

# Sequential Interpenetrating Polymer Networks from Bisphenol A Based Cyanate Ester and Bismaleimide: Properties of the Neat Resin and Composites

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**ABSTRACT:** Blends of varying composition of a bisphenol A based cyanate ester—viz., 2,2-bis-(4-cyanatophenyl) propane (BACY)—and a bisphenol A based bismaleimide—viz., 2,2-bis[4-(4-maleimido phenoxy) phenyl] propane (BMIP)—were cured together in a sequential manner to derive bismaleimide–triazine network polymers. Enhancing the bismaleimide content was conducive for decreasing the tensile properties and improving both the flexural strength and fracture toughness of the cyanate ester-rich neat resin blends. Although DMA analyses of the cured blend indicated a homogeneous network for the cyanate ester dominated compositions, microphase separation occurred on enriching the blend with the bismaleimide. Addition of bismaleimide did not result in any enhancement in  $T_g$  of the blend. Interlinking of the two networks and enhancing crosslink density through coreaction with 4-cyanatophenyl maleimide impaired both the mechanical and fracture properties of the interpenetrating polymer network (IPN), although the  $T_g$  showed an improvement. Presence of the bismaleimide was conducive for enhancing the mechanical properties of the composites of the cyanate ester rich blend, whereas a higher concentration of it led to poorer mechanical properties due to the formation of a brittle interphase. The IPNs showed reduced moisture absorption and low dielectric constant and dissipation factor, the latter properties being independent of the blend composition. © 1999 John Wiley & Sons, Inc. *J Appl Polym Sci* 74: 2737–2746, 1999

**Key words:** bisphenol A dicyanate; bisphenol bismaleimide; bismaleimide–triazine resins; sequential IPN; network interlinking; cyanatophenyl maleimide

## INTRODUCTION

Cyanate esters have evinced a lot of interest in high-performance applications in view of their attractive physical, dielectric, thermal, and mechanical characteristic. A large variety of cyanate ester resins with different backbone structures and properties are available. Among them, Bisphenol A dicyanate (BACY) is very versatile and is an ideal thermoset resin possessing most of the

above properties. The search for achieving further improvements in performance and reduction in cost have led to blends of these resin systems with a variety of thermoplastics and thermosets. Depending on the nature of the component of the blend, coreacted matrix or interpenetrating networks result. Several reports pertaining to synthesis and applications of various cyanate systems and their blends can be found in the recent reviews devoted to this area.<sup>1,4</sup> Among the blend components, bismaleimides (BMI) and epoxies have evinced special interest.

Bismaleimide–triazine resins (B-T resins) derived from the blend of dicyanate ester and bis-

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maleimide resins claim superiority over the component homopolymers in terms of physical and mechanical characteristics. Whereas the cyanate ester imparts processability and toughness, the bismaleimide confers thermal stability to the blend system. Several blends of bismaleimide and dicyanate ester have already been reported. Commercial blend formulations of bismaleimide-cyanate known as B-T resins such as Skyflex of Mitsubishi Gas Chemical Co. are available.<sup>5,6</sup> Several patented B-T resin formulations have been claimed and they find applications such as in electric motor coil windings, engineering materials in aircraft, reinforced plastics and injection moulding powders and in high speed circuits, etc.<sup>7,8</sup> The majority of the reported B-T systems contains bismaleimide such as bis(4-maleimido phenyl) methane or naphthalene based bismaleimides<sup>9</sup> with very high crosslink densities. It was earlier postulated that the two resins coreact during curing, but lack of support for the coreaction has now led to the conclusion that the two systems form an interpenetrating polymer network (IPN) and not a cocured matrix.<sup>10,11</sup> The IPN formed in these cases have been found to exhibit two  $T_g$ s and the use temperature of the blend is limited by the low  $T_g$  component.<sup>12-14</sup> The two  $T_g$ s result from the microphase separation caused by the two incompatible polymers. One way to obviate this is the addition of network linkers to promote the coreaction of the components and thereby facilitate partial homogenization of the linked B-T IPN matrix with concomitant improvement in  $T_g$ .<sup>12</sup> Alkenyl functional cyanate esters appear to be ideal for this purpose since they can serve the purpose of network interlinking through coreaction of the alkenyl function with maleimide. Several studies have focused on this area.<sup>12,15,16</sup> The coreaction between allyl and maleimide groups have been established.<sup>17</sup> An alternate method appears to realize a three-component blend wherein the B-T system can be blended with a molecule possessing both maleimide and cyanate groups. A recent patent claims such molecules.<sup>18</sup> Although this patent has claimed the superior thermal characteristics of the polymer of *m*-cyanatophenyl maleimide over poly(BACY) and improvement in mechanical characteristics on cocuring the asymmetrical crosslinker—viz., 4-(1-(*p*-maleimidophenyl)-1-methyl-ethyl) phenylcyanate (possessing both cyanate and maleimide groups)—with BACY, the role of these molecules as network interlinker in B-T systems has not been examined.

