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EFFECT OF JUTE FIBERS ON THE MECHANICAL PROPERTIES OF EPOXY RESIN

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ABSTRACT
Epoxy resins are widely used in industry by virtue of combinations of favorable characteristics including good mechanical and physical properties, ease of processing and low cost. However, these resins suffer from the disadvantage of brittleness, which limits their use in many applications.
In this work, polymeric composites were prepared from epoxy resin reinforced Bi-directionally (0^o - 90^o) by jute and glass fibers singly and in combination as a hybrid.
A comparison is made between the elastic modulus, material toughness and fracture toughness of the composites with those of un-reinforced epoxy to find out the effect of reinforcement on the composites at varying temperatures (0, 25, 40, and 60 C^o). Volume fraction for each reinforcement fibers (glass or jute) was 30% but for hybrid composite was (15% glass fibers and 15% jute fibers).
The results show that the jute- reinforced laminates have much better properties than the resin alone; but the properties are inferior to those of glass reinforced epoxy. The most appropriate role for the jute fibers is, to use them as filler fibers in combination with glass fibers to get moderate and acceptable mechanical properties during applications. The improvements in mechanical properties (elasticity modulus, material toughness, and fracture toughness) are 623%, 565%, and 593% respectively in comparison with un-reinforced epoxy samples.

Key words: **Composite, Jute Fibers, Glass fibers, Epoxy, Fracture Toughness**

تأثير ألياف الجوت على الخواص الميكانيكية لراتنج الايبوكسي

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الخلاصة
تستخدم راتنجات الايبوكسي بصورة واسعة في الصناعة وذلك لامتلاكها العديد من المزايا المرغوبة والتي تشمل الخواص الميكانيكية والفيزياوية الجيدة وسهولة التشكيل وقلة الكلفة . لكن إحدى مساوئ هذه الراتنجات هي صفة التقصف التي تحدد من استعمالها في العديد من الاستخدامات.
تم في هذا البحث تحضير مواد مركبة بوليمرية من راتنج الايبوكسي مع ألياف تقوية ثنائية الاتجاه (0^o -90^o) شملت ألياف الجوت والزجاج منفردة وسوية لتكوين ماده مركبة هجينة.
تم مقارنة معامل المرونة ومتانة المادة ومتانة الكسر للمواد المركبة مع راتنج الايبوكسي غير المقوى وذلك لملاحظة تأثير عملية التقوية على خواص المواد المركبة عند درجات حرارية مختلفة هي (0, 25, 40, 60) مْ . وقد كانت نسبة الكسر ألحجمي لألياف التقوية للنماذج المقواة بألياف الزجاج والمقواة بألياف الجوت هي(30%) و(15% ألياف زجاج مع 15%ألياف جوت) للمواد المركبة الهجينة.
أظهرت النتائج إن الخواص الميكانيكية للايبوكسي المقوى بألياف الجوت أعلى بكثير من الايبوكسي غير المقوى . ولكنه في نفس الوقت أقل من الايبوكسي المقوى بألياف الزجاج. إن الدور الأكثر ملائمة لألياف الجوت ، استخدامه كألياف مالئة سوية مع ألياف الزجاج لتحقيق خواص ميكانيكية معتدلة ومقبولة عند الاستخدام ، حيث كان مقدار التحسن في الخواص الميكانيكية (معامل المرونة ، متانة المادة، ومتانة الكسر هي 623% ، 565%، 593% على التوالي مقارنة بنماذج الايبوكسي غير المقواة).

الكلمات الأساسية : المواد المركبة ، ألياف الجوت ، ألياف الزجاج ، ايبوكسي ، متانة الكسر .

INTRODUCTION

The composite technology of a polymeric matrix reinforced with man-made fibers such as glass, kevlar, carbon etc. has come of age especially with the advances in aerospace applications since 1950s. The developments in composite material after meeting the challenges of aerospace sector have cascaded down for catering to domestic and industrial applications. Composites, the wonder material with light-weight, high strength-to-weight ratio and stiffness properties have come a long way in replacing the conventional materials like metals, woods etc. The material scientists all over the world focused their attention on natural composites reinforced with jute, sisal, coir, pineapple etc. primarily to cut down the cost of raw materials (Ishiaku et al.).

