Experimental study aimed at highlighting warnings for proper design, construction and control of geocomposite-reinforced asphalt pavements

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ABSTRACT

The proper use of interlayers in asphalt pavements can be an effective and economic option to enhance their service life. However, the presence of a foreign element at the interface should be properly taken into account during design, construction and control of reinforced pavements. Given this background, the present laboratory study investigated stiffness and interface bonding properties of reinforced asphalt systems in order to achieve fundamental information for a correct design as well as proper construction and control of reinforced pavements. To accomplish this objective, different composite reinforcements (grids/fabrics embedded in bituminous membranes) were studied as interlayers of double-layered systems prepared with both traditional and polymer-modified asphalt concretes. Dynamic flexural tests and static interface shear tests were carried out. Unreinforced reference systems was also studied for comparison purposes. Results confirmed the abovementioned warnings that will allow delineating some preliminary guidelines related to the use of reinforcements in pavements.

Keywords: Reinforced asphalt pavements, composite reinforcements, interface bonding properties, stiffness.

1. INTRODUCTION AND PROBLEM STATEMENT

Interlayer reinforcement systems can be considered an effective option to enhance the service life of asphalt pavements, particularly in the case of maintenance and rehabilitation projects [1–5]. Recently, attempts at producing composite materials by embedding grids or fabrics (high-stiffness/low-elongation products) in bituminous membranes (soft interlayers) have been carried out [6–11]. The idea is to obtain a product able to hold tensile stresses and strains (reinforcement action of grids/fabrics) while absorbing and relieving concentrated energy, especially along pavement discontinuities (stress-relieving action of membranes) [12–17]. Moreover, this kind of reinforcement system facilitates construction since it should be applied directly (without tack coats or levelling courses) over both new and milled surfaces [9, 10, 18]. It is worth noting that the membrane also provides waterproofing and/or anti-pumping properties.

Despite several promising laboratory and field results against fatigue and reflective cracking phenomena [6–11], some issues due to the presence of a “foreign” element at the interface could be detected [4, 5, 8, 16, 17, 19–22] and should be considered during design, construction and control.

Given this background, the present paper illustrates an experimental laboratory study aimed at investigating stiffness and interface bonding properties of double-layered asphalt systems reinforced with selected composite products (grids/fabrics embedded in bituminous membranes). This preliminary study is thus oriented towards the achievement of fundamental information for a correct design as well as proper construction and control of reinforced pavements, highlighting the main warnings to be taken into account. To this aim, different double layered asphalt systems were subjected to both dynamic flexural tests and static interface shear tests. The selected samples were prepared with both traditional and polymer-modified asphalt concretes. Unreinforced reference systems was also studied for comparison purposes.

2. MATERIALS AND METHODS

2.1 Materials

Different dense graded asphalt concretes prepared in the plant with crushed limestone aggregates and different types of bitumen were used to prepare the selected double-layered asphalt systems. In particular, the lower layer of the tested samples consisted of an AC16 asphalt concrete characterized by 16 mm nominal maximum aggregate size and 5.0% (by the weight of the mix) conventional 50/70 pen bitumen. Conversely, the upper layer was realized using asphalt concretes prepared with the abovementioned plain 50/70 pen bitumen or with a SBS (Styrene-Butadiene-Styrene) polymer modified binder, coded as PMB 25/55-75. Since both mixtures were constituted by 10 mm maximum size aggregates, they can be classified as AC10 and AC10 PMB, respectively. AC10 contained 6.5% plain 50/70 pen bitumen whereas AC10 PMB was manufactured with 5% of the PMB bituminous binder (by the weight of the mix).

In the case of the unreinforced double-layered slabs (reference configuration), a cationic emulsion containing 69% SBS polymer-modified bitumen (C69BP3) was applied as tack coat at the interface. Thanks to the presence of the bituminous membrane, reinforced systems did not need tack coats.

