The effect of alkanolamide loading on properties of carbon black-filled natural rubber (SMR-L), epoxidised natural rubber.pdf

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Material properties

The effect of alkanolamide loading on properties of carbon black-filled natural rubber (SMR-L), epoxidised natural rubber (ENR), and styrene-butadiene rubber (SBR) compounds

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A B S T R A C T

The effect of Alkanolamide (ALK) loading on properties on three different types of carbon black (CB)-filled rubbers (SMR-L, ENR-25, and SBR) was investigated. The ALK loadings were 1.0, 3.0, 5.0 and 7.0 phr. It was found that ALK gave cure enhancement, better filler dispersion and greater rubber–filler interaction. ALK also enhanced modulus, hardness, resilience and tensile strength, especially up to 5.0 phr of loading in SMR-L and SBR compounds, and at 1.0 phr in ENR-25 compound. Scanning electron microscopy (SEM) proved that each optimum ALK loading exhibited the greatest matrix tearing line and surface roughness due to better rubber–filler interaction.

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1. Introduction

In the rubber industry, it is very common to utilise reinforcing fillers to achieve rubber end products with a satisfactory level of strength or service life [1]. Carbon black (CB) and silica are the most popular reinforcing fillers for rubbers, and have been widely utilised. CB is commonly utilised for producing black rubber products, while silica is used in coloured products. Sometimes, they are also utilised in combination form (as hybrid filler) for the purpose of achieving their synergistic effect in order to produce better overall mechanical properties [2].

In our previous work [3], the preparation and application of alkanolamide (ALK) in silica-filled natural rubber (NR) compounds was reported. The ALK enhanced the mechanical properties viz. tensile strength, tensile modulus and hardness. The enhancement of these properties was attributed to the improvement of silica dispersion in the rubber compounds, and excellent crosslink density that stemmed from the incorporation of ALK. The results also indicated that ALK could function as an accelerator and internal plasticiser.

A further study on the comparison of effect of ALK and APTES-silane coupling agents on the properties of silica-filled NR compounds was also reported [4]. Due to its combined and unique function as an accelerator and internal plasticizer, at a similar loading, ALK produced a higher reinforcing efficiency than APTES.

It is important to investigate further the effect of ALK on the properties of several types of rubbers filled with CB. Hence, this study reports the effect of ALK on properties of CB-filled NR, epoxidised natural rubber (ENR) and styrene-butadiene rubber (SBR) compounds. The study is focused on the effect of ALK loading on cure characteristics and mechanical properties of the CB-filled rubbers compounds.
2. Experimental

2.1. Materials

NR grade SMR-L was obtained from Guthrie (M) Sdn. Bhd., Seremban, Malaysia, epoxidised natural rubber with 25 mol% epoxidation (ENR-25) was supplied by the Rubber Research Institute Malaysia (RRIM), and styrene-butadiene rubber (SBR), Taipeil 2012, was purchased from TSRC Corporation, Taiwan. N330-grade CB was supplied by the Cabot Corporation. Other compounding ingredients, such as sulphur, zinc oxide, stearic acid, N-isopropyl-N'-phenyl-p-phenylenediamine (IPPD) and benzothiazolyl disulphide (MBTS), were supplied by Bayer Co. (M) Sdn. Bhd., Petaling Jaya, Selangor, Malaysia. The ALK was synthesised in our laboratory using Refined Bleached Deodorized Palm Stearin (RBDPS) and diethanolamine. The reaction procedures and molecular characterisations of the ALK were given in our previous report [3]. The molecular structure of ALK is presented in Fig. 1.

2.2. Compounding

A semi-efficient vulcanisation system was used and Table 1 displays the compound formulation of CB-filled rubber compounds with and without ALK. The compounding procedure was performed on a two-roll mill (Model XK-160).

2.3. Cure characteristics

The cure characteristics of the CB-filled rubber compounds were obtained using a Monsanto Moving Die Rheometer (MDR 2000), which was employed to determine the scorch time (ts), cure time (t90) and torque difference (Mh-Ml) according to ISO 3417. Samples of the respective rubber compounds were tested at 150 °C. The rubber compounds were subsequently compression-moulded using a stainless steel mould at 150 °C, with a pressure of 10 MPa, and applying a laboratory hot-press based on respective curing times.

