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Reuse potential of Spent Media Filter as an additive for Trinidad road paving applications

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Abstract: Trinidad and Tobago (TT) is an industrialized economy with a vibrant manufacturing sector. The manufacture of edible oil produces spent media filter (SMF), which poses negative environmental and health impacts, is currently dumped using indiscriminate disposal practices. The TT National Environment Policy was developed to enhance recovery, recycling and reuse of waste material, providing alternative avenues for disposal and creating economic activity. Through this initiative, SMF was assessed for its reuse potential as a performance enhancer in Trinidad Lake Asphalt (TLA) and Trinidad Petroleum Bitumen (TPB) for road paving applications. Studies evaluating the rheological properties of these blends showed that for maximum stiffness, elasticity and viscosity, the optimum dosages were at 1% TLA-SMF and 2% TPB-SMF blends. For TLA-SMF blends, an improvement in the rutting resistance was observed with the 1% blend while the fatigue cracking improved for both 1% and 8% blends; TPB-SMF improvements were noted with the 1% blend for fatigue cracking and the 2% blend for rutting resistance. These optimum performing TLA-SMF and TPB-SMF blends also demonstrated superior temperature susceptibility characteristics. The study shows favourable results that SMF can be reused as a performance enhancer in TT asphaltic materials to mitigate SMF disposal issues.

Index Terms - **waste material reuse, road paving, rheological properties, rutting resistance, fatigue cracking resistance**

I. INTRODUCTION

The production of edible oil manifests numerous environmental issues ranging from generation of solid waste and by-products, water and energy consumption and management to atmospheric and greenhouse gas emissions (World Bank Group, 2015). Solid waste and by-products resulting from the processing of edible oil, in particular vegetable oil, range from organic material to non-organic matter where pre-treatment is obligatory prior to disposal in accordance with proper environmental practices. The majority of these waste is dumped in landfills posing environmental threats causing contamination of water passages with oily components and chemicals from processing, increased likelihood of landfill fire ignition and enhancement in the development of microorganisms which can lead to an increase in algae bloom (Maharaj, 2009).

One such waste product generated from the bleaching stage in the manufacture of edible vegetable oil that raises environmental issues related with its disposal is spent bleaching earth. The properties of the bleaching earth complement its ability to remove pigmented impurities from the edible oils being produced (Girgi, 2005). Referred to as spent media filter (SMF) in this study, this waste consists acid-activated clay and traces amounts of oil residue, making up its inorganic and organic components (Pollard, Sollars and Perry, 1993). With the increased demand for advocating safe, environmentally friendly waste disposal mechanisms, emphasis have been placed in devising alternative disposal methods through the practice of recycling or reusing the SMF (Pollard, Sollars and Perry, 1993). From previous studies, the chemical composition and properties of this waste product lends itself for usage as a plant fertilizer, animal feedstock and additive for brick, cement and bituminous mixtures (Hernandez and Kamal-Eldin, 2013, Loh, et al., 2013, Sangiogi, et al., 2014 and World Bank Group, 2015).

In the Caribbean, Trinidad and Tobago is actively involved in the production and manufacture sector; under the food and beverage sector, edible vegetable oil is produced and marketed both locally and regionally (Ministry of Trade and Industry, 2018). With the introduction of the National Environment Policy which focuses on promoting recovery, recycling, reuse or reclamation of waste material, alternative methods to disposal of waste are being explored (Ministry of the Environment and Water Resources, 2011). From the proven avenues of salvaging SMF, the addition to bituminous mixture would be a feasible option for Trinidad and Tobago as it possesses naturally occurring asphalt in the form of Trinidad Lake Asphalt (TLA) and refinery produced bitumen referred to as Trinidad Petroleum Bitumen (TPB). This will alleviate the problem of disposing the waste accumulated from the manufacture of edible vegetable oil whilst improving the marketability and performance of TLA and TPB.

TLA is well known for its usage in runway pavements due to its unique composition contributing towards its consistent properties, stability, durability and ability to resist cracking (Widyatmoko and Elliott, 2008 and Maharaj, 2009). Research conducted by Maharaj (2009) on the composition and rheological properties of TLA and TPB concludes the superiority of the TLA in comparison to the TPB based on its rheological properties. It is believed that the high G^* and low δ values obtained for the TLA samples were as a result of its unique composition compared to other asphaltic material.

One method of improving performance in withstanding temperature fluctuations, traffic flow and pavement structure constructions is the implementation of polymer modified asphalt binders (Maharaj, 2009). Other additives that have been considered for modification of TLA and TPB range from used tyre rubber, polyethylene, used car oil and waste cooking oil (Maharaj, Balgobin and Singh-Ackbarali, 2009, Maharaj, Singh-Ackbarali, St. George and Russel, 2009 and Maharaj and Singh-Ackbarali, 2011). A more in depth understanding of modifying bitumen and asphalt using SMF was achieved by understanding the materials' properties and its behaviour to additives of a similar nature through exploiting published work in this field. Similar work was conducted by Sangiogi et al. (2014) where the use of bleaching clays as a filler in the production to Hot Mix Asphalts was studied. The bleaching clay utilized in their study was obtained from the decolourization of vegetable oil having a high residual organic fat content, similar to the nature of the SMF. Sangiogi et al. (2014) noted changes in the asphalt performance by the additional of these additives on the physical and mechanical features of the mixture through tensile, stiffness and resistance to deformation and cracking through determining the mixtures' volumetric and dynamic chemical characterization.

The aim of this study is to determine the feasibility of modifying TLA and TPB with the addition of the waste SMF being produced from the processing of edible vegetable oil industry in Trinidad and Tobago. From similar studies of success in the utilization of a waste additive similar in nature to the SMF to successfully modify TLA and TPB blends, an interest in testing the implications of modifying TLA and TPB with the waste SMF was spurred. As completed in the previous studies, the influence of the blends would be assessed based on the rheological properties which is based on its stress-strain-time-temperature response (Airey, 2002).

