Behavior of Impregnated Paving Geotextiles: Study of Optimum Tack Coat Rate

N. S. Correia, S.M.ASCE[1]; J. G. Zornberg, M.ASCE[2]; and B. S. Bueno[3]

Abstract: Paving geotextiles are becoming increasingly used in highway construction overlays in order to recover cracked asphalt pavements. In antireflective cracking systems, the geosynthetic should have the ability to absorb and retain the asphalt tack coat to effectively bond the system to the existing pavement and overlay. However, the type and rate of tack coat impregnation can significantly influence the reinforcement mechanism, potentially leading to early overlay failure. Stiffness has been identified as the governing property to quantify the potential contribution of the interlayer to the asphalt overlay strength. In addition, the overall behavior of reinforced asphalt pavements may also be incorporated with an increased tensile strength of the geosynthetic. With the purpose of quantifying the often significant changes in the mechanical behavior of paving geosynthetics that occur after bitumen impregnation, a series of tensile strength tests were conducted in this study using nonwoven geotextiles with different rates of asphalt emulsion. Evaluation of the geosynthetics changes in tensile strength and tensile stiffness with increasing tack coat rates provides insight on the identification of an optimum bitumen dosage for these materials. A tack coat rate equal to the asphalt retention capacity was specifically evaluated in this study and was generally found to be the optimum rate that leads to the highest tensile strength and stiffness of impregnated of geotextiles. **DOI: 10.1061/(ASCE)MT.1943-5533.0001026.**

Author keywords: Geosynthetics; Paving geotextiles; Tensile stiffness; Asphalt retention; Asphalt emulsion.

Introduction

The use of paving geotextiles is becoming increasingly used in highway projects involving construction of overlays to retrofit existing asphalt pavements that failed due to existing cracking. Paving geotextiles have been reported to provide three main functions to enhance the performance of asphalt overlays: a stress-relief layer, a waterproofing barrier and as reinforcement (Khoddaii et al. 2009; Lytton 1989). Geotextile reinforcement in asphalt concrete layers provides additional tensile strength to the resulting composite by increasing the amount of energy that can be absorbed during repeated loading cycles (Mahrez et al. 2005). As reported by Pasquini et al. (2012), the mechanical properties of reinforced asphalt pavement systems increase with increasing geosynthetic tensile strength per unit length. Zamora-Barraza et al. (2010) report that the stiffness obtained from tensile tests on geosynthetics is a more relevant property than the maximum tensile strength. Specifically, the value of the unit tensile in the geosynthetic for deformations below 1.2% was found to be an appropriate measure of the initial modulus of the geosynthetic. Sprague et al. (1998) also state that stiffness constitutes the most critical property for the potential contribution of the interlayer to the strength of the overlay system.

Studies performed on the behavior of paving geosynthetics in asphalt concrete layers have shown the potential contributions of antireflective cracking systems using geosynthetics (Mounes et al. 2011; Pasquini et al. 2012; Zamora-Bazarra et al. 2011; Zou et al. 2007). However, the compilation of design specifications for paving geosynthetics used as antireflective cracking systems has been a difficult task, leading to largely empirical procedures. This is because the relative conditions of cracked asphalt pavements have not been fully quantified and full understanding of the reinforcement mechanism has not been achieved. In addition, the correct positioning and proper installation of the paving geosynthetic is crucial to the good performance of an antireflective system and requires further assessment (Cleveland et al. 2002).

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 attach the geosynthetic to the underlying plays an important role in this technique since using a tack coat with inadequate characteristics can 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. The tack coat rate was recommended to be somewhat above the optimum level, but not significantly above this level as this may cause shear strength losses at the interface of the underlying layer with the paving geosynthetic (Mounes et al. 2011). As stated by Lytton (1989), a slight excess of tack coat is believed to facilitate waterproofing against infiltrating water if cracks end up reflecting to the surface. According to Correia and Bueno (2011), rates of asphalt emulsion higher than $0.60\ \mathrm{L/m^2}$ are sufficient to significantly reduce the hydraulic conductivity of paving geotextiles. By reducing infiltration, the system becomes an efficient moisture barrier that enhances the pavement performance. However, the waterproof function depends on

[1]Ph.D. Candidate, Sao Carlos School of Engineering, Geotechnical Engineering Dept., Univ. of Sao Paulo, 400 Trabalhador Sao Carlense Ave., SP 13.566-536, Sao Carlos, Brazil (corresponding author). E-mail: nataliacorreia@usp.br

[2]Fluor Centennial Professor, Civil Engineering Dept.—GEO, Univ. of Texas at Austin, 1 University Station C1792 Austin, TX 78712-0280. E-mail: zornberg@mail.utexas.edu

[3]Titular Professor, Sao Carlos School of Engineering, Geotechnical Engineering Dept., Univ. of Sao Paulo, 400 Trabalhador Sao Carlense Ave., SP 13.566-536, Sao Carlos, Brazil. E-mail: bsbueno@sc.usp.br

Note. This manuscript was submitted on August 26, 2013; approved on January 8, 2014; published online on January 10, 2014. Discussion period open until October 28, 2014; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Materials in Civil Engineering***, © ASCE, ISSN 0899-1561/04014077(8)/$25.00.

the material properties and applied tack coat (Mounes et al. 2011).

