



EARLY LIFE FIELD PERFORMANCE OF INNOVATIVE SUSTAINABLE SEMI-FLEXIBLE PAVEMENTS

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Abstract

Semi-flexible pavements in heavy loads areas are recommended to guarantee good performance and safety. They are usually constructed by placing a wearing layer of grouted macadam, a composite material consisting of a porous Hot Mix Asphalt (HMA) skeleton grouted with a cementitious matrix. However, its use is limited as the production process is quite complex and laborious. An effective alternative to grouted macadam can be represented by the Ready to Mix (RTM), recently implemented to offer performances comparable to those of the grouted macadam and a most effortless put-in-place process, and contemporarily leading to environmental and economic advantages. The present research investigated the early life field performance of a semi-flexible pavement including an RTM base. Three Falling Weight Deflectometer testing campaigns were carried out from 2017 to 2021. In particular, the semi-flexible pavement was compared to a reference flexible pavement entirely made with HMA in terms of temperature sensitivity as well as bearing capacity.

Keywords: semi-flexible pavement, falling weight deflectometer (FWD), temperature sensitivity, field testing, RTM

1 Introduction

In recent years, semi-flexible pavements, characterised by the flexibility of asphalt concrete and equally high stiffness of cement concrete, started to gain more and more attention, especially in presence of heavy and slow-moving loads. The surface layer is generally a composite material, the grouted macadam (GM), obtained through a two stages process [1, 2] during which a porous hot mix asphalt (HMA) skeleton with high voids content (20 – 25%) is grouted with a highly flowable cementitious slurry. After a few curing days, the material develops a proper strength and is fully able to bear the traffic loads. GM has good durability and is characterised by an improved resistance to rutting, fatigue resistance, and low-temperature cracking, as well as low thermal susceptibility, good skid resistance and is unlikely subject to fire effects and corrosion due to fuel and chemicals [2-7]. GM production process is very time- and cost-consuming, beyond requiring careful control to guarantee the proper connectivity of the voids and workability of the slurry [8, 9]. Without such care, the pavement may incur a premature failure due to unfilled voids. Such drawbacks result in the limited use of semi-flexible pavement in some specific cases, such as circumscribed areas of airports, ports or industrial zones subjected to heavy loads [5, 9].

In recent years, Ready to Mix (RTM) material has been implemented as a sustainable and cost-effective alternative to GM [10, 11]. RTM is obtained by mixing at ambient temperature: aggregates, a slow-setting cationic asphalt emulsion (the amount is between 4.6%-6.8% by mixture weight), a specifically designed cementitious reactive filler including elastomeric polymers (about 25%-30%), and additional water, whose dosage is commonly around 5% (by mixture weight). Anyhow, it can be adjusted based on the desired flowability: RTM can be self-compacting or less fluid for compaction with mechanical rollers indeed. The grading distribution fits the Italian technical specifications for HMA binder courses [10, 12].

Laboratory tests showed RTM has excellent performances in terms of stiffness, strength, and fatigue resistance (high resistance to dynamic repeated loads), features that makes this material excellent as base layer. However, trial sections validated the use of RTM as surface layer too, showing also self-healing properties and reduced thermal sensitivity [10]. Investigations carried out so far demonstrated that RTM is a promising material, offering several advantages compared to GM and HMA. The mixing at ambient temperature leads to a reduction of energy consumption, pollutant emissions, and costs compared to GM and HMA. Besides, it allows for higher reclaimed asphalt usage and less virgin aggregate consumption. The one-stage process allows for shortening the time needed to install the pavement than those required for GM, cutting costs, and improving operational efficiency for lay-down. In addition, the higher stiffness moduli and fatigue resistance allow to reduce the thickness of the layer when compared to flexible pavements. Given all this, unlike GM, RTM can efficiently serve as structural layer, as in the investigation herein presented, and not only as a surface course [10].

