Chapter 4

DEVELOPMENT OF CONDUCTIVE NITRILE RUBBER

4.1 Introduction

Nitrile rubber, a copolymer of butadiene and acrylonitrile has good resistance to a wide variety of oils and solvents and hence is widely used in products like oil seals, pipe protectors and blow out preventors etc. The acrylonitrile (ACN) content varies usually from 20-50% by weight and accordingly NBR is usually classified into three types, viz., low acrylonitrile content NBR with less than 25%, medium with 25-35 % and high acrylonitrile content NBR with 35-50 %. NBR gives low gum strength, as there is no crystallinity in the polymer. The service temperature in presence of oxygen is estimated to be 130°C.

Major properties of the elastomer depend on the acrylonitrile content. As the acrylonitrile content increases, the oil resistance increases. Other properties affected by monomer ratio are processability, cure rate, heat resistance, and resistance to permanent set. With increased acrylonitrile content, processability is easier, cure rate is faster and heat resistance is better. But, resistance to
permanent set and die swell is decreased, and viscosity is increased as the acrylonitrile content increases.

The most common way to classify nitrile rubbers is by their bound acrylonitrile content, and by their viscosity. The bound acrylonitrile content as described above goes from about 20 - 50 % with the bulk as 25 - 40 % range. Mooney viscosity ordinarily ranges from 30 - 80.

Basically nitrile rubbers are compounded much like natural rubber. Since it does not crystallise, reinforcing fillers are necessary to obtain reasonable tensile, tear and abrasion properties. In black compounds, reinforcement is proportional to the amount and fineness of the black. Non-black fillers give best heat resistance and also can be used with compound used for food contact applications.

Fine precipitated silica is the most reinforcing among the non-black fillers. Plasticizers are used in almost all nitrile compounds first to aid processing and then to improve low temperature flexibility, resilience, and flexing, or to reduce hardness. Plasticizer level will ordinarily vary from 5 - 50 phr.

Nitrile rubber requires age resistors in addition to those they already have in order to give long service. Where staining is not a problem, amine type antioxidants may be used. If staining is objectionable, then phosphates or hindered phenol antioxidants will serve better.

Vulcanization of nitrile rubber is usually accomplished with sulphur, accelerator, and ZnO in combination with fatty acid as activator. In special cases, peroxide may also be used. NBR cures relatively fast, the higher acrylonitrile content, faster the cure rate. The amount of sulphur used is based on butadiene content and is generally lower than that used for natural rubber and ranges from 0.7-2.3 phr. The solubility of sulphur is considerably less and affect it’s uniform dispersion, for this reason, sulphur is added early in the mix.
Because of the relatively fast rate of cure, NBR is usually compounded with one accelerator, often of the sulphenamide class. Accelerator of the thiazole type like tetramethylthiuram monosulfide (TMTM) or tetramethylthiuram disulfide (TMTD) might be used when a faster curing is needed.

Electrically conductive polymer composites are widely used in various branches of engineering in many rubber and plastic products. Some of these applications include plastic batteries, sensors, electro chromic displays, EMI shielding, fuel cells, circuit boards etc. The basic and generally accepted concepts of conductivity are based on the fact that carbon black forms aggregates or network structures in the compositions. The degree of conductivity depends on the nature of these chain structures. In recent years papers relating to the effect of various factors influencing the conductivity of polymer compositions containing carbon black have been published - like type of carbon black, concentration of carbon black, type of polymer, temperature and degree of dispersion of carbon black in the polymer matrix. It is shown that starting at a certain level, an increase in the amount of carbon black in a composition leads to a marked increase in conductivity and this then tends asymptotically to a finite value.

The amount of electrically conductive fillers required to impart high conductivity to an insulating polymer can be dramatically decreased by the selective localization of the filler in one of the phase or at the interphase of a polymer blend. Not only the final cost of the material is decreased, but the problems associated with the excess of filler on the processing and mechanical properties of the final composites are alleviated. The localization of carbon black in an immiscible polymer blend is basically controlled by the mutual polymer-polymer and polymer-filler interaction.

