CHAPTER 8
Low-density Phenolic Syntactic Foams: Processing and Properties

Low density syntactic foams based on resole resins were processed and their mechanical performance was evaluated in terms of tensile, flexural and compressive properties. The properties of the resole phenolic syntactic foams were compared with syntactic foams based on an addition cure phenolic resin, propargyl ether novolac (PN) resin. The failure mode of various composites has been analysed by SEM and temperature dependency of mechanical properties and damping characteristics by DMTA.

A part of the results of this chapter has been published:
8.1 Introduction

Phenolic resins play an important role as matrix in composite materials for thermo-structural and ablative applications in aerospace industries. These excellent properties are due to the chemical structure, which is primarily made up of C-C bonds that are present in aromatic rings which are characteristics of phenolic groups. Under thermal stress, phenolic structure slowly breaks up releasing carbon [Nair, 2004]. In the present study, an attempt has been made to develop phenolic syntactic foams with glass microballoons so that they can serve as low-density ablatives. Similar epoxy- and phenolic-based syntactic foams have been successfully used for thermal protection of atmospheric re-entry space vehicles and to prevent structures from the extreme heat flux of rocket exhaust plumes [Re-entry Technology]. Phenolic syntactic foams are important in view of their low thermal diffusivity and high char-forming properties which are desirable for a good ablative [Guthrie et al.]. Further, syntactic foams are strong enough to encounter the aerodynamic shear and have adequate mass saving advantage. The low density thermal protection systems are advantageous in reducing weight of total payload, or the lift-off weight of the launch vehicle. Syntactic foams further provide the flexibility of modifying the physical and mechanical properties as per requirement, by varying the composition of constituent materials.

Introducing addition curable groups into phenolic resins is one important strategy to develop novel phenolic resins with new cure chemistry and highly improved properties. Addition cure type phenolic resins functionalised by phenyl maleimide, phenyl ethynyl, acetylene or propargyl groups, are reported to exhibit excellent thermal properties [Nair, 2004]. Among these, propargyl ether novolac has been shown to have advantages in terms of good processability, rheology and thermal characteristics.
Propargyl ether novolac (PN) resins are synthesised by the Williamson's reaction between novolac and propargyl bromide in presence of a base [Bindu et al., 2001, Nair et al., 2004]. The thermal cure chemistry of PN resin is well established [Nair et al., 2001].

In this chapter, the variation of mechanical properties of low-density phenolic syntactic foams as a function of volume percentage of microballoon is studied. The low density has been achieved by high microballoon loadings. Phenolic syntactic foams with different volume percentages of microballoons were processed and their mechanical performance has been evaluated in terms of tensile, flexural, compressive and corresponding specific properties. Since these syntactic foams could be used as core in sandwich structures and as ablative composites, it is important to optimise the volume percentage of microballoon and resin with respect to mechanical properties. The mechanical properties (tensile strength, flexural strength and compressive strength) of the phenolic syntactic foams were compared with similarly processed syntactic foams based on PN resin. SEM analyses of the failed samples have been done to explain the observed trends in mechanical properties. Finally, a comparison has also been made on the dynamic mechanical properties of syntactic foams based on phenolic resin and PN resin.

8.2 Experimental

8.2.1 Materials

Ash free phenolic resin (AFRP) was synthesised by the reaction between phenol and formaldehyde in the presence of triethyl amine as catalyst by a proprietary process developed in VSSC. The characteristics of phenolic resole resin are compiled in Table 2.1. PN resin was synthesised by a modification of the reported procedure [Bindu et al.,
The detailed procedure for the synthesis of PN resin is given in section 2.1.1.3. Its characteristics are given in Table 2.2. The properties of microballoon (K-37) are also discussed in chapter 2.

