Chapter 3

MECHANICAL AND RHEOLOGICAL BEHAVIOUR OF POLYSTYRENE/POLYDIENE BLOCK COPOLYMERS
Of the various classes of thermoplastic elastomers, those based on triblock copolymers of polystyrene/polydienes or polystyrene/hydrogenated polydienes are the largest and one of the earliest to be investigated.\textsuperscript{1} The styrenic thermoplastic elastomers represent a class of materials introduced during 1965. They have many of the physical properties of vulcanized rubbers such as softness, flexibility, resilience but are processed as thermoplastics.\textsuperscript{2,3} Styrenic thermoplastic elastomers have the basic structure Poly(styrene-b-butadiene-b-styrene) (SBS), poly(styrene-b-isoprene-b-styrene) (SIS) or the one with a hydrogenated central ethylene-butylene (EB) block poly-(styrene-b-ethylene-butylene-b-styrene) (SEBS). The most important feature of this structure is that they are phase separated systems.\textsuperscript{4-7} They have multiphase compositions in which the phases are chemically bonded by block copolymerization. At least one phase is a styrenic polymer that is hard at room temperature but becomes fluid when the polymer is heated, whereas another phase is a softer material that is rubber like at room temperature.
Styrenic thermoplastic elastomers are characterized by phase separated structures quite unlike the corresponding random copolymers in which the two phases polystyrene and polydiene retain many of the properties of the respective homopolymers. For example, such block copolymers have two glass transition temperatures ($T_g$) characteristic of the respective homopolymers whereas the equivalent random copolymers have a single intermediate $T_g$. While the incompatibility between the styrene and butadiene blocks have been identified as beneficial as far as the physical properties are concerned it has been shown to influence the processability adversely.  

The physico-mechanical properties of the styrenic block copolymers arise from the selection of the terminal and centre blocks. The terminal hard segments determine the upper service temperature while the elastomer segment control many of the properties such as thermal and oxidative stability, elastic nature etc.

Hysteresis loss under repeated deformation is of great importance with materials showing both thermoplastic and elastomeric behaviour. These studies are important since the elastomeric property of these materials can be demon-
strated more dramatically in a hysteresis curve than in a stress-strain curve.

1. Mechanical Properties of SIS, SBS and SEBS

Experimental

Commercially available SBS, SIS and SEBS were used for the present investigation. All the samples were further stabilized by 1% amine type antioxidant (Vulkanox 4010 NA) since it was found to be more efficient than phenolic types by Brabender dynamic stability test. Melting and homogenization of SIS and SBS were done at 150°C and SEBS at 200°C on a Brabender plasticorder model PL3S at 30 rpm. The homogenized material was compression moulded at the corresponding melting temperatures in an electrically heated laboratory hydraulic press. The mould was then water cooled and the compression moulded sheets taken out. After 24 hours, dumbbell shaped test pieces were punched out of this sheet using standard die.

Tensile testing of the test pieces was done on a Zwick Universal testing machine model 1445 at 25°C and at a crosshead speed of 500 mm/min.
Hysteresis studies were also done on the Universal testing machine at a crosshead speed of 50 mm/min and at a strain level of 50%. Hysteresis loss was determined by measuring the area under extension and retraction curves.

Results and Discussion

Fig. 3.1 shows the stress-strain curves of the tri-block copolymers. SIS having a styrene content of only 14% gives typically a rubber like elongation curve whereas SBS and SEBS having higher styrene content give plastic deformation to some extent. SEBS shows an inflection point or knee and has the maximum tensile strength among the three thermoplastic elastomers. SBS shows a sharp yield point indicating a close similarity in behaviour with plastics. Table 3.1 shows the tensile strength, elongation at break, hardness and specific gravity of these thermoplastic elastomers. The ultimate values are comparable to the properties of vulcanized rubbers.

