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Influence of tack coat rate on the properties of paving geosynthetics

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ABSTRACT

The use of geosynthetic reinforced asphalt overlay technique is becoming increasingly used to enhance the performance of cracked asphalt pavements. However, the compilation of design specifications for paving geosynthetics used as anti-reflective cracking systems has been a difficult task, leading to largely empirical procedures. Stiffness has been identified as the governing property to quantify the potential contribution of the interlayer to the asphalt overlay strength. Additionally, the asphalt binder forms a low hydraulic conductivity barrier that enhances bonding of the geosynthetic to the existing overlay. The type and rate of tack coat impregnation can significantly influence the reinforcement and waterproofing mechanism, potentially leading to early overlay failure. This paper presents the results of an experimental testing program conducted to quantify the influence of tack coating contents on the tensile strength and stiffness as well as the hydraulic conductivity of paving geosynthetics after emulsion asphalt impregnation. Both nonwoven geotextiles and composites involving geotextile and geogrid are considered in the study. Evaluation of the geosynthetics changes in tensile properties provides insight on the identification of an optimum bitumen dosage to enhance tensile strength and stiffness of impregnated geosynthetics. A tack coat rate equal to the asphalt retention capacity was specifically evaluated as baseline dosage, which was ultimately found to be an optimum dosage to enhance the mechanical properties for the effect of the tack coat rate on the tensile behavior of the geosynthetics. The use of asphalt emulsions were found to lead to a significant reduction in the hydraulic conductivity of paving geosynthetics.

Introduction

Paving geosynthetics such as nonwoven geotextiles and geotextile-geogrid have been used to minimize reflective cracking from an existing deteriorated pavement into new asphaltic overlay layers. Paving geotextiles have been reported to offer two main contributions to enhance the performance of asphalt overlays: a stress-relief layer and a hydraulic barrier (Khoddaii et al., 2009; Lytton, 1989). Geosynthetic reinforcement in asphalt concrete layers adds tensile strength to the resulting composite material by increasing its capacity to absorb energy during repeated

Abbreviations: AASHTO, American Association of State Highway and Transportation Office; ASTM, American Society for Testing and Materials; DER, Department of Highway of Sao Paulo State; GT, geotextile; GC, geogrid composite; PET, polyester; PP, polypropylene; UTS, ultimate tensile strength; XD, cross-machine direction.

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loading cycles (Mahrez et al., 2005). Geogrids and geocomposites incorporating geogrids have been reported to also contribute to the lateral restraining effect of pavements (Austin and Gilchrist, 1996; Tschegg et al., 2012). As reported by Pasquini et al. (2012), the mechanical properties of the asphaltic layers were reported to increase with increasing geosynthetic tensile strength.

However, Zamora-Barraza et al. (2010) report that the geosynthetic stiffness obtained from tensile tests is a more relevant property than the maximum tensile strength. Sprague et al. (1998) also states that stiffness constitutes the most critical property for the potential contribution of the geosynthetic to the strength of the overlay system. While these studies have shown the potential contributions of geosynthetics as anti-reflective cracking systems, the specifications for paving geosynthetics has been largely empirical. Accordingly, specifically, it is recognized that the relative conditions of cracked asphalt pavements should be better quantified and that the geosynthetic reinforcement properties that govern the enhanced performance should be identified and quantified. The geosynthetic must be able to absorb and retain the asphalt tack coat in order to effectively adhere to the underlying road surface (Maurer and Malasheskie, 1989). In addition, the amount of tack coat and the rate of application used to bond the geosynthetic to the underlying layer plays an important role. Indeed, use of tack coat of inadequate characteristics and/or rate may lead to early failure of the overlay (Lytton, 1989). Based on 65 field studies reported by Baker (1997), it was concluded that an inadequate tack coat was responsible for 75% of failures reported in identified case studies. As stated by Lytton (1989), the tack coat rate is recommended to be somewhat above the level as defined by the method for determining it, but not significantly above this level as this may cause shear strength losses at the interface of the underlying layer with the paving geosynthetic. A slight excess of tack coat may facilitate waterproofing if cracks end up reflecting to the surface. By minimizing water infiltration, the system becomes an efficient moisture barrier that enhances the pavement performance. FHWA (1984) reported a field hydraulic conductivity test in typical nonwoven geotextiles with tack coat rates ranging from 0.9 to 1.4 l/m^2, showing that in 33 out of 36 tests, the use of impregnated geotextiles allowed less water flow than in cases that did not use geotextiles as intermediate layers. In studies conducted by Marienfeld et al. (1999), results from modified permittivity test showed the tack coat rate ranging between 1.04 and 1.09 l/m^2 led to hydraulic conductivity values below of 10^{-6} cm/s. However, the actual values depended on the properties of geotextile and the applied tack coat.

