Sound Attenuation in Composite Friction Materials Containing Thermoplastic Elastomers

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ABSTRACT: Attempts have been made for the first time to modify and improve the sound attenuation ability of a friction material by the inclusion of combined plastic/rubber properties of thermoplastic elastomers (TPE) as viscoelastic polymeric materials, into the formulation. To evaluate the attenuation coefficient (α) and also the real part wave number (k') for the friction material, the viscoelastic parameters such as loss factor (tan δ) and elastic modulus (E') were measured by the use of dynamic mechanical analyzer (DMA). Styrene-butadiene-styrene (SBS), styrene-ethylene-butylene-styrene (SEBS) and nitrile rubber/polyvinyl chloride (NBR/PVC) blend system were used as TPE materials. However, SEBS and NBR/PVC were found to be much more effective in reducing the sound propagating speed as well as the sound level. All the friction materials containing TPEs exhibited more sound damping behavior at a wide range of temperature compared with the reference sample. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 101: 2187–2194, 2006

Key words: thermoplastic elastomer; friction material; sound attenuation; SBS; NBR/PVC; SEBS

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 friction materials 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 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 nonrepeatable. 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]

Sound in a brake system is excited at the interface or contact surface of the brake pad and the rotating disc surface, which is divided into a number of small contact plateaus. Plateaus are formed during the sliding contact against the brake disc and mainly consist of the harder constituents of the pad. They are not permanent but constantly change due to the wear and deformation of the pad during braking. The size and number of contact plateaus depends on the applied brake pressure and to some extent the heat buildup at the interface, as the two factors having the strongest influence upon the generation of the brake noise.[13]

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 the modifications of friction material, such as changes in the geometry of the friction material, and also mechanical properties of the components (stiffness, mass) have been reported.[14] Generating of sound in brake is also influenced by the boundary conditions of the system, especially braking pressure and temperature. Therefore, modification of

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the geometry and/or material properties cannot 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 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 damping behavior and therefore reducing the sound level, in a wide range of service temperature.

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 NBR/PVC (Nancar 1203, Nantex), 70/30(w/w), SBS (Sofprene-T,So.F.Ter SPA), and SEBS (Laprene, So.F.Ter SPA) with the styrene content of 25% were prepared separately. The level of each used TPE was varied as 2, 2.5, 3, and 4 wt %. The compounding of the formulation ingredients was carried out by the use of conventional dry mixing procedure. The prepared mix was preformed and then molded at 165°C in a hot compression press. The cured and molded sample was then surface finished and used for the desired tests.

Dynamic mechanical analysis

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 25–320°C at the rate of 5°C/min. The experiment was carried out at resonant mode, as it is particularly more informative for the highly filled and stiff samples. At resonant mode, dynamic mechanical analyzer (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 0.2 mm. 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 30 mm ×10 mm ×2 mm, and was cut from the molded compound.

Sound pressure reduction and sound speed measurement

Actual sound waves are transient signals with a finite time of duration. However, the harmonic wave is a basic signal since any transient signal can be represented as a superposition of harmonic wave with different frequencies. The plane harmonic wave is an idealization. For simplicity, it is assumed that the stress–strain relation in viscoelastic materials (friction materials) is linear.[15] In this case, for a plane harmonic sound wave propagating through the viscoelastic material, the sound attenuation coefficient is related to the complex dynamic modulus of the sample as follows:

$$(k'^2 - \alpha^2) + i(2k'\alpha) = \frac{\rho\omega^2}{M'(1+r^2)}(1+ir) \qquad (1)$$

where r represents $\tan\delta$, M' is the real part of modulus (E') in Pa, ρ is the density in kg/m^3, ω is the angular frequency in rad/s, α is the sound attenuation coefficient in Nepers/m, and $k' = 2\pi/\lambda$ is the real part of the wave number, where λ is the wavelength in m.

For a harmonic wave the sound speed (m/s) is simply related to the real part of the wave number (k'), according to the following relation:

$$C = \lambda f = \omega/k' \qquad (2)$$

The sound absorption (SL) is also related to the sound pressure as follows:

$$\mathrm{SL} = -10\log\left(\frac{p^2}{p_0^2}\right) = -20\log\left(\frac{p}{p_0}\right) \qquad (3)$$

where p is the acoustic pressure at distance x from the reference point where the pressure is p_0.