Hysteresis loss for the three thermoplastic elastomers at 50% strain is shown in Fig. 3.2. The nature of the hysteresis loops is different for each polymer. SBS exhibits highest hysteresis loss compared to the other two, when the applied strain is beyond the yield point. The retraction curves for all the polymers do not reach the
Fig. 3.1 Tensile stress-strain curves of SIS, SBS and SEBS.
Table 3.1 Physical properties of triblock thermoplastic elastomers

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Specific gravity</th>
<th>Tensile strength (MPa)</th>
<th>Elongation at break (%)</th>
<th>Hardness (Shore A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIS</td>
<td>0.92</td>
<td>15.5</td>
<td>1200</td>
<td>40</td>
</tr>
<tr>
<td>SBS</td>
<td>0.94</td>
<td>18.3</td>
<td>800</td>
<td>68</td>
</tr>
<tr>
<td>SEBS</td>
<td>0.91</td>
<td>22</td>
<td>500</td>
<td>72</td>
</tr>
</tbody>
</table>

Table 3.2 Hysteresis behaviour of triblock thermoplastic elastomers

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Hysteresis loss (J) at</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I cycle</td>
</tr>
<tr>
<td>SIS</td>
<td>0.544</td>
</tr>
<tr>
<td>SBS</td>
<td>0.744</td>
</tr>
<tr>
<td>SEBS</td>
<td>0.298</td>
</tr>
</tbody>
</table>
Fig. 3.2 Hysteresis curves of SIS, SBS and SEBS at 50% strain level
starting point indicating some plastic deformation. The hysteresis losses during the first three cycles are given in Table 3.2.

2. Rheological Behaviour of SBS and SIS

A striking feature of styrenic thermoplastic elastomers is their very high melt viscosities. The incompatibility between the styrene and the elastomer phase leads to higher melt viscosities in styrenic thermoplastic elastomers. While the incompatibility between the hard and soft segments has been identified as beneficial for good physical properties, it influences the processability adversely. Melt viscosity increases with the degree of incompatibility as seen from the behaviour of SEBS thermoplastic elastomer.

The melt viscosities of SBS and SIS block copolymers are found to be much higher than those of either polybutadiene, polyisoprene or random copolymers of styrene and butadiene of equivalent molecular weights. There have been only very few systematic studies in characterizing the rheological behaviour of these thermoplastic elastomers. The behaviour of these materials under different shear and temperatures have been reported as highly non-Newtonian and even Newtonian.
The complex nature of the melt seems to stem from the persistence of a two phase structure in the melt. This study on SBS and SIS thermoplastic elastomers have been taken up with the intention of throwing more light on their rheological behaviour.

**Experimental**

Melt rheological measurements were made using a capillary rheometer (Göttfert Viscotester 1500) using a capillary die of circular cross section (L/D ratio 30mm/l mm) and flat at the entrance region and also using a Brabender plasticorder model PL3S equipped with roller mixing heads at different temperatures and shear rates.

**Results and Discussion**

Shear stresses and shear rates at the wall were calculated using the expression for Newtonian flow in cylindrical capillaries

\[ \tau_w = \frac{\Delta P \cdot R}{2L} \]

\[ \gamma_w = \frac{40}{\tau R^3} \]

where \( \Delta P \) is the pressure drop across the capillary of radius
R and length L. The apparent viscosity at each shear rate was calculated according to the equation

$$\eta = \frac{\tau_w}{\gamma_w}$$

The power law exponent \( n \) was calculated using the relation

$$\tau_w = K_0 (\gamma_w)^n$$

where \( K_0 \) is a constant.

The temperature dependence of the viscosity was expressed in terms of an Arrhenius equation

$$\eta = Ae^{E/RT}$$

where \( E \) is the activation energy for viscous flow, \( R \) the gas constant, \( T \) the absolute temperature and \( A \) is a constant. The activation energy was calculated from plots of \( \eta \) vs. \( 1/T \).

The Brabender plasticorder (torque rheometer) has also been used to study the rheological behaviour of polymer
melts under processing conditions.\textsuperscript{15-17} It was shown that the relationship obtainable from this instrument

\[ M = C S^a \]

where \( M \) is the torque, \( S \), the rpm (revolutions per minute) and \( C \) and \( a \) are constants, resembles the familiar power law behaviour\textsuperscript{16-18}

\[ \eta = K \gamma^n \]

and hence could be used for calculation of the power law index \( n \).

