Evaluation of Specialty Natural Rubbers for Engine Mount Application

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Abstract. An engine mount secures the engine of a vehicle to its chassis. Successful application of elastomeric mounts as vehicle engine mounts has been observed over the years. Epoxidised Natural Rubber (ENR) and Deproteinised Natural Rubber (DPNR) are specialty rubbers with a potential for application in the development of engine mounts. In this study, a blend comprising natural rubber (NR) and polybutadiene rubber (BR) is used to produce the Original Equipment Manufacturer (OEM) part. Epoxidised Natural Rubber (ENR25 and ENR50) and Deproteinised Natural Rubber (DPNR) developed by Malaysian Rubber Board were used and compared with NR by evaluating both physical and mechanical properties of the rubbers with different filler loadings. The physical properties of NR exhibited excellent results opposed to other rubbers. However, a blend of ENR25 and BR reflected good compression set at 100°C for 96 hours. The performance of an engine mount comprising a blend of ENR50 and BR is promising in reference to the excellent mechanical properties over that of other rubbers. Dynamic stiffness and damping characteristics of the engine mount play an important role to achieve vibration isolation with acceptable engine motion control in a vehicle’s engine mount system. It is perceived that engine mounts produced with a blend of ENR50 and BR can improve vibration effects in dynamic conditions.

1. Introduction

Generally the vehicle engine mounting system consists of an engine and several numbers of mounts connected to the vehicle structure. In the current technology of automobile industries, engine mounting systems have been primarily used to support the weight of the engine. This will ensure that the engine can be freely maintained in its specific design position. Besides supporting the engine weight, it is able to isolate the driver and from both noise and vibration generated by the engine [1]. Static and dynamic stiffnesses are very important properties to cater the performance of engine. It is known that rubbers are extensively used in many applications because of their large reversible elastic deformation, excellent damping and energy absorption characteristics [2] and it is a common material used in automotive industries. The present study was motivated by the improvement of engine mount performance, the success of which depends on the capabilities of rubber. It is well known that rubber has an ability to deform and prevent of shocks and vibrations. This latter function depends on two properties of rubber to deform: firstly, its damping effect or departure from perfect elasticity (hysteresis) which enables it to absorb the energy of shock and vibration; secondly, the fact that by choosing the correct dimensions a rubber mounting can be made as it were “impervious” to vibrations of a given frequency [3]. Specialty rubbers such as epoxidized natural rubber (ENR) 25, ENR50 and deproteinised natural rubber (DPNR) have potential to be used in the development of automotive products. These materials cover a wide range of properties desirable to meet certain requirement in engineering application reduced creep, enhancement in resilience [4] and good
dynamic properties [5]. The advantages of ENR include excellent properties of damping, wet-grip or rolling resistance, oil resistance and gas permeability compared to NR [6]. In addition, DPNR has low creep and stress relaxation, low water absorption, low compression set and a more consistent modulus when subjected to conditions of variable humidity compared to NR [7, 8]. In the present investigation study, a comparative study on several types of natural and specialty rubbers was made by carrying out physical and mechanical tests. Polybutadiene Rubber (BR) was used and blended with natural and specialty rubbers to investigate the physical and mechanical properties of each rubber compound in the development of engine mount.

2. Materials and Methods

The modified rubber was compounded according to a compounding formulation for an engine mount as shown in Table 1. The compounds used in this investigation were Standard Malaysia Rubber CV 60, ENR 25, ENR 50, DPNR and Polybutadiene Rubber (BR). Eight rubber formulations containing two different loading of carbon black were mixed and cured as nominal 2mm thick sheets. NR is known for its inherent strength, its ability to withstand large deformations and resistance to crack propagation. BR, on the other hand, exhibits better abrasion resistance, resilience, and resistance to initiation of cracks. Therefore, a combination of NR and BR finds vast application in various rubber products, including the tread and sidewall of the tyre and elastomer part the engine isolate mount [9,10]. All rubber compounds were blended with BR because this synthetic rubber could improve the damping property. All the rubber compounds were prepared using a lab size two roll mill machine at temperature of 165°C.

