Chapter IV

Results and Discussion - NBR Rubber Nanocomposites
4.1 Introduction

NBR, also termed as Nitrile Rubber, is an emulsion copolymer of acrylonitrile and butadiene and the structure can be written as in Fig. 4.1. It is produced mainly by emulsion polymerization, and the butadiene unit may be incorporated in the cis - trans or vinyl configuration, where the latter is favoured by increasing the polymerization temperature.

![Chemical Structure of NBR Rubber](image)

**Fig. 4.1 Chemical Structure of NBR Rubber**

The presence of Acrylonitrile in the polymer imparts excellent fuel and oil resistance. Depending on the content of Acrylonitrile the polarity of rubber is decided and so the oil and fuel resistance as well. With increased Acrylonitrile content, there is an increase in Tg, reduction in resilience, lower die swell, decreased gas permeability, increased heat resistance, and increased strength. Because of unsaturation in the butadiene portion, NBR is still rather susceptible to attack by oxygen and ozone. Incorporation of nanofillers found to improve various properties like Heat resistance, barrier properties etc.

Vulcanization (from *Vulcanus*, the Roman god of fire and smithery) is the process whereby viscous and tacky raw rubber is converted into an elastic material through the incorporation of chemical crosslinks between the polymer chains. Hereafter the word vulcanization will be used interchangeably with *crosslinking* and *curing*. The invention of vulcanization is ascribed to Charles Goodyear, who in the late 1830s heated rubber in contact with sulphur and found that it became an elastic, non-sticky material. Since then the vulcanization technique has been developed enormously, to fit new materials and to meet the demands of modern production of rubber materials. However, sulphur is still the most frequently used vulcanization agent for rubbers containing unsaturations.
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Sulphur vulcanization always includes the use of accelerators, to speed up the crosslinking process, which would otherwise take many hours to perform. Depending on the amount of accelerator used, different lengths of sulphur crosslinks are obtained; as shown in Table 4.1.

**Table: 4.1 Types of curing systems**

<table>
<thead>
<tr>
<th>Type of system</th>
<th>Sulphur / accelerator ratio</th>
<th>Type of crosslinks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>&gt;2</td>
<td>-Sx-, cyclic sulphides</td>
</tr>
<tr>
<td>Semi EV</td>
<td>~1-2</td>
<td>C-S2-C, C-S-C</td>
</tr>
<tr>
<td>EV</td>
<td>&lt;0.3</td>
<td>C-S-C, C-S2-C-C</td>
</tr>
</tbody>
</table>

Moreover, the final properties of the vulcanizates will differ depending on the type of vulcanization system used. A conventional system will give better mechanical properties, such as tensile strength, than an EV system. On the other hand, the ageing properties will be the opposite since in this respect the EV system is superior to the conventional system. The semi EV system is a compromise and exhibits intermediate properties in both cases.

NBR being unsaturated, can be cured with Sulphur and accelerators system. The following Fig. 4.2 shows the schematic reaction mechanism which provides cross linking of Rubber with Sulphur.

![Fig. 4.2 Schematic representation of vulcanization of unsaturated elastomers](image)

![Fig. 4.3 Formation of polysulphidic MBTS via a complex with zinc](image)
When zinc or equivalently ZnO, is present as an activator in the vulcanization system, it catalyses the formation of macromolecular complexes. The rate of the increase of the amount of sulphur atoms embedded in the accelerator, e.g., MBTS, is increased when ZnO is present, because of the interaction of Zn$^{2+}$ with the accelerator. Due to the formation of the complex, sulphur insertion occurs more rapidly. A graphic representation is given in Fig. 4.2, where $S_x$ represents an ionized form of linear sulphur. Several other structures of these macromolecular complexes have been suggested in literature. In Fig. 4.3 the structure is shown in case zinc complexes with the accelerator polysulphides.