A viable method to realize compatible B-T systems appears to be based on selection of components having closely resembling structures to facilitate miscibility. The present study focuses on this approach. It describes the synthesis of a B-T system that comprised a polycyanurate derived from BACY and polybismaleimide formed from 2,2-*bis*-[4-(4-maleimido phenoxy) phenyl]propane (BMIP). Both monomers are based on bisphenol A and their structural similarity is expected to facilitate good miscibilization and thereby reduce probability of phase separation in the cured network. Moreover, BMIP has a relatively low crosslink density in the network to be formed. In a previous article, the cure and thermal characteristics of the blends were investigated.<sup>19</sup> The study revealed that in presence of dibutyl tin dilaurate (DBTDL), the components of the blend underwent curing sequentially and independently, possibly to form a sequential IPN. The study also led to optimization of the cure conditions of the blend.

The objective of the present work is to examine the dependency of physical, mechanical, and fracture properties, and of the dynamic mechanical behavior, of the cured system on the composition of the blend. The mechanical properties of the laminate composites as a function of the composition of the matrix are also described. This work also examines the effect of a network link agent (phase miscibilizer) on these properties of a typical neat resin blend.

## EXPERIMENTAL

### Materials and Monomers

Syntheses of BACY, BMIP, and 4-cyanatophenyl maleimide (CPM) have been described elsewhere.<sup>19</sup> Methyl ethyl ketone (MEK, Qualigens, India) was of reagent grade. Silane-treated, plain-weave E-glass of 0.18 mm thickness (Unnathi corporation, India) was used for composite fabrication. Dibutyl tin dilaurate (DBTDL, E Merck) was used as received.

### Instruments

Dynamic mechanical analysis was performed using a DuPont DMA-983 in nitrogen atmosphere at a frequency of 1 Hz and at a heating rate of 5 K/min. Samples were damped between two parallel vertical arms and subjected to flexural bend-

ing deformation mode of strain. Specimens of dimension  $60 \times 12 \times 2 \text{ mm}^3$  were used for analyses. The morphology of the polymer blends was studied with the help of scanning electron microscopy (SEM) with an accelerating voltage of 19 kV. A conductive layer of gold was coated over the fractured surface by plasma vapor deposition technique and were viewed with a Stereoscan MK250 Microscope (Cambridge Instruments).

### Preparation of Neat Resin Moulding

The blends of BACY and BMIP in different proportions (along with CPM in relevant cases) were melted separately and thoroughly mixed at 120°C. The liquid mixture was deaerated under vacuum at this temperature for 45 min. The temperature was brought down to 100°C, and DBTDL (0.1% by weight of BACY) was added to it and mixed well while keeping the mixture at this temperature for 40 min for prepolymerization. The moderately viscous resin thus obtained was then poured into an aluminum mold containing a thin coating of silicon mold release agent. It was cured by stagewise heating in an air oven. The polymerization was carried out at 150°C for 90 min and at 220°C for 1 h. The formed sheet was taken out and postcured in an air oven at 250°C for 3 h.

### Preparation of Composites

Glass cloth was impregnated with the MEK solution of the prepolymerized resin (concentration of BACY: 55% by weight) and dried at room temperature for about 18 h. They were cut into pieces of dimension  $12 \times 10 \text{ cm}^2$ , stacked, and molded in a hydraulic press between thick metallic platen to achieve the proper number of plies and thickness (around 5 mm). The stack was initially heated at 100°C for about 45 min until the resin flow ceased. Then the system was cured by programmed heating from 100 to 250°C as follows:

Temp (°C)	100	150	200	250
Hold Time (min.)	30	60	60	60

A pressure of 200 psi was maintained throughout the temperature regime. The laminates were then postcured at 250°C in an air oven for 2 h in a free-standing mode.