Rheology is defined as the study of the deformation or flow properties of materials based on the materials' elasticity and viscosity (Barnes, Hutton and Walters, 1989). The effect of adding modifiers to asphalt and bitumen bases is dependent on the chemical components and colloid structures of the additive and its compatibility with the base (He, Zheng, Chen and Kuang, 2019). In order to evaluate the impact of these modifications, the Strategic Highway Research Programme proposed the evaluating pavement service performance in relation to rheological properties where the dynamic rheological property is measured by the dynamic shear rheological test (Kenndey, et al., 1994 and He, Zheng, Chen, and Kuang, 2019).

These characteristics can be determined using Dynamic Shear Rheometer (DSR) which are overseen within the linear viscoelastic response (Airey, 2002 and He, Zheng, Chen and Kuang, 2019). The DSR utilizes the sinusoidal principle to apply oscillatory stress and strain onto the sample mould which is then placed between the parallel plates where the tests are conducted at varying temperatures and loading frequencies within the viscoelastic range (Airey, 2002). A Viscoanalyzer software was then used to analyse the complex modulus (G^*) and phase angle (δ) at varying frequencies and temperatures within the operational range of pavements. Widyatmoko and Elliott (2008) defines δ as a representation of viscoelastic response of the material where a value tending towards 90^o would indicate higher viscosity and vice versa for an elastic response whereas G^* indicates the stiffness or rigidity of the material and its ability to withstand deformation. These results were used to generate the viscosity, rutting factor and fatigue cracking factor of the modified TLA and TPB samples.

II. Research Methodology

The TLA and TPB (60/70 penetration) samples utilized in this study were obtained from the Lake Asphalt Company of Trinidad and Tobago and the Petroleum Company of Trinidad and Tobago respectively. A breakdown of the origin and description of the TLA and TPB samples is captured in **Table 1** (Mohamed, Ramjattan-Harry and Maharaj, 2017). The TLA which is obtained naturally from the Caribbean island of Trinidad and Tobago, contains a soluble bitumen component (maltenes and asphaltenes), mineral matter and other compositions (Widyatmoko and Elliott, 2008). The SMF under investigation was obtained from a well-established food processing plant located in Trinidad.

Table 1: Source and Specifications of TLA and TPB samples utilized in this study.

	TLA	TPB
Source	Natural product mined from the Pitch Lake. Obtained from the Lake Asphalt of Trinidad and Tobago Limited	By-Product of the Petroleum Fractionation Process. Obtained from the Petroleum Company of Trinidad and Tobago Limited.
Packing	Drum	Drum
Penetration at 25ºC (ASTM D5)	0-5	60-70
Specific Gravity (ASTM D70)	1.3-1.5 g/cm^3	1.00-1.06 g/cm^3
Softening Point (ASTM D36)	89-99 ºC	225 ºC
Flash Point (ASTM D92)	255-260ºC	49-56ºC

2.1 Materials and Preparation of Samples

The preparation of the sample blends for rheological measurements were done based on the recommended process by Polacco et al. (2004). Approximately 6 g of TLA was measured and transferred into a 50 cm^3 aluminium can, which was then placed in a Thermo Scientific Precision (Model 6555) thermoelectric heater and the temperature was raised 200 ºC. A IKA (Model RW20D) high shear digital mixer was submerged into the can and set at a speed of 3000rpm. Maintaining the system's temperature at 200 ± 1 ºC, the SMF was gradually added by weight % measure. This procedure was then repeated for the TBP sample. A breakdown of the concentrations of the modified samples analysed in this study can be seen in **Table 2**.

Table 2: Concentration of sample blends.

% SMF required in blends	Mass of sample 6g					
	Asphalt blend					
	TLA			TPB		
	Actual mass of TLA added (g)	Actual mass of SMF added (g)	Actual % SMF	Actual mass of TPB added (g)	Actual mass of SMF added (g)	Actual % SMF
0.00	6.0005	0.0000	0.00	6.0000	0.0000	0.00
1.00	6.0006	0.0602	1.00	6.0088	0.0600	1.00
2.00	6.0018	0.1202	2.00	6.0042	0.1203	2.00
4.00	6.0006	0.2403	4.00	6.0092	0.2404	4.00
6.00	6.0094	0.3602	5.99	6.0098	0.3600	5.99
8.00	6.0013	0.4806	8.01	6.0016	0.4803	8.00
16.00	6.0026	0.9602	16.00	6.0000	0.9608	16.01

After ensuring that the blend mixtures were of a homogenous state, each was stored in a desiccator under static conditions, in an oxygen-free environment for 24 hrs curing. In preparation for the rheological testing, the cans were removed from the desiccator, remixed with the high shear mixer followed by casting of the molten mixture into a ring stamp of dimensions 25 mm in diameter and 1 mm. Before testing commenced, the temperature of the samples was reduced to room temperature and stored in a Fisher Isotemp freezer at a temperature of -20 ºC until use.

2.2 Sample Characterization

The rheological properties of the asphaltic bends were determined using an ATS RheoSystems Dynamic Shear Rheometer (Viscoanalyzer DSR) under the strain-control mode, ensuring the applied strain was kept low to guarantee testing was within the linear viscoelastic range (Maharaj, Ramjattan-Harry and Mohamed, 2015 and Mohamed, Ramjattan-Harry, & Maharaj, 2017). The DSR testing was software controlled with the lower plate of the machine remaining fixed whilst the upper plate oscillated backward and forward. The plate-plate configuration (diameters 25 mm) test geometry was used for testing at a 1 mm space gap. Experiments were conducted within a 0.1 to 15.91 Hz frequency range at temperatures between 40 ºC and 90 ºC, varying at 10 ºC intervals. The selection of this temperature range was based on the actual pavement service temperature which lies between 55 ºC to 65 ºC.

The data obtained at the different oscillating shear frequencies and temperatures were stored and analysed using the Viscoanalyzer software. The values of the rheological parameters linked to the complex shear modulus (G*) and phase angle (δ) were calculated at the tried oscillating frequencies and temperature using the instrument's software.

