Damping Behavior of the Phenolic Based Composite Friction Materials Containing Thermoplastic Elastomers (TPEs)

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ABSTRACT: *Attempts have been made for the first time to produce a friction material with thermal sensitive modulus by the inclusion of combined plastic/rubber properties of thermoplastic elastomers (TPE) as viscoelastic polymeric materials into the formulation for the purpose of increasing the damping behavior. In order to evaluate the viscoelastic parameters such as loss factor (tan δ) and elastic modulus (E') for the friction material, dynamic mechanical analyzer (DMA) was used. Styrene-butadiene-styrene (SBS), styrene-ethylene-butylene-styrene (SEBS) and nitrile rubber/polyvinyl chloride (NBR/PVC) blend systems were used as TPE materials. However, NBR/PVC and SEBS were found to be more effective in damping behavior. All the friction materials containing TPEs exhibited more damping behavior at a wide range of temperature compared with the reference sample.*

KEY WORDS: *Thermoplastic elastomer (TPE), Friction material, Damping, SBS, NBR/PVC, SEBS, Phenolic resin.*

INTRODUCTION

The most important safety aspect of an automobile is its brake system, which must stop the vehicle quickly and reliably under varying conditions [1].

Friction materials for an automotive brake system should satisfy a number of requirements such as good wear resistance, stable friction force, no noise, and no vibration at wide ranges of temperatures, pressures, velocities, and environments. A great deal of effort has been given to the development of multiphase composites for a friction material since a single material has never been successful to meet the numerous performance related demands [2-8]. Friction material can be classified as organic (polymeric), carbon–based, and metallic. The polymeric based, are predominantly used in the automotive industry [9].

Similar to all other applications with friction interface, noise and vibration is inherent by-product of brake application [10]. In recent years, brake noise has become an issue of growing concern to the automotive industry, especially to the manufacturers of disc brake pads and friction materials [11], as it causes customer dissatisfaction. Although substantial research has been

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conducted into predicting and eliminating brake noise since 1930s, it is still rather difficult to predict or inhibit its occurrences [10].

The most significant complication in brake research is the fugitive nature of brake noise; that is, brake noise can sometimes be non–repeatable. Alternatively, small variations in operating temperature, brake pressure, rotor velocity or coefficient of friction may result in differing noise propensities or frequencies. Therefore, efforts to eliminate the brake noise and also design a noise free friction material have been widely carried out during the last decades [10,12].

Nonlinear vibrations in frictional systems have been observed to be associated with the occurrence of stable limit cycle type of self-excitations. This phenomenon is initiated by the onset of a dynamic instability of the system, causing the oscillation amplitudes to grow [13, 14]. When the two components, disc and pad, start to vibrate together, the damping characteristics of the brake system will be reduced as the vibration of the two components is in the resonance mode [15]. As a consequence, the friction forces may introduce more energy into the system than it can dissipate. Therefore to reduce the level of the brake noise as well as preventing of the brake squealing, one should design a friction material capable of damping the vibrations.

Various empirical methods have been developed to reduce the brake noise, and numerous solutions have been suggested. Research works have been carried out to find out the most effective ways in reducing the noise level. Effects of various parameters such as geometry of the friction pad, and also mechanical properties of the friction material (stiffness, mass) have been reported [16]. Generation of sound in a brake system is also influenced by the boundary conditions of the system, especially braking pressure and temperature. Therefore, modification of the geometry and/or material properties can not always be effective to control the noise. If the brake system generates more energy than dissipation, then increasing the damping characteristics of the friction material seems to be a more successful mechanism.

The object of the present work has been to include thermoplastic elastomeric materials (TPE) as an important class of viscoelastic polymeric materials having combined properties of plastics and rubbery polymers into the friction lining formulation for the purpose of the increasing the thermal sensitivity of the modulus and therefore increasing the damping behavior, in a wide range of service temperatures.

EXPERIMENTAL

Sample Preparation

Friction materials investigated in this study were non-asbestos organic (NAO) type containing novolac resin as binder, and also various other ingredients including mineral as well as metallic fillers.

