Chapter 6

Preparation and cure, mechanical and magnetic studies on rubber-nickel nanocomposites

In this chapter the preparation and characterization of rubber-nickel nanocomposites is described in detail. Extensive studies have been conducted on the preparation and characterization of rubber-ferrite composites of natural and synthetic rubber, some of them by my co-researchers [1-4]. It has been proved beyond doubt that they are suitable for many potential applications like, microwave absorbers, flexible magnetic materials, magnetostrictive materials and high dielectric material. But not much work has been conducted on the metal rubber composites till date. The main constraint has been the difficulty in synthesizing stable metal nanoparticles in bulk quantities. A novel method for synthesizing nickel nanoparticles has been developed and the details were discussed in the previous chapter. This method is very simple, inexpensive and efficient. Nickel nanoparticles can be prepared in large quantities using this method [5].

In this work, nickel particles in the size range 15-40 nm are synthesized using a chemical method and their rubber composites are prepared using a specific recipe evolved by trial and error. Two elastomer matrixes are selected for the preparation of the composites. One is the natural rubber, as it is a commonly and cheaply available natural elastomer in the locality and the other is a particular variety of synthetic elastomer called neoprene. The synthetic rubber used in this study was chloroprene rubber grade W which is commonly known as neoprene. This is the rubber widely used for making O rings for air sealing and this particular rubber has superior mechanical properties when compared to natural rubber [6, 7].
6.1 Compounding recipes

Composites are prepared with blank rubber (gum vulcanazite) sample and for five different loadings of nickel nanoparticles from 20 phr (part per hundred rubber by weight) to 100 phr for both type of rubber. Selecting appropriate ingredients for curing rubber is important for preparing good quality rubber composites. The compounding recipe consists of chemicals which facilitate cross-linking of the polymer chains of the elastomers and agents which accelerate the cross-linking process. The most suitable recipes are evolved over time by trial and error. The recipes for compounding both varieties of rubber are given below in a tabular form (table 6.1). The mass of various ingredients are given for 100 g of rubber.

<table>
<thead>
<tr>
<th>Natural rubber</th>
<th>Neoprene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingredients</td>
<td>Weight g</td>
</tr>
<tr>
<td>Natural rubber</td>
<td>100</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>4</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>2</td>
</tr>
<tr>
<td>CBS</td>
<td>1</td>
</tr>
<tr>
<td>Filler (Ni)</td>
<td>phr</td>
</tr>
<tr>
<td>Sulphur</td>
<td>2.5</td>
</tr>
</tbody>
</table>

*Table 6.1: Compounding recipe*

6.2 Mixing

Natural-rubber-nickel composites (NRNCs) as well as neoprene-rubber-nickel composites (NNCs) were prepared using the synthesized nickel powder and appropriate raw gum rubber samples. Appropriate recipes were chosen for both natural rubber and neoprene. The initial blending of the various ingredients with gum was done in a Brabender Plasticoder. A plasticoder is also called a torque rheometer, since it is used to measure the torque generated inside a polymer material, when the material is subjected to mastication, due to resistance [8]. Such measurements can be done under varied conditions of temperature and pressure. Plasticoder
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is widely used in mixing, blending and for processability studies of polymers. It consists of a jacketed mixing chamber of approximately 40 cc of volume (model PL3S), fitted with two horizontal split rotors connected to a rotating shaft. A dynometer balance shows the resistance offered by the test material undergoing mastication inside the jacketed mixing chamber. The speed of the rotors are controlled and displayed electronically and the temperature variation is achieved by a heating coil and controlling electronics. The rotors can be changed according to the nature and strength of the polymer used. The mixing of the rubber and the compounding materials was done according to the sequence prescribed by ASTM (ASTM D 3182, 1982). Rubber gum was charged into the mixing chamber and after the disappearance of the nerve of the rubber other compounding ingredients were added to the rubber. Both for natural rubber and neoprene composites, the mixing temperature was maintained at 60° C and at an angular speed of 50 rpm. The compound material is removed from the mixing chamber and further homogenization was carried out in a two-roll mill operated with a friction ratio of 1: 1.25. The compound was passed endwise six times through the two-roll mill, with a tight nip and finally rolled into a sheet by keeping the nip at a separation of 3 mm. These sheets are kept for 24 hours before evaluating the cure characteristics.