Based on these outcomes, the present research aims at deepening the knowledge about the early life field performance of semi-flexible pavements including RTM. To do that, three Falling Weight Deflectometer (FWD) surveys were carried out during a 4-years monitoring campaign on a trial field realised on an Italian interregional freeway. In particular, the effect of the temperature was examined to provide a relationship to correct the measured deflection and curvature.

2 Experimental campaign

2.1 General overview

The experimental trial section was built in July 2017 in Campello sul Clitunno (Italy) as part of the maintenance activities of the road SS3 “Flaminia” (pk. 136+131 and 136+207, direction Sud). Two sections, 100 m long each, were compared (1): a traditional flexible pavement structure (reference) – 4 cm HMA wearing course, 6 cm HMA binder, 10 cm HMA base (2) and an innovative semi-flexible pavement structure with 10 cm of RTM replacing the HMA base layer. The HMA materials included an SBS-modified asphalt and complied with the Italian road agency technical specifications [12]. In particular, the wearing course was a porous asphalt. RTM, optimised in a previous laboratory study [10], consisted of a mix at ambient temperature composed of 75% aggregate, 25% reactive filler, 8% cationic asphalt emulsion (C60B4 according to EN 13808) by aggregate weight and water. RTM was plant-produced following a specifically developed process. Right after the mixing was loaded onto dump trucks and transported to the construction site (maximum travel time 45 min) where was laid down using a standard road paver and compacted with a double-drum roller.

2.2 Testing program

The trial section field monitoring was carried out within three FWD testing surveys that took place in September 2017, June 2018, and January 2021. The FWD loading plate, segmented type, had a diameter of 300 mm.

Nine sensors positioned at 0, 200, 300, 450, 600, 900, 1200, 1500, and 1800 mm from the centre of the loading plate measured the deflections. The measuring stations were chosen along two alignments, corresponding to the right and the left wheel paths (herein identified as RT and LT, respectively). Three drops were performed in each measuring position. Table 1 lists the contact pressures applied under the loading plate during the three surveys and the testing temperatures. Deflections were normalised to a 1350 kPa target contact pressure by linear extrapolation for a direct comparison of the results obtained during the surveys. The temperature of the pavement was hourly measured by a probe thermometer according to ASTM D5858. The deflection data were normalised to a reference Weighted Mean Annual Pavement Temperature () of 25 °C through adjustment factors calculated as follows [13]:

$$AF = 1 + a(TAF - 1)^2 + b(TAF - 1) \quad (1)$$

where, AF is the deflection (or the curvature) at the WMAPT divided by the deflection at the measurement temperature, TAF is the ratio between and the measurement temperature (T_{meas}), a and b are regression coefficients.

Knowing layers thickness, the recorded deflection data has been analysed and backcalculated with ELMOD 6 to evaluate the bearing capacity of the two investigated pavement structures considering an elastic multi-layer model. The analysis allowed the determination of the surface modulus of the pavement structure E_s , the stiffness modulus of HMA layers (20 cm for the reference pavement and 10 cm for the semi-flexible) E_{HMA} , the stiffness modulus of RTM (10 cm) E_{RTM} and the subgrade modulus E_s .

Specifically, the moduli at the testing temperatures were obtained through an iterative process carried out using the Method of Equivalent Thickness (MET) implemented in the back-calculation software. The resulted HMA moduli were corrected for referring to a reference temperature of 20 °C using the following relationship proposed by the Asphalt Institute [14]:

$$E_{HMA} = 10^{\alpha(T_p^2 - T_{ref}^2)} E_{ref} \quad (2)$$

where α is the corrective coefficient related to the material temperature sensitivity, T is the reference temperature, T_p is the testing temperature (both temperatures in °F), E_{ref} is the HMA modulus at the reference temperature.