According to AASHTO M 288-06 (AASHTO 2011), the specified rate of asphalt binder application must be sufficient to satisfy the asphalt retention properties of the paving fabric, and bond the paving fabric and overlay to the old pavement. ASTM D 6140 (ASTM 2005b) 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 geosynthetics saturation [ASTM D 6140 (ASTM 2005b)] and provides a correction based on the asphalt cracking level 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 each project depending on the pavement conditions. This test should be performed on site with different tack coat quantities 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 the tack coat quantity enhances the material stiffness, possibly enhancing the paving geosynthetics reinforcement mechanism.

Based on the evaluation of the available technical literature, a systematic evaluation of the possible changes in the mechanical behavior of paving geotextiles after bitumen impregnation is needed, as the reinforcement benefit of paving geotextiles has typically not been considered as relevant, at least when compared to mechanism such as stress relief and waterproof. Accordingly, a thorough experimental study involving tensile tests was conducted in this investigation using paving nonwoven geotextiles with different rates of asphalt emulsion. An important parameter to be defined in this study is the optimum bitumen dosage for a given geotextile type. Specifically, the influence of tack coating contents on tensile strength and stiffness of geotextiles are investigated. A tack coat rate equal to the asphalt retention capacity is also evaluated as a baseline for the effect of the tack coat rate on the tensile behavior of geotextiles.

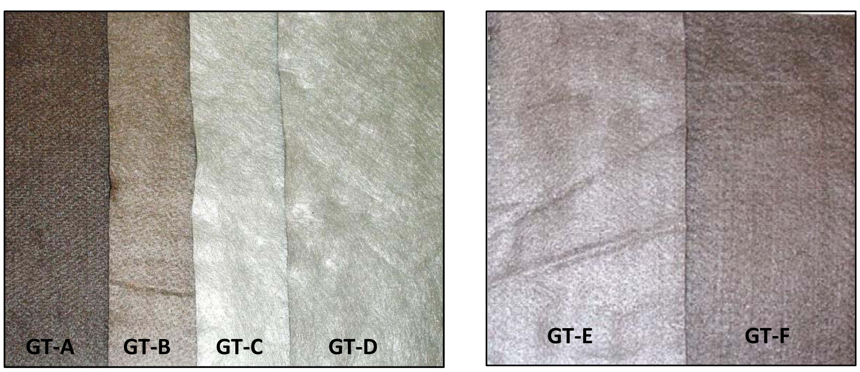
Materials and Methods

Paving Geosynthetics

Different paving geotextiles were used to investigate changes in tensile properties after asphalt emulsion impregnation. The set of materials contains needle-punched 100% polyester (PET) and 100% polypropylene (PP) nonwoven geotextiles. Fig. 1 illustrates the paving geotextiles used in this study. Physical and tensile properties in the cross-machine direction of the geotextiles are presented in Table 1.

Tack Coat Emulsion

Asphalt emulsion is a type of asphalt binder usually applied on paving geotextiles. Other asphalt binders include asphalt cements and asphalt cutbacks, although asphalt emulsions have been recommended as sealants for applications involving paving



(a) (b)

Fig. 1. Geotextile paving materials used in this study: (a) PET nonwoven geotextiles; (b) PP nonwoven geotextiles

Table 1. Properties of the Geotextiles Used in this Study

Material	Mass per unit area (g/m^2)	Polymer type	Filament type	Tensile properties (ASTM 2005a) Tensile strength (kN/m)	Tensile properties (ASTM 2005a) Strain at break (%)	Asphalt retention (L/m^2) (ASTM 2005b)
GT-A	146	PET	Short	6.86	94.39	1.15
GT-B	182	PET	Short	10.93	91.41	1.10
GT-C	151	PET	Long	7.30	61.42	1.00
GT-D	183	PET	Long	8.47	59.14	1.15
GT-E	165	PP	Short	8.62	94.26	1.10
GT-F	214	PP	Short	12.60	85.53	1.00

Table 2. Properties of the CRS Asphalt Emulsion Used in this Study

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

geotextiles. Emulsions consist of asphalt cement in an emulsified solution with water. Cationic aqueous rapid setting emulsion (CRS) was used here as the tack coat for geotextiles impregnation, in accordance with DNER-SP ET-DE-P00/043 (National Department of Transportation–Sao Paulo 2006) specifications. After spreading, the asphalt emulsion must be allowed to break (should separate from the water) before placing the new asphalt layer. The characteristics of the tack coat emulsion used in this study are shown in Table 2.

Procedure for Tensile Testing of Impregnated Geotextiles

Tensile tests were conducted on paving geotextiles to evaluate possible changes in the mechanical behavior of impregnated materials. The tensile strength was reported in terms of force per unit width as obtained from wide-width tests conducted in accordance to ASTM D 4595 (ASTM 2005a).

All materials evaluated in this study were tested in the cross-machine direction. Four impregnation rates were used on the paving geotextiles specimens used for tensile 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 approximately 10–20% above the asphalt retention capacity. The asphalt retention results for the various geotextiles are also listed in Table 1. The impregnation process involved using the predetermined quantity of emulsified asphalt to impregnate each geotextile material. The rapid setting action ranged from 30 min to 1 h.

