Field-scale production validation of Warm Mix Asphalt containing Crumb Rubber for motorway porous wearing course

S. D'Angelo, F. Cardone, G. Ferrotti, F. Canestrari
Università Politecnica delle Marche, via Brecce Bianche 12, 60131 Ancona (Italy)

F. M. Colasanti
Autostrade per l'Italia, via A. Bergamini 50, 00159 Rome (Italy)

ABSTRACT: Warm Mix Asphalt (WMA) technology in combination with crumb rubber (CR) from end-of-life tires (ELTs) can lead to a sustainable low environmental impact solution, while enhancing mechanical and acoustic performance of asphalt pavements. As part of a broader project, including a preliminary laboratory investigation, this research aims at evaluating the technical feasibility of WMAs modified with CR by dry process for porous wearing courses. Large-scale production and field trial on motorway section were conducted to assess the performance of the selected mixtures according to the Technical Specifications for the Italian motorway network. The experimental investigation included volumetric and workability analyses, mechanical tests and surface characterization on both laboratory specimens and cores taken from the field trial. The results show that when the CR content is lower than a critical amount no specific precaution has to be undertaken at production plant and during lay-down activities in order to guarantee satisfying workability, mechanical and surface properties.

1 INTRODUCTION

Warm Mix Asphalt (WMA) Technology has gained increasing attention in recent years as a sustainable alternative to traditional hot mix asphalt (HMA) (Milad et al. 2022). WMA is produced at temperatures 20-40 °C lower than HMA, resulting in reduced fuel consumption and greenhouse gas emissions during production and paving operations (Ferrotti et al 2024). Additionally, the lower mixing temperatures of WMA can lead to improved working conditions and longer hauling distances.

To enhance pavement performance and address environmental concerns related to tire disposal, the incorporation of crumb rubber (CR) from end-of-life tires (ELTs) into asphalt mixtures has also been explored. Furthermore, CR can improve the acoustic performance of pavements by reducing traffic noise (Puccini et al. 2019).

Combining WMA technology with CR presents a promising approach to produce environmentally friendly and high-performance asphalt mixtures (Wang et al. 2018). The reduced production temperatures of WMA minimize the degradation of CR particles, potentially improving the overall performance of the modified asphalt (Yu et al. 2018). Several studies have investigated the laboratory performance of WMA-CR mixtures, demonstrating their potential in terms of mechanical properties, workability and surface characteristics (Ziari et al. 2018). Additionally, the synergy between WMA and CR can further reduce the environmental impact by lowering the higher airborne emissions and energy consumption associated with CR handling. Moreover, it enhances the use of recycled materials (Picado-Santos et al. 2020). It has also been shown that this technology is promising when porous asphalt mixtures are considered. In fact, the rubber particles can improve durability and noise reduction properties of porous mixtures (Cetin 2013).

The purpose of this research, which is part of a wider project that started with a preliminary comprehensive laboratory characterization (D'Angelo et al. 2024), is to evaluate the technical feasibility of large-scale production of WMA-CR mixtures for Italian motorway network applications. The in-plant production of porous mixtures, the construction of a trial section and the performance assessment according to Italian motorway technical specifications were carried out.

2 EXPERIMENTAL RESEARCH

2.1 *Materials*

This research is focused on two rubberized semi-porous warm asphalt mixtures, previously optimized (D'Angelo et al. 2024) and produced with 6.5% polymer modified bitumen (PmB) and 1.5% or 2.0% CR from ELTs added by dry method (coded as

M1.5_plant and M2.0_plant, respectively). The PmB, classified as 45/80-70 and with a dynamic viscosity of 0.40 Pa·s at 160 °C, contains 4% SBS polymers. The CR, from truck tires, has a grain size of 300 to 600 µm.

The aggregate gradation of both WMAs included virgin basaltic aggregate which was proportioned to obtain a gap-graded structure ensuring an air voids content higher than 15% as well as a certain tire/road noise reduction. Additionally, 0.3% cellulose fibers (by aggregate weight) were added to prevent bitumen draindown, and 0.45% WMA chemical additive (by bitumen weight) was used for guaranteeing suitable mixing at a production temperature of 130 °C. Both WMA-CR mixtures were produced at a batch plant near the jobsite to avoid long hauling time.

