Effect of hyper-modified asphalt binder on wearing course mixtures cracking behaviour

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ABSTRACT

This paper presents a laboratory investigation aimed at evaluating the effect of employing hyper-modified asphalt binders in surface asphalt courses in terms of cracking resistance. Two different Hot Mix Asphalt (HMA) surface layers were investigated: an Open Graded Friction Course (OGFC) and a full-graded blend. Two different asphalt binders were employed: a highly modified binder composed by 6% of a traditional SBS polymer and an experimental hyper-modified binder composed by 7.5% of an innovative SBS polymer. Both natural aggregates and steel slags were used for asphalt mixture design. The cracking behaviour of the mixtures at intermediate temperatures were evaluated using a visco-elastic fracture mechanics-based cracking model entitled HMA Fracture Mechanics. The cracking behaviour of the mastics at intermediate temperatures was also investigated using a Modified Direct Tension Test (MDTT), together with a Digital Image Correlation (DIC) system. The results showed that the hyper-modified binder provides better performance than the traditional hard modified one when used in OGFC mixes. Conversely, no significant differences were observed in the results obtained from full-graded mixes.

Keywords: wearing course, hyper-modified asphalt binder, cracking, digital image correlation

1. INTRODUCTION

One of the most critical issues in flexible pavement design is to identify the most suitable material for providing the performance required for the specific course. In particular, the choice of suitable materials for a correct design of mixtures for surface layers is of fundamental importance to guarantee resistance and durability to the entire pavement. As discussed by many authors [1-4], the asphalt mixture cracking behaviour is closely correlated to the properties of the mastic of which it is composed, and consequently to the characteristics of the filler, asphalt binder and their interaction. Modified binders are often used to obtain mixtures that offer greater performance in terms of resistance to fatigue and rutting phenomena.

The present study focused on the evaluation of the effects of hyper-modified asphalt binders on the mechanical performance of two types of mixtures for surface layers: an Open Graded Friction (OGFC) mixture, called Micro B, and a full-graded mix, called SMA. Two different asphalt binders were employed: a highly modified binder and an experimental hyper-modified binder. Mixtures were composed by both traditional aggregates and steel-slags.

The cracking performance of the mixtures at intermediate temperature were evaluated using the visco-elastic fracture mechanics-based cracking model “HMA Fracture Mechanics” [5]. According to this model, only five tensile mixture properties, easily obtainable from the Superpave Indirect Tensile Test (IDT), are required to control the cracking performance of asphalt mixtures. They are the tensile creep rate as represented by the power law creep compliance relationship (m-value), the resilient modulus, the creep compliance, the dissipated creep strain energy to failure (DCSEf) and the total energy to fracture (FE). The cracking behaviour of the mastics at intermediate temperatures was investigated using a Modified Direct Tension Test (MDTT) developed by Montepara et al. [6]. Strain localization and damage distribution were observed using an in-house developed DIC software code, called DICe, which was completely re-designed from the first DIC code developed by Birgisson et al. [7]. Finally, a rutting test was performed on mixture slabs, in order to evaluate the influence of the two type of SBS polymer-modified binders on pavement permanent deformations.

2. MATERIALS

Two types of mixtures for wearing courses were investigated: an Open Graded Friction (OGFC) mixture, called Micro B, and a full-graded blend, called SMA (Splittmastix Asphalt). The mechanical characterization of the mixtures was evaluated according to the mix composition, varying aggregates and binder types. Two different highly modified asphalt binders were used: binder S, composed by 6% of a traditional SBS polymer, and binder K composed by 7.5% of an innovative SBS polymer. OGFC and SMA mixtures were 12.5-mm nominal maximum size prepared using the same aggregate type, consisting of both natural and synthetic aggregates. Natural aggregates were composed by limestone, marly limestone and calcarenite, while the synthetic ones derive from the processing of black slag from the steelworks. The filler employed was obtained by grinding carbonate rocks. Four different mix designs were performed for evaluating the optimum binder content according to the different aggregate gradation and aggregate composition, resulting in 5.2% for Micro B composed by natural aggregates, 3.3% for Micro B composed by both natural and synthetic aggregates, 6.2% for SMA composed by natural aggregates and 4.5% for SMA composed by both natural and synthetic aggregates. To label the mixtures an acronym was associated at each material; a detailed description of the mixtures is given in Table 1.