Changes in the internal structure of the geotextile after impregnation and, consequently, changes in their mechanical behavior were quantified. This included changes in the tensile properties of the geotextile under different deformation conditions. Five specimens in the transverse direction, measuring 200×200 mm, were prepared for each nonwoven geotextile and subsequently tested until rupture. Fig. 2 shows virgin and impregnated specimens of paving nonwoven geotextiles ready for tensile testing. Fig. 3 illustrates the tensile testing in progress of virgin and impregnated nonwoven geotextiles.

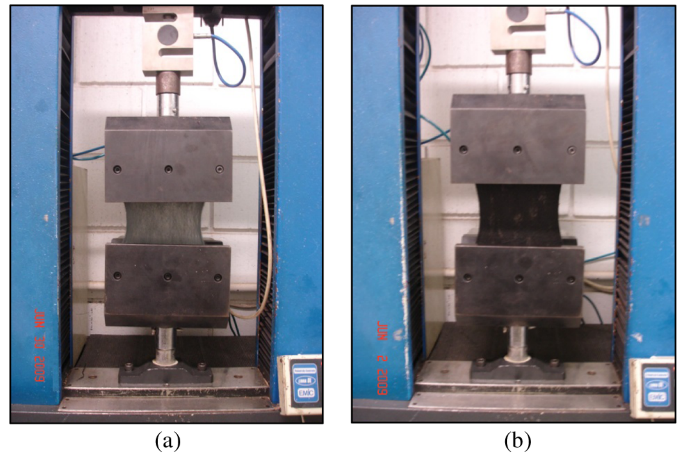


Fig. 3. View of tensile tests in progress: (a) virgin geotextile; (b) geotextiles impregnated with asphalt emulsion

Evaluation of Tensile Results

Fig. 4 provides the unit tension-strain curves of nonimpregnated paving geotextiles used in this study. The results shown in the figure correspond to the average curve obtained from five repeats of each one of the six geotextiles tested in cross-machine direction. Results of PET (GT-A, GT-B, GT-C, and GT-D) and PP (GT-E and GT-F) 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 antireflective cracking systems in both US and Brazilian specifications (ASHTO 2001; National Department of Transportation–Sao Paulo 2006), respectively.

Tensile tests were also conducted using impregnated geotextile specimens, which were also conducted in the cross-machine

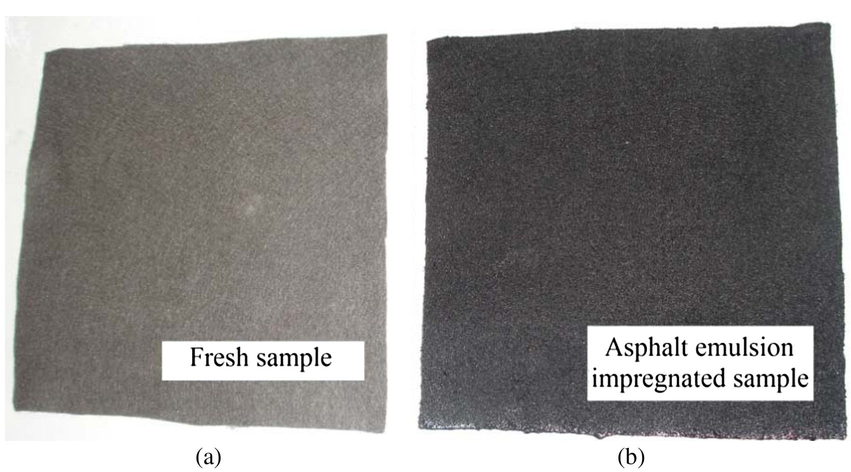


Fig. 2. Virgin and impregnated samples of paving nonwoven geotextiles

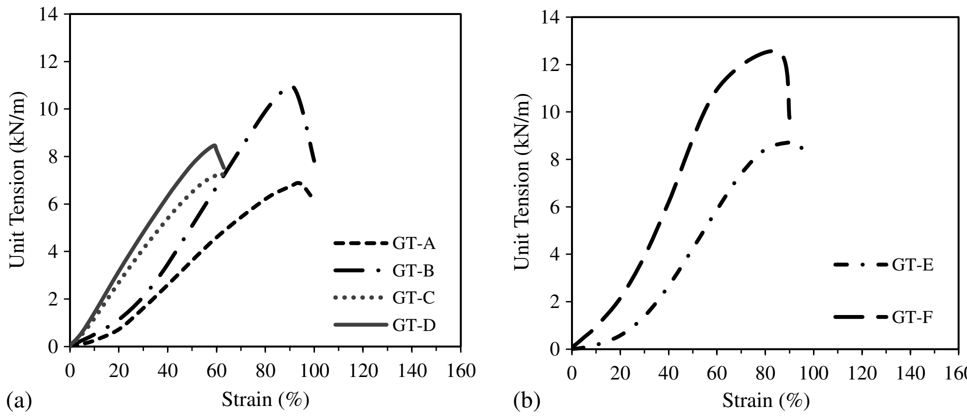


Fig. 4. Unit tension-strain curves for the geotextiles tested in the cross-machine direction: (a) PET; (b) PP