2.2 *Trial section*

To evaluate the workability, the mechanical performance and the surface properties of the rubberized WMA mixtures, a trial section was built at the movement area of Calenzano tollbooth on the Italian A1 motorway. The test section (100-meter long and 10-meter-wide) consisted in laying the two warm semi-porous mixtures with CR at 120 °C, in contiguous lanes. The construction operations included milling the existing pavement to a depth of 4 cm, cleaning the milled surface and applying a tack coat.

During resurfacing activities, the loose asphalt mixtures were taken from trucks for laboratory analysis. Two weeks after paving, cores (100 mm and 225 mm diameter) and slabs (500×500 mm^2) were taken from both trial section lanes and subjected to innovative tests for the evaluation of surface properties.

2.3 *Methods & experimental program*

According to the Italian motorway technical specifications, the loose mixtures were used to produce 100 mm-diameter specimens through a gyratory compactor (50 revolutions) or a Marshall equipment (50 blows on each side), depending on the test to be performed. The compaction temperature was kept constantly at 120 °C for all compaction methods.

The workability of the mixtures at 85% of the theoretical maximum density was assessed by calculating the Compaction Energy Index (CEI) from the gyratory compactor data, (Mahmoud & Bahia 2004). Strength properties were evaluated on gyratory specimens through Indirect Tensile Strength (ITS) test at 25 °C (EN 12697-23), while raveling resistance was assessed on Marshall specimens through Cantabro Test at 25 °C (EN 12697-17). Mechanical characterization was performed on both dry-conditioned (at 25 °C for 72 hours in a climatic chamber) and wet-conditioned specimens (at 40 °C for 72 hours in a water bath, followed by 3 hours at 25 °C in a climatic chamber, as per EN 12697-12) to evaluate the water sensitivity of the mixtures through the Indirect Tensile Strength Ratio (ITSR).

Surface properties were studied on the extracted slabs through innovative testing equipment, the Darmstadt Scuffing Device (DSD) (De Visscher & Vanelstraete 2016) and the Wehner-Schulze (WS) machine Canestrari et al. 2024). The DSD, in accordance with CEN/TS 12697-50, simulates raveling caused by shear and normal stresses of a tire on an asphalt specimen. Tests were conducted at 40 °C on both dry (72 hours in a climatic chamber at 40 °C) and wet (72 hours in a water bath plus 3 hours in a climatic chamber at 40 °C) conditioned slabs, rectified at 260×260 mm^2. Raveling resistance was evaluated by calculating the Mass Loss per Area (MLpA) parameter after 30 double thrust cycles.

The WS machine is equipped with specific units to first simulate the polishing effects due to the traffic loading and then measure the corresponding friction offered by the specimen surface which was properly wetted. The output data allows the calculation of friction after polishing (µFAP) at various intervals of polishing passes on 225 mm-diameter cores (EN 12697-49), conditioned at 20 °C. The μFAP_{60} of each core is determined as the friction value at 60 km/h, derived from the characteristic 6^{th} order polynomial of the fitted curve.

The overall experimental program, carried out on the two rubberized semi-porous warm asphalt mixtures (M1.5_plant and M2.0_plant), is summarized in Table1. Moreover, the testing results obtained in this trial section were compared with those of the preliminary laboratory characterization, detailed in D'Angelo et al. 2024 coded as M1.5_lab and M2.0_lab.

Table 1. Number of specimens tested.

Mixture	CEI	ITT*	Cantabro*	DSD*	WS
M1.5_plant	10	5+5	5+5	2+2	2
M2.0_plant	10	5+5	5+5	2+2	2

* Dry + wet conditioned specimens.