Table 1. Rubber compound formulation

| Ingredients/Name | CV60/BR (1) | ENR25/BR(1) | ENR50/BR(1) | DPNR/BR(1) | CV60/BR(2) | ENR25/BR(2) | ENR50/BR(2) | DPNR/BR(2) |
|------------------|-------------|-------------|-------------|------------|-------------|-------------|-------------|------------|
| NR (SMR CV60)    | 70          | -           | -           | 70         | -           | -           | -           | -          |
| ENR 25           | -           | 70          | -           | -          | 70          | -           | -           | -          |
| ENR 50           | -           | -           | 70          | -          | -           | 70          | -           | -          |
| DPNR             | -           | -           | -           | 70         | -           | -           | -           | 70         |
| BR               | 30          | 30          | 30          | 30         | 30          | 30          | 30          | 30         |
| Carbon black     | 26          | 26          | 26          | 26         | 36          | 36          | 36          | 36         |
| ZnO              | 5           | 5           | 5           | 5          | 5           | 5           | 5           | 5          |
| Stearic acid     | 2           | 2           | 2           | 2          | 2           | 2           | 2           | 2          |
| Sulfur           | 1.7         | 1.7         | 1.7         | 1.7        | 1.7         | 1.7         | 1.7         | 1.7        |
| CBS              | 1.3         | 1.3         | 1.3         | 1.3        | 1.3         | 1.3         | 1.3         | 1.3        |
| TMTD             | 0.5         | 0.5         | 0.5         | 0.5        | 0.5         | 0.5         | 0.5         | 0.5        |
| Oil              | 4           | 4           | 4           | 4          | 4           | 4           | 4           | 4          |
| Cure Condition (Time, Temperature) | 20 min, 165°C | 20 min, 165°C | 20 min, 165°C | 20 min, 165°C | 20 min, 165°C | 20 min, 165°C | 20 min, 165°C | 20 min, 165°C |
2.1 Measurement of rubber viscosity
Viscosity is a property of the fluid which opposes the relative motion between the two surfaces of the fluid that are moving at different velocities. This property is referred to evaluate of the flow of rubber compound. Viscosity of each rubber compound was measured using MV2000 by referring to the ISO 289-1 document, Part 1: Determination of Mooney viscosity.

2.2 Measurement of rubber compound hardness
Rubber hardness is essentially a measure of the reversible, elastic deformation produced by a specially-shaped indentor under a specified load. In the present investigation, three hardness buttons of each compound were cured and used for hardness tests. The test was carried out referring to BS ISO 48:2007.

2.3 Characterisation of tensile and elongation at break in aged and unaged conditions
Eighty tensile dumbbells represent of eight rubber compound formulations (Type 2, BS ISO 37:2005) were prepared for aged and unaged tensile and elongation at break tests. The dumbbells test pieces were aged at the condition of 70°C for 70 hours and the tensile strength tests were carried out according to the BS ISO37.

2.4 Characterisation of compression set property
Forty eight of test pieces were prepared according to ISO 815 (1993)/JIS K6258 (1993). Two type of compression set were carried out at temperatures of 22±3°C for 72 hours and 100°C for 90 hours respectively.

2.5 Product performance testing
An engine mount was produced using a mould with two cavities. In the moulding process, external and internal sleeve metals were used to produce an engine mount component. All the metal parts were going through metal treatment process. Four units of engine mount were cured using an injection machine and each cycle was produced using eight different rubber compounds. Static and dynamic tests were carried out on a servopulser Shimadzu testing machine. A special jig was designed and fabricated as shown in Fig. 1 and 2. The testing conditions are shown in Table 2.

Fig. 1. The overview of static compression test.
Fig. 2. Dynamic test setup on a Shimadzu testing machine
Table 2. Static and dynamic testing conditions

|                | Static Test                      | Dynamic Test      |
|----------------|----------------------------------|-------------------|
| Preload (mm)   | 0 - 11mm (2 times)               | 1000N             |
| No. of Cycle   | 5                                |                   |
| Speed rate (mm/min) | 13mm/min                      |                   |
| Static stiffness measuring | 850N - 1150N            |                   |
| Frequency (Hz), | 15, 40, 100               |                   |
| Displacement Amplitude (mm) | ±1.0mm, ±0.25mm, ±0.05mm |                   |

The static stiffness, $K_s$, was calculated using Equation 1.

$$K_s = \frac{(L_1 - L_2)}{(D_1 - D_2)}$$  

$L_1$ and $L_2$ indicate the load applied region in the actual application. The calculation load region is 850N – 1150N and $D_1$ and $D_2$ are the value of displacement at the load position as shown in Fig. 3.

![Fig. 3. Force and deflection curves for one of the static tests for 5 cycles.](image)

The absolute spring constant or dynamic stiffness, $K_d$, was calculated and each dynamic stiffness according to the frequency was obtained using the equation (1). Fig. 4 shows one example of testing data which was analysed to determine dynamic stiffness at frequency of 15Hz.
Because rubbers are not perfectly elastic, the strain during cyclic deformation always lags slightly behind the stress. If the relaxation between the force and the deformation is approximately linear the application of a sinusoidal deformation will result in a sinusoidal force of the same frequency but displaced in terms of phase by an amount termed the loss angle (Fig. 5)[11].