According to AASHTO M 288-05 (2001), the specified rate of asphalt tack coat application should satisfy the asphalt retention capacity of the paving geosynthetic, and be able to bond the paving fabric and overlay to the old pavement. ASTM D 6140 (2005) provides a test method to estimate the asphalt retention capacity of paving geosynthetics. This standard defines asphalt retention as the volume of asphalt cement that is retained per unit surface area of geosynthetic. Koerner (2005) states that the rate of asphalt binder is a function of the geosynthetic saturation (ASTM D 6140 2005) and provides a correction based on the cracking level of the asphalt surface. In addition, Alvarez (2008) reports an on-site asphalt binder test conducted to determine the optimum amount of asphalt binder to be used in a project depending on the pavement conditions. This test should be performed on site with different tack coat rates until achieving complete material saturation. Castro and Ballester (2006) conducted a study on the influence of the types of asphalt binder on the asphalt retention capacity of paving geotextiles, showing that significant variations in retention values may result depending on the type of asphalt binder used. Accordingly, both the quantity and type of asphalt binder affect the geosynthetic asphalt retention capacity. Finally, Correia and Bueno (2011) conducted a preliminary evaluation on the effect of different rates of asphalt emulsion on the tensile properties of the geosynthetics. The results of tensile strength tests on impregnated geosynthetics revealed that increasing tack coat rates leads to increasing material stiffness, possibly enhancing the reinforcement mechanism of paving geosynthetics.

Based on the evaluation of the available technical literature, a systematic evaluation is needed of the possible changes after bitumen impregnation of the properties of mechanical and hydraulic paving geosynthetics. For example, the reinforcement benefit of paving geosynthetics has been typically neglected, at least when compared to benefits expected from stress relief and waterproofing. Accordingly, a thorough experimental study involving tensile tests was conducted in this investigation using paving nonwoven geotextiles and a geocomposite impregnated with asphalt emulsion at different rates. An important parameter to be defined in this study is the optimum tack coat dosage recommended for a given geosynthetic type. Specifically, the influence of tack coat contents on the tensile strength and stiffness of these geosynthetics is investigated. A tack coat rate equal to the asphalt retention capacity is specifically evaluated as a baseline tack coat rate. In addition, water vapor transmission tests were conducted to investigate the hydraulic conductivity of the impregnated geosynthetics.

Experimental procedures

Materials

A total of seven paving geosynthetics were used to investigate changes in tensile and hydraulic conductivity properties after impregnation with asphalt emulsion. A cationic aqueous rapid setting emulsion (CRS) was used in this research as the tack coat for geosynthetics impregnation, in accordance with DER-SP ET-DE-P00/043 (2006) specifications. The characteristics of the tack coat emulsion used in this study are shown in Table 1. The geosynthetic materials used in this study include: four needle-punched 100% polyester (PET) nonwoven geotextiles with different masses per unit area; two 100% polypropylene (PP) nonwoven geotextiles with different masses per unit area; a geocomposite involving fiber glass geogrid and a 100% polypropylene nonwoven geotextile. Fig. 1 illustrates the

Table 1
Properties of the CRS asphalt emulsion used in this study.

Property (units)	Standard	Values
Viscosity Saybolt-Furol at 50 °C (Pa.s)	ASTM D 7496 (2009)	21.0
Sieve test (%)	ASTM D 6933 (2008)	0.1
Identification of cationic property	ASTM D 7402 (2009)	Positive
Residue by distillation (%)	ASTM D 6997 (2004)	63.0
Demulsibility (%)	ASTM D 6936 (2009)	64.1

paving geosynthetics used in this study. The physical, tensile and hydraulically properties of the geosynthetics are presented in Table 2.

Tensile tests of impregnated geosynthetics

The various paving geosynthetics were tested after emulsion impregnation at the target dosage in order to evaluate possible changes in their mechanical behavior due to of impregnation. For nonwoven geotextiles, the tensile strength was reported in terms of force per unit width, as obtained from wide-width tests conducted in

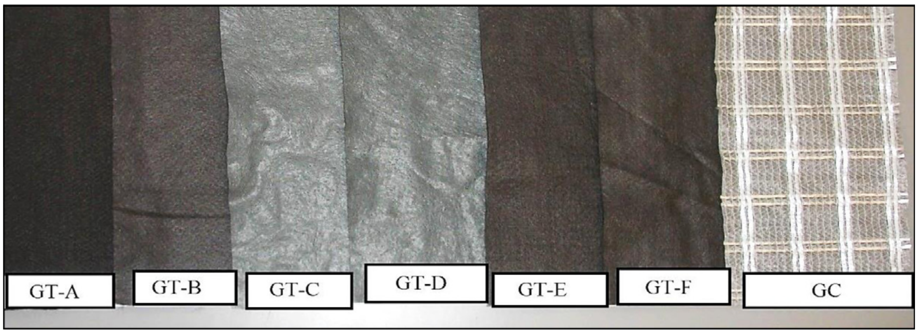

Fig. 1. Geosynthetic paving materials used in this study.

Table 2
Properties of non-impregnated geosynthetics used in this study.