### 8.2.2 Processing of the syntactic foams

The required amount of phenolic resin was taken in a beaker. Weighed amount of microballoon was then added in small lots. Mixing was done gently to avoid breaking of microballoons. The mixture was then placed in a rectangular mould of inner dimension 100 × 100 mm and then compression moulded to the required thickness (5 mm). In the processing of PN resin syntactic foams, since PN resin is very viscous, it was first dissolved in acetone. The solution was mixed with microballoon, and acetone was removed in vacuum oven at 60°C. The cure schedules for the two resin systems are as follows:

- **Phenolic:** 100°C (1/2 hr), 125°C (1/2 hr), 150°C (1 hr) and 180°C (2 hr)
- **PN resin:** 120°C (1/2 hr), 150°C (1 hr), 170°C (1 hr), 185°C (1 hr), 200°C (1/2 hr), 230°C (2 hr), 250°C (2 hr)

Stepwise curing was adopted in order to obviate the possibility of abrupt polymerisation at elevated temperature. The resin gets consolidated at lower temperature precluding the melt flow at high temperature on sudden increase in temperature.

100×100×5 mm blocks were fabricated for preparation of tensile, flexural and compressive strength test coupons. To study the impact of microballoon concentration, syntactic foams with different densities were processed by varying the volume percentage of microballoon. The density and volume percentage of each constituent in
the syntactic foams were determined and are given in Table 8.1. The samples Pl to P5, and PNM given in Table 8.1 correspond to phenolic and PN resin syntactic foams respectively.

8.2.3 Characterisation of the syntactic foams

The tensile, flexural and compressive properties of the foam composites were studied in accordance with ASTM D-3039, ASTM D-790 and ASTM D-695 respectively. A minimum of three specimens were analysed for tensile and flexural properties and five samples for compressive properties and the average value is reported. Dynamic mechanical properties of the foam composites were studied using the test method given in section 2.2.6. SEM analysis of the flexurally failed samples was done to study the failure mode of the foam composites.

8.3 Results and discussion

8.3.1 Curing of PF and PN resin

The cure schedule of PF resin was arrived at based on earlier work on cure kinetic study of phenolic resin [Pradeepa, 2002]. A typical rheogram depicting the cure profile of PF resin under dynamic conditions is given in Figure 8.1. The curing of PF resin occurs in three major steps. The first peak in rheogram at around 135-150°C is attributed to the addition of residual formaldehyde to the phenol. The rapid increase in modulus at 155°C is due to the major curing by the condensation of methylol groups. Part of the methylol groups condenses to form dimethylene ether linkages that undergo further condensation at ~180°C to form the methylene bridge (as shown in Scheme 8.1). These cure sequences are manifested in the DSC thermograms too as shown in Figure 8.2. The isothermal DMA of phenolic resin at 180°C is shown in Figure 8.3. The
modulus ($G'$) stagnates after one hour implying cure completion. The cure schedule of PF resin is fixed as 100°C (1/2 hr), 125°C (1/2 hr), 150°C (1 hr) and 180°C (2 hr).

Figure 8.1 Non isothermal DMA of phenolic resin at 5°C/min [Pradeepa, 2002]

Scheme 8.1 Various curing reactions in PF resin
Figure 8.2 DSC thermogram showing different reactions taking place during the curing of PF resin

Figure 8.3 Isothermal DMA of PF resin at 180°C [Pradeepa, 2002]

The cure schedule of PN resin was chosen based on detailed cure studies carried out earlier [Nair et al., 2004]. Non-isothermal DMA (Figure 8.4) was used to evaluate the gel time and cure time. From the figure it is evident that the resin cures at 200-220°C. The time for stagnation of storage modulus $G'$ in isothermal rheogram is indicative of the cure time, and this decreases with increase in temperature as shown in Figure 8.5. Since curing of PN resin is very exothermic (1.2 kJ/g), it is pre-cured at
lower temperature for longer periods. The cure schedule for PN resin is fixed as 120°C (1/2 hr), 150°C (1/2 hr), 170°C (1 hr), 185°C (1 hr), 200°C (1/2 hr), 230°C (2 hr), 250°C (2 hr). Post curing at 250°C ensures complete cure. The cure mechanism of PN resin is well documented as shown in Scheme 8.2.

