The role of reinforced interface adhesive layer to construct resilient pavement

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THE ROLE OF REINFORCED INTERFACE ADHESIVE LAYER TO CONSTRUCT RESILIENT PAVEMENT

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ABSTRACT

Resilience in general captures the goals of maintaining the continuity of performance and recovery to the desired function during an infrastructure designated service life. Nevertheless, pavement infrastructure is particularly vulnerable to the impacts of climate change due to being continuously exposed to outdoor conditions. Constructing a pavement that is resilient to a changing climate will necessitate challenging changes in materials, design, and execution techniques. Accordingly and irrespective of crucial parameters such as pavement structural and mix designs, interlayer bonding between pavement layers plays a crucial role in pavement durability. For instance, slippage of pavement layers occurs particularly during summer under heavy traffic loads. However, such distress has been exacerbated due to global warming which might be moderated using a proper adhesive layer. This study initially compared the shear resistance between pavement layers when conventional and polymer-modified bitumen (PMB) emulsions were applied as adhesive agents. Furthermore, the impacts of milk lime (slurry) and glass-fiber-reinforced adhesive layer were evaluated using the Leutner shear test. The results showed that incorporating PMB emulsion considerably enhanced bonding between layers and outperformed conventional materials. Although no considerable influence of slurry on shear resistance was found, less tack coat removal by paver during road execution was detected due to the presence of the slurry. The reinforced adhesive layer with glass fiber exhibited higher shear resistance, particularly for the specimens that were collected after being approximately one year in service. It was finally observed that a few parameters such as trapped moisture can destructively influence interface shear resistance.

Keywords: *Resilient Pavements, Interlayer Bonding, Tack Coat, Polymer Modified Emulsion, Glass Fiber Reinforcement, Shear Resistance, Leutner Shear Test.*

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1. INTRODUCTION

1.1. General

Infrastructures, particularly the road industry, play a pivotal role in the economy and development of all countries. However, global warming induces several threats to the durability of pavements worldwide. An increase in mean sea level, extreme rainfall and floods, heat extremes, and winter temperatures are some of these threats which can compromise the resilience of an infrastructure system [1, 2]. Detecting and tackling climate change factors and their impacts on pavement performance requires consideration of various regional or/and global uncertainties.

It is known that pavement durability and performance are directly related to the materials' properties, mix, and structural designs, as well as the production and construction process [3]. Considering the extreme climate-sensitivity of pavements due to constant exposure to intense alterations in weather conditions, one of the recent methods to enhance the resilience of pavement infrastructure is the optimization and reinforcement of existing materials. Asphalt pavements are constructed in a multi-layered system that generally bonds together using an adhesive layer such as emulsion. This adhesive layer provides an integrated structure for better-transferring stress of traffic loading and changes in environmental conditions to the next layers. While the absence or inadequacy of such a layer can result in a significant reduction in the shear strength resistance of the pavement structure and makes the system vulnerable to many distress types including layers slippage, cracking, potholes, raveling, rutting, deformations, and bulging [4]. The mentioned distress has been exacerbated due to global warming which might be moderated using a proper adhesive agent.

1.2. Adhesive layer

As mentioned earlier, a proper bond between adjacent asphalt layers enhances pavement service life. Previous study informed that a tack coat as an adhesive layer at the interface can considerably increase shear and fatigue life resistance [5]. To guarantee the continuous bonding between pavement layers several adhesive agents have been utilized, including conventional and modified emulsions, liquid asphalt, coal asphalt, epoxy resins, etc. For instance, comparison was made to evaluate the impacts of four types of tack coat including crumb rubber modified, liquid 60/70 bitumen, cationic slow-setting, and cationic rapid-setting emulsions at different application rates on asphalt layers shear resistance. It was reported that crumb rubber modified and liquid 60/70 bitumen at the optimum application rate of 600 g/m^2 outperformed emulsions [6]. On the contrary, a study on the possibility of reinforcing interlayer bond strength using geosynthetic products impregnated with asphalt as a tack coat showed that using such reinforcements reduced the shear strength by 20 to 50% depending on geosynthetic materials [7].