Material	Mass/unit area (g/m^2)	Polymer	Filament type	Thickness (mm)	Tensile strength (kN/m)	Strain at break (%)	Asphalt retention capacity (l/m^2)	Permittivity (s^{-1})	Permeability (cm/s)
GT-A	146	PET	Short	1,75	6.86	94.39	1.15	3,78	0.660
GT-B	182	PET	Short	1,36	10.93	91.41	1.10	2,28	0.300
GT-C	151	PET	Long	1,36	7.30	61.42	1.00	4,45	0.600
GT-D	183	PET	Long	1,86	8.47	59.14	1.15	1,89	0.340
GT-E	165	PP	Short	2,29	8.62	94.26	1.10	2,33	0.530
GT-F	214	PP	Short	1,37	12.60	85.53	1.00	1,69	0.240
GC	430	PP	Short	1,28	39.80	4.47	1.15	1,34	0.170

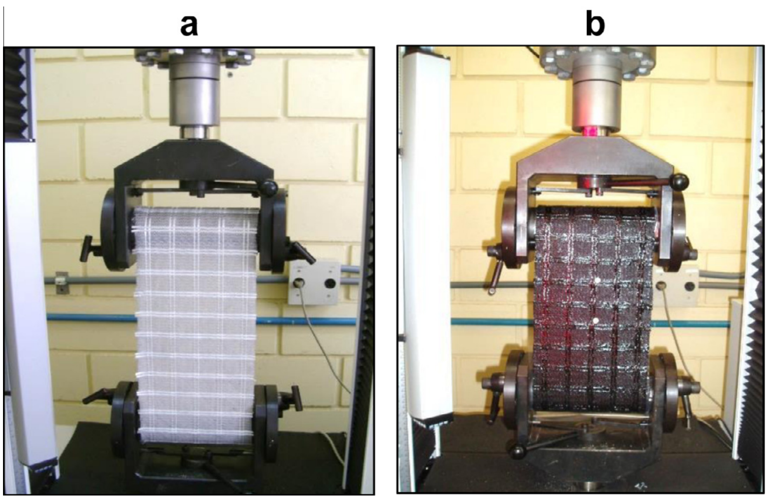

Fig. 2. View of tensile tests in progress: (a) virgin geogrid composite; (b) geogrid composite impregnated with asphalt emulsion.

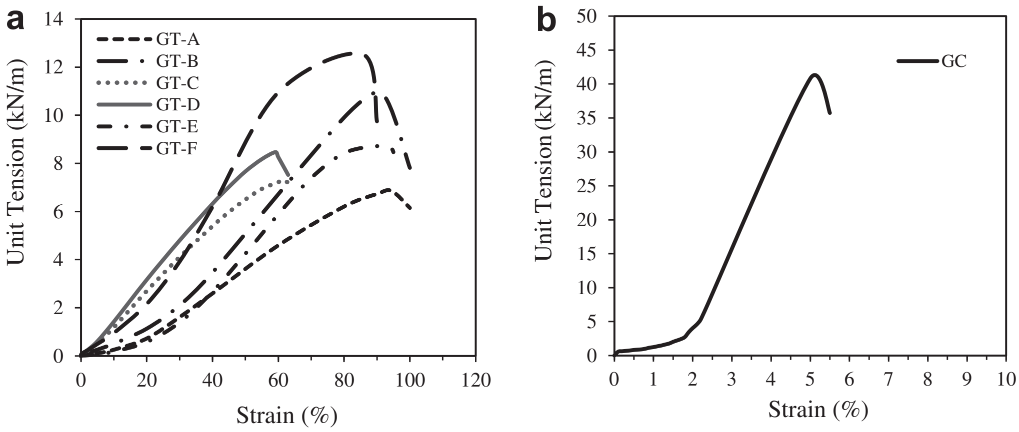

Fig. 3. Unit tension–strain curves for the geotextiles tested in the cross-machine direction: (a) nonwoven geotextiles; (b) geogrid composite.

