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Road and Rail Infrastructure III

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MOISTURE DAMAGE AND LOW TEMPERATURE CRACKING OF MODIFIED BITUMINOUS MIXTURES FOR ROAD PAVEMENTS

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Abstract

This paper presents an experimental evaluation of moisture damage and low temperature cracking behavior of three bituminous mixtures (Stone Mastic Asphalt, wearing course and base course asphalt concretes), made with steel slag aggregate and different asphalt binders (hard and soft polymer modified bitumen as well as crumb rubber modified bitumen). The asphalt concretes, designed with the traditional Marshall procedure, were tested under aged and unaged conditions. Indirect Tensile Strength Test were used in order to characterize the mixes. The experiments demonstrate that bitumen modified with crumb rubber (from scrap tires), allows to re-use a large amount of steel aggregate (up to 93%, depending on the mixes), with satisfactory results in terms of moisture and low temperature cracking resistance, also in the aged conditions.

Keywords: moisture damage, low temperature cracking, steel slag, crumb rubber, modified bitumen, road pavement

1 Introduction

Moisture damage, as well as thermal cracking at low temperatures, are relevant degradation phenomena that affect the durability and the service life of bituminous mixtures, used for road flexible pavements. The moisture damage resistance of a bituminous mixture is influenced by the content of bitumen and its adhesion to the grains of the lithic skeleton, as well as by the porosity of the asphalt concrete. Binder's rheological properties, especially the ductility, affect the low temperature cracking resistance of the mix.
The paper discusses the results of a laboratory testing concerning the moisture damage and the low temperature resistance of bituminous mixtures (Stone Mastic Asphalt – SMA and traditional ones) for base courses and wearing courses, made with Electric Arc Furnace (EAF) steel slag and three different bituminous binders, modified with fine crumb rubber or SBS polymers. Both aged and unaged samples were tested, in order to investigate the ageing effects.

2 Materials

2.1 Binders

Three different bitumens were used in the experiment for each mixture: Crumb Rubber Modified Bitumen (CRMB), as well as hard and soft SBS polymer modified bitumen (HPMB and SPMB respectively). The fine crumb rubber modified bitumen, as well as the hard and soft polymer modified bitumen, were produced in different private companies' industrial plants.

The asphalt rubber derived from the wet process technology [1]. In this paper, the presence of crumb rubber, hard and soft modified polymers in the mixtures is evidenced by the subscript “ar”, “hm”, “sm” next to the mixture acronym.

2.2 Aggregates

Two granular materials were used in the study: EAF slag and limestone filler. The slags utilized are the main by-product of steel production based on the electric arc furnace (EAF) technology [2]. The EAF slags were supplied by a steel mill in northern Italy, while the limestone filler derived from a quarry in the same area; the steel slags were available in three different fractions: 0/4, 4/8 and 8/14 mm.

2.3 Mixtures

Three mixes were designed: a Stone Mastic Asphalt mix (SMA), a Wearing Course Asphalt concrete (AC W) and a Base course Asphalt Concrete (AC B). The study of the grading curves was referred to the grading envelopes set by SITEB – Italian Society of Bitumen Technologists [3].

3 Methods

3.1 Mix design procedure

The Marshall procedure (EN 12697-34 Standard) was used for determining the optimal binder content. The mixes characterised by maximum bulk density, maximum Marshall Stability, a voids content of 4% for SMA, 5% for AC W, 6% for AC B, were considered optimal. The mechanical performances of the mixtures formulated in this way, were further verified by means of the indirect tensile strength test at 25°C (EN 12697-23 Standard).

3.2 Performance test programme

The performance approach has great relevance in order to properly promote the use of industrial by-products, as outlined also by other Authors [4, 5], therefore the resistance to moisture damage and to thermal cracking have been evaluated, for the asphalt concretes investigated. Indirect tensile strength test at 25°C on wet cylindrical samples have been performed on the nine asphalt concretes optimized in the mix design procedure, in order to investigate the moisture damage resistance. The specimens prepared by Marshall compactor, were furthermore subjected to indirect tensile test at 0°C, in order to evaluate the low temperature cracking. Some of the specimens were exposed to accelerated long-term ageing, by means of conditioning in an oven at 85 °C for 5 days [6], in order to evaluate the effect of seasoning on the mechanical properties of the mixtures and any benefits produced by the bitumen modified with crumb rubber, compared to binders modified with polymers.