![Figure 4.4](image1.png)  
**Fig. 4.4** Complex with the zinc ion stabilized with ligands

If the zinc coordinates with an amine that is released from a sulphenamide or with carboxylate ligands, which are present in systems with Stearic acid, the solubility and reactivity is strongly enhanced as shown in Fig. 4.4. The two aforementioned structures implied that zinc is covalently bonded in the sulphidic chain of the accelerator. Another, perhaps more probable representation of the complex formation is shown in Fig. 4.5.
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Fig. 4.5 Reaction between MBT and ZnO

A number of studies \(^1\)\(^-\)\(^4\) on the effect of ZnO on the vulcanization process has revealed that ZnO readily forms zinc-complexes with MBT upon heating, as shown in Fig. 4.5. Although this reaction readily occurs, the formation of an insoluble layer of ZMBT on the surface of ZnO particles, however, might be the reason that the reaction of ZnO with MBT does not proceed to completion \(^4\)\(^,\)\(^5\). A similar reaction with MBTS and ZnO upon heating was not observed as seen in Fig 4.6

Fig. 4.6 Thermal decomposition of TBBS and formation of MBTS

\((R-H = \text{Rubber hydrocarbon})\)
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The degree of crosslinking during vulcanization of a compound can be represented by its vulcanization curve, which shows some property proportional to the degree of crosslinking versus vulcanization time. This is done as a routine measurement (e.g., by oscillating disc or moving die rheometer) in the rubber industry and is of paramount importance in order to obtain products vulcanized to an optimum level.

In this thesis, the effect of nano fillers such as nanosilica, nanographite, nano TiO2 & nanoclay in NBR polymer have been studied and characterized. The use of liq. NBR and DOP as dispersion media was also studied and reported.

4.2 Results and discussion:

4.2.1. Rheological study and curing behavior.

The Fig. 4.7 (a) and Fig. 4.8 (a) depicts the scorch time and optimum cure time of polymer Nano- composites with increase in Nanographite respectively. As seen from these figures, the incorporation of nanographite in NBR matrix does not significantly affect any rheological parameters.

The Fig. 4.7 (b) depicts the scorch time of the NBR nanocomposites containing nano silica and nano TiO2 as fillers. As seen in the graph, incorporation of nanosilica in NBR matrix, have significant effect unlike nano TiO2 and Nanographite.

(a) Nanographite based

(b) Nanosilica and Nano TiO2

Fig 4.7 Optimum cure time of NBR composites
The presence of nanosilica increases the scorch time [Fig. 4.7 (b) as well optimum cure time [Fig. 4.8 (b)]. This may be due to the fact that silica will contain active acidic groups on the surface and will try to react with the basic accelerator leading to neutralization effect. Hence, the scorch time and optimum cure time increases as the loading of nano silica increase in NBR matrix. Whereas, the other nano fillers like nano TiO$_2$ and nanographite hardly contribute any change in their rheological data like scorch time and optimum cure time. One another reason for increase in optimum cure time and scorch time could be because of the silanol groups on the silica surface react with the activator as well as accelerator and, consequently, reduce the number of active sulphur donating agents which are necessary for sulfur vulcanization \[^{34}\] and finally leading to increase in cure time as it was seen in case of 5 phr loading of nanosilica in Fig. 4.8 (b) in which there was sudden increase in the curing time. This increase in curing time may also be attributes to the formation of agglomerates due to increased silica loading, which has been proved to be a natural tendency of nanoparticles, and creates a barrier in natural vulcanization process.
4.2.2. Mechanical properties of NBR – Nanosilica composites

The physical properties like tensile strength Fig. 4.9 (a), modulus Fig. 4.9 (b) of NBR nanocomposites found to show the increasing trend with increase in nano silica filler loadings. It can be observed that there is a steady increase in tensile strength with filler loadings of Nano-silica filler. Tensile strength can be regarded as catastrophic tearing of cracks initiated by micro voids, from filler surface. If the elastomeric network is capable of dissipating the input energy into heat, then less elastic energy will be available to break this polymer network. Incorporation of fillers is the major source of energy dissipation. Increasing amounts of filler loading to a large number of polymer chains to get adhered to the polymer. The increase in loading of nano-silica showed increase in Tensile strength and modulus properties due to reinforcement effect of filler-polymer interaction. Elongation at break also increases with loading of nano-filler because of the layer of silicate structure restrict the tearing of polymer molecules under stretching during tensile test.
Fig. 4.10 Physical properties of NBR – Nanographite composites

Fig. 4.10 (a) and Fig. 4.10 (b) depicts the physical properties like tensile strength, elongation at break and modulus properties of NBR nanographite based composites. As the loading of nanographite increases the modulus and tensile strength increases and the elongation at break decreases.

