## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Fig No</th>
<th>Title</th>
<th>Page No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Schematic phase diagrams displaying: (a) upper critical solution temperature (UCST) (b) lower critical solution temperature (LCST)</td>
<td>6</td>
</tr>
<tr>
<td>1.2</td>
<td>Various strategies of the Chemically Induced Phase Separation technique to generate different types of morphologies</td>
<td>10</td>
</tr>
<tr>
<td>1.3</td>
<td>SEM micrographs of various epoxy-DDS/SAN-15% blends after 7 h of isothermal curing at 160 °C and 10 MPa from PVT analysis blend showing secondary phase separation</td>
<td>12</td>
</tr>
<tr>
<td>1.4</td>
<td>Transmission electron micrographs of fractured surface of 80/20 crosslinked ER/ABS blends showing secondary phase separation</td>
<td>14</td>
</tr>
<tr>
<td>1.5</td>
<td>Structure of Epoxy group</td>
<td>16</td>
</tr>
<tr>
<td>1.6</td>
<td>Diglycidyl ether of bisphenol A epoxy resin</td>
<td>17</td>
</tr>
<tr>
<td>1.7(a)</td>
<td>Schematic Morphology map</td>
<td>20</td>
</tr>
<tr>
<td>1.7(b)</td>
<td>Time-temperature-transformation diagram</td>
<td>21</td>
</tr>
<tr>
<td>1.8</td>
<td>Reactions between epoxy and different curing agents</td>
<td>22</td>
</tr>
<tr>
<td>1.9</td>
<td>Reactions between epoxy and anhydride</td>
<td>23</td>
</tr>
<tr>
<td>1.10</td>
<td>Reactions between epoxy and alkoxide group</td>
<td>24</td>
</tr>
<tr>
<td>1.11</td>
<td>Reaction rate against time plot for neat resin and epoxy/PEEKOH12 blends cured at 150°C</td>
<td>28</td>
</tr>
<tr>
<td>1.12(a)</td>
<td>Fracture toughness versus plate thickness in the neat epoxy</td>
<td>33</td>
</tr>
<tr>
<td>1.12(b)</td>
<td>Fracture energy versus plate thickness in the neat epoxy</td>
<td>33</td>
</tr>
<tr>
<td>1.13</td>
<td>Schematic diagram of the typical acrylonitrile – butadiene-poly(styrene) (ABS) coreshell modifier particle</td>
<td>47</td>
</tr>
<tr>
<td>1.14</td>
<td>Schematic diagram showing the crack-pinning mechanism: (a) an opening crack pinned by the second phase particles and (b) successive stages of a crack initiating with and passing through a row of second phase particles</td>
<td>53</td>
</tr>
<tr>
<td>1.15</td>
<td>Schematic diagram showing the crack-pinning mechanism</td>
<td>54</td>
</tr>
<tr>
<td>1.16</td>
<td>Transmission electron micrograph of a microtomed section of HIPS, stained with osmium tetroxide</td>
<td>55</td>
</tr>
<tr>
<td>1.17</td>
<td>Schematic diagrams showing plastic deformation</td>
<td>56</td>
</tr>
</tbody>
</table>
1.18 Scanning electron micrographs of fracture surfaces (test temperature, 23°C). A: Unmodified epoxy polymer; B: Rubber-toughened epoxy polymer [volume fraction of rubber phase= 0.14]

1.19 Scanning electron micrograph of surface, normal to the crack plane, of rubber-toughened epoxy. The shear bands that occur at constant volume cause the furrows between the rubber particles, at approximately 45° to the maximum principal tensile stress

