Use of Modified Reclaimed Asphalt in Warm Mixtures

G. Ferrotti, Francesco Canestrari, J. Xiaotian, and Fabrizio Cardone

Abstract Warm Mix Asphalt (WMA) has the advantage over conventional Hot Mix Asphalt (HMA) of reducing pollutant emissions and energy costs. The use of WMA technologies can be fruitfully coupled with the addition of Reclaimed Asphalt (RA) improving asphalt mixture performance. However, this aspect needs to be investigated in more detail. In this regard, this paper focused on the optimization and performance investigation of a dense graded modified asphalt mixture for wearing courses, produced with WMA technology and percentages of RA up to 25%. Two WMA mixtures with two contents of RA were prepared by using a chemical additive. The results were also compared with an HMA control mixture produced with a lower RA content. Shear gyratory compacted specimens were used for a series of laboratory tests to evaluate the performance. The study of stiffness, water sensitivity, permanent deformation and fracture characteristics pointed out that appropriately designed WMA mixtures with RA can be produced without penalizing the performance with respect to the control mixture.

Keywords Warm mix asphalt · Reclaimed asphalt · Stiffness · Permanent deformation · Cracking

1 Introduction

Because of the great both economic and environmental benefits, the use of Reclaimed Asphalt (RA) has gained popularity. However, the stiff binder released by RA aggregates, especially when modified RA is considered, restricts its maximum amount allowed in Hot Mix Asphalt (HMA) due to the risk of mixtures with a reduced workability and more prone to some pavement distresses [1]. In this sense, Warm Mix Asphalt (WMA) technology can represent an effective technical solution for avoiding the downsides of high RA content. Indeed, the reduction of production

G. Ferrotti (✉) · F. Canestrari · J. Xiaotian · F. Cardone
Università Politecnica delle Marche, Ancona, Italy
e-mail: g.ferrotti@staff.univpm.it

H. Di Benedetto et al. (eds.), *Proceedings of the RILEM International Symposium on Bituminous Materials*, RILEM Bookseries 27,
https://doi.org/10.1007/978-3-030-46455-4_240

temperatures by 20–40 °C induces lower bitumen aging, thus mitigating the stiffening effect of the aged bitumen from RA and not penalizing the workability of the mixture [2]. Despite this benefit, additional concerns are related to the presence of Polymer Modified Bitumens (PMB) especially if both virgin and RA bitumens are polymer modified. Indeed, possible interactions between virgin and aged polymer chains as well as WMA additives may modify the rheological behavior of binder phase compromising the performance of the mixtures [3–5].

Given this background, the objective of this research is to evaluate the feasibility of using percentages of modified RA up to 25%, in WMA mixtures prepared with a modified bitumen. A laboratory mechanical characterization, also carried out on a conventional recycled HMA, allowed the potentialities of WMA technology combined to recycling techniques to be evaluated.

2 Experimental Program

Virgin (limestone, basalt, calcareous filler) and modified RA aggregates were used to produce the aggregate blends. The bitumen content of RA ($D_{max} = 5$ mm) was 8.1% by aggregate weight and the recovered bitumen had a penetration of 21 dmm and a softening point of 81 °C. An SBS polymer modified bitumen classified as PmB 45/80-70 was selected as the binder. A chemical WMA additive available on the market, having an alkyl-amide polyamines-based composition and characterized by a density at 25 °C of 0.94 g/cm^3, a flash point higher than 150 °C and a viscosity at 25 °C of 150 cP, was chosen.

Three dense-graded bituminous mixtures for wearing course were investigated: two WMAs and one HMA mixture as reference. The grading curves of the three asphalt mixtures were different and designed according to the Italian technical specifications for road construction [6]. The mixtures were coded as:

WMA-20-3.7, containing 20% RA, 3.7% added binder and 5.1% total binder;
WMA-25-3.7, containing 25% RA, 3.7% added binder and 5.5% total binder;
HMA-15-4.6, containing 15% RA, 4.6% added binder and 5.6% total binder.

