

Interlaminar fracture toughness of some polymer blends reinforced by fiber glass

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Abstract:

The interlaminar fracture toughness of polymer blends reinforced by glass fiber has been investigated. Epoxy (EP), unsaturated polyester(UPE), polystyrene (PS), polyurethane (PU) and their blends with different ratios (10%PS/90%EP), (20%PS/80%EP), (20%PU/80%EP) and (20%PU/80%UPE) were chosen as a matrices A sheet of composites were prepared using hand lay -up method, these sheet were cut as the double cantilever beam (DCB) specimen to determine interlaminar fracture toughness of these composites .Its found that, blending of EP,UPE with 20% of PU will improve the interlaminar fracture toughness ,but the adding of 10% PS, 20%PS to EP will decrease the interlaminar toughness of these composites.

دراسة المتانة الطبقية لبعض الخلائط البوليمرية المدعمة بالألياف الزجاجية

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الخلاصة:

في هذا البحث تم حساب المتانة الطبقية لبعض الخلائط البوليمرية المدعمة بالألياف الزجاجية . حيث استخدم راتنج الايبوكسي Ep والبولي استر UPS والبولستارين PS البولي يورثين PU لتحضير خلائط من البولمرات وبنسب (10%PS/90%EP), (20%PS/80%EP), (20%PU/80%EP) and (20%PU/80%UPE) قد استخدمت هذه الخلائط كمواد رابط لالألياف الزجاجية. تم تشكيل الواح من المتراكبات باستخدام تقنية التشكيل اليدوي، حيث تم تقطيع العينات وفقا الى فحص العتبة المزدوجة DCB وذلك لحساب المتانة الطبقية لهذه المتراكبات. وقد وجد ان خلط الايبوكسي والبولي استر مع 20% من البولي يورثين قد حسن من قيم المتانة الطبقية، على العكس من اضافة 10%، 20% من البولستارين الى الايبوكسي فقد قلل من قيم المتانة الطبقية.

Introduction

The polymer industry has emergence in the beginning of 1940, and from that time the engineering polymers have grown rapidly compare-ed with all engineering materials. Many traditional materials have many advantages such as higher strength and lower material cost compared with many polymers. The engineering polymers have two-dimensional advantages design constraints of reform any assembly operation(s). These characteristics resulted in final cost effectiveness for complex shapes.

The manufacturing processing of polymers require more attention compared with processing of alloys and ceramics. However, the number of processing related to polymer are less compared with other materials, but the process ability was not determined clearly. Unfortunately, the process ability of composite materials based on polymer matrix are much drawback. The important point to be considered by designer and manufacture is that many users still consider that the polymer used as cost reduction with low reliability.

The development of produced goods and services typically requires the interaction between the design stages, the selection of material, the manufacturing and production systems and the analysis of the principle. The interaction of these four variables is much complex in polymers and composite materials. Since many polymers and polymer related composites require net shape product, much attention is given to the design and analysis processes.

One of the main objectives of this study is to highlight the important of design during the manufacturing and testing of polymer and composite based polymers. From the point of development of materials, the research seeks the ability to produce strong blended /compound composite polymers. This was performed firstly by preparing different polymers, different blends and different composites, and Secondly by evaluating the structure-properties relationship ^[1].

Theoretical part

The Griffith's modified energy balance equation accounting for the plastic deformation that occurs near the crack-tip in most materials is ^[2]:

$$\text{EMBED Equation.3} \quad (1)$$

where u : is the irreversible strain energy due to plastic deformation. du : stored elastic energy dw : the external work don on specimen, dA : the area for crack propagated, γ :thermodynamic surface energy.

The left hand side of equation (1), is the input energy rate that is released during an incremental crack growth, and it is a function of load condition, geometry of the body, and orientation of the crack. Whereas, the right hand side is the energy absorption rate during the crack extension and its a constant for a given material. The crack tends to extend when the left hand side of equation (1) reaches a critical value equal to fracture toughness G_c , i.e. the right hand side value. The energy absorption during a macro crack growth in a composite is in the form of fiber breaks, matrix cracks, and fiber-matrix interface debonding. So equation should be replaced by EMBED Equation.3

which is define as ^[3]:

$$\text{EMBED Equation.3}$$

$U_{\text{fibr}}:$ energy absorption due to fiber break.

$U_{\text{mcp}}:$ energy absorption due to matrix crack perpendicular to the fiber direction.

$U_{\text{mcp}}:$ energy absorption due to matrix crack parallel to the fiber direction.

$U_{\text{fmid}}:$ energy absorption due to fiber-matrix interface debonding.

Area Method

The direct energy measurement, known as the area method ^{[4][5]}. The crack extension is related directly to the area enclosed between the loading and unloading curves as shown in Fig. (1) ^[6]

Fig. (1): Load showing the principle of the area method to determine G_c ^[6]

The model-I strain energy release rate is defined as:

EMBED Equation.3

(A: is the area enclosed by the load-unloading path. w: the width of specimen, da: the crack length.