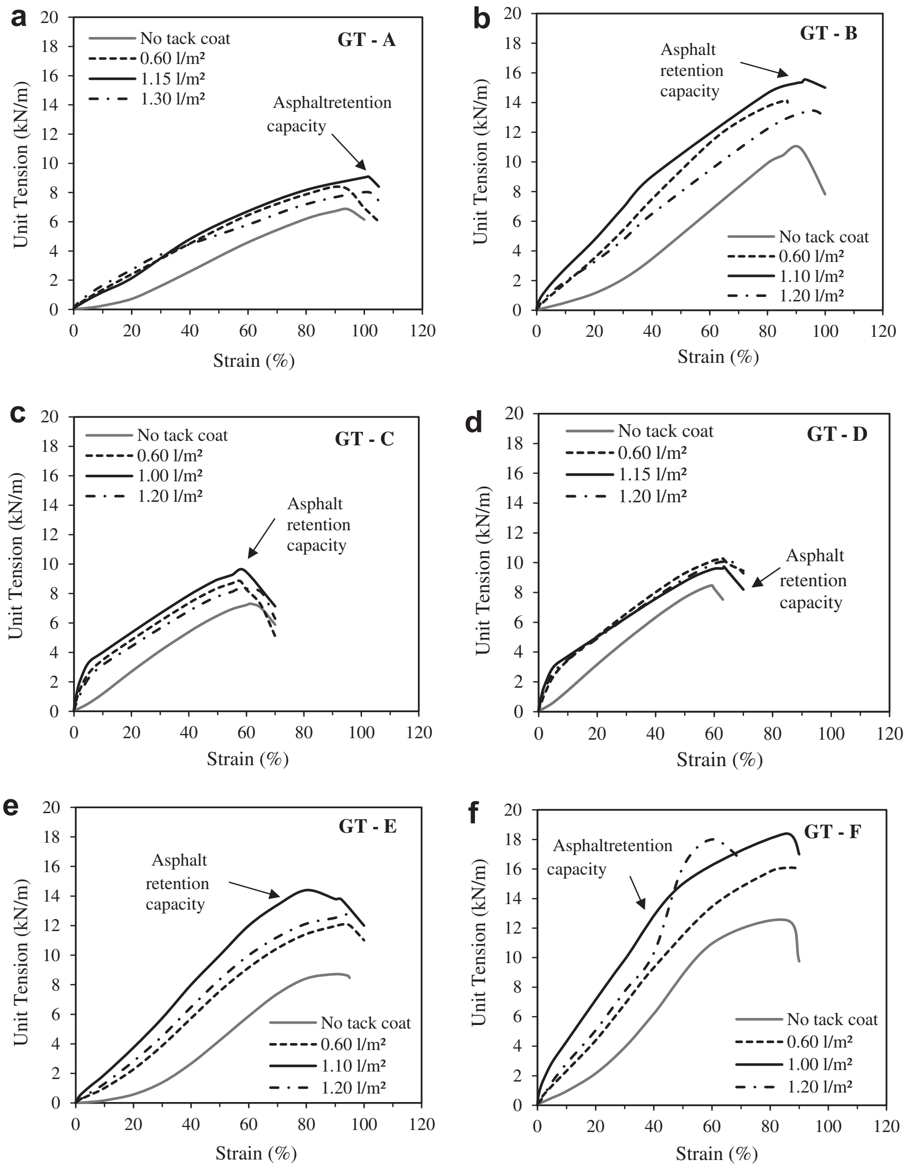

Fig. 4. Unit tension-strain curves of nonwoven geotextiles impregnated with different rates of emulsion: (a) GT-A; (b) GT-B; (c) GT-C; (d) GT-D; (e) GT-E and (f) GT-F.

accordance to ASTM D 4595 (2005). The geogrid composite specimens were tested following ASTM D 6637 (2011). All materials evaluated in this study were tested in the cross-machine direction. The impregnation process involved using the predetermined quantity of emulsified asphalt to impregnate each geosynthetic material. Details on the geosynthetic impregnation process are provided by Correia and Bueno (2011). Four impregnation rates were used on the geosynthetic specimens used in the tensile strength tests: (1) no tack coat; (2) a tack coat of 0.60 l/m^2, which is below the value usually applied in the practical applications; (3) a tack coat equal to the asphalt retention capacity of the geotextile, and (4) a tack coat rate approximately 10–20% above the asphalt retention capacity. The asphalt retention capacity for the various geosynthetics used in this study is also listed in Table 2.

Changes in the internal structure of the geotextile after impregnation and, consequently, changes in their mechanical behavior were quantified. This included variations in the unit tension properties of the geosynthetics for different strain levels. Five specimens in the cross-machine direction, measuring 200 mm × 200 mm, were prepared for the nonwoven geotextile products. For the geogrid composite, five samples measuring 200 mm × 1.0 m were prepared. Fig. 2 illustrates the tensile testing in progress of virgin and impregnated geogrid composite used in this study. Fig. 3 presents the results of unit tension strain curves for virgin geotextiles and geogrid composte in the cross-machine direction.

Impregnated permeation tests

Water vapor transmission tests (WVT) were conducted on samples of the impregnated geosynthetics, following ASTM E 96M (2005), water method, in order to compare the hydraulic conductivity results obtained after impregnation, in relation to the virgin material's hydraulic conductivity. Table 2 presents the hydraulic properties of virgin geosynthetics. Three impregnation rates used on geosynthetics specimens for the permeation tests include: (1) 0.60 l/m^2; (2) 0.90 l/m^2; and (3) 1.10 l/m^2. Consistent with ASTM E 96M (2005), impregnated geosynthetic samples were attached to cups where vapor water remained at saturation because of the presence of liquid water. Principles of mass conservation are then used to calculate the permittivity (or hydraulic conductivity) of the geosynthetics.

Results

Effect of impregnation on tensile strength

The results of tensile strength in this study were obtained by conducting five repeats of each one of the impregnated geosynthetic materials, tested in cross-machine direction. An average unit tension-strain curve was obtained using the five sets of results and represents an average response of the impregnated specimens. The coefficient of variation (CV) remained below 5% for all results obtained using virgin and impregnated geosynthetics. Table 2 provides the tensile results of virgin geosynthetics used in this study. The PET and PP nonwoven geotextiles present ultimate tensile strength (UTS) values ranging from 7.0 to 12.6 kN/m. These values are consistent with those required for paving geotextiles for anti-reflective cracking systems both in US and Brazilian specifications (ASHTO M 288-05 2001 and DER-SP ET-DE-P00/043, 2006), respectively. In the case of the geogrid composite, the reported tensile strength is the unit tension that corresponds to a strain of 12%. Fig. 4 presents the unit tension-strain curves for the six nonwoven geotextiles used in this study prepared using four different rates of impregnation (including virgin geotextiles). The results shown in the figure correspond to the average curve obtained from five repeats of each one of the six geotextiles. The figures show the results obtained using virgin geosynthetics (solid line) as well as the results for geosynthetics impregnated with a rate of 0.6 l/m^2, a rate corresponding to the asphalt retention capacity and a rate that exceeds than the asphalt retention capacity. The geotextiles generally did not show a significant change in the strain at breakage after impregnation. However, the ultimate tensile strength of the various geotextiles increased after impregnation. Fig. 5 presents the unit tension–strain curves of the geogrid

