8.1 Introduction

Rice husk is a widely available agricultural waste. India produces around 25 million tons of rice husks. It is largely used as a fuel in small scale, and in large scale for electrical power generation and thermal needs. Rice husk contains 20% ash and leaves large amount of residue (about 25%). This husk can be used as a fertilizer in agriculture or as an additive for cement and concrete fabrication. Due to its high silicon content, rice husk has become a source for preparation of elementary silicon and a number of silicon compounds especially silica, silicon carbide and silicon nitride. Therefore, the rice husks are one of the excellent sources of high grade amorphous silica.

There are several methods to prepare amorphous silica such as chemical pre-treatment with acid or base and combined with pyrolysis, thermal treatment and biological treatment with enzyme. However the chemical pre-treatment with acid before combustion was most frequently
implemented method for preparing high pure amorphous silica with low energy process.

Silica has been used as an important reinforcing agent in rubber compounds together with carbon black.\textsuperscript{11-15} Mixing of silica into rubber compound offers a number of advantages in tear strength, abrasion, heat resistance, hardness, high modulus, high resilience, improved rolling resistance, reduction in heat build-up and increase in the compound adhesion of multi component products. Reinforcement is usually defined as improvement in abrasion, tear, cutting and rupture resistance, in stiffness and hardness of vulcanized compounds through the incorporation of finely divided mineral particles. The most important factor in the capability of certain minerals to impart reinforcement to elastomers is the average particle size. Reinforcement is readily obtained with particle sizes smaller than 100nm and semi reinforcement with particle sizes smaller than 1000 nm. Particles larger than 10\textsuperscript{3} nm do not have reinforcing capabilities or have detrimental action.\textsuperscript{16} But the particles chemical structure is also a decisive factor. Silica has a number of hydroxyl groups on its surface, which results in strong filler-filler interactions and adsorption of polar materials by hydrogen bonds. Since intermolecular hydrogen bonds between hydroxyl groups on the surface of silica are very strong, silica can aggregate tightly exhibiting a complex geometry, from elementary particles to aggregates, agglomerates and clusters with dimensions from 0.05 to 40 \textmu m. This property can cause a poor dispersion of silica in a rubber compound.\textsuperscript{17}

Nowadays many attempts have been made to prepare mesoporous silica from the natural resources because of cost saving and environmental issue. From rice husk, soluble sodium silicate is extracted using caustic soda. The development of new mesoporous silica with properties different than the precipitated silica, especially their high BET surface areas and their organized
pore structures with pore sizes between 1.5-10 nm, make them potential materials in rubber reinforcing.

Supra molecular surfactant aggregates are used as surface directing agent for in-organics during condensation leading to mesoscopically ordered surfactant–inorganic composite. Porosity can be induced in the inorganic part by removal of the surfactant portion through thermal or chemical means.

In this study, we describe the preparation of mesoporous silica and rice husk silica from rice husk and their use as filler in natural rubber compounds in the modified form. Mesoporous silica is prepared from sodium silicate which in turn was prepared from fully burnt rice hull ash and rice husk silica (RHsilica) is prepared directly from rice husk.

This mesoporous silica and rice husk silica (RHsilica) are modified with antioxidant IPPD (N-Phenyl-N'-isopropyl)-p-phenylenediamine. The natural rubber vulcanizates with antioxidant modified mesoporous silica and precipitated silica are compared for bound rubber content and mechanical properties. Also the natural rubber vulcanizate with antioxidant modified RHsilica are compared with vulcanizate filled with neat RHsilica for mechanical properties.

Part D
USE OF ANTIOXIDANT MODIFIED MESOPOROUS SILICA IN NATURAL RUBBER

8.2 Experimental
Materials

Sodium silicate solution (commercial grade 27% SiO₂, 11.9% Na₂O), pluronic acid P₁₂₃, nitric acid, natural rubber, conventional zinc oxide, antioxidant
IPPD, stearic acid, precipitated silica, CBS (N-Cyclohexylbenzothiazyl sulphenamide) and sulphur.