Another study stated that an increase in temperature (particularly during summer) elevates the horizontal tensile stress which compromises the bonding between pavement layers [8]. In this regard, a group of researchers attempted to moderate heat storage in pavement layers using conductive adhesive layers. It was informed that modifying water epoxy resins as the adhesive layer using carbon fiber can enhance heat dissipation efficiency which in turn increased minimum shear resistance by approximately 1.3 MPa [9]. Aside from temperature impacts on interface bonding, surface characteristics of adjacent layers were also found to be influential on the interface bonding between asphalt layers and their interaction [10]. Similar study reported that although surface characteristics, mean texture depth, and film thickness play a key role in interlayer bonding, such factors' influence on interface bonding is more pronounced at elevated temperatures compared to lower temperatures [11]. Moreover, other studies also acknowledged that the interlayer shear strength of pavement layers can be influenced by moisture damage [12-14]. For instance, the shear bond strength between the chip-seal and asphalt pavement of various asphalt-aggregate combinations using different emulsion types and application rates was studied and the results showed that although polymer-modified emulsion and a higher percentage of fine aggregate improved the interface bonding, the increase in the number of freeze and thaw cycles reduced the shear resistance [15]. Several contradictions between the severity of moisture damage impacts on the shear resistance can be found in the literature. However, still, limited studies considered the possibilities to tackle such damages and reinforcing interface bonding.

In this study, the application of different tack coats including conventional, polymer-modified, and glass fiber-reinforced emulsions with and without milk lime (slurry) at two test tracks located near the Port of Antwerp-Bruges was investigated. The influence of different paving materials and their interaction with interface layers were also evaluated. The performance of tack coats was compared in two stages including right after the pavements execution as well as approximately one year after being in service to evaluate the resilience of interface layers when subjected to yearly Belgium's environmental conditions. This paper is outlined in the following way: A brief overview of previous works, followed by a short description of test tracks and utilized methods. The article then continued with the results and discussion. Conclusions are finally presented in the last section.

2. MATERIALS AND METHODS

2.1. Materials

In the first test track, the pavement structure was constructed in different layers and the road was divided into five sections as shown in Figure 1. The results related to the paved materials and their performance can be found in the earlier publication [16]. The tack coat between APO-A (dense asphalt concrete) layers was conventional cationic rapid setting emulsion (C60B3), and polymer-modified emulsion. While the adhesive agents between the top layer and the first base layer were varied as can be seen in Table 1. The glass fiber was utilized in this project due to its superb tensile strength and capability to improve moisture damage resistance [17]. The glass fiber properties are provided in Table 2.

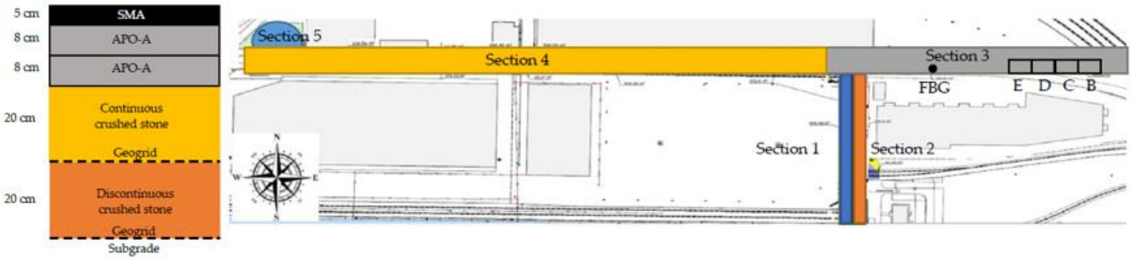

Figure 1. First test track structural design and sections.

Table 1. Tack coat application.

Experimental Factor	Section 1	Section 2	Section 3	Section 4	Section 5
Tack coat (between asphalt base layers)	Emulsion (C60B3)	Emulsion (C60B3)	Emulsion (C60B3)	PMB emulsion + lime slurry	PMB emulsion + lime slurry
Tack coat (between upper asphalt base and top layers)	PMB Emulsion + lime slurry	PMB Emulsion + lime slurry	PMB Emulsion + lime slurry E: PMB emulsion + lime slurry D: PMB emulsion + glass fibers (75 g/m^2) + lime slurry C: PMB emulsion+ glass fibers (75 g/m^2) B: PMB emulsion	PMB Emulsion + lime slurry	PMB Emulsion + lime slurry

Table 2. Glass fiber properties.

Parameter	Value
Density (g/cm^3)	2.68
Tensile strength (Mpa)	1400
Water Absorption (%)	1.1
Melting Temperature °C	860
Diameter (μm)	16
Length (mm)	38

In the second test track, the tack coat type was kept unchanged while the road was divided into five sections containing different paving materials and structural designs. The description of structural designs, employed materials, and applied tack coats can be found in Figure 2, Tables 3, and 4.

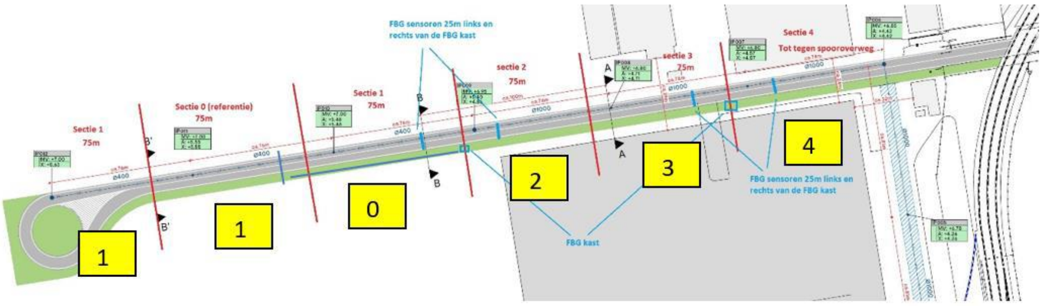

Figure 2. Second test track sections.

