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Evaluation of Mechanical Properties on Vulcanized SMRCV-60 and ENR-25 of Flexible-Rigid Body Vibration Isolator

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ABSTRACT

This paper presents the evaluation of tensile test results on mechanical properties of local natural rubber called the standard Malaysian rubber constant viscosity-60 and the epoxidized natural rubber 25% with different carbon loadings for vibration isolators. The tensile test was carried out to determine the breaking point for both specimens. Based on the results, the lowest recorded tensile strength was identified in rubber compound containing 0 phr carbon, and the maximum tensile strength values were evaluated with higher phr carbon. The results also showed that the carbon reinforcement was proportion with the values of the tensile strength. The recorded Young's Modulus and the values of the modulus depend on the values of carbon content in the rubber compound. By increasing the percentage of carbon, the modulus also increased. The pattern of the stress-elongation curve was also significantly changed by increasing the tensile strength. The deformation of the secondary bonding within rubber and fillers was also evaluated and the bonding became stronger by increasing the carbon. In conclusion, it is found that by increasing the carbon percentage in both types of rubber compound contributes to higher mechanical properties of the samples.

Keywords: Vibration Isolator, SMRCV-60. ENR-25, Flexibility.

1. INTRODUCTION

Rubbers are available in two types, which are synthetic and natural. Synthetic rubber is an artificial rubber that has been produced through a polymerization process of petroleum by-product. It is invented to reduce the dependency on natural rubber (NR) during War World 2. As for today, there are more than 20 types of synthetic rubber available for various applications. On the other hand, NR is naturally extracted from the rubber trees through the tapping process. It is a process of latex secretion by shearing a thin layer of rubber tree's bark using a special tapping knife (http://sarawakrubbertapper). There are more than 2,500 species of plants that are known to produce the latex. Despite that, only latex produced from the Hevea Brasiliensis tree is mostly used for rubbery products due to its quality. NR also has some adequate advantages over synthetic rubber. It is considered as green material since it can be continuously supplied by nature as compared to the synthetic rubber, which is derived from the non-renewable sources [1]. Besides that, the price of raw NR is more economical than synthetic rubber, which fluctuates depending on the current crude oil prices. Other than that, the properties of NR compound can be derived from better formulation and processing.

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Besides that, NR also allows low heat build-up in dynamic force to make it able to withstand large deformations and also possess the ability to instantly recover when distorted at room temperature [2]. It does not require extensive maintenance as NR is capable of maintaining itself for a long period of time. Additionally, NR exhibits inherent damping and spring-like performance to reduce the resonant effect. It can be bonded with other materials such as metal in order to increase its strength [3]. The main function of High Damping Natural Rubber (HDNR) is to withstand any possible large earthquake occurrence or environmental disaster in the future [4-6].

The invention of synthetic rubbers is initially to overcome the dependency on NR due to high demands of rubber supplies. Consequently, it has affected the demands of NR since synthetic rubber offers better resistance to oils, temperature and chemicals. Nevertheless, with specific compounding formulation, fillers additions, and accurate manufacturing process have enabled NR to be continuously used in various applications. The addition of fillers in NR compound can highly affect the properties and strength of the compounds depending on the filler types, sizes, and loading. Aside from that, it is also found that most of the industrial applications in Malaysia prefer to use the imported rubber instead of the locally manufactured rubber, although it possesses comparable qualities.

Besides, previous research found that the development of the laminated rubber-metal spring (LR-MS) for automotive mounting is currently in trend [7-11]. Therefore, the application of Malaysian NR, which is the vulcanized standard Malaysian rubber constant viscosity 60 (SMR CV-60) and the 25% mole epoxidized NR (ENR 25), reinforced with carbon black (CB) as the potential main material to be combined with metal plate for the development of LR-MS has become the interest of this study. Therefore, this study focuses on the investigation of mechanical properties for both vulcanized SMR CV-60 and ENR 25 through an experimental approach.