4 Results and discussion

4.1 Materials characterization

Table 1 reports the conventional engineering properties of the three bitumens used in the mixes. The elastic recovery data have been certified by the bitumen manufacturer. The crumb rubber modified bitumen, compared to the polymer modified binders, presented improved properties, in terms of penetration (- 24%) and softening point R&B temperature (+ 16%), particularly with respect to the soft modified bitumen. The ductility (evaluated according to the Italian standard) resulted adequate for all the binders.

Table 1 Bitumen characterization

Properties	Standard	CRMB	HPMB	SPMB
Penetration [mm/10]	EN 1426	45	52	59
Softening point [°C]	EN 1427	82	77	71
Ductility [cm]	CNR 44/74	over 100	over 100	over 100
Fraass breaking point [°C]	EN 12593	- 15	- 14	- 12
Elastic Recovery [%]	EN 13398	> 50	> 50	> 50

According to Italian Law, EAF slags are non-hazardous, special non-toxic and non-noxious refuse. They are a solid material, greyish in colour and with no particular smell; the pH is 10.7. By an X-ray fluorescence analysis, it can be observed that the slags contain a prevalence of FeO (33%) and CaO (29%), as well as SiO_2 (13%), and Al_2O_3 (9%). The SiO_2/CaO ratio characterizes the EAF slag as a substantially alkaline aggregate and therefore suitable to guarantee the necessary adhesion with the weakly acid bitumen.
Table 2 reports the physico-mechanical properties of the steel slags, plus the test protocols adopted. A direct test of the volumetric stability of the EAF slags, according to the Standard EN 1744/1 part 15.3, showed an expansion null after the 168 hours suggested in the test protocol. The steel slags demonstrated an excellent affinity with the bitumen, with no stripping of the grains coated with binder after 24 hours of immersion in water at 25 °C (Italian Standard CNR 138/92). This property obviously greatly enhances the durability of the bituminous mixtures.

Table 2 Physical and mechanical characteristics of EAF slags

Properties	Standard	EAF slag 0/4 mm	EAF slag 4/8 mm	EAF slag 8/14 mm
Los Angeles coefficient [%]	EN 1097-2	-	16	14
Equivalent in sand [%]	EN 933-8	86	-	-
Shape Index [%]	EN 933-4	-	1.9	2.9
Flakening Index [%]	EN 933-3	-	4.2	6.4
Freeze/thawing [%]	EN 1367-1	-	0.1	0.1
Fine content [%]	EN 933-1	2.7	0.0	0.0
Grain density [Mg/m^3]	EN 1097-6	3.757	3.719	3.685
Water absorption [%]	EN 1097-6	0.510	0.307	0.112
Stripping in water [%]	CNR 138/92	0	0	0

4.2 Grading and composition of the mixes

Table 3 reports the grading composition of the bituminous mixtures and proportions of the components, while the grading curves of the mixes are presented in Figure 1; the total amount of steel slag was 89%, 92%, 93% for AC B, AC W and SMA respectively. The nominal maximum aggregate size was 15 mm for the SMA and AC B, 10 mm for the AC W.

Table 3 Aggregate type and composition of the mixtures

Mix composition	Fraction [mm]	Quantity [%]		
		SMA	AC W	AC B
EAF steel slag	0/4	45	70	50
	4/8	22	12	13
	8/14	22	10	30
Filler (additive)	–	11	8	7

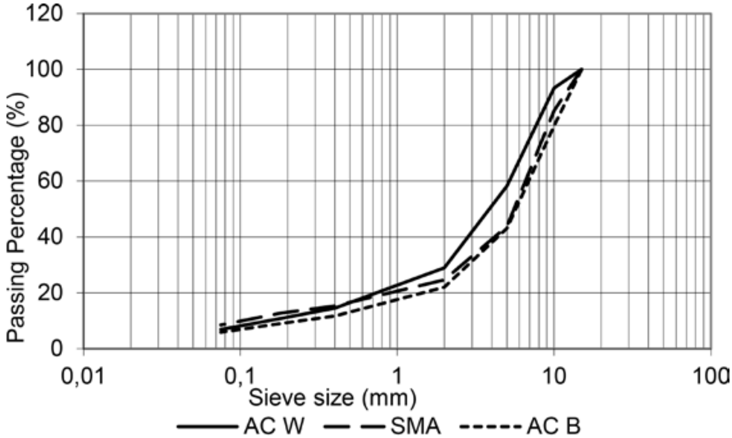

Figure 1 Design grading curves of the mixtures

4.3 Optimization of the mixture

Table 4 reports the Marshall mix design results, along with the Optimum Bitumen Content (OBC) and the Indirect Tensile Strength (ITS) values, of the bituminous mixtures.