This chapter is divided into four parts; Part I deals with the effect of concentration of acetylene black on the electrical conductivity and mechanical properties of nitrile rubber vulcanizates. Part II deals with the effect of blending of...
NBR with other polymers on the electrical conductivity and mechanical properties of the vulcanizates at the same dosage of acetylene black. Nitrile rubber blends with NR, EPDM and PVC was prepared and the electrical conductivity and mechanical properties are reported. Part III deals with the variation in conductivity and mechanical properties of the vulcanizates with different composition of NBR/NR blends at the same dosage of acetylene black. Part -IV deals with the effect of temperature on the electrical conductivity of these vulcanizates.

4.2 Experimental

4.2.1 Materials Used

Nitrile rubber (NBR), Natural rubber (NR), Polyvinylchloride (PVC), Ethylene –propylene-diene rubber (EPDM), Acetylene black (AB), Zinc oxide (ZnO), Magnesium oxide (MgO), Stearic acid (SA), Dibenzthiazyldisulphide (MBTS), Sulphur, Tetramethylthiuramdisulphide (TMTD), and Dioctylphthalate (DOP) conforming to the specifications given in Chapter 2 were used in the present investigation.

4.3 Part-I Studies On Conductive Nitrile Rubber

4.3.1 Sample Preparation

The compounds were prepared as per the formulation given in Table- 4.1 on a two-roll mill of size (15 x 33 cm). The compounds were kept for 24 hrs. for maturation.

The optimum cure time (time for attaining 90% of the maximum torque) of each sample was determined at 150°C using Goettfert Elastograph Model 67.85
The compounds were compression molded at 150°C in an electrically heated hydraulic press, into 2mm thick sheets. For this, the mould was pre-heated to 150°C; a piece of preformed material was placed directly in the mould cavity, and compressed under a hydraulic pressure of 200 Kgcm⁻². Upon completion of the required cure cycle, the pressure was released and the sheet was stripped off from the mould and suddenly cooled by plunging into cold water. After a few seconds, the samples were taken from water. Dumb-bell shaped specimens were punched out of these compression-moulded sheets along the mill grain direction. The tensile properties were measured on a Zwick UTM model 1445 according to ASTM D 412 at a crosshead speed of 500 mm/min. The values presented are the average of three samples.

### Table 4.1 Formulation of compounds

<table>
<thead>
<tr>
<th>Mix</th>
<th>A₁</th>
<th>A₂</th>
<th>A₃</th>
<th>A₄</th>
<th>A₅</th>
<th>A₆</th>
<th>A₇</th>
<th>A₈</th>
<th>A₉</th>
<th>A₁₀</th>
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<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>AB</td>
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<td>60</td>
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<tr>
<td>ZnO</td>
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<td>4</td>
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<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
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<td>1.5</td>
<td>1.5</td>
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<td>1.5</td>
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<tr>
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<td>1</td>
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</tr>
<tr>
<td>TMTD</td>
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<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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<td>DOP</td>
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<td>3</td>
<td>4</td>
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<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

The Hardness (Shore-A) of each sample was noted according to ASTM D 2240. Resistivity of each sample was determined using two-probe method. Data presented are the average of three samples. The samples with typical dimensions of 3x1x2 cm were prepared for direct current electrical conductivity measurements. The sample was inserted between two electrodes. The contact resistance between the sample and the electrode was minimized using silver paint. A potential of 6 V
was applied and the resulting current through the circuit was noted. Measurements were carried at a rotary vacuum of $10^{-2}$ torr. The current was measured using a digital multimeter (APLAB model 1087). Resistance of the samples were calculated using the equation, $R = \frac{V}{I}$, where, 'V' is the applied voltage and 'I' is the resulting current. The resistivity in each sample was calculated using the equation, $\rho = \frac{R}{A/t}$, where 'A' is the area of the sample, and 't' is the thickness of the sample. Conductivity is the reciprocal of resistivity.