### Mechanical Testing

The test specimens were machined from the cured sheet (both for neat resin and for the composite)

and tested in accordance with the following American Society for Testing and Materials (ASTM) testing standards using an Instron universal testing machine, model 4202.

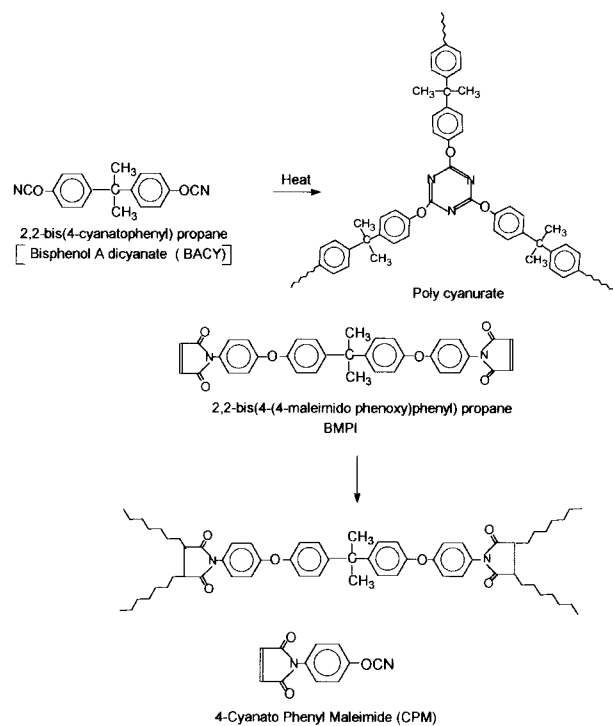
Tensile tests	ASTM D638	(neat resin molding)
Fracture toughness	ASTM STP 410	(neat resin molding)
Flexural strength	ASTM D790	(neat resin molding and composite)
0° Compressive strength	ASTM D3410	(composite)
Interlaminar shear strength (ILSS)	ASTM D2344	(composite)

### Determination of Resin Content

The resin content in the composite was determined by pyrolysis of the specimens in air at 800°C for 4 h and estimating the mass loss. The resin content was in the range 26–30% by weight.

## RESULTS AND DISCUSSION

Blends of BMIP and BACY in varying proportions were cured in presence of 0.1% of DBTDL (with respect to BACY). The blend was cured in steps of increasing temperature and a final cure of 3 h at 250°C was given as suggested from the cure analysis of the prepreg by dynamic mechanical analyses. The two monomers were found to cure sequentially and independently, and hence it was concluded that they form an IPN. The polymerization is shown in Scheme 1. The earlier study has established that the polycyanurate formed in presence of DBTDL has practically the same structure and physical and mechanical properties as those obtained by other reported catalysed polymerizations.<sup>20</sup> Although there may be contributions by other mechanisms to a minor extent as observed in previous studies,<sup>21</sup> the major polymerization is expected to proceed by the cyclotrimerization of the cyanate groups. Bismaleimides are known to undergo polymerization by other mechanisms in the presence of added nucleophiles. However, the principal mechanism of thermal polymerization is by the addition polymerization as depicted in Scheme 1. Detailed cure studies had been performed to arrive at the optimum cure conditions of the blend.<sup>19</sup> During formation of the IPN, network interlocking has been found to retard the polymerization kinetics of the components of the blend.<sup>22</sup> Such an aspect was not



**Scheme 1** Structures of components of the blend and mechanism of network formation.

considered here during the cure analysis, since the optimization was done in terms of the mechanical strength buildup of the cured blend as monitored by both isothermal and dynamic DMA.