![Figure 8.4 Non-isothermal DMA of PN resin in air. Heating rate 5°C/min. Parallel plate rheometry, controlled stress at 100 Pa, 4 Hz [Nair et al., 2004].](image)

![Figure 8.5 Cure profiles for propargyl novolac resin in air at different temperatures by parallel plate rheometry in controlled strain mode [Nair et al., 2004].](image)
8.3.2 Density profile of the syntactic foams

The density and volume percentage details of the syntactic foams are given in Table 8.1. The density of the foams decreased with increase in microballoon volume percentage due to the incorporation of low-density microballoons. The variation of density with volume percentage of microballoon is shown in Figure 8.6. The measured densities of the syntactic foams were lower than the theoretical value due to the entrapment of air during the mechanical mixing of the constituents of the foam. These entrapped air acts as voids in the syntactic foam. The void percentage has been calculated using the relation,

$$\text{Void percentage} = \frac{V - [W \times W_R / \rho_R + W \times W_M / \rho_M]}{V} \times 100$$

where $V$ and $W$ are the volume and weight of foam block; $W_R$ and $W_M$ are the weight fractions of resin and microballoon; $\rho_R$ and $\rho_M$ are the density of the resin and the true density of the microballoon, respectively.
density of microballoon respectively. This void content excludes the void created by the empty space within the microballoon.

Table 8.1 *Composition and density of the processed syntactic foams*

<table>
<thead>
<tr>
<th>Syntactic foam code</th>
<th>Composition (Vol. percentage)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Resin</td>
<td>Microballoon</td>
</tr>
<tr>
<td>Pl</td>
<td>26.5</td>
<td>68.5</td>
</tr>
<tr>
<td>P2</td>
<td>22.3</td>
<td>72.1</td>
</tr>
<tr>
<td>P3</td>
<td>19.0</td>
<td>73.9</td>
</tr>
<tr>
<td>P4</td>
<td>16.8</td>
<td>76.0</td>
</tr>
<tr>
<td>P5</td>
<td>15.3</td>
<td>79.3</td>
</tr>
<tr>
<td>PNM</td>
<td>26.8</td>
<td>70.2</td>
</tr>
</tbody>
</table>

Figure 8.6 *Dependency of density on volume percentage of microballoon*

The void content is lower in PN resin syntactic foam (PNM) than in phenolic syntactic foam (P1) with almost the same density. The higher void content in phenolic syntactic foam can be attributed to the inherent property of resole phenolic resin to form voids during curing, due to the evolution of volatiles. Therefore, for syntactic foams
containing same material composition, PN resin syntactic foams exhibited marginally higher density than phenolic syntactic foams. The processed phenolic syntactic foams exhibited lower void content than what is reported in literature for other syntactic foams. This is due to the wide range of particle size distribution of the microballoons, which makes it possible for low size microballoons and resin to occupy voids created by the arrangement of large size microballoons as illustrated in the SEM picture (Figure 8.7). Since void content is an important factor affecting the mechanical properties of syntactic foams, the lower void content in PN resin syntactic foam is advantageous. The density of the syntactic foams is higher than that of cellular foams due to inclusion of glass microballoon fillers.

![SEM picture illustrating the well packing of small and large microballoons in P2](image)

**Figure 8.7** SEM picture illustrating the well packing of small and large microballoons in P2

### 8.3.3 Mechanical properties of the phenolic syntactic foams

The mechanical properties of phenolic syntactic foams (P1-P5), PN resin syntactic foam (PNM) and neat resin [Landrock, 1995] are listed in Table 8.2. Though inferior to the neat resin properties, the tensile strength (TS) and flexural strength (FS) increased with increase in microballoon volume percentage and maximised at 72-74
percentage by volume of microballoon. The properties decreased on further addition of microballoon in the present series. The variation in tensile and flexural strength with microballoon volume fraction can be related to the difference in interfacial bonding between microballoon and resin upon microballoon loading. The interfacial strength has been found to vary with microballoon volume fraction. When the resin content is high, smearing of the resin over microballoon occurs, making the interfacial strength excellent. Therefore, we expect tensile and flexural strength to decrease with increase in microballoon volume fraction. But in the present study, initially the tensile and flexural strength values were found to increase with increase in microballoon content. This has been attributed to the inherent brittle nature of phenolic resin, which is reduced by adding microballoons at low volume percentages. Therefore, the microballoons act as a kind of reinforcing filler at low loading levels. Therefore, the tensile and flexural strength increased initially.

