service temperatures by means of simulative tests concerning stiffness master curves, fatigue life and rut resistance. In the second phase, the modified bitumen-bound was not investigated. Both phases also include investigations on a standard bitumen-bound mixture. Results of the first phase revealed that polymers guarantee the same, if not better, performances than modified bitumen on the corresponding bituminous mixtures. Results of the second phase showed that polymers increase the mixtures' performances at in-service temperatures. In particular, polymers reduce mixtures' Stiffness at low temperatures, increase fatigue life at intermediate temperatures and reduce rutting deformations at high temperatures.

1. Introduction

In recent decades, the ever-increasing traffic volume on transportation infrastructures (e.g. roads and airports) has brought about the need to produce high quality materials for construction, rehabilitation and maintenance operations. In the field of flexible pavements, in which bituminous mixtures are the most important material in terms of their structural and functional performance, this requirement is currently satisfied through the use of polymer-modified bitumen as the binder [1–6]. In other words, bitumen modification is a technique in which a certain type and dosage of polymers is added to the binder in order to improve its viscoelastic characteristics. Modified bitumen is produced prior to the manufacturing of the bituminous mixtures. It is important to note that, as they are unstable materials, modified bitumens require refineries with high quality equipment for their manufacture. Therefore, it is clear that in some parts of the world, such as in developing countries, it would be very difficult to produce and use such modified binders, even though, in these countries, infrastructures are those most subjected to traffic volume growth.

For all these reasons, another technology, based on the use of additives, has been recently developed. Unlike modifier agents, additives aim to obtain the required pavement performance, working not on the binder but on the bituminous mixtures. In fact, polymers can be added directly during the production of the bituminous mixture. As for previous studies on the topic, over the last decade works of other researchers have been devoted to highlight the effects of additives on porous wearing courses [7] or on dense grade bituminous mixtures by focusing on a restricted number of

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performances, such as dynamic moduli [8,9], rutting [10,11], fatigue [12].

Within the framework described above, a research study was carried out in the Road Research Laboratory of Politecnico di Milano, with the aim of understanding the effects of polymers on the performances currently required to dense grade bituminous mixtures. To this end, the goals of the investigation were:

- comparing polymers-added bituminous mixtures with a modified bitumen-bound mixture;
- evaluating the effects of polymers on the performances of the corresponding mixtures at in service temperatures.

According to the goals described above, the investigation was divided into two main phases.

During the first phase, the comparative investigation was performed by measuring constructability parameters (e.g. self-compaction and workability), volumetric characteristics (e.g. air voids, voids in the mineral aggregates, and voids filled with bitumen), and mechanical performance (e.g. dynamic moduli). The second phase included simulative mechanical tests concerning stiffness master curves in a temperature ranging from −5 °C up to 30 °C, fatigue life at 20 °C, and the rut resistance at 60 °C.

This paper provides an overview of the results obtained and describes some details of the specific protocols followed during the research project.

2. Experimentation

2.1. Key materials

The composition of asphalt mixtures was determined according to the current specifications for binder courses provided by the Italian Road and Highways Administration (ANAS). Therefore, a single particle-size distribution of aggregates (Fig. 1) and a single value of bitumen content (%B equal to 4.0% by weight of mixture) for all the mixtures were chosen.

The key materials used in the study were natural calcareous aggregates provided by a local contractor, a standard 70/100 penetration, unmodified bitumen [13], a 4% SBS modified bitumen (50/70–60 according to the European Specifications [13]) and a calcareous filler (filler/bitumen ratio equal to 1.1). In line with technical literature [14], preliminary viscosity tests were performed on the two bitumens and results showed a mixing/compaction temperature equal to 150/140 °C for the standard bitumen and 170/160 °C for the modified one, respectively.

During the experimentation, two polymers were utilized for comparison: the first one was made of amorphous polyolefin with a low molecular weight and a low fusion point, belonging to the family of EVA (ethyl-vinyl-acetate), herein named polymer A, while the second was mainly composed of LDPE (low density polyethylene), named polymer B. More specifically, polymer B is a compound made of LDPE, EVA and other polymers with a low molecular weight and a medium fusion point. Polymers are provided as small pellets, workable at room temperature, in order to be easily stored or added directly into the mixing chamber during the production of the bituminous mixture. Fig. 2 shows the flexible semi-soft granules at room temperature, while Table 1 reports the basic physical properties of both polymers.

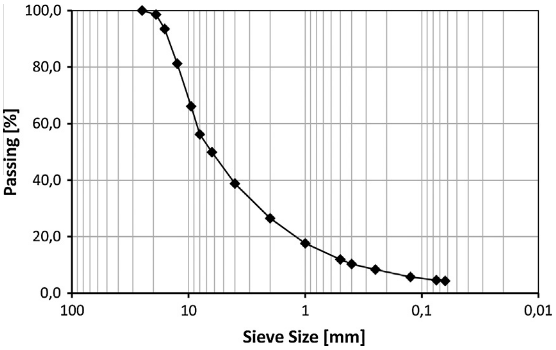

Fig. 1. Gradation of the aggregates.

