Chapter 3

PREPARATION AND PROPERTY EVALUATION OF PHENOL CARDANOL FORMALDEHYDE RESOL RESIN

3.1 Introduction
3.2 Experimental
3.3 Results and discussion
3.4 Conclusions
3.1 Introduction

This chapter contains the details of the study conducted on the preparation and modification of phenol cardanol formaldehyde resol resins. Cardanol is one of the important naturally occurring phenols. It is obtained from cashew nut shell liquid (CNSL). Cashew nut shell liquid, a byproduct of the cashew industry, is obtained from the shell of the cashew nut. About 30-35% CNSL is present in the shell, which amounts to approximately 67% of the weight of the nut. Natural CNSL contains four main components namely, cardanol, cardol, anacardic acid and 6-methyl cardol\(^1\). Commercial grade CNSL contains hardly any anacardic acid because of decarboxylation during the heating process which converts anacardic acid to cardanol. The three main components of cardanol are themselves mixtures of four constituents differing in side chain unsaturation viz. saturated, monoene, diene and triene. The structures of the side chains in the four major components of CNSL are identical. Fig.3.1 represents the chemical structure of the main components.

For different values of \(n\), the following structures result for the side chain.

\[
\begin{align*}
&\text{n=0, } (\text{CH}_2)_7-(\text{CH}_2)_7\text{CH} ; & \text{n=2, } (\text{CH}_2)_2\text{CH} =\text{CH}(\text{CH}_2)_2\text{CH}_3 \\
&\text{n=4, } (\text{CH}_2)_2\text{CH} =\text{CH}-\text{CH}_2 =\text{CH} =\text{CH}(\text{CH}_2)_2\text{CH}_3 \\
&\text{n=6, } (\text{CH}_2)_2\text{CH} =\text{CH}-\text{CH}_2 =\text{CH} =\text{CH}-\text{CH}_2 =\text{CH} =\text{CH}_2
\end{align*}
\]

Cardanol gives most of the reactions of phenol even though the reactivity of cardanol is less. Therefore, complete or partial replacement of phenol by cardanol in phenol formaldehyde resin will be a desirable step because of various
advantages like cost effectiveness, support to the agricultural sector and the indirect conservation of petroleum deposits. But it is known that resins entirely based on cardanol do not possess good mechanical properties. It is also a matter of interest to find out how far various properties of phenol formaldehyde resin are affected by replacement of phenol by cardanol.

A number of works have been reported on the synthesis and modification of cardanol formaldehyde resins and its applications\textsuperscript{2,3,4,5,6,7,9\textsuperscript{[2-7]}}. Some reports have also appeared on the use of CNSL for this purpose. Incorporation of CNSL into phenol, in both resol and novolacs, decreased the tensile strength but led to an improvement in impact strength in the case of wood flour-based laminates of these resins\textsuperscript{8\textsuperscript{[8]}}. But the thermal properties of phenol-cardanol based resin show deterioration with increase in the cardanol content\textsuperscript{9\textsuperscript{[9]}}.

In this part of the study, first, resols were synthesized by the reaction of a mixture of phenol and cardanol in various molar ratios (ranging from 1:0 to 0.9:0.1) with formaldehyde (PCF resin) keeping the total phenol to formaldehyde ratio as 1:1.75. Further, prepolymer of phenol-formaldehyde (PF) and cardanol-formaldehyde resin (CF) with the same F/P ratio were separately synthesized and blended (PFCF). The physical, mechanical, and thermal properties of these resins were estimated for comparison as well as to find out the optimal ratio between phenol and cardanol.

3.2 Experimental

3.2.1 Materials

Commercial CNSL was supplied by Vijayalakshmi Cashew Exports Pvt. Ltd., Kollam, Kerala, India. Cardanol was separated from it by distillation under reduced pressure (1 mmHg). The pale yellow fraction collected at 230-240°C is cardanol\textsuperscript{10\textsuperscript{[10]}}.

3.2.2 Synthesis of PCF resin and resin blend PFCF

Phenol and cardanol in the percentage molar ratios 100:0, 98:02, 96:04, 94:06, 92:08 and 90:10 were mixed in a two necked RB flask provided with a
mechanical stirrer and a reflux condenser. 1 mole of this blend was then reacted with formaldehyde (1.75 moles) in the presence of NaOH (0.25 moles on a total phenolic component basis) as per the procedure in Section 2.2.2. These five resins were designated as PCF2, PCF4, PCF6, PCF8 and PCF10 corresponding to molar percentages of cardanol 2, 4, 6, 8 and 10 respectively.