Three factory-produced 2.5 mm thick reinforcing products were evaluated during the laboratory research study. The “controlled” production in the factory should provide higher guarantee of high-performance reinforced pavement since the related drawbacks could be limited as much as possible. In this case, this attempt was accomplished by combining two bituminous membranes (similar to those typically used as roofing material) having different compounds with two fibreglass grids as detailed in the following:

- composite ELS, obtained by embedding a thin fibreglass sheet into an elastomeric SBS modified membrane (“factory-made” SAMI – Stress Absorbing Membrane Interlayer);
- composite PL5, obtained by embedding a 5 mm square mesh fibreglass grid into a SBS/APP (atactic polypropylene plastomeric) modified membrane;
- composite EL12, obtained by embedding a 12.5 mm square mesh fibreglass grid into an elastomeric SBS modified membrane.

PL5 and PL12 were characterized by a tensile strength of 20 kN in both longitudinal and transversal direction whereas reinforcement ELS was characterized by a tensile strength of 8 kN and 4 kN in longitudinal and transversal direction, respectively.

2.2 Specimen preparation

Tested specimens were obtained from slabs (300 × 400 × 50 mm^3) prepared in laboratory through a steel roller compactor compliant with EN 12697-33 standard. First, AC16 was compacted to obtain the 30 mm thick lower layer (5.1% target air void content). Then, the bituminous emulsion (unreinforced configuration UN) or the proper composite reinforcement (reinforced configurations) were applied on the cooled surface. The emulsion was hand-spread on the unreinforced interface with a rate of 150 g/m^2 of residual bitumen. Finally, AC10 or AC10

PMB were compacted to obtain the 20 mm thick upper layer (4.4% target air void content). Thus, eight double-layered systems were prepared as summarized in Table 1.

For each configurations, six cylindrical specimens (100 mm nominal diameter) as well as six prismatic specimens (400 mm long, 50 mm wide and 50 mm thick) were obtained to assess the possible reductions in stiffness and interface shear resistance by performing dynamic four point bending (4PB) tests and static shear bond tests (SBT), respectively.

TABLE 1 Tested configurations

Configuration	Upper layer	Reinforcement
P0	AC10	None
PS	AC10	ELS
P5	AC10	PL5
P12	AC10	EL12
M0	AC10 PMB	None
MS	AC10 PMB	ELS
M5	AC10 PMB	PL5
M12	AC10 PMB	EL12

2.3 Shear bond test

The SBT (prEN 12697-48) consists of inducing a relative displacement at constant rate between the two parts of the double-layered cylindrical specimens without applying a normal load (pure shear test). In this research, SBTs were carried out at 20 °C applying two nominal speeds (1.27 and 50.8 mm/min) in order to investigate the time-dependent behaviour of the bituminous interfaces. For each configuration and test condition, three replicates were carried out.

During the test, both the applied shear load and the relative displacement at the interface δ are measured. This allowed the calculation of the interlayer shear stress τ, dividing the shear load by the initial cross sectional area of the specimen. The main SBT parameters used to assess the interface shear properties of the tested samples are: i) the interlayer shear strength τ_{max} (i.e. the maximum calculated shear stress); ii) the interlayer deformation rate at failure υ_{max} (i.e. the ratio between the shear deformation at failure δ_{max} and the time to reach the failure).

2.4 Dynamic modulus test

According to EN 12697-26, 4PB test consists of applying a cyclic loading/displacement on a beam specimen through inner movable clamps positioned at the middle of the sample that is held at its extremities by outer fixed clamps. In this research, 4PB frequency sweep stiffness tests were performed in strain-controlled mode (non-destructive strain amplitudes $\varepsilon_0 = 50$ μstrain) at 6 test frequencies (0.1, 0.3, 1, 3, 10 and 30 Hz) in order to assess the time-dependent stiffness response of the bituminous systems. Also in this case, tests were carried out at 20 °C taking into account six replicates for each configuration and test condition.

During the test, the applied load and the corresponding controlled displacement at the mid-span of the beam are continuously measured. Thus, the norm of complex modulus E* (based on the linear elastic beam theory) and the corresponding phase angle δ (time lag between the applied displacement and the corresponding load response) can be returned. According to EN 12697-26, the mechanical properties measured at the 100th loading cycle are assumed as representative of the intrinsic (undamaged) condition of the tested specimens.