6.3 Cure analysis

The cure characteristics of the mixed composite were determined using circular sheets of the homogenized compounds cut in specific size placed in a rubber processing analyzer (RPA). RPA is a completely automated and highly sophisticated mechanical and rheological analyzer which can be used to determine the properties of polymers before, during and after the process of curing [8]. By measuring visco-elastic properties of rubber and other polymeric elastomers, RPA can provide key information on the processability of the compounds, their cure characteristics and of cured samples. Automatic temperature control with an accuracy of 0.5° C and homogeneous heat distribution is available inside the cure chamber. Shearing strain is applied on the circular sample using a pair of biconical dies, placed below and above the sample. The lower biconical die is oscillated using a direct drive servo motor system, whose frequency and angle of oscillation can be varied through a wide range of values. Throughout the experiment the frequency of the oscillation was kept at 50 Hz. The torque produced in the specimen due to the oscillation of the
lower die through a small deforming angle is transmitted to the upper biconical die and a torque transducer on the upper die senses the torque accurately and passes on to a computer controlled measuring system for analysis. RPA can be used to make measurements of the properties of the samples under varied conditions such as fixed or varied strain, and all the conditions for measurements can be pre-programmed and automated. The data is used for real time display of the parameters in a graphical format using a computer program and also stored in the memory for future analysis.

In the present study cure characteristics of the composites were determined using a Rubber Processing Analyzer (RPA 2000 of n-technology), at a temperature of 150°C for natural-rubber composites and 160°C for neoprene-rubber by measuring modulus and torque against time at a pre-programmed strain. Different cure parameters outputs from the RPA are listed below.

- Minimum torque \((D_{\text{max}})\)
  Torque obtained by mix after homogenizing at the test temperature and before the onset of cure.

- Maximum torque \((D_{\text{min}})\)
  Maximum torque recorded at the completion of cure.

- Optimum cure time, \(t_{90}\)
  This is the time taken for obtaining 90% of the maximum torque

- Scorch time, \(t_{10}\)
  It is the time taken for two unit rise above minimum torque (i.e. about 10% vulcanization)

- Cure rate index
  Cure rate index is calculated from the following equation
  \[
  \text{Cure rate index} = \frac{100}{t_{90} - t_{10}}
  \]

Figure 6.1 shows a representative cure characteristic of nickel-rubber composites. The solid line is the cure rate curve and the broken line is the cure graph. Typically the torque decreases a little initially, for a very short duration and this is due to the decrease in viscosity through heating. On the onset of cross-linking, the torque starts to increase as the material becomes more resistant to shearing and torque reaches a maximum value. From the maximum
value of the torque, it decreases by very small amounts when the curing is complete. The cure time of the sample is given by time taken to reach 0.9 times the maximum torque. This is the time the sample is to be cured for preparing the rubber-nickel composites. The cure time may increase or decrease with the loading. In certain cases the filler material may act as a catalyst for the chemical reaction taking place during curing and in such cases the cure time decreases as the percentage of filler material increases in the composite.

![Diagram](image)

*Figure 6.1 Typical cure characteristic of an elastomer*

### 6.4 Cure characteristics of NRNCs

Figure 6.2 shows the cure characteristics of NRNCs for different loadings of nickel nanoparticles from 0 to 100 phr. There is a progressive increase in the maximum torque attained by the samples as the content of the nickel in the samples increases. The interaction between filler and matrix is better understood by analyzing the cure characteristics obtained from the RPA.

