Preparation and Studying the Fracture Toughness of Laminate Composites

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ABSTRACT
Binary polymer blend was prepared by the mechanical mixing of epoxy resin (EP) with polycarbonate (PC) in different weight ratios of (0, 5, 10, 15 and 20%). Charpy impact test was carried out on these blends to determine the values of impact strength (I.S). It was found that the blend of the ratio (20wt. %) of PC has the highest (I.S) compared with other ratios. For this reason, this percentage of mixing was selected to fabricate the composite materials. Hand lay-up method was utilized to synthesize the (single and hybrid) laminate composites with fiber volume fraction (Φ=15%). Glass and Kevlar fibers were used to reinforce the epoxy and its polymer blend with different sequences of skin and core layers of the composite. The values of Young's modulus (E), impact characteristics (I.S, Gc, Kc) and hardness were determined for these composites. It is found that the values of (E) and hardness decrease while the values of material toughness (Gc) increase with increasing the blending ratio of the polymer blend. It can also be noticed that the composite reinforced with Kevlar fibers records the highest value of (Gc) compared with other composites.
Keywords: Polymer blends, Epoxy, Polycarbonate, Laminate Composites.

INTRODUCTION
There is difference between the blend and composite because the main constituents in the composites remain recognizable while these may not be recognizable in blends [1].

Polymer blends are physical mixtures of two or more polymers with/without any chemical bonding between them. The objective of polymer blending is a practical one of achieving commercially viable products through either unique properties or lower cost than some other means. The subject is vast and has been the focus of much work, both theoretical and experimental [2].

In composites, researchers can make use of tougher and lighter materials, with properties that can be tailored to suit particular design requirements. The first use of modern composite materials in the aircraft industry was about 30 years ago in military aircrafts and first use of modern composite materials in commercial aircrafts was by Airbus in 1983 [3].

Fracture toughness test is an approach of expressing a material resistance to brittle fracture when a break happens. If the material has a high value of fracture toughness it'll most likely exhibit ductile fracture but the brittle fracture is incredibly characteric of materials which have low fracture toughness [4]. In other words, the linear-elastic fracture

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toughness of a material is established from the critical stress intensity factor (k) at the moment when a small crack in the material starts to grow [4].

As a result, the engineering community must be careful about the study of the fracture problems which may appear in any design application. From the previous studies about the fracture of composites, it is found that most composite materials can offer a higher material strength with lighter weight compared to the conventional isotropic materials. Thus, composite materials are on their way to be the most desirable material in the aerospace industry [5]. For this reason, there are many researches in the polymer field who aim to improve the toughness of material and investigate the mechanisms by which such an improvement can be obtained [6].

Tewfik *et al*. [7] calculated the flexibility and durability of the fracture coefficient for substance composed of composite of fiber epoxy reinforced with fiber and copper wires supported by other low carbon steel and a third supported hybrid reinforcement (50% copper wire and 50%low carbon steel wire), and compared the properties of these materials with those of pure epoxy at different temperatures. It was found that the modulus of elasticity increases in the case of reinforcement with wire and becomes least at increasing the temperature. Durability of the material is increasing with reinforcement with wire (various kinds) as well as durability increases with increased temperature.
Sreenivasulu *et al*.[8] observed the effect of polycarbonate content on flexural properties of Epoxy-PC blend matrix. Epoxy-PC containing 10%wt.of PC showed maximum flexural strength. Polycarbonate (10% of weight) toughened epoxy-bamboo fiber composites have been developed with varying fiber content and it is evident that the flexural strength of the composites is increased with the increase in the fiber content. It is also observed that the longitudinally oriented composites show superior properties to transversely oriented composites. In addition to flexural strength, toughness also increased with increase in fiber content.

The current study is interested in the toughness of material of each of polymer blend and composite where in material science, fracture toughness could be a property that describes the capability of a material which contains a crack to resist break, and is one amongst the necessary properties of any material for several design applications [4].

Our research aims to study the mechanical behavior of the (epoxy/polycarbonate) polymer blend before and after the reinforcement with glass and Kevlar fibers (single and hybrid) then determine the fracture and toughness properties of the materials prepared. Also, comparison is made between the properties of pure epoxy and polymer blend reinforced with the fibers mentioned above.

Experimental work

Materials

Two types of materials were used to prepare the binary blend as matrix. The first is epoxy resin and the second is polycarbonate. Epoxy (EP) with its hardener, type (quickmast105) was supplied by Don Construction Products Company (DCP), Jordan while the polycarbonate (PC) was obtained from the local market in pellets form. The density of EP and PC are (1.04, 1.2) g/cm^3 respectively. The reinforcement materials were glass fibers (type E) and Kevlar fibers (type 49). These fibers were obtained from the local market as woven roving (mat). The density of glass and Kevlar fibers is (2.6, 1.44) g/cm^3 respectively.