1.20 SEM of fracture surface of rubber toughened epoxy showing cavitated rubber particles

1.21 Schematic diagrams showing the particle-bridging mechanism

1.22 A schematic diagram showing crack-path deflection mechanism

1.23 SEM micrograph of cleavage fractured surface showing slow crack propagation in rubber modified epoxies

1.24 SEM micrograph of cleavage fractured surface showing fast crack propagation in rubber modified epoxies

1.25 A schematic diagram to describe the different toughening mechanisms

1.26 Structure of natural rubber

2.1 Chemical structure of DGEBA

2.2 Chemical structures of NMA and BDMA

2.3 DSC thermogram of epoxy resin

2.4 Schematic diagram of a Nanoindenter

3.1 DSC thermogram of HTLNR

3.2 DSC thermogram of ETLNR

3.3 GPC of HTLNR

3.4 GPC of ETLNR

3.5 IR spectrum of HTLNR

3.6 IR spectrum of ETLNR

3.7 Chemical structure of HTLNR

3.8 'H-NMR Spectrum of HTLNR

3.9 Structure of ETLNR

3.10 'H-NMR Spectrum of ETLNR

3.11 'C-NMR Spectrum of HTLNR

3.12 'C-NMR Spectrum of ETLNR
4.1 Plot showing UCST behavior of uncured DGEBA/ETLNR and DGEBA/HTLNR blends 143
4.2 DSC curves of DGEBA/ETLNR in the uncured state 144
4.3 DSC curves of DGEBA/HTLNR in the uncured state 144
4.4 Variation of $T_g$ with rubber content in ETLNR and HTLNR modified epoxy resin 146-
4.5 Comparison of experimental and theoretical values of glass transition temperatures of DGEBA/ETLNR blends 147
4.6 Comparison of experimental and theoretical values of glass transition temperatures of DGEBA/HTLNR blends 147
4.7 Optical micrographs of DGEBA/ETLNR blends cured for various timings at 120°C 149
4.8 Optical micrographs of DGEBA/HTLNR blends cured for various timings at 120°C 151
4.9 SEM micrographs at a curing time of 30 minutes at 120°C of cryofractured surfaces of epoxy/HTLNR blends (a) 5 wt% (b) 10 wt% (c) 15 wt% and (d) 20 wt% HTLNR 154
4.10 SEM micrographs at a curing time of 60 minutes at 120°C of cryofractured surfaces of epoxy/HTLNR blends (a) 5 wt% (b) 10 wt% (c) 15 wt% and (d) 20 wt% HTLNR 155
4.11 SEM micrographs at a curing time of 90 minutes at 120°C of cryofractured surfaces of epoxy/HTLNR blends (a) 5 wt% (b) 10 wt% (c) 15 wt% and (d) 20 wt% HTLNR 155
4.12 SEM micrographs at a curing time of 120 minutes at 120°C of cryofractured surfaces of epoxy/HTLNR blends (a) 5 wt% (b) 10 wt% (c) 15 wt% and (d) 20 wt% HTLNR 156
4.13 SEM micrographs at a curing time of 120 minutes at 120°C of cryofractured and extracted surfaces of epoxy/HTLNR blends (a) 5 wt% (b) 10 wt% (c) 15 wt% and (d) 20 wt% HTLNR 156
4.14 SEM micrographs of cryofractured surfaces of 20 wt% HTLNR modified epoxy cured at 120°C for 2 hours showing secondary phase separation 157
4.15 Variation of number average, weight average, volume average and area average domain sizes with rubber content in DGEBA/HTLNR blends at different curing times (a) 30°C (b) 60°C (c) 90°C and (d) 120°C 160-161
4.16 SEM micrographs at a curing time of 30 minutes at 120°C of cryofractured surfaces of epoxy/ETLNR blends (a) 5 wt% (b) 10 wt% (c) 15 wt% and (d) 20 wt% ETLNR 162
4.16 ii  SEM micrograph at a curing time of 30 minutes at 120°C of cryofractured surfaces of epoxy/10 wt% ETLNR blends at higher magnification.

4.17  SEM micrographs at a curing time of 60 minutes at 120°C of cryofractured surfaces of epoxy/ETLNR blends (a) 5 wt% (b) 10 wt % (c) 15 wt% and (d) 20 wt% ETLNR

4.18  SEM micrographs at a curing time of 90 minutes at 120°C of cryofractured surfaces of epoxy/ETLNR blends (a) 5 wt% (b) 10 wt % (c) 15 wt% and (d) 20 wt% ETLNR

4.19  SEM photomicrographs at a curing time of 120 minutes at 120°C of cryofractured surfaces of epoxy/ETLNR blends (a) 5 wt% (b) 10 wt % (c) 15 wt% and (d) 20 wt% ETLNR

4.20  SEM photomicrographs at a curing time of 120 minutes at 120°C of cryofractured and extracted surfaces of epoxy/ETLNR blends (a) 5 wt% (b) 10 wt % (c) 15 wt% and (d) 20 wt% ETLNR

4.21  SEM photomicrographs at a curing time of 120 minutes of cryofractured surfaces of epoxy/20 wt% ETLNR blends (a) at 120°C and (b) at 180°C illustrating secondary phase separation

4.22  Variation of number average, weight average, volume average and area average domain sizes with rubber content in DGEBA/ETLNR blends at different curing times (a) 30°C (b) 60°C (c) 90°C and (d) 120°C