The cure parameters are shown in table 6.2. The maximum torque, that represents the shear modulus of the fully vulcanized rubber composites, increases with increase in loading of nickel. At the time of mixing due to the effect of high shearing forces the elastomer breaks down facilitating active sites on the molecules [9]. Rubber bound nickel particles formed by the
interaction with active sites on polymer molecules cause the enhancement of shear modulus of the composites. This is a clear indication that the presence of nanometer sized nickel particles has a reinforcing effect in the natural rubber matrix. Minimum torque of the rubber compound is a measure of viscosity of the compound. In NRNC, the minimum torque remains almost steady up to filler loading of 60 phr and after that it registers an increase. The absence of large variations in minimum torque indicates that the processability of rubber is not hindered due to the addition of nickel nanoparticles. At higher filler ratios, the occlusion of rubber within and between filler aggregates may take place and causes immobility of elastomer layers resulting in an increase in minimum torque.

<table>
<thead>
<tr>
<th>Filler loading (phr)</th>
<th>0 phr</th>
<th>20 phr</th>
<th>40 phr</th>
<th>60 phr</th>
<th>80 phr</th>
<th>100 phr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum torque (dNm)</td>
<td>0.153</td>
<td>0.101</td>
<td>0.127</td>
<td>0.13</td>
<td>0.179</td>
<td>0.251</td>
</tr>
<tr>
<td>Maximum torque (dNm)</td>
<td>3.095</td>
<td>3.4</td>
<td>3.8</td>
<td>4.32</td>
<td>4.4</td>
<td>4.8</td>
</tr>
<tr>
<td>Scorch time (min)</td>
<td>3.82</td>
<td>3.53</td>
<td>3.16</td>
<td>2.85</td>
<td>1.91</td>
<td>1.62</td>
</tr>
<tr>
<td>Cure time (min)</td>
<td>9.3</td>
<td>7.83</td>
<td>7.39</td>
<td>6.32</td>
<td>5.47</td>
<td>5.2</td>
</tr>
</tbody>
</table>

*Table 6.2: Cure parameters of Natural rubber nickel composites*
Torque variation in gum and filled compounds can be analyzed with the help of an equation proposed by Wolf and Westlinning [10, 11]. According to them the relative torque difference between minimum and maximum torques of the gum and filled compounds is directly proportional to the filler loading. The Wolf and Westlinning equation can be written as

\[
\frac{D_{\text{max}} - D_{\text{min}}}{D_0^{\text{max}} - D_0^{\text{min}}} - 1 = \alpha_F \frac{m_f}{m_p}
\]  

(6.1)

where \(D\) indicates the torques with the subscripts max and min for maximum and minimum and the superscript 0 for the blank rubber samples. The masses of filler and polymer in the compound are indicated by \(m_f\) and \(m_p\) respectively and \(\alpha_F\) is a specific constant whose value can give some indications about the final state of filler in the composites. The plot of \(\frac{D_{\text{max}} - D_{\text{min}}}{D_0^{\text{max}} - D_0^{\text{min}}} - 1\) against \(\frac{m_f}{m_p}\) is depicted in figure 6.3. The slope of this curve gives \(\alpha_F\) and we have obtained a near straight line graph passing closely through the origin and \(\alpha_F\) is found to have an average value of 0.550 with an error of only 0.042. The variation in \(\alpha_F\) is minimal and this indicates that the dispersion of nickel particles in the natural rubber matrix is uniform. The presence of nickel nanoparticles as filler in the natural rubber matrix does not produce any chemical interaction and the observed increase in maximum torque is purely because of physical reasons.
The plot of difference in torque (\(\Delta\) torque) with filler loading (figure 6.4) is also a near perfect straight line, again a clear indication of chemically non-interacting filler in the matrix. Due to low volume ratio of nickel particles resulting from its high density, inter particular attachments of polymer chains may be absent at all loadings, and this can be another reason for the linear variation of torque difference with the filler loading.