2. MATERIAL AND METHODS

2.1 Materials and Sample Preparation

Two types of NR compound were used in this study, which was the vulcanized standard Malaysian rubber constant viscosity 60 (SMR CV-60) and the vulcanized epoxidized NR with 25 mol % (ENR 25). The collaboration with the Malaysian Rubber Board (MRB) allowed the material preparation including the milling, mixing, and the vulcanizing processes to be prepared in MRB laboratory at Sungai Buloh, Selangor in order to maintain the quality of compounded rubber as required by MRB.

The composition of ingredients for the rubber compound was prepared based on part per hundred of rubber (phr). A 100 g of NR contains 5 g of zinc oxide, 5 g of stearic acid, 0.8 g of sulfenamide (CBS), 3.25 of sulphur, 3 g of santoflex 13, 2 g of parafin wax, and various range of CB (0 to 60 g). The addition of sulphur helps to increase the crosslink in rubbers resulting in the improvement of rubber texture from soft to hard. Meanwhile, the other ingredients such as zinc oxide, stearic acid, and CBS work as the accelerator to boost up the sulphur crosslink efficiency. The N330 CB type was used as the filler since it is known as the most effective carbon in polymer reinforcement. Thus, in this study, the carbon loading in NR compound was set as the changing parameter, which was varied at 0, 20, 40 and 60 phr. Besides that, santoflex 13 and paraffin wax were also added into the compound as the ozone protective agent.

The overall process for material preparation is shown in Figure 1. The equipment specifications and procedures for mixing and vulcanization processes were referred to the practice as in ASTM D3182: Standard Practice for Rubber-Materials, Equipment, and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets. It was used as a guideline for preparing the standard vulcanized rubber sheets. The compounding process was started by mixing the dried NR with other ingredients in the rolling machine for about 10 to 15 minutes.

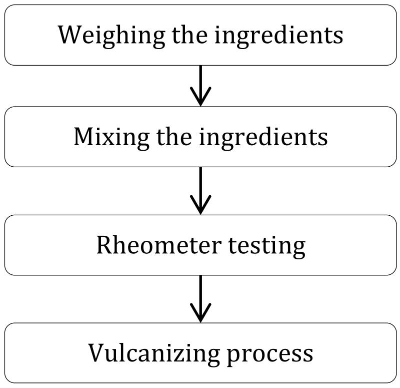

Figure 1. Process of material preparation.

Then, the compound was left to rest for at least four hours to reach its steady-state before proceeding to the next process. Rheometer test was conducted by MRB laboratory officer in order to obtain the parameter for the last process, which was the vulcanization process. The compounds were vulcanized at the temperature of 150˚C for 8 to 12 minutes, depending on CB composition of the NR compound. Vulcanizing process refers to a process of treating the rubber material with sulphur in the presence of great heat to improve its elasticity and hardness. The final product was moulded into two forms, which are 2 mm rubber sheet for the tensile test and 6 mm height of cylinder for the compression test.

2.2 Tensile Test

In this study, the tensile test was conducted to measure the maximum applied force at specified elongation and the maximum elongation at breaking point, if any, for vulcanized SMR CV-60 and ENR 25 NR specimens, filled at different carbon loadings (0, 20, 40, and 60 phr). This test was also conducted to verify that the prepared samples meet the specified requirement of the application performance. Thus, the tensile test was conducted by following the guideline as stated in ASTM D412 – Method A: Standard Test Method for Vulcanized Rubber and Thermoplastic Elastomer-Tension. This standard focuses on the guidelines to evaluate the tensile properties of the vulcanized rubber compound.

For the experimental purpose, a dumbbell shape specimen as shown in Figure 2 was cut from the 2 mm rubber sheet by following all the dimensions of Die B as stated in the standard. The test was conducted using the Universal Testing Machine (UTM) with a standard temperature of 23 ± 2˚C. The specimen was griped at both ends with the 30 mm of benchmark distance on each side. It was stretched with the rate of jaw separation of 500 ± 50 mm/min. However, there was a limitation in this test, where the specimen could only be stretched up to 450% of the original dimension due to the maximum height that can be reached by the UTM machine.

Figure 2. Tensile test specimen

The measured tensile properties from this test are tensile stress ($\sigma_{tensile}$), elongation ($\%_{elongation}$), tensile Young's Modulus ($E_{tensile}$), and tensile set (E_{set}). Tensile stress was calculated by using Eq. (1),

$$\sigma_{tensile} = \frac{F}{A} \tag{1}$$

where F the is the force at specified elongation, which is obtained directly from the testing machine and A is the cross-sectional area of the unstrained specimen.