2.4. Tensile, hardness, and resilience properties

Dumbbell-shaped samples were cut from the moulded sheets. The tensile tests were performed at a cross-head speed of 500 mm/min using an Instron 3366 universal tensile machine, according to ISO 37. The tensile strength (TS), stress at 100% elongation (M100), stress at 300% elongation (M300), and elongation at break (EB) were determined. The hardness measurements of the samples were performed according to ISO 7691-1, using a Shore A type manual durometer. The resilience was studied by utilising a Wallace Dunlop Triposmeter, according to BS 903 Part A8. The rebound resilience was calculated according to Equation (1):

\[
\%\text{ Resilience} = \left(1 - \frac{\cos \theta_2}{\cos \theta_1}\right) \times 100
\]

where \( \theta_1 \) is the initial angle of displacement (45°) and \( \theta_2 \) is the maximum rebound angle.

2.5. Scanning electron microscopy (SEM)

The tensile fractured surfaces of the rubber compounds were examined using a Zeiss Supra-35VP scanning electron microscope (SEM) to obtain information regarding the filler dispersion, and to detect the possible presence of micro-defects. The fractured pieces were coated with a layer of gold to eliminate electrostatic charge build-up during examination.

2.6. Measurement of rubber–filler interaction

The rubber–filler interactions were determined by swelling the cured CB-filled rubber compounds in toluene, according to ISO 1817. Test pieces with dimensions of 30 mm × 5 mm × 2 mm were prepared from the moulded sheets. The initial weights were recorded prior to testing. The test pieces were then immersed in toluene and conditioned at room temperature in a dark environment for 72 hours. After the conditioning period, the weights of the swollen test pieces were recorded. The swollen test pieces were then dried in the oven at 70 °C for 15 minutes and were allowed to cool at room temperature for another 15 minutes before the final weights were recorded. The Lorenz and Park’s equation [5–7] was applied and the swelling index was calculated according to Equation (2):

\[
\frac{Q_f}{Q_g} = ae^{-z} + b
\]

where, the subscripts f and g referred to filled and gum vulcanisates, respectively; \( z \) was the ratio by weight of filler to hydrocarbon rubber in the vulcanisate; while \( a \) and \( b \) were constants. The higher the \( \frac{Q_f}{Q_g} \) value, the weaker is the rubber–filler interaction.

**Table 1**

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Content (phr)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber**</td>
<td>100.0</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>5.0</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>2.0</td>
</tr>
<tr>
<td>IPPD</td>
<td>2.0</td>
</tr>
<tr>
<td>MBTS</td>
<td>1.5</td>
</tr>
<tr>
<td>Sulphur</td>
<td>1.5</td>
</tr>
<tr>
<td>CB N330</td>
<td>30.0</td>
</tr>
<tr>
<td>ALK</td>
<td>0.0; 1.0; 3.0; 5.0; 7.0</td>
</tr>
</tbody>
</table>

* parts per hundred parts of rubber.

** Table 1 Composition of the rubber compounds. **

**Fig. 1.** Molecular structure of Alkanolamide.
In this study, the weight of the toluene uptake per gram of hydrocarbon rubber (Q) was calculated based on Equation (3).

\[
Q = \frac{\text{Swollen} - \text{Dried weight}}{\text{Initial weight}} \times 100 / \text{Formula weight}
\]

(3)

3. Results and discussion

3.1. Effects of ALK on cure characteristics of CB-filled rubber compounds

The effects of ALK on the scorch and cure times of CB-filled SMR-L, ENR-25, and SBR compounds are shown in Figs. 2 and 3, respectively. The addition of each 1.0 phr of ALK into the control compounds caused a decrease in the scorch and cure times. Cure enhancements were observed, which indicated that ALK can be considered a co-curing agent. Since amine is an ingredient of accelerator activators [8], the amine part of ALK caused the cure enhancement.

It was also seen that, the higher the ALK loading, the more pronounced the cure enhancement phenomenon became. This was simply attributed to the higher content of amine present in the CB-filled rubber compounds.

At a similar ALK loading, the scorch and cure times of both SMR-L and ENR-25 were shorter than those of SBR. According to Chouch and Chang [7,9], the cure rate of a rubber compound depends on the number of allylic hydrogen atoms in the statistical repeat unit, whereby a higher content of allylic hydrogen resulted in a lower overall apparent activation energy of curing, thus increasing the cure rate. Therefore, shorter scorch and cure times of SMR-L and ENR-25 were attributed to a higher allylic hydrogen content of these rubbers compared to that of SBR. Generally, a statistical repeated unit of natural rubber (SMR-L or ENR-25) and SBR have 7 and 3 allylic hydrogen atoms, respectively [9].