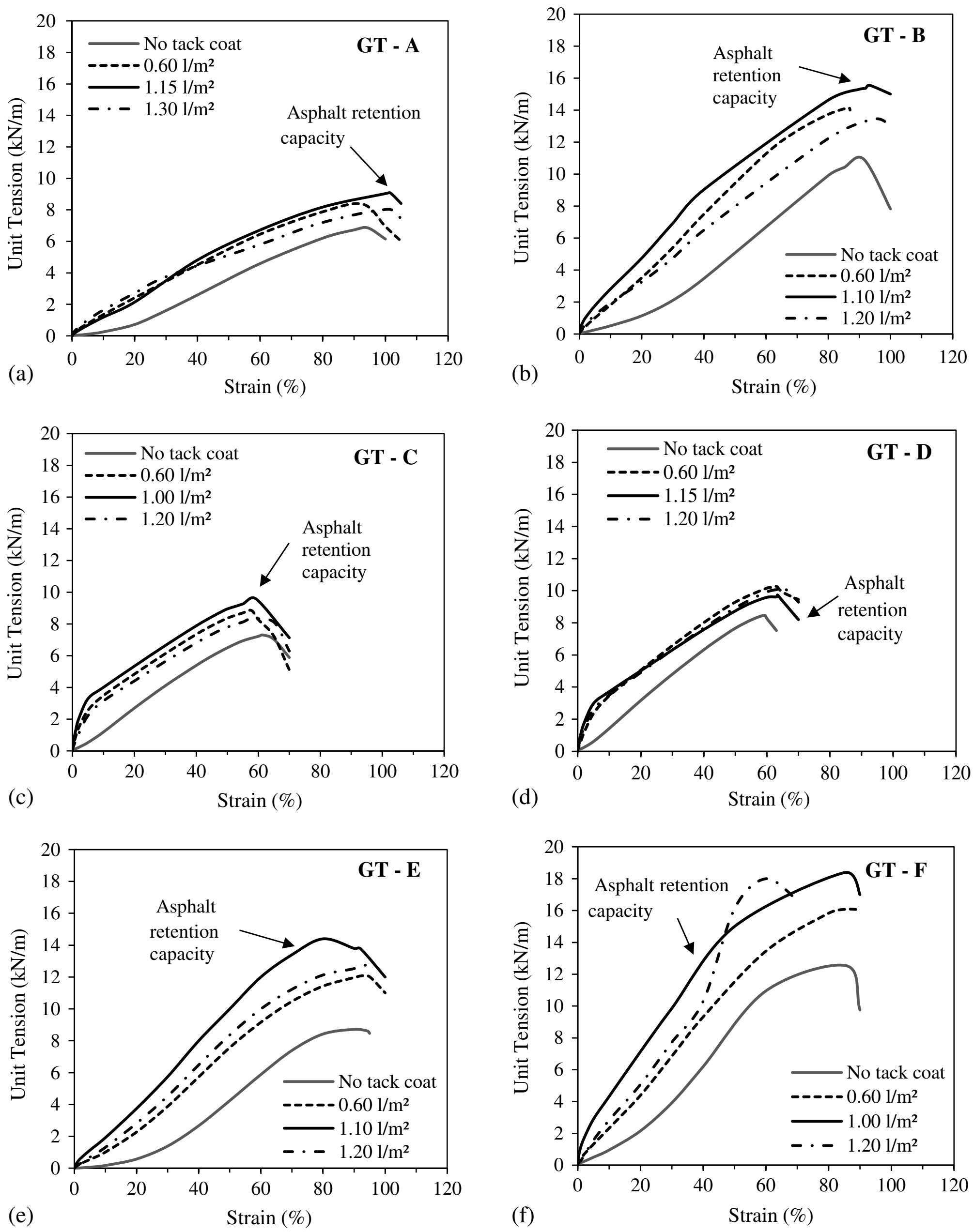


Fig. 5. Unit tension-strain curves of nonwoven geotextiles impregnated with different rates of emulsion: (a) GT-A; (b) GT-B; (c) GT-C; (d) GT-D; (e) GT-E; (f) GT-F

direction. Fig. 5 presents the unit tensile-strain curves for the six nonwoven geotextiles prepared using four different rates of impregnation (including the nonimpregnated sample results). The results shown in the figure also correspond to the average curve obtained from five repeats of each one of the six geotextiles tested. 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. The figures show the results obtained using nonimpregnated geotextiles (solid line) as well as geotextiles impregnated with a rate of $0.6\ \mathrm{L/m^2}$, a rate corresponding to the asphalt rate capacity and a rate higher than the asphalt retention capacity. Fig. 6 summarizes the experimental results by presenting the increase in geotextile ultimate tensile strength as a fraction of the UTS 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. The asphalt retention capacity as tack coat impregnation for the materials tested is highlighted in the figure. For most of the geotextiles tested in this study (GT-A, GT-B, GT-C, GT-E, GT-F), the use of a tack coat rate equal to the asphalt retention leads to the highest value of ultimate tensile strength. The average rate of asphalt tack coat emulsion for these materials was $1.07\ \mathrm{L/m^2}$ (residual), which is similar to the tack coat rate typically recommended for practical applications. Accordingly, the geotextile asphalt retention capacity appears to correlate well with an optimum tack coat rate to be selected in order to maximize the tensile strength of the geotextile paving product. Noticeably, this value of the optimum rate was consistent for all six geotextiles tested in this study, which includes products from different manufactures as well as different polymers and physical properties.