### Mechanical Properties of Blends

Polycyanurates are generally tougher than epoxies and bismaleimides. The mechanical properties are also good. Since bismaleimides are brittle, they cannot be served per se without toughening either through chemical modification or through blending. Toughening with thermoplastics and rubbers generally risks the thermomechanical

properties of bismaleimides. Hence, it was of interest to see whether these properties are amended through formation of an IPN between the two systems. An earlier study on similar IPN has claimed the toughening of bismaleimides with polycyanurates, although no data on fracture properties were given.<sup>12</sup> Majority of the reports on bismaleimide-cyanate ester IPNs are in the form of patents wherein the bismaleimide components are characterized by high crosslink density. In the present study, a bismaleimide (BMIP), having appreciable spacing between the double bonds, constituted by flexible phenyl ether groups, has been employed. This molecule is expected to be tougher than the conventional bismaleimides and bears some structural resemblance to the dicyanate ester. The structural similarity of the components is expected to minimize the probability of phase separation in the IPN to be formed on curing.

The mechanical properties of the cured blends were evaluated as function of the blend composition. The compositions richer in BMIP were found to be relatively brittle and possessed high propensity to develop microvoids on curing. They were difficult to mold in the free-standing mode and subsequently cut into void-free test specimens. Hence, only the cyanate-rich systems were considered for neat resin castings. Blend compositions with BMIP contents up to 40% by weight were molded and analyzed for tensile properties and fracture toughness by ASTM procedures. Results are given in Table I.

### Tensile and Flexural Properties

On blending with BMIP, the tensile strength of polycyanurate was found to decrease. Polybismaleimides are generally characterized by poor tensile properties and the reduction in tensile strength in the IPN is an effect of averaging of the

**Table I** Mechanical Properties of Neat Resin Moldings

Ref. of IPN	Composition (wt % of BMIP)	$K_{1C}$ (MN/m <sup>3/2</sup> )	Tensile Strength (MPa)	Elongation (%)	Tensile Modulus (MPa)	Flexural Strength (MPa)
BT0	0	3.8	70	2.4	3140	95
BT1	10	3.5	68	2.3	3100	100
BT2	20	3.4	64	2.3	3531	105
BT3	30	4.1	59	2.1	3825	114
BT4	40	5.3	46	1.6	3603	117

**Table II** Effect of Network Interlinker (CPM) on Mechanical Characteristics of the IPN, BT3

Polymer Reference	Wt % of CPM	$K_{1C}$ (MN/m <sup>3/2</sup> )	Tensile Strength (MPa)	Elongation (%)	Tensile Modulus (MPa)	Flexural Strength (MPa)
0BT3-0	0	4.1	59	2.1	3825	114
BT3-5	5	3.5	70	2.2	3745	92
BT3-10	10	3.1	71	2.7	3431	88
BT3-15	15	3.2	62	1.9	3991	86
BT3-20	20	2.7	44	1.3	3562	86

two systems. The increased crosslink density contributed by the bismaleimide is responsible for the enhanced modulus and reduced elongation. However, the flexural strength showed an increasing trend on enhancing the polybismaleimide content in the network. Since the specimen are subjected to a combination of compressive and tensile load under three-point bend for the flexural test, the enhanced flexural strength indirectly implies an improvement in the compressive strength imparted by the maleimide.

### Fracture Toughness

The fracture toughness measures the stress intensity factor or the resistance of the material towards initiation of crack. The results show that the mode I fracture toughness ( $K_{1C}$ ) tends to decrease in the beginning and subsequently increases on enhancing the maleimide content. The brittle bismaleimide network might be triggering the crack propagation at lower concentrations of it in the network. However, blocking of the propagating cracks by the IPN junctions at higher concentration of the maleimide must be outweighing its role in initiation of the crack.

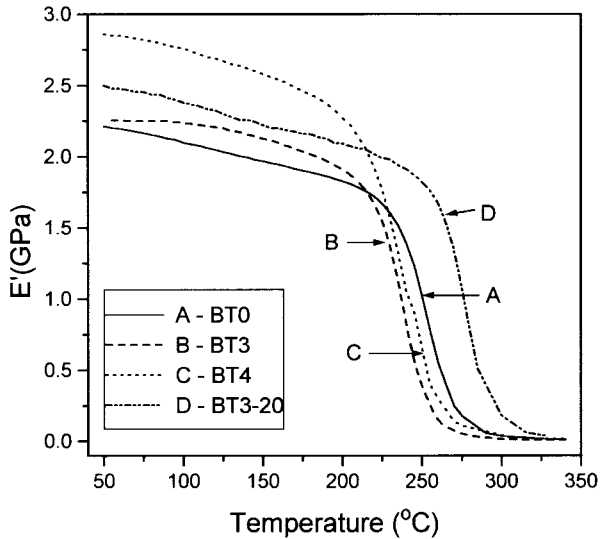
### Effect of Network Linker on Mechanical and Fracture Properties