The scorch and cure times of ENR-25 were lower than those of SMR-L, even although NR has the same reactivity as ENR-25. The lower scorch and cure time of ENR-25 was attributed to the presence of epoxide groups in the ENR-25 molecule, which activated the adjacent double bonds and made them more susceptible and ready for curing.

Table 2 shows the torque difference (\(M_d - M_u\)) of the three types of rubber compounds. The incorporation of 1.0 phr of ALK into the control compounds produced compounds with higher torque difference values. SMR-L and SBR have similar trends of torque difference which increased with the addition of ALK up to 5.0 phr, and decreased beyond the loading.

\(M_d\) difference indicates the degree of crosslink density of a rubber compound \(10-31\). The greater the value, the higher the crosslink density. The addition of ALK up to the optimum loading (5.0 phr) increased the torque difference of SMR-L and SBR. This was attributed to the additional function of ALK as an internal plasticizer agent, which plasticized and softened the filled compounds. This resulted in reduced viscosity and improved processability of the CB dispersion and rubber-CB interaction. The rubber-CB interaction can be defined as additional physical crosslinks [14,15] and, together with sulphide crosslinks, contributes to total crosslink density [16,17].

The reductions of the torque difference beyond 5.0 phr were most probably attributed to the dilution effect of the excessive amounts of ALK formed layers—which not only absorbed and attracted CB and some of curatives inside the layers, but also reduced the total crosslinks produced. In contrast to SMR-L and SBR, the torque difference of ENR-25 increased with the addition of ALK at a relatively lower loading, 1.0 phr, and then decreased with further increase in the loading. ENR-25 is a polar rubber due to the presence of some epoxy groups. Amine can utilize the epoxy groups as crosslinking sites [18,19]. Thus, increased torque difference due to the addition 1.0 phr of ALK was contributed to, not only by the formation of additional physical crosslinks, but also, presumably, by the formation of amine-epoxy crosslinks which were formed simultaneously during the curing process. The amine-epoxy crosslinks can also be considered as another type of cross link and, together with physical and sulphide crosslinks, contribute to the total crosslink density of the CB-filled ENR-25 compound.

The reduction of the torque difference beyond 1.0 phr can be attributed to the dilution effect of the excessive amounts of ALK, which not only reduced the total crosslink density (as happened with SMR-L and SBR systems), but also facilitated a significant formation of amine-epoxy crosslinks which disrupted the stereo regular structure of ENR-25, making the compound less elastic.
improved dispersion, and the plasticizer which earlier as ALK of are function as filler in easier processability of viscosity the compound not which only viscosity the The of compound a to, and is measure the minimum filler represents filler in agglomeration interaction. Those values were similar to those of minimum torque (\(M_L\)) in Table 2. The minimum torque represents the filler–filler inter-agglomeration [22], and the value is used to measure the relative viscosity of a rubber compound [23]. The lower the value, the lower the viscosity of the compound which not only results in easier processability of filler dispersion, but also weakened the filler–filler interaction. The decreased trends of both minimum torque and \(L\) values were attributed to the function of ALK as an internal plasticizer, as mentioned earlier, which reduced the viscosity of the rubber compounds and, consequently, improved the CB dispersion.

3.2. Effects of ALK on filler dispersion

The degree of CB dispersion in the three different types of rubber compounds due to the addition of ALK can be determined quantitatively by Equation (4) [3,4,20,21]

\[
L = \eta_f - M_r
\]

where: \(\eta_f = \frac{M_d}{M_g}\) and \(M_r = \frac{M_{df}}{M_{dg}}\), where \(M_d\) and \(M_{df}\) are the minimum and maximum torques of the filled compounds; and \(M_g\) and \(M_{dg}\) are the minimum and maximum torques of the unfilled/gum rubber compound. A lower value of \(L\), at a particular loading, means a better degree of CB dispersion.