**Preparation of mesoporous silica**

For the preparation of silica sphere, 2gm of triblock co-polymer P$_{123}$ (poly-ethylene oxide bis poly-propylene oxide bis poly-ethylene oxide) was dissolved in 30-80 gm of aqueous nitric acid at 30°C. This solution was then quickly added to a mixture of 5.2 gm of sodium silicate solution and 15 gm of deionized water at 30°C with stirring at 600 rpm for 2 hrs. The solid product was filtered and washed repeatedly with warm deionized water, dried and then calcined at 600°C for one hour in air.

**Preparation of antioxidant (IPPD) modified mesoporous silica**

IPPD (antioxidant) was mixed with mesoporous silica in torque rheometer (brabender plasticorder) at 50 rpm, 80°C for 5 minutes.

**Characterization of mesoporous silica**

Small angle XRD is generally used to probe the mesopore structural ordering of the material and to determine the phase structure of the developed material. Powder XRD of mesoporous silica was taken on a Rigaku D/max–c system with Ni–filtered Cu Kα radiation (λ - 1.5406 Å, within the 2θ range 0-6 at speed of 1°/minute). The Brunauer, Emmet and Teller method has been adopted as a standard procedure for surface area determination of powdered samples. Surface area analysis was done using micromeritics BJH surface analyzer tristar 3000. Measurements were carried out under nitrogen adsorption at liquid nitrogen temperature. Infrared absorption spectrum was collected using ThermoAvtar 370 spectrometer. The morphology of mesoporous silica was observed using transmission electron microscope (TEM). The transmission electron microscope (TEM) images were taken on a JEOL GEM 3010 transmission electron microscope operating at 300 KV.
Rubber compounding

The natural rubber was compounded on a laboratory two roll mixing mill (16 x 33 cm) as per the formulation given in Table 8.1.

Table 8.1 Base formulation for NR compounds

<table>
<thead>
<tr>
<th>Ingredients phr</th>
<th>Mix A</th>
<th>Mix B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural rubber</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>ZnO</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>IPPD</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Precipitated silica</td>
<td>-</td>
<td>1.6</td>
</tr>
<tr>
<td>Mesoporous silica</td>
<td>2.6</td>
<td>-</td>
</tr>
<tr>
<td>with IPPD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CBS</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>S</td>
<td>2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

After complete mixing of the ingredients, the stock was passed six times through tight nip gap and finally sheeted out at a fixed nip gap. The samples were kept overnight for maturation.

Testing

The cure characteristics of all mixes were determined using rubber process analyzer RPA 2000, as per ASTM standard, D 2084-01. Subsequently, the rubber compounds were vulcanized up to the optimum cure time at 150°C in an electrically heated hydraulic press. The mouldings were cooled quickly in water at the end of the curing cycle and stored in a cool dark place for 24 hrs prior to physical testing.

Thermal ageing

Thermal ageing was carried out at a temperature of 100°C for 24 hrs, 48 hrs and 96 hrs as per ASTM D 573-1999. Tensile testing before and after thermal ageing were carried out according to ASTM D 628-54 standard.
**Bound rubber content**

Mesoporous silica is incorporated into natural rubber by mixing 20 parts of mesoporous silica into 100 parts of natural rubber on a laboratory two roll mixing mill (16 x 33 cm) at room temperature (Sample I). Sample II of natural rubber and precipitated silica, commonly used as reinforcement load for rubber, was prepared in the same way and used as reference for comparison with the result obtained with the mesoporous silica. The compounded samples were cut in small pieces and put over a stainless steel sieve (40 µm meshes), then extracted with the toluene. The toluene is changed with fresh toluene three times during 4 days and finally dried for one day at 80°C. Bound rubber content is determined by using the following equation 8.1.

\[
\text{BRC} \% = \frac{b-a}{m-a} \times 100 \quad \text{......... (8.1)}
\]

The BRC is calculated from the weight of the residue after extraction (b), the weight of the initial mixture (m) and the amount of silica present in the initial mixture (a), determined by calcination at 600°C.