The relation between absorption and the attenuation coefficient (α) is presented below:

$$-20\log\left(\frac{p(1m)}{p_0}\right)\{dB/m\} = 20\log(e)\alpha\{\text{Nepers/m}\} \qquad (4)$$

where p (1 m) is the acoustic pressure at 1 m from the reference point.[15]

Substitution of the data obtained from DMA in eq. (1), the attenuation coefficient (α), and real part of wave number (k') were evaluated, and then sound speed (m/s) and absorption level (dB/m) for all the friction materials were calculated by the use of eq. 2 and 4.

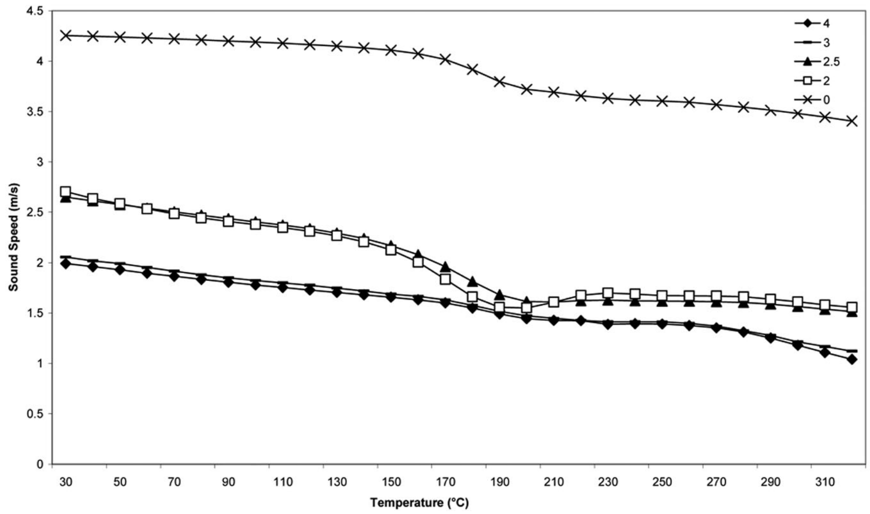

Figure 1 Variation of sound propagating speed through the cured friction material containing various levels of NBR/PVC as TPE.

RESULTS AND DISCUSSION

Figures 1 and 2 exhibit the variation of sound speed and sound absorption of the friction material composed of NBR/PVC as TPE, respectively. It is clearly observed that the maximum sound absorption occurs at about 200°C, and the onset of glass transition by the material appears at about 150°C. Both the sound propagation speed and sound level 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 retarding effect upon the sound propagation decreases, as the mobility of the TPE chain segments becomes possible, which facilitates the propagation of the sound wave.

However, it is clearly seen that, with increasing the percent of the NBR/PVC as TPE system in the friction material, the degree of the sound absorption increases within the transition range of temperature. This is explained to be due to the increase of the viscoelastic behavior of the NBR/PVC chain segments within the cured friction material network,

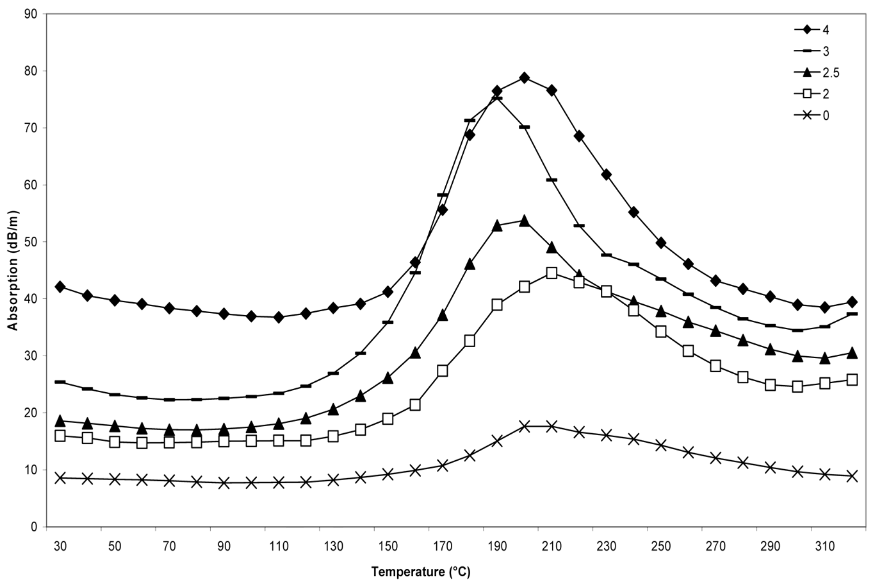

Figure 2 Sound absorption versus temperature for the cured friction material having different amount of NBR/PVC blend system as TPE.