Based on data in Table 2, values of \(L\) for CB dispersion in the three different types of rubber phase are presented in Fig. 4. It can be seen that ALK reduced the value of \(L\). The higher the ALK loading, the lower the value of \(L\), which indicated better CB dispersion. The trends of \(L\) values were similar to those of minimum torque (\(M_L\)) in Table 2. The minimum torque represents the filler–filler inter-agglomeration [22], and the value is used to measure the relative viscosity of a rubber compound [23]. The lower the value, the lower the viscosity of the compound which not only results in easier processability of filler dispersion, but also weakened the filler–filler interaction.

The decreased trends of both minimum torque and \(L\) values were attributed to the function of ALK as an internal plasticizer, as mentioned earlier, which reduced the viscosity of the rubber compounds and, consequently, improved the CB dispersion.

3.3. Effects of ALK on rubber–filler interaction

Better filler dispersion means stronger rubber–filler attachments/interactions. The rubber–filler interaction due to the addition of ALK into the CB-filled rubber compounds, and based on the Lorenz and Park’s equation, is presented in Fig. 5.

It can be seen that, for both SMR-L and SBR systems, the \(Q_f/Q_g\) values decreased with increasing the ALK loading up to 5.0 phr, and then increased with further increase in the loading [88]. The decreased \(Q_f/Q_g\) indicated that the rubber–filler interaction in the rubbers systems became stronger, which was attributed to the capability of ALK as a plasticizer which improved the dispersion of CB.

The increased \(Q_f/Q_g\) beyond 5.0 phr is most likely due to the excessive loading of ALK, which reduced the viscosity continuously and further dispersed the filler. Further positive contribution to rubber–filler interaction was not observed in this case. In all probability, only a part of the total filler was dispersed in the rubber phase, and the rest was dispersed inside layers of excessive ALK and had no contribution to rubber–filler interaction.

For the ENR-25 system, \(Q_f/Q_g\) value decreased at 1.0 phr of ALK, and then increased with increasing ALK loading. The decreased \(Q_f/Q_g\) again indicated stronger rubber–filler interaction due to the plasticizing effect of ALK, which increased the physical crosslinks. However, the increase of the \(Q_f/Q_g\) value at more than 1.0 phr of ALK weakened the rubber–filler interaction due to the excessive amount of ALK, as occurred in SMR-L and SBR compounds.

![Fig. 4. The L values of CB in rubber phases.](image1)

![Fig. 5. The Q_f/Q_g values of CB with and without ALK.](image2)
3.4. Effects of ALK on mechanical properties

Table 3 shows the effects of ALK on the tensile modulus (M100 and M300), hardness, and resilience of the CB-filled SMR-L, ENR-25 and SBR compounds. The incorporation of ALK up to 5.0 phr for SMR-L and SBR, and at 1.0 phr for ENR-25 enhanced these properties, but beyond those loadings these properties decreased.

Tensile modulus and hardness of a rubber vulcanisate are only dependent on the degree of crosslinking [24,25]. Resilience is enhanced to some extent as the crosslink density rises [26,27]. The enhancements of tensile modulus, hardness and resilience up to the optimum loadings were attributed to a higher crosslink density, and the deteriorations of those properties beyond those optimum loadings were attributed to a lower crosslink density. This explanation is in line with the torque difference data in Table 2.

The effects of ALK on the elongation at break (EB) of the CB-filled SMR-L, ENR-25 and SBR compounds are presented in Table 3. It can be seen that ALK caused an increasing trend of EB for all the rubbers. The EB increased with increase of the ALK loadings. Again, this can be attributed to the function of ALK as an additional plasticizer which modified the flexibility of vulcanisates of the CB-filled rubbers. ALK provided a free volume which allowed more flexibility for the rubber chains to move. The higher the ALK loading, the greater was the free volume, and the more flexible the rubber chains. Presumably, free volume was in the layers of excessive ALK.

The effects of ALK on the tensile strength of the CB-filled SMR-L, ENR-25 and SBR compounds are shown in Table 3. The additions of ALK up to 5.0 phr for SMR-L and SBR, and 1.0 phr for ENR-25, enhanced the tensile strength, but beyond those loadings caused a decrease in tensile strength.

The enhancements in tensile strength up to the optimum loadings were attributed the capability of ALK to soften and plasticize the filled compounds in order to gain a stronger rubber-filler interaction. This explanation is in line with the results in Fig. 5 and the SEM micrographs of the CB-filled rubbers vulcanisates in Fig. 6. The micrographs of the CB-filled rubber vulcanisates with the optimum ALK loadings (b, e, and h) exhibit homogeneous micro dispersion of CB as a result of the incorporation of ALK.