The cure time of NRNC shows a steady and linear decrease with filler loading as given in table 6.2. The cure time for gum compound was found to be 9.3 minutes and for the compound with 100 phr, the cure time decreases to 5.2 minutes. It was observed that, though the maximum torque increases with filler loading, the time taken to reach the maximum torque decreases sharply. Nickel is a well-known catalyst used in many organic chemical reactions [12]. The presence of fine particles of nickel appears to activate the process of cross-linking of natural rubber and the observed decrease in cure time is due to the catalytic action of nickel particles in the curing reaction. The cure rate index (CRI) of the NRNC compounds is depicted in figure 6.5 and shows a sharp increase initially, up to a filler loading of 60 phr and afterwards it shows a decrease. A decrease in CRI is because of the wetting of the surface of filler particles by the elastomer molecules [8, 13]. The volume fraction of nickel particles is small as already pointed out and the
wetting effect cannot produce any significant decrease in CRI in the initial stages. The decrease in CRI at higher filler loadings is an indication of such wetting becoming significant when the volume fraction increases. The variation of scorch time with filler loading is given in table 6.2.1 and the decrease in scorch time is mainly due to the activation in cross-linking reaction by the presence of fine particles of nickel.

**Figure 6.4:** Variation of torque difference with filler loading (NRNCs)

**Figure 6.5:** Variation in cure rate index with filler loading (NRNCs)
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6.5 Cure characteristics of NNCs

As shown in figure 6.6 there is a progressive increase in the maximum torque in the case of nickel-neoprene composites also. There is a rapid increase in the maximum torque from 60 phr of nickel onwards. The maximum torque shows a complete saturation in 0, 20 and 40 phr samples only. Other samples do not show saturation of torque but show a slight positive slope even after a time of 30 minutes. There is a progressive increase in the cure time with the percentage of nickel content.

![Cure characteristics of nickel neoprene composites](image)

**Figure 6.6: Cure graphs of NNCs**

The main features of the cure characteristics of NNC are presented in table 6.3. The variation of minimum torque and maximum torque of the NNC during the process of curing is shown in this table. The maximum torque increase steadily with nickel loading and in neoprene rubber matrix also the fine particle nickel act as a reinforcing agent. But at 100 phr loading, maximum torque drops slightly and this may due to the effect of agglomeration at high volume fraction of filler. The minimum torque also increases with the loading of filler particles and the effect is almost similar to NRNCs. The steady increase in minimum torque can be attributed to the immobilization of elastomer chains at the surface of the filler particles.
### Table 6.3 Cure parameters of Neoprene-rubber nickel composites

<table>
<thead>
<tr>
<th>Filler loading (phr)</th>
<th>0 phr</th>
<th>20 phr</th>
<th>40 phr</th>
<th>60 phr</th>
<th>80 phr</th>
<th>100 phr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum torque (dNm)</td>
<td>0.275</td>
<td>0.29</td>
<td>0.422</td>
<td>0.425</td>
<td>0.53</td>
<td>0.536</td>
</tr>
<tr>
<td>Maximum torque (dNm)</td>
<td>3.161</td>
<td>4.399</td>
<td>4.929</td>
<td>5.815</td>
<td>7.845</td>
<td>7.24</td>
</tr>
<tr>
<td>Scorch time (min)</td>
<td>0.99</td>
<td>1.03</td>
<td>0.88</td>
<td>1.11</td>
<td>1.01</td>
<td>0.75</td>
</tr>
<tr>
<td>Cure time (min)</td>
<td>11.16</td>
<td>15.27</td>
<td>16.08</td>
<td>19.02</td>
<td>21.13</td>
<td>22.3</td>
</tr>
</tbody>
</table>

The plot of \[ \frac{\frac{D_{\text{max}}}{D_{\text{min}}} - \frac{D_0}{D_0}}{D_{\text{max}} - D_0} - 1 \] against \[ \frac{m_f}{m_p} \] as depicted in figure 6.7 is a straight line passing very nearly through the origin (zero). The average value of the constant \( \alpha \) is 1.46 with an error of only around 0.2. The linear behaviour of the plot between \[ \frac{\frac{D_{\text{max}}}{D_{\text{min}}} - \frac{D_0}{D_0}}{D_{\text{max}} - D_0} - 1 \] against \[ \frac{m_f}{m_p} \] is a clear indication of non-interacting filler particles. As in the case of NRNC samples the plot of \( \Delta \text{torque} \) with loading also is a straight line and is given in figure 6.8.