Similarly, Fig. 4.11 depicts the physical properties like tensile strength, elongation at break and modulus properties of NBR nano TiO$_2$ based composites. As the loading of nano TiO$_2$ increases the modulus and tensile strength increases and the elongation at break decreases.

Fig. 4.11 Physical properties of NBR – Nano TiO$_2$ composites
The hardness of nanocomposites increases with the increasing loading of fillers as shown in the figures 4.12 (a) & (b).

![Graph showing the hardness properties of NBR–Nano composites](image1)

(a) Nano TiO2 & Nano Silica based  
(b) Nanographite based

**Fig. 4.12** Hardness properties of NBR – Nano composites

### 4.2.3 Tear Strength

Fig.4.13 shows the effect of nano fillers on tear strength of polymer Nano composites. It was observed that the tear strength increases as the loading of Nano filler increases. This is due to the strong polymer filler network developed between the nano silica and NBR polymer.

![Graph showing the tear resistance properties of NBR–Nano composites](image2)

(a) Nano TiO2 & Nano Silica based  
(b) Nanographite based

**Fig. 4.13** Tear Resistance properties of NBR – Nano composites
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The energy required for tearing the specimen at the nick where in nano silica has stronger bond with the polymer net work which elongates more than the expected values and hence the tear strength also increases. This corroborates the increases in tensile strength which is also increases as the loading increases. The same cases with all the nanofillers like nano TiO$_2$ and nano graphite.

4.2.4 Ageing studies:

Table 4.2 show the retention of physical properties of NBR TiO$_2$ nanocomposite ageing at 100 °C/ 24 hrs. It has been observed that the increase in loading of nano TiO$_2$ fillers improve the heat resistance properties of the nanocomposites. The retention of tensile strength has been increased from 69 % to 93 % with 1 phr of TiO$_2$ and there after a marginal increase in retention with increase of nano TiO$_2$ loadings. This shows that even with very less amount of nano filler leads to increase in heat resistance which is not seen any other conventional fillers and or compounding ingredients. Similarly, as the Table 4.2 indicates, retention of elongation at break also found from 85 % to 95 % with an introduction of 1 phr of nano TiO$_2$.

Table: 4.2 Physical properties of NBR TiO$_2$ nanocomposites after ageing at 100 °C / 24 hrs

<table>
<thead>
<tr>
<th>Properties</th>
<th>NBT 0</th>
<th>NBT 1</th>
<th>NBT 3</th>
<th>NBT 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retention of Tensile Strength, %</td>
<td>69</td>
<td>93</td>
<td>96</td>
<td>97</td>
</tr>
<tr>
<td>Retention of Elongation at break %</td>
<td>85</td>
<td>95</td>
<td>99</td>
<td>97</td>
</tr>
<tr>
<td>Increase in Hardness SA [Points]</td>
<td>+4</td>
<td>+1</td>
<td>+1</td>
<td>+2</td>
</tr>
</tbody>
</table>

The nano fillers intercalate between in the layers of polymeric chains and hence, the radicals generated during heat ageing will be separated by the presence of nanofillers leading to rejoining the polymeric chains will predominate than the degradation of polymers. The changes in hardness after ageing, was found very minimal and hence it is added advantage of having retention of most of other properties of such compounds. The results of ageing studies also corroborated by thermal degradation studies by TGA that the incorporation of nano TiO$_2$ increases thermal stability of NBR – nanocomposites.
Table 4.3 show the retention of physical properties of NBR graphite nanocomposite after ageing at 100 °C / 24 hrs. It has been observed that the increase in loading of nano nanographite fillers improve the heat resistance properties of the nanocomposites. The retention of tensile strength has been increased from 70 % to 75 % with 3 phr of nanographite and there after a marginal increase in retention (by 6 %) with increase of nanographite loadings upto 9 phr. This shows that even with very less amount of nano filler leads to increase in heat resistance which is not seen any other conventional fillers and or compounding ingredients. Similarly, as the table 4.2 indicates, retention of elongation at break also found from 80 % to 85 % with an introduction of 3 phr of nanographite.