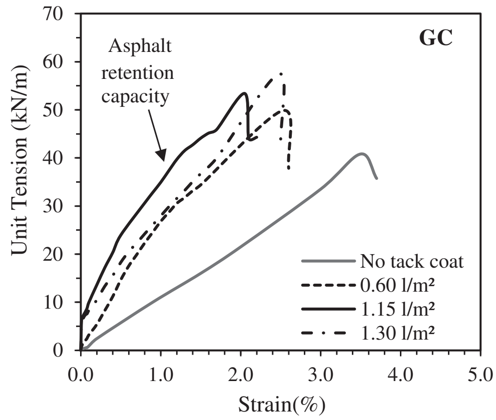

Fig. 5. Unit tension-strain curves of geogrid composite impregnated with different rates of emulsion.

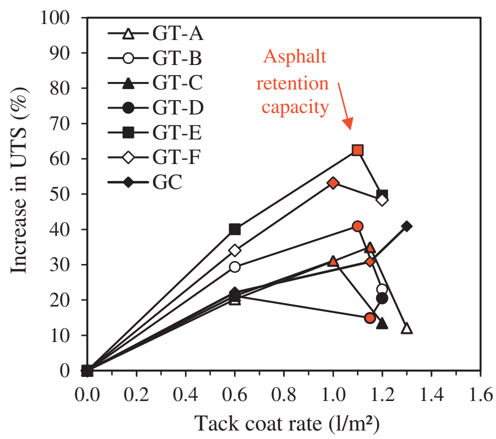

Fig. 6. Increase in the UTS as function of tack coat rate for the geosynthetic paving materials used in this study.

composite (GC) after impregnation, as well as the results for virgin sample results. The ultimate tensile strength of the geogrid composite shows an increasing trend after impregnation; however, unlike the nonwoven geotextiles, the geogrid composite shows a significant reduction in the strain at breakage after impregnation. Fig. 6 summarizes the experimental results by presenting the increase in geosynthetics ultimate tensile strength (UTS) as a fraction of the UTS of virgin geosynthetics for the various rates of asphalt impregnation considered in this study. Increases of up to 62% on the ultimate tensile strength of the geotextiles were obtained after impregnation. Use of a tack coat impregnation rate equal to the asphalt impregnation capacity is identified in the figure for the various paving geosynthetics. For most of the geotextiles tested in this study (GT-A, GT-B, GT-C, GT-E, GT-F), use of a tack coat rate equal to the asphalt retention capacity leads to the highest value of ultimate tensile strength. The average rate of asphalt tack coat emulsion for the geosynthetic materials used in this study was 1.07 l/m^2 (residual), which is similar to the tack coat rate typically recommended for practical applications. Accordingly, the geosynthetic asphalt retention capacity appears to correlate well with the optimum tack coat rate that should be selected in order to maximize

