The Use of Rubber Blends in Rubber Products Manufacturing Industry

By

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ABSTRACT

Rubber blends are widely used in the product manufacturing industry and very much popular in these days because it has shown very good properties compared to mono polymer products. In day to day life we experience many applications of rubber blend in rubber product, especially in tyres, flooring, water hoses, etc. In most of industries. These products are directly exposed to natural weather condition, when they are used in out door purposes.

In this study we used commercially available three different types of elastomers. Generally, the synergistic effect of the each type of blend compound can be studied by observing several physical properties. These parameters are Tensile strength [ASTM D 412], Tear strength [ASTM D 624], Elongation @ Break [ASTM D 412], Hardness [ASTM D 2240], Abrasion [DIN 53516], Specific Gravity (SG) [ASTM D 1298], Swelling Resistance(Weight increase %) [ASTM D 471].

Our study shows that the above properties are greatly affected by when change the major polymer composition. When comparing the results obtained for the above physical properties we can clearly conclude that the composition of the rubber compound directly affects some physical properties.

In this study we can select suitable blend (Polymer composition) compound according to the product application & customer requirement. Hence we can overcome most of the problems which will appear while using the product.
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</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>NR</td>
<td>Natural Rubber</td>
</tr>
<tr>
<td>SBR</td>
<td>Styrene Butadiene Rubber</td>
</tr>
<tr>
<td>NBR</td>
<td>Acrylo Nitrile Butadiene Rubber</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Standard for Testing and Material</td>
</tr>
<tr>
<td>MH</td>
<td>Maximum torque</td>
</tr>
<tr>
<td>Ts2</td>
<td>Time taken to complete 2% Curing</td>
</tr>
<tr>
<td>DRC</td>
<td>Dry Rubber Content</td>
</tr>
</tbody>
</table>
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1. Introduction

1.1. IMPLICATION

There has been considerable success in overcoming the problems posed by the blends considered, and in realizing some of the opportunities to provide new alternatives for elastomers in a range of applications. Whilst these developments have been made within the context of essentially four specific blend systems, the solutions may be more widely applicable.

Some care must be exercised in generalizing the particular solutions found to the problem of obtaining even cross-link distribution in NR/NBR blends. It is evident that a cure system which is ideal for blends with NBR at one level of acrylonitrile content may well be quite inappropriate for blend with NBR at a somewhat different acrylonitrile content. Nonetheless, the principle of identifying cure systems which will give near-even crosslink distribution should be applied to all blends of elastomers different in polarity. Furthermore, one general rule has emerged – it appears that every polar thiuram accelerators, TMTM and TMTD, Should be avoided in NR/NBR blends.

The ageing, the approach adopted to developing blends with a combination of high damping, good physical properties and a low dependence of properties on temperature could be applied to other blends of elastomers differing in property. However, the particular combination of NR with ENR has the distinct advantage that both elastomers are inherently high strength due to strain-induced crystallization.

1.2. Elastomers used for Blends

Elastomer is a big fancy word, and all it means is “Rubber”. Some polymers which are elastomers include cis 1,4-polyisoprene or natural rubber, polybutadiene, polyisobutylene and acrylonitrile-butadiene. What make elastomers special is the fact that they bounce. But just saying “they bounce” is kind of vague. Let’s be more specific. What makes elastomers special is that they can be stretched to many times their original length, and can bounce back into their original shape without permanent deformation.
1.2.1. Natural Rubber

Natural Rubber is the prototype of all elastomers. It is extracted in the form of latex from the bark of the *Hevea sp.* tree. The rubber is collected from the latex in a series of steps involving preservation, concentration, coagulation, dewatering, drying, cleaning and blending. Because of its natural derivation, it is sold in a variety of grades based on purity, viscosity, viscosity stability, oxidation resistance, and rate of the cure.

The pure dry natural rubber contain 100% *cis* – 1, 4 polyisoprene with weight average molecular weight from 1 to $2.3 \times 10^6$. The natural rubber has some tendency to spontaneous crystallization due to their high molecular regularity. The natural rubber shows high tensile strength and resistance to cutting, tearing, and abrasion.

The rubber polymer network allows elasticity and flexibility to be combined with crystallization- induced strength and toughness when stretched. The elastic nature of the rubber molecules also account for the exceptional resilience of rubber products. The natural rubber is one of the preferred sidewall elastomers in radial tyres.

1.2.1.1. Composition and chemical structure of natural rubber

Natural rubber (*Hevea*) latex varies in its composition but the following may be considered the typical.

*Table 1.1:* Typical composition of natural rubber latex

<table>
<thead>
<tr>
<th>Materials</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 DRC</td>
<td>33</td>
</tr>
<tr>
<td>2. Total solid content</td>
<td>36</td>
</tr>
<tr>
<td>3. Proteinous substances</td>
<td>1-1.5</td>
</tr>
<tr>
<td>4. Resinous substance</td>
<td>1-1.5</td>
</tr>
<tr>
<td>5. Ash</td>
<td>&lt;1</td>
</tr>
<tr>
<td>6. Sugars</td>
<td>1</td>
</tr>
<tr>
<td>7. Water</td>
<td>60</td>
</tr>
</tbody>
</table>
The rubber molecules consist virtually entirely of cis-1,4-polyisoprene:

\[
\begin{align*}
&\text{CH}_3 \quad \text{H} \\
&\text{C} = \text{C} \quad \text{H} \\
&\text{CH}_2 - \quad \text{CH}_2 - \quad \text{CH}_2 - \quad \text{CH}_2 - \quad \ldots \quad \text{CH}_2 - \\
\end{align*}
\]

*Figure 1.1. The chemical structure of Natural Rubber (NR)*

There is no evidence for any trans materials or for any 1,2- or 3,4-isoprene polymer in the natural product, in contrast to the synthetic polyisoprenes. There is some evidence for a few carbonyl groups attached to the chain and which may be a site for cross linking and lead to the formation of gel. There is some dispute as to the nature of these groups, both aldehyde and lactone groups have been suggested. The presence of the occasional epoxy group in the chain has also been postulated.

1.2.1.2. Molar Mass Distribution

The molecular weight of the natural polymer is very high but varies between lattices from different clones. In one study the number average molecular weight \((M_\text{n})\) was found to range from \(0.25 \times 10^6\) to \(2.71 \times 10^6\) and the weight average molecular weight \((M_\text{w})\) from \(3.4 \times 10^6\) to \(10.17 \times 10^6\). The average values from \(M_\text{w}/M_\text{n}\) for 12 different clones is 6.72 with values for individual clones ranging from 3.63 to 10.94.

1.2.1.3. Properties

The natural rubber molecule is an unsaturated aliphatic hydrocarbon polymer of very regular structure. Whilst the molecular weight of the raw polymer is so high that entanglements make solution difficult, masticated rubber will dissolve in aliphatic hydrocarbons and other liquid of similar solubility parameter\(^9\). It will also react with chemicals known to be reactive to carbon – carbon double bonds, will be a good electrical insulator when pure and will burn in air as may be predicted from the structure.
The very flexible chain backbone leads to a very low $T_g$ of about $-73 \, ^\circ C$. Because of the stiffening effect of the methyl group on the chain backbone this value is somewhat higher than that for $cis$ – polybutadiene. The natural rubber molecule is capable of crystallization and the unsaturated raw polymer has a crystalline melting point ($T_m$) of about $+25 \, ^\circ C$. Crystallization may also be induced by stretching samples such as in a tensile test. As a result of this stress-induced crystallization, the tiny crystal structures formed act rather like reinforcing particles and, unlike SBR which does not crystallize, enable gum and lightly loaded stocks to exhibit high vulcanize strengths.

1.2.1.4. NR Grades available in Sri Lanka

Classification of natural rubber by visual grading in accordance with guidelines laid down in the Green Book – International Standards of Quality and Packing in Natural Rubber is given below\(^9\).