### 4.3.2 Results and discussion

Figures 4.1-4.5 shows the physical properties of the vulcanizates. It was found that cure time of the compounds was decreased as the amount of acetylene black increased as shown in Figure 4.1 because of the accelerating effect of acetylene black on vulcanization, up to about 60 phr of acetylene black. Above 60 phr, the change in cure time with the concentration of acetylene black was negligible and it remained almost constant.

![Figure 4.1 Variation in cure time of the compounds of NBR Containing different amounts of acetylene black](image-url)
Development of conductive nitrile rubber

Hardness (Shore-A) of the compounds increased with an increase in the concentration of acetylene black. But above 60 phr of acetylene black, the change in hardness with increase in the amount of acetylene black was negligible. This was because, a saturation point was reached at a concentration of 60 phr of acetylene black as shown in Figure 4.2. Figure 4.3 shows the variation in elongation at break of the vulcanizates containing different amounts of acetylene black. Elongation at break decreased with an increase in the amount of acetylene black as expected up to about 60 phr of acetylene black and thereafter it remained almost as constant.

Tensile strength of the vulcanizates was increased as the concentration of acetylene black increased as shown in the Figure 4.4. It was because; acetylene black was acting as reinforcing filler in nitrile rubber.

![Graph of hardness vs. concentration of acetylene black](image)

**Fig. 4.2** Variation in hardness of vulcanizates with the amount of acetylene black
Fig. 4.3 Variation in elongation at break of vulcanizates with the amount of acetylene black

Fig. 4.4 Variation in tensile strength of vulcanizates with the amount of acetylene black
As the amount of acetylene black was increased, the modulus of the vulcanizates increased as shown in the figure 4.5. As the amount of acetylene black was increased, the conductivity of the composites was increasing. Figure 4.6 shows the variation in resistivity of pure nitrile rubber vulcanizates with the concentration of acetylene black at room temperature. At low concentration of acetylene black, the resistivity of the sample was very high. This was because, the particles of acetylene black were isolated from each other and a conducting through-going path was not formed. As the amount of acetylene black was increased, the resistivity decreased rapidly up to 40 phr of acetylene black and there after, the decrease in resistivity was very slow. It was due to the formation of aggregates of acetylene black particles to form a conducting path through the polymer chain. Once saturation was reached, contact resistance between the clusters was no longer significant and so at higher loadings, the decrease in resistivity was not rapid.

![Graph showing variation in modulus of vulcanizates with the amount of acetylene black](image)

**Fig. 4.5 Variation in modulus of vulcanizates with the amount of acetylene black**
PART II

Studies On Conductivity of Blends of NBR With NR, EPDM And PVC

4.4.1 Sample preparation

NBR/NR and NBR/EPDM blends were prepared by masticating the individual rubbers separately and then mixing well on the two-roll mill and the other ingredients were added according to the formulation given in the Table 4.2.

NBR/PVC blend was prepared on a Brabender Plasticorder PL3S at a rotor speed of 40 rpm at 150° C as per the formulation given in Table 4.3. PVC was
mixed with DOP and stabilizer, melted in the Plasticorder, then NBR was added and mixing was continued for 5 more minutes. Other ingredients were added to this NBR/PVC mix on a two-roll mill as per the formulation given in Table 4.2.
4.4.2 Results and discussion

The cure time and the mechanical properties of different blends of NBR with NR, EPDM and PVC are given in Table 4.4. NBR/PVC blend was having more hardness than NBR/NR and NBR/EPDM blends. It was due to the presence of PVC in the vulcanizate, which is a thermoplastic material. At the same dosage of acetylene black, the NBR/PVC vulcanizate had higher tensile strength and modulus compared to NBR/NR and NBR/EPDM blend. The tensile strength and modulus of the blend depends on the individual polymers and their compatibility.