Both PF and CF resol resins with phenol to formaldehyde ratio 1:1.75 were also synthesized separately as per the procedure given earlier. Blends of these resins (PFCF) were prepared by mixing both PF (R1.75) and CF (1.75) in such a way that each blend maintained the same phenol to cardanol molar ratio as in the PCF resin. PFCF blends were designated as PFCF2, PFCF4, PFCF6, PFCF8 and PFCF10. Due to the high viscosity of CF resin, it was dissolved in a minimum quantity of methyl ethyl ketone (MEK) initially and then mixed with PF resin using a mechanical stirrer. The solvent was subsequently removed by applying vacuum.

3.2.3 Morphological studies- Scanning electron microscopy

Scanning electron microscope (SEM) is a very useful tool in polymer research for studying morphology. Scanning electron microscope (JOEL JSM 840A Scanning Microscope) was used to investigate the morphology of the fractured surfaces. In this technique, an electron beam is scanned across the specimen resulting in back scattering of electrons of high energy, secondary electrons of low energy and X-rays. These signals are monitored by detectors (photo multiplier tube) and magnified. An image of the investigated microscopic region of the specimen is thus observed in a cathode ray tube and photographed using black and white film. The SEM observations reported in the present study were made on the fracture surface of the tensile specimens. Thin specimens were prepared and mounted on a metallic stub with the help of a silver tape and conducting paint in the upright position. The stub with the sample was placed in a JFC-1100E ion-sputtering unit for gold coating of the sample to make it conducting. The gold-coated sample was subjected to SEM.
3.2.4 Thermogravimetric analysis

Thermogravimetric analysis of the cured resins were performed as described in Chapter 2, Section 2.2.3.

3.2.4.1 Evaluation of kinetic parameters

The TGA data can also be used to study the kinetics of decomposition which provide an insight into the thermal stability of polymeric materials. There are many proposed methods to calculate the kinetic parameters of decomposition and the reported values depend not only on the experimental conditions, but also on the mathematical treatment of data.

i) Formulation of the rate equation

For many kinetic processes, the rate of reaction may be expressed as a product of a temperature dependent function; k(T), and a composition- or conversion-dependent term; f(X):

\[ r = \frac{dX}{dt} = \kappa(T) f(X) \]

where T is the absolute temperature in Kelvins; X is the conversion i.e. weight of polymer volatilized/initial weight of polymer and r is the rate of change of conversion or composition per unit time, t. The temperature dependent term in Equation (3.1) is the reaction rate constant, which is assumed to obey the usual Arrhenius relationship:

\[ \kappa(T) = Ae^{E_a/RT} \]

where \( E_a \) is the activation energy of the kinetic process, A is the pre-exponential factor and R is the universal gas constant. The conversion-dependent function, f(X), is generally a complicated form. A particular term is usually valid only for a limited range of experimental conditions. If it is assumed that a simple n^th order kinetic relationship holds for the conversion-dependent term such that:

\[ f(X) = (1 - X)^n \]
and that the quantity (1-X) can be replaced by W, the weight fraction remaining in a TGA run, then:

\[ r = \frac{dW}{dt} = AW^n \exp \left(-\frac{E_a}{RT}\right) \] .............................................. (3.4)

\[ \ln r = \ln(-\frac{dW}{dt}) = \ln A + n \ln W - \frac{E_a}{RT} \] ...................................... (3.5)

Published methods of deriving the kinetic parameters from TGA data center around Equation 3.5. They may be either differential i.e. involving the derivative term, \(-\frac{dW}{dt}\) or integral i.e. based upon an integration of Equation 3.5. The emphasis in these methods is on finding a way of plotting the data to provide a rapid visual assessment of the order of the reaction and its activation energy.

\textbf{ii) Integral method}

The integral methods involve the integration of Equation (3.1) by separation of variables. By substituting Equation (3.2) into this expression and defining \( \beta = \frac{dT}{dt} \) as the heating rate, the following is obtained:

\[ F(x) = \int_{x_0}^{x} dX \cdot f(x) = \int_{T_0}^{T} \exp\left(-\frac{E_a}{RT}\right) dT \] ......................................... (3.6)

where \( T_0 \) is the initial temperature in the TGA analysis and \( T \) is the final temperature. For constant heating rate \( \beta \) and if \( T_0 \approx 0 \), Equation (3.6) becomes:

\[ F(x) = \int_{x_0}^{x} \exp\left(-\frac{E_a}{RT}\right) dT \] ...................................................... (3.7)

The different integral methods involve an approximation of the right-hand integral term in Equation (3.7).