**Table 1.2. Available Grades of natural rubber**

<table>
<thead>
<tr>
<th>Section</th>
<th>Available Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ribbed smoked sheets: Made entirely from coagulated rubber sheets properly dried and smoked.</td>
<td>1XRSS Superior quality</td>
</tr>
<tr>
<td></td>
<td>1RSS Standard quality</td>
</tr>
<tr>
<td></td>
<td>2RSS Good fair average quality</td>
</tr>
<tr>
<td></td>
<td>3RSS Fair average quality</td>
</tr>
<tr>
<td></td>
<td>4RSS Low fair average quality</td>
</tr>
<tr>
<td></td>
<td>5RSS Inferior fair average quality</td>
</tr>
<tr>
<td>2. White and pale crepes: Prepared from fresh coagula of NR latex under controlled conditions (classified as either thin or thick)</td>
<td>1X Superior quality pale crepe</td>
</tr>
<tr>
<td></td>
<td>1 Standard quality pale crepe</td>
</tr>
<tr>
<td></td>
<td>2 Good fair average quality pale crepe</td>
</tr>
<tr>
<td></td>
<td>3 Fair average off-colour pale crepe</td>
</tr>
<tr>
<td>3. Estate brown crepe: from cup lump, other high – grade scraps and pre-cleaned tree bark scrape (classified as either thin or thick)</td>
<td>1 X Clean light brown crepe</td>
</tr>
<tr>
<td></td>
<td>2 X Inferior grade</td>
</tr>
<tr>
<td></td>
<td>3 X Inferior grade</td>
</tr>
<tr>
<td>4. Compo crepes</td>
<td>Grades 1,2,3</td>
</tr>
<tr>
<td>5. Remills – thin brown crepes</td>
<td>Grades 1, 2, 3, 4</td>
</tr>
<tr>
<td>6. Thick blanket crepe – amber</td>
<td>Grades 2, 3, 4</td>
</tr>
<tr>
<td>7. Flat bark crepes: earth scraps</td>
<td>Grades standard, hard</td>
</tr>
</tbody>
</table>
1.2.2. Acrylonitrile Butadiene Rubber (NBR)

A somewhat simplistic way of describing acrylonitrile – butadiene rubbers, commonly known as nitrile rubbers, is to say that they are the special purpose rubbers with the conventional technology. Commercially available for over 50 years, they are known primarily for their resistance to liquid fuels such as petrol and other hydrocarbons.

Acrylonitrile Butadiene copolymers were first prepared in 1930 with pilot-plant production commencing in 1934 and full-scale production in 1937, the product being marketed as Buna N°.

In recent years materials related to nitrile rubbers have been developed. These include carboxylated NBR, epoxy-modified NBR, hydrogenated NBR, copolymers containing isoprene and alternating copolymers.

1.2.2.1. Chemical structure of NBR

Nitrile rubber is represented by the basic chemical structure given below

\[-(CH_2-CH=CH-CH_2)-(CH_2-CH)-CN\]

Figure 1.2. The chemical structure of NBR°

There are two obvious features of this structure:

1. The double bond which facilitates sulphur vulcanisation but which is also susceptible to oxidation and ozone attack;
2. The polar acrylonitrile group which confers resistance to hydrocarbon oils but tends to raise the \(T_g\) of the rubber with several other directly consequent effects.

There are a number of variables which lead to important differences between commercial grades. The following are important:

1. Acrylonitrile content – the dominate variable;
2. Additional monomers or substitutes for acrylonitrile and butadiene;
3. Average molecular weight;
4. Molecular weight distribution;
5. Branching;
6. Microstructure;
7. Stabilizer incorporated on manufacture.
1.2.2.1.1. Effect of Acrylonitrile Content

Increasing the acrylonitrile content will clearly raise the minimum service temperature down to which the rubber may be used\(^2\). This in ability of nitrile rubber to remain rubbery at low temperature is obviously an advantage. Higher acrylonitrile contents also lead to lower resilience, greater hardness and higher compression set, are generally considered as there is increase in a slight increase in hardness, abrasion resistance and tensile strength at normal ambient temperatures\(^4\).

On the other hand, increasing the acrylonitrile content increases the petrol resistance and swelling in hydrocarbon oils. Since there is a very close relationship between Tg and swelling, compromises have to be arrived. As a result most grades have nominal acrylonitrile contents between 28 and 45%\(^4\).

1.2.2.1.2. Use additional or alternative Monomers.

Substituted acrylonitrile such as methacrylonitrile have also been used to produce polymer with somewhat different flow and solubility characteristics\(^4\). No commercial grades are known to be available at the time of writ.

1.2.2.1.3. Effect of molecular weight, molecular weight distribution.

The molecular weight can influence properties in three ways\(^4\):

1. By influencing flow properties. Lowering the molecular weight lowers the viscosity and generally results in easier calendering and extrusion. Compounding is also generally easier with lower compounding heat build-up.

2. The higher molecular weight rubbers have better stability during open cure, can accept higher loadings of filler and plasticizer, and are less susceptible to air entrapment. These improvements are presumably the result of the higher green strength of the higher molecular-weight polymer compound.

3. Vulcanizate properties such as tensile strength and resilience are slightly higher with higher-molecular weight polymers. This can be attributed to the fact that with low-molecular -weight polymers the proportion of non -load-bearing chain ends in the network is higher.
1.2.2.2. General vulcanizate properties of NBR

A. Excellent resistance to aliphatic hydrocarbon oils, fuels and greases.
B. Very good heat resistance in the absence of air.
C. Good hot air resistance (long term 90 °C; 40 days 120 °C; 3 days 150 °C)⁹.
D. Very low gas permeability for a rubber.
E. Low permanent set.
F. Moderate low - temperature flexibility.
G. Moderate ozone resistance and poor resistance to sunlight ageing.
H. Poor electrical insulation properties.
I. Moderate tear and tensile strength.

1.2.2.3. Blending Characters of NBR

The blending of NBR with other polymers is a long-established practice. This has been done for various purposes such as to reduce cost, to modify rheological properties or to confer specific chemical or mechanical properties to the vulcanizate. Such blends may be with another rubber or with plastic material such as PVC. Whereas in some instances the NBR is only a minor component introduced to toughen a plastic material, this section will be confined to a consideration of blends leading to rubbery vulcanizates.

As with all rubber blends due consideration should be made to following facts⁶.

1. Compatibility on a molecular scale is rarely if ever achieved and multi-phase systems may be produced.
2. Additives, particularly those used for cross-linking, may have different levels of solubility in the components of the blend and may thus be unevenly partitioned between the polymers.
3. Curing rates, with a given system, vary between polymers.
4. Rubber-filler interactions vary between rubbers.
1.2.2.4. Commercial grades of NBR

Table 1.3. Commercial grades of NBR

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Commercial Grade</th>
<th>Bound Acrylonitrile (%)</th>
<th>Moony viscosity (ML1+4 100°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zeon Corporation Ltd</td>
<td>DN 2850</td>
<td>28</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>DN 3335</td>
<td>33</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>DN 3350</td>
<td>33</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>DN 3380</td>
<td>33</td>
<td>80</td>
</tr>
<tr>
<td>Hyundai Petrochemicals Co.Ltd</td>
<td>B 6850</td>
<td>34</td>
<td>50</td>
</tr>
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<td></td>
<td>B 6840</td>
<td>34</td>
<td>40</td>
</tr>
<tr>
<td>Korea Kumho Petrochemical Co., Ltd</td>
<td>KNB25LM</td>
<td>28</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>KNB25M</td>
<td>28</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>KNB25LH</td>
<td>28</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>KNB35LL</td>
<td>34</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>KNB35L</td>
<td>34</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>KNB35LM</td>
<td>34</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>KNB40M</td>
<td>46</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>KNB40H</td>
<td>46</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>KNB0230</td>
<td>35</td>
<td>56</td>
</tr>
</tbody>
</table>

1.2.3. Styrene-Butadiene Rubber (SBR)

Styrene-butadiene rubbers were first prepared in Germany in 1929. The bulk of SBR produced is prepared by emulsion polymerisation, the product sometime being referred to as ESBR to distinguish it from the solution-polymerised rubber which first appeared in the 1960 and are sometime designated SSBR².

Whilst for long regarded as the SBR of the future, solution SBR development has been retarded by the generally difficult economics surrounding general-purpose synthetic rubber production with production capacity greatly outstripping demand in recent years¹⁰, thus discouraging the replacement of production plant.
1.2.3.1. Chemical structure of SBR

Whilst styrene and butadiene may be copolymerised in any ratio, most commercial SBR rubbers produced outside the CPEC bloc employ a target bound-styrene content of 23.5%. Because of molecular weight differences between the two monomers this is equivalent to about one styrene unit per six butadiene units or one pendant benzene ring per 26 main chain carbon atoms. Thus the following formal formula for SBR polymer tends to overemphasize the importance of the benzene ring.

\[-(-\text{CH}_2 - \text{CH}=\text{CH} - \text{CH}_2)-(-\text{CH}_2 - \text{CH} -)\-\]

**Figure 1.3. The chemical structure of SBR**

A typical cold-polymerized emulsion SBR will have the following structural characteristics:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monomer arrangement</td>
<td>Random</td>
</tr>
<tr>
<td>Cis-1,4-Polybutadiene content, %</td>
<td>9</td>
</tr>
<tr>
<td>Trans-1,4-Polybutadiene content, %</td>
<td>76</td>
</tr>
<tr>
<td>1,2-Butadiene (vinyl) content, %</td>
<td>15</td>
</tr>
<tr>
<td>Gel content</td>
<td>Negligible-moderate</td>
</tr>
<tr>
<td>Molecular weight</td>
<td>$M_n \sim 100,000, , M_w, 320,000 - 400,000$</td>
</tr>
<tr>
<td>Molecular weight distribution</td>
<td>Broad ($M_w/M_n = 3 - 5$)</td>
</tr>
</tbody>
</table>

The principle variations between grades of emulsion SBR polymers are:

1. Styrene content;
2. Molecular weight;
3. Molecular weight distribution;
4. Emulsifier system used;
5. Coagulation system used
1.2.3.2. General properties of SBR

The properties of SBR may be divided into two categories:

1. Properties in which they are similar to natural rubber;
2. Properties in which they differ from natural rubber;

Like natural rubber, SBR is an unsaturated hydrocarbon polymer. Hence unvulcanized compounds will dissolve in most hydrocarbon solvents and other liquids of similar solubility parameters whilst cured stocks will show extensive swelling. SBR will also be subjected to olefin-type reactions such as oxidation, ozone attack, halogenation and hydrohalogenation although the activity and detailed mechanisms differ because in SBR there is no activating methyl group adjacent to the double bond. Both materials may be reinforced by carbon black whilst neither may be classed as heat-resistant rubbers.