Fig.3.3 shows the variation of viscosity with shear rate of SBS in the range of shear rates generally encountered in most polymer processing operations. The figure clearly shows the highly non-Newtonian behaviour of the melts. As expected, the curve lowers with increasing temperature which is a general feature of polymer melts due to the increased mobility of the polymer molecules at higher temperatures. The viscosities increase as the shear is decreased and apparently approach infinite values at low shear rates, particularly at lower temperatures. This could be attributed to the existence of a two phase structure in the melt.
Fig. 3.3 Variation of viscosity with shear rate of SBS at different temperatures.
Fig. 3.4 shows the plot of shear stress versus shear rate of SBS at 160 and 180°C. It is interesting to note that each curve can be represented as two straight lines. The two straight lines may represent distinct flow behaviour. The initial straight line may be the flow region where poly-styrene domains act as reinforcing filler in the rubber matrix. The flow involves the transfer of hard blocks through the polydiene phase. This additional energy required for flow accounts for the higher melt viscosities. The slope of the initial line, the power law index, when this type of flow prevails is comparable to the value of filled rubbers.¹⁹,²⁰

At higher shear rates the behaviour becomes more non-Newtonian and the power law index values are comparable to that of raw rubbers.¹⁹,²⁰ With increase in temperature, the critical shear rate at which the flow transition occurs shifts to lower values and both the flow regimes tend to become more Newtonian as evidenced by the increase in power law index in both cases. It is likely that the critical shear rate at which the flow transition takes place, further comes down and the first flow regime may be completely absent at higher temperatures. Thereafter, the flow may become nearly Newtonian as indicated by the increase in the power law
Fig. 3.4 Plot of shear stress vs. shear rate of SBS at 160°C and 180°C.
exponent with increase in temperature. This might be the reason for a near Newtonian behaviour at high temperature. The power law indices calculated from the slopes of the straight lines are shown in Table 3.3.

Fig. 3.5 shows the variation of viscosity with absolute temperature. The straight lines obtained indicate Arrhenius type behaviour and from the slopes activation energies may be determined. The activation energy of viscous flow is found to decrease with increase in shear rate (Table 3.4). This is probably due to the large reduction in viscosity with increase in shear rate.

The rheological data of SBS obtained from the Brabender plasticorder are shown in Figs. 3.6–3.8. As expected torque/rpm representing viscosity decreases with increase in temperature and shear rate (rpm) (Fig. 3.6). The variation of shear stress (torque) with shear rate (rpm) is shown in Fig. 3.7. Even though only low ranges of shear rates could be investigated in this equipment, data are available at lower temperatures compared to those of the capillary rheometer. The data show the behaviour of the melts as more non-Newtonian compared to their behaviour
Table 3.3 Power law indices for SBS and SIS

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Temp. °C</th>
<th>Flow Indices</th>
<th>Lower shear</th>
<th>Upper shear</th>
<th>Temp. °C</th>
<th>Flow Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBS</td>
<td>160</td>
<td>0.48</td>
<td>0.16</td>
<td></td>
<td>130</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>170</td>
<td>0.50</td>
<td>0.19</td>
<td></td>
<td>SBS</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>0.64</td>
<td>0.24</td>
<td></td>
<td>150</td>
<td>0.11</td>
</tr>
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<td>SIS</td>
<td>160</td>
<td>0.41</td>
<td>0.10</td>
<td></td>
<td>130</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>170</td>
<td>0.45</td>
<td>0.12</td>
<td></td>
<td>SIS</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>0.50</td>
<td>0.16</td>
<td></td>
<td>150</td>
<td>0.13</td>
</tr>
</tbody>
</table>
Fig. 3.5 Variation of viscosity with reciprocal absolute temperature of SBS at various shear rates.
### Table 3.4 Activation energy of viscous flow for SBS and SIS