Although the tensile strength and Young's modulus of jute are lower than those of glass fibers, the specific modulus of jute fiber is superior to that of glass and on a modulus per cost basis, jute is far superior. The specific strength per unit cost of jute, too, approaches that of glass. Therefore, where high strength is not a priority, jute may be used to fully or partially replace glass fiber without entailing the introduction of new techniques of composite fabrication. The need for using jute fibers in place of the traditional glass fiber partly or fully as reinforcing agents in composites stems from its lower specific gravity (1.29) and higher specific modulus (40 Gpa) of jute compared with those of glass (2.5 & 30 Gpa respectively). Apart from much lower cost and renewable nature of jute, much lower energy requirement for the production of jute (only 2% of that for glass) makes it attractive as a reinforcing fiber in composites. The comparison of mechanical properties for jute & glass fibers is given in Table 1 (Nangia and Biswas, 2007).

The jute composites may be used in everyday applications such as lampshades, suitcases, paperweights, helmets, shower and bath units. They are also used for covers of electrical appliances, pipes, post-boxes, roof tiles, grain storage silos, panels for partition & false ceilings, bio-gas containers, and in the construction of low cost, mobile or pre-fabricated buildings which can be used in times of natural calamities such as floods, cyclones, earthquakes, etc (George et al. 2004).

Some studies have been conducted to investigate the use of jute as reinforcement for plastics. For example, Gassan and Bledzki (Gassan and Bledzki, 2000) have incorporated jute fibers in polypropylene and studied the effect of process variables, such as the curing temperature and time, on mechanical properties. Considerable work has also been done by Authors (Zoin Al- Abedin, 2007) and (Holberg and Houston, 2006) on jute- reinforced unsaturated polyester resin; however, their work is more oriented towards application than on the evaluation of properties.

The aim of this work is to investigate the mechanical properties of jute, glass, and jute/ glass hybrid bidirectional (0^o - 90^o) laminates, which could occupied an important field of composite materials.

The following tests have been conducted on epoxy resin and composite materials in the present study (1) tensile test and (2) material toughness test.

Theoretical View

Fracture mechanics can be defined as material breaks into two parts due to the effects of external forces. Griffith was the first person who fixed the basic principles of fracture mechanics by energy balance theory. Griffith studies the process which occurred to the crack by reverse thermodynamics process. He supposed existence of static equilibrium condition for crack through the effects of energies given by equations 1 and 2:

$$U = (-W_L + U_o) + U_S \qquad (1)$$

Where W_L: External performed work on system.

U_o: Saved energy in system.

U_S: Required energy to create new surface (free surface energy).

U: External impact energy.

Therefore fracture mechanics is calculated from impact energy (U) if engineering sample dimensions and crack depth (a) are measured. When crack growth occurred, malleability will

increase for material according to the value of saved energy, therefore if malleability changes and crack depth (a) are known, absorbed energy is calculated by the following equation (Boresl and Schmidt, 2002):

$$U = \frac{1}{2} P^2 C \tag{2}$$

Where P: applied load in Newton
C: malleability.

If sample width is B in meter then:

$$G_c = \frac{1}{B} \frac{dU}{da} \tag{3}$$

$$G_c = \frac{1}{B} \frac{dU}{dC} \frac{dC}{da} \tag{4}$$

Where: G_C is material toughness when crack occurred.
This term (G_C) is one of the material properties, and it is regarded as absorbed energy by crack unit area, also it represents released critical strain energy which is given by the following equation:

$$G_c = \frac{P^2}{2B} \frac{dC}{da} \tag{5}$$

From both equations 2 and 5, absorbed energy is calculated by impact test:

$$U = G_C B \frac{C}{dC / da} \tag{6}$$

Practically, U is calculated for different crack depths.

$$G_c = \frac{U}{BDC} \frac{dC}{d(a/D)} \tag{7}$$

Where D: Sample thickness in meter.
So, engineering configuration function Φ is given by malleability C:

$$\Phi = \frac{C}{dC / d(a/D)} \tag{8}$$

So equation 8 can be solved to calculate material toughness G_C:

$$U = G_C BD\Phi \tag{9}$$

The relationship between absorbed energy (U) and engineering configuration function (Φ) is linear, and the slop of this line is material toughness G_C (Boresl and Schmidt, 2002):

Irwin (Huges et al., 2002) developed fracture mechanism in engineering materials. He observed that the stress rate near the crack increased proportionality with crack depth square root $\sqrt{\pi a}$. Therefore, stress intensity factor is given by:

$$K = Y\sigma\sqrt{\pi\, a} \tag{10}$$

Where σ : stress.

Y: Engineering configuration coefficient.