4.23  SEM micrograph showing protrusions in (a) epoxy/10 wt% ETLNR and (b) epoxy/15 wt% ETLNR blends

4.24  Scanning electron micrographs of cryofractured, unextracted surfaces of DGEBA/ETLNR blends cured at 180°C

4.25  Scanning electron micrographs of cryofractured and extracted surfaces of DGEBA/ETLNR blends cured at 180°C

4.26  Scanning electron micrographs of cryofractured unextracted DGEBA/HTLNR blends cured at 180°C

4.27  Scanning electron micrographs of cryofractured and extracted surfaces of DGEBA/HTLNR blends cured at 180°C

4.28  Variation of domain sizes with rubber content of completely cured (a) DGEBA/ETLNR and (b) DGEBA/HTLNR blends

4.29  Suggested mechanism for secondary phase separation in epoxy/HTLNR and epoxy/ETLNR blends

4.30  Scanning electron micrographs of cryofractured surfaces of DGEBA/ETLNR(L) blends cured at 180°C
4.31 Variation of domain size with rubber content of completely cured DGEBA/ETLNR (L) blends

4.32 Atomic force microscopic images of neat epoxy resin (5 x 5 μm) (a) height image (b) phase image

4.33 Atomic force microscopic images of epoxy/ETLNR blends (5 x 5 μm) (a) 5 wt% ETLNR (b) 10 wt% ETLNR (c) 15 wt% ETLNR and (d) 20 wt% ETLNR

4.34 Atomic force microscopic images of epoxy/5 wt% HTLNR (5 x 5 μm) (a) height image (b) phase image

4.35 Atomic force microscopic image of epoxy/10 wt% HTLNR blends (5 x 5 μm)

4.36 Atomic force microscopic images of epoxy/15 wt% HTLNR blends (a) height image (5 x 5 μm) (b) phase image (5 x 5 μm)

4.37 Atomic force microscopic height image of epoxy/20 wt% HTLNR blends (5 x 5 μm)

5.1 Mechanism of curing reaction of epoxy with nadic methyl anhydride

5.2 Typical mechanism of curing reaction of epoxy with anhydride and tertiary amine

5.3 FTIR spectrum of epoxy resin LAPOX B-11

5.4 FTIR spectrum of uncured epoxy resin mixed above UCST with (a) ETLNR and (b) HTLNR

5.5 FTIR spectrum of 10 wt% HTLNR modified epoxy cured at 120°C for different cure timings

5.6 FTIR spectrum of 10 wt% ETLNR modified epoxy cured for different timings

5.7 FTIR spectra of epoxy/10 wt% HTLNR blends at different cure stages in the range 4500 to 200 cm⁻¹: (a) 0 min (b) 120°C (10mins) (c) 120°C (20mins) (d) 120°C (30mins) (e) 120°C (60mins) (f) 120°C (120mins) (g) 120°C (3 hours) 180°C (2 hours) 200°C (2 hours)

5.8 FTIR spectra of epoxy/10 wt% HTLNR blends at different cure stages in the range 2000 to 200 cm⁻¹: (a) 0 min (b) 120°C (10mins) (c) 120°C (20mins) (d) 120°C (30mins) (e) 120°C (60mins) (f) 120°C (120mins) (g) 120°C (3 hours) 180°C (2 hours) 200°C (2 hours).
5.9 FTIR spectra of epoxy/10 wt% ETLNR blends at different cure stages in the range 4000 to 200 cm\(^{-1}\). (a) 0 min (b) 120\(^{\circ}\)C (10mins) (c) 120\(^{\circ}\)C (20mins) (d) 120\(^{\circ}\)C (30mins) (e) 120\(^{\circ}\)C (60mins) (f) 120\(^{\circ}\)C (120mins) (g) 120\(^{\circ}\)C (3 hours) 180\(^{\circ}\)C (2 hours) 200\(^{\circ}\)C (2 hours)

5.10 FTIR spectra of epoxy/10 wt% ETLNR blends at different cure stages in the range 2000 to 200 cm\(^{-1}\). (a) 0 min (b) 120\(^{\circ}\)C (10mins) (c) 120\(^{\circ}\)C (20mins) (d) 120\(^{\circ}\)C (30mins) (e) 120\(^{\circ}\)C (60mins) (f) 120\(^{\circ}\)C (120mins) (g) 120\(^{\circ}\)C (3 hours) 180\(^{\circ}\)C (2 hours) 200\(^{\circ}\)C (2 hours)