Table 3. Structural designs and materials for each section.

	Section 0	Section 1	Section 2	Section 3	Section 4
5 cm surface layer	SMA-C2	APT-PoA	SMA-C2	SMA-C2	APT-V
2 x 8 cm base layer	APO-A	APO-A	APO-PoA	APO-PoA	APO-V
Base	20 cm unbound base geogrid 1: biaxial	20 cm unbound base geogrid 1: biaxial	20 cm unbound base geogrid 2: triaxial	25 cm lean asphalt (2 x 12,5 cm + tack coat)	25 cm lean asphalt (2 x 12,5 cm + tack coat)
	20 cm unbound base geogrid 1: biaxial	20 cm unbound base geogrid 1: biaxial	20 cm unbound base geogrid 2: triaxial	10 cm sub-base (granulates)	10 cm sub-base (granulates)
Subbase	Existing soil acts as the subbase (M1 > 35 MPa)				

Table 4. Tack coat application overview.

Location	Section 0	Section 1	Section 2	Section 3	Section 4
Upper asphalt base and surface layer	C60BP3 (AA)	C60BP3 (AA)	C60BP3 (AA)	C60BP3 (AA)	C60BP3 (AA)
Between asphalt base layers	C60BP3 (AA)	C60BP3 (AA)	C60BP3 (AA)	C60BP3 (AA)	C60BP3 (AA)
Below lower asphalt base layer	C60B4 A1	C60B4 A1	C60B4 A1	C60B4 A1	C60B4 A1
Between lean asphalt layers	-	-	-	C60B4 A1	C60B4 A1

2.2. Methods

To compare the difference between utilized materials and interface bonding conditions, three cores with 150 mm diameters per section were drilled following EN 12697-27:2017 standard. It should be mentioned that cores were drilled twice: immediately after road construction, and after being in service for about one year to evaluate climate conditions' impacts on pavement resilience and their long-term performance. Subsequently, the shear resistance of the interface between pavement layers was determined using the Leutner Shear test in accordance with EN 12697-48:2021 standard procedures. The shear bond test (SBT) evaluates the resistance to horizontal shear stresses in the interlayer of two adjacent pavement layers and clarifies the interlayer bond quality. In other words, the SBT assesses the resistance to the stresses generated by traffic either accelerating or braking, as well as the impacts of different thermal movements when the layers are made out of different materials.

Prior to the testing, the dimension of the specimen was determined based on EN 12697-29 to the nearest 0.1 mm. The specimens were placed in a climate chamber at 20 °C for a minimum duration of 4h. The SBT test was then performed at the loading rate of 50 mm/min. Several parameters were then calculated including maximum shear force (kN), maximum shear stress (MPa), and shear stiffness modulus (MPa/mm) as well as Shear energy to the peak load (Nm) from the shear force-deflection graphs. The methods and equations to determine the abovementioned factors can be found in EN 12697-48:2021 standard.

3. RESULTS AND DISCUSSION

The results obtained from the first test track are provided in Figures 3 to 6. Figure 3 indicates that the polymer-modified tack coat outperformed conventional emulsions. The slight difference between the performance of conventional emulsions can be correlated to several reasons such as fluctuation in tack coat application rate or potential tack coat removal by the paver during construction. The application rate was targeted at a residual binder rate of 300 g/m^2. However, the measurements obtained by sorbent pads revealed that the average binder residual rates in some of the sections did not meet the target value and varied between approximately 100 to 300 g/m^2 in the case of the base layers and around 240 to 320 g/m^2 for the adhesive layer between base and surface layers. In addition and despite proper sample conditioning prior to the testing, a trace of water was detected between a few layers during the shear test performance, particularly for the adjacent layers which produced using a higher nominal maximum aggregate size. Such water traces resulted in lower shear resistance. The small proportion of moisture between asphalt layers can be either due to the penetration of water during coring procedures or insufficient waiting period (before emulsions setting) and construction of the upper pavement layer which resulted in trapped water between layers.

Furthermore, it can be seen that reinforcement using fiber can slightly improve tack coat performance based on an approximately 5% increase in the maximum shear force. However, the corresponding value was reduced when a tack coat, slurry, and fibers were used concurrently. It can be inferred that fiber and slurry might not be compatible due to the fiber's potential to absorb water which can considerably compromise shear resistance. The results of sections constructed using emulsion and slurry exhibit approximately similar values compared to the other sections. It can therefore be hypothesized that slurry may not influence the tack coat performance either negatively or positively. However, less tack coat removal by paver due to the existence of the slurry was observed during road execution.