The formulation having no TPE material was used as reference. Twelve friction materials composed of different amounts of nitrile rubber/polyvinyl chloride (NBR/PVC), 70/30 (w/w), styrene- butadiene- styrene (SBS) and styrene-ethylene-butylene-styrene (SEBS) with the styrene content of 25 percent were prepared separately. The specifications of the used materials such as resin and TPEs have been listed in Tables 1, 2, 3, respectively. The level of each used TPE was varied as 2, 2.5, 3, and 4 weight percent. The compounding of the formulation ingredients was carried out by the use of conventional dry mixing procedure. The prepared mixture was preformed and then was molded at 165°C in a hot compression press under a pressure of 10 MPa for 5 min. The cured and molded sample was then surface finished and was used for the desired tests.

Dynamic Mechanical Analysis (DMA)

To evaluate and study the viscoelastic behavior of the prepared samples, dynamic mechanical analyzer model 983 Du Pont Instruments was employed and variation of viscoelastic parameters was followed within the temperature range of 25°C-320°C at the rate of 5°C/min. The experiment was carried out at resonant mode (varied frequency and temperature), as it is particularly more informative for the highly filled and stiff samples. At resonant mode, DMA operates on the mechanical principles of forced resonant vibratory motion at fixed amplitude. As the cured composite friction materials have high elastic modulus, therefore smooth faced vertical clamps were used with oscillation amplitude of 0.2mm. The DMA thermograms illustrates the variation of elastic modulus (E’), loss modulus (E’’) as well as loss factor ($\tan \delta = E''/E'$) as a function of the temperature. Poison’s ratio was estimated to have the value of 0.44. Each tested sample was in the form of block with the dimension of

Table 1: Specifications of the used phenolic resin.

Type	Grade/Producer	Hexa content (wt (%)	Flow distance (mm)	B time (sec)	Melting point (°C)
Novolac resin	Resitan, IP 502, Iran	9.1	48	86	89

Table 2: Characteristics of the used NBR/PVC.

Material	Grade/Producer	Density (gr/cm^3)	Bound acrylonitrile (%)	Mooney Viscosity, Ml_{1+4}@100°C
NBR/PVC	Nancar 1203,, Nantex, Taiwan	1.07	33	60

Table 3: Specifications of the SBS and SEBS materials.

Material	Grade/Producer	Density (gr/cm^3)	Tensile Strength (Mpa)	HDT (°C)	Surface Hardness
SBS	Sofprene-T, So.F.Ter SPA, Italy	0.94	20	-20	SA80
SEBS	Laprene, SO.F.Ter SPA, Italy	0.9	8	-20	SA55

30mm × 10mm × 2 mm, and was cut from the molded compound. All samples were examined at atmospheric condition.

RESULTS AND DISCUSSION

Figs. 1 and 2 exhibit the variation of elastic modulus and tanδ of the friction materials composed of NBR/PVC as TPE, respectively. It is clearly observed that the maximum of tan δ occurs at about 200°C, and the onset of glass transition by the material appears at about 150°C. Both the elastic modulus and tan δ remain almost constant at temperatures below 150°C, as the mobility of the TPE chain molecules are highly retarded, and hence the molded friction material behaves as an solid elastic. This is explained to be attributed to the high level of the particulate ingredients loaded into the network of the TPE/resin hybrid in the friction material. However, above 200°C, the mobility of the TPE chain segments becomes possible which causes the decrease of elastic modulus.

It is clearly seen that, with increasing the percent of the NBR/PVC as TPE in the friction material, tan δ increases within the transition range of temperature. This is explained to be due to the increase of the viscoelastic behavior of the samples with increasing the NBR/PVC amount in the cured friction material network, and consequently more viscous damping behavior of the samples.

The effects of the inclusion of thermoplastic elastomers with block type of microstructure such as SBS and SEBS, upon the viscoelastic behavior of the molded friction material, have been demonstrated in Figs. 3-4 and 5-6, respectively. Two distinct phase transition regions are clearly seen in these figures. The first damping peak appeared at a lower temperature zone than the main peak, is mainly attributed to the presence of styrenic block in the microstructure of the SBS and SEBS chains. This is evidenced by the average glass transition temperature of about 90°C for polystyrene. The structural incompatibility between the styrenic blocks and the phenolic resin segments with high polarity causes the friction material to exhibit two transition temperature regions, and consequently two damping zones. This would lead to the conclusion that the friction pads composed of SBS or SEBS can show damping behavior within two different ranges of temperature while braking the car wheels.