**Table 4.3 Physical properties of NBR -Graphite nanocomposites after ageing at 100 °C/ 24 hrs**

<table>
<thead>
<tr>
<th></th>
<th>NBG-0</th>
<th>NBG-3</th>
<th>NBG-6</th>
<th>NBG-9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retention of Tensile Strength (%)</td>
<td>70</td>
<td>75</td>
<td>78</td>
<td>81</td>
</tr>
<tr>
<td>Retention of Elongation at break (%)</td>
<td>80</td>
<td>85</td>
<td>82</td>
<td>78</td>
</tr>
<tr>
<td>Change in Hardness (Shore A)</td>
<td>+4</td>
<td>+6</td>
<td>+5</td>
<td>+4</td>
</tr>
</tbody>
</table>

The nano fillers in general, intercalate between the layers of polymeric chains when it is mixed with polymers. During ageing process, the polymeric molecules gets dissociated and leading to degradation of properties, which is visible that there is a drastic reduction of tensile and elongation at break. However, tremendous improvement has been found with introduction of nanofillers. It could be the reason that the radicals generated during heat / thermal ageing will be separated by the presence of nanofillers leading to rejoining the polymeric chains rather than the degradation of polymeric chains. So, the strength of polymers are retained more than that of the compound without any nanofillers where in lots of degradation takes place. The changes in hardness after ageing, was found almost similar even after addition of nanographite. Increase in thermal degradation found through TGA studies corroborates the findings of heat resistance of nanocomposites.
Table 4.4 show the retention of physical properties of NBR silica nanocomposite after ageing at 100 °C/ 24 hrs. It has been observed that the increase in loading of nanosilica fillers improve the heat resistance properties of the nanocomposites.

Table 4.4 Physical Properties of NBR – silica nanocomposites after air ageing at 100°C/ 24 hrs

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>NBS-0</th>
<th>NBS-1</th>
<th>NBS-3</th>
<th>NBG-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retention of Tensile Strength (%)</td>
<td>70</td>
<td>92.5</td>
<td>98</td>
<td>62.5</td>
</tr>
<tr>
<td>Retention of Elongation at break (%)</td>
<td>80</td>
<td>70</td>
<td>68</td>
<td>65</td>
</tr>
<tr>
<td>Changes in Hardness (Shore A), Points</td>
<td>+4</td>
<td>+ 3</td>
<td>+ 2</td>
<td>+2</td>
</tr>
</tbody>
</table>

The retention of tensile strength increases as the nano silica reacts with the base polymer and forms new C-Si-O bond between two polymeric chains which has been characterized by FT-IR spectroscopy also. The retention of tensile strength increases due to restriction of bond cleavage of C-Si-O bond in nano composites which is stronger than that of C-C or C-H bonds in polymeric chains having no nano silica fillers. As the dose increases, inter molecular distance between the polymer chains increases as the nano fillers gets physically absorbed between the chains leading to separation of polymer chains and hence the polymer chains breaks down faster than that of C-Si-O bonds formed due to presence of nano silica filler in the polymer network. Changes in hardness after ageing is not significant where as the changes in elongation at break are quite significant after ageing.

4.2.5 Scanning electron microscopy

The SEM photographs in Fig. 4.14 shows that the uniform dispersion of ingredients in polymer matrix. The EDS spectra were taken on the scanned area of SEM to locate the dispersion of nano silica and its intensity. It has been found that as the dose of nano fillers in PNCs increases the intensity of silica in the EDS spectra also more.
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Fig. 4.14 Scanning Electron Micrograph of polymer nanocomposites containing nano silica at different loadings

From the SEM analysis shows that the nano fillers were distributed well within the polymer matrix. as seen for the particle mapping which can be identified as red color nanoparticles are found to be nano silica in the NBR matrix.

Fig. 4.15 Scanning Electron Micrograph of polymer nanocomposites Containing nano graphite fillers
Similarly SEM photographs in Fig. 4.16 & 4.17 show that the uniform dispersion of ingredients in polymer matrix. The EDS spectra were taken on the scanned area of SEM to locate the dispersion of nano silica and its intensity. It has been found that as the dose of nano fillers in PNCs increases the intensity of Nano TiO$_2$ in the EDS spectra also more which finally leads towards enhancement of multiple properties of nanocomposite as discussed in this chapter.