Table 4.4 Properties of the Mixes

<table>
<thead>
<tr>
<th>80/20 Blend</th>
<th>Cure Time at 150°C (in min.)</th>
<th>Hardness (Shore A)</th>
<th>Elongation at Break (%)</th>
<th>Tensile Strength (N mm⁻²)</th>
<th>Modulus at 100 % elongation (N mm⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBR/NR</td>
<td>4.16</td>
<td>83</td>
<td>189.58</td>
<td>15.69</td>
<td>9.97</td>
</tr>
<tr>
<td>NBR/EPDM</td>
<td>3.64</td>
<td>80</td>
<td>221.42</td>
<td>9.62</td>
<td>9.37</td>
</tr>
<tr>
<td>NBR/PVC</td>
<td>4.6</td>
<td>90</td>
<td>186.86</td>
<td>17.26</td>
<td>13.59</td>
</tr>
</tbody>
</table>

The variation in electrical resistivity on adding acetylene black to different blends of nitrile rubber with PVC, NR and EPDM is shown in Figure 4.7. NBR/NR blend had low resistivity than NBR/EPDM blend whose resistivity was lower than NBR/PVC blend. This behavior can be explained by the difference in the dispersion of acetylene black in different phases as well as in the interphase. Blends always have more conductivity compared to the individual polymer. This was due to the selective localization of acetylene black in one phase or at the interphase of the polymer matrix.
Fig. 4.7 Variation in resistivity of vulcanizates with the amount of acetylene black

With some exceptions, compatibility of the components of a blend may roughly be predicted by the solubility parameters of the components. The nearer the values of solubility parameters, the better will be the compatibility. Table 4.5 shows the solubility parameters of the polymers used.

Table 4.5 Solubility parameter of the polymers

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Solubility parameter $(J/m^3)^{1/2} \times 10^{-3}$</th>
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</thead>
<tbody>
<tr>
<td>EPDM</td>
<td>16</td>
</tr>
<tr>
<td>NR</td>
<td>16.2</td>
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<td>PVC</td>
<td>19.8</td>
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<tr>
<td>NBR</td>
<td>20.5</td>
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</table>
NR and NBR differ widely in polarity. NBR is a polar rubber, while NR is a nonpolar rubber. They have quite different solubility parameters as given in Table-4.5 and this results in limited degree of mixing at the interphase of the blend. So when their blends were prepared, the acetylene black got dispersed at the interphase between the two rubbers. So the number of contact points was increased and the gap width between the aggregates of acetylene black particles were decreased. So a conducting path was easily formed and the conductivity was increased. The conductivity of NBR/NR blend was more than that of pure NBR and NR vulcanizates.

NBR/PVC blend is technically compatible at all ratios. Their solubility parameters are very close to each other. NBR acts as a nonmigrating plasticizer to PVC. Presence of a plasticizer decreases the conductivity. It can be explained by the well dispersion of acetylene black in NBR/PVC blend. There was no localization of acetylene black aggregates, by which, the number of contact points were decreased and the gap width was increased. Therefore the conductivity was lower than pure NBR vulcanizates as well as NBR/NR and NBR/EPDM blends.

It is evident from Table- 4.5 that the NBR/EPDM blend, which has a large difference in solubility parameter, should form an incompatible blend, and indeed it does. EPDM is generally placed between unsaturated, high diene rubbers (NR, SBR, BR, CR, NBR) and IIR (weak interaction), with regard to its interaction with black. Therefore, even though the NBR/EPDM blend is more incompatible than NBR/NR blend, the conductivity of NBR/EPDM blend was lower than that of NBR/NR blend. The exceptional behavior of NBR/EPDM blend is already reported.
4.5 PART-III

Studies On Conductive NBR/NR Blends

4.5.1 Sample preparation

NBR/NR blends of varying composition were prepared as per the formulation given in Table 4.6. 80/20 NBR/NR blends containing different amounts of acetylene black were prepared and the electrical conductivity and mechanical properties of the vulcanizates were studied.