K: Stress intensity factor which called fracture toughness and symbolize (K_C) at critical stress, its unit is (MN / $m^{3/2}$). K_C related with fracture toughness G_C by the following Equation (Mike and Brady, 2007):

$$K_c = \sqrt{EG_c} \tag{11}$$

Where E: Elasticity modulus of material.

Fracture toughness changes with temperature, material type, sample dimensions, and test classification (Bledzki, 1999). Fracture toughness (K_C) measured by impact test regarded as fracture resistance of the material under the applied load effects, and this depends on impact rate. Fracture mechanism is classified into ductile and brittle fracture. Both of them are important in practical applications, but brittle fracture is more dangerous due to non existence of observable deformation before or after fracture. Studying of necessary forces to break the linking between the material molecules is important to evaluate the fracture resistance of material (Al-Kafi et al., 2006).

Experimental Work

The resin system used in the present study is the epoxy resin, Diglycidl ether of Bisphenol ADGEBA CY 233 submitted by Ciba- Geigy Company. Bulk resin sheets were prepared by mixing resin with 25% (%wt.) hardener Hy -2992 modified amine. The mixture was degassed by centrifuging, and then cast between two glasses sheets (300*300 mm) treated with wax and polyvinyl alcohol solution as a released agent. Great care was taken in the casting process to avoid introducing air bubbles. The thickness was controlled carefully, using feeler gauges. The cast resin was then cured at room temperature for 24 hrs followed by post curing at 80 ^oC for 3 hrs.

Two types of fibers reinforcements were used in the preparation of composites.

1. Glass plain fabric (Fiberglass Ltd., UK).
2. Jute plain fabric (State Enterprise for Fabrics, India).

The composite materials were prepared by hand lay-up technique. A first coat of epoxy resin containing the required amount of hardener was applied on the glass sheet, followed by laying out the reinforcement. The resin was then applied over the reinforcement fibers with roller to ensure the removal of air bubbles, also to impregnate the reinforcement thoroughly with resin over the entire area, and then allowed to cure at room temperature for 24 hrs followed by post curing at 80 ^oC for 3 hrs.

The amounts of reinforcement fibers were calculated according to the following Equation [12]:

$$\Theta = \frac{1}{1 + \frac{1-\Psi}{\Psi}\frac{\rho_f}{\rho_M}} \tag{12}$$

Where Θ : Volume fraction of fibers %.

Ψ : Weight fraction of fibers %.

ρ_f: Fiber density in kg / m^3.
ρ_M: Matrix density in kg / m^3.

Volume fraction for each reinforcement fibers (glass or jute) was 30% but for hybrid composite was (15% glass fibers and 15% jute fibers). The samples were cut out from the laminates. The Sharpy impact samples are prepared according to ISO.179. And for the tension tests the samples are prepared according to ANSI/ ASTM D36. The strain rate was maintained approximately at 5mm/ min. All samples are stored in a desiccator for 24 hrs before testing.

Results and Dissociation

Figures (1, 2, 3, and 4) showed impact energy (U) variation with engineering configuration coefficient (BDΦ) by variable crack depth (a) under different test temperatures for epoxy material before and after reinforcement with 30% jute, 30% glass and hybrid reinforcement fibers (15% glass + 15% jute).

All previous figures showed that fracture impact energy was decreased with increasing of crack depths due to decreasing cross section area of sample under shock test. Furthermore fracture energy was increased with temperature due to bonding loss between molecular series and sliding movement between each other and this gives possibility to absorb partial of fracture energy. This behavior will lead to increasing of fracture energy. But it was decreased at low temperatures due to the brittleness of material. The molecules were arrested and the bonding between them became in maximum tension status (Saha et al., 1999).

Fig.(1) shows the extremely brittle nature of bulk resin is reflected on the low values of impact energy. Reinforcing the resin with jute, glass, and hybrid fibers seems to produce a composite with better impact resistance. This behavior is attributed to the arresting or retarding the fracture by the fibers (Bledzki, 1999) in addition to the effect of closely weaved fibers which act to spread the impact force over a wider area.

Material toughness (G_C) was calculated for each sample from the tendency of linear relationship between fracture energy (U) and engineering configuration coefficient BDΦ (as in Figures 1- 4). From the plot diagram of the material toughness variation over the temperatures 0-60 ^oC (Fig.5), it is obvious that the relation is not linear, in addition, material toughness increasing always with temperature for all epoxy samples and with all reinforcement fibers due to increasing the absorbed energy. It's important to denote that this range of temperature (0-60 ^oC) represents the most working temperatures for these types of composites in service and applications.