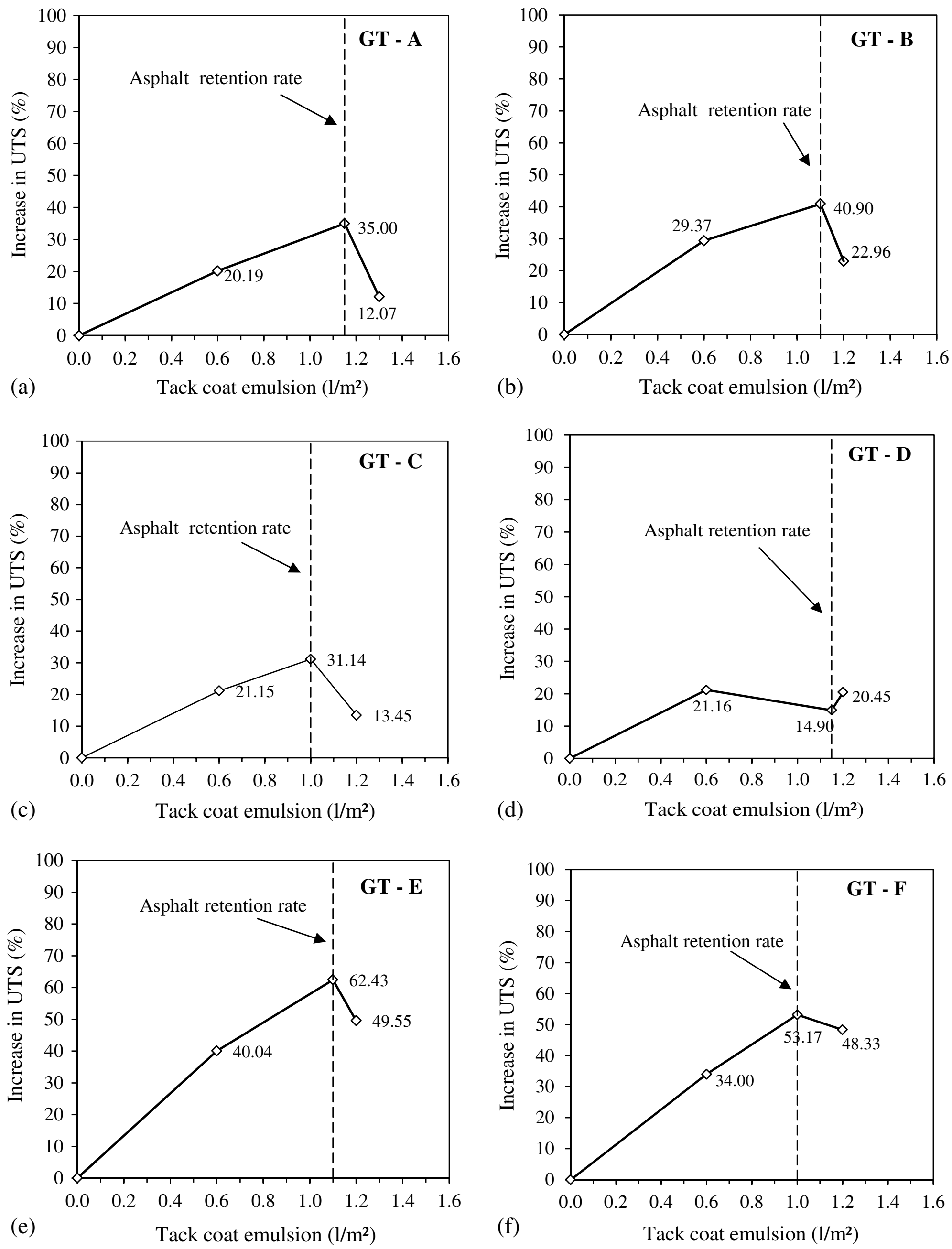


Fig. 6. Increase in the UTS as function of tack coat emulsion rate: (a) GT-A; (b) GT-B; (c) GT-C; (d) GT-D; (e) GT-E; (f) GT-F

Evaluation of Stiffness Results

The results of tensile tests were used to define the secant stiffness of the geotextiles 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 curves for the PET and PP nonwoven geotextiles tested after tack coat emulsion impregnation. Consistent with the results presented in Fig. 6, the impregnation seems to provide a considerable increase in the stiffness values obtained for comparatively low strain levels. In addition, the use of a tack coat rate equal to twice the asphalt retention capacity shows the maximum stiffness values for all six 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 used in order to achieve the maximum values of stiffness.