3. RESULTS AND DISCUSSION

3.1 Interlayer shear bond properties

Figure 1 depicts representative results obtained through SBT tests carried out on the P systems (upper layer prepared with the plain AC10 mixture). Similar findings were found in the case of M systems (upper layer prepared with the AC10 PMB asphalt mixture) and are not reported for the sake of brevity. A clear different behaviour between the reference unreinforced configuration (P0) and the reinforced configurations can be observed at both testing speed.

The experimental data show a brittle behaviour in the case of unreinforced systems that were characterized by a physical failure of the interface being the two layers of the specimen separated at the end of the test. This response reflects in a clear high τ_{max} followed by a quick reduction of the measured shear stress. Conversely, the reinforced systems exhibited a ductile behaviour being the two layers of the reinforced specimens still held together by the membrane at the end of the test (the asphalt layers shifted each other without physical failure). As a consequence, such reinforced samples were characterized by a definitely low τ_{max} and a very slow increase of τ during the test. Among the studied reinforcements, characterized by fairly comparable results, the composite membrane ELS (elastomeric membrane containing a thin fibreglass sheet) showed slightly higher performance. Based on previous similar experiences [9, 10, 18], this is probably due to the fact that the grids contained in the PL5 and EL12 further reduced the cohesion of the bituminous membrane, thus lowering the overall interlayer shear properties.

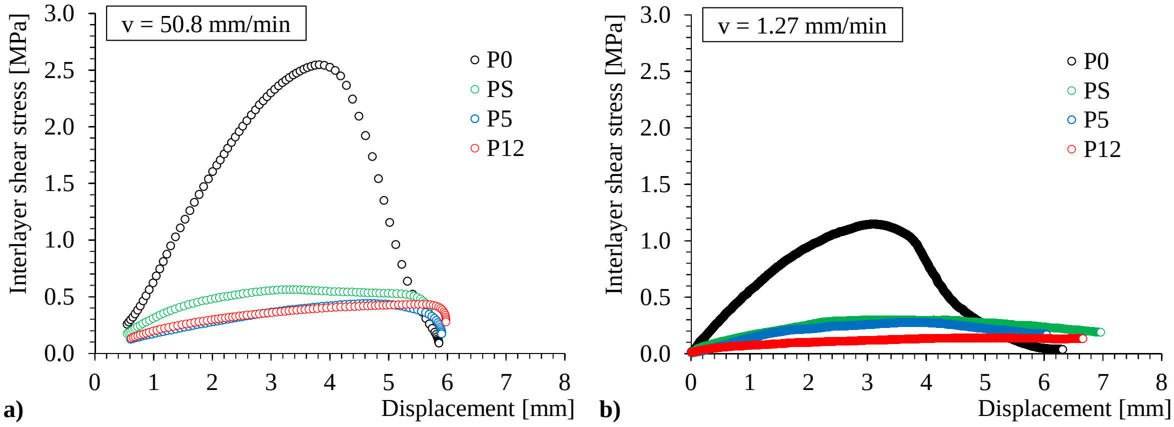

FIGURE 1 SBT representative results for P systems at 50. 8 (a) and 1.27 (b) mm/min

The overall SBT findings are resumed in Figure 2 where, according to [23], isothermal curves are constructed using a logarithmic model for the linear regression of the experimental data reported in terms of τ_{max} as a function of the corresponding υ_{max}. Obviously, the higher the deformation rate the higher the shear strength of all the tested configurations due to the viscous nature of the bituminous interfaces. Moreover, it is worth noting that the isothermal model of the P0 system was found to be practically identical to the results obtained by other researchers performing a similar test program with other materials [23]. Such results were also in very good agreement with the master curve of the interlayer shear strength found by the same researchers [23]. These facts confirm the reliability of the present experimental data and it seems to suggest that the shear properties are mainly due to the characteristics of the interlayer rather than to those of the bituminous mixtures. On the other hand, very different responses can be outlined for the geocomposite-reinforced systems, regardless the type of asphalt concrete used for the upper layer. In particular, undoubtedly lower shear strength can be guaranteed even if such strength is clearly less time-dependent than that of the corresponding unreinforced configuration.