III. RESULTS AND DISCUSSION

The impact of adding SMF to TLA and TPB samples was assessed through varied analysis of its rheological measurements, complex shear modulus (G*) and phase angle (δ) utilized in the Strategic Highway Research Program (SHRP) project (Kenndey, et al., 1994) and the Asphalt Research Program Superpave specification (Specification for Superpave Binders,Canadian Strategic Highway, 1995). Specification for Superpave Binders (1995) approach assesses the rheology-performance relationship through the creation of the black curve plots. The black curve/diagram gives a visual representation of G* against δ for a dynamic test, eliminating the influence of temperature and frequency on the parameters (Airey, 2002). Disparities from the unmodified blend curves may signify modifications in composition or molecular structure due to the occurrence of processing, ageing or polymer addition which in turn impacts the performance capability (Maharaj, Ramjattan-Harry and Mohamed, 2015). When choosing the optimized blend based on the black curve, plots tending towards the top left of the graph, indicating maximum resistance to deformity and recoverability, would be selected.

The black curves for the TLA and TPB modified samples, **Fig. 1** and **Fig. 2**, illustrated that the performance of samples was influenced by the addition of the SMF based on the shifting of the blended curves from the unmodified samples. This trend was noted for both the TLA and TPB blends where the deviations in the rheological parameters of the TPB blends at higher concentration of the SMF were more predominant **Fig. 2**. Of the two samples undergoing modification, the TLA blends displayed superior performance results (higher stiffness and elasticity parameters, **Fig. 1**) compared to the TPB blends. The results of these black curves have established that the addition of the SMF can manipulate the performance of TLA and TPB.

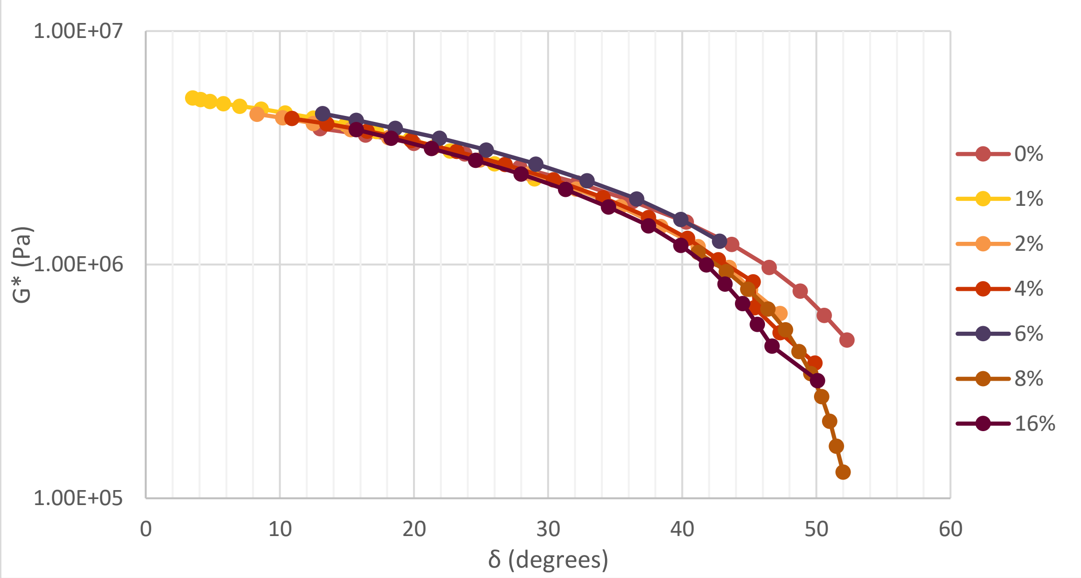

Figure 1: Black curves for SMF modified TLA blends measured at 1.59 Hz and 60 ºC.

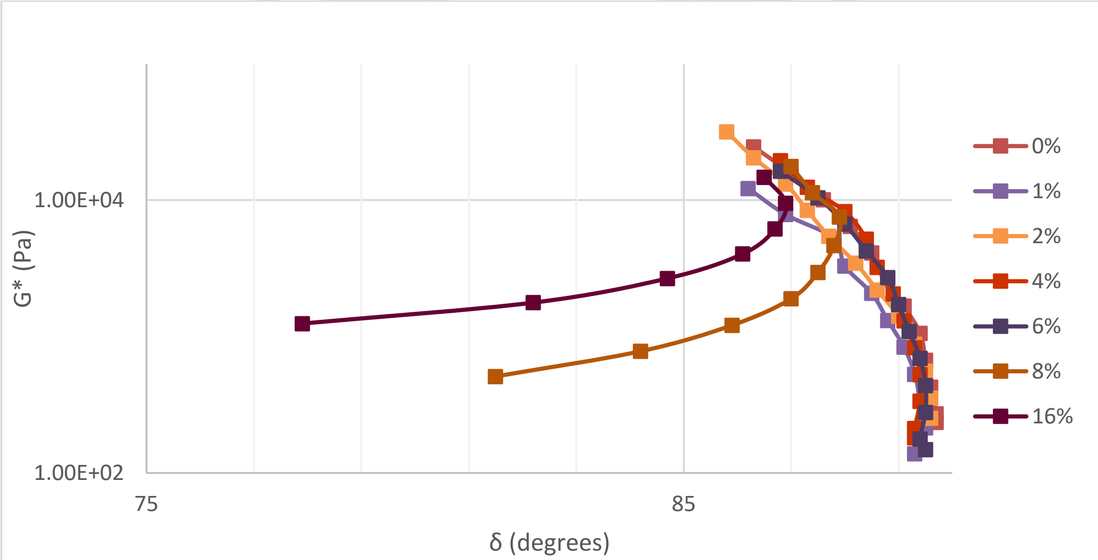

Figure 2: Black curves for SMF modified TPB blends measured at 1.59 Hz and 60 ºC.