In an earlier study, a bisallyl dicyanate was used as a network linker on polycyanurate–polybismaleimide IPN and was found to enhance the  $T_g$ , while retaining the fracture characteristics particularly in unidirectional composites.<sup>12,23</sup> However, the effect on mechanical properties of neat resin moldings has not been described. In the present work, a new network interlinker—viz., CPM—was served at different concentration levels in a typical IPN blend constituted by 30% of BMIP (i.e., BT3). Since CPM contains both cy-

anate and maleimide groups, its role in network interlinking is unambiguous. Although, 3-cyanatophenyl maleimide has been claimed in a patent, it has not been examined as a network linker in IPN.<sup>18</sup> CPM was synthesized from *N*-(4-hydroxy)phenyl maleimide as described previously.<sup>19</sup> The mechanical properties and fracture toughness of the neat resin moldings, containing varying concentrations of CPM, were studied, and results are compiled in Table II. Tensile strength and elongation showed a decreasing trend, particularly at concentrations exceeding 10% of CPM. The flexural strength showed a systematic decrease with increasing concentration of CPM. There is an overall increase in modulus, although the variation with composition is not regular. All these results point to the fact that interlinking impairs the mechanical properties. This is particularly reflected in a rapid decrease in the fracture toughness values on enhancing the CPM concentration in the IPN. It appears that CPM leads to increased crosslink density of the IPN, which totally accounts for the observed trend in all mechanical properties of the system containing it. In previously reported cases, the interlinker has been tried in cyanate/BMI blends that are inherently incompatible, wherein the interlinker helps homogeneous the network, leading to improved fracture properties. It may be remarked that the interlinker chosen in this study has extremely short spacing between the functional groups and its participation in the network formation leads to higher crosslinking causing drastic impairment of mechanical properties of the resultant IPN.

### Dynamic Mechanical Analysis of IPNs

Earlier reports on similar IPNs have demonstrated existence of two  $T_g$ s in the DMA analyses due to the existence of microphases in the IPN.<sup>13,14</sup> The DMAs of the pure polycyanurate



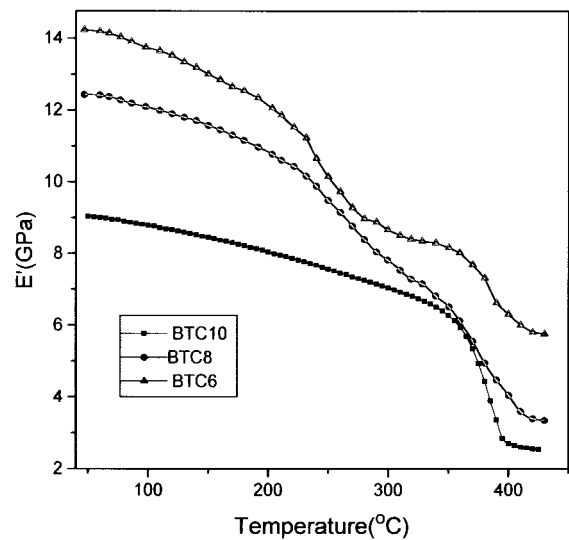
**Figure 1** Dynamic mechanical spectrum of the cured neat resins.