5.11 FTIR spectra of completely cured epoxy/HTLNR blends in the range 2000 to 500 cm\(^{-1}\)

5.12 FTIR spectra of completely cured epoxy/ETLNR blends in the range 2000 to 500 cm\(^{-1}\)

5.13 DSC thermograms of DGEBA/HTLNR blends cured at 120\(^{\circ}\)C for different timings (a) neat (b) 5wt% (c) 10wt% (d) 15wt% (e) 20wt%

5.14 DSC thermograms of DGEBA/ETLNR blends cured at 120\(^{\circ}\)C for different timings (a) 5wt% (b) 10wt% (c) 15wt% (d) 20wt%

5.15 DSC thermograms of completely cured DGEBA/ETLNR blends

5.16 DSC thermograms of completely cured DGEBA/HTLNR blends

5.17 Dynamic DSC thermograms of neat epoxy at different heating rates

5.18 Conversion versus time for the neat epoxy and epoxy/HTLNR blends cured isothermally at 120\(^{\circ}\)C

5.19 Conversion versus time for the neat epoxy and epoxy/HTLNR blends cured isothermally at 150\(^{\circ}\)C

5.20 Conversion versus time for the neat epoxy and epoxy/HTLNR blends cured isothermally at 180\(^{\circ}\)C

5.21 Conversion versus time for 15 wt% epoxy/HTLNR blends cured isothermally at different temperatures

5.22 Rate versus time for the neat epoxy and epoxy/HTLNR blends cured isothermally at 120 \(^{\circ}\)C

5.23 Rate versus time for the neat epoxy and epoxy/HTLNR blends cured isothermally at 150 \(^{\circ}\)C

5.24 Rate versus time for the neat epoxy and epoxy/HTLNR blends cured isothermally at 180 \(^{\circ}\)C

5.25 Rate versus conversion plot for epoxy/HTLNR blends at 120\(^{\circ}\)C

5.26 Rate versus conversion plot for epoxy/HTLNR blends at 150\(^{\circ}\)C
5.27 Rate versus conversion plot for epoxy/HTLNR blends at 180°C
5.28 lnk\textsubscript{1} against 1/T plot for neat epoxy and epoxy/HTLNR blends
5.29 lnk\textsubscript{2} against 1/T plot for neat epoxy and epoxy/HTLNR blends
5.30 Experimental and autocatalytic conversion of epoxy/HTLNR blends at 120 °C
5.31 Experimental and autocatalytic conversion of epoxy/HTLNR blends at 150 °C
5.32 Experimental and autocatalytic conversion of epoxy/HTLNR blends at 180 °C
5.33 Plot of f (\(\alpha\)) versus \(\alpha\) for epoxy/HTLNR blends
6.1 Variation of tan delta of neat epoxy resin as a function of cure temperature
6.2 Variation of tan delta with temperature of the neat and HTLNR modified systems at the cure temperature 180°C
6.3 Variation of loss modulus with temperature for neat and DGEBA/HTLNR blends
6.4 Plot of storage modulus versus temperature for neat and DGEBA/HTLNR blends
6.5 Variation of tan delta with temperature of DGEBA/ETLNR blends
6.6 Variation of loss modulus with temperature of DGEBA/ETLNR blends
6.7 Variation of storage modulus of DGEBA/ETLNR blends
6.8 Effective crosslink densities of DGEBA/HTLNR and DGEBA/ETLNR blends
6.9 Variation of tan delta with temperature of DGEBA/ETLNR(L) blends
6.10 Variation of loss modulus with temperature of DGEBA/ETLNR (L) blends
6.11 Variation of storage modulus versus temperature of DGEBA/ETLNR(L) blends
7.1 Variation of G', G" and complex viscosity for neat epoxy resin at 120°C
7.2 Change in complex viscosity versus time for neat epoxy at different cure temperatures
7.3 Complex viscosity versus time for HTLNR blends at 140 °C
7.4 Complex viscosity versus time for HTLNR modified epoxy at 120, 140 and 160°C
7.5 Variation of $G'$, $G''$ and complex viscosity for epoxy/5 wt\% HTLNR blends at 120$^\circ$C