**Table 8.2 Mechanical properties of the syntactic foams**

<table>
<thead>
<tr>
<th>Sample reference</th>
<th>TS (MPa)</th>
<th>FS (MPa)</th>
<th>CS (MPa)</th>
<th>STS (MPa/kg/m³) x 10³</th>
<th>SFS (MPa/kg/m³) x 10³</th>
<th>SCS (MPa/kg/m³) x 10³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neat resin</td>
<td>20-70</td>
<td>50-105</td>
<td>70-210</td>
<td>18-58</td>
<td>40-88</td>
<td>58-175</td>
</tr>
<tr>
<td>P1</td>
<td>8 ± 2</td>
<td>17 ± 2</td>
<td>35 ± 3</td>
<td>14 ± 4</td>
<td>30 ± 4</td>
<td>61 ± 5</td>
</tr>
<tr>
<td>P2</td>
<td>13 ± 3</td>
<td>24 ± 1</td>
<td>25 ± 2</td>
<td>24 ± 6</td>
<td>44 ± 2</td>
<td>46 ± 4</td>
</tr>
<tr>
<td>P3</td>
<td>14 ± 2</td>
<td>21 ± 1</td>
<td>19 ± 2</td>
<td>28 ± 4</td>
<td>42 ± 2</td>
<td>38 ± 4</td>
</tr>
<tr>
<td>P4</td>
<td>13 ± 1</td>
<td>18 ± 2</td>
<td>17 ± 3</td>
<td>27 ± 2</td>
<td>37 ± 4</td>
<td>35 ± 6</td>
</tr>
<tr>
<td>P5</td>
<td>9 ± 1</td>
<td>13 ± 1</td>
<td>14 ± 1</td>
<td>19 ± 2</td>
<td>28 ± 2</td>
<td>30 ± 2</td>
</tr>
<tr>
<td>PNM</td>
<td>6 ± 1</td>
<td>9 ± 1</td>
<td>12 ± 2</td>
<td>10 ± 2</td>
<td>16 ± 2</td>
<td>21 ± 3</td>
</tr>
</tbody>
</table>
The decrease in tensile and flexural strength after attaining a maximum value can be ascribed to the poor wetting of microballoons by resin, which renders the resin to microballoon interface weak. The syntactic foams failed easily at high volume fraction of microballoon due to easy debonding between microballoon and matrix. A similar trend of increase in mechanical properties with increase in microballoon concentration followed by decrease in the properties with further microballoon concentration has been reported for polybenzoxazine-based syntactic foams. In the case of polybenzoxazine syntactic foams, the optimum properties were observed at 68 vol % of microballoons [Kumar, 2008; Kumar et al., 2008].

The compressive strength (CS) showed a gradual decrease in value with increase in microballoon volume percentage, i.e. the compressive strength decreased with decrease in density of the syntactic foams. The compressive strength of the three-phase syntactic foams primarily depends upon properties of microballoon, the degree to which they can be packed into a volume i.e. density and strength of the bond holding the microballoons [Whitehouse et al., 1967]. The resin carries most of the load during compressive loading. Neat phenolic resin is having a compressive strength in the range 58-175 MPa [Landrock, 1995]. However, when microballoons are incorporated, the compressive strength decreases due to the easy crushing of microballoons, which is having average crush strength of ca. 20 MPa only. Thus, inclusion of microballoon interrupts the transfer of load in the matrix, acting as weak points for the failure of the material.

The specific mechanical properties of the syntactic foams, which are very important in comparing syntactic foams with different densities, are included in Table 8.2. The specific mechanical properties followed the same trend as the corresponding
mechanical properties. i.e. specific tensile and flexural strength get optimised at 72-74 percentage by volume of microballoon. However, specific compressive strength consistently decreased with increase in microballoon volume percentage. This shows the high susceptibility of the compressive property to the microballoon loading. Though the compressive strength goes on decreasing with microballoon volume percentage, syntactic foams with a particular density can be chosen depending upon the strength requirement. It may be remarked that although the inclusion of microballoon considerably decreased the mechanical properties, the specific properties of some of the syntactic foams were comparable with those of the neat resin. This point out the applicability of phenolic syntactic foams for use in lightweight structural materials.

The flexural and compressive modulus values of the phenolic syntactic foams with different microballoon volume percentage are given in Table 8.3. Both the modulus values followed the same trend as the corresponding strength values.