The WMA mixtures were mixed and compacted at 130 °C and 120 °C respectively, whereas the HMA mixture were mixed and compacted at 170 °C and 160 °C, respectively.

For each mixture a series of cylindrical specimens (D = 100 mm) were prepared by means of a gyratory compactor to the same target air voids content (equal to 5%). Specimens were then subjected to a mechanical characterization in terms of Indirect Tensile Strength (ITS), water sensitivity (Indirect Tensile Strength Ratio—ITSR), stiffness (Dynamic Modulus |E*| and Indirect Tensile Stiffness Modulus—ITSM), fatigue (Indirect Tensile Fatigue Test—ITFT) and rutting resistance.

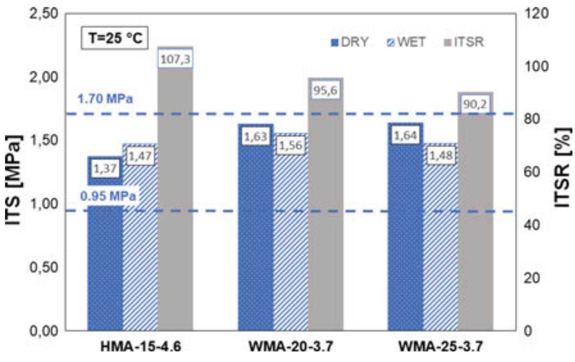


Fig. 1 ITS and ITSR results

3 Results and Discussions

3.1 Indirect Tensile Strength (ITS) Test and Water Sensitivity

ITS test was performed at 25 °C, according to EN 12697-23. Six replicates were performed for each mixture, three in dry condition and three in wet condition, where the conditioning was performed according to EN 12697-12 (Method A). The Indirect Tensile Strength Ratio (ITSR) value was calculated as ratio between the ITS values in wet and dry conditions. Figure 1 shows the average ITS and ITSR values for all the investigated mixtures. In both dry and wet conditions, the ITS values of WMA mixtures are higher than the reference HMA and satisfied the local technical specification requirements (0.95 < ITS < 1.70). However, WMAs show a slightly lower moisture resistance, especially for higher RA contents.

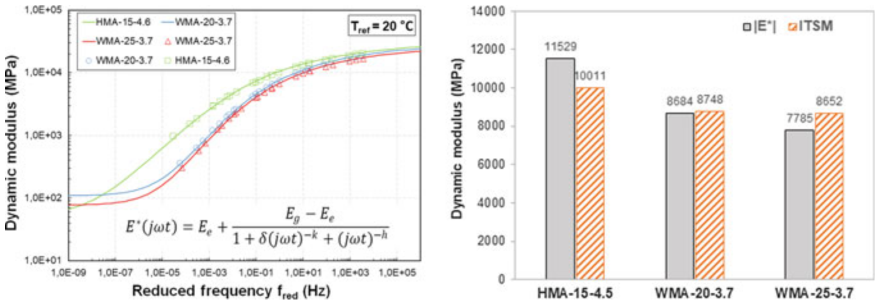
3.2 Stiffness

Dynamic complex modulus was measured to evaluate the stiffness of mixtures, at 4 temperatures (from 5 to 50 °C) and 6 frequencies (from 0.1 to 20 Hz) by means of Asphalt Mixture Performance Tester (AMPT). Two replicates were performed for each mixture.

The Huet–Sayegh (HS) model [7] was used to fit the frequency dependency of the dynamic modulus |E*| and the Williams-Landel-Ferry (WLF) equation [8] was used to model the shift factor trend with temperature. The dynamic modulus master curves of all mixtures at $T_{ref} = 20$ °C are shown in Fig. 2a and the parameters of HS (E_g, E_e, k, h, δ, t) and WLF ($C1$ and $C2$) models are listed in Table 1. It can be observed that both WMA mixtures showed lower dynamic moduli with respect to the reference HMA, over the entire range of loading frequency. This is mainly imputable to the less oxidation effects that WMA mixtures experienced during the lower temperature production process. Therefore, compared to the reference HMA

