Experimental Study of Natural Rubber Based Shock Attenuation Device

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Abstract

In this experimental study, the effect of reinforcing filler on the shock attenuating properties of Natural rubber was studied. The filler employed for the study was Carbon black & silica. Two compositions with different filler loadings were formulated. Samples for tensile, tear and hardness were tested. Shock attenuation devices were fabricated out of the two compositions and tested for dynamic loading by Drop-weight method. SEM micrographs were also obtained for analysis. Shock transmission experiment results clearly show that varying the amount of Carbon black (in filler) plays a role in changing the shock attenuation properties of the device.

Keywords: Natural Rubber, Carbon Black, reinforcing filler, shock, mechanical property

1. INTRODUCTION
Natural rubber (NR) is widely used for various applications due to its high tensile strength, low compression set, good resilience, resistance to wear and tear and easy
availability. It is also economical to use. Besides automobiles, NR also finds uses as hoses, conveyor belts, gloves and shock and vibration absorption components. As a matter of fact, Natural rubber based shock absorbing bearings and devices are widely used in many industries to effectively eliminate the possibility of shock energy transmission to sensitive machinery. In order to improve its service properties, fillers are often incorporated into the NR polymer matrix. These reinforcing fillers, by virtue of their good surface activity, contribute to improved inter phase interaction between NR polymer chain and filler thereby leading to an improvement in the mechanical properties. Karasek et. al.\textsuperscript{1} reviewed the literature on filler dispersion and filler-polymer interactions. Previous studies by authors\textsuperscript{2-4} explore the behavioral response of elastomeric materials due to different reinforcing filler loadings. They reported that the mechanical properties of the vulcanizates are greatly influenced by the type and quantity of the filler material. Moreover, there is an optimum level of reinforcement for achieving best mechanical properties from these elastomers. In another interesting study, Hamzah et. al.\textsuperscript{5} investigated the dynamic loading behavior of elastomeric materials by varying the Carbon black type. In short, it is important to research the effect reinforcing filler will have on an elastomeric composition meant for a specific application. This paper results from an experimental study of a general purpose shock attenuating device designed and fabricated with two different compositions of NR with Carbon black & silica as the reinforcing filler. The filler was added in two different loadings by varying the Carbon black content. In addition, the samples from the two compositions were tested for tensile, tear and hardness for a general evaluation of their mechanical properties. SEM micrographs were also obtained for analysis of filler level dispersion. Shock attenuation devices were fabricated out of the two compositions and tested for uni-directional dynamic loading by Drop-weight method with transmissibility measurements serving as indicators of shock attenuation capacity of different NR compositions. The various test results are discussed in the end.

2. THEORY

The impact or mechanical shock is a non-periodic excitation which is characterized by a sudden and severe application of force. The introduction of damping in the system results in a decrease of maximum as well as residual response. However, very little work has been reported in literature in damped systems under shock excitation\textsuperscript{6}.

For a single degree of freedom (SDOF) when an undamped spring is subjected to a half sine shock pulse, the governing equation can be written as\textsuperscript{7}

\[
m\ddot{x} + kx = F(t) = \begin{cases} 
F_0 \sin \left( \frac{\pi t}{\tau} \right) & t \leq \tau \\
0 & t \geq \tau 
\end{cases}
\]  

(1)
The response for \(0 < t < \tau\) is given as:

\[
x = \frac{F_0}{m\omega_o} \int_0^t \sin \frac{\pi \tau}{\tau} \sin \omega_o (t - \tilde{t}) d\tilde{t}
\]

(2)

For \(t \leq \tau\) the response is given as:

\[
x = \left[\frac{F_0}{k} \frac{\sin \frac{\pi t}{\tau} - \frac{\pi}{\omega_o \tau} \sin \omega_o t}{1 - \left(\frac{\pi^2}{\omega_o^2 \tau^2}\right)}\right]
\]

(3)

For \(t > \tau\) the response is given as:

\[
x = -\left(\frac{F_0}{k}\right) / \left(1 - \left(\frac{\pi^2}{\omega_o^2 \tau^2}\right)\right) \left[\sin \omega_o t + \sin \omega_o (t - \tau)\right]
\]

(4)

Where, \(m\) denotes the mass, \(k\) denotes the stiffness, \(\omega_o\) denotes the natural frequency, \(\tau\) the shock pulse duration and \(F(t)\) denotes the forcing function. The response of a system to shock impulse is largely dependent on its natural frequency and duration of shock pulse. It is well established that the product of natural frequency and duration of shock pulse decides the response amplitude. For a response value of \((xk/F_0)_{\text{max}} < 1\) the product of natural frequency and duration of shock pulse has to be smaller as is clearly seen in Fig.1