3 RESULTS AND DISCUSSION

3.1 *Workability and mechanical performance*

Figure 1 shows that the volumetric characteristics (air void AV content) and CEI values of the two plant-produced mixtures are very similar, with minimal deviation. Thus, the different percentages of CR do not affect the workability and the AV of the plant-produced mixtures, while meeting the technical specification limit (AV@50girations≥15%). Compared with the lab-produced mixtures, the plant-produced mixtures show a slightly penalized aptitude for compaction (higher CEI values), resulting in higher AV content.

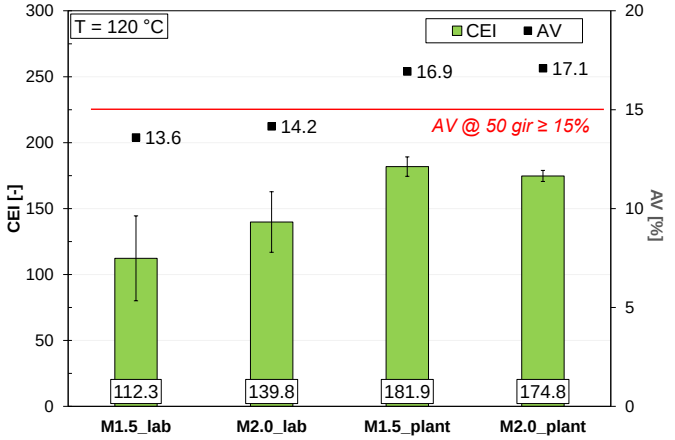

Figure 1. Workability (CEI) and volumetric characteristics (AV) of plant- and lab-produced mixtures, and Italian Motorway Technical Specification limit.

Figure 2 indicates that the increase in the CR content in both plant- and lab-produced mixtures results in lower average ITS values. The lower ITS of the plant-produced mixtures as compared with laboratory mixtures can probably be attributed to the higher AV content (Figure 1). This means that the CR effect, combined with the volumetric structure of the specimen, results in a penalized resistance of the plant-produced mixtures with respect to the technical specification requirements.

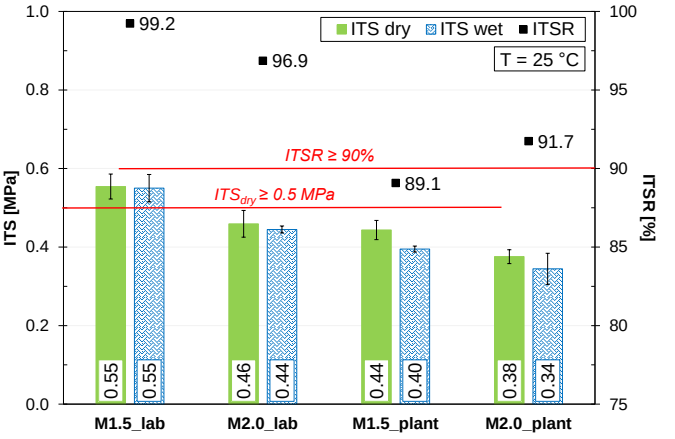

Figure 2. ITS and ITSR values of plant- and lab-produced mixtures, and Italian Motorway Technical Specification limit.

As regards the ITSR values, Figure 2 shows acceptable water susceptibility of plant-produced mixtures, which substantially meet the Technical Specification limit. The comparison between dry and wet conditions shows that plant mixtures have reduced water resistance compared to lab data, likely due to higher AV content (Figure 1) which promotes the water action.

Figure 3 shows Cantabro test results in terms of Particle Loss (PL), whose lower values result in higher raveling resistance.

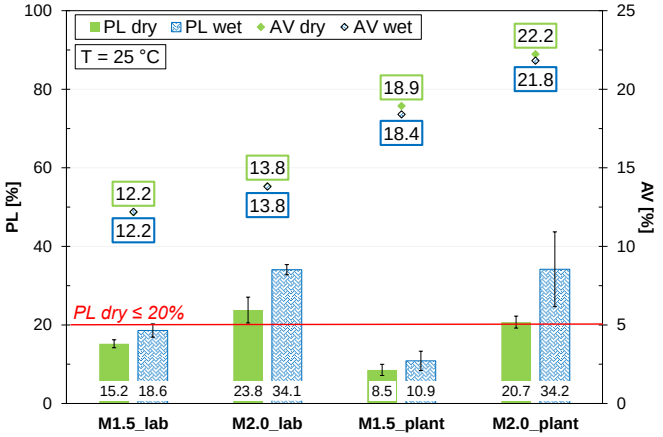

Figure 3. Raveling resistance in terms of PL and AV of plant- and lab-produced mixtures, and Italian Motorway Technical Specification limit.