The difference between the two materials may be considered under the three categories given below.

I. Difference in the material supplied;
II. Difference in processing behaviour;
III. Difference in vulcanizate properties.

1.2.3.3. Vulcanisation character of SBR

The efficient vulcanisation systems for use with natural rubber blend to related studies on SBR given below.

A. Conventional SBR vulcanizate have a monosulphide cross-link content similar to that of an EV natural-rubber system.

B. The replacement of a conventional curing system by an EV system in SBR vulcanizate increases the monosulphide content to about twice that of an NR EV system.

C. Whereas the cross-link densities of conventionally cured SBR vulcanizates increase on aging at elevated temperature (e.g. 110 °C), the EV-cured material has a very stable cross link density at the same temperature.
### Table 1.4. Commercial grades of SBR

<table>
<thead>
<tr>
<th>Category</th>
<th>Common Indication</th>
<th>Mooney Viscosity ML(1+4)</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Hot Polymerized SBR</td>
<td>1009 NS</td>
<td>97</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>1018 NS</td>
<td>125</td>
<td>0.94</td>
</tr>
<tr>
<td>B Cold Polymerized SBR-LTP</td>
<td>1509 NS</td>
<td>34</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>1507 NS</td>
<td>35</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>1505 NS</td>
<td>40</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>1500 ST</td>
<td>52</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>1502 NS</td>
<td>52</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>1570 NS</td>
<td>125</td>
<td>0.94</td>
</tr>
<tr>
<td>C. Oil Extended SBR-LTP</td>
<td>1720 NS</td>
<td>40</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>1778 NS</td>
<td>55</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>1712 ST</td>
<td>37</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>1705 ST</td>
<td>50</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>1721 ST</td>
<td>55</td>
<td>0.97</td>
</tr>
<tr>
<td>D. SBR-Carbon Black/Oil-LTP Master Batch</td>
<td>1609 ST</td>
<td>61</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>1620 ST</td>
<td>66</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td>1606 ST</td>
<td>56</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td>1805 NS</td>
<td>58</td>
<td>1.14</td>
</tr>
</tbody>
</table>
1.3. Strategy adopted for each blend

The strategy adopted for each of the blend systems was to\textsuperscript{1}:

A. Confirm general principles behind a new approach to overcoming practical difficulties,
B. Identify technically and economically viable solutions to the difficulties.
C. Establish rules of use of the solutions where appropriate.
D. Demonstrate the feasibility of the solutions in a target application.

The overall thrust was to enable the rubber product manufacturing industry to use its own knowledge and resources to elaborate the solutions for particular problems within its market sector.

1.4. Factors affecting blend properties.

In addition to the normal considerations of compounding a vulcanizate of a single elastomer for a particular end use-such as filler type and loading, type of cure system and level, and antidegradants-there are a number of factors which arise in blends of elastomers, primarily because these almost always have more than one polymer phase. Truly miscible elastomer blends are rare, particularly in commercial use, the most notable exception probably being blend of NBR with a natural rubber or cis-1,4-poly(isoprene). These factors may be summarized as\textsuperscript{1}:

- Polymer ratio
- Phase morphology
- Interfacial adhesion/cross linking
- Distribution of filler between the elastomers
- Distribution of cross links between the elastomers
- Distribution of plasticizer links between the elastomers.

An attempt is made to illustrate these in figure 1.4 which is a representation of a section through a model vulcanized blend of two elastomers.
Figure 1.4. A section of a model blend of two elastomers A and B, containing filler, Plasticizer (P) and cross links (X).

Polymer ratio, the relative amounts of each elastomer, is readily controlled and is often dictated by the end use in mind. The blend depicted in Figure 1.4 has a polymer volume ratio of about 3:1. Phase morphology has two aspects-type and size. Whilst type of phase morphology—at its simplest whether one phase is dispersed within another, as in Figure 1.4, or whether both are continuous— is largely governed by the polymer volume ratio, other factors such as the relative viscosity of the two elastomer phases can play a role.

Control of phase size is more complicated; obviously the conditions of preparation of the blend have a major influence. Here, only mixing of elastomers is considered. In general, the shear used in mixing, the smaller the phase size attained although some elastomers undergo chain scission during mixing and there can be an optimum degree of mixing before phase size increase again. In practice, there are often constraints imposed on the extent of mixing which may be used—due either to economic considerations or such pragmatic consideration as an unacceptably high batch temperature.
Interfacial tension also play a role in the control of interfacial adhesion and cross-linking between the two elastomers-high interfacial tension means little mixing of the two elastomers at the interface. If there is little mixing of the two elastomers at the interface, the opportunity for cross-linking between two is reduced, and this can cause a weakness at the interface. Although there is no scale in Figure 1.4, the sharp phase boundary suggests little phase mixing at the interface and hence also relatively large phase size.

The remaining factors listed relate to distribution of entities between the polymer phase of the blend. Distribution of filler has been considered often in the past. In Figure 1.4, filler appears to be essentially evenly distributed between the two phase. Distribution of the most commonly used filler, carbon black, is generally readily controllable by preparing well-mixed master batches of the each elastomer containing the desired loading of black. The generally good interaction of the elastomer with the surface of the carbon black, forming the so-called bounder rubber\(^1\), ensures that there is little transfer of filler between the two elastomer on cross-blending of the master batches. Whilst a marked maldistribution of carbon black may cause difficulties in some blends, the ability to control filler distribution in this way can be put to good use-as will be seen of NR and NBR blend.

Distribution of plasticizer has not been considered so much in the past, perhaps because many compounds do not contain large quantities of plasticizer. However, when substantial quantities of plasticizer must or may be used, the distribution of this ingredient can affect properties and can be used to advantage.

1. 5. Homoginizer used in blend

The Homoginizer 501 is the most commonly used Homoginizer in the rubber industry. This improves the homogeneity of rubber blends with different polarity and viscosity. It imparts the to raw compounds better building tack and facilitates easy processing during mixing. They act as polymeric plasticizer and homogenizing agents\(^6\). They are particularly suitable for improving the dispersion of fillers and other rubber chemicals.
1.5.1. Specifications of Homoginizer 501

Table 1.5. Specifications\(^6\) of Homoginizer 501

<table>
<thead>
<tr>
<th>Composition</th>
<th>Polymerisates of unsaturated aromatic hydrocarbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>light-brown pellets</td>
</tr>
<tr>
<td>Density at 20 °C (g/cm(^3))</td>
<td>1.1</td>
</tr>
<tr>
<td>Ash %</td>
<td>0.1</td>
</tr>
<tr>
<td>Softening point (°C)</td>
<td>100 ± 5</td>
</tr>
<tr>
<td>Dosage (phr)</td>
<td>3-15</td>
</tr>
<tr>
<td>Solubility</td>
<td>Soluble in aromatics, partly soluble in benzene</td>
</tr>
<tr>
<td>German Food Legislation</td>
<td>Not approved</td>
</tr>
<tr>
<td>Storage Stability</td>
<td>At least 2 years</td>
</tr>
</tbody>
</table>
2. EXPERIMENTAL METHODS

2.1 INTRODUCTION
In order to prepare rubber blends for the experimental work, the under mentioned rubbers were selected. The blends were based on different combinations of Natural rubber (NR) with selected synthetic rubbers and their blend proportions have been selected depending on the demand that exit for such blends in the Rubber products manufacturing industry. The blends were prepared as per accepted standard methods; subsequent mixing, test piece moulding and testing procedures have been carried out according to ASTM and DIN standard procedures. The Technological and other specialized properties of prepared blends were compared with that of 100% NR in order to ascertain the compromise of improvements to the virgin rubber by the blended synthetic rubbers.

- Ribbed Smoked Sheet No. 3 (Natural Rubber)
- Nitrile Rubber of Medium Acrylonitrile Content (NBR - 33% ACN)
- Styrene Butadiene Rubber (SBR 1502)

2.2. COMPOUNDING PROCEDURE

a) Selection of the raw material:
As per the formulation different type of compounding ingredients that serve different vulcanizate properties were selected. The moisture level and purity of materials used in preparing the test compounds were taken into consideration in view of their effect on ultimate properties of the vulcanizates. Where ever possible standard materials from reputed rubber chemical manufacturers were utilized for this purpose.
b) Formulation
As shown in the Appendix B, different compound formulae were designed to carry out the experimental work. The compound based on 100% NR was taken as the reference sample for all purposes of comparative testing and evaluation of properties of blended samples against the reference.

c) Process:
In the preparation of compound sample batches, the mixing conditions such as batch size, temperature of mixing, machinery used, and time of mixing and mixing schedules were maintained at consistent levels for all test batches. The standard Tensile sheet mould conforming ASTM 412 to was used for the purpose of moulding vulcanize sheets for punching out Dumbbell test pieces to determine Stress/Strain properties.