It should be informed that to verify the satisfactory performance of tack coat application, the recommended shear stress is 1.3 MPa in Belgium. Figure 4 clearly shows that all the materials met the requirements based on maximum shear stress higher than 1.3 MPa. Figure 4 shows that the results of maximum shear stress follow the same trend as the maximum shear force. From Figure 5 it can be observed that almost all the specimens have a shear stiffness modulus of around 0.75 Mpa/mm. Such a trend was expected since all the samples were tested immediately after construction where no traffic or weather conditions influenced their performance. Hence, the ratio of modulus and deformation remained approximately constant. The small difference between the values can be correlated to the fluctuation in the tack coat application rates and water trace between layers as explained earlier. The difference between the shear stiffness modulus of similar adhesive layers applied between different layers can be correlated to the surface roughness which makes better bonding between layers. The impacts of surface characteristics on interface performance are explained in the following paragraph. Furthermore, the shear energy results show a similar trend compared to the maximum shear force where higher energy requires to split the layers containing the polymer-modified adhesive compared to the layers constructed using conventional emulsions. Figure 6 also indicates that fibers can slightly improve the shear resistance by approximately 10%. Such a finding denotes that fiber can enhance pavement layers' stability against shear deformation.

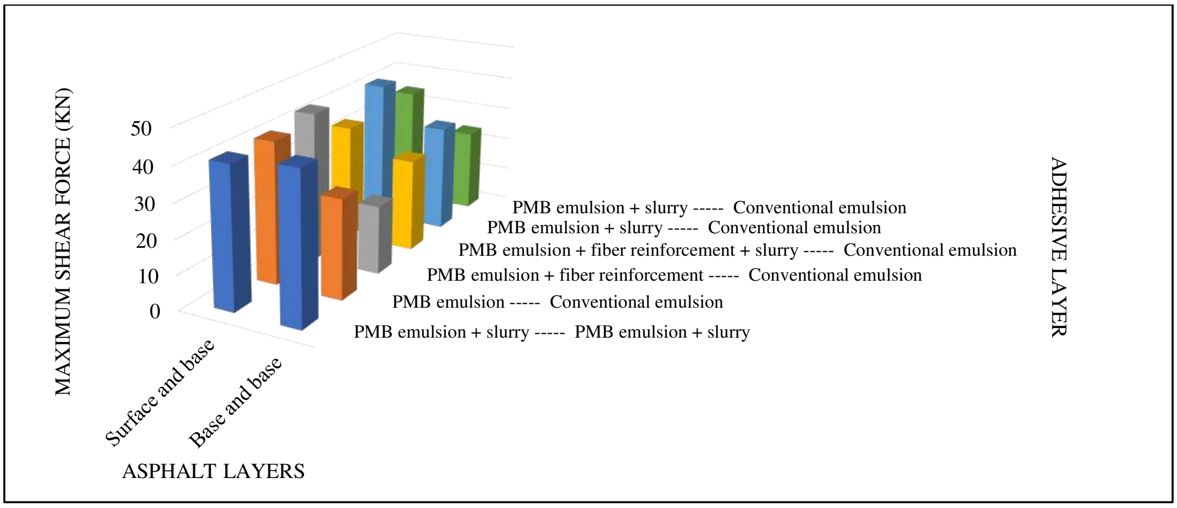

Figure 3. Maximum shear force for specimens from the first test track.