![SEM EDS pictures](images)

**Fig. 4.16**: Mapping of nano TiO$_2$ distribution in NBR Nanocomposites through SEM with different Nano-TiO$_2$ doses (1) 1 phr (2) 3 phr (3) 5 phr [In the Pictures red colour particles are Nano TiO2]

4.2.6. Energy-dispersive X-ray spectroscopy:

![EDS spectra](images)

**Fig. 4.17** EDS spectra of NBR nanocomposites containing different Loadings of Nano TiO$_2$
4.2.7 Thermogravimetric analysis

![Thermogravimetric analysis graph]

**Fig 4.18** Thermograms of NBR Silica Nano Composites

**Table 4.5** Initial degradation and maximum degradation temperature of NBR- Silica nanocomposites

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Initial temp °C</th>
<th>Maximum degradation temp. °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBS 0</td>
<td>357</td>
<td>422</td>
</tr>
<tr>
<td>NBS 1</td>
<td>359</td>
<td>423</td>
</tr>
<tr>
<td>NBS 3</td>
<td>360</td>
<td>425</td>
</tr>
<tr>
<td>NBS 5</td>
<td>361</td>
<td>427</td>
</tr>
</tbody>
</table>

Fig. 4.18 depicts the thermogram of NBR-silica nanocomposites. Through DTG curve, we have calculated the initial temperature at which the degradation starts and also the maximum degradation temperature.

The initial degradation temperature and final degradation temperature have been tabulated in Table 4.5. It can be seen from table 4.5 that the thermal stability of the nanocomposite increases and hence the initial & final degradation temperature increases as the nano-fillers loading increase.
Similarly as in case of Nano silica, Fig. 4.19 depicts the thermogram of NBR-TiO₂ nanocomposites. Through DTG curve, we have calculated the initial temperature at which the degradation starts and also the maximum degradation temperature.

The initial degradation temperature and final degradation temperature have been tabulated in Table 4.6. It can be seen from Table 4.6 that the thermal stability of the nanocomposite increases and hence the initial & final degradation temperature increase as the nano-fillers loading increase.

**Table 4.6 Initial degradation and maximum degradation temperature of NBR-TiO₂ nanocomposites**

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Initial temp °C</th>
<th>Maximum degradation temp. °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBT 0</td>
<td>357</td>
<td>422</td>
</tr>
<tr>
<td>NBT 1</td>
<td>362</td>
<td>457</td>
</tr>
<tr>
<td>NBT 3</td>
<td>364</td>
<td>465</td>
</tr>
<tr>
<td>NBT 5</td>
<td>365</td>
<td>475</td>
</tr>
</tbody>
</table>
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Fig 4.20 Thermograms of NBR Graphite Nanocomposites

Table 4.7 Initial degradation and maximum degradation temperature of NBR-Graphite nanocomposites

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Initial Temp. (Ti °C)</th>
<th>Maximum Temp. (Tmax °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBG-0</td>
<td>338</td>
<td>454</td>
</tr>
<tr>
<td>NBG-3</td>
<td>340</td>
<td>459</td>
</tr>
<tr>
<td>NBG-6</td>
<td>343</td>
<td>460</td>
</tr>
<tr>
<td>NBG-9</td>
<td>346</td>
<td>463</td>
</tr>
</tbody>
</table>

The thermograms of PNCs show that there is an increase in initial and maximum degradation temperature of PNCs. For cross linking type of polymers, the thermal stability is expected to improve due to the formation of more compact three dimensional cross linking networks, which is more thermally stable. As the loading of nano fillers increases, there is increase in thermal stability due to increase filler – polymer interaction and thereby occurring strong net works and bonds between polymers – fillers. Therefore, the initial and maximum degradation temperature increases as the loading of nano fillers increases as shown in Table 4.5 to 4.7. In all the cases, The NBR- TiO₂ nanocomposite found to give more thermal stabilities. For example, with 3 phr of nanofillers NBT3 is
found to be 465 °C where as that for others like NBG 3. NBS3 are 459 °C, 425 °C respectively. These show that TiO$_2$ gives more thermal stability for the polymer nanocomposite

**4.2.8 Fourier transforms infra-red spectroscopy**

FT-IR spectra in the middle IR region (3000–400 cm$^{-1}$) were obtained on a Nicolet 6700 FT-IR spectrometer. The spectra were normalized to enable direct comparison of the intensities of the absorption bands corresponding to vibrations of organic cations.