2.2.1. Process of Mastication
The RSS sheet was cut into approximately 4” X 4” pieces for easy feeding into the Banbury. The mastication of NR was carried out by a Laboratory size Banbury machine. The Banbury rotor speeds, temperature of mastication and time of mastication were kept constant. The inside temperature of the Banbury was maintained around 85°C during mixing.

The undermentioned Banbury schedule indicates sequence of adding materials and mastication cycle time used in masticating NR to required plasticity level.

<table>
<thead>
<tr>
<th>step#</th>
<th>Description/Sequence</th>
<th>Time/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>RSS No.3</td>
<td>0</td>
</tr>
<tr>
<td>02</td>
<td>Pepton</td>
<td>2</td>
</tr>
<tr>
<td>03</td>
<td>Open the Ramp</td>
<td>4</td>
</tr>
<tr>
<td>04</td>
<td>Open the Ramp</td>
<td>8</td>
</tr>
<tr>
<td>05</td>
<td>Dump</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 2.1. Banbury Mastication Operation Schedule
2.2.2. Reference Sample Batch Preparation
Processing Equipments utilized to prepare the compound batch are:
- Lab Scale Banbury
- Lab scale Two Roll mill

**Table 2.2. Banbury Mixing Sequence**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Description/Adding Ingredient</th>
<th>Time/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Masticated RSS</td>
<td>0</td>
</tr>
<tr>
<td>02</td>
<td>CI Resin + ZnO+ Stearic Acid + 6PPD</td>
<td>1</td>
</tr>
<tr>
<td>03</td>
<td>C/Black 1/2 + Oil 1/2</td>
<td>3</td>
</tr>
<tr>
<td>04</td>
<td>C/Black 1/2 + Oil 1/2</td>
<td>6</td>
</tr>
<tr>
<td>05</td>
<td>Dump</td>
<td>8</td>
</tr>
</tbody>
</table>

**Table 2.3. Addition of Balance compounding Ingredients on the mixing Mill**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Description/Adding Ingredient</th>
<th>Time/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Add compound &amp; Band</td>
<td>0</td>
</tr>
<tr>
<td>02</td>
<td>Sulfur /Accelerator</td>
<td>1</td>
</tr>
<tr>
<td>03</td>
<td>Disperse with Roll making</td>
<td>3</td>
</tr>
<tr>
<td>04</td>
<td>Discharge</td>
<td>6</td>
</tr>
</tbody>
</table>

*Temperature on roll surface was maintained at 40 - 60 °C*

2.2.3. Blending of Rubbers

I. Instruments
- Lab Scale Banbury
- Lab Scale Two Roll Mill

II. Compounding Parameters & Cycle Time

A. In Banbury
Table 2.4. Cycle Time For Blend In Banbury

<table>
<thead>
<tr>
<th>Step#</th>
<th>Description/Adding Ingredient</th>
<th>Time/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Masticated RSS + SBR or BR or NBR</td>
<td>0</td>
</tr>
<tr>
<td>02</td>
<td>CI Resine + ZnO+ S/Acid + 6PPD</td>
<td>3</td>
</tr>
<tr>
<td>03</td>
<td>C/Black 1/2 + Oil 1/2</td>
<td>5</td>
</tr>
<tr>
<td>04</td>
<td>C/Black 1/2 + Oil 1/2</td>
<td>7</td>
</tr>
<tr>
<td>05</td>
<td>Dump</td>
<td>8</td>
</tr>
</tbody>
</table>

B. On Mill [Temperature = 40 °C – 60 °C]

Table 2.5. Cycle Time For Blend On Mill

<table>
<thead>
<tr>
<th>Step#</th>
<th>Description/Adding Ingredient</th>
<th>Time/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Add compound &amp; Band</td>
<td>0</td>
</tr>
<tr>
<td>02</td>
<td>Sulfur/Accelerator</td>
<td>1</td>
</tr>
<tr>
<td>03</td>
<td>Disperse with Roll making</td>
<td>3</td>
</tr>
<tr>
<td>04</td>
<td>Discharge</td>
<td>6</td>
</tr>
</tbody>
</table>

2.2.4. Blend compound Preparation with Homoginizer:

I. Instruments
   - Lab Scale Banbury
   - Lab Scale Two Roll Mill

II. Compounding Parameters & Cycle Time

Table 2.6. Cycle Time For Blend with Homoginizer In Banbury

<table>
<thead>
<tr>
<th>Step#</th>
<th>Description/Adding Ingredient</th>
<th>Time/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Masticated RSS + SBR or BR or NBR + Homoginizer</td>
<td>0</td>
</tr>
<tr>
<td>02</td>
<td>CI Resin + ZnO+ S/Acid + 6PPD</td>
<td>3</td>
</tr>
<tr>
<td>03</td>
<td>C/Black 1/2 + Oil 1/2</td>
<td>5</td>
</tr>
<tr>
<td>04</td>
<td>C/Black 1/2 + Oil 1/2</td>
<td>7</td>
</tr>
<tr>
<td>05</td>
<td>Dump</td>
<td>8</td>
</tr>
</tbody>
</table>
**B. On Mill** [Temperature = 40 °C – 60 °C]

*Table 2.7. Cycle Time For Blend with Homoginizer On Mill*

<table>
<thead>
<tr>
<th>Step#</th>
<th>Description/Adding Ingredient</th>
<th>Time/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Add compound &amp; Band</td>
<td>0</td>
</tr>
<tr>
<td>02</td>
<td>Sulfur/Accelerator</td>
<td>1</td>
</tr>
<tr>
<td>03</td>
<td>Disperse with Roll making</td>
<td>3</td>
</tr>
<tr>
<td>04</td>
<td>Discharge</td>
<td>6</td>
</tr>
</tbody>
</table>

2.3. **PRESSING FOR PREPARE THE TEST SPECIMENS**

2.3.1. **Test Sample Sheets for Tensile and Tear Strength tests**

**A. Blank Preparation**

I. **Dimension**

- 5 mm
- 12 cm
- 15 cm

![Figure 2.1 Blank for plane sheet](image)

II. **Blank Weight = 110 g**

**B. Pressing**

I. **Press & Mould Details**

- Mould Dimensions - 15.3 cm x 12 cm x 2 mm
- Mould Temperature - 150 °C
- Max Ram Pressure - 20 lb/in²
- Curing Time – 7 min
C. Cycle

*Table 2.8. Press Cycle for prepare tensile article*

<table>
<thead>
<tr>
<th>Step#</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Silicone was applied on Both side of Mold</td>
</tr>
<tr>
<td>02</td>
<td>Blank was Inserted in to Mould Cavity</td>
</tr>
<tr>
<td>03</td>
<td>The Pressure was Applied 20 lb/in²</td>
</tr>
<tr>
<td>04</td>
<td>Bumping (Air Released) 15 x 2</td>
</tr>
<tr>
<td>05</td>
<td>Curing</td>
</tr>
<tr>
<td>06</td>
<td>Discharge</td>
</tr>
</tbody>
</table>

2.3.2. Hardness button for Hardness test

A. Blank Preparation

I. Dimension

\[
\begin{align*}
2.5 \text{ cm} & \\
1.2 \text{ cm} & 
\end{align*}
\]

*Figure 2.2 Blank for Hardness Button*

II. Blank Weight = 30 g

B. Pressing

I. Press & Mould Details

a. Mould Dimensions - 2.5 cm diameter circle
b. Mould Temperature - 150 °C
c. Max Ram Pressure - 20 lb/in²
d. Curing Time - 7 min
C. Cycle

*Table 2.9. Press Cycle for prepare Hardness buttons*

<table>
<thead>
<tr>
<th>Step#</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Silicone was applied on Both side of Mold</td>
</tr>
<tr>
<td>02</td>
<td>Blank was Inserted in Mould Cavity</td>
</tr>
<tr>
<td>03</td>
<td>The Pressure was Applied 20 lb/in2</td>
</tr>
<tr>
<td>04</td>
<td>Bumping (Air Released) 15 x 2</td>
</tr>
<tr>
<td>05</td>
<td>Curing</td>
</tr>
<tr>
<td>06</td>
<td>Discharge</td>
</tr>
</tbody>
</table>

2.3.3. Abrasion Articles for Abrasion test

A. Blank Preparation

I. Dimension

![Blank Dimensions](image)

*Figure 2.3. Blank for Abrasion article*

II. Blank Weight = 60 g

B. Pressing

I. Press & Mould Details

a. Mould Dimensions - 10.5 cm x 2 cm x 1.5 cm  
b. Mould Temperature - 150 °C  
c. Max Ram Pressure - 20 lb/in2  
d. Curing Time – 7 min
C. Cycle

Table 2.10. Press Cycle for Abrasion article

<table>
<thead>
<tr>
<th>Step#</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Silicone was applied on Both side of Mold</td>
</tr>
<tr>
<td>02</td>
<td>Blank was Inserted in to Mould Cavity</td>
</tr>
<tr>
<td>03</td>
<td>The Pressure was Applied 20 lb/in2</td>
</tr>
<tr>
<td>04</td>
<td>Bumping (Air Released) 15 x 2</td>
</tr>
<tr>
<td>05</td>
<td>Curing</td>
</tr>
<tr>
<td>06</td>
<td>Discharge</td>
</tr>
</tbody>
</table>

2.4. TESTING METHODS

Seven testing methods were used to determine advantages of blended compounds comparison to the reference compound. All these tests were carried out according to International Standards.