The variation of cure behaviour of neoprene rubber composites is totally different from that of natural rubber composites. The cure time in NNC steadily increases with the filler content. In NNCs there is a steady increase in the maximum torque with the increase in filler loading. It is obvious that the cross-linking process in neoprene is not catalysed by nickel. The maximum torque and the cure time increases almost in the same ratio since the time taken to reach maximum torque increases as there is enhancement in maximum torque. Cure rate index (CRI) of neoprene composites shows a decrease with the increase in the filler content as depicted in figure 6.9. The wetting of surface of the particles is more effective in neoprene in comparison to natural rubber. The neoprene polymer chains are smaller than that of natural rubber and this may be a reason for the enhanced wetting of particles by the polymer in the case of neoprene.
Figure 6.7 Wolf and Westlinning plot of Neoprene-rubber nickel composites

Figure 6.8 Variation of torque difference with filler loading (Neoprene-rubber nickel composites)
6.6 Moulding of the composites

Nickel rubber composites are moulded in the form of thin sheets of 10cm x 7.5cm x 2 mm size using dies made of stainless steel. An electrically heated hydraulic press is used for the compression moulding and curing of the test specimens. This hydraulic press has platens of size 45 x 45 cm and a pressure of 140 kg cm\(^{-2}\) was applied on the rubber sheets undergoing curing and moulding. The natural rubber composites had been moulded at a temperature of 150°C and the neoprene samples at 160°C. On completion of the required cure time, as determined from the cure time analysis, the pressure was released and the sheet was removed off from the mould and suddenly cooled by dipping into cold water and stored in a cool dark place. Twelve specimens were prepared in all; six in each category of rubber and these specimens were used for the subsequent analysis and characterization.

6.7 X-ray diffractometry

Twelve samples of rubber-nickel composites were prepared, six in each type of rubber, from varying loading percentages from 0 phr to 100 phr. The rubber-nickel composite samples were subjected to structural characterization immediately after they were moulded into sheets.
using X-ray diffractometry and the resulting XRD patterns are shown in figure 6.10 (NRNCs) and in figure 6.11 (NNCs). The characteristic peaks of nickel are clearly visible in all the samples [13]. In the sample of 0 phr (blank rubber) a broad peak centered approximately at 22° of 2θ is observed in both types of samples and this is due to the short range orientation of polymer molecules of cured rubber [14, 15]. Diffraction peaks marked 1 to 5 are due to various curing agents remaining unreacted in the blank rubber. The broad peak at 22° vanishes as we increase the content of nickel since the large diffraction peaks of crystalline nickel with fcc structure becomes predominant. There are no shifts in the positions of the diffraction peaks of the nickel and this indicates that no structural change has occurred to the nickel particles due to the heat treatment. Peaks corresponding to NiO are present in the pattern and this indicates the presence of trace amounts of NiO which had arisen due to the heat treatment at 150°C and 160°C or the heat generated while mixing. But this presence of NiO did not affect the magnetic properties of the composites in any significant manner.

Fig 6.10: XRD pattern of Natural rubber nickel composites
6.8 Mechanical properties

Evaluation of the mechanical properties of the rubber-nickel composites are carried out using a UTM (universal testing machine), model Instron 4500. Dumb-bell shaped sample pieces are cut using a sharp die with a cross section of 2mmx2mm. Parameters namely tensile strength, modulus at different strains and elongation at the breaking point, which are some of the most important indications of the mechanical strength of the material were determined and the variations in these properties with loading were studied for both natural rubber and neoprene composites. An evaluation of these properties of NRNCs and NNCs is given in the following sections.