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Capillary Rheometer</th>
<th>Brabender Plasticorder</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shear rate (S⁻¹)</td>
<td>Activation energy (KJ mole⁻¹)</td>
</tr>
<tr>
<td>SBS</td>
<td>23</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>57</td>
<td>3.43</td>
</tr>
<tr>
<td></td>
<td>115</td>
<td>2.3</td>
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<tr>
<td></td>
<td>230</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>576</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>1152</td>
<td>0.4</td>
</tr>
<tr>
<td>SIS</td>
<td>23</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>57</td>
<td>2.5</td>
</tr>
<tr>
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<tr>
<td></td>
<td>576</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>1152</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Fig. 3.6 Variation of torque/rpm with rpm of SBS at different temperatures.
Fig. 3.7 Variation of torque with rpm of SBS at different temperatures.
Fig. 3.8 Variation of torque/rpm with reciprocal absolute temperature of SBS at different rpms.
in the capillary rheometer. However, these data cannot be fully taken as representing the rheological behaviour of the melts, since chances of oxidative degradation are much more in the Brabender plasticorder. Also, the shear rate is not uniform throughout the mixing chamber and the stability of temperature at the set value is poor. The flow indices calculated from the Brabender data (Fig.3.7 and Table 3.3) are lower than the values obtained for capillary rheometer. The activation energies (Fig.3.8 and Table 3.4) calculated from the Brabender plasticorder show the same trend of variation as the values obtained from the capillary rheometer. But the values are larger than those obtained from the capillary. This is probably due to the lower temperatures to which they belong and other factors which are relevant to this instrument already mentioned.

Figs.3.9-3.11 show the rheological behaviour of SIS obtained from the capillary rheometer. The variation of viscosity with shear rate (Fig.3.9) closely resembles the behaviour of SBS. From Fig.3.10 it can be observed that the flow curves of SIS also can be approximated by two straight lines characterizing two distinct flow behaviour. The behaviour at lower shear rate is less non-Newtonian than that at high shear rates as shown by the values of the power law exponents (Table 3.3). The activation
Fig. 3.9 Variation of viscosity with shear rate of SIS at different temperatures
Fig. 3.10 Variation of shear stress with shear rate of SIS at different temperatures.
Fig. 3.11 Variation of viscosity with reciprocal absolute temperature of SIS at different shear rates.
energy of flow is comparable to that of SBS and decrease with increase in shear rate (Fig.3.11 and Table 3.4).

Figs.3.12-3.14 show the rheological behaviour of SIS from Brabender plasticorder. Fig.3.12 represents the variation of viscosity with shear rate and Fig.3.13 the variation of shear stress with shear rate. The power law indices calculated from Fig.3.13 are given in Table 3.3. Fig.3.14 permits the calculation of activation energies of viscous flow. As in the case of SBS, the rheological data obtained from the Brabender plasticorder do not agree well with those obtained from the capillary rheometer.

3. Viscous and elastic behaviour of SEBS triblock copolymer

Excellent resistance to creep and compression set, high tensile and tear strength are some of the factors which differentiate SEBS saturated triblock copolymers from their unsaturated counterparts, SBS and SIS. Because of their excellence in mechanical properties and heat resistance it is important to study the processing behaviour of these TPEs. The viscous and elastic behaviour of these TPEs are described in this section.
Fig.3.12 Variation of torque/rpm with rpm of SIS at different temperatures.
Fig. 3.13 Variation of torque with rpm of S1S at different temperatures.
Fig.3.14 Variation of torque/rpm with reciprocal absolute temperature of SIS at different rpms.
Experimental

Viscous and elastic properties of SEBS triblock copolymer were measured on a capillary rheometer (Götffert Viscotester 1500) using capillary dies of circular cross sections with L/R ratios 60, 40 and 20 at different shear rates and temperatures varying over a range of 20–3000 S\(^{-1}\) and 200–250°C respectively.

From volumetric flow rates at various applied pressures, values of apparent shear stress at wall (\(\tau_{\text{w,app}}\)), apparent shear rate (\(\dot{\gamma}_{\text{w,app}}\)) and apparent viscosity (\(\eta_{\text{app}}\)) were calculated.