Table 4 Mix design results

Mixtures	OBC [%]	VMA [%]	VFB [%]	Bulk density [g/cm³]	MS [daN]	MQ [daN/mm]	ITS [MPa]	ITS (post ageing) [MPa]
SMA/ar	6.0	23.5	82.9	3.306	1,986	482	2.35	2.38
SMA/hm	6.0	23.3	82.8	3.277	1,580	455	2.17	2.23
SMA/sm	6.0	23.1	82.7	3.248	1,324	405	2.04	2.14
AC W/ar	5.0	21.3	76.5	3.338	2,203	523	1.63	1.67
AC W/hm	5.0	21.2	76.4	3.307	1,551	507	1.55	1.62
AC W/sm	5.0	21.0	76.2	3.275	1,530	462	1.46	1.58
AC B/ar	4.0	19.0	68.5	3.325	1,295	450	1.57	1.64
AC B/hm	4.0	18.9	68.3	3.292	1,164	393	1.38	1.48
AC B/sm	4.0	18.7	68.0	3.258	1,222	336	1.23	1.38

For all the mixes the requisites fixed by the Italian Road Technical Standards [3] were guaranteed, with Marshall Stability (MS) and Quotient (MQ) higher than 1,100 daN and 300 daN/mm for AC B, 1,200 daN and 350 daN/mm for AC W, 1,000 daN and 350 daN/mm for SMA. The additional requisite for the SMA, relative to a minimum ITS value equal to 0.6 MPa, was completely satisfied, thus demonstrating the acceptability of these mixtures for road construction. Moreover, for SMA mixes a percentage of Voids in the Mineral Aggregate (VMA) higher than 17% [7] and a percentage of Voids Filled with Bitumen (VFB) between 75% and 85% [1] are needed, whilst for AC W and AC B mixes the requirement is a VMA percentage higher than 15% [8]. According to data in Table 4, all the volumetric requisites are verified for the designed mixes. The mixes with crumb rubber modified bitumen showed better Marshall results as well as ITS values, than the corresponding asphalts with SBS polymer modified binders. All the mixtures presented slightly higher ITS values after the ageing conditioning (up to 12% more than the unaged mix, depending on the asphalt concrete type), even if the hardening phenomenon affects significantly the SBS mixtures more than the crumb rubber asphalts.

4.4 Resistance to moisture damage

The damage caused by the immersion in water is expressed by the Tensile Strength Ratio (TSR). It has been computed as the ratio between the indirect tensile strength of the specimens treated by means of 15 days of immersion in a thermostatic bath at 25 °C (ITS_{wet}) and untreated (ITS_{dry}), respectively. Table 5 presents the ITS_{wet} and the TSR values, for the mixtures studied.

Table 5 Moisture damage – Indirect tensile strength and TSR values

Mixtures	ITSwet [MPa]	ITSwet (post ageing) [MPa]	TSR [%]	TSR (post ageing) [%]
SMA/ar	2.24	2.32	95	97
SMA/hm	1.90	2.06	88	92
SMA/sm	1.73	1.94	85	91
AC W/ar	1.46	1.50	89	90
AC W/hm	1.28	1.36	83	84
AC W/sm	1.17	1.29	80	82
AC B/ar	1.36	1.43	86	87
AC B/hm	1.07	1.18	78	80
AC B/sm	0.94	1.07	76	78

The mixtures made with crumb rubber modified bitumen were clearly characterized by the less pronounced moisture susceptibility, as it is demonstrated by the highest TSR values computed, also in conditions of post-ageing. However it should be stressed that all the asphalts have shown a reasonable resistance to moisture damage. In fact, the limit value of the TSR below which a bituminous mixture may present problems of stripping, usually equal to 70% [1], has been overcome by all the asphalts.