Test methods

a) Tensile strength [ASTM D 412:1997]
b) Tear strength [ASTM D 624:1997]
c) Elongation @ break [ASTM D 412:1997]
d) Hardness [ASTM D 2240:1997]
e) Abrasion resistance [DIN 53516:1987]
f) Specific gravity (SG) [ASTM D 1298:1997]
g) Swelling resistance (Weight increase %) [ASTM D 471:1997]

2.4.1. Tensile strength (Tensile stress) test

\[
\text{Tensile strength} = \frac{\text{Load at break point} \: / \: \text{N}}{\text{Initial cross-sectional Area} \: / \: \text{mm}^2}
\]

Units of tensile strength: Mega pascal (MPa) = N / mm²
2.4.2. Elongation at break

\[
\text{Elongation at break} \% = \frac{\text{Extended length} \times 100}{\text{Original length}}
\]

Elongation is also called as tensile strain.

2.4.3. Tear Strength

\[
\text{Tear Strength} = \frac{\text{Maximum load at break point}}{\text{Thickness}} / \text{N} / \text{mm}
\]

Units of tear strength = N / mm

2.4.4. Aging test

- The specimens were aged in a Wallace aging oven at 100 °C for 48 hours and subsequently measured the tensile strength, elongation and tear strength.
- All specimens were conditioned for 2h at 23 °C before subjecting the samples for testing.

2.4.5. Preparation of test pieces for tensile Measurements

Five Specimens were cut from one sheet using the specimen cutter and accordingly 10 dumbbell & tear strength specimens samples were prepared.

I. Dumbbell tensile specimens
A. Apparatus
   - ASTM D 412 Standard Cutter

B. Conditioning Temperature – 23°C
C. Conditioning Time – 3 h
D. Sample Dimensions
I. Tear specimens
A. Apparatus
   - ASTM D 624 Standard Cutter
B. Conditioning Temperature – 23°C
C. Conditioning Time – 3 h
D. Sample Dimensions
   
   All dimensions relate to standard cutter size

2.4.6. Test speed of Tensometer
The speed of separation of jaws or the test speed was set at 500 mm/min for all thickness of specimens\textsuperscript{13}.

2.4.7. Procedure (Tensile strength & Elongation)
The thickness and width of specimens were measured. Then a specimen was placed in the tensile testing machine. Then the jaws were clamped uniformly & tightly. Then machine was set to motion (applied the load) and recorded the load (to measure stress) & elongation at the break. The ten test pieces were tested and got average reading\textsuperscript{13}.
2.4.8. **Procedure (Tear strength)**

The thickness of specimens were measured. Then a specimen was placed in the tensile testing machine. Then the jaws were clamped uniformly & tightly. Then machine was sat to motion (applied the load) and recorded the load at the break. The ten test pieces were tested and got average reading 13.

2.4.9. **Hardness Test [ASTM D 2240]**

This test method permits hardness measurements based on either initial indentation or indentation after a specified period of time, or both.

2.4.9.1. **Preparation of test pieces**

I. Hardness Button

A. Apparatus

- Standard mould for sample preparation

B. Conditioning Temperature – 23°C

C. Conditioning Time – 3 h

D. Sample Dimensions

All Dimensions relate to the standard

![Diagram](image.png)

*Figure 2.6 Hardness test pieces*

2.4.9.2. **Procedure**

The specimen was placed on a hard, horizontal surface. Then durometer was Hold in a vertical position with the point of the indentor at least 12 mm (0.5 in) from any edge of the specimen. The pressure was applied to the specimen as rapidly as possible. Then the scale reading was taken with in 5 sec and make one measurement at each of three of five different point.
2.4.10. Abrasion [DIN 53516]

I. Abrasion Button

A. Apparatus
   - DIN 53516 Standard Cutter

B. Conditioning Temperature – 23°C

C. Conditioning Time – 3 h

D. Sample Dimensions

All Dimensions, relate to Standard cutter Size

\[
\begin{align*}
A &= \frac{\Delta m \cdot S_0}{\rho \cdot S} \\
A &= \text{Abrasion volume loss in mm}^3 \\
\Delta m &= \text{Loss in Mass in mg} \\
\rho &= \text{density in g/cm}^3 \\
S_0 &= \text{Nominal abrasive grade (200 mg)} \\
S &= \text{Abrasive grade in mg}
\end{align*}
\]
2.4.10.1. Procedure:

The test was carried out at 23 °C and not earlier than 16 h after vulcanization. The three run was made with the standard elastomer, followed by a maximum of ten runs with one or more of the elastomers to be tested;

The test piece was weighed to the nearest 1 mg, then fixed firmly in the holder in such a way that a length of 2 mm protrudes from the opening. This length was controlled by mean of a gauge. The sledge and swivel arm were moved to the starting point and the automatic test run was started.

2.4.11. Specific Gravity (SG) [ASTM D 1298]

1. SG Button

A. Apparatus

- Wallace specific Gravity machine

B. Conditioning Temperature - 23°C

C. Conditioning Time - 3 h

D. Sample weight = 5 - 12 g

E. Sample Dimensions

![Figure 2.8. SG test pieces](image)

2.4.11.1. Procedure

- glass beaker was filled with distilled water
- A needle was fit and sinker to beam
- The level screw was adjusted with the sliding weight at the bottom of the long arm, until the pointer reads 1.00 accurately.
- The needle was removed from the arm and impaled the test piece on it.
- The needle was replaced, with test piece, on beam.
- The sliding weight was adjusted on the long arm, first with the major weigh and finally with the minor weight, until the pointer registers accurately with the mark 'A' on the back plate.
The test piece was raised the beam to lift, and placed the beaker of distilled water on the platform. The platform and beaker were raised until the piece is immersed.

The arm was gently released and read the specific gravity from the scale.

2.4.12. **Swelling Resistance (Weight increase %) [ASTM D 471]**

I. Sample

A. Apparatus
   - Standard cutter
B. Conditioning Temperature – 23°C
C. Conditioning Time – 3 h
D. Sample Dimensions
   - Thickness = 2 mm

![Figure 2.8. Immerse test pieces](image)

2.4.12.1. Procedure

- Each specimen were weighed in air to the nearest 1mg and immersed in the test tube containing 100 cm³ of the test liquid.
- Test liquids are,
  I. Caltex automatic Transmission fluid - Texamatic 1888
  II. Lockheed Super 105 D.O.T. 3 /SSB 9115 (break Oil)
  III. IRM – 903 ASTM Oil
  IV. Olina Vegetable Oil
  V. Lanka cutting Oil EP
- Sample was taken within 48 hour time interval and specimens were transferred into the cool clean portion of the test liquid for 30 to 60 min. then dipped the specimens quickly in acetone at room temperature, blotted lightly with filter paper free of lint and foreign material, and weighed immediately.
- Then swelling (Weight increased) % was calculated

\[
\text{Weight increase %} = \frac{\text{Final weight [W2]} - \text{Initial weight [W1]}}{\text{Initial weight [W1]}} \times 100
\]
2.4.13. Process Details

- The Rheometer values were studied as process parameters.
### Chapter 03

#### 3. Test Results

**Table 3.1. Sample No & The blend ratio**

<table>
<thead>
<tr>
<th>Sample No</th>
<th>01</th>
<th>02</th>
<th>03</th>
<th>04</th>
<th>05</th>
<th>06</th>
<th>07</th>
<th>08</th>
<th>09</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer ratio-NR:SE</td>
<td>100:0</td>
<td>80:20</td>
<td>70:30</td>
<td>60:40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polymer ratio-NR:NBR</td>
<td></td>
<td>80:20</td>
<td>70:30</td>
<td>60:40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compatibilizer</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>consist</td>
<td>consist</td>
</tr>
</tbody>
</table>