Tensile stress is presented in MPa units. In addition, the elongation of the strained specimen was calculated by using Eq. (2),

$$\varepsilon_{tensile} = 100[l - l_0]/l_0 \tag{2}$$

where l represents the specified elongation between the benchmarks and l_0 represents the original length between the benchmarks.

In this study, the specimen elongation was presented in percentage (%).

The tensile Young's Modulus was obtained through the ratio of the tensile stress to the tensile strain. For the tensile set measurement, which refers to the measurement of permanent changes on the specimen length after the tensile test, the specimen needed to be rested for 10 minutes after released before the new distance between the benchmarks was measured by using a ruler. The following Eq. (3) was used to calculate the tensile set of vulcanized rubber.

$$E_{set} = 100[l - l_0]/l_0 \tag{3}$$

where l is equal to the new benchmark distance after 10 minutes of rest and l_0 is the original benchmark distance.

Meanwhile, the relative tensile properties were also calculated, which represent the strength of vulcanized SMR CV-60 and ENR 25 at different carbon loadings. The relative tensile properties between NR compounds at different carbon loadings were also calculated by using Eq. (4) as follows:

$$\text{Relative tensile properties} = 100(\sigma_{filled} / \sigma_{unfilled}) \tag{4}$$

where σ_{filled} represents NR stress value at certain carbon loading and $\sigma_{unfilled}$ represents NR stress value for the NR compound without carbon loading.

3. RESULTS AND DISCUSSION

Table 1 presents the tensile properties for SMR CV-60 at 0, 20, 40, and 60 phr of carbon loadings. Based on the obtained results, SMRCV60-0, which is the vulcanized rubber compound containing 0 phr of carbon, has recorded the lowest tensile strength with the value of 5.9 MPa at 449% of elongation. The maximum tensile strength value increases as the CB reinforcement into the rubber compounds increases. SMRCV60-20 and SMRCV60-40 have recorded the maximum tensile strength values of 13.9 MPa at 447% of elongation and 24 MPa at 448% of elongation, respectively. The highest tensile strength value has been recorded by the SMRCV60-60, which is the vulcanized rubber compound with the highest carbon loading, with the value of 26 MPa at 353% of elongation. The tensile results for the SMR CV-60 have been plotted into the graph of tensile stress versus the percentage of elongation as shown in Figure 3.

Table 1 Tensile properties for the vulcanized SMRCV-60 compounds

Carbon loading (phr)		0	20	40	60
SMRCV-60	Maximum Tensile Stress, σ_{max} (MPa)	5.9	-	-	-
	Maximum Elongation, (%)	449	-	-	-
	Young's Modulus, $E_{tensile}$ (MPa)	1.5	-	-	-
SMRCV-60	Maximum Tensile Stress, σ_{max} (MPa)	-	13.9	-	-
	Maximum Elongation, (%)	-	447	-	-
	Young's Modulus, $E_{tensile}$ (MPa)	-	4.6	-	-
SMRCV-60	Maximum Tensile Stress, σ_{max} (MPa)	-	-	24	-
	Maximum Elongation, (%)	-	-	448	-
	Young's Modulus, $E_{tensile}$ (MPa)	-	-	7.9	-
SMRCV-60	Maximum Tensile Stress, σ_{max} (MPa)	-	-	-	26
	Maximum Elongation, (%)	-	-	-	353
	Young's Modulus, $E_{tensile}$ (MPa)	-	-	-	8.5