Table 1 FWD testing parameters (contact pressure and temperature)

Testing survey	Contact pressure [kPa]		Testing temperature [°C]	
	Reference section	RTM section	Reference section	RTM section
September 2017	2700*	1700	32	27
June 2018	1600	1600	31 - 34	28
January 2021	1350	1350	11	10

*the first survey was carried out using an Heavy Weight Deflectometer

3 Results and analysis

Fig. 1 shows an example of the deflections measured by the sensors for both types of pavement structures, as well as the normalised deflections to the target contact pressure. In general, for all the measurements taken, it was observed that the deflections measured in the RTM section were lower than those of the reference section with only HMA.

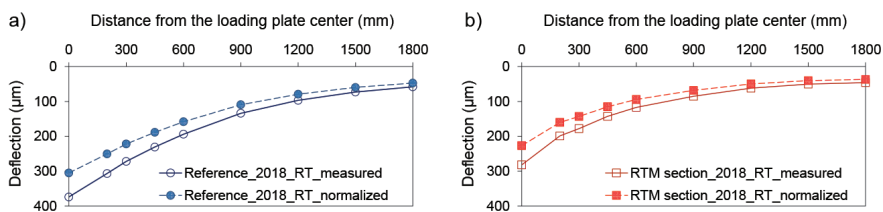


Figure 1 Example of deflections obtained for reference a) and RTM b) sections

3.1 Influence of the temperature

Fig. 2 depicts the variation of the deflections measured for the reference section within the three FWD surveys under the loading plate centre (D_1) and 200 mm apart (D_2) in both alignments (RT and LT). Along with measured data, also normalised data through Eq. 1 were considered. Table 2 lists the coefficients and R^2 , obtained from the literature [13]. In particular, normalised data for D_2 were obtained after the normalisation of the Surface Curvature Index SCI_{200} (the difference between D_1 and D_2). As expected, temperature rise led to an increase in deflections for both D_1 and D_2 . This behaviour was more pronounced for D_1 . The deflection variation as function of temperature was estimated through linear regressions, whose equations are displayed in Fig. 2. Based on these relationships and considering a temperature range from 5°C to 45°C, the increase in the deflections can be estimated around 111% and 63% for D_1 and D_2 , respectively.

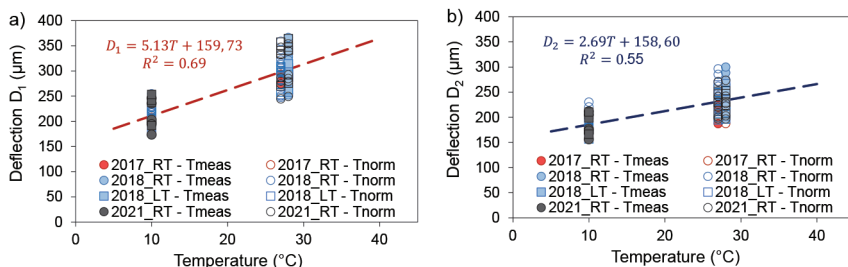


Figure 2 Variations of D_1 a) and D_2 b) with temperature for reference section

Fig. 3 shows the variation of D_1 and D_2 measured for the RTM section within the FWD surveys. As an innovative material, no relationships exist to correct the temperature. D_1 increased with the temperature increase, as observed in the reference section (Fig. 2a). The slope of the D_1 – temperature relationship was lower, though. This confirms that the RTM pavement structure is less prone to increased deformation under dynamic loads when the temperature rises. The variation of D_2 with the temperature was negligible (Fig. 3b), differently from what measured for the reference section (Fig. 2b). Based on the relationships derived through linear regression reported in Fig. 3, D_1 increases by about 34%, passing from 5 to 45°C. In contrast, the increase of D_2 is about zero. Therefore, the contribution to the deformation of the layers under RTM can be neglected.