This method is still valid for non-linear elastic load-displacement response is observed, in contrast to the compliance methods for which only linear elastic response can be treated ^[7].

Experimental part

Materials used

Samples were based on four thermoset and thermoplastic polymers. The polymers were chosen either as individual or as blends. For better mechanical properties, they were reinforced with chopped strand mat of E- glass fiber. The properties, symbols, hardener, accelerators supplier of the used polymer are given in Table (1).

Table (1): Characteristics of materials used in this work.

Materials	Symbol	Type	Hardener	Accelerator	Supplier	Epoxy Resin	EP	Araldite	Cy-223	HY 953	Ciba-Geigy
		Swiss	Unsaturated Polyester Resin	UPE	Viapad						
H-265	MEKP 1%	Cobalt naphthenate 6%	Vlanova kunstharz	Austria	Polyurethane Resin	PU	WEBAC				
			1403Tgb-Nr	Isocyanate							
			HYG	WEBAC-HEMIE							
			GMBH-FAH	Germany	Polystyrene Resin	PS	(monomer)	Styrene Resinous			
			C-6186	Benzoyl-peroxide (initiator)	Water bath at 70°C	Resinous					
				Chemical							
				L.T.D							
				C-6186							
				Germany							

Material Preparation

1- Epoxy resin

A clean disposable container was used for mixing epoxy and its hardener. The container put on a sensitive electronic balance of accuracy 0.01gm with the required Epoxy resin. An exact amount of special hardener (commercial type HY953) was added to the resin in the container with ratio 1:3. The content was mixed thoroughly by a fan type stirrer before using for sheet casting.

2- Unsaturated Polyester (UPE)

100 gm of UPE resin was mixed with 0.5gm accelerator (Cobalt naphthenate). A 2gm

hardener (Methyl Ethyl Keton Peroxide) were added to the mixture and the content again were mixed thoroughly until a homogeneous state of the mixture was obtained. After complete mixing, the mixture was ready to produce blend sheet casting, and preparation sheet of required blends or composite.

3- Polyurethane (PU)

A sufficient amount of the isocyanate hardener was added to 100gm of PU resin (polyol). The ratio of hardener to resin was 1:2 by weight. The mixture was ready for further application as bend sheets casting and or preparation of composite sheets.

4- Polystyrene (PS)

For 100 gm of styrene (monomer) a 3gm benzoyl peroxide was added as initiator were mixed at room temperature (25°C~50% R.H) for two minutes.

For polymerization the mixture was heated at 70-80 °C for 20 min. in water bath. High viscous styrene polymerization takes approximately 25 min. by using continues stirring .The mixture become ready to use for blending purpose.

Polymer Blends Preparation

Three types of polymer blends were synthesized through this project; Epoxy with PU where as UPE was mixed with PU only. The best compatibility for three blends was found to be (20%PU/80%EP), (20%PS/80%EP), (10%PS/90%EP) and UPE, (20%PU/80%UPE) ^[8].

Composites Sheet Preparation

Hand lay-up methods were used in this study to prepare sheets of composite. Aluminum film of 0.01mm thickness was inserted through the mid surface of the laminate to initiate artificial primary crack of 3.81 cm in length at one end sufficient number of specimens were cut out of the sheets prepared as DCB test are shown at Fig.(2). The specimen edges were polished using abrasive emery papers of grades 300 and 1000 respectively.

Fig. (2): the shape of DCB specimen

Mechanical test

DCB Test

For this test, the Instron (model 1122) with 500 N load cell were used at tension mode. The crosshead speed was fixed to 0.5 mm/min. To feed crack opening with constant displacement. The crack length was measured visually with a traveling microscope of magnification factor of 20, to observe the crack propagation, both edges of the DCB specimen were coated with a type writer correction fluid, when fluid dried. Fine marks were made on these edges at the end of the primary crack (i.e. zero extension) crack length was recorded with the help of microscope placed in front of the specimen edge, Fig. (3). The crack opening displacement was then increased with constant rate equal to the cross head speed .At critical crack opening displacement crack extends through the specimen with a length proportional to elastic energy released. The applied load then reduced to zero by reverse the direction of loading. This loading-unloading cycle started again to cause further crack growth during the loading-unloading cycles, the load was continuously plotted as a function of loading time by Instron chart recorder ^[1].

Surface Analysis

Fractography of the surface fracture and the delaminated layers were examined by optical microscope. The surfaces were viewed in both transmitted and reflected modes of Olympus type (BH-2) with maximum magnification of (x1000). Photographs were directly taken by the aid of an automatic camera fixed at the top of the microscope. Further detail on the surface marks, fiber pull-out, fiber debonding, and damages to fiber-to-matrix interfaces were investigated by an SEM type (Jeol, model JSM-6400). The samples were coated before they examined with 300 Å gold layer using (Jeol, model JFC-1100E ion sputter) coater.