The deterioration of tensile strength after the optimum loadings can be attributed to the excessive amount of ALK which caused a more pronounced softening effect, resulting in weaker rubber–filler attachments/interactions. An additional explanation for the ENR-25 system is that ALK also initiated a more dominant amine-epoxy interaction. This interaction promoted a significant amount of ring-opened product, and disrupted the stereo regular structures of the ENR-25 molecule. The disruption of stereo regular structures of the ENR molecule made it less elastic and reduced the strength [19].

3.5. Scanning electron microscopy (SEM) study

Fig. 6 shows SEM micrographs of fractured surfaces of the vulcanisates of CB-filled SMR-L, ENR-25 and SBR, with and without ALK, which were taken at magnification 500X.

It can be clearly observed that the CB-filled rubber vulcanisates with optimum ALK loadings (micrographs of Fig. 6(b), (e) and (h)) exhibit significant matrix tearing lines and surface roughness. They show greater matrix tearing lines and surface roughness compared to those of the control rubber vulcanisates (Fig. 6(a), (d) and (g)). This indicates greater rubber–filler interaction which altered the crack paths, leading to increased resistance to crack propagation, thus causing an increase in properties such as tensile modulus, tensile strength and hardness.

The micrographs of the tensile fractured surfaces were in good agreement with the graphs in Fig. 5, which showed that the Qf/Qg values were lowest at the optimum loadings.