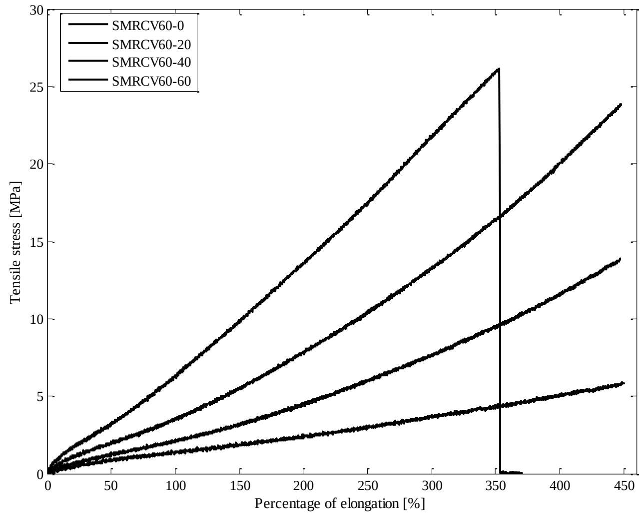

Figure 3. Graph of tensile stress versus the percentage of elongation (SMR CV-60)

Comparatively, the tensile properties of the vulcanized ENR 25 are tabulated in Table 2. By referring to the obtained results, it can be observed that the tensile stress value increases with the increase of carbon loadings for the vulcanized ENR 25. The maximum tensile stresses have been recorded by the vulcanized ENR 25 are 5.2 MPa for the ENR25-0 at 441% of elongation, 15.2 MPa for the ENR25-20 at 441% of elongation, 25 MPa for the ENR25-40 at 446% of elongation, and lastly 27 MPa for the ENR25-60 at 352% of elongation. The highest Young's Modulus value has been recorded by the sample with the highest carbon loading, which is ENR25-60 at 8.5 MPa, follows by ENR25-40 at 8.00 MPa and ENR25-20 at 5.4 MPa. Eventually, the lowest Young's Modulus is recorded by the sample without carbon loading, which is ENR25-0 with the value of 1.4 MPa. In addition, Figure 4 shows the graph of the tensile.

Table 2 Tensile properties for the vulcanized ENR-25 compounds

Carbon loading (phr)		0	20	40	60
ENR 25	Maximum Tensile Stress, $\sigma_{\max}$ (MPa)	5.2	-	-	-
	Maximum Elongation, (%)	441	-	-	-
	Young's Modulus, $E_{tensile}$ (MPa)	1.4	-	-	-
ENR 25	Maximum Tensile Stress, $\sigma_{\max}$ (MPa)	-	15.2	-	-
	Maximum Elongation, (%)	-	441	-	-
	Young's Modulus, $E_{tensile}$ (MPa)	-	5.4	-	-
ENR 25	Maximum Tensile Stress, $\sigma_{\max}$ (MPa)	-	-	25	-
	Maximum Elongation, (%)	-	-	446	-
	Young's Modulus, $E_{tensile}$ (MPa)	-	-	8.0	-
ENR 25	Maximum Tensile Stress, $\sigma_{\max}$ (MPa)	-	-	-	27
	Maximum Elongation, (%)	-	-	-	352
	Young's Modulus, $E_{tensile}$ (MPa)	-	-	-	8.5

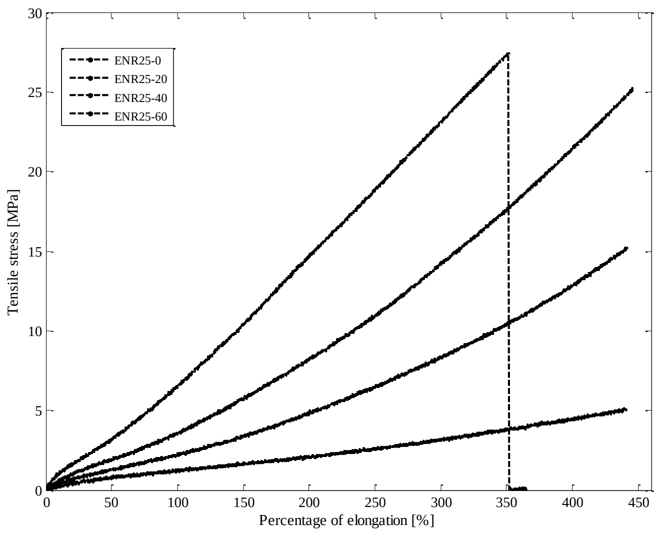

Figure 4. Graph of tensile stress versus the percentage of elongation (ENR 25).