EMBED Word.Picture.8

Fig. (3): The loading Technique for DCB Test

Discussion

Toughness of GF/EP and GF/UPE Composites

The load displacement curves for DCB specimens of EP and UPE composites are shown at Fig. (4), (5). Complete cycles of these curves represent the loading and unloading parts in which the crack were extend from initial crack length to final crack length. The sector area represent to the strain energy, which released during crack extension. This area however did proportional to the crack length. A result accepted of an isotropic material like composites under test. It is well known that the crack moves nominally through the resin-rich region between plies. The crack tip will occasionally imping on misalign fibers. Since the fibers are much stronger than the resin, the interaction of crack tip with the glass fibers increases resistance to crack growth, assuming that interfacial bond is stronger than the matrix. The cracks will prefer to move through the weaker resin rather than breaking the stronger fibers. If the resin-rich between plies has an average thickness of less than one fiber diameter, the thinner resin-rich region, mean corrugated fracture surfaces and more frequent in the crack-tip interaction with the fibers, Fig. (6).

Each of the forging effects altered the energy absorbed per unite area of crack extension. Hence different values of G_c should be obtained. The values of G_c for each sector of EP and UPE matrix composites are shown at Table (2). The preceding discussion assumes that the cracking propagates principally through the resin rather than at the resin-fibers interface. If the interfacial toughness is less than the resin toughness, cracking may occur at interface cause a debonding of fiber at the delamination fracture surface Fig.(7).

Blending Effect

A significant process zone, where extensive deformation and microcracking occurs, will generally precede the crack extension in a ductile resin. The energy dissipation in this process zone prior to fracture is normally much larger than the energy associated with creation of new surface and constitutes the bulk of the energy absorbed per unit area of crack extension.

The net result of these deformational processes is the large crack tip plastic zone, develops before the crack advances. The larger this zone, mean the greater fracture energy.

The plastic zone size r_p is inversely proportional to the square yield stress σ_y , it may also be shown that G_c is directly proportional to r_p [10]. is that:

$$r_p \propto 1/(\sigma_y)^2$$

$$G_c \propto r_p$$

However, the crack–tip deformation in the ductile material were not restricted to the matrix larger between the plies, but also extended to the matrix between the plies of layers above and below the crack plane, depending on the thickness of matrix between the layers of glass fibers.

The thicker resin – rich region should increase the fracture toughness by increasing the zone size and, the fracture surface become more deform Fig. (8). The load – displacement curves of these composites are shown at Fig. (9) (10). From these curves, the toughness G_c was computed for each sector. The results are listed in table (4). A high fracture toughness value is observed at sector 2 and 3, which indicate that PU additives in general enhance the G_c values.

As the resin- rich region between plies is thin, the fracture toughness should be approached, and the lower level of the fracture toughness should be observed. A result may explain at the first sector from Table (3). Beside PU and EP at 20/80 ratio may not fully miscible. Hence isolated phases of PU and EP will be formed. Consequently, the probability of cracking at he interfaces will be increases.

On 10%PS/90%EP,20%PS/80%EP matrices composites. Fig. (11),(12) shows the non linear behavior when the specimen were unloaded, that means there are large zone of deformation extended to up and down of the mid plane of the path of the crack extension. Fig. (13), (14) shows the deformation which appeared as white color zone and debonding between fibers–matrix because of the matrix has a very high ductility, the fibers became very ineffective, especially when fiber matrix debonding easily , this indicate that the easily the pooring interfacial bonding between the fibers and matrix.

As a result Table (4) shows the values of G_c for 10%PS/90%EP and 20%PS/80%EP matrix composites .The value of G_c for sector (2) and (3) for 20%PS/80%EP cannot be measured because of high deformation occurs on the arm of DCB specimens Fig. (9), (10).

Fig. (4): Load, unload-displ. Curves for unsaturated Polyester matrix composites

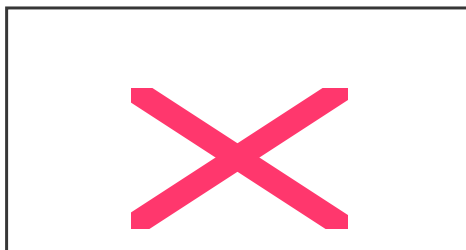
Fig. (5): Load, unload-displ. curves for Epoxy matrix composites

Epoxy matrix composites (x170)