In order to define the optimum asphalt bitumen dosage for the tested materials, the stiffness was estimated for all nonwoven geotextiles for increasing values of tack coat rate considering the strain levels of 0.03, 0.05, and 0.1% (Fig. 8). An optimum tack coat rate could be defined for all materials. The optimum tack coat rate was found to be approximately 1.12 $\mathrm{L/m^2}$ for GT-A, GT-B, GT-D, and GT-E. The asphalt retention capacity as a tack coat has been found to be the most appropriate amount to provide a considerable increase in the stiffness for all geotextiles tested, as highlighted in Fig. 8.

In fact, a tack coat rate equal to the asphalt retention capacity is the most beneficial amount to use for impregnation of all geotextiles evaluated in this study considering both UTS and stiffness increase. It is clear that there is an optimum impregnation rate that leads to an enhanced mechanical behavior of the geotextiles, as all

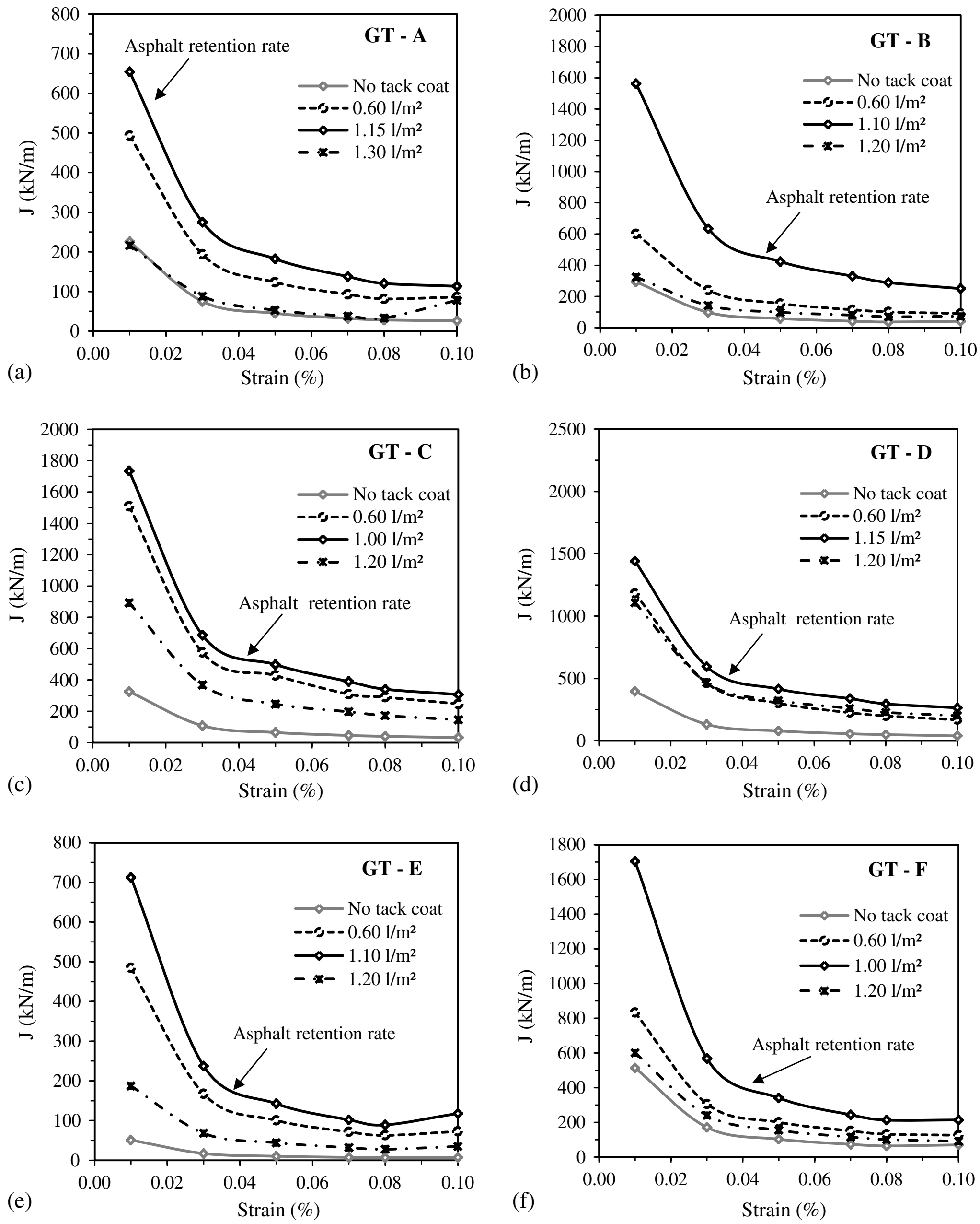


Fig. 7. Stiffness curves (J) as function of percentage strain for paving geotextiles with different rates of asphalt emulsion: (a) GT-A; (b) GT-B; (c) GT-C; (d) GT-D; (e) GT-E; (f) GT-F