Fig.(6) illustrates the variation of elasticity modulus over the temperatures range (0-60 ^oC). In case of reinforced epoxy with fibers, Elasticity modulus was increased for all composite materials. Furthermore, elasticity modulus is decreased when temperature is increased.

Fracture toughness K_C for each sample was calculated according to Eq.(11). At the same test conditions for E and G_C as shown in Fig.(7). It is obvious that fracture toughness was increased for composite materials in comparison with unreinforced epoxy, which was affected slightly with increasing temperatures.

The results of the tests on mechanical properties clearly show that the jute fibers, when introduced into the resin matrix as reinforcement, considerably improve the mechanical properties, but the improvement is lower than that obtained by introduction of glass fibers. Hence, the jute fibers can be used as reinforcement where moderate mechanical properties are required.

Another potential use for the jute fibers is to use them as a partial replacement of the glass fibers where mechanical properties of the components are not very high. Thus it can be used as a filler fiber, replacing the glass as well as the resin in a hand lay-up component.

The main problem of the present work has been that it is difficult to introduce a large quantity of jute fibers into the JRP laminates because the jute fibers, unlike glass fibers, soak up large amount of resin. This problem is partly overcome when hybridizing with glass fibers is carried out. This result is in agreement with those given by Shah and Lakkad (Shah and Lakkad, 1981).

Conclusions

1. Jute fibers improve the material toughness of epoxy resin composites. Hybrid fabric (15% Glass fiber + 15% Jute fibers) performs identically in this respect, while glass fibers provided an enormous improvement of material toughness to the composite.
2. Glass fiber reinforced epoxy showed the higher elasticity modulus, material toughness, and fracture toughness. The improvement was: 947, 895, and 921% respectively in comparison with unreinforced epoxy at room temperature.
3. In case of reinforcement epoxy resin with jute fibers alone or in combination with glass fibers, elasticity modulus increased by 413, and 623% respectively in comparison with unreinforced epoxy at room temperature.
4. Using jute fibers alone or in combination with glass fiber improve material toughness of unreinforced epoxy resin by 526, and 565% respectively at room temperature.
5. Using jute fibers alone or in combination with glass fiber improve fracture toughness of unreinforced epoxy resin by 466, and 593% respectively at room temperature.

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Table1.0: Mechanical Properties of Epoxy, Glass, and Jute Fibers (Nangia and Biswas, 2007).

Property	E-glass	Jute	Epoxy
Specific Gravity	2.5	1.3	1.1
Tensile Strength (MN/m^2)	3400	442	104
Young's Modulus (MN/m^2)	72	55.5	6.94
Specific Strength (MN/m^2)	1360	340	-
Specific Modulus (GN/m^2)	28.8	42.7	-

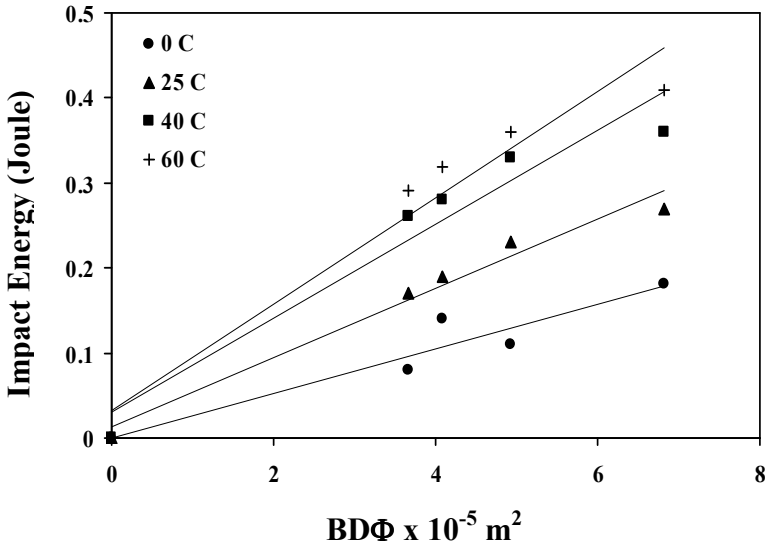

Fig. 1: Impact energy - BDΦ curve for unreinforced epoxy.