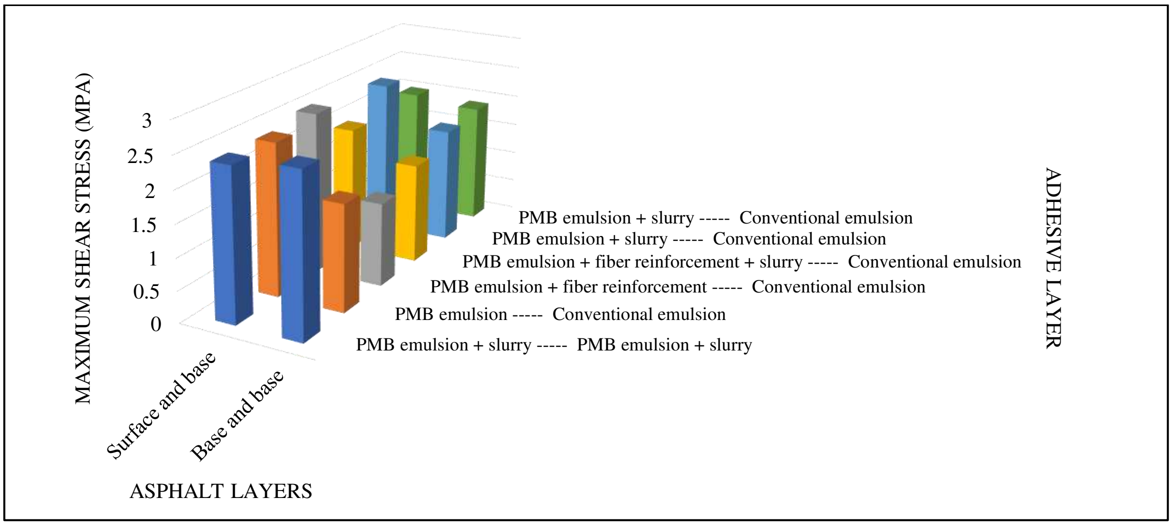

Figure 4. Maximum shear stress for specimens from the first test track.

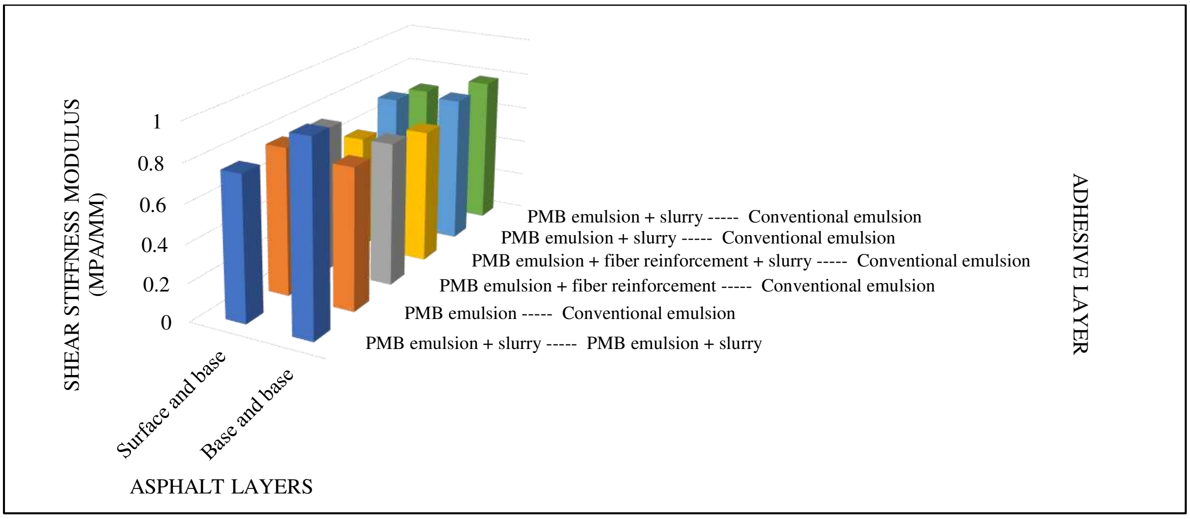

Figure 5. Shear stiffness modulus for specimens from the first test track.

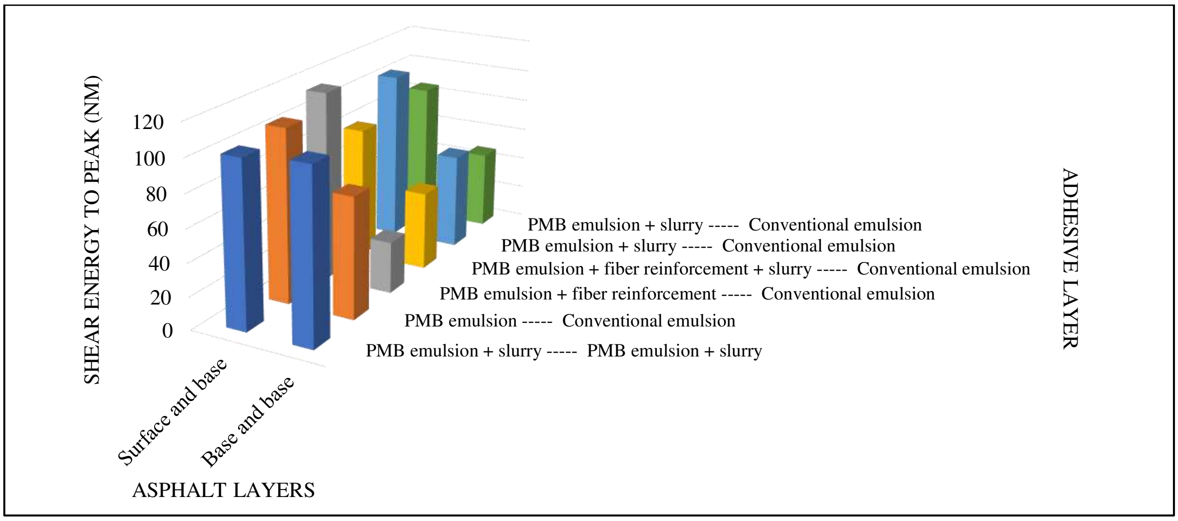

Figure 6. Shear energy for specimens from the first test track.