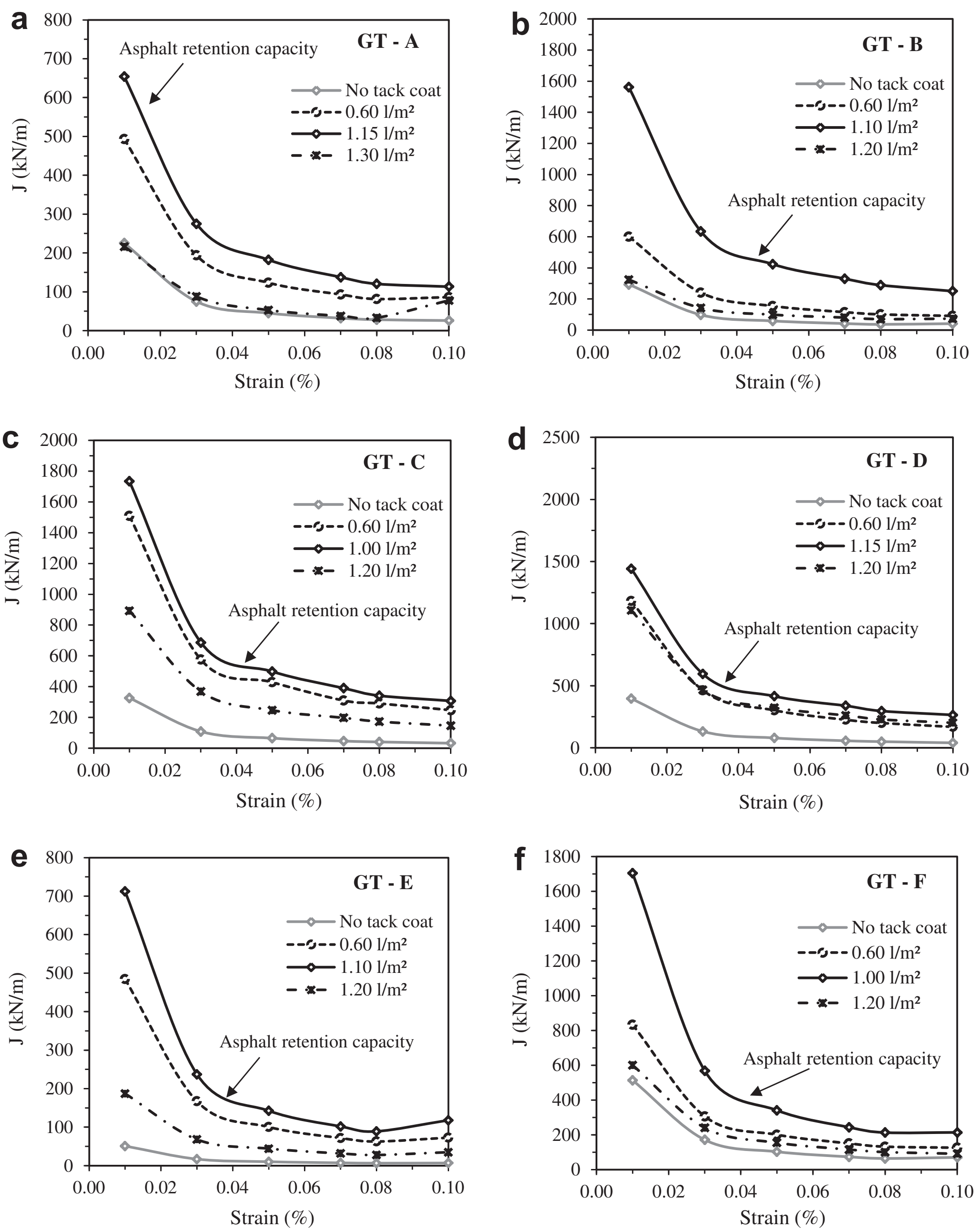

Fig. 7. Stiffness curves (J) versus percentage strain for paving geotextiles with different rates of asphalt emulsion: (a) GT-A; (b) GT-B; (c) GT-C; (d) GT-D; (e) GT-E and (f) GT-F.

the tensile strength of the geosynthetic paving product. Noticeably, the asphalt retention capacity was found to be the optimum rate for the significant majority of the geosynthetics tested in this study, which includes products from different manufactures as well as different polymers and physical properties.

Effect of impregnation on the stiffness

The results of tensile tests were used to define the secant stiffness of the geosynthetics evaluated in this study. The stiffness was defined for strain values ranging from 0.01% to 0.1%. Fig. 7 shows the stiffness (J) as a function of percent strain for the nonwoven geotextiles tested in this study for increasing rates of tack coat emulsion impregnation. Consistent with the results presented in Fig. 6, impregnation provides often considerable increase in the stiffness values obtained for comparatively low strain levels. In particular, the use of a tack coat rate equal to the asphalt retention capacity shows the maximum stiffness values for all six nonwoven geotextiles tested in this study. Based on these results, a tack coat rate equal to the asphalt retention capacity corresponds to the optimum emulsion content to be selected in order to achieve the maximum stiffness values.

In order to further evaluate the optimum asphalt bitumen dosage for the tested materials, the stiffness was estimated for all nonwoven geotextiles for increasing values of