![Fig.1 Standard response curve to a half-period sine pulse for damped system, where \(\zeta = c/c_c\)](image)

The above figure shows the response of a single degree of freedom (SDOF) spring mass system with viscous damping to a half sine shock pulse excitation. The peak...
amplitude may occur before or after the termination of pulse depending upon the relationship between the natural frequency $\omega_0$ and the pulse duration $\tau$. It can be shown that the peak amplitude will occur before the termination of the pulse for $\omega_0 \tau > \pi$. A plot of the peak amplitude as a function of the pulse duration is referred to as a shock spectrum. The shock spectra of other simple pulses are very similar to shock spectra shown in Fig. 1.

3. MATERIALS AND METHODS

3.1 Materials

The natural rubber sample used in this study was supplied by M/s Indian Rubber Manufacturers Research Association, Thane. The compound was formulated using a sulfur conventional vulcanization system. The two compositions (in parts per hundred rubber, phr) as given in Table.1

Table.1: Rubber Compositions in parts per hundred rubber (phr)

<table>
<thead>
<tr>
<th>Components</th>
<th>Role</th>
<th>*COMP1 (phr)</th>
<th>**COMP2 (phr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR (Natural rubber)</td>
<td>Main polymer</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Zinc Oxide</td>
<td>Activator</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>Activator</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>6PPD (Paraphenylen diamines)</td>
<td>Anti-oxidant</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Aromatic oil</td>
<td>Plasticizer</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Carbon blackN555+silica</td>
<td>Filler</td>
<td>90</td>
<td>120</td>
</tr>
<tr>
<td>CI resin</td>
<td>Binder</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Si69</td>
<td>Filler binder</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Sulfur+MBTS</td>
<td>Curative+ Accelerator</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

*Composition1
**Composition2

3.2 Mixing and cure characteristics

Mixing was carried out in two-roll mill as per ASTM D 3184-80. The cure characteristics of the mixes were measured by using a Monsanto rheometer at 150° C. The respective cure time ($t_{90}$) and scorch time ($t_2$) values were taken from the rheograph. Subsequently, the compounds were compression molded at 150° C based on respective $t_{90}$ values.

3.3 Mechanical properties

Specimens for tensile and tear testing were punched out from the vulcanized sheets as shown in Fig. 2 (a) & (b)
Tensile testing was done as per IS 3400 (Part 1):2012 using dumb-bell specimens and at a rate of grip separation of 500mm/min. Tear testing was done as per IS 3400(Part 17):2012. Both tensile and tear test were carried out on an Instron machine Model 3365. For the hardness test, a Shore A type durometer was employed to find out the hardness of the vulcanizates. The hardness test was conducted as per IS 3400(Part 23):2002.

3.4 Shock attenuation test

The detailed procedure to design general purpose shock attenuation devices is well described\(^8\). The method considers total load on the device and the maximum allowable deflection and proceeds to arrive at the vertical and lateral stiffness by fixing the rubber part dimensions and rubber hardness. Layers of rubber are arranged in series with in between steel plates to stabilize such devices. Few samples of such general purpose shock attenuation devices were fabricated for shock testing by Drop-weight method as shown in Fig.3 (a). Such devices find applications in High speed trains, Steam piping in Nuclear power plants which encounter heavy vibrations during start-up and shut-down, heavy machinery industry etc. Using half-sine shock pads, 1800g shocks were generated and transmitted along the major axis across the attenuation device as shown in Fig. 3(b). This testing was conducted on a VST shock testing machine. Accelerometers mounted at the other end measured the transmitted shock values. Shock testing is carried out by subjecting the test samples to standardized mechanical impact (half sine pulse) on a pneumatic shock testing machine. The test is of a free fall kind. The pneumatic shock testing machine VST model 2424(250) PA-PC employed for this study produced a half sine pulse of ~1800g acceleration in less than 5 milliseconds to evaluate the above devices. The accelerations were produced in the vertical direction using compressed air to force the
carriage to impact on the shock machine base. Elastomer pads were used between the carriage and the base to generate half sine pulses. The basic structure of the machine is heavy steel which will not deteriorate under repeated shocks. The structure contains sufficient mass, so that no additional ballast will be required. The structure is supported on four passive air springs to isolate the shock pulses from the floor. The test item mounts on a solid aluminum carriage provided with steel inserts on the top surface. The carriage is supported and guided by the lifting and driving piston. Dual caliper friction brakes were used as a rebound brake and as a quick release mechanism.