Further assessments of the impact on the resilience and durability of these blends were derived from calculating the rutting resistance ($G^*/\sin\delta$) and fatigue cracking resistance ($G^*\sin\delta$), as outlined by the Strategic Highway Research Program (Kenndey, et al., 1994). These mathematical correlations were calculated based on the following equations, Eqs. (1) and (2), (Maharaj, Ramjattan-Harry and Mohamed, 2015), varying temperatures.

$$W_{c1} = \pi\sigma_0^2 \frac{1}{G^*/\sin\delta} \qquad (1)$$

where W_{c1} is work dissipated per load cycle at a constant stress and σ_o is the stress applied during the load cycle

$$W_{c2} = \pi\varepsilon_0^2 \, (G^*\sin\delta) \qquad (2)$$

where W_{c2} is the work dissipated per load cycle at a constant strain and $\mathcal{E}_0$ is the strain during the load cycle

Rutting resistance is the ability of the pavement to maintain its original form after exposure to the resultant work from traffic cycles (DOTs, FHWA and University of Washington, 2020). From Eq. (1), a high G* and low δ, corresponding to a material with superior stiffness and elasticity properties, will result in a high rutting resistance value; the larger the rutting resistance parameter, the greater the ability of the material to withstand the development of rutting faults which occur at the earlier stages of a road pavement's life span (DOTs, FHWA and University of Washington, 2020). **Fig. 3** and **Fig. 4** show the plots of G*/sinδ against concentration for the TLA and TPB blends respectively at a fixed 60 ºC whilst varying frequencies. The TLA blends demonstrated in **Fig. 3** similar trend lines for the three frequencies examined displaying maximum rutting resistance at the 1% SMF blend indicating uniformity in performance response at each blend. It also shows that further addition of the SMF decreases the rutting resistance capability, in some cases even lower than the unmodified blend. The TPB plot, **Fig. 4**, also yielded a uniformed pattern obtaining maximum resistance at the 2% blend, which was lower in comparison to the TLA

1% blend indicating the superiority of the TLA modified sample. However, for the TBP modified blends, **Fig. 4** illustrates that further addition of the SMF beyond the optimum 2% blend contributed slight variations to the rutting resistance.

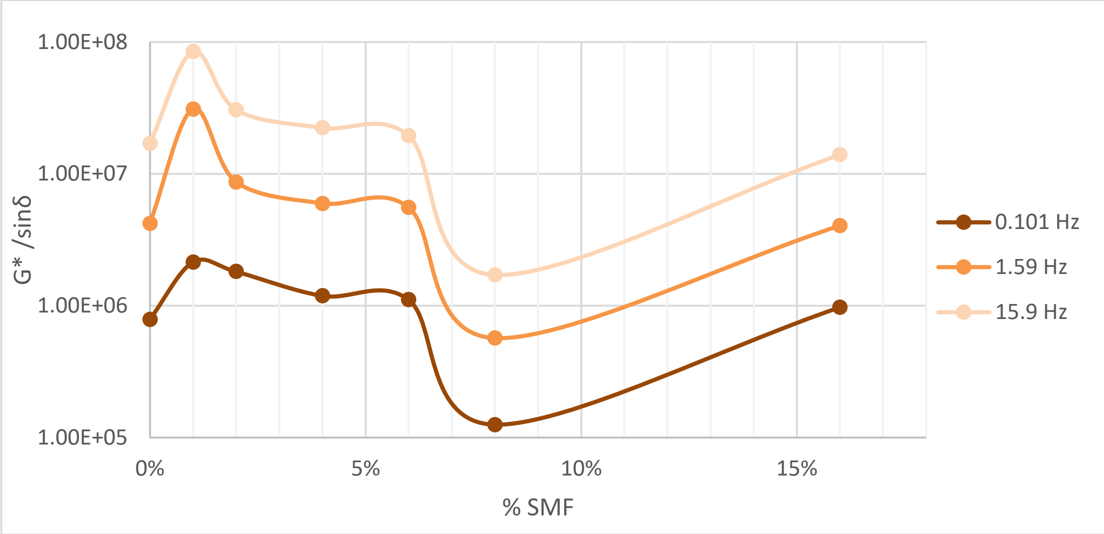

Figure 3: The influence of increasing amounts of SMF on the rutting resistance parameter(G*/sinδ) of TLA at 60 ºC for varying load frequencies.

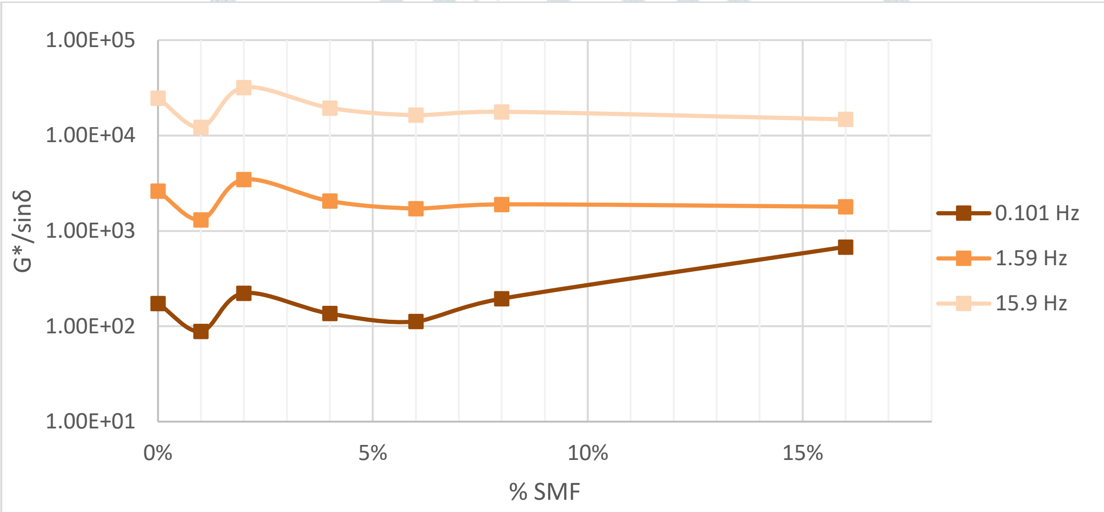

Figure 4: The influence of increasing amounts of SMF on the rutting resistance parameter(G*/sinδ) of TPB at 60 ºC for varying load frequencies.