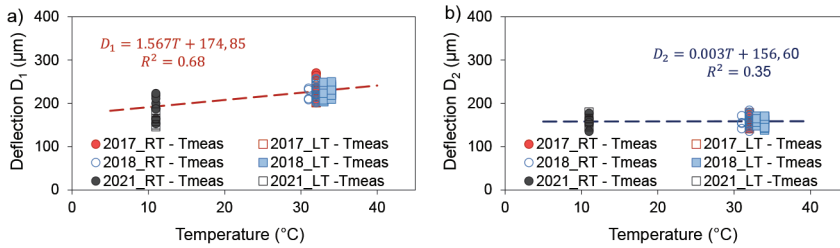


Figure 3 Variations of D_1 a) and D_2 b) with temperature for RTM section

3.2 Definition of the temperature correction coefficients

As stated above, no temperature correction coefficients for RTM can be found in the literature due to the novelty of the material. Therefore, this research attempted to define the coefficients to use in Equ.1 for RTM, considering the average experimental data and the experimental relationship defined in the previous paragraph and described in Fig. 3. Fig. 4 shows the relationship between the adjustment factors as a function of θ identified for D_1 and SCI_{200} . The correction coefficients and are listed in Table 2.

Fig. 5 compares the deflection and curvature temperature correction charts of flexible pavements with HMA layers of 100 mm and 200 mm [13] with those derived for the semi-flexible pavement investigated in this research (100 mm of HMA + 100 mm of RTM). The slope of the correction chart proposed in the literature for a 200 mm HMA layer is much higher than those derived for the semi-flexible pavement. On the contrary, the curves of the 100 mm HMA layer and the semi-flexible pavements are somewhat similar, especially in terms of curvature. This indicates that the thermal density of the RTM layer is basically null, and the variation in the deflections measured are mainly due to the HMA layers. At high temperatures, the results confirm the better resistance to permanent deformations of the semi-flexible pavement including RTM when compared to the reference one. The asphalt emulsion seems not to influence the thermal susceptibility of the material, and the impact of the cementitious components of the reactive filler appears predominant. In addition, the material showed good performance also at low temperatures, indicating a potential improvement in terms of fatigue and low-temperature cracking resistance compared to the traditional section. This can be attributed to the polymers contained in the reactive filler.

Table 2 Coefficients for the temperature correction of D_1 and SCI_{200} for flexible pavements [13] and semi-flexible pavements (proposed)

Pavement structure	Layer-thickness	Parameter	< 25 °C		> 25 °C	
			a	b	a	b
Flexible (reference)	HMA – 20 cm	D_1	-0,1245	0,4218	-0,0890	0,5513
		SCI_{200}	-0,2890	1,2971	0,5679	1,5841
Flexible	HMA – 10 cm	D_1	-0,0613	0,2106	-0,2045	0,2678
		SCI_{200}	-0,1740	0,7184	0,0430	0,8983
Semi-flexible	HMA – 10 cm RTM – 10 cm	D_1	-0.0424	0.1406	-0.2887	0.1503
		SCI_{200}	-0.1207	0.6418	0.2710	0.6750

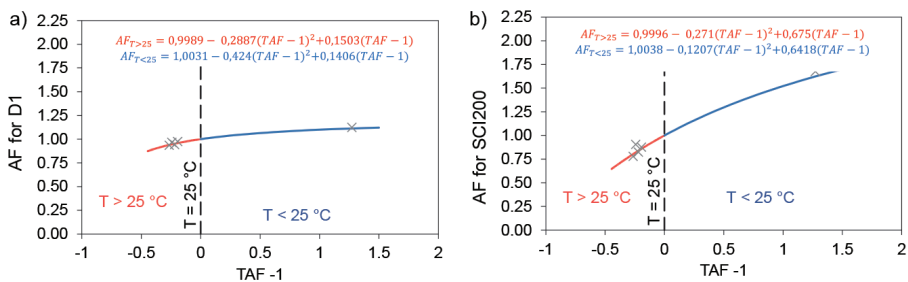


Figure 4 Correlation between (TAF-1) and for D₁ a) and for SCI₂₀₀ b)