Table 1 HS and WLF model parameters

	E_g (MPa)	E_e (MPa)	k (−)	h (−)	δ (−)	t (s)	$C1$ (−)	$C2$ (°C)
HMA-15-4.6	32182	50	0.138	0.389	2.002	0.822	22.9	166.5
WMA-20-3.7	28015	109	0.184	0.503	2.405	0.322	18.3	138.5
WMA-25-3.7	25109	77	0.192	0.513	2.52	0.36	15.4	117.1



a) b)

Fig. 2 Dynamic modulus master curves of mixtures at T_{ref} = 20 °C (**a**), ITSM versus |E*| @ 2 Hz at 20 °C (**b**)

mixture, the WMAs showed a significantly reduced stiffening effect mainly due to aging. Moreover, both WMA mixtures showed a similar trend for the master curves, highlighting the prevalent role of aging rather than RA content on the development of stiffness properties.

Stiffness properties were also measured by the ITSM at 20 °C, according to EN 12697-26. Figure 2b reports the comparison between the ITSM values and the dynamic moduli identified in the master curves at the same temperature (20 °C) and frequency (2 Hz–comparable with the rise time of 124 ms) of the ITSM tests. Figure 2b shows that ITSM results are consistent with the dynamic modulus data obtained through uniaxial compression test, confirming lower stiffness of both WMA mixtures compared to the reference mixture.

3.3 *Rutting Performance*

Rutting resistance of mixtures was determined by performing cyclic compression tests at 60 °C, according to EN 12697-25. Two replicates were performed for each mixture. A cyclic axial stress with an amplitude of 0.3 MPa and a steady confining pressure of 0.2 MPa were adopted during the entire test (10,000 load cycles). The cumulative axial strain of the specimen was recorded and the creep curve was built.

The creep rate f_c (i.e. slope of the least square linear fit of the quasi linear part of the creep curve) and the permanent deformation after 1000 load cycles ε_{1000}

Table 2 The rutting parameter results

Mixture	f_c (μstrain/cycle)	ε_{1000} (%)
HMA-15-4.6	0.081	0.834
WMA-20-3.7	0.044	0.53
WMA-25-3.7	0.048	0.423

(i.e. deformation calculated from the least square power fit of the quasi linear part at 1000th cycle) were used to characterize the rutting potential of the mixtures. Specifically, the lower the value of these parameters, the higher the rutting resistance of the mixture.

The average values of the rutting parameters of WMA mixtures, shown in Table 2, are remarkably lower than those of the reference mixture, indicating that WMA mixtures exhibited higher rutting resistance. These results highlight that despite the mitigated stiffness due to the reduced production temperature, the WMA mixtures would not experience any permanent deformation accumulation risk in the early period of their service life.

3.4 *Fatigue Performance*

ITFT was carried out at 20 °C according to the British standard BS DD ABF (1997). During the test, the number of loading cycles was recorded until the complete failure of the specimen was obtained.

Three initial strain levels (100, 125 and 150 με) were selected for each mixture and the corresponding stresses to be applied were calculated by using the ITSM values (Fig. 2b) measured before the fatigue tests. Two specimens were tested for each strain level. The ITFT results are shown in Fig. 3, where the initial horizontal strain $\varepsilon_{h,initial}$ is plotted as a function of the number of loading cycles to failure N_f. Test data were analyzed according to a power law regression and the fatigue curve