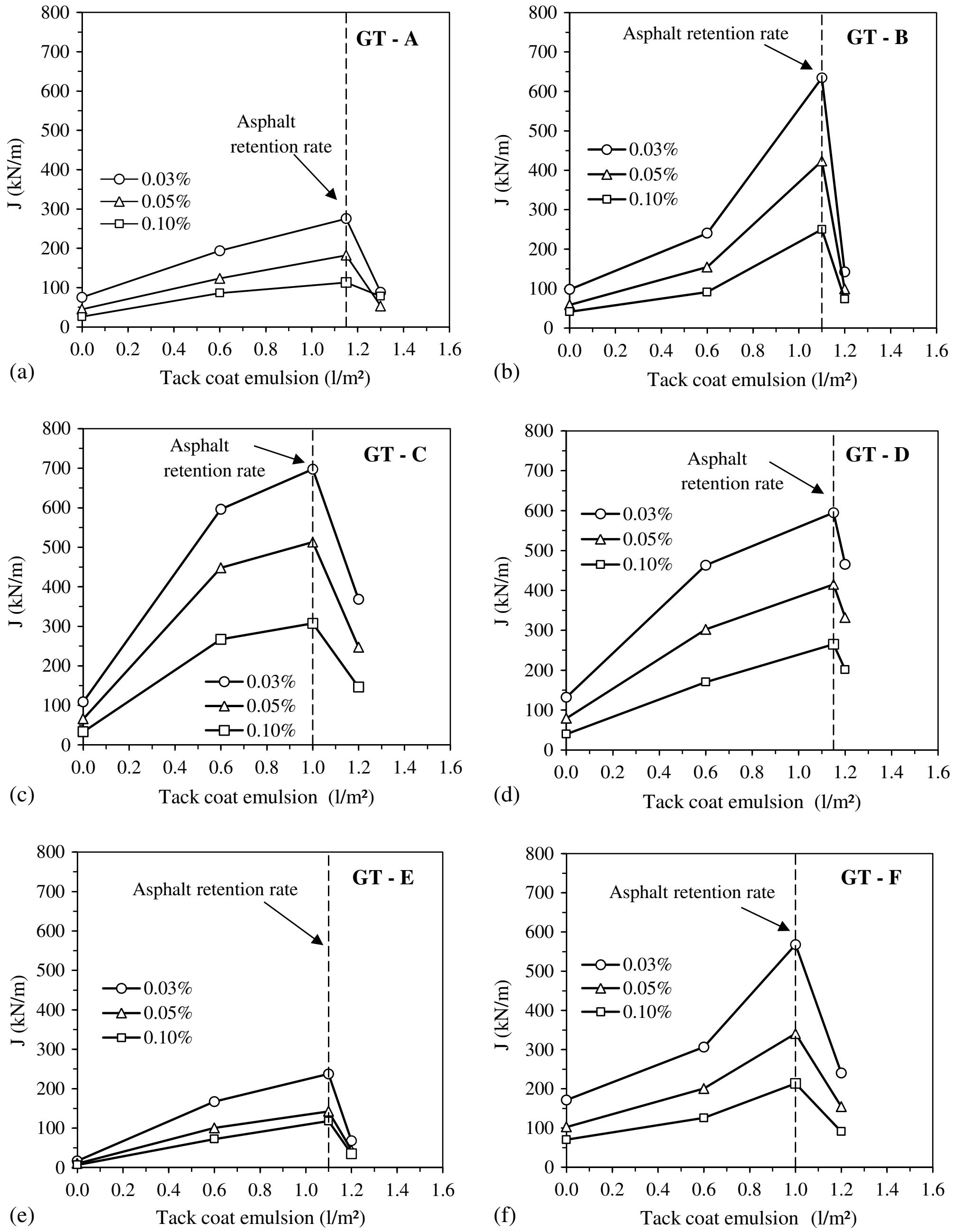


Fig 8. Stiffness curves (J) as function of tack coat rate for different strain levels in paving geotextiles: (a) GT-A; (b) GT-B; (c) GT-C; (d) GT-D; (e) GT-E; (f) GT-F

materials tested showed that the highest amount of impregnation did not lead to the highest tensile strength or stiffness response.

Conclusions

This paper presents the results of an experimental testing program conducted to assess the influence of tack coating contents on the maximum tensile strength and stiffness increase of paving geotextiles. A tack coat rate equal to the asphalt retention capacity was evaluated as a baseline for the effect of the tack coat rate on the tensile behavior of geotextiles.

The results of the tensile tests indicate that impregnation did not result in significant changes in the strain at breakage. However, impregnation led to increases of up to 62% on the ultimate tensile strength of nonwoven geotextiles results after impregnation were noted. In addition, the impregnation led to a considerable increase in stiffness values specifically for strain levels up to 0.05%. A tack coat rate equal to the asphalt retention capacity is the most beneficial amount to use for impregnation of all geotextiles evaluated in this study considering both UTS and stiffness increase. It is clear that there is an optimum impregnation rate that leads to an enhanced mechanical behavior of the geotextiles, as all materials tested showed that the highest amount of impregnation did not lead to the highest tensile strength or stiffness response. Overall, there were no significant differences in the response to impregnation among the six geotextiles tested in this study, which correspond to different manufactures, as well as different polymers or physical properties. Asphalt overlay reinforcement using high-stiffness paving materials holds promise in the rehabilitation of pavements.

Accordingly, with a reliable estimate of impregnated geotextile stiffness, reinforced asphalt overlays can be designed and reinforcement materials can be specified, thus optimizing the cost-benefit ratio of this technique.