**Thermogravimetric analysis**

The thermograms of natural rubber and silica composites are recorded with a thermogravimetric analyzer Q-50, TA instruments. It is computer controlled instrument that permits the measurement of the weight changes in the sample material as a function of temperature. The sample placed in a temperature programmed furnace is subjected to temperatures in the range of 30°C to 800°C with a heating rate of 10°C/minute and the corresponding weight changes were noted with the help of an ultra sensitive microbalance. Air and nitrogen were used as purge gases.
Soxhlet extraction

Weighed ($W_1$) small pieces of vulcanized samples from mix A and mix B and placed inside thick filter paper. This is then loaded into the main chamber of soxhlet extractor. Soxhlet extractor is placed onto a flask containing the extraction solvent acetone. The solvent is heated to reflux for 16 hrs. The nonsoluble portion of the sample in filter paper is weighed ($W_2$).

\[
\text{Acetone extractable (\%) } = \frac{W_1 - W_2}{W_1} \times 100
\]

Using equation (8.2) acetone extractable in percentage is calculated.

8.3. Results and discussion

8.3.1 Characterization of mesoporous silica

**Figure 8.1** Low angle XRD pattern of mesoporous silica

Figure 8.1 shows low angle XRD pattern of mesoporous silica. Well resolved peak at 100 plane and two weak peaks at 110 and 200 planes indicates well ordered mesoporous silica with 2D hexagonal structure.\textsuperscript{18-21}
Mesoporous silica has BET surface area of about 507 m$^2$/g and pore size distribution around 5.5 nm. But precipitated silica has BET surface area of about 67 m$^2$/g.

![FTIR spectrum of mesoporous silica](image)

**Figure 8.2** FTIR spectrum of mesoporous silica

Figure 8.2 shows FTIR spectrum of mesoporous silica. Spectrum shows a wide O-H stretching band around 3400 cm$^{-1}$, due to freely vibrating OH groups and a band at 1637 cm$^{-1}$ due to O-H bending vibration. The peak at 1090 cm$^{-1}$ is due to Si–O–Si asymmetric stretching vibration. The peak at 967 cm$^{-1}$ is due to Si–OH stretching vibration. The peaks at 800 cm$^{-1}$ and 463 cm$^{-1}$ are due to Si–O–Si symmetric stretching and bending vibrations respectively.
Figure 8.3 shows transmission electron microscopic (TEM) image for mesoporous silica. The TEM image also indicates that the material has a highly ordered 2-D hexagonal structure similar to that of SBA15 obtained from tetraethylorthosilicate (TEOS).20,21

8.3.2 Cure characteristics

Cure characteristics of the mixes A and B are given in the Table 8.2.

<table>
<thead>
<tr>
<th>Property</th>
<th>Mix A</th>
<th>Mix B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scorch time, min</td>
<td>4.82</td>
<td>4.10</td>
</tr>
<tr>
<td>Optimum cure time, (t90) min</td>
<td>9.15</td>
<td>9.28</td>
</tr>
<tr>
<td>Cure rate index (%)</td>
<td>23.09</td>
<td>19.30</td>
</tr>
<tr>
<td>Min torque, dNm</td>
<td>0.101</td>
<td>0.078</td>
</tr>
<tr>
<td>Max torque, dNm</td>
<td>5.18</td>
<td>4.90</td>
</tr>
<tr>
<td>Δ torque, dNm</td>
<td>5.08</td>
<td>4.83</td>
</tr>
</tbody>
</table>

Antioxidant modified mesoporous silica filled composites exhibited higher rate and extent of cure over that of conventional silica. Generally the
polar nature of silica surface adsorbs a part of the curative and or silica- zinc ion interaction leads to slowing down of the curing reaction. This will result in an increased cure time and a reduced cure rate index. But the cure characteristics of antioxidant modified mesoporous silica composite indicate improvement in these values.

Scorch safety has increased and cure time was found to be lower for antioxidant modified mesoporous silica compound. This might have resulted from the improved rubber–filler interaction.