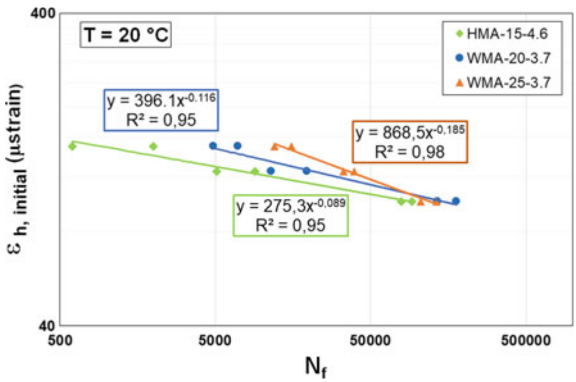


Fig. 3 Fatigue curve of mixtures at 20 °C

(i.e. $\varepsilon_h = a \cdot N_f^{-b}$) was reported for each mixture. The obtained high R^2 values (> 0.95) for all mixtures indicate good reliability to predict fatigue life by using this fitting model. From the analysis of fatigue curves, it can be noted that, at high and medium strain levels, WMA mixtures can withstand higher numbers of loading cycles than the reference one, highlighting a better fatigue behavior for WMA mixtures; whereas, at low strain levels, comparable behaviour is expected between WMAs and HMA. These results are consistent with the stiffness analysis, which suggests that the higher stiffness of the reference mixture could result in a more brittle tendency. Moreover, the comparison between WMA mixtures shows that a higher RA content results in a slightly higher fatigue resistance, especially at higher strain level.

4 Conclusions

This paper focused on the performance analysis of dense graded recycled WMA mixtures for wearing courses produced with different modified RA amounts (20 and 25%) and an SBS modified bitumen. The mixtures were analyzed in terms of strength and stiffness properties, moisture susceptibility, rutting and fatigue behavior by testing gyratory compacted specimens.

Compared to a conventional recycled HMA, the investigated WMA mixtures showed:

- higher strength properties in both dry and wet conditions but a higher moisture susceptibility that tends to increase with the increase in RA content;
- lower stiffness properties and higher fatigue resistance. This finding highlights that lower production temperatures (i.e. WMA technologies) reduce short-term aging effects leading to stiffness mitigation as well as improved fatigue performance. The increase in RA content did not affect the stiffness of WMAs but allowed the achievement of higher fatigue resistance;
- significantly higher rutting resistance despite lower stiffness properties. Besides, no RA content effect on the rutting behavior was observed.

Overall, the outcomes of this experimental investigation strongly supported the practical use of percentages of modified RA, up to 25%, in WMA mixtures prepared with a modified bitumen.

Acknowledgements This research was sponsored by ASFALTI s.r.l. This support is greatly acknowledged. Data analysis and opinions are those of the Authors and do not necessarily reflect those of the sponsoring agency.

References

1. Capitão, S.D., Picado-Santos, L.G., Martinho, F.: Pavement engineering materials: review on the use of warm-mix asphalt. Constr. Build. Mater. **36**, 1016–1024 (2012)
2. Zaumanis, M., Mallick, R.B.: Review of very high-content reclaimed asphalt use in plant-produced pavements: state of the art. Int. J. Pavement Eng. **16**(1), 39–55 (2015)
3. Stimilli, A., Virgili, A., Canestrari, F.: Warm recycling of flexible pavements: Effectiveness of Warm Mix Asphalt additives on modified bitumen and mixture performance. J. Clean. Prod. **156**, 911–922 (2017)
4. Stimilli, A., Frigio, F., Sciolette, S., Canestrari, F.: In-plant production of warm recycled mixtures produced with SBS modified bitumen: A case study. In Proceedings of the AIIT International Congress on Transport Infrastructure and Systems, TIS 2017, pp. 143–151. Taylor and Francis Group, London (2017)
5. Ragni, D., Ferrotti, G., Lu, X., Canestrari, F.: Effect of temperature and chemical additives on the short-term ageing of polymer modified bitumen for WMA. Mater. Des. **160**, 514–526 (2018)
6. ANAS S.p.a.: Capitolato Speciale di Appalto – Norme Tecniche: Pavimentazioni stradali/aeroportuali. Rev. 24/04/2009, Ente Nazionale delle Strade (2009)
7. Sayegh, G.: Viscoelastic properties of bituminous mixtures. In Proceedings of the 2nd International Conference on Structural Design of Asphalt Pavements, Washington, D.C. (1967)
8. Ferry, J.D.: Viscoelastic Properties of Polymers. Wiley, New York (1961)