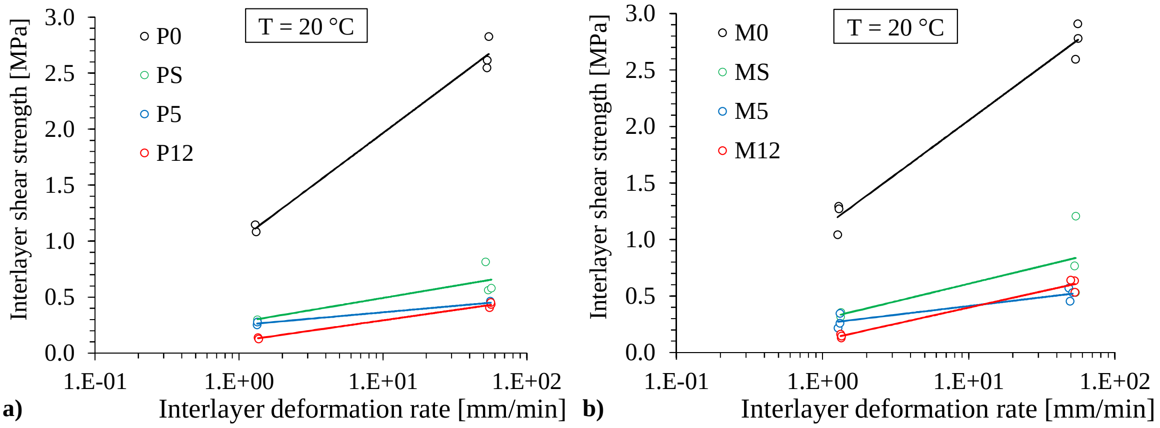

FIGURE 2 Isothermal regression lines for SBT results: P systems (a) and M systems (b)

Average results at 50.8 mm/min nominal deformation rate are also depicted in Figure 3 along with the error bars reporting the maximum and minimum τ_{max} for each tested configuration. Similar trends (not reported here) were observed at 1.27 mm/min deformation rate. Corresponding P and M systems denoted analogous results thus demonstrating that interface shear properties mainly derives from the interlayer configuration, regardless the use of plain or polymer-modified asphalt concrete as upper layer. Moreover, the significant reduction (70–90%) of the shear strength due to the presence of the composite reinforcement is clearly observable, confirming literature findings [1, 5, 8–10, 14, 19–21]. Thus, specific studies are needed to establish if this reduced interface shear strength could affect in a decisive manner the mechanical response of the pavement taking into account the effective temperature and traffic conditions.

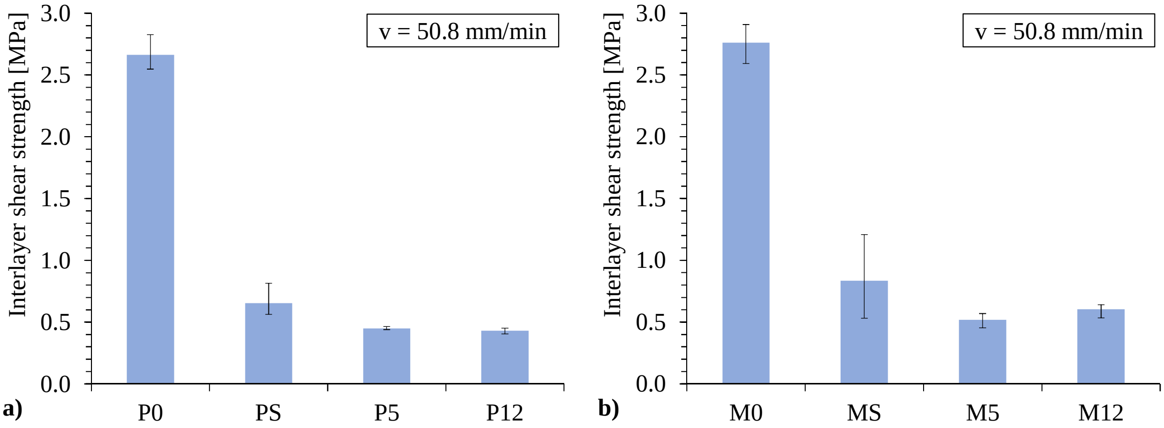

FIGURE 3 Average interlayer shear strength at 50.8 mm/min for P (a) and M (b) systems