![FT-IR spectrum of NBT series](image)

**Fig. 4.21 FT-IR spectrum of NBT series**

In the ATR analysis absorbance peaks the intensity ratio of the 2238 cm$^{-1}$ nitrile stretching band to the 1443 cm$^{-1}$ methylene deformation or scissoring band the intensity ratio of the 2238 cm$^{-1}$ nitrile stretching band to the 969 cm$^{-1}$ C-H out of plane bending band of the trans-butadiene double bond and the absolute intensity of the 2238 cm$^{-1}$ nitrile stretching band. The peaks in the region of 640-660 cm$^{-1}$ indicates the presence of the titanium dioxide in anatase form in the nano composites.
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Fig. 4.22 FT-IR spectrum of NBS series

The rubber nanocomposites were analyzed in the region of 3000-400 cm\(^{-1}\) and the spectra were normalized to Si-O stretching band near 1041 cm\(^{-1}\) to enable direct comparison of the intensities of the absorption bands. The peaks in the region of 1100 cm\(^{-1}\) indicates the presence of the quartz form the nano silica along with the peaks present in the region of 2237 cm\(^{-1}\) for the C-H stretching from the nitrile region of the base polymer.

4.2.9 X-Ray diffraction analysis

Fig 4.23 XRD analysis of the NBR nano TiO\(_2\) composites
Fig 4.24 XRD analysis of NBR nano silica composites

The XRD studies reveal that the nano silica alone exhibits a crystalline structure and upon incorporation in polymer structure the peak intensity reduced. This shows that the silica has intercalated between the polymer molecules intermolecular distance \( d \) calculated for PNCs with different doses of nano silica is given in Table 4.8 where as, in case of nano TiO\(_2\) intercalation was not found as much as in case of nanosilica Fig. 4.23. From the differences in the peak of XRD data, it clearly predictable that polymer chains penetrated the silicate layers better than nano TiO\(_2\) leading to improvement in some of the specific properties.

Table 4.8 Polymer nano silica composites XRD analysis

<table>
<thead>
<tr>
<th>Code</th>
<th>(2 \theta)</th>
<th>(d) ((\text{°A}))</th>
<th>(I/I_1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBS 1</td>
<td>3.99</td>
<td>22.099</td>
<td>13</td>
</tr>
<tr>
<td>NBS 3</td>
<td>3.88</td>
<td>22.70</td>
<td>92</td>
</tr>
<tr>
<td>NBS 5</td>
<td>3.91</td>
<td>22.56</td>
<td>100</td>
</tr>
</tbody>
</table>
4.3 Conclusion

1. Incorporation of nano-fillers like Nanoclay and Nanosilica improves the physico-mechanical properties of NBR nanocomposites. The increase in dosage of nano-fillers showed the increasing trends for tensile strength and modulus properties till an optimum level and then decreases.

2. Thermal Characterization of NBR based nanocomposites were done using TGA and results revealed that the incorporation of nano fillers increases the minimum degradation temperature and maximum degradation of polymer nanocomposites [PNCs]. This was also corroborate with increase in thermal ageing studies of PNCs.

3. The SEM / EDS spectra showed that the nanoparticles were well dispersed within polymer matrix.

4. Through Thermogravimetric analysis, it has been found that addition of nano-silica increases thermal stability which is also corroborated by the retention of physico-mechanical properties even after ageing at 100 °C for 24 hrs.

5. Polymer nanocomposites were further characterized by X ray Diffraction studies, which showed that there is a shift in the 2θ value towards higher side, indicating intercalation of rubber chains in it. The silicate layers, expanding the silicate gallery spacing.

6. EDS mapping of SEM image showed the well distributed nano silica particles in the polymer matrix also confirms the findings of FT-IR and thermal characterization of polymer nanocomposites.
4.4 References