8.3.3 Thermal ageing studies

Variation of tensile strength of vulcanizates of mix A and mix B before and after ageing at 100 °C for 96 hours are shown in Figure 8.4.

Retention in property is slightly improved for IPPD bound mesoporous silica. Higher concentration of antioxidants may be incorporated in the pores of mesoporous silica which indicates slow leaching of antioxidant IPPD from the pores of mesoporous silica.

Figure 8.4 Variation of tensile strength of vulcanizates of mix A and mix B before and after ageing at 100°C for 96 hours
8.3.4 Bound rubber content

Bound rubber content of samples I and II are shown in Table 8.3. This determination is based on the assumption that the fraction of polymer, which does not interact or is not bonded to the silica, is soluble in toluene. Bound rubber is the rubber that is trapped by the filler aggregates after mixing. The rubber chains are attracted either physically or chemically to form a rubber shell on the surface of the silica particles. The bound rubber fraction of an uncured compound is the amount of rubber that is not extracted when it is exposed to a good solvent. It is observed that BRC increases with increasing the BET surface area of the silica.23.

<table>
<thead>
<tr>
<th>Mix</th>
<th>Bound rubber content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesoporous silica + NR</td>
<td>21.05</td>
</tr>
<tr>
<td>Precipitated silica + NR</td>
<td>6.65</td>
</tr>
</tbody>
</table>

It can be concluded that sample I with mesoporous silica gives a higher percentage of bound rubber content compared to that containing precipitated silica (sample II). The high bound rubber content values show that there will be a higher rubber-filler interaction with the mesoporous silica compared to conventional precipitated silica.

8.3.5 Thermogravimetric analysis

The thermograms of natural rubber with precipitated silica and mesoporous silica are recorded. Figure 8.5 shows the thermograms of NR with precipitated silica and mesoporous silica. It can be seen that initiation of degradation is found delayed for mesoporous silica composite. This indicates that NR is more stabilized by mesoporous silica. It is clear from the Table 8.4 that the temperature of complete degradation has improved with mesoporous silica. There is slight increase in maximum degradation temperature for
mesoporous silica composite. The rate of degradation showed no considerable change.

![Figure 8.5 Thermograms of the composites](image)

**Table 8.4 Thermogravimetric values of composites**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Initiation temp. °C</th>
<th>Max. deg temp. °C</th>
<th>Rate at max deg. %/°C</th>
<th>Completion temp. °C</th>
<th>25% deg Temp °C</th>
<th>Residue %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample I</td>
<td>321.7</td>
<td>391.97</td>
<td>1.670</td>
<td>495.36</td>
<td>321.79</td>
<td>14.81</td>
</tr>
<tr>
<td>(meso)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample II</td>
<td>316.2</td>
<td>388.17</td>
<td>1.672</td>
<td>461.05</td>
<td>316.26</td>
<td>12.69</td>
</tr>
<tr>
<td>(ppt)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**8.3.6 Soxhlet extraction studies**

Acetone extractable of NR vulcanizates is shown in Table 8.5.

**Table 8.5 Acetone extractable of NR vulcanizates**

<table>
<thead>
<tr>
<th>Vulcanizates</th>
<th>Acetone extractable (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.93</td>
</tr>
<tr>
<td>B</td>
<td>6.47</td>
</tr>
</tbody>
</table>
Soxhlet extraction studies also shows that percentage of acetone extractable in vulcanizate A is lesser than vulcanizate B which indicates that mesoporous silica interact with polymer strongly compared to precipitated silica.

**8.4 Conclusions**

1. Mesoporous silica prepared from commercially available sodium silicate (which in turn was prepared from fully burnt rice hull ash) exhibits specific properties, such as very fine size and good dispersion of the particles besides of its high surface area and porosity can give rise to strong interactions with natural rubber.

2. Retention in tensile strength on thermal ageing is improved for IPPD bound mesoporous silica composite.

3. Bound rubber content is increased for mix with mesoporous silica compared to mix with precipitated silica.

4. Percentage of acetone extractable is found to be lesser for vulcanizate with mesoporous silica compared to vulcanizate with conventional precipitated silica.