Among the integral methods, the Coats and Redfern approach\(^{12}\) seems to be the most suitable from a practical point of view and is preferred over others and is applied here. The activation energy and the order of reaction were evaluated utilizing this equation for reaction order \( n \neq 1 \), which when linearised for a correctly chosen \( n \) yields the activation energy from the slope.

\[ \ln\left[1 - (1 - \alpha)^{1-n}/T^2(1 - n)\right] = \ln[AR/\beta E] - \frac{E_a}{RT} \] ........... (3.8)
For all \( n \) values this equation can be written as:

\[
\ln \left( \frac{g(\alpha)}{T} \right) = \ln \left( \frac{\alpha A R}{\beta E} \right) \left( 1 - 2RT \right) - E/nRT \quad \text{..........
(3.9)}
\]

for \( n \neq 1 \), \( g(\alpha) = \{ 1 - (1-\alpha)^{1/n} / (1-n) \} \); for \( n = 1 \), \( g(\alpha) = -\ln(1-\alpha) \).

where \( \alpha \) is the fraction decomposed, \( T \) the temperature (K), \( n \) is the order of reaction, \( A \) is the Arrhenius constant, \( R \) the universal gas constant, \( E_a \) the activation energy and \( \beta \) the heating rate. The plot of the left hand side of the Equation (3.9) against \( 1/T \) should be a straight line with slope \( = E_a / R \) for the correct value of \( n \).

In the case of crosslinked polymers (as the present one), a first order kinetics is usually assigned since they undergo degradation by a random process. The activation energy (\( E_a \)) was determined from the plot of \( \ln[-\ln(1-\alpha)/T^2] \) against the reciprocal of absolute temperature (1/T).

3.3 Results and discussion

3.3.1 Physical properties

Table 3.1 shows the variation of gel time, specific gravity and TSC of PCF and PFCF resins.

<table>
<thead>
<tr>
<th>Mole% of Cardanol in the resin</th>
<th>Gel time (sec.)</th>
<th>Specific gravity</th>
<th>TSC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PCF</td>
<td>PFCF</td>
<td>PCF</td>
</tr>
<tr>
<td>0</td>
<td>440</td>
<td>440</td>
<td>1.2675</td>
</tr>
<tr>
<td>2</td>
<td>455</td>
<td>455</td>
<td>1.2663</td>
</tr>
<tr>
<td>4</td>
<td>485</td>
<td>470</td>
<td>1.2515</td>
</tr>
<tr>
<td>6</td>
<td>525</td>
<td>495</td>
<td>1.2448</td>
</tr>
<tr>
<td>8</td>
<td>543</td>
<td>530</td>
<td>1.2319</td>
</tr>
<tr>
<td>10</td>
<td>575</td>
<td>555</td>
<td>1.2190</td>
</tr>
</tbody>
</table>

PFCF samples show lower gel time and specific gravity than PCF resins. The lower gel time of PFCF resin may be due to a faster rate of curing of PF resin
compared to CF resin. In PCF resin, cardanol units have been incorporated into the backbone and become an integral part of the main chain. This can slow down the curing process. The general lowering of specific gravity in cardanol-containing PF resins may be due to the bulkiness of cardanol units. The total solid content is slightly higher for PFCF resin in most cases.

Fig. 3.2 Variation of % soluble matter with cardanol content

Fig. 3.2 shows the variation of soluble matter in the cured resin with cardanol content in the resin. For both resins the soluble matter gradually increases. This indicates that the amount of unreacted cardanol or extractable oligomers increases with increase in cardanol content.

3.3.2 Mechanical properties

The effect of cardanol content on the tensile strength of resol resin is shown in Fig. 3.3. Tensile strengths of both PCF and PFCF resins decrease gradually with increase in the cardanol content. But up to 6 molar % of cardanol content in the resin, the tensile strength of the resin is not seriously affected. The fall in the tensile strength with further increase in the cardanol content may be due to a lower extent of crosslinking. This is understandable in view of the lengthy side chain. On comparing
the tensile strengths, the PCF resin shows comparatively higher strength. A more even distribution of cardanol rings can be expected in the case of PCF resin. This may lead to better tensile strength whereas a higher local concentration of cardanol can cause lower levels of polycondensation and crosslinking.