Fig. 4. A hysteresis loop of load-stroke displacement at frequency of 15 Hz

Fig. 5. Response of a linear viscoelastic material to an imposed sinusoidal shear strain of amplitude $\gamma_o$. The stress of amplitude $\tau_o$ leads the strain by the phase angle $\delta_o$. The in-phase modulus $G' = \tau_o'/\gamma_o$ and the out-of-phase modulus $G'' = \tau_o''/\gamma_o$, where $\tau_o'$ and $\tau_o''$ are the amplitudes of the in and out-of-phase stress respectively [11].
It is convenient to consider the elastic, in-phase response and the viscous, out-of-phase in terms of two moduli. The overall response can then be expressed as a complex modulus. For instance, in shear the modulus (stress amplitude/strain amplitude),

\[ G^* = G' + jG'' \]  

where \( G' \) is the in-phase, 'storage' modulus and \( G'' \), the out-of-phase, 'loss' modulus. Modulus alone is here used to refer to \( G^* \). The phase or loss angle \( \delta \) is given by

\[ \tan \delta = \frac{G'}{G''} \]

3. Results and Discussion

3.1 Viscosity cure of rubber compounds

The most common parameter used to assess flow behavior is viscosity particularly in the injection mould processing of engine mount production. Rubber flow is very important for shaping process. Basically, viscosity affects both mixing and fabrication processes [12]. In the present study, the value of rubber viscosity is determined to correlate with other mechanical properties. Table 3 shows the results of Mooney viscosity for each rubber. ENR 50 shows high Mooney viscosity follow by ENR 25, DPNR and NR. The number proportional with the torque as viscosity index (Mooney viscosity) is shown in Table 3.

| Rubber | Mooney Viscosity (MV) |
|--------|-----------------------|
| NR     | 57                    |
| ENR 25 | 88                    |
| ENR 50 | 91                    |
| DPNR   | 70                    |

Here, the specialty rubbers have high values of viscosity compared to natural rubber. The viscosity of NR is sufficiently low and ease to incorporate with compounding ingredients. However, the viscosity of specialty rubbers is sufficiently high which can improve dispersion in the mixing process of rubber compound for engine mount [12].

3.2 Hardness of rubber compound

The results of hardness are shown in Fig. 6 according to the different rubber compounds. The results indicate that hardness increased with the increasing carbon black loading from 26phr to 36phr. ENR 50/BR showed high hardness compared to other rubber compounds followed by the hardness of DPNR. It is believed that the hardness of rubber compound can be increased using specialty rubber and this will be an alternative approach to optimise rubber hardness. The mechanism of the increase of hardness is because of the specialty rubbers have been epoxidised and deproteinised compared with NR and ease to blend completely with BR. This will helps all compounding ingredients incorporated into rubber.
3.3 Tensile strength

Tensile test was undertaken using all different rubber compounds. Fig. 7 shows the histogram of tensile strength versus carbon black loading for each rubber compound. The NR/BR showed high tensile strength compared to other rubber compounds. However, the tensile strength of DPNR/BR compound is higher than ENR 50/BR and ENR 25/BR compounds, respectively. Most of the tensile strength increased slightly when the loading of carbon black increased from 26phr to 36phr. The increase of carbon black gives more reinforcing filler and the degree of reinforcement into rubber.

3.4 Elongation at break

Fig. 8 shows the histogram of elongation at break of each rubber compound versus carbon black loading. The elongation at break of DPNR/BR compound was above 464% which is higher than other rubber compounds. In contrast, ENR 50/BR compound shows the lowest elongation at break among the rubber compounds. Most of the elongation at break slightly reduced when the carbon black loading is increased from 26phr to 36phr. It is confirmed that the increase of carbon black loading give less flexibility to the rubber compounds.
Fig. 8. Histogram of elongation at break versus carbon black loading

3.5 Tensile strength and elongation at break in normal and aged condition

Figs 9 and 10 show the results of tensile strength and elongation at break in both of unaged and aged conditions. The comparison of carbon black loading for these two properties was also carried out. In Fig. 8, DPNR/BR compound showed the lowest different percentage of tensile strength among other rubber compounds (T1- 26phr of carbon black) which was 3.26% between unaged and aged conditions. This is because of DPNR/BR compound has good dispersion of reinforcing filler compared with other compounds. In contrast, the different percentages of tensile strength in normal and aged conditions for specialty rubber compound (ENR 25/BR and ENR 50/BR) using 26phr of carbon black (T1) are higher than NR/BR and DPNR/BR compounds which are above 20%. Nevertheless, the different percentage of rubber compounds using 36phr of carbon black (T2) for normal and aged conditions was not very significant which less than 8%. DPNR/BR showed the lowest different percentage of tensile strength compared to other compounds. In Fig. 10, the elongation at break for rubber compound using 26phr of carbon black in unaged and aged was more significant compared with the rubber compound using 36phr of carbon black. However, the different percentage of the elongation at break for ENR50/BR rubber compound using 36phr of carbon black is higher than that of ENR 50/BR rubber compound using 26phr of carbon black. This because of the elongation at break after ageing process of ENR50/BR compounds with carbon black loading of 36phr is lower compared to ENR50/BR compounds with carbon black loading of 26phr.
It is found that the ageing process of all rubber compounds using 26phr and 36phr of carbon black reduced the tensile strength and the elongation at break. The different percentages of both properties are paramount to evaluate all the rubber compounds whether their properties changed significantly.