Acknowledgments

The authors thank the Coordination for the Improvement of Higher Education Personnel (CAPES) for the financial support to this study.

References

AASHTO. (2001). "Standard specification for geotextile specification for highway applications." *M 288–05*, Washington, DC.

AASHTO. (2011). "Standard specification for geotextile specification for highway applications." *M 288–06*, Washington, DC.

Alvarez, A. D. C. (2008). "Repaving principal highways in Caracas Venezuela using nonwoven needle punched, and impregnated with asphalt emulsion geotextiles." *CD Proc., First Pan American Geosynthetics Conf. and Exhibition*, IFAI, 1256–1264.

ASTM. (2004). "Standard test method for distillation of emulsified asphalt." *D-6997*, West Conshohocken, PA.

ASTM. (2005a). "Standard test method for tensile properties of geotextiles by the wide-width strip method." *D-4595*, West Conshohocken, PA.

ASTM. (2005b). "Standard test method to determine asphalt retention of paving fabrics used in asphalt paving for full-width applications." *D-6140*, West Conshohocken, PA.

ASTM. (2008). "Standard test method for oversized particles in emulsified asphalts (sieve test)." *D-6933*, West Conshohocken, PA.

ASTM. (2009a). "Standard practice for identifying cationic emulsified asphalts." *D-7402*, West Conshohocken, PA.

ASTM. (2009b). "Standard test method for determining demulsibility of emulsified asphalt." *D-6936*, West Conshohocken, PA.

ASTM. (2009c). "Standard test method for viscosity of emulsified asphalt by Saybolt Furol viscometer." *D-7496*, West Conshohocken, PA.

Baker, T. L. (1997). "Results of melt through asphalt absorption and permeability tests." Amoco Fabrics and Fibers, Austell, GA.

Castro, D., and Ballester, F. (2006). "Influence of asphalt cement type and oven type on asphalt retention capacity of paving geotextiles." *Geosynth. Int.*, 13(2), 83–86.

Cleveland, G. S., Button, J. W., and Lytton, R. L. (2002). "Geosynthetics in flexible and rigid pavements overlay systems to reduce reflection cracking." *Rep. No. FHWA/TX-02/1777*, Texas Dept. of Transportation Research and Technology Implementation Office, TX.

Correia, N. S. C., and Bueno, B. S. (2011). "Effect of bituminous impregnation on nonwoven geotextiles tensile and permeability properties." *Geotext. Geomembr.*, 29(2), 92–101.

Khoddaii, A., Fallah, S., and Moghadas Nejad, F. (2009). "Effects of geosynthetics on reduction of reflection cracking in asphalt overlays." *Geotext. Geomembr.*, 27(1), 187–195.

Koerner, R. M. (2005). *Design with geosynthetics*, 5th Ed.

Lytton, R. L. (1989). "Use of geotextiles for reinforcement and strain relief in asphalt concrete." *Geotext. Geomembr.*, 8(3), 217–237.

Mahrez, A., Karim, M. R., and Katman, H. Y. (2005). "Fatigue and deformation properties of using glass fiber reinforced bituminous mixes." *J. East. Asia Soc. Trans. Stud.*, 6, 997–1007.

Maurer, D. A., and Malasheskie, G. J. (1989). "Field performance of fabrics to retard reflective cracking." *Geotext. Geomembr.*, 8(3), 239–267.

Mounes, S. M., Karim, M. R., Mahrez, A., and Khodaii, A. (2011). "An overview on the use of geosynthetics in pavement structures." *Sci. Res. Essays*, 6(11), 2234–2241.

National Department of Transportation–Sao Paulo. (2006). "Anti-reflective cracking systems with geosynthetics." *DNER-SP ET-DE-P00/043*, Technical Specification, Sao Paulo, Brazil.

Pasquini, E., Bocci, M., Ferrotti, G., and Canestrari, F. (2012). "Laboratory characterisation and field validation of geogrid-reinforced asphalt pavements." *Road Mater. Pavement Des.*, 14(1), 17–35.

Sprague, C. J., Allen, S., and Tribbett, W. (1998). "Tensile properties of asphalt overlay geosynthetics reinforcement." *Transportation Research Record 1611, Paper No. 98-0519*, *Design with geosynthetics*, R. M. Koerner, ed., 5th Ed., 2005.

Zamora-Barraza, D., Calzada-Perézb, M., Castro-Fresnoc, D., and Vega-Zamanillob, A. (2010). "New procedure for measuring adherence between a geosynthetic material and a bituminous mixture." *Geotext. Geomembr.*, 28(5), 483–489.

Zamora-Barraza, D., Calzada-Perézb, M., Castro-Fresnoc, D., and Vega-Zamanillob, A. (2011). "Evaluation of anti-reflective cracking systems using geosynthetics in the interlayer zone." *Geotext. Geomembr.*, 29(2), 130–136.

Zou, W., Wang, Z., and Zhang, H. (2007). "Field trial for asphalt pavements reinforced with geosynthetics and behavior of glass-fiber grids." *J. Perform. Construct. Facil.*, 10.1061/(ASCE)0887-3828(2007)21:5(361), 361–367.