![Graph showing variation of tensile strength with cardanol content](image1)

**Fig. 3.3** Variation of tensile strength with cardanol content

![Graph showing variation of % elongation with cardanol content](image2)

**Fig. 3.4** Variation of % elongation with cardanol content
The effect of cardanol content on elongation at break is shown in Fig. 3.4. The elongation at break increases in both cases and shows a maximum between 4-6 mole percent of cardanol. The PCF resin exhibits greater increase in elongation at break compared to the PFCF resin. This may presumably be due to the difference in the distribution of cardanol units in the resin. In the case of PCF resin, the cardanol units are directly linked to the phenol units and became an integral part of the prepolymer chain. Hence the cardanol side chain is more likely to impart a plasticizing effect.

Variation of the tensile modulus of resol resin with cardanol content is shown in Fig. 3.5. Both PCF and PFCF show similar trends in tensile modulus values. Tensile moduli of both types of resols gradually decrease with increase in the cardanol content. But the decrease is more prominent in PFCF resol resin. The decrease in the modulus may be due to the plasticizing effect of the hydrocarbon chain in the cardanol.

![Fig. 3.5 Variation of tensile modulus with cardanol content](image)

The variation of energy absorption during tensile fracture is shown in Fig. 3.6. Both show similar variations in energy absorption. Here also 4-6 mole % of
cardanol content in the resol resin shows a maximum. The increase in the energy absorption indicates improved toughness of the modified resin.

Fig. 3.6 Variation of energy absorbed (at break) in tensile mode of fracture with cardanol content

Fig. 3.7 Variation of flexural strength with cardanol content

Fig. 3.7 depicts the variation of flexural strength with cardanol content. In both cases the flexural strength decreases gradually with increase in cardanol content.
At lower cardanol contents, flexural strength falls only marginally in PCF resin whereas it is still considerable in the case of PFCF resin. This may possibly be due to the heterogeneous nature of the PFCF resin. The general decrease in the flexural strength of both resol resins is due to the flexibility imparted by the aliphatic side chain in the cardanol unit. Flexural modulus of resol resins containing cardanol shows a regular decrease with increasing cardanol content (Fig. 3.8) in both cases as expected. The plasticizing effect of cardanol units and reduction in crosslink density may be responsible for the reduction of flexural modulus. An appreciable decrease in the modulus values can be observed in PFCF resol resin above 4 mole % of cardanol.

Fig. 3.9 depicts the variation of maximum displacement with molar % of cardanol. The variations in maximum displacement values with cardanol content show almost similar trends by PCF and PFCF resins in the early stages. In PCF resins the value increased slightly up to 6 molar % of cardanol and then sharply decreased. The maximum displacement values of PFCF resols showed almost steady values in the beginning. However at higher molar % of cardanol the maximum displacement values are found to have a gradual decreasing tendency.
Fig. 3.9 Variation of maximum displacement with cardanol content.

The Variation of energy absorbed in flexural mode of fracture is Fig. 3.10. In both cases, the energy absorption is increased only nominally with molar % of cardanol. Above this it shows a decreasing tendency.
However, the replacement of phenol by cardanol up to ~ 8 molar percentage does not affect both the maximum displacement and energy absorption values.

Fig. 3.11 indicates the variation of impact strength of PCF and PFCF resins with cardanol content. The impact strength of both PCF and PFCF resins are higher than the neat resin up to 7-8 mole percent of cardanol. At higher cardanol contents it decreases. The improvement in the impact strength may be due to lower crosslink densities and the flexibility imparted by the long hydrocarbon chains in the cardanol units. On comparing the impact strength of PCF and PFCF resol resins the latter shows better impact properties. As can be seen from the SEM pictures, microscopically the two constituent resins of PFCF resin exist in different phases. This heterogeneity may be the reason for the better impact strength of PFCF resin in addition to the plasticizing effect of the side chain of cardanol units.