3.6 Compression set of rubber compound

Figures 11 and 12 show the histogram of compression set versus carbon black loading for two different ageing conditions. ENR 25/BR showed the lowest percentage of compression set compared to other rubber compounds at 70°C for 22 hours as shown in Fig. 11. Fig. 12 shows DPNR/BR which is the lowest compared to other rubber compounds after aged at 100°C for 96 hours. These results showed that specialty rubbers have good compression set except ENR25/BR compound which the compression set is higher at 100°C for 96 hours. Based on the results of compression set, it is assumed that specialty rubbers have good density and an efficient cure system compared with natural rubber.
3.7 Performance test results of engine mount

The evaluation of an engine mount using all rubber compounds is essential to ensure that the performance of the component is adequate with engine specification requirement. Fig. 13 shows static stiffness of each engine mount using four different rubber compounds. The results indicate that static stiffness of rubber compound using 36phr of carbon black (T1) is higher than rubber compound using 26phr of carbon black (T2). ENR 50/BR showed high static stiffness compared to other rubber compounds. This is because the epoxidation process of 50% epoxy moles (ENR50%) can induce more interaction with reinforcing fillers particularly carbon black and become superior against natural rubber due to random arrangement of the epoxy groups on the main chain of the polymer.

Dynamic stiffness is also an important property in the development of engine mount. The higher the content of carbon black loading can increase static stiffness, dynamic stiffness and tan delta. The response of a mounted body to a vibration about the static deflection is controlled by the dynamic stiffness. For the filled rubber, the dynamic stiffness is determined by the slope of the force-deflection curve in retraction away from the static deflection point; the slope at this point of the force-deflection curve for loading may be substantially less, resulting
in the so-called dynamic/static ratio. Fig. 14 and 15 show results of dynamic stiffness for engine mount using 26phr and 36phr of carbon black. ENR 50/BR rubber compound showed high dynamic stiffness compared to other rubber compounds at all frequencies (15Hz, 40Hz and 100Hz). This is because ENR50/BR compound showed excellent crosslink density with more interaction between rubber matrix and carbon black of 26phr and 36phr. ENR 25/BR showed high dynamic stiffness compared with DPNR/BR and CV60/BR. These results proved that the use of ENR can improve dynamic stiffness of rubber compound. ENR/BR has potential to replace CV60/BR rubber compound in the development of engine mount.

![Fig. 14. Histogram of dynamic stiffness of engine mount using 26phr of carbon black for each rubber compound.](image1)

![Fig. 15. Histogram of dynamic stiffness of engine mount using 36phr of carbon black for each rubber compound.](image2)

The tan delta quantifies the way in which a material absorbs and disperses energy. It expresses the out-of-phase time relationship between an impact force and the resultant force that is transmitted to the supporting body. Fig. 16 showed the histogram of tan delta of engine mount versus rubber compounds according to carbon black loading at 15Hz. ENR 50/BR shows...
high tan delta compared to other rubber compounds. This rubber compound demonstrates the greatest capability to dissipate energy and contribute more effective in damping properties. The higher the tan delta, the greater the damping coefficient, the more efficient the material will be in effectively accomplishing energy absorption and dispersal.

Fig. 16. Histogram of tan delta of engine mount versus rubber compound at 15Hz.

4. Conclusion

The comparison of physical and mechanical properties for BR blends with NR, ENR and DPNR has been successfully undertaken. The higher the amount of carbon black loading increases the physical and mechanical properties. The ageing process of all rubber compounds using 26phr and 36phr of carbon black reduced the tensile strength and the elongation at break. The specialty rubbers showed good compression set compared to NR. ENR 50/BR blends showed excellent physical and mechanical properties among rubber compounds. ENR 50/BR indicates high tan delta compared to other rubber compounds. Thus, it is apparent from the engineering aspect that ENR 50/BR can be considered as a potential material for automotive engineering application such as engine mount since the tan delta is significantly higher than the rest of the rubber compounds.

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