**3.1. Physical property**

**Table 3.2. Physical property test results**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Standard</th>
<th>Sample No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>01</td>
</tr>
<tr>
<td>Tensile Strength/MPa</td>
<td>ASTM D 412:1995</td>
<td>23.22</td>
</tr>
<tr>
<td>Elongation %</td>
<td>ASTM D 412:1995</td>
<td>461</td>
</tr>
<tr>
<td>Tear strength/Nmm(^{-1})</td>
<td>ASTM D 624:1995</td>
<td>141.78</td>
</tr>
<tr>
<td>Abrasion volume loss/mm(^3)</td>
<td>DIN 53516:1987</td>
<td>57</td>
</tr>
<tr>
<td>Hardness/shore A</td>
<td>ASTM D 2240:1997</td>
<td>72</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>ASTM D 1298:1997</td>
<td>1.15</td>
</tr>
</tbody>
</table>

**3.2. Modulus**

**Table 3.3. Modulus test results**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Sample No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>01</td>
</tr>
<tr>
<td>Modulus at 100%</td>
<td>3.74</td>
</tr>
<tr>
<td>Modulus at 300%</td>
<td>12.8</td>
</tr>
</tbody>
</table>
### 3.3. Swelling results [Weight increase%]

**Table 3.4. Swelling results**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Sample No</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 48 hours</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td>01 02 03 04 05 06 07 08 09 10</td>
</tr>
<tr>
<td>Swell % in ASTM Oil</td>
<td>41.86 38.52 32.14 35.02 29.28 24.33 17.72 23.25 20.29 12.56</td>
</tr>
<tr>
<td>Swell % in Cooking Oil</td>
<td>18.38 15.67 13.59 12.99 15.42 10.58 8.55 12.46 7.86 5.98</td>
</tr>
<tr>
<td>Swell % in Break Oil</td>
<td>1.44 0 1.11 0.84 0.00 2.57 2.42 0.49 0.80 1.58</td>
</tr>
<tr>
<td>Swell % in Transmission Oil</td>
<td>35.02 27.37 27.64 26.04 24.1 20.21 15.01 21.25 15.16 12.58</td>
</tr>
<tr>
<td>Swell % in Cutting Oil</td>
<td>29.99 26.97 22.92 21.36 9.37 9 8.33 7.14 7.54 5.57</td>
</tr>
<tr>
<td>Swell % in Petrol</td>
<td>124.86 124.5 123.6 122.8 101.22 87.29 74.32 89.56 68.25 57.89</td>
</tr>
</tbody>
</table>

### 3.4. Aging test results

**Table 3.5. aging test results**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Sample No</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 24h aged @ 100 °C</td>
<td>01 02 03 04 05 06 07 08 09 10</td>
</tr>
<tr>
<td>Tensile Strength/MPa</td>
<td>10.14 10.71 11.47 12.69 10.08 12.17 13.62 14.78 15.02 18.01</td>
</tr>
<tr>
<td>Elongation @ break %</td>
<td>200 150 135 125 125 125 125 180 175 170</td>
</tr>
<tr>
<td>Tear strength/Nmm-1</td>
<td>67.72 65.9 57.44 50.8 60.7 69.52 74.5 71.54 80.45 85.42</td>
</tr>
</tbody>
</table>

### 3.5. Results of processability

**Table 3.6. Processability test results**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Sample No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>01 02 03 04 05 06 07 08 09 10</td>
</tr>
<tr>
<td>MH</td>
<td>65.86 75.52 74.22 76.64 65.75 58.12 52.57 61.52 55.68 50.32</td>
</tr>
<tr>
<td>ML</td>
<td>12.85 9.9 9.04 9.77 7.73 8.84 8.53 9.63 10.23 9.9</td>
</tr>
<tr>
<td>Ts2</td>
<td>0.94 0.82 0.77 0.81 0.52 0.57 0.53 0.64 0.65 0.63</td>
</tr>
<tr>
<td>Tc90</td>
<td>2.1 1.86 1.9 1.97 1.39 1.19 1.26 1.36 1.28 1.21</td>
</tr>
<tr>
<td>Plasticity No</td>
<td>30 30 29 31 26 31 30 23 26 27</td>
</tr>
</tbody>
</table>
3.6. Relationship between polymer ratio vs. Tensile Strength

Composition vs Tensile strength

3.7. Relationship between polymer ratio vs. Tear Strength

Composition vs Tear strength
3.8. Relationship between polymer ratio vs. Elongation at the break

**Composition vs. Elongation at the break**

- Elongation at the break % for NR
- Elongation at the break % for NBR

![Graph showing elongation at the break for NR and NBR compositions](image)

3.9. Relationship between polymer ratio vs. Abrasion loss

**Composition vs Abrasion Volum loss**

- Abrasion loss/mm³ for NR
- Abrasion loss/mm³ for NBR

![Graph showing abrasion loss for NR and NBR compositions](image)
3.10. Relationship between polymer ratio vs. Swelling resistance for ASTM Oil

Composition vs. Swelling resistance for ASTM Oil

3.11. Relationship between polymer ratio vs. Swelling resistance for Cooking Oil

Composition vs Swelling resistance for Cooking Oil

35
3.12. Relationship between polymer ratio vs. Swelling resistance for Break Oil

**Composition vs. Swelling resistance for Break Oil**

- Swell % in Break Oil for NR: SBR
- Swell % in Break Oil for NR: NBR
- Swell % in Break Oil for NR: NBR [Homo]

3.13. Relationship between polymer ratio vs. Swelling resistance for Transmission Oil

**Composition vs. Swelling resistance for Transmission Oil**

- Swell % in Transmission Oil for NR: SBR
- Swell % in Transmission Oil for NR: NBR
- Swell % in Transmission Oil for NR: NBR [Homo]
3.14. Relationship between polymer ratio vs. Swelling resistance for Cutting Oil

Composition vs. Swelling resistance for Cutting Oil

3.15. Relationship between polymer ratio vs. Swelling resistance for Petrol

Composition vs Swelling resistance for Petrol
3.16. Relationship between polymer ratio vs. Modulus at 300%

Composition vs. Modulus at 300%

3.17. Relationship between polymer ratio vs. Tensile Strength after 24 h aged @ 100 °C

Composition vs Tensile Strength after 24 h aged @ 100 °C
3.18. Relationship between polymer ratio vs. MH value in Rheograph

Composition vs. MH value in Rheograph

MH /dNm for NR : SBR
MH /dNm for NR : NBR [Homo.]

3.19. Relationship between polymer ratio vs. Scorch time [Ts2]

Composition vs. Scorch time [Ts2]

Scorch safety [Ts2] /min for NR : SBR
Scorch safety [Ts2] /min for NR : NBR [Homo.]
3.20. Relationship between polymer ratio vs. Plasticity Number

Composition vs. Plasticity Number

- Plasticity Number for NR: SBR
- Plasticity Number for NR: NBR
- Plasticity Number for NR: NBR [Homo.]
Chapter 4

4. Discussion, Conclusion & Further works

4.1. Discussion of the results

4.1.1. Basic background of work study and results

The whole project was based on making synthetic and Natural rubber blends by changing their composition according to the well organized procedure. Then achieved different kind of properties which are important in manufacturing rubber products to meet special requirements needed by customer satisfaction.

In this study, 3 different elastomers which are widely used in the rubber manufacturing industry were selected. The proportion of the polymer in the blend was changed and observed and study about their performance how can satisfy the customer requirements based on their application. In these days the principle customers request some products from manufacture with physical property or any other technical parameter which should be included in products because the majority of principal customers are knowledgeable in the field. So, In this study we have found that we can get completely or partially different properties by changing polymer composition in the formulation. In this study I was strongly concerned about processability parameters of rubber compounding such as MH, Ts2, Plasticity, etc.. Because ultimately we have to concern about profitable & quality in the end products. So we should always maintain very good production rate that mean we have to ensure very good productivity.

Considering what happen to the physical property, technical detail and processability parameters when the polymer composition or polymer ratio in the different kinds of blends is changed.
4.1.2. Change of the Tensile Strength and modulus with polymer ratio:

When the results are observed very carefully, we can see the reduction of the tensile strength and modulus with increase of the synthetic rubber percentage in blend. This is mainly due to their structure property and compatibility. But when considering the same blend with Homoginizer specially NR: NBR blend was shown opposite results such as when the synthetic rubber amount is increased we can see an increment of strength. So this is mainly due to the action of the Homoginizer & if we can make a blend with better homogeneity, we can expect very good strength properties.

4.1.3. Change of the Elongation with polymer ratio:

The elongation is a evidence for flexibility of the product. We can clearly observe from the results that the elongation is reduced when the ratio of the synthetic polymer in the blend is increased. There was no significant different of the change in the elongation after adding the homoginizer. However this is good evidence to control the flexibility of the product because some customers request low flexibility products and some customers request very high flexible products. So this results is very very useful to product design such as for make a suitable formula.