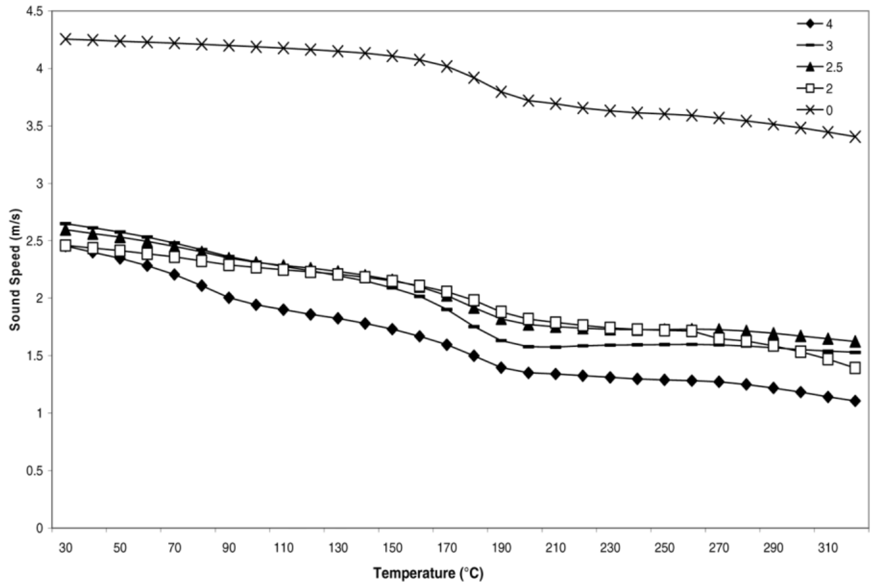

Figure 3 Variation of sound propagating speed through the cured friction material containing various levels of SBS as TPE.

and consequently more viscous retardation exerted upon the propagation of the sound.

The effects of the inclusion of thermoplastic elastomers with block type of microstructure, such as SBS and SEBS, upon the viscoelastic behavior and also degree of sound damping characteristics of the molded friction material, have been demonstrated in Figures 3–6, 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 reduce the sound intensity and fading its energy to propagate

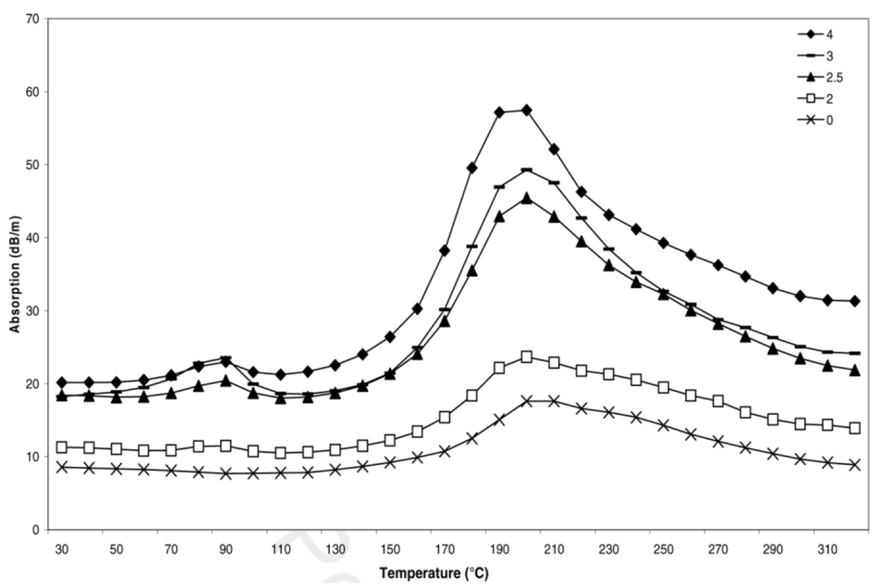

Figure 4 Sound absorption versus temperature for the cured friction material having different amount of SBS as TPE.