![Image](a)

![Image](b)

**Fig.3** (a) Photograph of a general purpose shock attenuation device fabricated for this study (b) Shock test under progress

### 4. Results and discussions

#### 4.1 Cure characteristics and mechanical properties

The cure characteristics and mechanical properties of the two compositions are as shown below in Table 2 for comparison purposes:

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>COMP1</th>
<th>COMP2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cure time</td>
<td>minute</td>
<td>9.99</td>
<td>12.94</td>
</tr>
<tr>
<td>Scorch time</td>
<td>minute</td>
<td>2.83</td>
<td>3.10</td>
</tr>
<tr>
<td>Hardness</td>
<td>Shore A</td>
<td>70</td>
<td>79</td>
</tr>
<tr>
<td>Tensile strength at rupture</td>
<td>(kg/cm²)</td>
<td>138</td>
<td>105</td>
</tr>
<tr>
<td>Elongation at break</td>
<td>%</td>
<td>320</td>
<td>220</td>
</tr>
<tr>
<td>Modulus (@100%)</td>
<td>kg/cm²</td>
<td>41</td>
<td>55</td>
</tr>
<tr>
<td>Modulus (@200%)</td>
<td>kg/cm²</td>
<td>91</td>
<td>96</td>
</tr>
<tr>
<td>Modulus (@300%)</td>
<td>kg/cm²</td>
<td>130</td>
<td>------</td>
</tr>
<tr>
<td>Tear Strength</td>
<td>(Kg/cm)</td>
<td>41</td>
<td>42</td>
</tr>
</tbody>
</table>
From Table.2, it is clear that the cure time and scorch time are both dependent on the filler level viz. the Carbon black content with both values showing an increasing trend. Hardness also shows an increase with increase in Carbon black content. This implies that the resilience is decreasing with increase in Carbon black content. Filler aggregates form a filler network in a polymer matrix. Hence, this effect could be due to a restriction in the mobility and deformability of the matrix with an increase in the Carbon black loading. Tensile strength as well as Elongation at break values are decreasing with an increase in the Carbon black content. This is supportive of the observation from earlier researches⁴ that appropriate filler loading provides optimum reinforcement beyond which the filler only serve as diluents. As a matter of fact, an optimum cross linked NR- Carbon black filled surface shows proper polymer-filler interaction. At an excess cross-link density level, the matrix becomes stiff and failure becomes brittle in nature. Modulus values also indicate better cross-link density at lower loading of Carbon black filler. Tear strength is a measure of the resistance to failure of a material when it is subjected to continued stretching. Tear strength values show little change and remain nearly same with change in Carbon-black loading.

4.2 Response under dynamic loading
The response behavior under dynamic loading of the shock attenuation devices fabricated from the two compositions under uni-directional dynamic loading is shown in the Fig. 4(a) & (b)

![Fig.4 (a) Shock transmission across COMP1](image)  ![Fig.4 (b) Shock transmission across COMP2](image)

From Fig. 4(a) & (b) it is clear that transmission of shock across the attenuation device increases by ≈8% as the loading of Carbon black increases. Carbon black is widely reported in literature to have major influence on the dynamic properties of compounded rubber as it is a source of hysteresis or damping. In an earlier study⁹ concerning the effect of fillers on the dynamic mechanical behavior of NR reported a decrease in tanδ_max value with an increase in the amount of Carbon black filler
incorporation in the NR. The value of $\tan \delta_{\text{max}}$ (the ratio of the viscous to the elastic response) is a measurement of damping or hysteresis. In this case also it appears that the damping capacity suffers on account of over-loading of filler.

### 4.3 SEM Micrographs study

SEM studies were carried out to find the filler dispersion in the rubber matrix. Model Auriga FEG supplied by Carl Zeiss, Germany was utilised for carrying out SEM imaging. The micrographs from SEM are shown in Fig. 5(a) & (b).

![SEM micrograph of (a) COMP1 (b) COMP2](image)

From the micrographs, it is seen that the filler has dispersed evenly in COMP1 whereas the filler appears to have been pulled out of matrix in COMP2. This agglomeration and pulling out of the filler in COMP2 could be leading to a deterioration of mechanical properties.

### 5. CONCLUSIONS

From this experimental study, it is quite clear that Carbon black & silica as a reinforcing filler in NR have a major influence on the polymer’s curing as well as mechanical properties. Also varying the Carbon black content (in filler) helps to achieve improvement in various important mechanical properties. Moreover, the performance of NR under dynamic loading is dependent on filler loading as a variation led to a loss in tangent modulus among the two compositions investigated in this study. An even distribution of filler would lead to greater uniformity in the overall matrix which will lead to improved mechanical properties. NR as a component in a shock attenuation device is effective in arresting the transmission of shock.

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REFERENCES