Figure 3 indicates that for both plant- and lab-produced mixtures, the PL value increases with the AV and the CR content increase, in both dry and wet condition. Moreover, the plant-produced mixtures show better resistance to raveling than the lab ones and fully meet the Italian Motorway Technical Specification limit (PL dry $\leq$ 20%) especially for the M1.5_plant mixture.

3.2 *Surface properties*

The raveling resistance of the warm rubberized mixtures was also investigated with the DSD test and expressed as Mass Loss per Area (MLpA), whose lower values result in higher raveling resistance. Figure 4 shows that the higher the CR amount, the higher the MLpA value, consistently with Cantabro test results (Figure 3) in both dry and wet condition. Moreover, the mixtures with lower CR amount seem to be less sensitive to water effect with improved raveling resistance for wet with respect to dry condition. Similarly to other test findings, the higher average AV content characterizing the cores from the trial section as compared to the lab ones results in a lower raveling resistance of the plant-produced mixtures.

The WS tests on dry-conditioned cores allowed the pavement friction, expressed as μFAP_{60}, to be measured for the studied mixtures. Figure 5 shows the average μFAP_{60} at 20 °C versus the number of polishing cycles, for both plant mixtures and for a reference hot mix (HP_ref) without CR, currently used on Italian motorway network, reported for comparison purpose. The results indicate that both plant-produced mixtures provide comparable friction values throughout all polishing cycles, with no significant differences. This suggests that increasing the CR content from 1.5% to 2.0% does not negatively affect pavement friction.

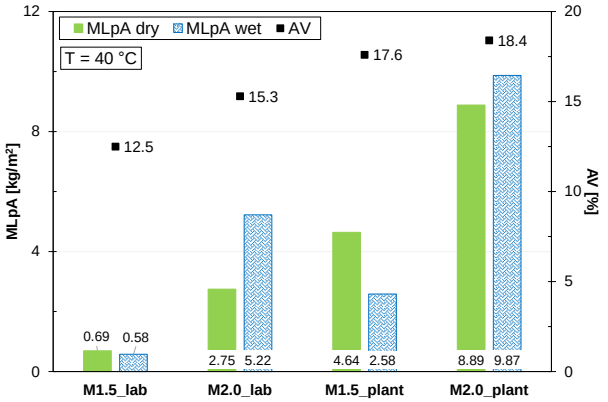

Figure 4. Raveling resistance in terms of MLpA and AV of plant- and lab-produced mixtures.

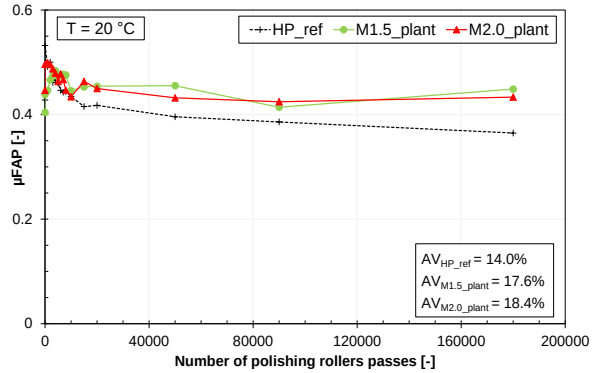

Figure 5. Friction in terms of μFAP of plant-produced mixtures and current hot mix without CR.

Furthermore, the results show that the warm rubberized mixtures (M1.5_plant and M2.0_plant) guarantee better μFAP values even after extensive polishing action than the HP_ref mixture, currently used on Italian motorways. These findings suggest that large-scale production and lay-down operation of asphalt porous mixture with CR and WMA technology do not compromise the friction level of semi-porous wearing course of road pavement.