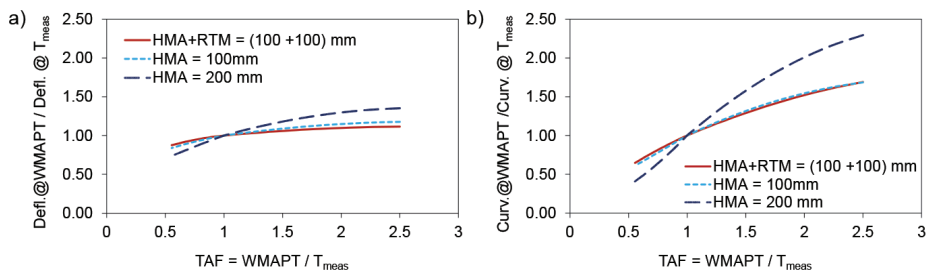


Figure 5 Comparison of the temperature correction charts for flexible pavements [13] and semi-flexible with RTM (proposed): a) deflection, b) curvature

3.3 Stiffness evaluation

Table 3 reports the moduli at 20°C obtained from the back analysis: the surface modulus E_e , the HMA layer modulus E_{HMA} , the RTM layer modulus E_{RTM} and the subgrade modulus E_s . As regards the reference pavement, E_e was comparable within the three testing campaigns, ranging between 1201 and 1430 MPa. The E_{HMA} showed a slight reduction within the years: about 3.3% after one year and 10% after almost 3.5 years, compared to the 2017 value. This suggests that the effects of heavy traffic loads (i.e., fatigue) may be predominant compared to the stiffening effect due to ageing. Likewise the reference pavement, the variation in E_e of the semi-flexible structure was smallest for the three testing campaigns, being lower than 10.5%. The average E_{HMA} increased from 2496 MPa (standard deviation 969 MPa) to 3314 MPa (973 MPa) from 2017 to 2021, showing opposite behaviour to that observed for the reference pavement. The RTM layer was much stiffer than the other layers (about 6 to 11 times larger than HMA). Compared to 2017, E_{RTM} reduced by about 24% and 28% in 2018 and 2021, respectively. During the first year, the RTM was subjected to a substantial stiffness reduction that may be due to a modification in the material structure. After that, the modulus reduction can be considered negligible. Therefore, most of the load was transmitted to the stiffer RTM layer in the semi-flexible pavement, leading to better support for the HMA layer and improving the load distribution in the underlying layer. Consequently, the HMA is likely less subjected to fatigue damage, and the ageing effect is prevalent. In both cases, the subgrade showed a similar good performance.

Table 3 Stiffness modulus from backcalculation: a) reference pavement, b) semi-flexible pavement (error bars represent the standard deviation)

Parameter	Reference section			RTM section		
	2017	2018	2021	2017	2018	2021
E_e [MPa]	1344	1201	1430	1627	1597	1797
E_{HMA} [MPa]	11034	10670	9986	2496	2334	3314
E_{RTM} [MPa]				26227	19890	18796
E_s [MPa]	488	453	471	476	413	430

4 Conclusions

This research examined the early life field performance of sustainable semi-flexible pavements obtained by substituting the traditional hot mix asphalt (HMA) with the ready to mix (RTM) material in the base layer. Three FWD surveys were conducted from September 2017 to January 2021, comparing deflections of the semi-flexible pavement with a reference flexible (HMA) one. Measured deflections and back analysed moduli indicated an overall good performance of the semi-flexible pavement over the years. Correction coefficients for the central deflection and the curvature were proposed to compare temperature effects on the two pavement structures. Temperature correction coefficients of semi-flexible pavements including the RTM base could also be conveniently exploited at the pavement design stage: the analysis showed that RTM can be considered not susceptible to temperature variation. RTM showed stiffness moduli around one order of magnitude higher than HMA. Consequently, the RTM layer supports most of the traffic load, reducing fatigue damage on upper HMA layers and improving load transmission to the subgrade. In conclusion, RTM can be considered a promising material to be used as a base layer in semi-flexible pavements for heavy loads infrastructure. Future studies should validate the proposed temperature correction method, assess different pavement structure thicknesses or RTM compositions, and explore the fatigue resistance of the material to relate field and laboratory-measured performance.

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