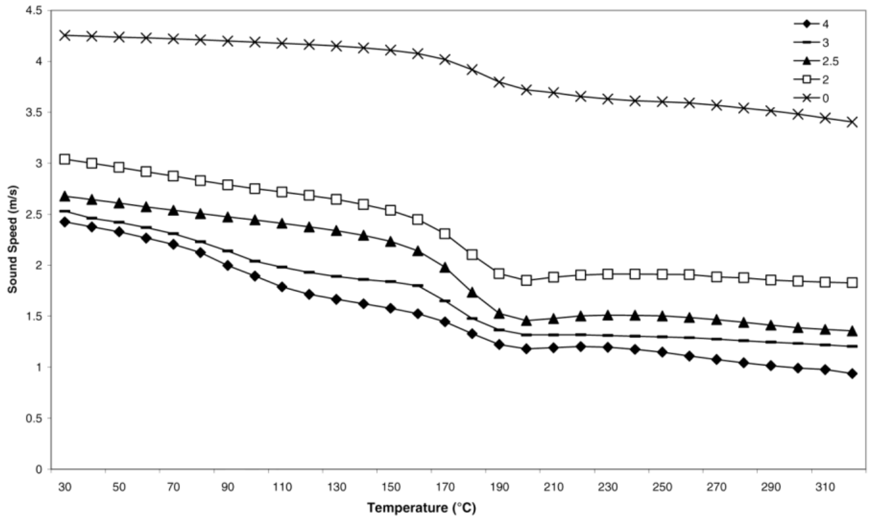

Figure 5 Variation of sound propagating speed through the cured friction material containing various levels of SEBS as TPE.

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 response to the propagating wave.

Above 200°C, the sound propagating speed reaches almost to a constant value for all the friction samples having SBS or SEBS TPEs, which is explained to be due to the increase of the segments thermal energy, and hence decrease in the viscous response of the friction material network toward the propagating wave.

In Figures 7–10, the sound 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 much more damping behavior and also more attenuation of the sound intensity, 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 confirmed by comparing the DMA thermograms of uncured NBR/PVC and the blend sample of phenolic resin and NBR/PVC cured by hexamethylene tetramine (Hexa), shown in Figure 11. It is clearly observed that the

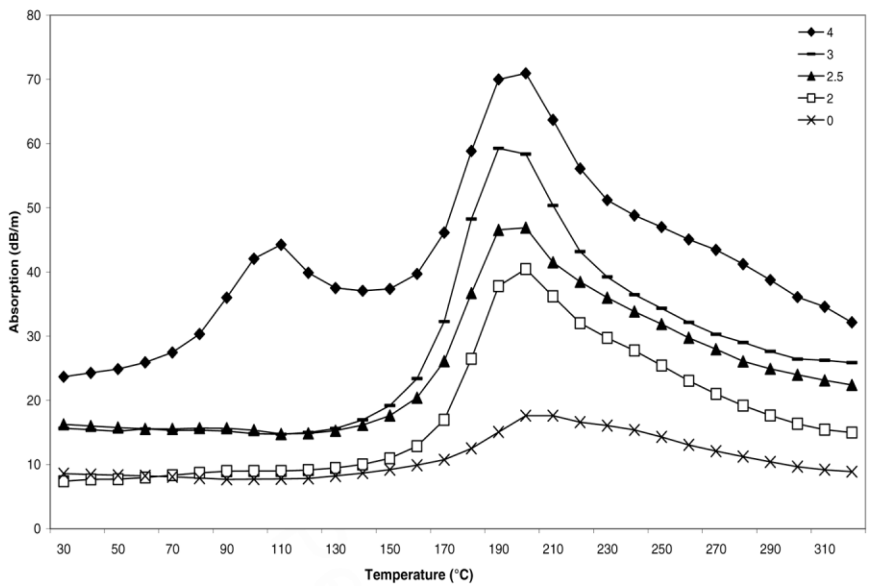

Figure 6 Sound absorption versus temperature for the cured friction material having different amount of SEBS as TPE.