4.1.4. Change of the Tear strength with polymer ratio:

Tear strength is one of the good parameters to get an idea about resistance to usage. That mean some rubber product may tear off while it use in some places. As well this property is a very good processability parameter also because some of the compression moulding products will tear off or broken while removing the product from mould. This tear property changing pattern is much similar to tensile strength variation. That means when the synthetic polymer ratio is increased without adding any Homoginizer or compatibilizer in to rubber blend it shows a reduction of tear strength than the 100% NR compound. But when we incorporate the Homoginizer into this blend we can see opposite results.
4.1.5. Change of the Abrasion loss with polymer ratio:

The abrasion loss is one of the important parameters to find out the durability of rubber products when it is in use under abrasive environment. By studying the results we can clearly visualize the abrasion loss was reduce [increase the abrasion resistance] when we increase the SBR amount in NR: SBR blend compare with the 100% NR compound. i. e. mean we can get very good abrasion resistant products by increasing the amount of SBR in NR: SBR Blend. But we have to consider about cost factor of the product because at these days SBR is comparatively more expensive than the NR.

But when we consider NBR: NR blend it shows an increase in abrasion volume loss [decrease of the abrasion resistance] due to adding of the NBR in to 100% NR compound. But from the results we can observe a reduction of abrasion volume loss with increase of NBR percentage in NBR: NR blend. However it is higher than 100% NR compound, but when the NBR amount is increased up to 40% with homoginizer the abrasion loss is compatible to the 100% NR product level. But at this stage this product is more expensive than 100% NR product due to very high price of NBR and homoginizer. So we should carefully consider about product cost with these combinations.

4.1.6. Change of the Swelling properties with polymer ratio

Rubber products are widely used in various industries these days. So these rubber products most of the time contact with different kinds of oil which are used in these Industries. If rubber products start to sell due to contact with oil it is a very big problem to further use with its' given original performance. Therefore we have to very much consider about swelling resistance of rubber products under different kind of oils.

When the results are observed very carefully we can see an improvement of oil resistance [reduction of swelling percentage] when we increase the SBR amount or NBR amount in NR: SBR or NR: NBR blends than 100% NR compound. But NR: NBR blends show much better resistance than the NR:SBR blend. But the break oil shows some different results than other oils due to their structural properties. The 100% NR compound gives
excellent resistance to break oils. When we increase the NBR amount in the NR:NBR blend, the break oil resistant was cam down than in case of the 100% NR compound.

The NR:NBR blends with Homoginizer show better oil resistance than the NR:NBR blend without Homoginizer because of that improved mixing at molecular level made due to use of Homoginizer. So we have to consider customer requirement specially where he going to apply this product, which type of oils will contaminate and how long it contaminate per day, according to this information we have to decide what degree it should be resistant so than we can select suitable blend type.

4.1.7. Change of the Aging properties with polymer ratio:
The aging properties are very important to predict how long a product can be use under hot or cold environment as well as how it is resistant to hot environment. So this parameter is very important because most of the industrial application are subjected to open environment.

When observe the aging results , it was improved when increase the amount of synthetic polymers in blend. The NR: NBR blend with Homoginizer has show best age resistant than other blends and the resistant was increase with increase of NBR component. So according to customer requirement we can select suitable blend.

4.1.8. Change of the Process parameters with polymer ratio:
Process parameter was very important to us in order to get proper idea about productivity of the some product. This is very very important to make the final decision about end product cost.

When study the result very carefully we can see reduction of MH value of Rheo graph when increase the NBR % in NR: NBR blend. So it will effect to build up low resistant against to the pressure apply from compression moulding machine to mould the product. It will helpful to make the product very easily. As we as it was give some softness at the hot stage that mean before release the product from mould. So it is also helpful to remove the product from mould. But too low value and too high value is not suitable as well it
was depend on type of the mould and design of the product. The NR: SBR blend shown opposite results than NR: NBR Blend.

When consider the Ts2 value it has given us clear indication about process safety of the compound. If some compound gave very good process safety we can minimize damage occur while process specially mixing and moulding. And it will be very helpful to increase the storing time of the compound. When observe the results we can seen reduction of Ts2 with increase of synthetic rubber component in blend. Specially consider the NR:NBR blend it was shown reduction of Ts2 with increase of NBR amount in blend than 100% NR compound. But SBR:NR blend not shown much more reduction than NR: NBR Blend. So when we set the parameter of process condition that mean mixing time milling time, Pressuring time, mixing temperature, milling temperature and etc.. should be very careful with this Ts2 value. That mean when use high NBR content blend we have to maintain the low mixing temperature and quick pressuring patterns. So this is very important to get high productivity with minimum rejected % of the product.

When increase the synthetic polymer in their blend we can seen increment of the plasticity number but when consider the NBR:NR blend with Homoginizier it was shown relatively low plasticity than 100% NR compound. Because of that Homoginizier was acted as very good dispersing and softening agent. But plasticity number also gone up when increase the NBR component in this NR:NBR blend with Homoginizier . The low plasticity number is very helpful to make low weight product with minimum rejection. This parameter is very important to compression moulding product. If we use compound with high plasticity number we have to increase the pressure of the press otherwise it will be effect to make high weight or damaged product. So this plasticity number is very important process parameter.
4.2. Conclusion

When study results and observation of the physical properties and process it is going to be vary according to the composition of the blend in the formulation. We can get more benefits when we use blended two or more compound instead of normal single polymer compound. We can achieve most of the customer requirement by changing the polymer ratio and polymer types in the blend. The most of the rubber blend show synergistic effect and hence we can full fill the customer requirement. We can increase the oil resistant of any product by making the product with NBR: NR blend compound instead of NR Compound and when increase the NBR content in blend it was shown increment of oil resistant for the most of petroleum based oils. The Homoginizer was help to get proper blend and hence improve the properties of final product as well it was helpful to improve the process also.

4.3. Further Work

I. Can study the blooming resistant of the blend by using different type of blends.

II. We can investigate fire resistant properties of different kind of blend.

III. Can start good research based on conductive properties of product by using different type of blend.

IV. Can investigate incorporation efficiency of filler in rubber compound by using different blend hence can be find out economic advantages of rubber blends.

V. We can find out energy consumption of different blend in their processing stage, hence we can investigate economic advantage of the rubber blends.
References


11. Annual Book Of ASTM Standards, 9, Rubber, 1997, 09.01


APPENDIX-A

A1. Monsanto 500 Tensile testing machine

A1.1. Manu. Details: UNITED KINGDOM
SERIAL NO: 1187
MODEL NO: T 500
SERIAL NO: 481
LOAD CELL CAPACITY: 5000 N & 50 Kg

AMPS: 50/60 HZ
POWER 900 VA MAX.

A1.3. Recording unit: Printing papers Alpha N210 – 184

Figure A1: Monsanto 500 Tensile testing machine
A2. Shore A Hardness Tester

MADE IN INDIA
ASTM D 2240
DIN 53 505

Figure A2: Shore A Hardness tester

A3. Monsanto Rheo meter 100

Figure A3: Fully computerized Monsanto Rheo meter 100
A4. ABRASION TESTER.

A4-1. Manu. Details: VEB THUTRINGER INDUSTRIES WORK RAUENSTEIN

A4-2. Model Details: TYPE: APGI
GERATE Nr: 613.10
FABRIKET Nr: 064/68
DIN Abration Paper

250 V
12 A
50 Hz

Figure A4: DIN Abrasion tester
A5. WALLACE SPECIFIC GRAVITY BALANCE.

CAT – REF 13
H.W. WALLACE 7 CO Ltd
St. JAMEES Rd
CROYDON – ENGLAND  CR 92 HR
MADE IN ENGLAND.

Figure A5: Wallace Direct Reading Specific Gravity Balance

A6. WALLACE AGING OVEN.

A6-1. Manu. Details: REF 078
SERIAL NO 085057/3
MADE IN ENGLAND.
A6-2. Power Supply: VOLTS – 230 1/Ph 50 Hz
WATTSS 2400

Figure A6: Wallace Aging oven
A7. LABORATORY BANBURY

A7-1. Manu. Details: DEVID BRIDGE & COMPANY
Castetion Rochdale
England.
Engineers to the Rubber & Plastic Industries.
MC No 57.1111
Date 20.01.58

A7-2. Motor:

A. Type: 90396/6UR RHL744.4
rpm = Front: 72
Back: 60

B. Speed: Operator side =rpm 60
Front side =rpm 70

Figure A7: Laboratory Banbury
A8. LABORATORY TWO ROLL MILL.

VICKERS RUWOLT

A8-1 Manu. Details: RPM = 1:1 = Operator Side 27
Front side 27
1:1.4 = Operator Side 27
Front side 37

A8-2 Motor: Australian Electrical Industries (Pvt) Ltd.
AUSTRALIA.
TYPE: AKFE 944
HP: 7.5 CMR - 55 Co Volts 415
RPM: 1450
AMPS: 10.2
CYCLES: 50
N.P. 12
B.S. 2613; 1955

Figure A8: Laboratory Mill
A9. LABORATORY PRESS

A9-1 Manu. Details: WABASH – HYDRAULIC PRESS
Model: 25.12.4T MBX
Serial No: 5827
WABASH METAL PRODUCTS Company.
INC.
Hydraulic Division,
WABAST, INDIANA.