Similar to the friction material having NBR/PVC, as the concentration of the SBS or SEBS increases, the capability of the cured friction material to damping increases within the two transition zones. This is suggested to be the result of increase in the amount of styrenic block segments which are mainly involved in the viscous and retarding responses.

Above 200°C, elastic modulus reaches almost to a constant value for all the friction samples having SBS or SEBS TPEs. This is explained to be due to the enough thermal energy required by all the polymeric segments within the network for responding to the applied stress field, and therefore insignificant change in the modulus by temperature.

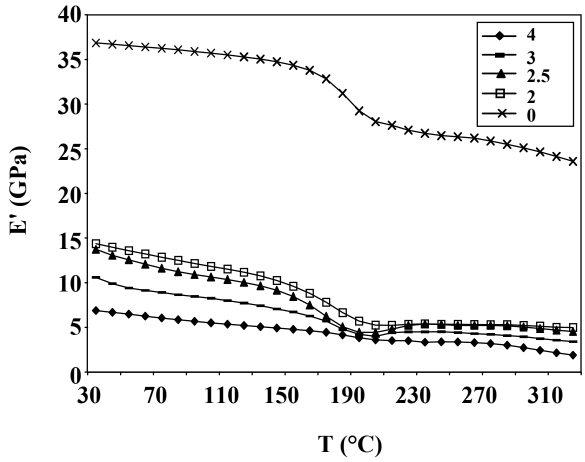

Fig. 1: Variation of elastic modulus of the cured friction material containing various levels of NBR/PVC as TPE.

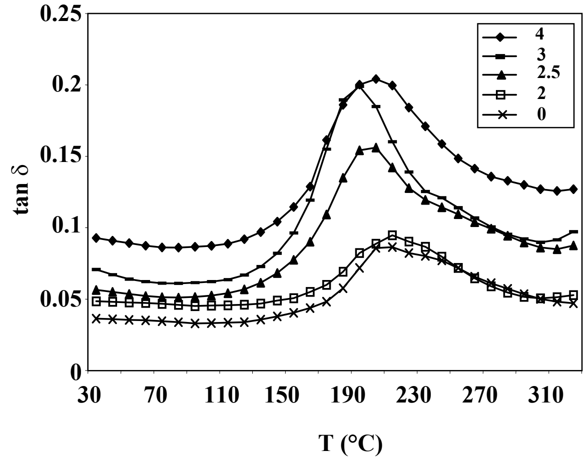

Fig. 2: Tan δ versus temperature for the cured friction material having different amount of NBR/PVC blend system as TPE.

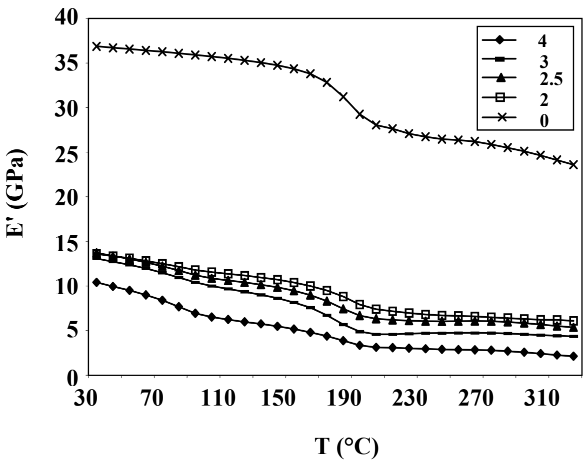

Fig. 3: Variation of elastic modulus of the cured friction material containing various levels of SBS as TPE.