7.6 Variation of $G'$, $G''$ and complex viscosity for epoxy/10 wt\% HTLNR blends at 120$^\circ$C

7.7 Variation of $G'$, $G''$ and complex viscosity for epoxy/15 wt\% HTLNR blends at 120$^\circ$C

7.8 Variation of $G'$, $G''$ and complex viscosity for epoxy/20 wt\% HTLNR blends at 120$^\circ$C

7.9 Gelation time for epoxy/HTLNR blends at different temperatures

7.10 Vitrification time for epoxy/HTLNR blends at different temperatures

7.11 $\ln(t_{gel})$ against $1/T$

7.12 Variation of complex viscosity of the ETLNR modified blends with time at the temperature 120$^\circ$C

7.13 Complex viscosity versus time for 15 wt\% ETLNR blends at different temperatures

7.14 Variation of gelation time with temperature in DGEBA/ETLNR blends

7.15 Plot of $\ln t_{gel}$ vs $1/T$ of DGEBA/ETLNR blends

7.16 Plot of Complex viscosity versus time for 5 wt\% ETLNR modified DGEBA/ETLNR blends

8.1 Stress-strain plot of DGEBA/HTLNR blends

8.2 Variation of (a) tensile strength and (b) elongation at break as a function of rubber content in DGEBA/HTLNR blends

8.3 Variation of toughness as a function of (a) rubber content and (b) domain size in DGEBA/HTLNR blends

8.4 (a) Flexural stress-strain behaviour of DGEBA/HTLNR blends (b) Flexural strength of DGEBA/HTLNR blends as a function of rubber content

8.5 Variation of fracture energy and fracture toughness of DGEBA/HTLNR blends with rubber content

8.6 Variation of impact strength of (a) unnotched and (b) notched DGEBA/HTLNR blends

8.7 SEM photomicrographs of (a) neat epoxy and (b) 20 wt \% HTLNR blend surfaces after impact measurements

8.8 Variation of stress-strain behaviour of DGEBA/ETLNR blends with rubber content
8.9 Variation of (a) tensile strength (b) modulus and (c) elongation at break of DGEBA/ETLNR blends with rubber content
8.10 Variation of toughness of DGEBA/ETLNR blends with rubber content and domain size
8.11 Variation of (a) flexural strength and (b) modulus of DGEBA/ETLNR blends with rubber content
8.12 Variation of fracture energy and fracture toughness of DGEBA/ETLNR blends with rubber content
8.13 SEM micrographs of (a) 5 wt% (b) 10 wt% (c) 15 wt% and (d) 20 wt% epoxy/ETLNR blend surfaces after impact measurements
8.14 Variation of (a) unnotched and (b) notched impact strength of DGEBA/ETLNR blends with rubber content
8.15 SEM photomicrograph of the fractured surface of neat epoxy resin
8.16 Cavitation in epoxy/HTLNR blend
8.17 Crazing and shear banding in epoxy/HTLNR blend
8.18 Cavitation, particle bridging and shear banding in epoxy/HTLNR blend
8.19 Particle bridging in epoxy/HTLNR blend
8.20 Tailing in epoxy/HTLNR blend
8.21 (a) Cavitation (b) crack deflection and (c) crack bifurcation and shear banding in epoxy/ETLNR blend
8.22 (a) Variation of modulus and hardness of DGEBA/HTLNR blends
8.22 (b) Variation of modulus and hardness of DGEBA/ETLNR blends with rubber content
8.23 (a) Variation of impact strength and \( \frac{E}{H} \) values as a function of ETLNR content
8.23 (b) Variation of impact strength and \( \frac{E}{H} \) values as a function of HTLNR content
9.1 TGA curve of neat epoxy
9.2 TGA curve of HTLNR
9.3 TGA curve of ETLNR
9.4 TGA curves of neat epoxy and epoxy/ETLNR blends
9.5 TGA curves of neat epoxy and epoxy/HTLNR blends
9.6 Variation of mass loss with composition in epoxy/ETLN blends
9.7 Variation of mass loss with composition in epoxy/HTLN blends
9.8 Plots of $\ln \left[ \ln \left( 1 - \alpha \right)^{-1} \right]$ versus $\theta$ of neat and epoxy/HTLN blends
9.9 Plots of $\ln \left[ \ln \left( 1 - \alpha \right)^{-1} \right]$ versus $\theta$ of neat and epoxy/ETLN blends
9.10 Dielectric constant as function of HTLN and ETLN content
9.11 Variation of the dielectric constant with frequency in epoxy/HTLN blends
9.12 Variation of the dielectric constant with frequency in epoxy/ETLN blends
9.13 Variation of volume resistivity with frequency as function of HTLN loading
9.14 Variation of volume resistivity with frequency as function of ETLN loading.
9.15 Variation of conductivity as a function of frequency of epoxy/HTLN blends
9.16 Variation of conductivity as a function of frequency of epoxy/ETLN blends
9.17 Variation of conductivity as a function of rubber content in epoxy/HTLN and epoxy/ETLN blends
9.18 Variation of dissipation factor for epoxy/HTLN blends
9.19 Variation of dissipation factor for epoxy/ETLN blends