4 CONCLUSIONS

Based on the experimental results, the following conclusions can be drawn:

- large-scale production of rubberized warm semi-porous asphalt mixtures is technically feasible without specific precaution in both plant and lay-down activities and it can guarantee satisfying workability and volumetric characteristics;
- however, failure to meet the Technical Specifications requirements in terms of ITS, suggests caution in the use of warm mixtures with crumb rubber on the Italian motorway network, especially for the 2% CR mixture which is strongly discouraged;
- differently, the warm mixture with 1.5% CR, showed encouraging ravelling performance, such that a comprehensive evaluation on its technical suitability in different real-world operating environments would validate its use for routine maintenance activities on the Italian motorway network.

ACKNOLEDGMENTS

The activities presented in this paper were sponsored by *Autostrade per l'Italia S.p.A.* (Italy), which gave both financial and technical support within the framework of the *Highway Pavement Evolutive Research* (HiPER) project. The results and opinions presented are those of the Authors.

REFERENCES

Cetin, A. (2013). Effects of crumb rubber size and concentration on performance of porous asphalt mixtures. *International Journal of Polymer Science*, *2013*(1), 789612.

D'Angelo, S., Cardone, F., Cuciniello, G., Virgili, A., & Canestrari, F. (2024, July). Laboratory Investigation of Warm Porous Asphalt Mixtures Containing Crumb Rubber for Motorway Wearing Course. In *International Conference on Maintenance and Rehabilitation of Pavements* (pp. 352-361). Cham: Springer Nature Switzerland.

De Visscher, J., & Vanelstraete, A. (2016). A new performance test for resistance to ravelling by traffic: laboratory and field experience in Belgium. In *8th RILEM International Symposium on Testing and Characterization of Sustainable and Innovative Bituminous Materials* (pp. 785-796). Springer Netherlands.

Ferrotti, G., Mancinelli, E., Passerini, G., & Canestrari, F. (2024). Comparison of energy and environmental performance between warm and hot mix asphalt concrete production: A case study. *Construction and Building Materials*, *418*, 135453.

Canestrari, F., Mariani, E., Ingrassia, L.P. (2024) Use of Wehner-Schulze machine to evaluate pavement skid resistance: A review, Journal of Traffic and Transportation Engineering (English Edition), available online.

Mahmoud, A. F. F., & Bahia, H. (2004). *Using gyratory compactor to measure mechanical stability of asphalt mixtures*. Wisconsin Highway Research Program.

Milad, A., Babalghaith, A. M., Al-Sabaeei, A. M., Dulaimi, A., Ali, A., Reddy, S. S., ... & Yusoff, N. I. M. (2022). A comparative review of hot and warm mix asphalt technologies from environmental and economic perspectives: towards a sustainable asphalt pavement. *International Journal of Environmental Research and Public Health*, *19*(22), 14863.

Picado-Santos, L. G., Capitão, S. D., & Neves, J. M. (2020). Crumb rubber asphalt mixtures: A literature review. *Construction and Building Materials*, *247*, 118577.

Puccini, M., Leandri, P., Tasca, A. L., Pistonesi, L., & Losa, M. (2019). Improving the environmental sustainability of low noise pavements: comparative life cycle assessment of reclaimed asphalt and crumb rubber based warm mix technologies. *Coatings*, *9*(5), 343.

Wang, H., Liu, X., Apostolidis, P., & Scarpas, T. (2018). Review of warm mix rubberized asphalt concrete: Towards a sustainable paving technology. *Journal of cleaner production*, *177*, 302-314.

Yu, J., Yu, X., Gao, Z., Guo, F., Wang, D., & Yu, H. (2018). Fatigue resistance characterization of warm asphalt rubber by multiple approaches. *Applied Sciences*, *8*(9), 1495.

Ziari, H., Naghavi, M., & Imaninasab, R. (2018). Performance evaluation of rubberised asphalt mixes containing WMA additives. *International Journal of Pavement Engineering*, *19*(7), 623-629.