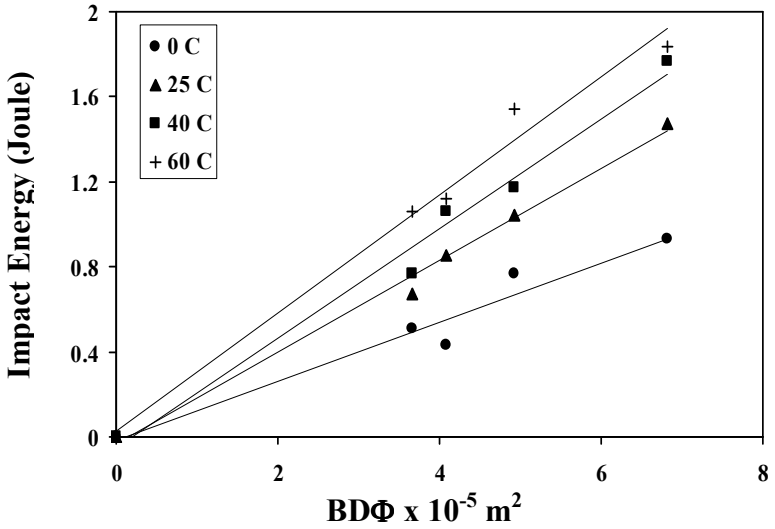

Fig. 2: Impact energy - BDΦ curve for jute fiber reinforced epoxy.

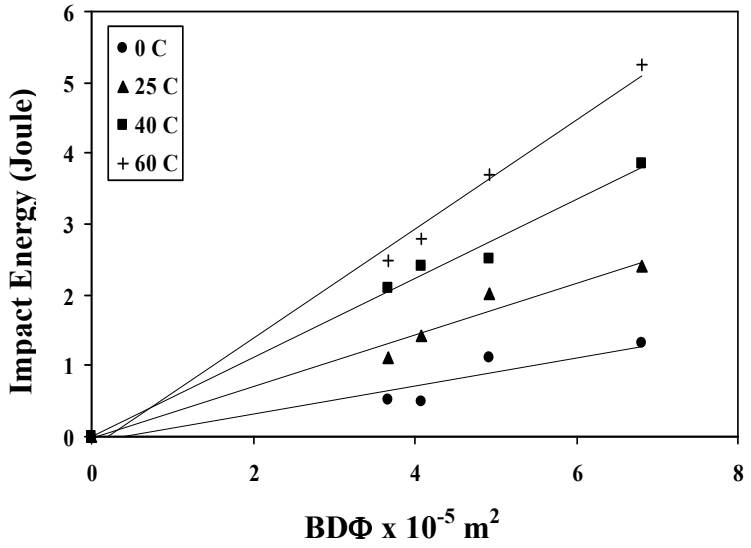

Fig. 3: Impact energy - BDΦ curve for glass fiber reinforced epoxy.

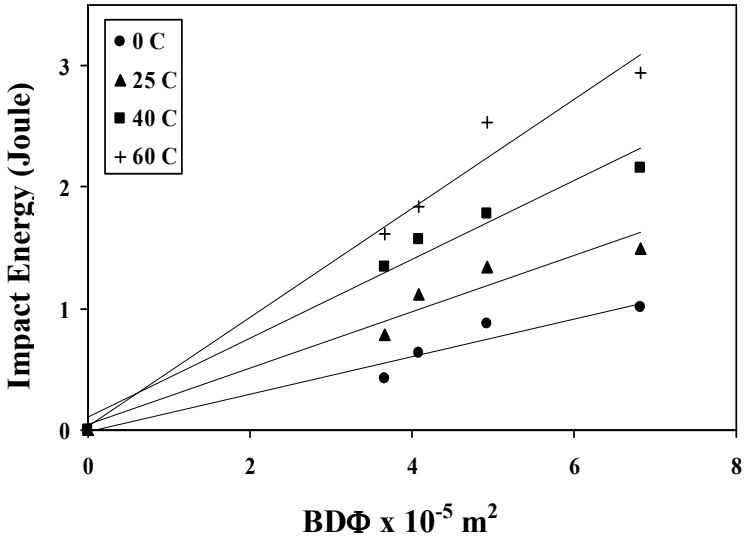

Fig. 4: Impact energy - BDΦ curve for hybrid fiber (15% glass + 15% jute) reinforced epoxy.