2.2. Experimental program

As mentioned above, the investigation herein described consisted of two main phases.

Phase 1 involved eight bituminous mixtures prepared in the lab: a modified bitumen-bound mixture (named M-BM), a standard bituminous mixture made by using the 70/100 unmodified bitumen (named BM), three mixtures incorporating polymer A and three containing polymer B. Dosages were fixed at 3%, 6% and 9% by weight of 70/100 unmodified bitumen. In this paper, these mixtures are identified by an alphanumeric code formed by the acronym of the mixture (BM) followed by the polymer identification (A or B) and the dosage (3%, 6% or 9%); e.g., the code of a bituminous mixture containing 3% of polymer A will be BM-A-3%.

Mixing operations were performed using a lab mixer, obtaining 60 kg per time. Mixing procedures were performed and verified according to Authors' previous experience [15,16] in order to obtain a reasonable homogeneity of the mixtures.

Specimen compaction was carried out by using a Gyratory Shear Compactor (GSC), according to the protocol specifications defined within the Strategic Highway Research Program [17] (1.25° gyration angle, 30 rev min^{-1} gyration speed, 600 kPa vertical pressure, 150 mm mold diameter). A minimum of three cylindrical specimens for each mixture were compacted at 100 gyrations of GSC. During the GSC compaction, self-compaction C_1 and workability k parameters were measured. These parameters are currently used by pavement engineers to quantify the compaction properties and consequently to compare different mixtures, as proven by previous investigations [18,19]. Furthermore, all GSC compacted specimens were compared using both a volumetric characterization, including the analysis of voids (%v), voids in the mineral aggregate (VMA) and voids filled with bitumen (VFB), and the measure of the dynamic modulus at 20 °C, according to the EN 12697-26 Annex C [20].

Based on the results obtained during Phase 1, which will be described in Section 3.1, Phase 2 aimed at evaluating the individual effects of each type and dosage of polymers on the corresponding mixtures, without considering the mixture bound with modified bitumen, investigating a total amount of seven mixtures. To this end, simulative mechanical tests were performed. Roller compactor slabs (500 × 260 × 50 mm) were prepared imposing a target air void equivalent to that obtained during the first phase. The equipment employed included a prismatic mold on which a series of metal plates was set. The compaction energy was transferred by means of two twin steel wheels moving horizontally over the plates (kneading compaction, EN 12697-33) [21]. The slabs were used both to measure rutting resistance (EN 12697-22 [22]) and to obtain beams (prismatic specimens) for four point bending tests (Stiffness according to EN 12697-26 Annex B [19] and fatigue resistance according to EN 12697-24 Annex D [23].

The Stiffness of the mixtures was determined by performing four point bending tests (4-PBT) with a minimum of three prismatic specimens for each mixture. Each specimen was tested in a controlled-strain mode, imposing a strain level of 50 micro-strain at four different temperatures (−5, 10, 20, 30 °C) and seven frequency levels (0.5, 1, 2, 4, 6, 8, 10 Hz). The applied load was a symmetric sinusoid in order to impose equal deformations on the upper and lower faces of the prismatic specimen.

The values collected at all temperatures and different loading frequencies were used to obtain the master curves of the dynamic modulus by following the numerical method proposed by AASTHO [24], which applies temperature shift factors (α_T) based on the theory of Arrhenius.

In this regard, a nonlinear least squares regression was performed in order to minimize the summed square error (SSE) between the estimated values (taken from the model) and the experimental ones. The calibration of the model base was carried out using the Solver function of a self-made spreadsheet.

In order to quantify the fatigue resistance, the samples were tested under four-point bending (the same applied to determine dynamic modulus) in a strain-controlled mode at a strain level of 300 micro-strain, imposing a haversine wave at a frequency of 10 Hz. All tests were carried out at 20 °C using a minimum of three specimens. Two failure criteria were established: the number of cycles after which a 50% reduction of the initial dynamic modulus occurs (recorded after one hundred cycles) or, if necessary, a maximum of 1.5 million cycles.

Wheel tracking tests were performed to determine the rutting resistance of mixes at 60 °C. According to this method, a rubber wheel moves across the 500 × 260 × 50 mm slab at speed of 37 passes/min, applying a repetitive load (700 N) for 10,000 passes. The final Rut Depth (RD) in dry conditions and the WTS (Wheel Tracking Slope) were measured according to the European Standard EN 12697-22 part B, in air [23].

3. Results and discussion

3.1. Phase 1: comparative investigation

In Figs. 3–5 the average results related to constructability parameters, volumetric characteristics and mechanical performances are shown as a function of the type and dosage of polymers, including those of the two reference mixtures (BM and