From the log \(\tau_{\text{w,app}}\) vs. log \(\dot{\gamma}_{\text{w,app}}\) plots, values of power law exponent 'n' were calculated.

Rabinowitsch correction was applied using values of 'n' to obtain true shear rate (\(\dot{\gamma}_{\text{w}}\)) according to the following expression:\(^{23}\)

\[
\dot{\gamma}_{\text{w}} = \frac{(3n+1)}{4n} \dot{\gamma}_{\text{w,app}}
\]

Bagley correction\(^{24}\) was applied to obtain true shear stress at wall (\(\tau_{\text{w}}\)) from the expression

\[
\tau_{\text{w}} = \frac{\Delta P - P_c}{L} \frac{R}{2}
\]
where the entrance pressure loss $P_c$ was evaluated from plots of $\Delta P$ vs. $L/R$ values.

The true viscosity was then calculated using the expression

$$\eta = \tau_w/\dot{\gamma}_w$$

The entrance pressure loss $P_c$ was also taken as an index of the elasticity of the melts. Elasticity of the melts was also measured from the die swell ratio $D_e/D$ where $D_e$ is the diameter of the extrudate and $D$ that of the die. Extrudates emerging from the capillary die were collected carefully at different shear rates and diameter was measured after 24 hours. The extrudate surface at various shear rates was photographed to look for surface roughness.

**Results and discussion**

Fig.3.15 shows the variation of viscosity of SEBS with shear rate. The melt shows a strong non-Newtonian behaviour similar to the behaviour of SIS or SBS. The viscosities increase as the shear is decreased and apparently approach infinite values at low shear rates particularly at low temperatures which may be attributed to the existence of two phase structure.
Fig. 3.15 Variation of viscosity with shear rate of SEBS at different temperatures.
Fig. 3.16 shows the plot of shear stress versus shear rate of SEBS at 220°C and 240°C. Here also, the curve can be represented as two straight lines. The slope of the initial line, the power law index, is comparable to the value of filled rubbers. The behaviour becomes more non-Newtonian at higher shear rates at all temperatures and the power law index values are comparable to that of raw rubbers. The transfer of polystyrene domains during flow through highly associated EB blocks require additional energy and this accounts for the higher melt viscosities of SEBS than SBS and SIS. As the shear rate is increased, the polystyrene domains also get destroyed due to high shearing and the behaviour becomes similar to raw elastomers. The shear rate at which the flow transition takes place is termed as critical shear rate. As the temperature is increased, the critical shear rate shifts to lower values and both the flow regimes tend to become more Newtonian. The power law indices calculated from the slopes of the straight lines and the shear rate at which the flow transition occurs at 220°C, 230°C and 240°C are shown in Table 3.5.

Variation of viscosity with reciprocal absolute temperature is shown in Fig. 3.17. The straight lines indicate Arrhenius type behaviour and the activation energies
Fig. 3.16 Variation of shear stress versus shear rate of SEBS.
Table 3.5 Power law indices for SEBS

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Power law index values at Lower shear rate region</th>
<th>Power law index values at Upper shear rate region</th>
<th>Critical shear rate for the flow transition (s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>220</td>
<td>0.57</td>
<td>0.22</td>
<td>416</td>
</tr>
<tr>
<td>230</td>
<td>0.61</td>
<td>0.26</td>
<td>363</td>
</tr>
<tr>
<td>240</td>
<td>0.66</td>
<td>0.33</td>
<td>302</td>
</tr>
</tbody>
</table>
Fig. 3.17 Variation of viscosity with reciprocal absolute temperature of SEBS.
calculated from the slopes of the straight lines are given in Table 3.6. Activation energy of viscous flow is found to decrease with increase in shear rate, probably due to reduction in viscosity with increase in shear rate. Compared to other diene triblock copolymers, activation energy of viscous flow for SEBS is very high. This may be due to the high entanglement density of the EB blocks, sharp phase separation and strongly associated styrene/domain structure.