![Fig. 3.11 Variation of impact strength with cardanol content](image-url)
Fig. 3.12 shows the variation of abrasion loss with cardanol content. It is clear from the graph that the abrasion loss increases with the increase in the cardanol content. Compared to PCF resin, PFCF shows better abrasion resistance. The CF resin phase separates during the curing process and occupies the microvoids formed by the curing of PF resins and gets separately cured therein. As a result, the density of PFCF resin is higher compared to the PCF resin and hence it exhibits higher abrasion resistance.

Fig. 3.13 Variation of hardness with cardanol content
The variation of hardness with cardanol content is shown in Fig. 3.13. For both PCF and PFCF resol resins a general lowering of hardness can be seen. The large bulky group in the cardanol imparts flexibility and softness to the cured resin due to poor molecular packing.

![Graph showing variation of hardness with cardanol content](image)

**Fig. 3.13** Variation of hardness with cardanol content

There is a general decrease in the compressive strength of the PCF and PFCF resins with increase in cardanol content as shown in Fig. 3.14. Compressive strength of both PCF and PFCF resins decreases gradually with increase in cardanol content. The plasticizing effect of cardanol as well as a lower level of packing due to the side groups may have resulted in the reduction of compressive strength of both resins.

### 3.3.3 Morphological studies

Scanning electron micrographs of neat resin, PCF4 and PFCF4 are shown in Figs. 3.15 (a) to (c).

All the micrographs contain microvoids in the cured resin. Even though all the resins were cured slowly and with care, formation of microvoids could not be avoided. The formation of microvoids is an inherent problem of PF resins even
when it contains added diluents to reduce the viscosity and facilitate easy escape of the condensation byproducts \(^{13}\).[13]

Fig. 3.15 Scanning electron micrograph of fractured surfaces of (a) PF (b) PCF4 and (c) PFCF4

Referring to Micrograph (a) the fracture path for neat resin is narrow and ends at microvoids indicating rapid crack propagation along the axis of crack growth. The fracture surface is also very smooth. Micrograph of PCF4 (b) shows a profusion of cracks far broader and the fractured surface is rougher indicating greater energy absorption. Referring to PFCF4 (c), the fractured surface is more rough and cracks are still broader. Another interesting feature of Micrograph (c) is that it contains filled microvoids. This may be due to the difference in the cure rate of PF resin and CF resin. PF resin cures at a faster rate than the CF resin. This causes the separation of CF resin
along with the condensation byproducts like water which proceed to fill the microvoids. The filling of the microvoids and broader crack areas lead to greater energy absorption than that recorded by PCF and neat resins. This is also reflected in improvement of the impact strength of PFCF resin over the other two.

3.3.4 Thermal studies

i) TGA

The thermograms of neat resin, PCF4, PCF6, PFCF4 and PFCF6 are shown in Fig. 3.16. The results of thermal studies are summarized in Table 3.2.

The temperature for 10% and 20% degradation is higher for phenolic resins containing cardanol. The initial loss is mainly due to the loss of volatiles, mainly water, from the cured resin. The reduction in the amount of volatiles in the cardanol-containing phenolic resins may be due to the repulsion between the polar volatiles and non-polar side chain units which leads to easy escape of volatiles during curing. But the temperature at maximum rate of degradation is shifted to a lower temperature range. This is because of easier degradation of the hydrocarbon chain in the cardanol unit. The hydrocarbon chain degrades normally at around 420-430°C. The residue also reduces with increase in the cardanol content. On comparing the thermal stability of PCF and PFCF resins,
Table 3.2 Thermal decomposition characteristics of cured phenolic resins

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature at different stages of degradation (°C)</th>
<th>Temp. at max. degradation (°C)</th>
<th>Residue (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
<td>20%</td>
<td>30%</td>
</tr>
<tr>
<td>PF</td>
<td>194</td>
<td>406</td>
<td>512</td>
</tr>
<tr>
<td>PCF4</td>
<td>218</td>
<td>417</td>
<td>467</td>
</tr>
<tr>
<td>PFCF4</td>
<td>288</td>
<td>434</td>
<td>472</td>
</tr>
<tr>
<td>PCF6</td>
<td>273</td>
<td>429</td>
<td>430</td>
</tr>
<tr>
<td>PFCF6</td>
<td>272</td>
<td>416</td>
<td>442</td>
</tr>
</tbody>
</table>

PFCF resin shows better thermal stability. PCF4 and PFCF4 resins show the same thermal resistance at advanced stages. This is evident from the fact that 50% degradation temperatures for PF, PFCF4 and PCF4 resins are all in excess of 800°C. Figs. 3.17 shows the kinetic plots (Coats-Redfern plots) of PF, PCF4, PFCF4, PCF6 and PFCF6 degradation. The calculated values of activation energy, $E$ along with correlation coefficient and pre-exponential factor (Arrhenius constant, $A$) are given in Table 3.3.