### Table 3
The mechanical properties of CB-filled rubber compounds at various ALK loadings.

<table>
<thead>
<tr>
<th>CB-Filled Rubber Compounds</th>
<th>ALK Loadings</th>
<th>0.0 (Control)</th>
<th>1.0</th>
<th>3.0</th>
<th>5.0</th>
<th>7.0</th>
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<tr>
<td>SMR-L</td>
<td>M100, MPa</td>
<td>1.28 ± 0.20</td>
<td>1.30 ± 0.21</td>
<td>1.33 ± 0.21</td>
<td>1.36 ± 0.23</td>
<td>1.25 ± 0.27</td>
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<tr>
<td></td>
<td>M300, MPa</td>
<td>4.92 ± 0.18</td>
<td>5.02 ± 0.20</td>
<td>5.05 ± 0.23</td>
<td>5.15 ± 0.22</td>
<td>4.32 ± 0.25</td>
</tr>
<tr>
<td></td>
<td>EB, %</td>
<td>835.8 ± 20.2</td>
<td>885.8 ± 23.7</td>
<td>932.8 ± 22.8</td>
<td>966.3 ± 21.0</td>
<td>1072.7 ± 17.8</td>
</tr>
<tr>
<td></td>
<td>TS, MPa</td>
<td>25.3 ± 0.9</td>
<td>27.5 ± 1.4</td>
<td>28.6 ± 1.0</td>
<td>29.2 ± 1.2</td>
<td>28.3 ± 0.7</td>
</tr>
<tr>
<td></td>
<td>Hardness, Shore A</td>
<td>50 ± 0.4</td>
<td>51 ± 0.4</td>
<td>52 ± 0.7</td>
<td>54 ± 0.6</td>
<td>49 ± 0.7</td>
</tr>
<tr>
<td></td>
<td>Resilience, %</td>
<td>58.4 ± 0.6</td>
<td>59.2 ± 0.6</td>
<td>60.1 ± 0.7</td>
<td>65.5 ± 0.8</td>
<td>65.0 ± 0.8</td>
</tr>
<tr>
<td>ENR-25</td>
<td>M100, MPa</td>
<td>1.75 ± 0.18</td>
<td>1.82 ± 0.20</td>
<td>1.58 ± 0.25</td>
<td>1.44 ± 0.22</td>
<td>1.33 ± 0.24</td>
</tr>
<tr>
<td></td>
<td>M300, MPa</td>
<td>5.82 ± 0.15</td>
<td>6.49 ± 0.15</td>
<td>5.62 ± 0.18</td>
<td>5.19 ± 0.20</td>
<td>4.75 ± 0.22</td>
</tr>
<tr>
<td></td>
<td>EB, %</td>
<td>825.7 ± 21.2</td>
<td>852.4 ± 23.3</td>
<td>881.1 ± 22.9</td>
<td>944.6 ± 20.2</td>
<td>975.0 ± 22.6</td>
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<tr>
<td></td>
<td>TS, MPa</td>
<td>30.5 ± 0.9</td>
<td>31.1 ± 0.8</td>
<td>30.7 ± 0.9</td>
<td>30.3 ± 1.1</td>
<td>29.7 ± 1.1</td>
</tr>
<tr>
<td></td>
<td>Hardness, Shore A</td>
<td>60 ± 0.3</td>
<td>61 ± 0.3</td>
<td>59 ± 0.8</td>
<td>57 ± 0.9</td>
<td>54 ± 0.8</td>
</tr>
<tr>
<td></td>
<td>Resilience, %</td>
<td>56.7 ± 0.6</td>
<td>59.2 ± 0.5</td>
<td>57.5 ± 0.5</td>
<td>55.1 ± 0.7</td>
<td>53.5 ± 0.7</td>
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<tr>
<td>SBR</td>
<td>M100, MPa</td>
<td>1.31 ± 0.09</td>
<td>1.34 ± 0.09</td>
<td>1.39 ± 0.12</td>
<td>1.43 ± 0.10</td>
<td>1.35 ± 0.09</td>
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<tr>
<td></td>
<td>M300, MPa</td>
<td>3.18 ± 0.06</td>
<td>3.89 ± 0.07</td>
<td>4.47 ± 0.08</td>
<td>4.73 ± 0.08</td>
<td>3.58 ± 0.09</td>
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<td></td>
<td>EB, %</td>
<td>770.9 ± 17.5</td>
<td>776.1 ± 18.9</td>
<td>782.1 ± 19.8</td>
<td>828.2 ± 19.2</td>
<td>866.7 ± 20.2</td>
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<tr>
<td></td>
<td>TS, MPa</td>
<td>18.2 ± 0.2</td>
<td>18.8 ± 0.5</td>
<td>19.1 ± 0.6</td>
<td>19.8 ± 0.6</td>
<td>18.1 ± 0.8</td>
</tr>
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<td></td>
<td>Hardness, Shore A</td>
<td>55 ± 0.2</td>
<td>56 ± 0.2</td>
<td>57 ± 0.3</td>
<td>58 ± 0.3</td>
<td>56 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>Resilience, %</td>
<td>55.1 ± 0.4</td>
<td>56.1 ± 0.4</td>
<td>56.7 ± 0.6</td>
<td>58.4 ± 0.5</td>
<td>56.4 ± 0.6</td>
</tr>
</tbody>
</table>
enhancement in rupture energy, due to a greater rubber–filler interaction, was responsible for the roughness and the matrix tearing line of the fractured surface. The micrographs of the tensile fractured surfaces were in good agreement with the results obtained by other researchers [28,29] who reported that an increase in rupture energy was responsible for the roughness and the matrix tearing line of the fractured surface.

The matrix tearing lines and surface roughness of micrographs of Fig. 6(c), (f), and (i) were smoother than those of micrographs of Fig. 6(b), (e), and (h), which indicated a lower crosslink density and a more pronounced plasticizing or lubricating effect of the excessive ALK.

4. Conclusions

From this study, the following conclusions can be drawn:

1. Alkanolamide can be utilised as a new curative additive in carbon black-filled natural rubber, epoxidised natural rubber and styrene-butadiene rubber compounds. Alkanolamide increased cure rate, degree of filler dispersion and rubber–filler interaction. The cure rate and degree of filler dispersion increased with increasing the alkanolamide loading, while rubber–filler interaction increased up to an optimum loading.

2. A 5.0 phr loading of alkanolamide was the optimum loading in carbon black-filled natural rubber and styrene-butadiene rubber compounds, whilst 1.0 phr loading of alkanolamide was the optimum loading in epoxidised natural rubber compound.

3. The alkanolamide improved the tensile modulus, hardness, resilience and tensile strength of the carbon black-filled natural rubber, epoxidised natural rubber and styrene-butadiene rubber compounds, especially up to the optimum loading.

4. Morphological studies of the tensile fractured surfaces of carbon black-filled rubbers vulcanisates, at the optimum alkanolamide loadings, indicated that the surfaces exhibited the greatest matrix tearing line and surface roughness due to better rubber–filler interaction.

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