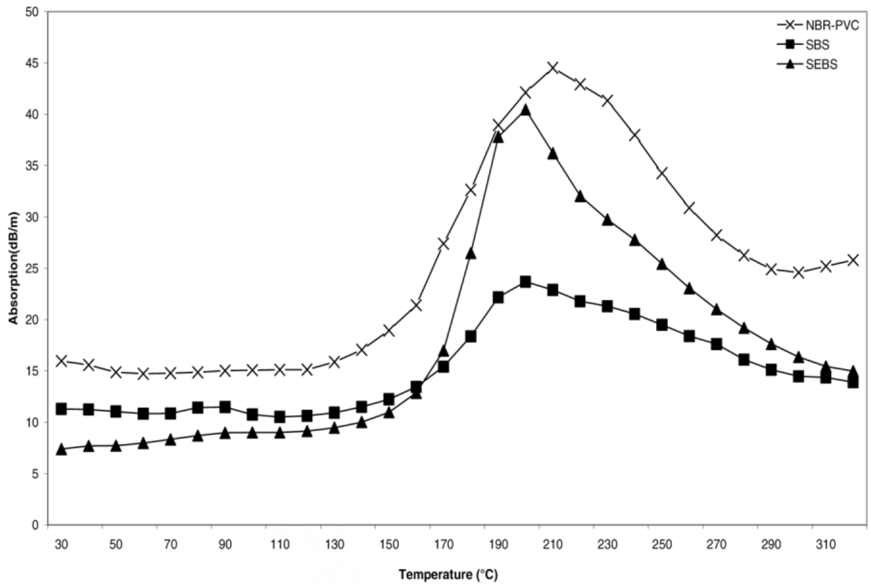

Figure 7 Sound absorption versus temperature for cured friction material having 2 wt % of different TPEs.

crosslinked sample shows much lower damping characteristics, which is attributed to the inclusion of the NBR and PVC segments inside the resin network, and leading to the reduction of viscous motion of chain segments due to the more interaction between the NBR/PVC segments and phenolic resin moieties. In the case of NBR/PVC samples, the uncrosslinked NBR segments are able to response more viscous like motions leading to the more damping of the applied dynamic field. It is also seen that the damping peaks (tan δ) for both samples have appeared in the same range of temperature. This indicated that NBR segments are not crosslinked by Hexa, and thus leads to the formation of semi interpenetrating network, while the resin/Hexa composed of NBR/PVC is heated.

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 as well as the sound damping characteristics of the cured pad in a wide range of temperatures. The NBR/PVC blend system showed to be more effective in the attenuation

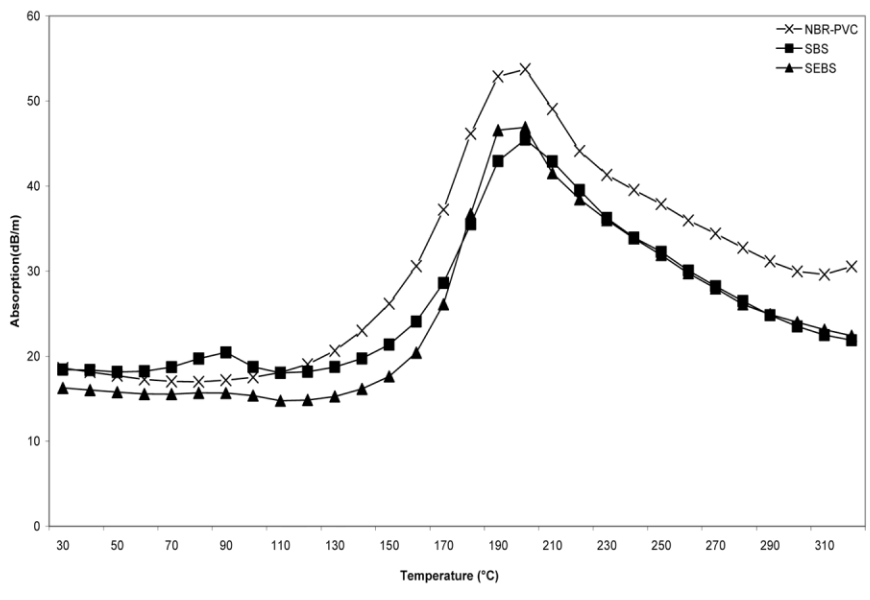

Figure 8 Sound absorption versus temperature for cured friction material having 2.5 wt % of different TPEs.