Table 4.6 Formulation of compounds

<table>
<thead>
<tr>
<th>Mix</th>
<th>C₁</th>
<th>C₂</th>
<th>C₃</th>
<th>C₄</th>
<th>C₅</th>
<th>D₁</th>
<th>D₂</th>
<th>D₃</th>
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<tbody>
<tr>
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<td>9</td>
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</tbody>
</table>

4.5.2 Results and discussion

Figure 4.8 represents the variation in cure time of NBR/NR blends of varying composition, at the same dosage of acetylene black (60 phr). Cure time of the compounds was decreased with increase in the amount of NR in the blend.
Fig. 4.8 Variation in cure time of vulcanizates with the composition of NBR/NR blends containing 60 phr of acetylene black

Fig. 4.9 Variation in cure time of vulcanizates of 80/20 NBR/NR blends with the concentration of acetylene black
This was because, the dispersion of sulphur was easier when the amount of NR was increased, and therefore fast curing takes place. Figure 4.9 shows the variation in cure time of 80/20 NBR/NR blends with the concentration of acetylene black. Cure time of the blends decreased with increase in the amount of acetylene black due to the accelerating effect of acetylene black on vulcanization. Table 4.7 gives the hardness, tensile strength and elongation at break of various blends.

![Graph showing variation in cure time of 80/20 NBR/NR blends](image)

**Fig.4.9 Variation in cure time of 80/20 NBR/NR blends with the concentration of acetylene black.**

Figure 4.10 represents the variation in resistivity of NBR/NR blends of varying composition, at the same dosage of acetylene black (60 phr). The 80/20 - NBR/NR blends had the lowest resistivity compared to other blends. The graph shows there was a decrease in resistivity, and it reached a minimum value near 80/20-blend. This can be explained by the fact that, when the amount of one phase was small and the other phase was large, the acetylene black will be dispersed nonuniformly in the continuous phase and so the number of contact points were increased and the gap width was decreased. When both the polymer become approximately equal, the acetylene black will be uniformly dispersed in both phases.
and the continuity of the conducting path will be decreased, which resulted in a decrease in conductivity. Depending on the interaction of polymer with the acetylene black, there may be redistribution of acetylene black from the component with less interaction with the elastomer zone with more black-rubber interaction (at the interface of two elastomers)\(^9\),\(^10\). The distribution of acetylene black also depends on the solubility parameter of the individual elastomers of the blends.

**Table 4. 7 Properties of the Mixes**

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Hardness (Shore A)</th>
<th>Elongation at Break(%)</th>
<th>Tensile Strength (N mm(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(_1)</td>
<td>83</td>
<td>189.58</td>
<td>15.69</td>
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<td>C(_2)</td>
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<tr>
<td>C(_4)</td>
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</tr>
<tr>
<td>C(_5)</td>
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<td>221.3</td>
<td>17.46</td>
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<tr>
<td>D(_1)</td>
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<td>15.69</td>
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</tr>
<tr>
<td>D(_3)</td>
<td>90</td>
<td>160.45</td>
<td>17.99</td>
</tr>
<tr>
<td>D(_4)</td>
<td>91</td>
<td>143.51</td>
<td>18.77</td>
</tr>
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</table>

Figure 4.11 shows the variation in resistivity of 80/20-NBR/NR blends with the concentration of acetylene black. Resistivity was decreased with increase of acetylene black concentration. i.e., the electrical conductivity of the vulcanizates increased with increase in the amount of acetylene black similar to NBR vulcanizates.
Fig. 4.10 Variation in resistivity of vulcanizates with the composition of NBR/NR blends containing 60 phr of acetylene black.

Fig. 4.11 Variation in resistivity of 80/20 NBR/NR blends with the concentration of acetylene black.
Effect Of Temperature On The Electrical Conductivity Of NBR And Its Blends With NR, EPDM And PVC

4.6.1 Results and Discussion

Figures 4.12-4.19 represents the variation in resistivity of different vulcanizates with temperature. When temperature was increased from 25°C to 150°C, the resistivity of all compounds increased at first, and then decreased. Similarly, on cooling, the resistivity of all compounds at first decreased, and then at low temperature, the resistivity further increased with temperature. For different vulcanizates, the temperature at which the change in resistivity takes place was different and it depends on the composition of the different vulcanizates. All compounds which contain acetylene black has a chain of aggregates of acetylene black as well as there are insulating interlayers of the polymer.