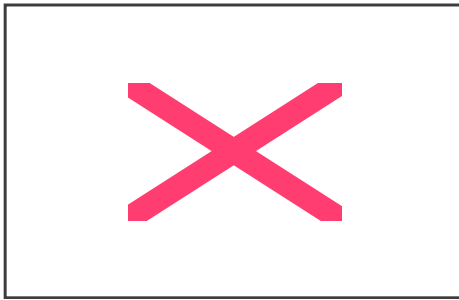
Polyester matrix composites (x300)

Fig. (6): SEM micrographs of the fracture surface showing corrugated region and the fiber blunting of crack tip

Table (2): Values of G_c

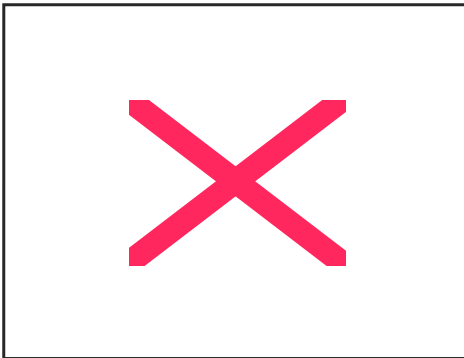


Polyester matrix composites (X500)

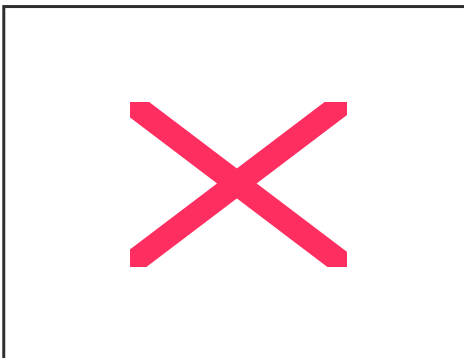


Epoxy matrix composites (x900)

Fig. (7): SEM micrographs of the fracture surface showing corrugated region and the fiber blunting of crack tip



20%PU/80UPE matrix composites (x350)



20%PU/80EP matrix composites (x1100)

Fig. (8): SEM micrographs of the fracture surface showing corrugated region and the fiber blunting of crack tip

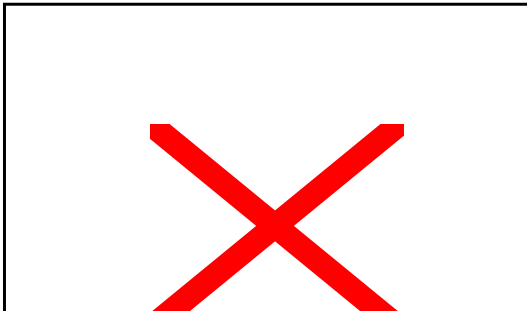


Fig. (9): Load, unload-displ. Curves 20%PU/80UPE matrix composites

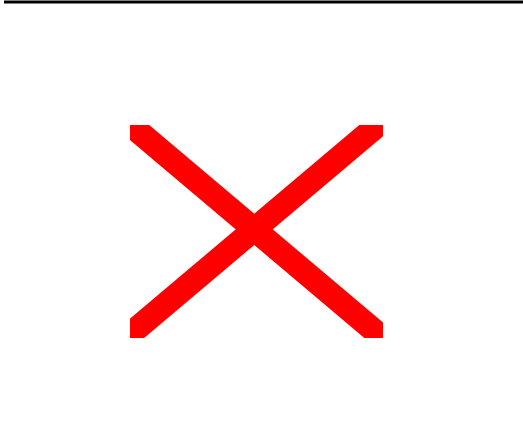


Fig. (10): Load, unload-displ. Curves 20%PU/80EP matrix composites

Fig. (11): Load, unload-displ. Curves 10%PS/90EP matrix composites

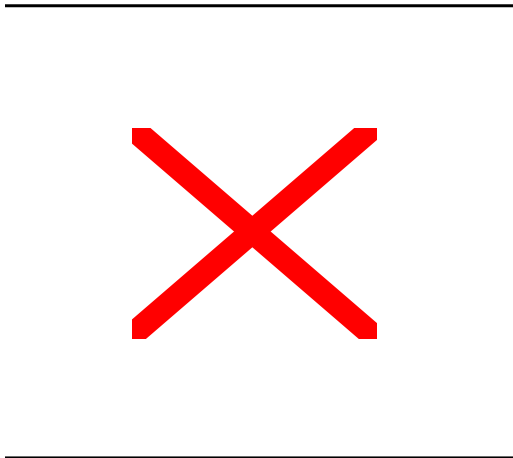


Fig. (12): Load, unload-displ. Curves 20%PS/80EP matrix composit

Fig. (13): Photograph Show high deformation on arm of DCB for (10%PS/90%EP) matrix composites

Fig. (14): Photograph Show high deformation on arm of DCB for (20%PS/80%EP) matrix composites

Table (3): Value of Gc for composites with deferent matrices blends

EMBED PBrush

Table (4): Value of Gc composites with deferent matrices blends

EMBED PBrush

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