![Fig. 3.17 Coats-Redfern plots for phenolic resins](image-url)
The activation energy of the phenolic resin decreases as the cardanol content in the resin increases. Arrhenius constant also follows the same trend. Both the $E$ value and $A$ factor are comparably higher for PFCF resin. This indicates better thermal stability for the blend of PF and CF resins. Cardanol can lead to a decrease in thermal stability due to the presence of the long hydrocarbon chain which is more susceptible to thermal attack. However, the better thermal stability of the PFCF resin over PCF resin may be due to the stabilization of the radical formed by the thermal cleavage of the side chain of the cardanol unit by the phenolic resol resin which is a separate entity in the PFCF resin.

**Table 3.3** Activation parameters for the thermal degradation of cured resols

<table>
<thead>
<tr>
<th>Sample</th>
<th>$E$ (KJ/mol)</th>
<th>$A$ ($\times 10^2$)</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF</td>
<td>79.3</td>
<td>1.2134</td>
<td>0.9820</td>
</tr>
<tr>
<td>PCF4</td>
<td>70.6</td>
<td>0.5060</td>
<td>0.9814</td>
</tr>
<tr>
<td>PFCF4</td>
<td>70.8</td>
<td>0.5661</td>
<td>0.9802</td>
</tr>
<tr>
<td>PCF6</td>
<td>46.9</td>
<td>0.0226</td>
<td>0.9847</td>
</tr>
<tr>
<td>PFCF6</td>
<td>57.6</td>
<td>0.0557</td>
<td>0.9824</td>
</tr>
</tbody>
</table>

ii) DMA

Fig. 3.18 shows the variation of storage modulus ($E'$) of neat resin, PCF4 and PFCF4 with temperature. The initial storage modulus of the neat PF sample is higher than the other two. PFCF4 has the least storage modulus among the three. The decrease in the initial storage modulus of cardanol modified PF resin is due to the flexibility imparted by the cardanol units.
Fig. 3.18 Storage modulus (E') with temperature

Fig. 3.19 % Retention of E' with temperature

Fig. 3.19 depicts the % retention of E' with temperature. The retention of E' is greater for the neat resin. But for the samples PCF4 and PFCF4 the E' value decreased by 10-15%. The storage modulus of PFCF4 decreased sharply with the increase in temperature up to ~170°C and then increased. This may be due to residual crosslinking of PFCF4, which can result from the difference in the cure
rates of PF and CF resins. Interestingly the % retention of $E'$ at higher temperatures is higher for PFCF4 than PCF4. This supports the higher thermal stability of the former compared to the later which is confirmed by thermal studies.

![Fig. 3.20 tan δ with temperature](image)

Fig. 3.20 indicates the variation of $\tan \delta$ with temperature. The $\tan \delta$ values are very low for both the neat resin and PCF4. This may be due to the homogeneity and also high crosslink density of these resins. But the $\tan \delta$ values of PFCF4 are very high. This can be attributed to residual crosslinking and also lower crosslink density of the sample.

### 3.4 Conclusions

Phenol cardanol formaldehyde was synthesised by two different methods. The gel time increased whereas the specific gravity of uncured resin followed a reverse trend on incorporating cardanol units into the PF resin. The mechanical properties of both PCF and PFCF resins are comparable. But PFCF resins showed better impact strength and abrasion loss compared to PCF resins. The SEM micrographs of the tensile fractured samples of PCF and PFCF resins exhibit different surface morphologies. This is partly responsible for the better impact strength and abrasion loss of PFCF resins.
Thermal properties of the cardanol containing PF resins are poor compared to the neat resin due to the presence of the side chain in cardanol. However, the blends of PF and CF resins show better thermal stability than PCF resin. DMA analysis confirms better flexibility for cardanol containing PF resins, which is indicated by the lower storage modulus values for these resins. The % retention of storage modulus with temperature decreased for all samples, but the neat resin retains its rigidity to a greater extent compared to cardanol modified samples. The higher retention of E’ for PFCF resin at higher temperature compared to PCF resin shows better thermal stability of the former.

References