and typical cured blends are shown in Figure 1. Those of the bismaleimide-dominated resins shown in Figure 2 were done using their glass laminate composites, since they could not be shaped in to a DMA specimen in the neat form (being too brittle). The polybismaleimide showed higher  $T_g$  at around 380°C as against the polycyanurate with a  $T_g$  around 250°C. The cyanate ester rich blends showed a single  $T_g$  observed at slightly lower temperature than that of the polycyanurate itself. The dynamic flexural storage modulus ( $E'$ ), which varies in tune with the mechanical properties, drops practically to zero value at the end of the transition. In other words, the bismaleimide is found not to contribute to the  $T_g$  of the blend nor did it manifest an independent transition for itself. It appears that for this composition (rich in polycyanurate), the blend is homogeneous and the polybismaleimide has more the role of a plasticising component. However, in bismaleimide-rich systems investigated as its glass composite, two glass transitions, corresponding to each component, could be detected. This shows that when the BMIP content exceeds about 50% by weight, the second phase due to the maleimide surfaces. However, the  $T_g$  of the polycyanurate component remains unaltered, which limits the high temperature serviceability of the blends. The  $T_g$  of the cyanate ester rich blend was, however, augmented on addition of the network interlinker. Here also, a single  $T_g$ , between those of the components of the IPN was observed

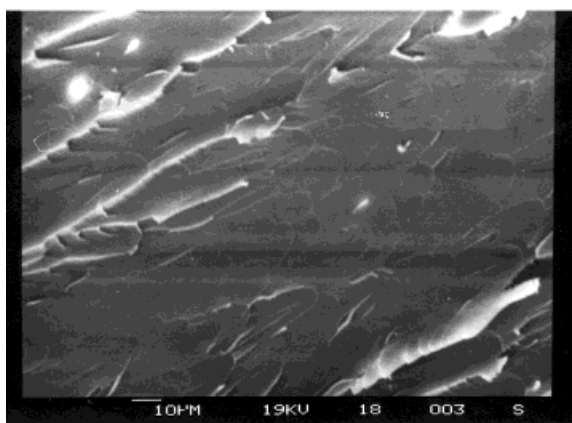
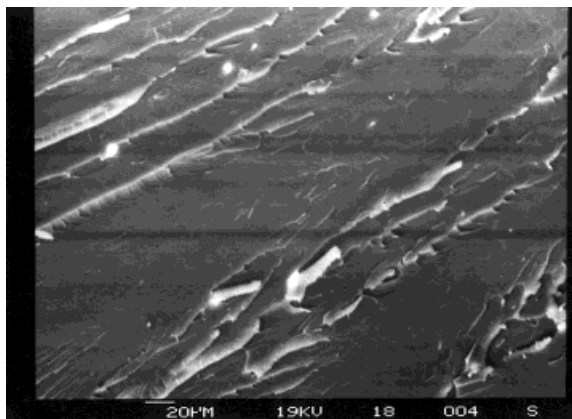
confirming homogeneity of the linked network. The increased crosslinking induced by this interlinker is responsible for the enhancement in  $T_g$ . A typical DMA thermogram of the linked IPN is included in Figure 1 where the  $T_g$  of the IPN is shown to increase by about 50°C on adding 20% of CPM. This also lends support to the fact that CPM really links the network to one with a higher crosslink density.

### Scanning Electron Microscopic (SEM) Analysis

The fractured surfaces of the neat resin castings were analyzed by SEM. Typical micrographs are shown in Figure 3 for two different magnifications for the resin BT3. River pattern nodules were seen and no visible phase separation could be detected in the region between the nodules even at higher magnifications. These kinds of module are indications of increased resin toughness as they are known to initiate new microcracks and dissipate energy and change direction of crack propagation. The fracture patterns were nearly the same for all IPNs. However, on adding the interlinker, the pattern changed altogether, as shown in Figure 4 for atypical case. River type ridges, indicative of brittle failure, were seen in the fractograph. The density of the ridges increased on enhancing the CPM concentration in the IPN, implying enhanced propensity for brittle failure in tune with the results on mechanical properties. The BMIP-rich systems did not fur-



**Figure 2** Dynamic mechanical spectrum of the cured glass laminate composite.



**Figure 3** SEM micrographs of fractured surface of BT3 at two different magnifications.

nish meaningful micrograph due to the presence of large amount of microvoids in the neat resin, cured without applying pressure.