Acronym	Mixture	Aggregate	Binder
MNS	Micro B	Natural	S
MNK	Micro B	Natural	K
MSK	Micro B	Natural and Steel Slag	K
SNS	SMA	Natural	S
SNK	SMA	Natural	K
SSK	SMA	Natural and Steel slag	K

TABLE 1 Description of the asphalt mixtures

3. EXPERIMENTAL METHODS

3.1 Asphalt Mixture Cracking Behaviour: HMA Fracture Mechanics

The cracking behaviour of asphalt mixtures was evaluated according to the visco-elastic model "HMA Fracture Mechanics" developed at the University of Florida [5], which introduces the concept of the existence of an energy threshold as a key parameter for the interpretation of the cracking mechanism in asphalt mixtures. This concept is based on the observation that micro-damage, i.e. damage not associated with the initiation and propagation of the fracture, is totally healable, while macro-damage, i.e. the formation of a real fracture, is irreversible. Based on this model, five properties of the material were identified to define its performance in terms of cracking resistance and permanent deformation accumulation. These parameters are obtained from three tests in indirect tensile configuration according to the Superpave IDT procedure [8]:

The resilient modulus is a non-destructive test to measure the elastic stiffness of the material. It is defined as the ratio of the applied stress to the recoverable strain when repeated loads are applied. The Resilient Modulus and the Poisson coefficient are calculated using equations developed on the basis of a finite element analysis.

The creep test is a non-destructive test used to determine the creep compliance and associated parameters. Creep compliance is defined as the ratio of the time-dependent strain over stress; thus, it is related to the ability of a mixture to relax stresses. Since it well represents the time-dependent behaviour of asphalt mixture, it is commonly used to evaluate the rate of damage accumulation of asphalt mixtures. The slope of the creep compliance curve at 1000 seconds is a measure of the rate of permanent deformation: the higher the slope, the higher the rate of permanent deformation.

The strength test is a destructive test used to determine the failure limits of asphalt mixtures, including tensile strength, failure strain and fracture energy. Tensile strength is the maximum tensile stress the mixture can withstand before a not-healable macro-crack occurs while failure strain is the horizontal strain at tensile strength. Energy-based parameters are easily determined from the stress-strain response of a tensile strength test, as discussed by Roque et al. [5]. Fracture Energy (FE) density is the energy per unit volume required to fracture a mixture and it is determined as the area under the stress-strain curve at first fracture, while Dissipated Creep Strain Energy (DCSE) at failure is defined as the fracture energy minus the elastic energy at the time of fracture.

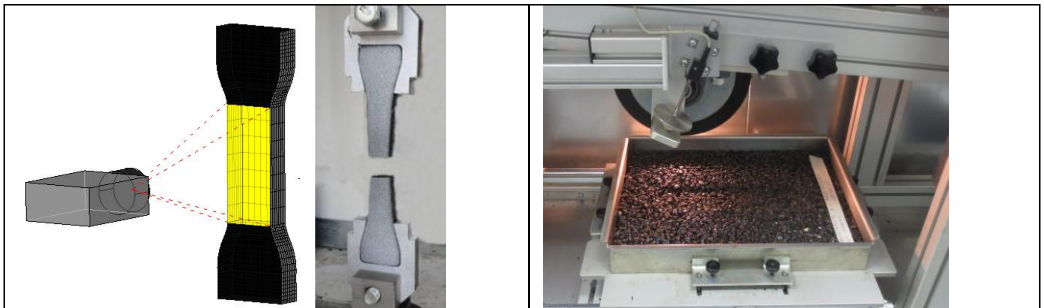
3.2 Asphalt Mastic Cracking Behaviour: Modified Direct Tension Test (MDTT)

The cracking behaviour of the mastics was investigated using a Modified Direct Tension Test (MDTT) developed on purpose, to identify crack initiation and interpret mastic fracture response at intermediate temperature. All the details can be found elsewhere [6]. MDTT tests were performed at 10°C using an MTS closed-loop servo-hydraulic loading system. The specimen was fixed at one end and pulled from the other end applying a constant stroke of 1.68 mm/sec until rupture occurs [6].