Variation in the rutting resistance parameters, for both blends, with changes in temperature were captured in **Fig. 5** and **Fig. 6**. For the TLA modified blends, **Fig. 5**, the rutting resistance was negatively impacted seen in the decrease the G*/sinδ value as the temperature rose. The outliers noted were the 1% and 8% blends which displayed maximum and minimum rutting resistance capabilities respectively. The rutting resistance performance of the TPB modified blends, **Fig. 6**, also plummeted as the temperature increased, however, the blends showed little variation from the unmodified TPB sample; a slight increase was noted for the 2% blend within the 55 ºC to 70 ºC temperature range making this blend marginally superior to the others.

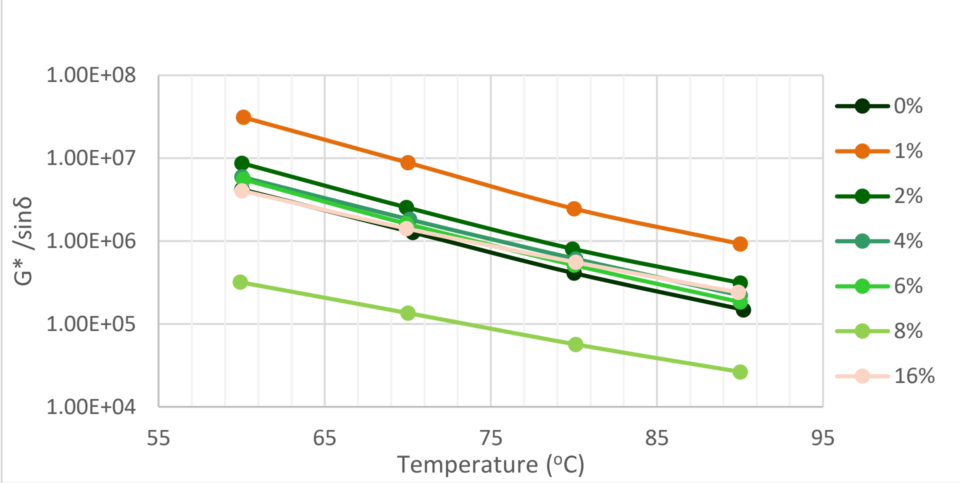

Figure 5: The influence of increasing amounts of SMF on the rutting resistance parameter(G*/sinδ) of TLA at 1.59 Hz for varying temperatures.

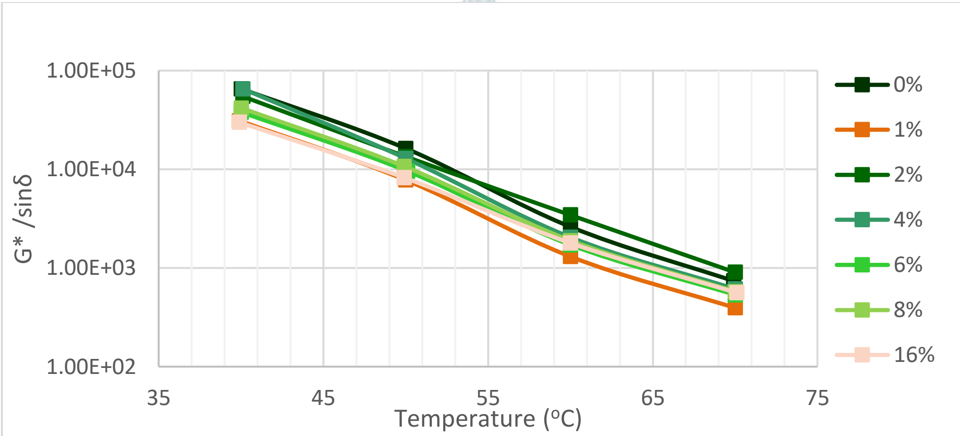

Figure 6: The influence of increasing amounts of SMF on the rutting resistance parameter(G*/sinδ) of TPB at 1.59 Hz for varying temperatures.

Fatigue cracking which is seen as cracks appearing on road pavements, occur as a result of repeated exposure to loading compounded with a weak, thin pavement foundation, poorly designed asphaltic material or changed in the strain tolerance due to long-term aging (Brown, et al., 2009). Based on Eq. (2), the binder should demonstrate elastic and moderately rigid properties in order to be able to rebound from the work applied (low G* and δ values) (DOTs, FHWA and University of Washington, 2020). In **Fig. 7** and **Fig. 8**, we see the impact of adding varied amounts of SMF to the TLA and TPB samples respectively at a constant temperature (60 °C) whilst varying the frequency. With the addition of the SMF to the TLA samples, a decrease in the fatigue cracking resistance is observed as the frequency is ramped up (**Fig. 7**). Maximum fatigue cracking resistance was reached at 8% at the lower frequencies which shifted to 2% at the higher frequency tested. The TPB blended fatigue cracking resistance graph, **Fig. 8**, was similar to the rutting resistance graph, **Fig. 4**. The rationale behind this result was the highly viscous nature of the TPB modified samples having δ values tending towards 90° which demonstrated minimal impact on the mathematical calculations of the rutting and fatigue cracking resistance parameters. For the TPB blends, the 1% modification showed the best results based on the lowest fatigue cracking resistance for all three frequencies assessed.

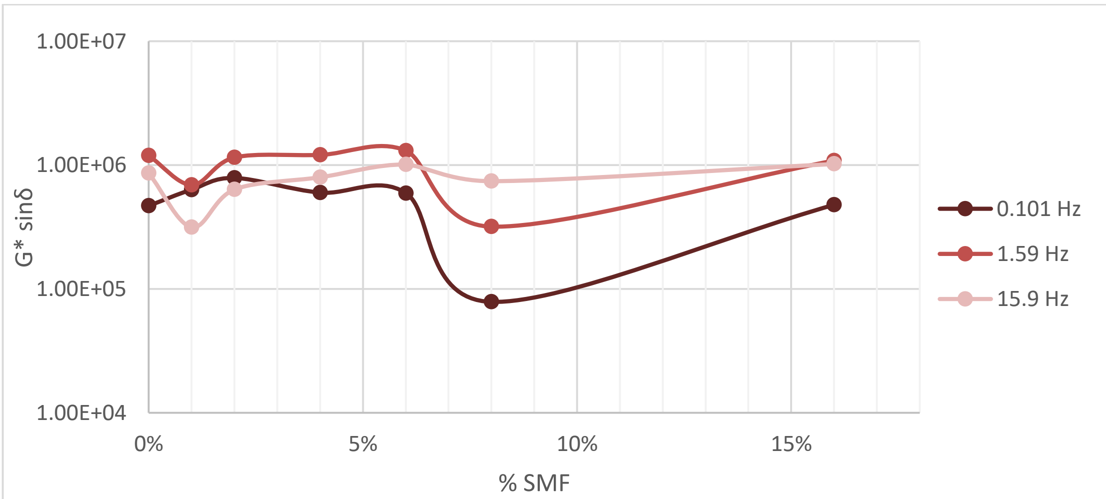

Figure 7: The influence of increasing amounts of SMF on the fatigue cracking resistance parameter(G*sinδ) of TLA at 60 °C for varying load frequencies.