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**Part - E**

**USE OF ANTIOXIDANT MODIFIED RICE HUSK SILICA IN NATURAL RUBBER**

**8.5 Experimental**

**RHsilica Preparation**

Rice husk was thoroughly cleaned with tap water. The cleaned husk was mixed with 0.4 M hydrochloric acid in the ratio of 100 g husk per 1 litre.
acid and heated until boiled for 30 minutes. Then the mixture was maintained at 105°C for 3 hours. During this step, the color of the husk gradually changed from yellow to dark brown. After the reaction, the acid was completely removed from the husk by washing with tap water. It was then dried overnight in an oven at 110°C. The treated husk was burnt in an electric furnace by controlling the temperature so that it reached 600°C in one hour. After burning at 600°C for 6 hours, silica was obtained in the form of white ash. The shape of the silica is similar to the shape of the husk, but smaller in size. It was then grind to fine powder to get silica in smaller particle size.

![Figure 8.6](image)

Figure 8.6 (a) rice husk (b) rice husk after treatment with acid (c) RHsilica

Preparation of antioxidant modified RHsilica

1phr of antioxidant (IPPD) was mixed with 50phr of RHsilica in torque rheometer (brabender plasticorder) at 50 rpm, 80°C for 5 minutes.

Rubber compounding

The natural rubber was compounded with antioxidant modified RHsilica and neat RHsilica on a laboratory two roll mixing mill (16 x 33 cm) as per the formulation given in Table 8.6.
Table 8.6 Compounding formulation of mixes

<table>
<thead>
<tr>
<th>Ingredients (phr)</th>
<th>Mix C</th>
<th>Mix D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Rubber</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>ZnO</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>RHsilica</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Modified RHsilica</td>
<td>51</td>
<td>-</td>
</tr>
<tr>
<td>IPPD</td>
<td>-</td>
<td>1.0</td>
</tr>
<tr>
<td>Naphthenic oil</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>DEG</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>CBS</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>TMTD</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Sulphur</td>
<td>2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

After complete mixing of the ingredients, the stock was passed six times through tight nip gap and finally sheeted out at a fixed nip gap. The samples were kept overnight for maturation.

Testing

The cure characteristics of all mixes were determined using rubber process analyzer as per ASTM standard, D 2084-01, subsequently, the rubber compound were vulcanized up to the optimum cure time at 150°C in an electrically heated hydraulic press. The moldings were cooled quickly in water at the end of the curing cycle and stored in a cool dark place for 24 hrs prior to physical testing.

8.6. Results and Discussion

8.6.1 Characterization of RHsilica

Bulk density

Bulk density is defined as the weight per unit volume of a material. It is primarily used for powders or pellets. The test can provide a gross measure of particle size and dispersion, which can affect material flow consistency and
reflect packaging quantity. Bulk densities of silica samples are given in Table 8.7. The bulk density of RHsilica is found to be higher due to the smaller particle size of RHsilica compared to precipitated silica.

Table 8.7 Bulk density of silica samples

<table>
<thead>
<tr>
<th>Samples</th>
<th>Bulk Density m²/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial silica</td>
<td>0.96</td>
</tr>
<tr>
<td>RHsilica</td>
<td>1.34</td>
</tr>
</tbody>
</table>

BET surface area measurements

The Brunauer-Emmett-Teller method was used for the analysis of surface area of RHsilica and commercial silica at liquid nitrogen temperature. Rice husk silica exhibits surface area of 224 m²/g whereas the surface area of commercial silica is found to be 178 m²/g.

Powder X-ray diffraction

The X-ray diffraction pattern of rice husk silica is presented in figure 8.7.

Figure 8.7 X-ray diffraction pattern of rice husk silica
Silica obtained from rice husk is found to be completely amorphous with a broad diffraction peak centered on \(2\theta\) degrees \(\approx 22\). From XRD analysis the crystallite size of rice husk silica is found to be around 20 nm.