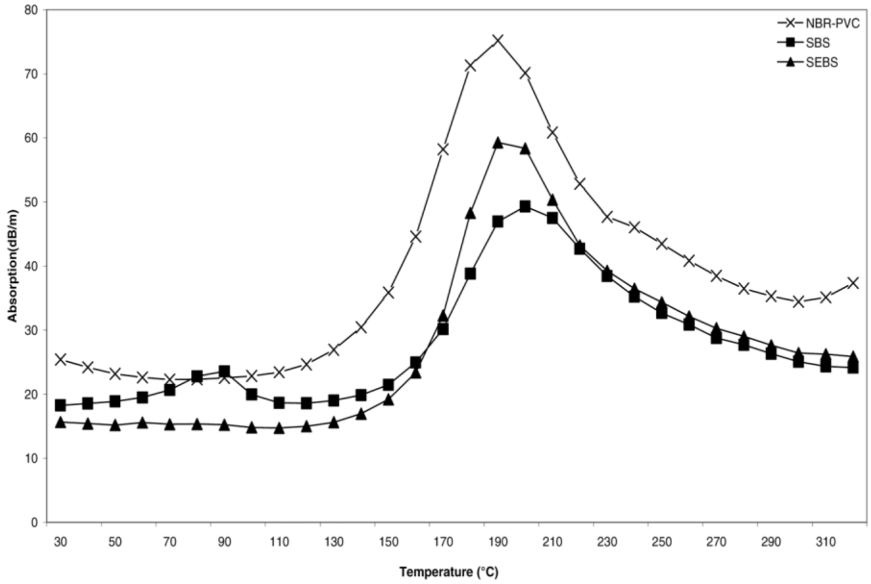

Figure 9 Sound absorption versus temperature for cured friction material having 3 wt % of different TPEs.

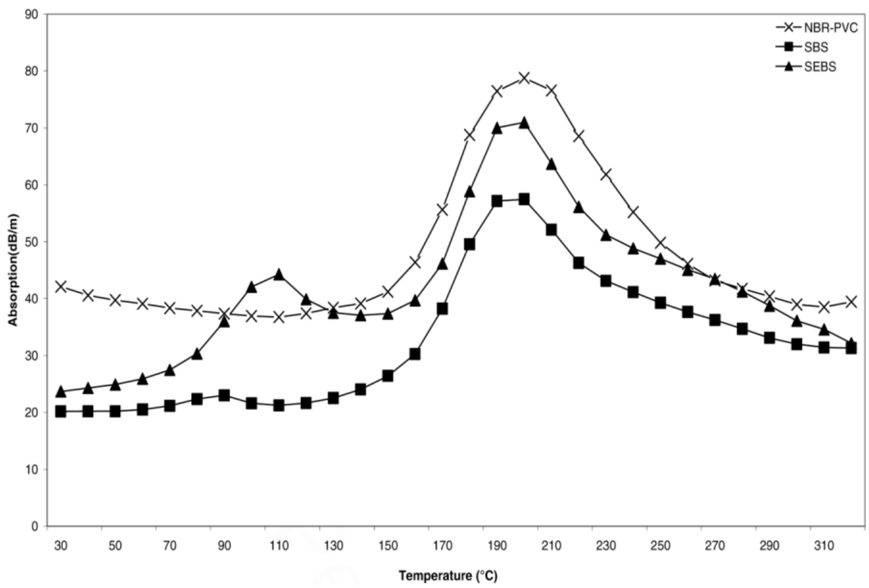

Figure 10 Sound absorption versus temperature for cured friction material having 4 wt % of different TPEs.

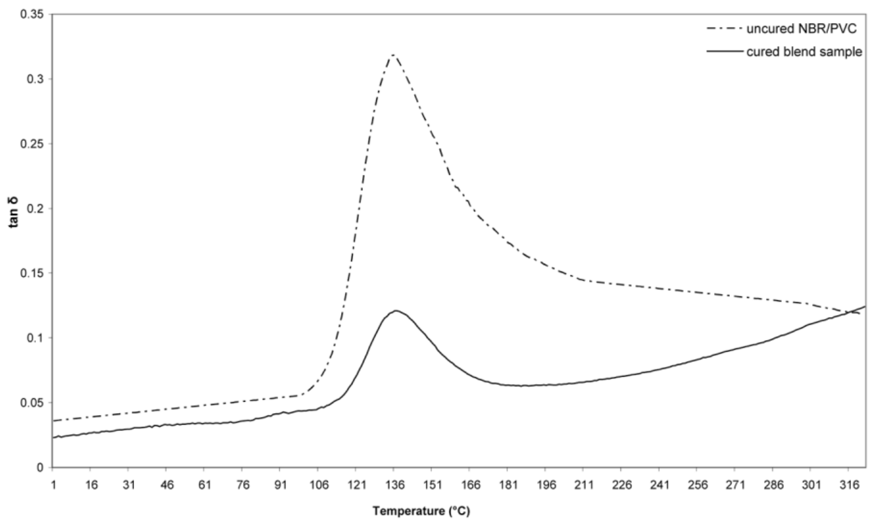

Figure 11 Tan δ versus temperature for uncured NBR/PVC and the blend sample of phenolic resin and NBR/PVC cured by Hexa.

of the sound intensity as well as propagating speed. 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 toward the braking forces.

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