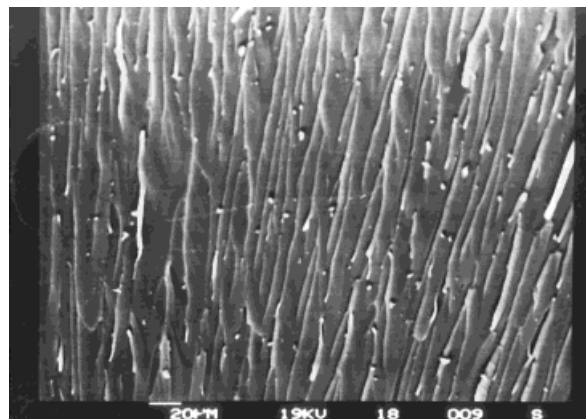
### Physical Properties of the Blends

#### *Specific Gravity*

Specific gravity is a crucial parameter when the resin is meant for an aerospace application wherein weight saving is a major matter of concern. Neat polycyanurate has a specific gravity of 1.22, which was moved to only 1.26 on adding 40% of BMIP. This increase in specific gravity is negligible; results can be found in Table III.

#### *Water Absorption*

Resins meant for spacecraft structures should have low moisture absorptivity. The moisture ab-



**Figure 4** SEM micrographs of fractured surface of network interlinked BT3-20.

sorbed in earth can be liberated in space, which could condense at the cryogenic temperatures, damaging the functions of critical optical surfaces and the pointing accuracy of critical antennae. It can also be a problem for damage-tolerant large-space structures. One of the salient features of cyanate esters is their low moisture uptake, demanding their choice as resins in structural composite for many components in spacecrafts.<sup>24,25</sup> Table III gives the equilibrium moisture uptake of specimens of the cured blends soaked in boiling water for 24 h. It is found that the moisture uptake of the blend as a whole is substantially less than that of the state-of-the art matrices like epoxies, where it is of the order of 4–5%. Interestingly, the moisture uptake decreases on forming the IPN. The polar maleimide was expected to enhance the moisture absorption in line with the general observation where bismaleimides display high tendency for absorbing moisture.<sup>25</sup> Despite having a hydrophobic backbone, the polycyanurates also absorb a trace amount of moisture, which is believed to be accommodated in the open

**Table III** Physical Properties of the Cured IPNs

IPN	Specific Gravity	Moisture Absorption (wt %)	Dielectric Constant (1 MHz)	Dissipation Factor (tan $\delta$ )
BT0	1.22	1.49	3.612	0.022
BT1	1.24	1.34	3.690	0.019
BT2	1.24	1.30	3.565	0.016
BT3	1.26	1.27	3.508	0.021
BT4	1.25	1.25	3.603	0.021

**Table IV Mechanical Properties of the Glass Laminate Composites**

Blend Composition				
Reference	Wt % of BMIP	ILSS (MPa)	Flexural Strength (MPa)	0° Compressive Strength (MPa)
BTC0	0	58	544	293
BTC1	10	62	562	269
BTC2	20	59	526	280
BTC3	30	71	620	307
BTC4	40	70	663	318
BTC6	60	50	488	280
BTC8	80	42	410	250
BTC10	100	40	340	220

network space between linked triazine in the network. Formation of tight IPN networks fill this space and prevents diffusion of water in to the network. Since water diffusion is prevented in the IPN, moisture uptake is less than that of the individual polymer network components.

#### **Dielectric Properties**

Polymeric materials required for high-speed circuits and microwave transparent structures such as radomes are to be characterized by low dielectric constant ( $Dk$ ) and dissipation factor ( $\tan \delta$ ) for better electrical performance and signal speed. Moreover, the moisture absorptivity also has to be minimum as this can alter the  $Dk$  values. These features make cyanate ester the resin of choice in high-speed printed circuit boards in microelectronic industry.<sup>26</sup> The dielectric constant of the neat resin molding at 25°C and 60% relative humidity at 1 MHz is given in Table III. The dielectric constant and the dissipation factors remain practically unaltered on enhancing the BMIP content in the IPN. The values are close to those reported for pure polycyanurate under dry conditions.<sup>27</sup>