The variety of asphalt mixtures in the second test track, with different nominal maximum aggregate sizes (NMAS), gradation, and texture, led to the research on such parameters' influence on the interface bonding performance. The shear test results are provided in Figures 7 to 10. The results indicate that approximately all the cores performed satisfactorily in terms of maximum shear force with values above 35 kN (Figure 7). Figure 8 also illuminates that all the tested specimens met the Belgium shear resistance requirement based on maximum shear stress higher than 1.3 MPa. Figure 9 shows that for approximately all samples the shear stiffness modulus of specimens is around 1 Mpa/mm. From the changes in the results, it can be inferred that variations in the types of asphalt mixtures influenced the interface shear resistance. This finding is in line with the previous study [10]. All the results presented in Figures 7 to 9 follow a similar trend where an increase in NMAS from the surface layer (below sieve 10 mm) to the lower layers which contain coarser aggregate gradation (below sieve 20 mm) resulted in an increase in the shear resistance. Such a trend can be correlated to either deeper penetration of emulsion in a coarser surface due to higher surface porosity which led to better pavement layer bonding or better interlocking of layers due to rougher surfaces. The trend of shear energy to reach the peak load is slightly different compared to the other parameters. For instance Figure 10 shows that the lower layer of Section 1 requires the least energy to reach peak load. During the testing, a small trace of water was detected in this section. Since the section is located at the beginning of the second test track (as can be seen in Figure 2), such a trend can be correlated to the allocation of insufficient time for the emulsion setting before the construction of the upper layer. However, this section requires further investigation to achieve a concrete conclusion.

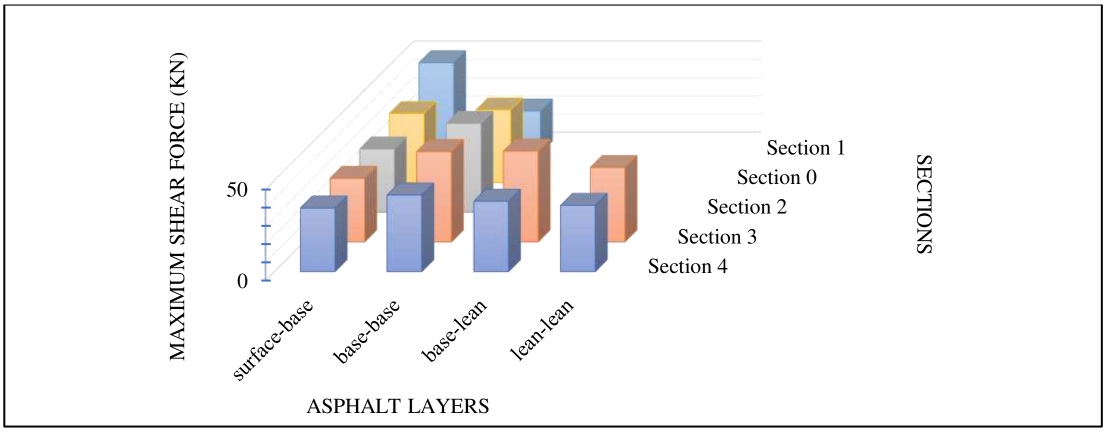

Figure 7. Maximum shear force for specimens from the second test track.