Failure is defined as the point on the stress-strain curve where the load reaches its maximum. The rapid loading rate and the interpretation of the test only up to fracture allow for a continuum representation. Strains were obtained from DICe system, interpolating all the strain values of the grid points located at the 46x20 mm specimen central cross-sectional area. MDTT test configuration is shown in Figure 1a.

3.3 Asphalt mixture's rutting resistance: Wheel Tracker

The wheel tracker consists in a wheel equipped with a hard rubber tyre (200 mm in diameter) which transmits a load of 700 ± 10 N on an asphalt mixture slab 300x400 mm in size and 30 mm thick placed on a mobile support which moves forwards and backwards horizontally (230±5 mm @53Hz). The all equipment is located inside a climatic chamber to assure a controlled test temperature of 60°C ± 1.0°C. A LVDT measures the rut depth at the centre of the slab (deformation greater than 0.1 mm). The slabs were prepared according to UNI EN 12697-33 and compacted using the Roller Compactor. The test configuration is shown in Figure 1b.



1.a) MDTT Configuration | 1.b) Wheel Tracker

FIGURE 1. Test Configurations

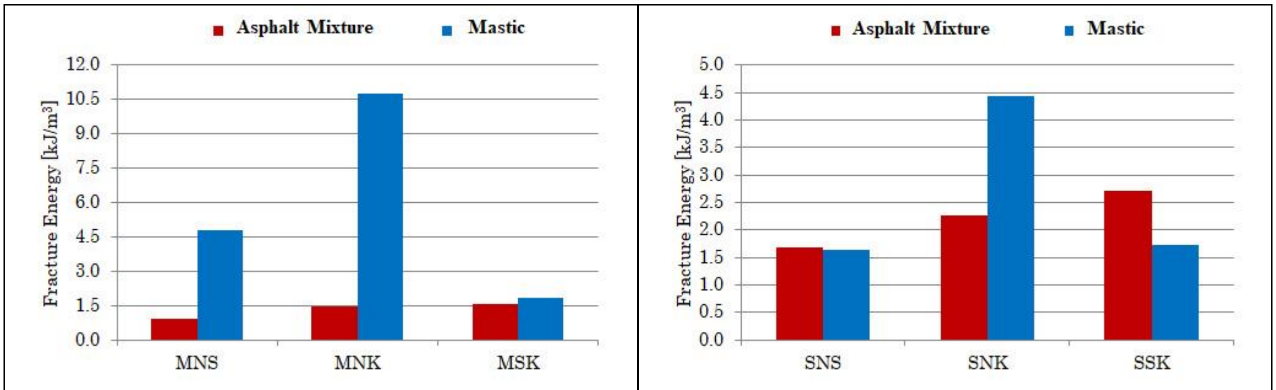
4. RESULTS AND DISCUSSION

Results of the Superpave IDT are summarized in Table 2. The Resilient Modulus is an indicator of the elastic stiffness of the material. Looking at the results, it is evident that this parameter is not influenced by the type of asphalt binder but rather by the nature of the aggregates: in fact, the presence of steel-slags in the Micro B asphalt mixture increases the Resilient Modulus by about 18%.

The results of the fracture tests show that both asphalt mixtures and mastics composed by asphalt binder K have higher tensile strength and fracture energy than those composed by bitumen S (Fig. 2a-2b). However, it should be noted that in the case of SMA mixture, steel-slags also contribute significantly to the increase in performance (Fig. 2b).