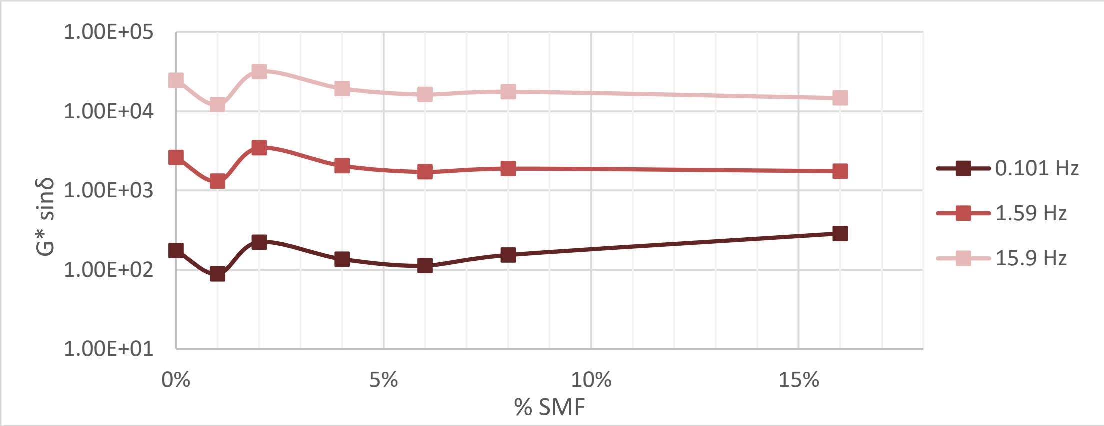

Figure 8: The influence of increasing amounts of SMF on the fatigue cracking resistance parameter(G*sinδ) of TPB at 60 ºC for varying load frequencies.

The influence of temperature on the performance of the TLA and TPB SMF revealed enhanced performance for both the TLA and TPB blends as the temperature increased based on the decreasing G*sinδ value. When looking at the δ value of the TLA blended samples, the elasticity of the blends dropped with increase in temperature which marginally affected the sinδ values. The TLA blend plots, **Fig. 9**, showed similar trend lines to the rutting resistance plots, **Fig. 5**, however, the magnitude of the rutting resistance against the fatigue cracking resistance was slightly higher for each corresponding blend and temperature. The blend which showed potential for the highest fatigue cracking resistance was the 8% TLA blend. It was noted that behaviour of the 1% blend did not follow the observed trend lines displaying a curve shaped plot rather than the declining line. This occurrence would be investigated to determine the rationale behind the results.

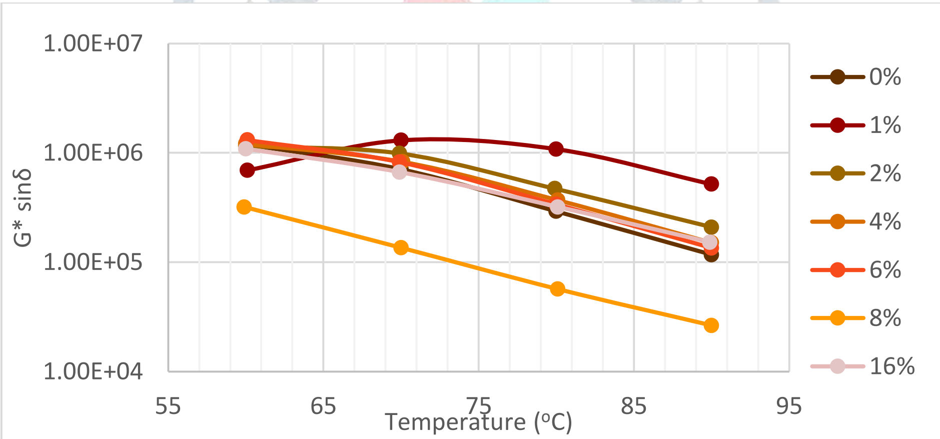

Figure 9: The influence of increasing amounts of SMF on the fatigue cracking resistance parameter(G*sinδ) of TLA at 1.59 Hz for varying temperatures.

The TPB blends were highly viscous, as seen in the black curves showing δ values tending towards 90º. The rutting resistance plots, **Fig. 6**, were identical to the fatigue cracking results obtained, **Fig. 10**. The optimum performing TPB blend favourable response to temperature increase was the 1% SMF blend.

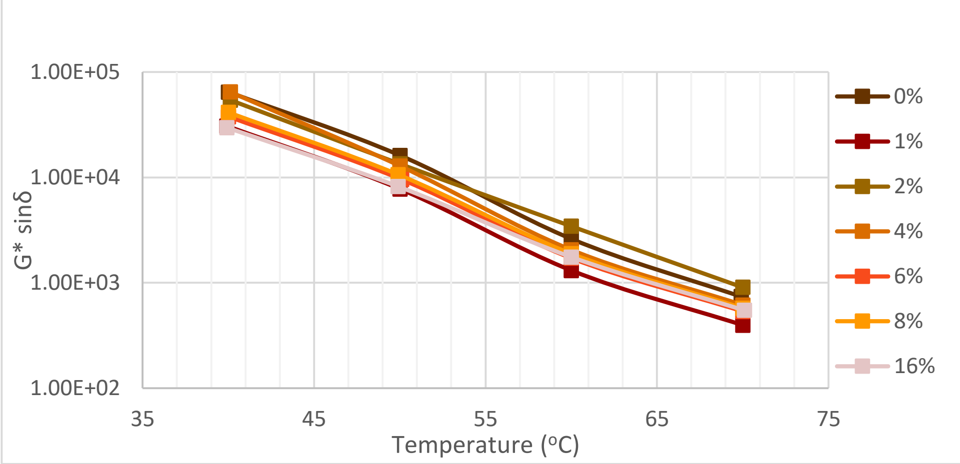

Figure 10: The influence of increasing amounts of SMF on the fatigue cracking resistance parameter(G*sinδ) of TPB at 1.59 Hz for varying temperatures.