As the temperature was increased, the resistivity at first increased and at higher temperature region, the resistivity of the vulcanizates slightly decreased. This unexpected behaviour in NBR vulcanizates was attributed to the simultaneous occurrence of two competing processes. First, there was an increase in resistivity, due to the thermal expansion of nitrile rubber, which was higher than that of acetylene black, resulting in an increase in the gap width between the aggregates; and with increasing temperature, some of the aggregates of acetylene black breaks down and so the gap width between the aggregates increased and so conductivity was decreased. The second process comprises activation of conductivity at relatively high temperatures, as in non-crystalline semi-conductors. The
occurrence of the observed anomalies depends on the nature and the degree of filling of the carbon black used\textsuperscript{14}, on the mixing process, and on the extent of thermo-oxidative ageing\textsuperscript{15}.

On cooling, the resistivity of the vulcanizates at first decreased. This may be either due to the contraction of nitrile rubber so that the gap width between aggregates of acetylene black decreased or due to the reagglomeration of the particles resulting in a decrease in gap width\textsuperscript{3,5,6}. At low temperature, the resistivity further increased or remained as constant. This was because, at low temperature, the reagglomeration of the acetylene black particles may be complete in NBR and also, the contraction of the rubber may not be changing the gap width between the aggregates.

The nature of the hysteresis loop in the $\rho = f(T)$ curve during the heating-cooling cycle is shown in figures 4.12- 4.19. It has reported that the hysteresis loop results from the thermal mismatch between filler and polymer\textsuperscript{6,16}. The uneven thermal expansion of nitrile rubber and acetylene black may be one of the reasons for the creation of a hysteresis loop.

Figure 4.12 shows the variation in the resistivity of nitrile rubber vulcanizate with 60 phr of acetylene black with temperature. When temperature was increased, some of the aggregates of carbon black break down and the gap width between the aggregates increased and so the resistivity was increased up to about 55\textdegree C and thereafter the resistivity decreased with increase in temperature. The decrease in resistivity may be due to the thermal activation of charge carriers present in the rubber matrix\textsuperscript{12}. A similar observation has been reported earlier by Abo-Hashem and colleagues\textsuperscript{5} in butyl rubber mixed with SRF carbon black. They have observed a decrease in conductivity below 60\textdegree C for the composites containing 40 and 70 phr SRF; above 60\textdegree C, thermally activated behaviour show an increase in conductivity during the heating cycle. It was reported that the structure of SRF black suffers from slight breakage below 60\textdegree C and reformation above 60\textdegree C, wherein the
increase in free volume holes becomes appreciable. Silicone rubber containing ISAF black (N-234) also has been reported to show an unexpected observation like this. So the resistivity decrease may also be due to the reformation of acetylene black aggregates in the heating cycle itself.

Fig. 4.12 Variation in resistivity with temperature for nitrile rubber vulcanizate with 60 phr acetylene black

On cooling, reagglomeration of the particles took place, the gap width between the aggregates of acetylene black decreased, and the conductivity increased. During cooling, the size of the aggregates of acetylene black may be greater than that at the heating time. This may be one of the reasons for the higher conductivity on cooling than on heating; thus the hysteresis loop resulted. Also, it has been reported that the resistivity of silicone rubber compounds decreased after heat ageing at 150-250°C. The decrease in resistivity during ageing was explained to be due to the increase in the concentration of the carbon black in the system, as a result of a loss of mass (3.8% after 55000 hrs at 150°C). Here also
after heating cycle, aging of nitrile rubber takes place, and the conductivity on cooling was higher than on heating; thus, the hysteresis loop was formed.