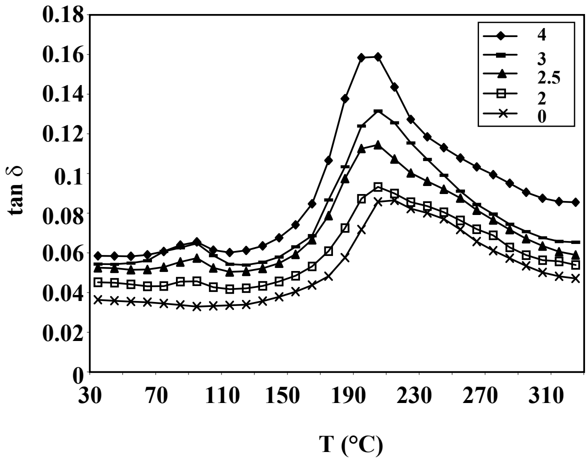

Fig. 4: Tan δ versus temperature for the cured friction material having different amount of SBS as TPE.

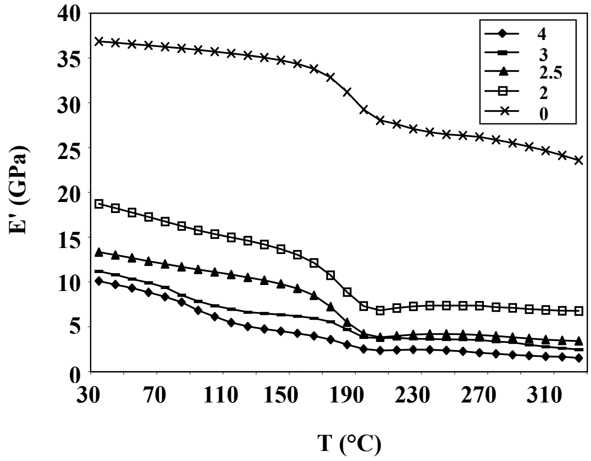

Fig. 5: Variation of elastic modulus of the cured friction material containing various levels of SEBS as TPE.

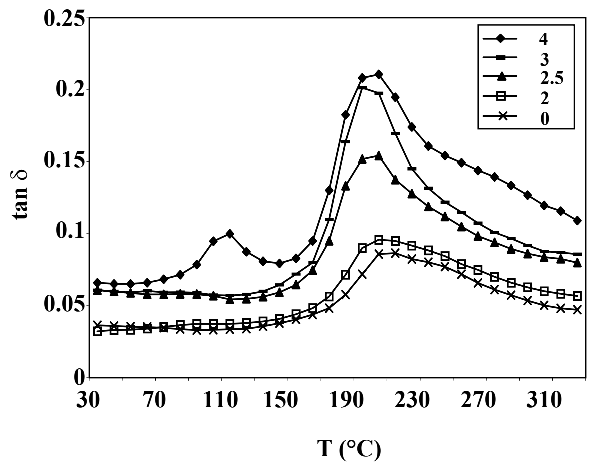

Fig. 6: Tan δ versus temperature for the cured friction material having different amount of SEBS as TPE.

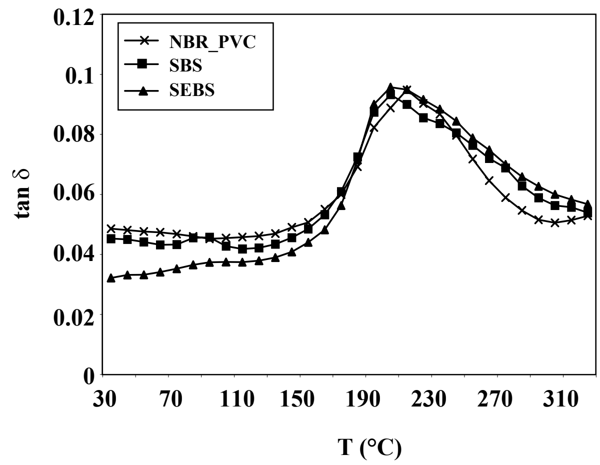

Fig. 7: Tan δ versus temperature for cured friction material having 2 weight percent of different TPEs.