From the previous discussions on the results obtained, the resultant of the modification using the SMF has influenced the rigidity and deformity properties of both samples ultimately altering the viscosity of the blends. Viscosity, according to Wang et al. (2018) is the measure of a material's resistance to flow and deformation. Based on the definition stated previously for G^*, a stiffer material that is a high G^* value would infer limited movement, increasing likelihood for the occurrence of cracking [24]. **Fig. 11** illustrates that the addition of the SMF influences the flow properties of TLA and TPB. The master plots of TLA and TPB showing the effect of varying frequencies with corresponding G^* and δ values at a fixed 60 ºC seen in Mohamed, Ramjattan-Harry and Maharaj (2017) shows the superiority of the TLA in comparison with the TPB where the TLA demonstrated more desirable rheological performance results (higher elasticity and stiffness). The stiffness associated with greater flow resistance is supported in **Fig. 11** where the TLA modified blends' viscosity were higher than the TPB modified blends. The 1% TLA and 2% TPB blends displayed high viscosity values equating to maximum stiffness.

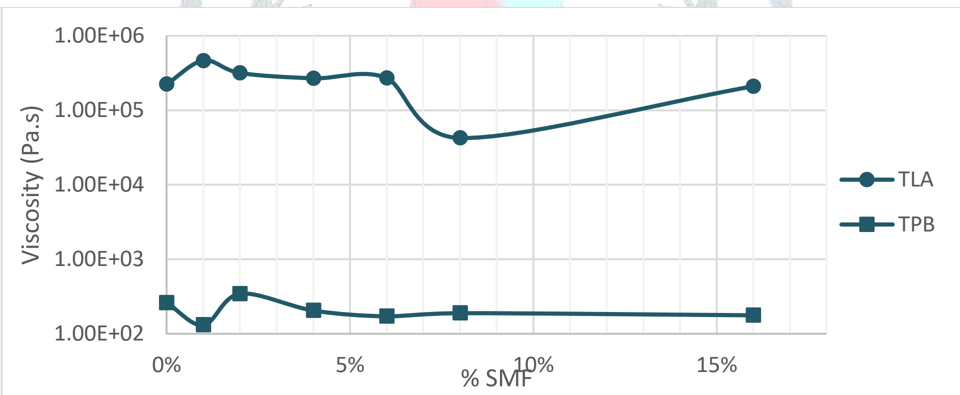

Figure 11: The effect of increasing SMF content on viscosity (Pa.s) of the modified TLA and TPB blends at a frequency of 1.59 Hz and temperature of 60 ºC.

Fig. 12 and **Fig. 13** exemplifies the effect of varying frequency on the viscosity of the TLA and TPB blends keeping the temperature fixed. The viscosity of the TPB, **Fig. 13** blends showed little change in the viscosity with increased frequency, the 2% blend demonstrating optimum performance. This behaviour also supports the high δ values showed in the black curve, **Fig. 2**. Of the TLA blends illustrated in **Fig. 12**, the 1% having maximum viscosity. **Fig. 14** and **Fig. 15** further demonstrates the effect of varying temperature on the viscosity of the SMF modified TLA and TPB blends which show a decrease in viscosity with increases in temperature where the 2% blend for the TLA and TPB modification performed at desired operation parameter. This is results is expected as the intermolecular forces between the particles become weaker with an increase in frequency and temperature, allowing the TLA and TPB blended samples to flow easier, signifying that viscosity is dependent on temperature and frequency (Wang, Liu, Apostolidis and Scarpas, 2018).

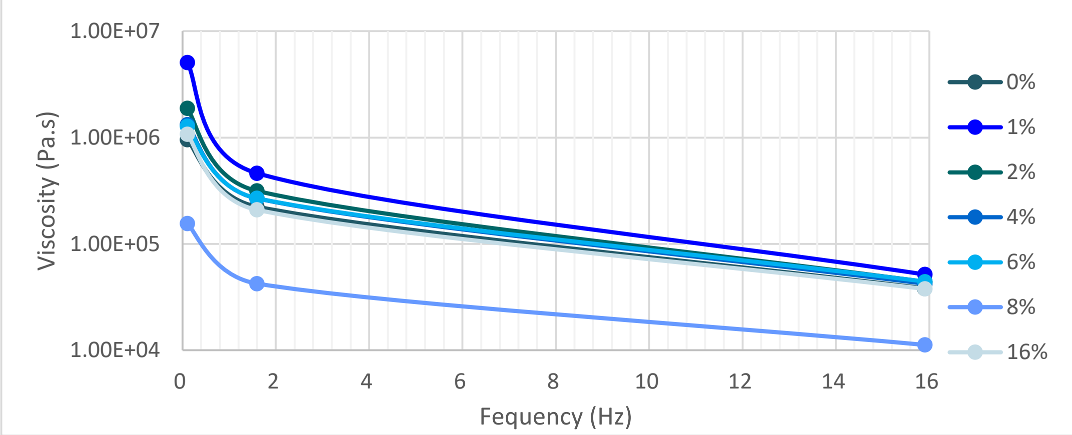

Figure 12: The effect of increasing frequency (Hz) on viscosity (Pa.s) of modified TLA blends at 60 ºC.