**Fourier Transform Infra-red Spectroscopy**

![Figure 8.8 – FTIR spectrum of RHsilica](image)

According to Wagner’s report,\(^{22}\) the strong band at approximately 1100 cm\(^{-1}\) is assigned to Si-O vibration. The bands at 798 cm\(^{-1}\) and 470 cm\(^{-1}\) are the characteristic bands of amorphous silica.\(^{25}\) However the broad absorption band at 3200-3750 cm\(^{-1}\) is found only on silica. This band is attributed mainly to the vibration of silanol groups and the hydrogen bonding interaction between water and adjacent silanol groups. Unlike silica, the results reveal the lower number of hydroxyl or silanol groups on the surface of RHsilica and hence reduced silica-silica agglomeration.

**8.6.2 Cure characteristics**

Cure characteristics of the mixes C and D are given in the Table 8.8.
Table 8.8 Cure characteristics of mixes C and D

<table>
<thead>
<tr>
<th>Property</th>
<th>Mix C</th>
<th>Mix D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scorch time, min</td>
<td>0.438</td>
<td>0.51</td>
</tr>
<tr>
<td>Optimum cure time (t90) min</td>
<td>4.45</td>
<td>4.98</td>
</tr>
<tr>
<td>Cure rate index (%)</td>
<td>24.92</td>
<td>22.37</td>
</tr>
<tr>
<td>Min torque, dNm</td>
<td>0.042</td>
<td>0.052</td>
</tr>
<tr>
<td>Max Torque, dNm</td>
<td>6.279</td>
<td>4.723</td>
</tr>
<tr>
<td>∆ torque, dNm</td>
<td>6.237</td>
<td>4.671</td>
</tr>
</tbody>
</table>

Compound with antioxidant modified RHsilica exhibited higher rate and extent of cure over that of compound with neat RHsilica. The cure graph of the compound with antioxidant modified RHsilica (nr rhs brab) and with neat RHsilica (nr rhs neat) is shown in figure 8.9.

![cure graph](image)

**Figure 8.9** Cure graph of the compounds with modified RHsilica (nr rhs brab) and neat RHsilica (nr rhs neat)

The maximum torque is a measure of crosslink density and stiffness in the rubber. It is found that compound with modified RHsilica increases the torque values compared to neat RHsilica compound. This increase is due to
the presence of silica rubber crosslink that imparts more restriction to deformation. Antioxidant modified RHsilica compound shows higher cure rate due to the adsorption of antioxidant on to the surface of RHsilica. From the industrial viewpoint, this is an advantage, since time and energy consumption during production could be reduced.

8.6.3 Mechanical properties

Vulcanizate reinforced with modified RHsilica had a higher tensile modulus than the vulcanizate reinforced with neat RHsilica. The results are shown in Figure 8.10.

![Graph showing tensile modulus of NR vulcanizates with RHsilica](image)

**Figure: 8.10;** Tensile modulus of the NR vulcanizates with RHsilica

Vulcanizate reinforced with modified RHsilica also showed improved tear strength as presented in Figure 8.11.
The abrasion resistance is higher for vulcanizate filled with modified RHsilica compared to vulcanizate with unmodified silica. This is shown in figure 8.12.

Hardness of the composites filled with modified RHsilica and with neat RHsilica is shown in Figure 8.13.
Figure 8.13 Hardness of NR vulcanizates with RHsilica

Figure 8.14 shows the results of the compression set test. It is found that vulcanizate reinforced with modified RHsilica demonstrated better compression set compared to vulcanizate filled with neat RHsilica.

Figure 8.14 Compression set test of the NR vulcanizates with RHsilica
8.7 Conclusions

1. The compounds with IPPD modified RHsilica exhibited higher cure rate than compounds with neat RHsilica. From the industrial viewpoint, this is an advantage since time and energy consumption during production could be reduced.

2. The overall mechanical properties of vulcanizates with IPPD modified RHsilica were found to be better than vulcanizates with neat RHsilica. These properties are tensile modulus, tear strength, abrasion resistance, compression set and hardness. Thus IPPD modified RHsilica has great potential for use as reinforcing filler in natural rubber products.
8.8 References