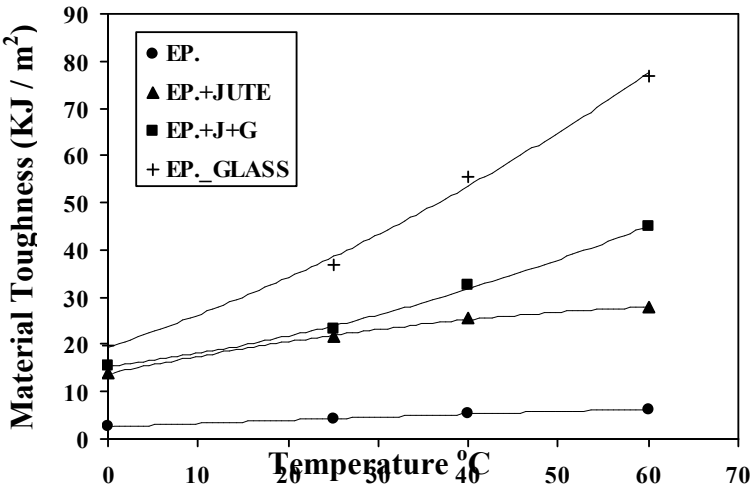

Fig. 5: Material Toughness- Temperature Curve.

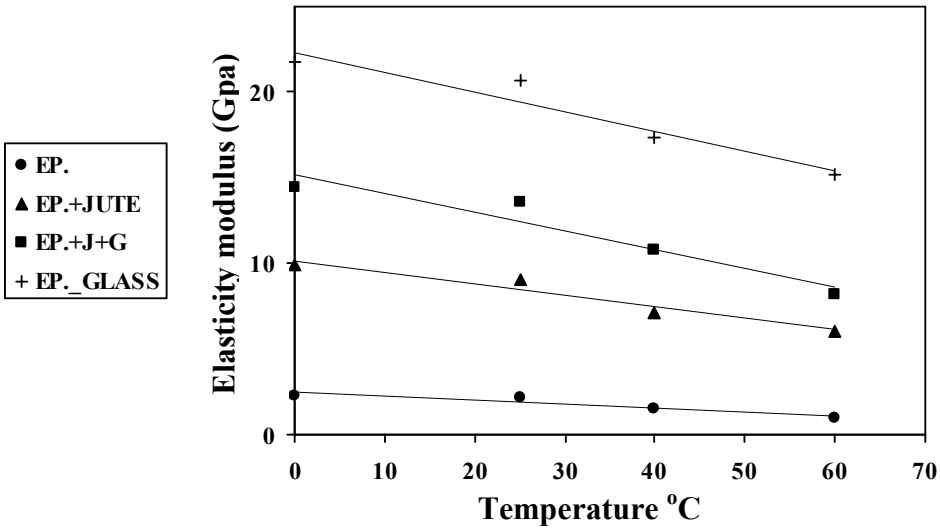

Fig. 6: Elasticity modulus- Temperature Curve.

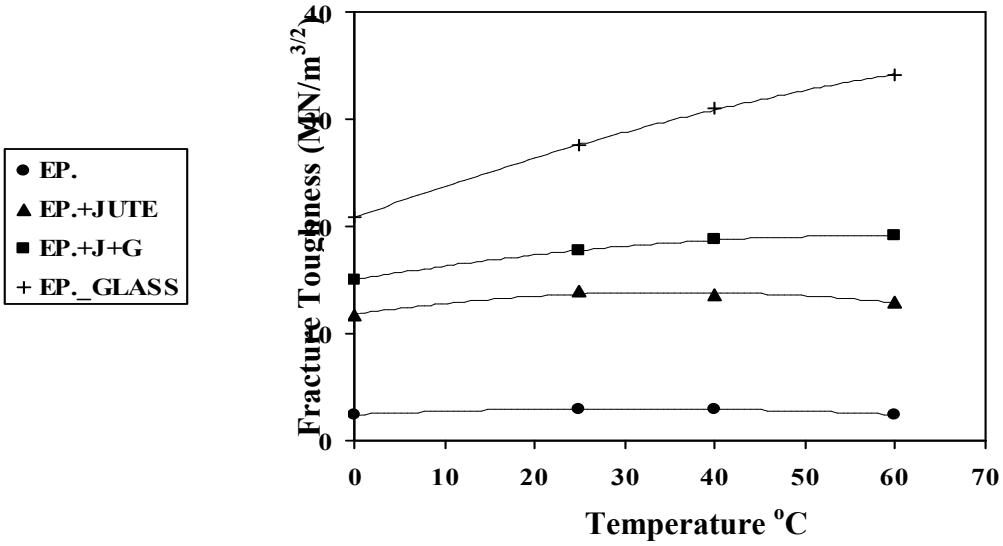

Fig. 7: Fracture Toughness- Temperature Curve.