Based on the tensile properties of both vulcanized SMR CV-60 and ENR 25 as presented in Table 1, Table 2, Figure 3 and Figure 4, it clearly shows that both NR grades display the rubber-like elasticity behaviour, where a large strain is visible under the low-stress level. This behaviour is closely related to the crosslinking between rubber chains. The crosslinking of rubber chain occurs during the vulcanization process, where the rubber chain is cross-linked with the sulphur (S) molecule, which turns the sticky raw NR into an elastic NR compound. Figure 5 explains the pattern of the stress-elongation curve of all samples under tensile loading. The curve starts with a significant increment of stress values and starts to grow slowly in region A. At this point, the coiled rubber starts to uncoil as the load is applied, resulting of low modulus reading. As the load is continuously applied, the uncoiled chain is stretched until it is fully extended and becomes tense. The deformation of the secondary bonding (between the rubber and fillers) also starts in this region. As the load is further applied, the stress shifts to the covalent bond between the rubber molecules, in which contributes to the increment of stress and modulus value as shown in region B. The elasticity of NR compound reduces along with the excessive extension and finally resulting in the elastic deformation due to chains overstretching as shown in region C.

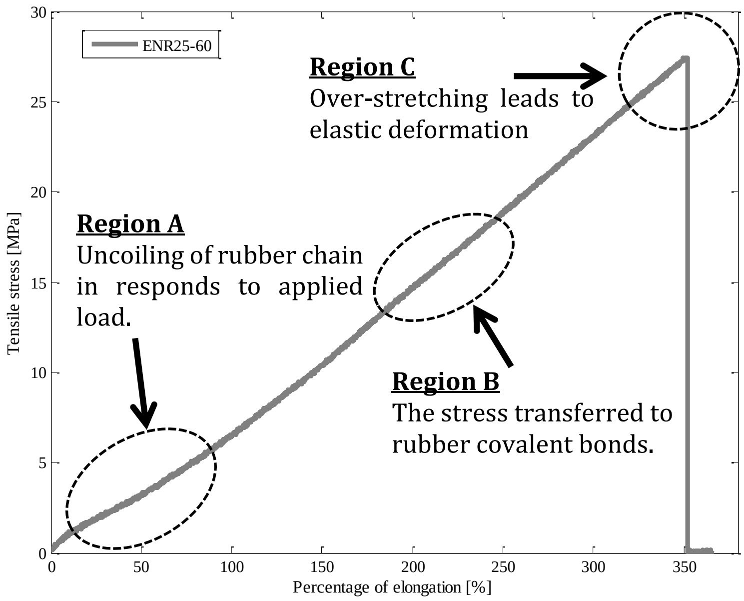

Figure 5. The pattern of the stress-strain curve in tensile testing.

In addition, the state of elasticity for vulcanized NR can be influenced by the sulphur content. Low sulphur content produces a soft and flexible rubber, while high sulphur content produces a rigid and hard rubber. High sulphur content produces more strands of a sulphur atom during crosslinking and the uncoiling of rubber chain becomes more restricted under the applied load. Based on the tensile test results, it can be proved that the usage of 3.25 g of sulphur does not significantly affect the mechanical properties of both NR compounds and can be considered as a sufficient amount. However, excessive sulphur content can lead to sulphur blooming, which is a phenomenon where the sulphur does not dissolve during the compounding and vulcanizing processes. It moves up to the surface of the NR compound. This phenomenon has been investigated through microscopic study and will be discussed in the next sub-chapter.

On the other hand, the graphs of stress-percentage elongation between SMR CV-60 and ENR 25 at different carbon loadings are compared and presented in Figure 6. It is found that the stress value of the specimens for both vulcanized NR compounds increases as the carbon loading increases. This is due to the effect of matrix-fillers interaction that strongly influences the behaviour and mechanical properties of both vulcanized NR compounds [12]. The increase of carbon loading in the compound increases the hardness of NR, thus enhances the ductility and it becomes less elastic [13]. Thus, high stresses are needed to stretch the specimens. The presence of N330 grade of CB also contributes to the increase of stress value in the NR compound, since N330 provides better orientation of NR chain as compared to other grades of CB.