**Table 8.3 Flexural and compressive modulus values of the syntactic foams**

<table>
<thead>
<tr>
<th>Syntactic foam code</th>
<th>Flexural modulus (GPa)</th>
<th>Compressive modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>2.5 ± 0.2</td>
<td>1050 ± 50</td>
</tr>
<tr>
<td>P2</td>
<td>3.8 ± 0.2</td>
<td>890 ± 20</td>
</tr>
<tr>
<td>P3</td>
<td>3.1 ± 0.3</td>
<td>770 ± 40</td>
</tr>
<tr>
<td>P4</td>
<td>2.9 ± 0.1</td>
<td>530 ± 20</td>
</tr>
<tr>
<td>P5</td>
<td>2.2 ± 0.2</td>
<td>480 ± 10</td>
</tr>
</tbody>
</table>

The mechanical properties of the phenolic syntactic foam (P1, density=570 kg/m$^3$) have been compared with PN resin based syntactic foam of comparable density
Low-density Phenolic Syntactic Foams: Processing and Properties

(PNM, density=581 kg/m³). The mechanical properties of PN resin syntactic foam showed inferior values for tensile, flexural and compressive properties, even though it exhibited slightly lower void content. PN resins possess very few -OH groups and is generally hydrophobic and it may not get the microballoon wet as good as the conventional phenolics. Previous observations have also shown that PN resins do not yield strong composites [Nair et al., 2004].

The mechanical properties for various phenolic foam systems viz. phenolic syntactic foams with IG-101 and silas microballoon [Okuno and Woodhams, 1974], conventional phenolic foams [Okuno and Woodhams, 1974], syntactic foams based on polybenzoxazine [Kumar et al., 2008], and syntactic foams based on epoxy-allyl phenol-bismaleimide blend [Devi et al., 2007] (chemical structure of the resins shown in Scheme 8.3) are given in Table 8.4.

Scheme 8.3 Structure of individual resins in epoxy-allyl phenol-bismaleimide blend, (a) dialyl bisphenol A (DABA), (b) Novolac epoxy (EPN) resin and (c) bismaleimido bisphenol A (BMI-P)
Table 8.4 Comparison of the mechanical properties of various phenolic foam systems

<table>
<thead>
<tr>
<th>System</th>
<th>MB type</th>
<th>Density (kg/m(^3))</th>
<th>Vol. % of MB</th>
<th>Tensile strength (MPa)</th>
<th>Flexural Strength (MPa)</th>
<th>Compressive Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenolic K-37</td>
<td>570</td>
<td>68.5</td>
<td>8</td>
<td>17</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>PN resin K-37</td>
<td>581</td>
<td>70.2</td>
<td>6</td>
<td>9</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Phenolic IG-101</td>
<td>800</td>
<td>60</td>
<td>-----</td>
<td>23</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Phenolic Silas</td>
<td>820</td>
<td>60</td>
<td>-----</td>
<td>9.5</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Polybenzoxazine K-37</td>
<td>512</td>
<td>61.4</td>
<td>1.0</td>
<td>3.8</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Phenolic foam (Cellular)</td>
<td>800</td>
<td>-----</td>
<td>-----</td>
<td>11</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Epoxy-allyl phenol-bismaleimide blend</td>
<td>540</td>
<td>-----</td>
<td>18</td>
<td>29</td>
<td>51</td>
<td></td>
</tr>
</tbody>
</table>

Phenolic syntactic foams processed using K-37 microballoons exhibited superior mechanical properties compared to syntactic foams based on polybenzoxazines. However, the mechanical properties showed lower value than syntactic foams based on epoxy-allyl phenol-bismaleimide blend. The specific mechanical properties of phenolic syntactic foams with K-37 exhibited higher values than phenolic syntactic foams with IG-101 and silas microballoons and conventional phenolic foams.

8.3.4 Microscopic fracture analyses of the syntactic foams

In order to explain the various failure modes, the SEM pictures of the flexurally failed samples of the syntactic foams have been presented. In the case of syntactic foams with high resin concentration, matrix fracture and microballoon breakage are the important factors that contribute to foam failure. The SEM pictures of the flexurally
failed samples of P1 and PNM, which have the almost same composition, are shown in Figure 8.8 (a) and 8.8 (b) respectively. The more void content in P1 is evident from the SEM picture (Figure 8.8 (a)). In the case of P3, which is having the highest tensile and flexural properties, the failure occurs by a combination of microballoon breakage, matrix fracture and microballoon debonding (Figure 8.9). Here, the fracture surface appears to be more intact.