The resistivity values shown in the graph during the cooling cycle was only up to 50°C, because the cooling rate was very low below 50°C. If we extrapolate the curve to room temperature, the cooling cycle endpoint will be the same as that of the starting point of the second heating cycle. The heating-cooling cycle was repeated for checking the reproducibility of the variation in conductivity with temperature. The resistivity was decreased on heating and remained constant on cooling during second cycle. This was because, some permanent change due to ageing takes place for the rubber and a steady state was reached after one cycle.

Figure 4.13 shows the variation in the resistivity of 80/20 NBR/PVC blend with temperature containing 60 phr of acetylene black. On heating, resistivity of the vulcanizate was increased up to 40°C and thereafter the resistivity decreased with increase of temperature. On cooling, the change in resistivity was very low compared to that in the heating cycle, and the resistivity slowly decreased with decrease in the temperature. In the second cycle, the variation in resistivity with temperature was very low. This may be because, a steady state might have reached after one heating-cooling cycle from 25- 150°C.

Figure 4.14 shows the temperature dependence of resistivity for 80/20 NBR/EPDM blend containing 60 phr of acetylene black. On heating, the resistivity increased up to 75°C, due to the thermal expansion of the nitrile rubber. This may also be due to the disintegration of acetylene black aggregates. At higher temperature, the resistivity decreased with increase of temperature. On cooling, the resistivity decreased due to the contraction of nitrile rubber and may also be due to the reagglomeration of acetylene black particles. In the second cycle, the variation in resistivity with temperature was very low. This may be due to the steady state reached after one heating-cooling cycle from 25- 150°C as in NBR/PVC blend.
Fig. 4.13 Resistivity variation with temperature for 80/20 NBR/PVC blend containing 60 phr of acetylene black.

Fig. 4.14 Resistivity variation with temperature for 80/20 NBR/EPDM blend containing 60 phr of acetylene black.
Figures 4.15-4.19 show the temperature dependence of resistivity for NBR/NR blends of different composition containing 60 phr of acetylene black. On heating, the resistivity was increased first, due to the thermal expansion of the nitrile rubber and disintegration of acetylene black aggregates. At higher temperature, the resistivity decreased with increase of temperature, due to the thermal activation of conductivity. On cooling, the resistivity decreased, and the change in resistivity was similar to that of pure NBR vulcanizate mixed with acetylene black. In the second cycle, the variation in resistivity with temperature was very low.

Fig. 4.15 Resistivity variation with temperature for 80/20 NBR/NR blend containing 60 phr of acetylene black
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Fig. 4.16 Resistivity variation with temperature for 70/30 NBR/NR blend containing 60 phr of acetylene black

Fig. 4.17 Resistivity variation with temperature for 50/50 NBR/NR blend containing 60 phr of acetylene black
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Fig. 4.18 Resistivity variation with temperature for 30/70 NBR/NR blend containing 60 phr of acetylene black

Fig. 4.19 Resistivity variation with temperature for 20/80 NBR/NR blend containing 60 phr of acetylene black
4.7 Conclusions

1 The electrical conductivity of nitrile rubber vulcanizates was increased with the amount of acetylene black.

2 Blends of nitrile rubber with NR, PVC and EPDM were more conducting than pure NBR vulcanizates, containing the same amount of acetylene black.

3 NBR/NR blends were more conducting than NBR/EPDM and NBR/PVC blend, at the same dosage of acetylene black.

4 80/20 - NBR/NR blend was more conducting than other NBR/NR blends, at the same dosage of acetylene black.

5 Electrical conductivity depends on the degree of dispersion of acetylene black at the interphase and the polymer matrix in the case of polymer blends.

6 The electrical conductivity of the NBR vulcanizates decreased with increase in temperature at first and thereafter the conductivity increased with increase in temperature during the heating cycle.

7 During the cooling cycle, the conductivity increased at first and then decreased slowly.

8 The change in conductivity during the cooling cycle was negligible compared to that during the heating cycle.

9 The change in conductivity during the second heating-cooling cycle was very low compared to that in the first cycle.
4.8 References