Asphalt Mixture	Resilient Modulus [Gpa]	EE [kJ/m^3]	$DCSE_f$ [kJ/m^3]	$DCSE_{min}$ [kJ/m^3]	Tensile Strenght [Mpa]	Fracture Energy [kJ/m^3]	Failure Strain (strain)	Energy Ratio
MNS	11.54	0.09	0.82	1.62	1.37	0.91	1293.65	0.53
MNK	11.97	0.12	1.35	1.01	1.71	1.47	1384.5	1.62
MSK	14.39	0.11	1.47	0.7	1.74	1.58	1489.58	4.18
SNS	18.52	0.16	1.52	0.6	2.42	1.68	1105.19	2.56
SNK	16.48	0.21	2.05	0.51	2.63	2.27	1401.33	4.69
SSK	16.86	0.26	2.46	0.47	2.96	2.72	1562.68	5.63

TABLE 2. Superpave IDT Results



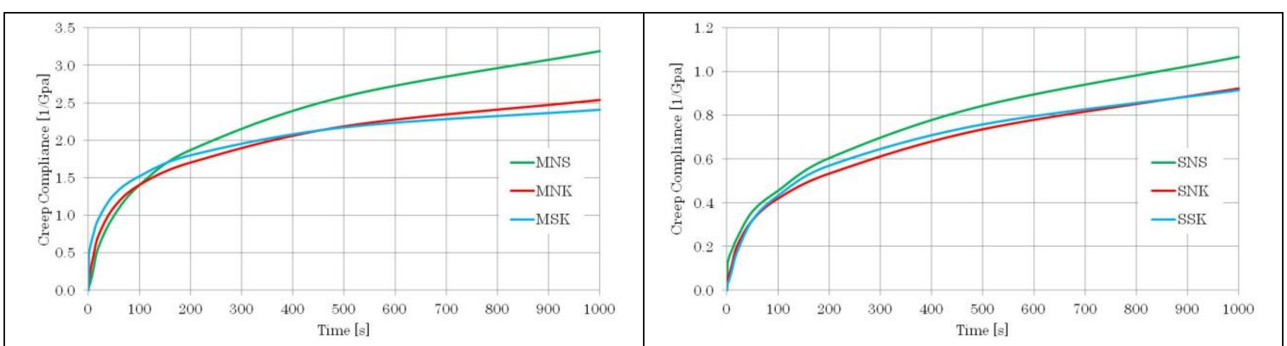
2.a) Micro B 2.b) SMA

FIGURE 2. Fracture Energy of Asphalt Mixtures and Binders

The results of the creep and rutting tests on the Micro B mixture have shown how the combination of bitumen K and steel-slags decreases permanent deformations, in fact at a higher creep corresponds a higher deformation obtained with the wheel tracker. On the other hand, the results obtained on SMA mixture have shown that it is not only the presence of binder K that decreases the tendency to accumulate permanent deformations, but also the presence of steel-slags (Table 3). In both cases, observation of the rutted slabs have shown no clear damage, either in term of stripping or ravelling. Figures 3a and 3b show creep compliance curves for the two mixes.

Mixture	Creep Compliance [1/Gpa]	Max Deformation [mm]	Mixture	Creep Compliance [1/Gpa]	Max Deformation [mm]
MNS	3.19	2.86	SNS	1.07	1.7
MNK	2.54	2.67	SNK	0.92	1.33
MSK	2.41	1.5	SSK	0.91	1.42

TABLE 3. Creep and Rutting Results



3.a) Micro B 3.b) SMA

FIGURE 3. Creep Compliance Curves of Asphalt Mixtures

5. CONCLUSIONS

The present study has highlighted how two hyper-modified asphalt binders influence differently the mechanical performance of asphalt mixtures Binder K (7.5% of innovative SBS polymer) has shown to perform significantly better in terms of tensile strength and fracture resistance than bitumen S (6% traditional SBS polymer) when used for a OGFC mixture. The results obtained for the full-graded blend have, on the other hand, shown that the presence of binder K does not give any benefits that could justify the use of one asphalt binder rather than the other. In addition, it was shown that in both types of surface mixtures, the use of steel-slags provides an increase in the cracking resistance of the mixture while allowing a decrease in the percentage of bitumen in the mixture. This brings benefits from both an economic and environmental point of view, since the recycling of synthetic aggregates avoids exploiting natural resources.

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