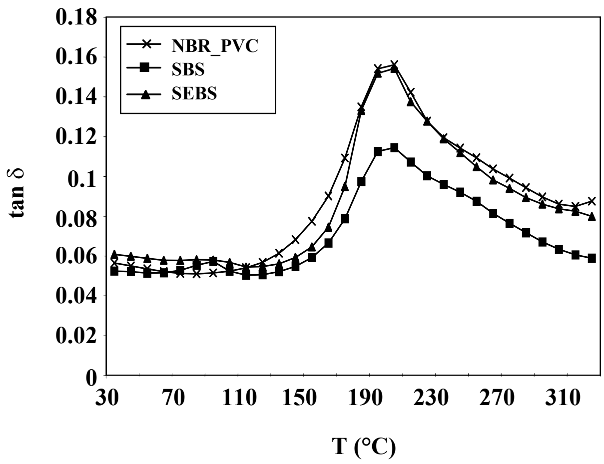

Fig. 8: Tan δ versus temperature for cured friction material having 2.5 weight percent of different TPEs.

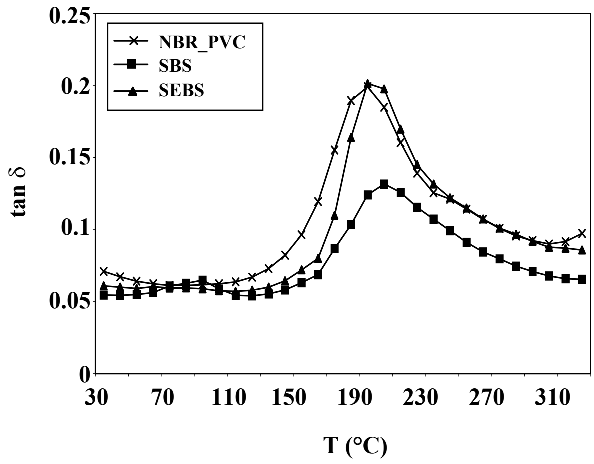

Fig. 9: Tan δ versus temperature for cured friction material having 3 weight percent of different TPEs.

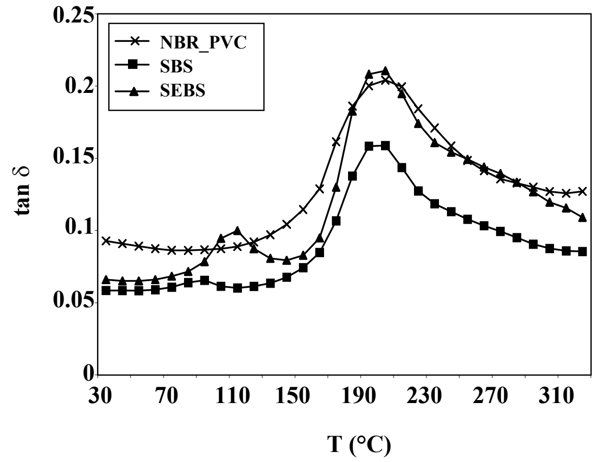

Fig. 10: Tan δ versus temperature for cured friction material having 4 weight percent of different TPEs.

In Figs. 7-10, the damping behavior of the cured friction materials composed of different levels of NBR/PVC, SBS and SEBS as thermoplastic elastomeric ingredient, in a wide range of temperature has been exhibited and compared. It is obviously seen that, the samples having NBR/PVC show more damping behavior particularly within the temperature transition zones. This is suggested to be due to the better structural compatibility between NBR/PVC chain segments and phenolic resin network which leads to the formation of a semi interpenetrating network in which the motions of the NBR and PVC segments are quite retarded. This is in consistence with the temperature transition behavior showed by the friction material which includes NBR/PVC, Fig. 2.

CONCLUSIONS

The obtained results showed that the incorporation of NBR/PVC, SBS and SEBS type of thermoplastic elastomers into the formulation of a friction material, with phenolic resin as the main matrix, can have profound effect upon the viscoelastic behavior of the cured pad in a wide range of temperatures. The NBR/PVC blend system showed to be more effective in the damping behavior. Increasing the concentration of the TPE material in the formulation did also increase the degree of damping especially within the temperature transition region. TPE materials can help one to design and optimize the friction material formulation with desired viscoelastic properties towards the braking forces.

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