Fig.3.18 shows Bagley plots (variation of ΔP as a function of L/R ratios) of SEBS at 200°C. The linearity of Bagley plot confirms the absence of slippage at the capillary wall, otherwise slippage will cause curvature in the Bagley plot.26

Variation of end correction factor \( P_c \) against log shear rate are shown in Fig.3.19. The increase in \( P_c \) with shear is gradual at lower shear rates whereas a sharp variation occurs at higher shear. This may mean that elastic effects sharply increase with shear rates and may dominate the viscous effects at higher shear rates.

Effect of shear rate on die swell ratio which is a direct measure of melt elasticity is shown in Fig.3.20. The die swell ratio increases with increase in shear rate.
Table 3.6 Activation energy of viscous flow for SEBS

<table>
<thead>
<tr>
<th>Capillary shear rate ($s^{-1}$)</th>
<th>Activation energy (KJ mole$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>68.4</td>
</tr>
<tr>
<td>230</td>
<td>44.6</td>
</tr>
<tr>
<td>1150</td>
<td>26.5</td>
</tr>
<tr>
<td>2300</td>
<td>24.0</td>
</tr>
</tbody>
</table>
Fig. 3.18 Variation of $\Delta P$ as a function of L/R ratios for SEBS at 200°C.
Fig. 3.19 Variation of entrance pressure loss, $P_c$ with shear rate of SEBS.
Fig. 3.20  Effect of shear rate on die swell ratio of SEBS
as expected whereas it decreases with increase in temperature. Bogue and White\textsuperscript{27} suggested use of the parameter recoverable shear strain, $\gamma_R$, for describing and distinguishing the fluid elasticity of different viscoelastic fluids as a function of shear stress. $\gamma_R$ was calculated and is given in Fig.3.21. The two step variation of recoverable shear strain at lower temperatures gradually diminishes as the temperature increases. This marks the elongational flow of the matrix and the deformation and breaking up of the dispersed polystyrene phase.

Fig.3.22 shows the variation of extrudate swell ratio with L/R ratio of capillary die. As expected, the melt elasticity behaviour of the triblock copolymer decreases with increase in length of the capillary die.

Flow curves in terms of corrected values of shear stress and shear rate are presented in Fig.3.23. Variation of viscosity is nonlinear and the corrected viscosity is slightly lower than that of the apparent viscosity. The difference is negligible at high shear rates.

Another important factor in processability is flow instability or melt fracture\textsuperscript{28,29} which shows surface roughness of the material when extruded at certain critical output
Fig. 3.21 Effect of shear rate on recoverable shear strain of SEBS.
Fig. 3.22 Variation of extrudate swell ratio with L/R ratio for SEBS.
Fig. 3.23 Flow curves in terms of corrected values of shear stress and shear rate of SEBS.
rate. Melt fracture phenomena occur through mechanisms which are not satisfactorily known, although their occurrence seems to be strictly related to the elastic components of the polymer.

Photographs of the extrudates are presented in Figs.3.24 and 3.25 as typical examples of the observed effect of temperature and shear rate on the distortion of extrudate surface of SEBS. For any given temperature, extrudate surface roughness was found to increase with increasing shear rate. A decrease in melt elasticity at higher temperature decreases the surface roughness as seen from Fig.3.25.

Conclusions

1. The ultimate properties such as tensile strength and elongation at break of the triblock copolymers SBS, SIS and SEBS are similar to those of vulcanized rubbers. But the stress-strain curve of SBS shows yield point indicating similarity with the behaviour of plastics. This behaviour is further exemplified in the hysteresis behaviour where SBS shows maximum hysteresis loss.

2. SBS, SIS and SEBS exist as phase separated systems in the melt and they exhibit two distinct flow behaviour depending upon the temperature and shear rate. Their elastic behaviour is also derived from their two phase structure.
Fig. 3.24: at 210°C
Extrudate photographs of SEBS at various shear rates.

Fig. 3.25: at 250°C
Extrudate photographs of SEBS at various shear rates.

<table>
<thead>
<tr>
<th>Shear rate (s⁻¹)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<tbody>
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<td></td>
<td>23.0</td>
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<td>230.0</td>
<td>576.0</td>
<td>1152.0</td>
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REFERENCES