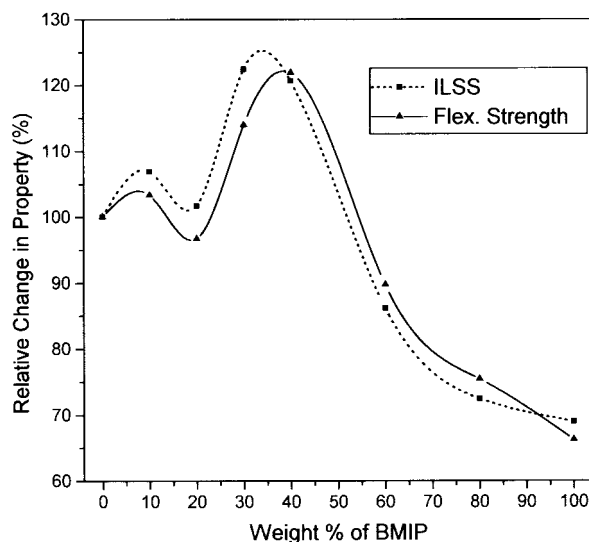
#### **Mechanical Properties of Composites of the Blend**

Since the neat resin does not have any meaningful strength, bismaleimides are almost exclusively served as their composites in many structural and thermostructural applications in aerospace.<sup>28</sup> The tough cyanate esters too find their way as composites in majority of applications. It was of interest to investigate how their blends behave in their composites. It is generally acknowledged that the trend in mechanical perfor-

mance of the neat resin is not translated to the composites as such, since the failure mechanisms are different in both cases. Glass laminate composites of the blends of varying compositions were molded under pressure employing the same high-temperature cure schedule as for the neat resin molding. In this case, blends in the entire composition range were subjected to investigation. The optimization of the cure schedule for the composite has been described in the previous article.<sup>19</sup> The resin content in the cured polymer worked out to be in the range 26–30% by weight. The mechanical properties of the composites for the entire composition range are compiled in Table IV.

The ILSS is a critical property decided mostly by the resin-reinforcement interaction. A higher ILSS ensures a stronger interphase and prompt transfer of load from resin to reinforcement. On enhancing the BMIP content in BACY, the ILSS initially increases and then shows a decreasing tendency on augmenting its concentration beyond 50%. The polar BMIP, in small quantities, adds to the fiber wetting by the resin and enhances the ILSS. However, at higher concentrations of BMIP, its brittle nature dominates and leads to an easy failure at the interphase. In other words, higher concentration of it is detrimental for the composite properties. Increasing the concentration of the bismaleimide also has been responsible for enhancing the flexural strength of the neat resin in cyanate ester dominated blend (Table I). The same trend is reflected in the flexural strength of the composite for the cyanate ester dominated region. It may be recalled that for the neat resin, the presence of BMIP decreases the tensile strength (Table I). This implies that under





**Figure 5** Dependency of the relative changes in ILSS and flexural strength of the composite on BMIP content of the matrix.

the flexural load, the composites fail at the interphase and not in the matrix. As a result, the flexural strength follows the same trend as ILSS. The relative changes in both ILSS and flexural strength with blend composition follows nearly the same trend as demonstrated in Figure 5. At higher concentration of the bismaleimide, the brittleness caused by it is responsible for the poor performance of the composite. Interestingly, the compressive strength of the composite also manifested a similar trend, initially showing an increase and then decreasing on augmenting BMIP content. These trends in ILSS and flexural strength are different from those reported in the case of a blend of a commercial, tough bismaleimide and an allyl functional dicyanate ester, wherein the possible coreaction between the two components led to slight improvement in these properties of carbon fiber unidirectional (UD) composites.<sup>12,22</sup>

## CONCLUSIONS

On curing the catalyzed blend of BMIP and BACY, a sequential IPN network was formed. Although tensile properties were adversely affected, increasing the bismaleimide content in the network led to amelioration of the flexural strength and fracture toughness of the cyanate ester rich compositions. For the cyanate ester rich

blends, a single  $T_g$  was observed in the DMA thermogram of the cured network, indicating phase miscibilization, which was also supported by the SEM micrographs. Clear phase separation was evidenced in the DMA of bismaleimide-dominated compositions. Incorporation of an asymmetrical network interlinking agent possessing both maleimide and cyanate groups in the system led to impairment of mechanical and fracture characteristics due to increased crosslink density, although it was conducive for enhancing the  $T_g$  of the cured blend. SEM analysis in this case indicated brittle failure of the matrix. Although the presence of bismaleimide was conducive for enhancing the mechanical properties of the laminate composites of the cyanate ester rich compositions, further increase in the bismaleimide content led to diminution of the properties due to the enhanced brittleness of the system.

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