The same figure also shows that both vulcanized NR with the highest carbon loading break at 350% of elongation. The mechanical properties of NR compound can be highly affected by its fillers content, where the content of the high filler can diminish mechanical properties due to poor filler dispersion. It normally happens in the NR compound with one type of filler. Thus, in recent studies, the researchers tried to combine CB with another type of filler so that higher filler loading can be added into the NR compound without affecting the mechanical properties. Besides that, Figure 6 clearly shows that the stress value of SMR CV60 and ENR25 specimens with similar carbon loading increases with similar strength pattern as the elongation increases before it starts to distinct from each other at a certain point. Accurately, the stress value starts to distinct from each other after the deformation of the secondary bonding. It is apparent from this graph that the tensile stress value for ENR 25 is larger than SMR CV-60. The observation also excludes the compound without carbon loading, where it appears that SMRCV60-0 stress value is larger than ENR25-0.

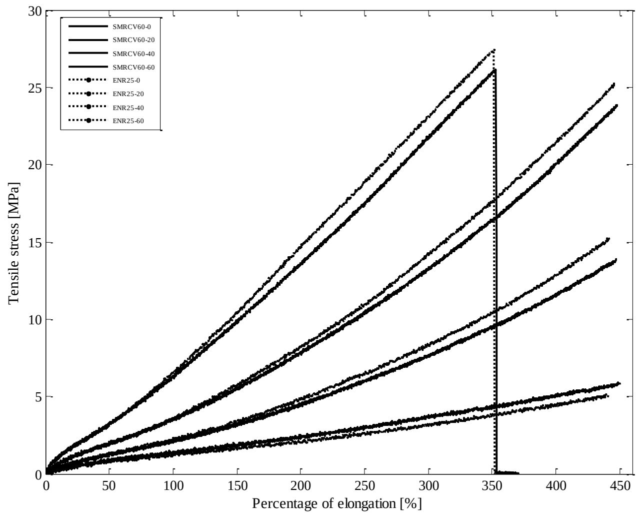

Figure 6. Comparison between the SMR CV-60 and the ENR 25 on the graphs of the tensile stress versus the percentage of elongation at different carbon loadings.

On top of that, the tensile modulus of both vulcanized NR compounds is compared in Figure 7. At the same figure, Young's Modulus value for ENR25-0 is slightly lower than SMRCV60-0. However, there is a big difference in Young's Modulus value when 20 phr of CB is added into the NR compound. The Young's Modulus value for ENR20-20 is larger than the SMRCV60-20. But, the gap between these modulus values is getting smaller as CB loading is increased to 40 and 60 phr. It is also found that the maximum tensile stress and the percentage of elongation influence the value of Young's Modulus.

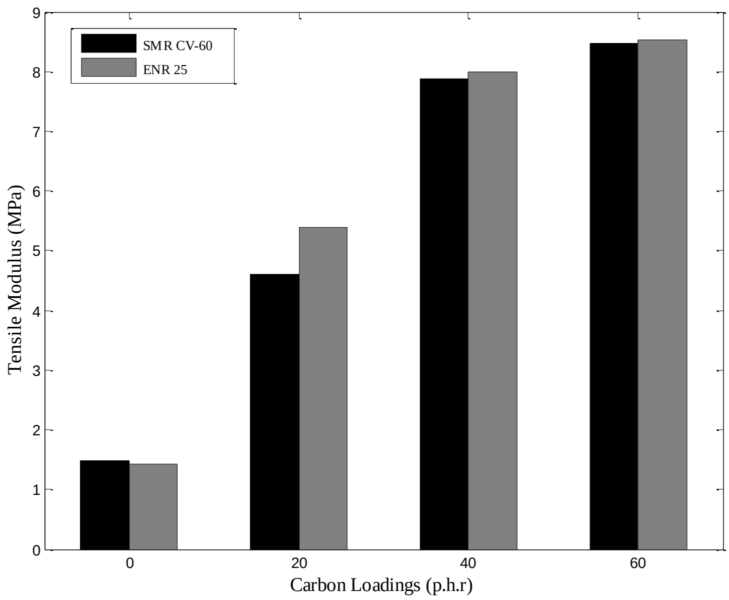

Figure 7. Comparison of the tensile modulus between SMR CV-60 and ENR 25.