![Figure 8.8](image1.png)

(a)

![Figure 8.8](image2.png)

(b)

**Figure 8.8** SEM picture of the flexurally failed surface of (a) P1 and (b) PNM illustrating matrix fracture and microballoon breakage as the dominant failure modes.
Figure 8.9 SEM image of P3 depicting matrix fracture, microballoon debonding and microballoon breakage

When the resin content is low, microballoon breakage and microballoon debonding were found to be the major failure modes, as evident in the SEM picture of P4 and P5 (Figure 8.10 (a) and 8.10 (b) respectively). The bonding among the microballoons is very weak in these cases as seen from the SEM pictures. Thus, moving from the high resin content case to low resin one, the failure mode changes from matrix fracture and microballoon breakage to microballoon debonding and microballoon breakage.
8.3.5 Dynamic Mechanical Analysis of the syntactic foams

The dynamic mechanical properties of both phenolic and PN resin syntactic foams were studied to assess their temperature capabilities. The dynamic mechanical properties of the composite samples were obtained from the DMA curves. The modulus values obtained from the DMA are of great importance since it gives an idea about the viscoelastic behaviour of polymeric and composite materials. The variation of storage modulus (or elastic modulus, $E'$) and tan delta (damping coefficient) over a wide range of temperature (35-300°C) has been studied for P1 and PNM. The typical DMA thermograms of P1 and PNM are shown in Figure 8.11 (a) and 8.11 (b).

The storage modulus values gradually decreased with increase in temperature for both the syntactic foams. In the case of PNM, the decrease of storage modulus with temperature is linear up to 300°C, whereas for P1, there is a steep reduction in the $E'$ in the temperature range 160-210°C. The stiffness values of the syntactic foams are dominated by the rigid glass microballoons, which do not undergo any transition in this temperature range. Thus, the steep decrease in storage modulus for P1 in the temperature
Figure 8.11 The variation of (a) storage modulus and (b) tan delta with temperature for Pl and PNM
range 160-210°C is a feature of phenolic resin which is known to undergo softening in this temperature range. $T_{\text{max}}$, the maximum use temperature of the syntactic foams is taken as the temperature at which the storage modulus starts decreasing steeply in the thermograms. $T_{\text{max}}$ assessed this way, was found to be 160°C for P1. This is a useful input for structural design involving these foams as far as thermal performance is concerned. PN resin has a $T_g$ greater than 300°C [Wang et al., 2006] and the continuous decrease in $E'$ cannot be attributed to the damping of the resin. Rather, it implies a weak bonding between the microballoon and resin which relaxes the applied stress. The tan $\delta$ profile shows a maximum at 200°C for phenolic, in tune with $T_g$ of the cured matrix. For PN resin syntactic foam the maximum occurs at 270°C, close to the resin $T_g$. Analysis shows that the absolute tan $\delta_{\text{max}}$ values of the syntactic foams are lower than those of the neat resin materials, due to diminution in overall flexibility as a result of the rigid fillers.

8.4 Conclusions

Low-density phenolic syntactic foams with different densities were prepared by varying the volume percentage of microballoon. The dependence of tensile, flexural, compressive and the corresponding specific properties on the volume percentage of the microballoons has been investigated. Tensile and flexural strength of the composite increased with volume fraction of microballoon and maximised at 72-74 percentage by volume of microballoon. Both the properties decreased with further addition of microballoon. The corresponding specific properties also manifested similar order. Compressive and specific compressive strength decreased with increase in volume percentage of microballoon. The flexural and compressive modulus values also followed the same trend as respective strength values. The mechanical properties and dynamic mechanical properties of the phenolic syntactic foam were better than those of...
PN resin based syntactic foams of the same composition. PN resin syntactic foams exhibited lower void content than phenolic syntactic foams. PN resin has comparatively poor binding property. This is evident from the continuous decrease in modulus with temperature for PN resin syntactic foam. The $T_g$ of PN resin syntactic foam is higher ($270^\circ\text{C}$) than that of phenolic syntactic foam ($200^\circ\text{C}$). The combined effect of good specific mechanical properties and the likely ablative characteristics make these syntactic foams important light weight aerospace materials.