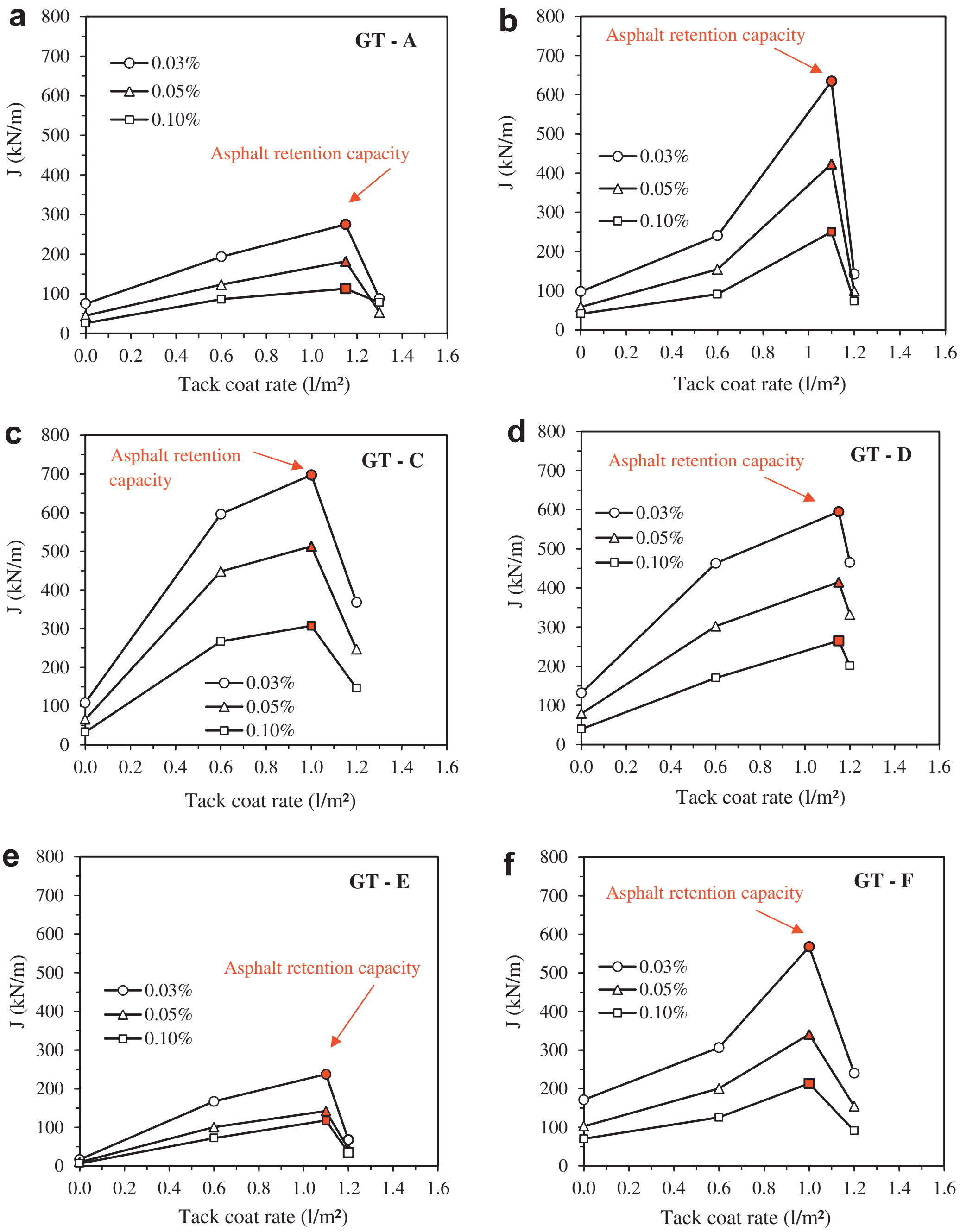

Fig. 8. Stiffness curves (J) versus tack coat rate at different strain levels for paving geotextiles: (a) GT-A; (b) GT-B; (c) GT-C; (d) GT-D; (e) GT-E and (f) GT-F.

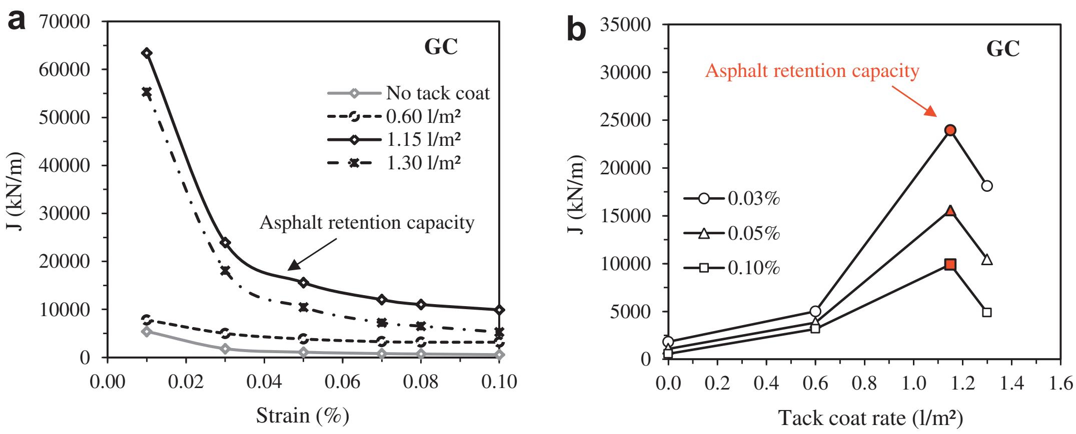

Fig. 9. Tensile results for geogrid composite: (a) stiffness curves versus percentage strain with different rates of asphalt emulsion; (b) increase in the UTS as function of tack coat rate.

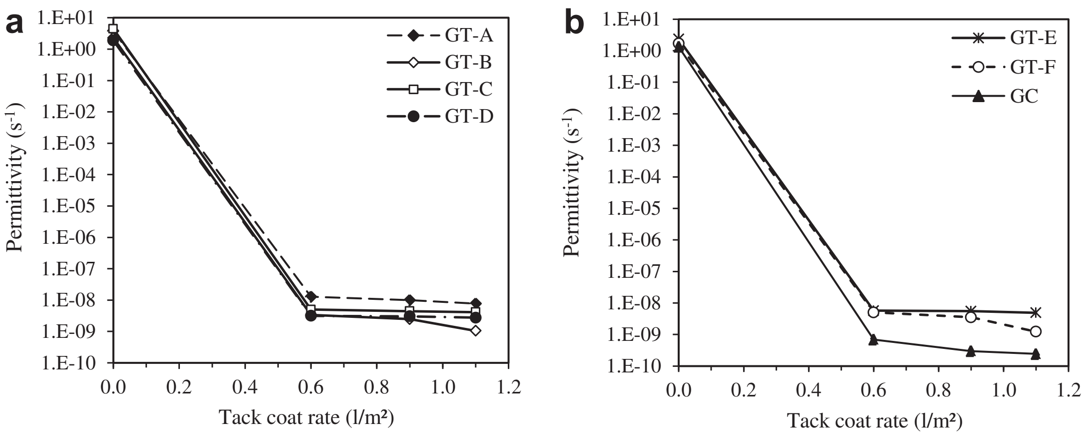

Fig. 10. Permittivity values of impregnated geosynthetics with different rates of emulsion: (a) PET nonwoven geotextiles; (b) PP nonwoven geotextiles and geogrid composite.

tack coat rate considering the strain levels of 0.03%, 0.05% and 0.1%, as shown in Fig. 8. An optimum tack coat rate could be defined for all materials. Use of asphalt retention capacity as a tack coat was found to be the most appropriate amount to provide a considerable increase in the stiffness for all geotextiles tested, as highlighted in Fig. 8.