3.2 Stiffness properties

4PB frequency sweeps experimental results are summarized in Figure 4 where the average stiffness moduli are plotted as a function of the test frequency for each interface configuration. Error bars representing the minimum and maximum registered values are also reported.

It can be noted that, according to previous studies [10, 21, 22, 24], the lower bonding at the interface reported above (§3.1), due to the presence of the reinforcements at the interface, also causes a reduction of the overall stiffness of the double-layered systems with respect to the corresponding unreinforced configurations, regardless the material used for the upper layer. According to the previous considerations, the composite product ELS produced a lower de-bonding effect (S systems) than PL5 and EL12, thus reflecting the hierarchic behaviour observed in terms of interface shear strength.

Finally, a slight decrease in stiffness can be generally observed if a polymer-modified asphalt concrete is used instead of a plain mixture for the preparation of the upper layer, regardless the interlayer. Thus, the enhanced properties of the polymer-modified binder seems to provide a contribution in enhancing the stiffness of both unreinforced and reinforced systems.

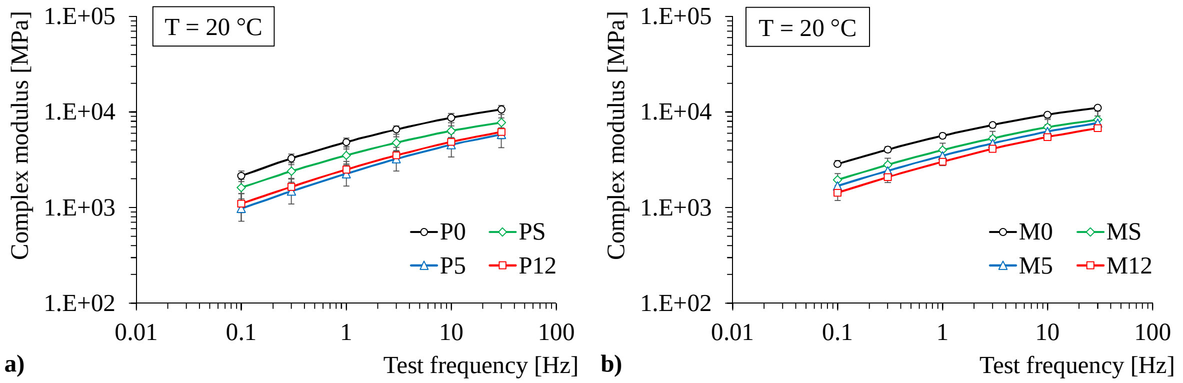

FIGURE 4 Average complex stiffness modulus for P (a) and M (b) systems (ε_0 = 50 µstrain)

6. CONCLUSIONS AND RECOMMENDATIONS

The present laboratory study was aimed at outlining issues related to design, construction and control of reinforced pavements. In particular, three composite products were taken into account as reinforcements for asphalt systems prepared with both plain and polymer modified asphalt mixtures. Such products were obtained by embedding grids/fabrics into selected bituminous membranes. Based on the results coming from interlayer shear strength tests and stiffness tests, the following preliminary conclusions and recommendations can be reported:

- a proper "application" of the reinforcement consists not only of taking particular care on the conditions (cleanness, dryness, etc.) of the laying surface but also of designing the installation depth taking into account the predicted stresses and strains at the interface;
- a proper mechanistic design of reinforced pavements should consider a lower stiffness of the reinforced double layered system;
- the control of the stiffness response of new or just-rehabilitated reinforced pavements is not the right way of verifying the contribution of the reinforcement since it is mainly addressed to enhance the cracking resistance rather than to increase the bearing capacity.

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