The restoring stress developed inside the material for a particular strain is a good indication of its mechanical strength. In figure 6.12 the stress of NRNCs for different strains are shown for various filler loadings [15, 16-18].

Fig 6.11: XRD pattern of Neoprene-rubber nickel composites
It can be observed that the stress increases with the filler loading for all strains starting from 50% elongation of the original length to 300% elongation. So it is clear that the incorporation of nickel nanoparticles in natural rubber matrix enhances its mechanical property. But there is a steady decrease of stress at the breaking point (breaking stress) with the filler percentage as indicated in figure 6.13. The reason for this may be the microscopic discontinuities introduced in the matrix material due to the presence of the filler material. But the materials are not strained to the breaking point in its ordinary applications, and the lowering of breaking stress is not a flaw for the material in comparison to the increased elastic properties at different strains, from 50% to 300%. Again, from figure 6.14 it is clear that the strain at breaking point also decreases with the filler loading. But even at the minimum strain (for the 100 phr sample) the sample can be stretched to a length of 7.5 times the original length. The decrease in breaking stress is actually due to the fact that at higher loadings the composite breaks at lower elongations. Formations of agglomerations of nickel inside the composite material can be a reason for breaking at lower elongations.
The mechanical properties of NNCs are more or less similar to the properties of NRNCs. If we examine the stress at different elongations (figure 6.15) it can be seen that it increases with the loading. As in the case of natural rubber, the presence of nickel in the matrix reinforce the
matrix and enhance elastic modulus. Neoprene-rubber sheets become mechanically strong as the percentage of nickel nanoparticles increases in it. At the same time the breaking stress and breaking strain decrease with the percentage of nickel nanoparticles in the composites (figures 6.16 and 6.17). All the reasons proposed for the nickel natural rubber composites can be attributed to neoprene rubber too. But it is clear that these changes in the mechanical properties are actually determined by nickel nanoparticles as filler rather than the matrix material since the same kind of behavior is observed in both matrixes.

![Graph showing elastic properties of NNCs for different loading of nickel](image)

*Figure 6.15: Elastic properties of NNCs for different loading of nickel*

![Graph showing breaking stress of NNCs with filler loading](image)

*Figure 6.16: Breaking stress of NNCs with filler loading*
6.9 Magnetic properties of NRNCs and NNCs

The magnetic properties of the nanocomposites were determined by an EG&G PAR 4500 Vibrating Sample Magnetometer at room temperature with a maximum magnetic field of 15000 Oe with increments of 150 Oe. Hysteresis loops are plotted for all the samples.

The magnetic properties of cured rubber samples clearly indicate that the ferromagnetic characteristics of nickel particles are retained in the NRNC and NNC samples. Figure 6.18 and 6.19 depict the magnetic hysteresis of NRNC and NNC samples respectively. A steady increase in saturation magnetization with increase in filler fraction can be observed in both composite samples from the magnetization curves and the magnetic properties are identical in both types of composites.

The magnetic properties of NRNCs and NNCs were evaluated under similar conditions. It was observed that the coercivity of the samples did not show any variation with the concentration of nickel particles in the composites. Further the coercivity values remain nearly the same in both series of composites as depicted in figure 6.20 and 6.21 which are the enlarged central region of the magnetic hysteresis loop. The reason for a small enhancement in the coercivity observed in NRNCs is not clear. However it could be due to the higher shear modulus.
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of natural rubber compared to neoprene rubber. The remanent magnetization keeps a linear variation with the increase in concentration of nickel nanoparticle again keeping exactly the same characteristics in both composite types.