The relative tensile properties for both SMR CV-60 and ENR 25 rubber compounds are shown in Table 3. The relative tensile properties represent the strength of vulcanized SMR CV-60 and ENR 25 at different carbon loadings. It shows that the strength of NR compound increases as the carbon loading is increased. ENR shows better reinforcement with CB rather than SMR CV-60.

Table 3 Relatives tensile properties for SMR CV-60 and ENR 25 compounds

Relative tensile properties				
Carbon loading (phr)	0	20	40	60
SMR CV-60	100%	-	-	-
SMR CV-60	-	135.71%	-	-
SMR CV-60	-	-	306.80%	-
SMR CV-60	-	-	-	344.56%
ENR 25	100%	-	-	-
ENR 25	-	194.58%	-	-
ENR 25	-	-	387.81%	-
ENR 25	-	-	-	430.75%

Concurrently, tensile set studies the ability of NR compound to recover after a large force is applied to both Malaysian NR grades, which are the vulcanized SMR CV-60 and ENR 25. The tensile set refers to the extension that remains after being stretched [14-16]. It is not exactly permanent as the remaining extension can be recovered to its original length, due to rubber's viscoelasticity behaviour and with the presence of temperature [14-18]. The residual extension between the sample's benchmark was recorded after it was stretched at the room temperature and released [19-20]. The samples were then allowed to rest at a fixed time of 10 minutes before they were measured. The new benchmark distance for the samples is tabulated into Table 4.

Table 4 Tensile set for SMR CV-60 and ENR 25 compounds

Carbon loading (phr)		**0**	**20**	**40**	**60**
Tensile set (%)	SMRCV-60	2.50	-	-	-
	SMRCV-60	-	11.25	-	-
	SMRCV-60	-	-	18.75	-
	SMRCV-60	-	-	-	20
Tensile set (%)	ENR 25	3.75	-	-	-
	ENR 25	-	6.25	-	-
	ENR 25	-	-	13.75	-
	ENR 25	-	-	-	16.25

Based on the data, it is found that the tensile set value for both vulcanized rubbers increases as the carbon loading increases. NR compound without carbon loading, which is the SMRCV60-0 and ENR25-0 have recorded the lowest residual extension after being stretched with the values of 2.50% and 3.75%, respectively. For the samples with 20 phr of carbon loading, it is found that the residual extension increases significantly for the sample of SMRCV60-20 with the value of 11.25%. Conversely, for the sample of ENR25-20, the residual extension increases twice the value of the sample without carbon loading with 6.25%.

The residual extension is continuously increasing as the carbon loading increases. For the samples that contain 40 phr of CB show that SMRCV60-40 has recorded 18.75% of residual extension while ENR25-40 has recorded an increment in residual extension with the value of 13.75%. In addition, the longest residual extension can be observed in the samples that contain 60 phr of CB loading, which are 20% for SMRCV60-60 and 16.25% for ENR25-60.

The relationship between CB loading and tensile set behaviour for both SMR CV-60 and ENR 25 can be observed in Figure 8, which presents the graph of tensile set versus CB loading. In general, the graph shows that the tensile set value is significantly increasing as the CB loading increases in both grades of NR. Besides, the graph also shows that the tensile set value for vulcanized SMR CV-60 is slightly higher as compared to vulcanized ENR 25, except for the samples without carbon loading where ENR25-0 is slightly higher than SMRCV60-0.

4. CONCLUSION

This paper presents the evaluation of tensile test results on mechanical properties of vulcanized SMRCV-60 and ENR-25 with different carbon loadings for vibration isolator application. The mechanical properties under investigation were tensile strength, Young's Modulus, breaking point, pattern of the stress-elongation curve and the deformation of the secondary bonding. All the samples were prepared and cut into a dumbbell shape. They were stretched using Universal Testing Machine (UTM). The results showed the best outcome of the investigated properties were for the samples with the highest carbon loading. At the end of the study, one conclusion can be made. The mechanical properties for both rubber compounds depend on the percentage of applied carbon black in the compound. By increasing the percentage of carbon black, the value of tensile strength. Young's Modulus, breaking point, elongation and deformation of the secondary bonding also increases.

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