Fig. 9 shows the effect of asphalt impregnation stiffness for the case of the geogrid composite. Fig. 9a shows the stiffness (J) for increasing strain values, while Fig. 9b shows the stiffness as a function of the tack coat rate for strain levels of 0.03%, 0.05% and 0.1%. In particular, a tack coat rate equal to the asphalt retention capacity is the optimum amount to use for impregnation of all geosynthetics evaluated in this study considering both the UTS and the stiffness increase. In summary, the results clearly show the existence of an optimum impregnation rate that leads to an enhanced mechanical behavior of paving geosynthetics.

Effect of impregnation on hydraulic conductivity

Fig. 10 presents results of permittivity (i.e. the hydraulic conductivity divided by the thickness of the geosynthetic) as obtained from water vapor transmission tests conducted using samples with different rates of cationic asphalt emulsion. The results indicate that the permittivity decreased sharply after impregnation. However, impregnation with rates beyond approximately 0.6 l/m^2 does not reduce significantly more the permittivity values. In particular, products GT-A, GT-C, GT-D and GT-E, showed negligible changes in permittivity values with increase tack coat rate beyond

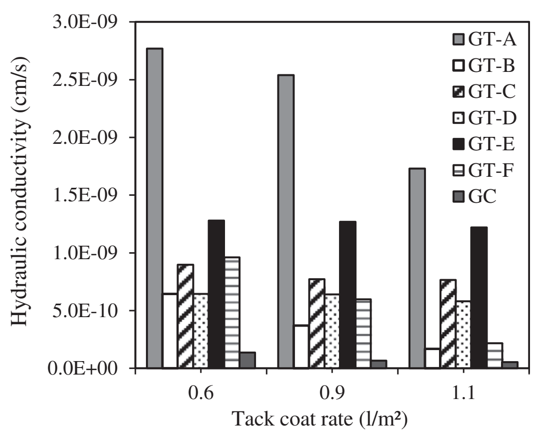

Fig. 11. Hydraulic conductivity as function of tack coat rate for the geosynthetic paving materials used in this study.

0.6 l/m^2. However, an additional reduction in reduction is permittivity is observed for GT-B (57%) and GT-F (64%) for impregnation rates beyond 1.10 l/m^2 (approximately the value of asphalt retention capacity). The geogrid composite showed decreases in permittivity values that are even more significant that those obtained with the nonwoven geotextiles. Fig. 11 shows the hydraulic conductivity results for all geosynthetics evaluated in this study. Even though some differences in hydraulic conductivity are noted among the various products it should be noted that the hydraulic conductivity values are all within the same order of magnitude, particularly for all nonwoven geotextiles, which show hydraulic conductivity values ranging from 10^{-09} to 10^{-10} cm/s after impregnation. The geogrid composite results in an even lower hydraulic conductivity value (10^{-11} cm/s). After impregnation these results indicate that impregnated geosynthetics may have hydraulic conductivity values that are consistent with those of geomembranes (10^{-12} cm/s). Accordingly, these results indicate that waterproofing barrier is certainly a viable mechanism that contributes to enhance pavement performance in the field applications.

Conclusions

Experimental testing program was conducted to quantify changes in mechanical and hydraulic properties of paving geosynthetics after they are subjected to emulsion impregnation. Both nonwoven geotextiles and geogrid composite were investigated. The results of the tensile tests on nonwoven geotextiles indicate that impregnation did not result in significant changes in the strain at breakage, although the geogrid composite showed a decreasing strain at breakage with increasing emulsion rate. On the other hand, impregnation led to increases of up to 62% in the ultimate tensile strength of all geosynthetics tested in this study. In addition, impregnation led to a considerable increase in stiffness values of all paving geosynthetics, particularly for comparatively low strain levels (0.05%). A tack coat rate equal to the asphalt retention capacity was found to be the most beneficial impregnation rate for the use of all geosynthetics evaluated in this study if the objective is to increase both ultimate tensile strength and the stiffness after impregnation. The results clearly show that there exists an optimum impregnation rate that leads to an enhanced mechanical behavior of the geosynthetics, as all materials tested showed that a beyond certain impregnation rate, a decrease is observed in tensile strength and stiffness. In terms of hydraulic properties, all geosynthetics significant decrease in hydraulic conductivity after sample impregnation, reaching values of approximately 10^{-9} cm/s, which is consistent with hydraulic conductivity values of geosynthetics used as hydraulic barriers. The geogrid composite resulted in even lower values of hydraulic conductivity (10^{-11} cm/s) after impregnation. Continued increase in tack coat rate beyond values of approximately 0.6 l/m^2 did not continue to reduce permittivity values for most of the materials.

Asphalt overlay reinforcement using paving geosynthetics holds significant promise in the rehabilitation of pavements. To this effect, relevant properties of impregnated geosynthetics were defined in this study. Overall, significant improvements in mechanical and hydraulic properties result after emulsion impregnation.

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