Heater Watts: 4000

A9-3 Motor details: Motor H.P.: 01
Motor Amps: 3.6

A9-4. Pressing Details: Compression Cylinder Bore & Stock: 5x6
Force (Tons) Compr. 25

Figure A9: WABASH Hydraulic Press
### Typical Formulation

#### B1

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**TOTAL** 185.400 1000.000 103792.48

**COST PER KG** 109.26

#### B2

**Formula Type** 80:20-NR:SBR

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**TOTAL** 186.100 1000.000 103614.81

**COST PER KG** 108.55

#### B3

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**TOTAL** 186.200 1000.000 103118.72

**COST PER KG** 108.55

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**B1**
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### Formula Type: 80:20-NR:NBR

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### Formula Type: 70:30-NR:NBR

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COST PER KG

109.31

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COST PER KG

113.94

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<tr>
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<tr>
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<td>5.285</td>
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<tr>
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<td>5.285</td>
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<td>CIR Resin</td>
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<td>5.285</td>
<td>180.00</td>
<td>951.37</td>
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<tr>
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<td>15.856</td>
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<tr>
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<td>13.214</td>
<td>23.00</td>
<td>303.91</td>
</tr>
<tr>
<td>13</td>
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<td>1.566</td>
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<tr>
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<td>7.400</td>
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COST PER KG

113.65
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<th>ITEM NAME</th>
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<th>RATE</th>
<th>VALVE</th>
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<tr>
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<td>60.000</td>
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<td>688.79</td>
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<td>6PPD</td>
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<td>362.91</td>
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<td>2047.83</td>
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<td>15.856</td>
<td>69.00</td>
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<td>13.214</td>
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<td>303.91</td>
</tr>
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**TOTAL**

<table>
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<tr>
<th>ITEM NAME</th>
<th>PHR</th>
<th>WEIGHT</th>
<th>RATE</th>
<th>VALVE</th>
</tr>
</thead>
<tbody>
<tr>
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</table>

**COST PER KG**

|           |       |         |        | 113.42  |
APPENDIX-C
Rheometer Test Report

C1. Rheometer test report of the Reference [Sample No : 01 ]

Report Date: 03-10-2004
Compound ID: Reference-R2
Upper Die Temperature set point : 180.0 °C
Lower Die Temperature set point : 180.0 °C

<table>
<thead>
<tr>
<th>Test ID.</th>
<th>MH</th>
<th>ML</th>
<th>Tc90</th>
<th>Ts2</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI Limit</td>
<td>55.00</td>
<td>10.00</td>
<td>1.40</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>LO Limit</td>
<td>35.00</td>
<td>5.00</td>
<td>0.70</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>c3</td>
<td>65.85 f+</td>
<td>12.85 f+</td>
<td>2.10 f+</td>
<td>0.94 f+</td>
<td><em>Fail</em></td>
</tr>
</tbody>
</table>
C2. Rheometer test report of Sample No: 02

Report Date: 03-10-2004
Compound ID: 80:20-NR:SBR
Upper Die Temperature set point: 180.0 °C
Lower Die Temperature set point: 180.0 °C

<table>
<thead>
<tr>
<th>Test ID</th>
<th>MH</th>
<th>ML</th>
<th>Tc90</th>
<th>Ts2</th>
<th>Pass/Fa</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI Limit</td>
<td>55.00</td>
<td>10.00</td>
<td>1.40</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>LO Limit</td>
<td>35.00</td>
<td>5.00</td>
<td>0.70</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>TEST-01</td>
<td>75.52 f+</td>
<td>9.90</td>
<td>1.86 f+</td>
<td>0.82</td>
<td>&quot;Fail&quot;</td>
</tr>
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</table>
C3. Rheometer test report of Sample No : 03

Report Date: 03-10-2004
Compound ID: 70:30-NR:SBR
Upper Die Temperature set point : 180.0 °C
Lower Die Temperature set point : 180.0 °C

![Rheometer test graph]

<table>
<thead>
<tr>
<th>Test ID</th>
<th>MH</th>
<th>ML</th>
<th>Te90</th>
<th>Ts2</th>
<th>Pass/Fa</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI Limit</td>
<td>55.00</td>
<td>10.00</td>
<td>1.40</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>LO Limit</td>
<td>35.00</td>
<td>6.50</td>
<td>0.70</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>TEST-03</td>
<td>74.22 f+</td>
<td>9.04</td>
<td>1.90 f+</td>
<td>0.77</td>
<td>&quot;Fail&quot;</td>
</tr>
</tbody>
</table>
C4. Rheometer test report of Sample No: 04

Report Date: 03-10-2004
Compound ID: 60:40-NR:SBR
Upper Die Temperature set point: 180.0 °C
Lower Die Temperature set point: 180.0 °C

<table>
<thead>
<tr>
<th>Test ID.</th>
<th>MH</th>
<th>ML</th>
<th>Tc90</th>
<th>Ts2</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI Limit</td>
<td>55.00</td>
<td>10.00</td>
<td>1.40</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>LO Limit</td>
<td>35.00</td>
<td>6.50</td>
<td>0.70</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>TEST-04</td>
<td>76.64 f+</td>
<td>9.77</td>
<td>1.97 f+</td>
<td>0.81</td>
<td>&quot;Fail&quot;</td>
</tr>
</tbody>
</table>
C5. Rheometer test report of Sample No: 05

Report Date: 05-10-2004
Compound ID: 80:20-NR:NBR
Upper Die Temperature set point: 180.0 °C
Lower Die Temperature set point: 180.0 °C

<table>
<thead>
<tr>
<th>Test ID.</th>
<th>MH</th>
<th>ML</th>
<th>Tc90</th>
<th>Ts2</th>
<th>Pass/Fail</th>
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</thead>
<tbody>
<tr>
<td>HI Limit</td>
<td>60.00</td>
<td>10.00</td>
<td>1.40</td>
<td>0.90</td>
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</tr>
<tr>
<td>LO Limit</td>
<td>35.00</td>
<td>6.50</td>
<td>0.70</td>
<td>0.50</td>
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<tr>
<td>TEST-05</td>
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<td>7.73</td>
<td>1.39</td>
<td>0.52</td>
<td>&quot;Fail&quot;</td>
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C6. Rheometer test report of Sample No : 06

Report Date: 05-10-2004
Compound ID: 70:30-NR:NBR
Upper Die Temperature set point: 180.0 °C
Lower Die Temperature set point: 180.0 °C

![Graph showing torque vs time with data points]

<table>
<thead>
<tr>
<th>Test ID</th>
<th>MH</th>
<th>ML</th>
<th>Tc90</th>
<th>Ts2</th>
<th>Pass/Fa</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI Limit</td>
<td>60.00</td>
<td>10.00</td>
<td>1.40</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>LO Limit</td>
<td>35.00</td>
<td>6.50</td>
<td>0.70</td>
<td>0.50</td>
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<tr>
<td>TFST-S</td>
<td>58.12</td>
<td>8.84</td>
<td>3i 1.19</td>
<td>0.57</td>
<td>Pass</td>
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</table>
C7. Rheometer test report of Sample No: 07

Report Date: 05-10-2004
Compound ID: 60:40-NR:NBR
Upper Die Temperature set point: 180.0 °C
Lower Die Temperature set point: 180.0 °C

<table>
<thead>
<tr>
<th>Test ID.</th>
<th>MH</th>
<th>ML</th>
<th>Tc90</th>
<th>Ts2</th>
<th>Pass/Fa</th>
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</thead>
<tbody>
<tr>
<td>HI Limit</td>
<td>60.00</td>
<td>10.00</td>
<td>1.40</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>LO Limit</td>
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<td>8.53</td>
<td>1.26</td>
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</table>

C-07
C8. Rheometer test report of Sample No: 08

Report Date: 10-10-2004
Compound ID: 80:20-NR:NBR[Homo.]
Upper Die Temperature set point: 180.0 °C
Lower Die Temperature set point: 180.0 °C

<table>
<thead>
<tr>
<th>Test ID.</th>
<th>MH</th>
<th>ML</th>
<th>Tc90</th>
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</thead>
<tbody>
<tr>
<td>LO Limit</td>
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<td>0.70</td>
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<tr>
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<td>0.90</td>
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</tr>
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<td>1.36</td>
<td>0.64</td>
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C9. Rheometer test report of Sample No: 09

Report Date: 10-10-2004
Compound ID: 70:30-NR:NBR[Homo.]
Upper Die Temperature set point: 180.0 °C
Lower Die Temperature set point: 180.0 °C

<table>
<thead>
<tr>
<th>Test ID</th>
<th>MH</th>
<th>ML</th>
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<th>Ts2</th>
<th>Pass/Fa</th>
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</thead>
<tbody>
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C10. Rheometer test report of Sample No: 10

Report Date: 10-10-2004

Compound ID: 60:40-NR:NBR[Homo.]

Upper Die Temperature set point: 180.0 °C
Lower Die Temperature set point: 180.0 °C