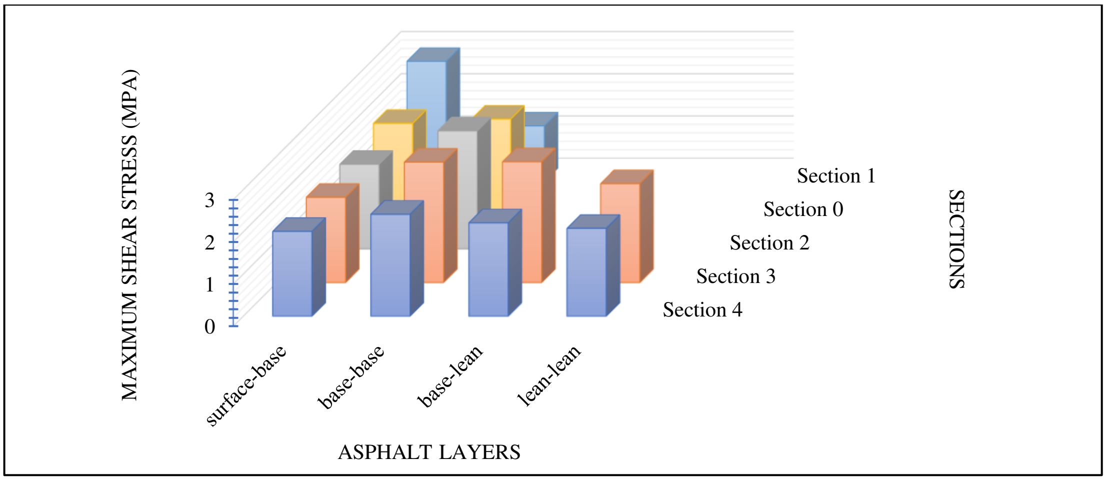

Figure 8. Maximum shear stress for specimens from the second test track.

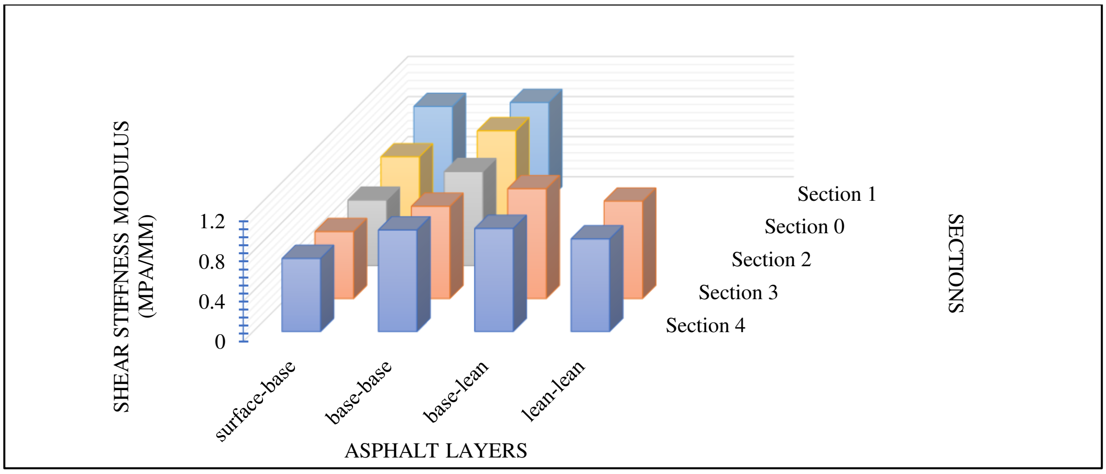

Figure 9. Shear stiffness modulus for specimens from the second test track.

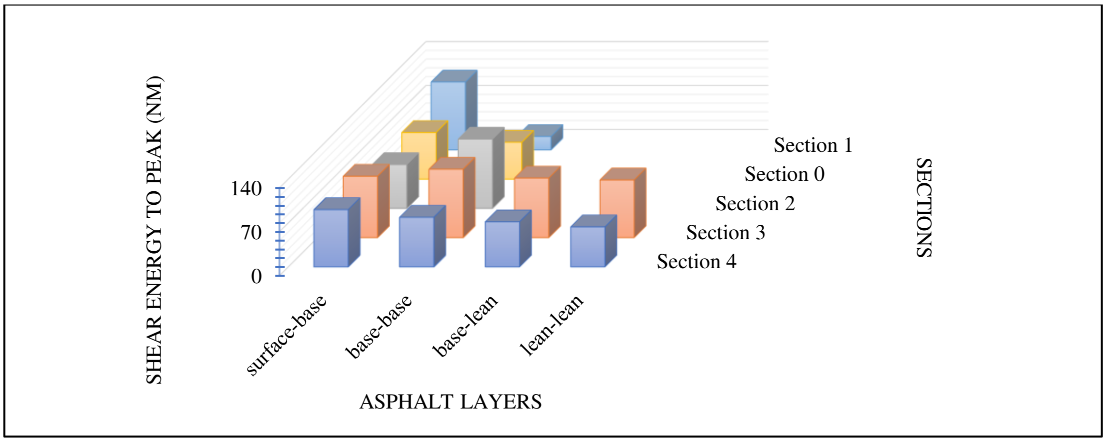

Figure 10. Shear energy for specimens from the second test track.