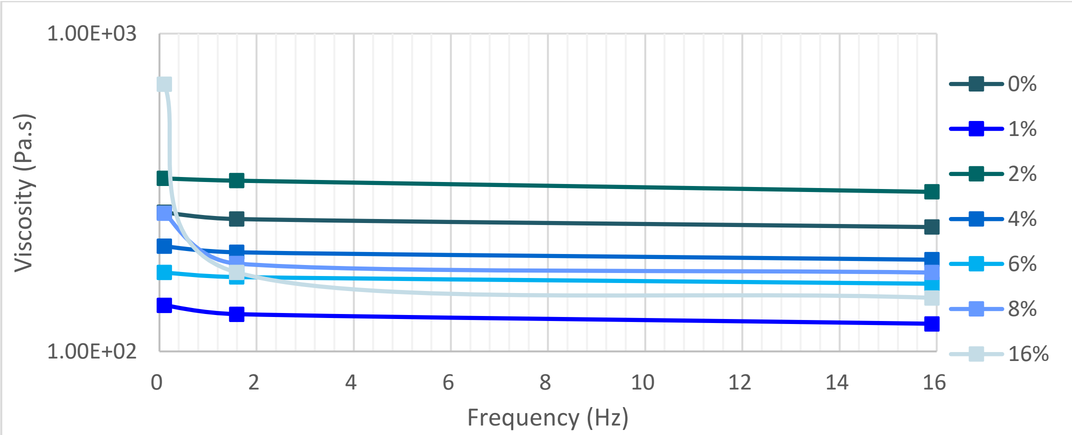

Figure 13: The effect of increasing frequency (Hz) on viscosity (Pa.s) of modified TPB blends at 60 ºC.

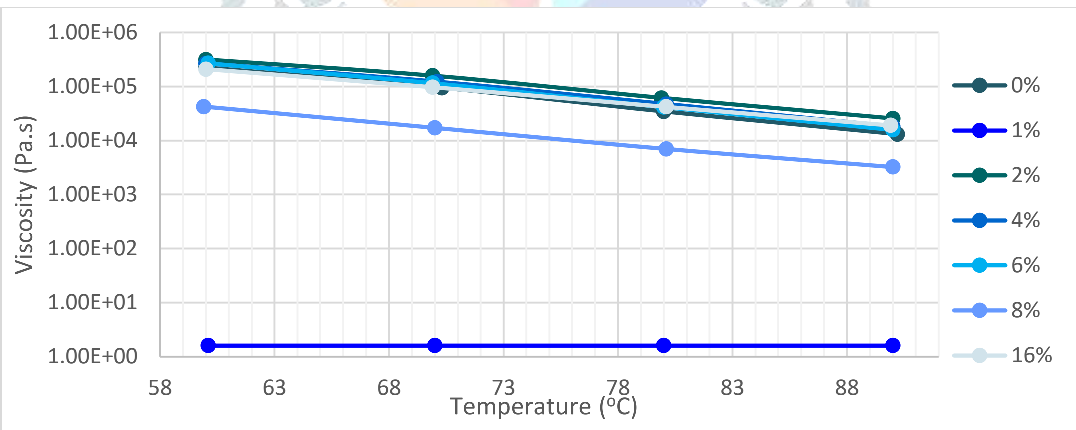

Figure 14: The effect of increasing temperature (ºC) on viscosity (Pa.s) of modified TLA blends at 1.59 Hz.

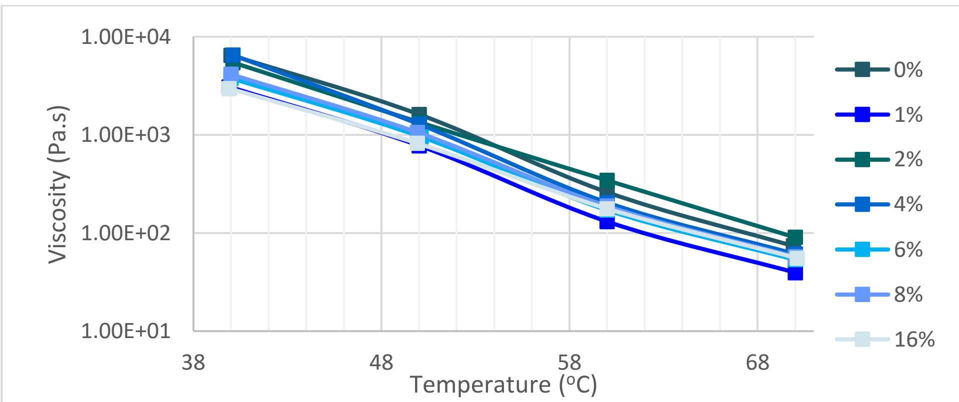

Figure 15: The effect of increasing temperature (ºC) on viscosity (Pa.s) of modified TPB blends at 1.59 Hz.

IV. CONCLUSION

The modification of the TLA and TPB by the addition of SMF resulted in changes in the rheological properties of the blends as validated in the deviations in the material's viscosity and rutting and fatigue cracking resistance parameters. The shift in G* and δ values seen in the black curves for both sample confirm the impact of blending the samples with the SMF whilst demonstrating the versatility of modifying both TLA and TPB based on the performance demand of its application.

Optimum dosages of SMF resulting in maximum stiffness and elasticity ((high G* and low δ respectively) as well as viscosity were 1% and 2% for TLA and TPB respectively. When compared to the unmodified TLA material, improvements in the rutting resistance and fatigue cracking resistance parameters were noted in the 1% and 1% and 8% SMF blends. For TPB, improvements were noted with 1% SMF addition for fatigue cracking and 2% SMF addition for rutting resistance. Optimum dosages observed for fatigue cracking and rutting resistance for TLA and TPB also demonstrated superior temperature susceptibility characteristics. It was noteworthy to mention that due to the minor change to δ on the addition of the SMF wt%, the plots for G*sin δ and G*/sin δ were close to identical. Of both materials, the TLA blends display superior performance recovery as compared to TPB blends.

The results of this study offers evidence that the addition of SMF to asphaltic materials used in road paving in TT can enhanced performance characteristics of the modified blends while also serving as a reuse strategy to mitigate the disposal issues associated with this waste product. This study provides the framework for future work towards the implementation of this strategy.

V. ACKNOWLEDGEMENT

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