4.5 Resistance to thermal cracking

Materials damage can be expressed by strain energy density function, according to the following relation [9]:

$$\frac{dW}{dV} = \int_{0}^{\varepsilon_0} \sigma_{ij} d\varepsilon_{ij} \tag{1}$$

where:

σ_{ij} stress;
ε_{ij} strain.

In the indirect tensile test, the area under the stress–strain curve, computed for the peak stress and the corrispondent peak strain, represents the critical value of dW/dV. The critical value of dW/dV at 0°C can be used to estimate the resistance to low temperature cracking [9]. The low temperature cracking test results, namely the peak strain and the critical value of dW/dV, determined for the indirect tensile tests performed at 0°C on the mixtures studied, are presented in Table 6.
The crumb rubber asphalt concretes were characterized by higher peak strain and critical values of dW/dV, with respect to the correspondent polymer modified mixes (increments of dW/dV of up to 117%, depending on the mixture type), thus demonstrating an improved ductility at low temperature and therefore a greater resistance to thermal cracking. The beneficial effect of the crumb rubber modified bitumen is relevant also for the mixtures in conditions of post-ageing.

Table 6 Low temperature cracking test results

Mixtures	Peak strain [%]	Critical value of dW/dV [kJ/m³]	Peak strain (post ageing) [%]	Critical value of dW/dV (post ageing) [kJ/m³]
SMA/ar	1.76	94.74	1.52	72.72
SMA/hm	1.65	72.53	1.12	35.87
SMA/sm	1.42	43.66	0.99	34.77
AC W/ar	1.26	67.00	1.15	58.97
AC W/hm	1.09	39.13	1.07	30.49
AC W/sm	0.93	35.07	0.91	29.32
AC B/ar	1.21	51.83	1.10	49.70
AC B/hm	1.07	35.48	0.90	28.58
AC B/sm	0.89	28.88	0.67	27.66

5 Conclusions

The experimental investigation, conducted on bituminous concretes of the SMA, AC W, AC B type (all made with EAF steel slags), has demonstrated the clearly better performance of the crumb rubber mixtures compared with those of similar type but made with SBS polymer modified bitumen. The results are relevant for the moisture damage resistance, but they are really significant in terms of low temperature cracking resistance. The worst performance have been always recorded for the soft polymer modified mixtures. The effectiveness of the crumb rubber modified bitumen in the increase of moisture damage and low temperature resistance was relevant also for the mixtures in conditions of post-long term ageing. There is a full agreement in the ranking of the mixes, between the different performance tests used in the investigation, namely moisture damage and low temperature cracking tests.

References

[1] Chiu, C. & Lu, L.: A laboratory study in stone matrix asphalt using ground tire rubber, Construction and Building Materials, 21, pp. 1027–1033, 2007.

[2] Liapis, I. & Likoydis S.: Use of electric arc furnace slag in thin skid-resistant surfacing, Procedia – Social and Behavioral Sciences, 48, pp. 907-918, 2012.

[3] Capitolato d'appalto per pavimentazioni stradali con bitume modificato, SITEB, Roma, 2000 [in Italian]

[4] Correira, A.G., Roque, A.J., Ferreira, S.M.R. & Fortunato, E.: Case study to promote the use of industrial byproducts: the relevance of performance tests, ASTM Special Technical Publication, 1540 STP, pp. 267-293, 2012.

[5] Xie, J., Chen, J., Wu, S., Lin, J,. Wei., W.: Performance characteristics of asphalt mixture with basic oxygen furnace slag, Construction and Building Materials, 38, pp. 796-803, 2013.

[6] Artamendi, I., Allen, B,. Phillips, P.: Influence of temperature and aging on laboratory fatigue performance of asphalt mixtures, Advanced Testing and Characterization of Bituminous Materials conference, Rhodes, pp. 185-194, 2009.

[7] National Asphalt Pavement Association, Guidelines for materials, production, and placement of stone matrix asphalt (SMA), Technical Working Group (TWG), Publication N. IS 118, 1994.

[8] Asphalt Institute, Superpave Level 1 Mix Design, Superpave Series N. 2, USA, 1995.

[9] Wu, S., Xue, Y., Ye, Q. & Chen, Y.: Utilization of steel slag as an aggregate for stone mastic asphalt (SMA) mixtures, Building and Environment, 42, pp. 2580-2585, 2007.