To evaluate the influence of climate conditions and traffic on the performance of interface layers as well as their resilience, the cores were collected from the same test tracks after approximately one year of being in service. Since coring can compromise pavement integrity, this time the cores were only drilled in the sections where different paving materials and adhesive layers were used to avoid unnecessary pavement deterioration. The results of these cores are provided in Tables 5 and 6. The maximum shear force presented in tables indicates that the obtained results exhibit approximately similar quantities and trends compared to the corresponding values determined immediately after the road execution. Tables 5 and 6 also show that the results of maximum shear stress after one year remained above the specified range in Belgium standard (1.3 MPa). Moreover, a slight reduction in the shear stiffness modulus compared to the first measurements (particularly for the lower layer by approximately 10% and 20% for the first and second test tracks, respectively) can be observed from these tables. Although no considerable changes in the shear energy of the first test track can be found in table 5, Table 6 shows a small increase in the shear energy of the interface, particularly for lower layers. The second test track was subjected to lower traffic loading. It can therefore be assumed that such an increase can be resultant of pavement settlement after one year of being in service which led to better pavement layers interlocking, hence, a higher shear energy requirement to reach the peak load. Overall, the findings show that the adhesive layers in both test tracks are performing well and neither traffic nor changes in the climatic conditions throughout a year compromised their performance. The results also show that sections incorporated fiber exhibit no considerable difference compared to the section without reinforcements. However, the reinforcement impacts will be further investigated in the following years to reach more detailed conclusions.

Table 5. Properties of specimens collected from the first test track after one year in service.

Measured properties	**Pavement layers**									
	Interface between surface and base					Interface between base and base				
	Sections					Sections				
	A	B	C	D	E	A	B	C	D	E
Maximum shear force (kN)	41.02	42.11	39.73	44.02	35.46	35.89	33.12	25.37	31.40	26.96
Maximum shear stress (MPa)	2.34	2.40	2.27	2.51	2.02	2.05	1.89	1.45	1.79	1.54
Shear stiffness modulus (MPa/mm)	0.70	0.67	0.64	0.79	0.70	0.73	0.73	0.57	0.79	0.58
Shear energy to peak (Nm)	117.55	111.95	105.01	94.45	94.84	76.32	75.80	46.62	49.52	48.86

Note: Section A: Interface adhesive layer between both surface and base as well as base and base layers is polymer-modified emulsion plus slurry;

Section B: Interface adhesive layer between surface and base layers is polymer-modified emulsion while adhesive layer between base and base layers is conventional emulsion

Section C: Interface adhesive layer between surface and base layers is polymer-modified emulsion plus glass fiber reinforcement while adhesive layer between base and base layers is conventional emulsion

Section D: Interface adhesive layer between surface and base layers is polymer-modified emulsion plus glass fiber reinforcement plus slurry while adhesive layer between base and base layers is conventional emulsion

Section E: Interface adhesive layer between surface and base layers is polymer-modified emulsion plus slurry while adhesive layer between base and base layers is conventional emulsion

Table 6. Properties of specimens collected from the second test track after one year in service.

Measured properties	**Road sections**								
	4			3			0		
	Targeted interface between pavement layers								
	Surface-base	Base-base	Base-lean	Surface-base	Base-base	Base-lean	Surface-base	Base-base	Base-lean
Maximum shear force (kN)	34.52	43.71	NA	39.38	49.84	49.85	38.44	46.80	NA
Maximum shear stress (MPa)	1.97	2.49	NA	2.25	2.84	2.84	2.19	2.67	NA
Shear stiffness modulus (MPa/mm)	0.69	0.76	NA	0.58	0.74	0.86	0.59	0.92	NA
Shear energy to peak (Nm)	90.75	144.85	NA	127.50	154.14	151.02	121.29	133.02	NA

4. CONCLUSIONS

This study explored the difference between the incorporation of different tack coats including conventional, polymer-modified, and glass fiber-reinforced emulsions with and without milk lime (slurry). Moreover, the influence of different paving materials and their interaction with adhesive layers were also evaluated. The performance of tack coats was compared in two-time intervals including immediately after the pavements execution as well as approximately one year after being in service to evaluate the resilience of interface layers when subjected to yearly Belgium's environmental conditions. The following conclusions in the form of bullet points can be drawn from this study:

- The results showed that all the materials (in both testing stages) met the Belgium shear resistance requirements based on the shear stress values higher than 1.3 MPa.
- The results indicated that the polymer-modified tack coat outperformed conventional emulsions in all terms.
- tack coat application rate and potential tack coat removal by the paver during construction can influence the interface shear resistance.
- The presence of moisture between pavement layers considerably reduced shear resistance.

- Reinforcement of the interface layer using glass fiber can slightly improve tack coat performance however such a trend was less pronounced after being in service for one year.
- Although slurry exhibited no considerable influence on the results, concurrent application of fiber and slurry reduced shear resistance. Such results can be correlated to the fiber's potential to absorb water which compromised the expected performance of the interface layer.
- The results obtained from different paved mixtures showed that an increase in NMAS can increase the shear resistance either as a result of better tack coat coverage or better interlocking of layers due to rougher surfaces.
- Aside from a slight reduction in the shear stiffness modulus of interface layers after being in service for one year, the trend of other results remained approximately unchanged when the tests were performed at two different time intervals.

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