Figure 6.18: Magnetic hysteresis of Natural rubber nickel composites

Figure 6.19: Magnetic hysteresis of NNC samples
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#### Sample phr (mass of nickel in 100g rubber)

<table>
<thead>
<tr>
<th>Sample phr (mass of nickel in 100g rubber)</th>
<th>Total mass (Nickel + rubber + curing agents)</th>
<th>Calculated magnetization emu/g</th>
<th>Observed magnetization emu/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>129.5</td>
<td>7.4</td>
<td>7</td>
</tr>
<tr>
<td>40</td>
<td>149.5</td>
<td>12.8</td>
<td>11</td>
</tr>
<tr>
<td>60</td>
<td>169.5</td>
<td>16.9</td>
<td>14</td>
</tr>
<tr>
<td>80</td>
<td>189.5</td>
<td>20.2</td>
<td>17</td>
</tr>
<tr>
<td>100</td>
<td>209.5</td>
<td>22.9</td>
<td>20</td>
</tr>
</tbody>
</table>

*Table 6.4: The calculated and observed saturation magnetizations of NRNC samples*

#### Sample phr (mass of nickel in 100g rubber)

<table>
<thead>
<tr>
<th>Sample phr (mass of nickel in 100g rubber)</th>
<th>Total mass (nickel + neoprene + curing agents)</th>
<th>Calculated magnetization emu/g</th>
<th>Observed magnetization emu/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>130.5</td>
<td>7.4</td>
<td>7.1</td>
</tr>
<tr>
<td>40</td>
<td>150.5</td>
<td>12.8</td>
<td>11.6</td>
</tr>
<tr>
<td>60</td>
<td>170.5</td>
<td>16.9</td>
<td>14.3</td>
</tr>
<tr>
<td>80</td>
<td>190.5</td>
<td>20.2</td>
<td>18.2</td>
</tr>
<tr>
<td>100</td>
<td>210.5</td>
<td>22.9</td>
<td>20.7</td>
</tr>
</tbody>
</table>

*Table 6.5: The calculated and observed saturation magnetizations of Neoprene-rubber nickel composites*
**Figure 6.20:** Central region of the magnetic hysteresis of Natural rubber nickel composites showing the coercivity and remanant magnetizations

**Figure 6.21:** Central region of the magnetic hysteresis of Neoprene-rubber nickel composites showing the coercivity and remanant magnetizations
Evaluation of the magnetic properties of the nickel-rubber and nickel-neoprene composites reveals that the magnetic properties of the filler particles are completely retained in the composites. The calculated values of saturation magnetizations in composites are presented in Table 6.4 and 6.5 (NRNCs and NNCs respectively) along with the measured saturation magnetization of each sample of composites. It can be observed that these two values are in good agreement. These composites can act as flexible magnetic materials and can be permanently magnetized.

6.10 Conclusion

The cure characteristics of natural-rubber-nickel and neoprene-nickel nanocomposites were evaluated and the cure properties of these two series of composites were compared. There is an increase in the maximum torque values in both series of composites and this establishes the reinforcing effect of nanoparticles of nickel in elastomeric matrices. The variation in Wolf and Westlinning constant is minimal in both the composites and this shows that the dispersion of nickel in natural rubber and neoprene rubber matrices is uniform and filler elastomer interaction is totally absent. The presence of nickel nanoparticles in the matrices doesn’t produce any chemical interaction and the observed increase in maximum torque is purely due to certain physical reasons. The curing process of natural rubber appears to be catalysed by the presence of nickel particles and such an effect is not observed in neoprene rubber composites. Incorporation of nickel nanoparticles had improved the elastic modulus of both natural rubber and neoprene band nanocomposites. The saturation magnetization and the remanence of the composites increase in a linear fashion with the concentration of nickel particles. The coercivity of the samples remains a constant in all samples in both of the series of composites. Thus incorporation of nickel nanoparticles in matrices like natural rubber and neoprene rubber can result in magnetic nanocomposites with the required mechanical and magnetic properties. This can be achieved by tuning the loading of the fillers. Further they can also be potential materials for microwave absorbers.
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