Sample preparation

All samples in this study were manufactured by hand lay-up technique. Before the casting process, polymer sheets (transparent papers) were prepared as moulds with dimensions of (20*12*0.5) cm. The outsides of mould were surrounded with sticking tape (fablon) to prevent the leakage of polymeric material from it. PC pellets obtained from the local market were used (Fig.1a). After dissolving PC pellets with chloroform (Fig.1b), epoxy resin was mixed with dissolved PC (Fig.1c) at different weight percentages to prepare the binary polymer blend casts. Five sheets of (epoxy/PC) blend of (0, 5, 10, 15 and 20 wt. %) of PC were prepared as shown in Fig. (2). These plates were left at room temperature for (24hours), and then removed from the moulds after the solidification; the casts were put into oven at (50ºC) for (1hour) to complete the curing process. Depending on the obtained values of impact strength, it was found that the best weight ratio of mixing between the two polymers which records the highest value is (20wt.%) of PC. The selected ratio (20% PC) was reinforced with three types of reinforcement of (Glass, Kevlar fibers and a hybrid of the two types). The volume fraction (Φ) of fibers for each type is (15%).This means that Φ is similar for single and hybrid reinforcement. By applying the rule of mixture (equation no.1), the reinforcement process was carried out by adding a layer of polymer blend to the prepared moulds then woven fibers were placed uniformly in these moulds above this layer, finally remaining amount of the polymer blends was poured above the arranged fibers. Two arrangements of sequence of these four layers were performed as shown in Fig.(3). It can be noticed in Fig.(3a) that Kevlar fibers represent the skin layers of hybrid composite while glass fibers represent the core layers of it. In contrast, Fig.(3b) shows inverse case.

$$\Phi = \frac{1}{1+\left(\frac{1-\Psi}{\Psi}\right)\times\left(\frac{\rho_f}{\rho_m}\right)} \quad \ldots\ldots\ldots\ldots (1)[9]$$

Where (Φ, Ψ) are the volume and weight fractions of the fibers respectively,

(ρ_f, ρ_m) are the density of fibers and matrix respectively.

Test procedures

Bending test instrument, type (3-point test) manufactured by PHYWE, Germany was used to determine the values of Young's modulus of the samples.
The values of Young’s modulus are calculated from the relations [10]:

$$I = \frac{b \times t^3}{12} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where I is the moment of area (mm^4) , b is the width of sample (mm), t is the thickness of the sample (mm).

$$E = \frac{M \times g \times L^3}{48 \times I \times S} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Where E is the Young's modulus, (M/S) is the slope of the curve obtained from the relationship between the mass and deflection of each sample. g = 9.8 m/s^2, L is the distance between two supports (10cm).

Charpy impact test instrument, model IMI manufactured by AMITYVILLE, New York was used to determine the impact energy of the samples. The impact strength (I.S) is calculated by the following equation [11]:

I.S=Uc/A ….. (4)

Where, I.S is the impact strength (kJ/m^2), Uc is the energy of fracture (kJ) and A is the cross sectional area of the sample (m^2). The values of material toughness (Gc) are calculated by the following equation [11]:

$$Gc = Uc/bd\phi \quad \ldots\ldots. (5)$$

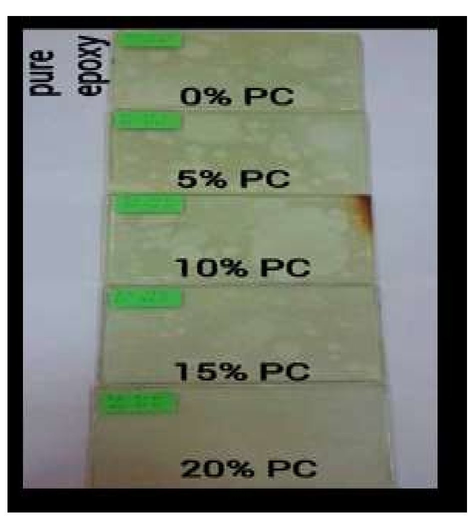
Where: b and d are the width and thickness of sample, respectively. ϕ is the geometrical function. $\phi = 0.135(a/d)^{-0.77}$, (a) is the depth of notch of the sample. (a= 0.25, 0.5, 0.75, 1, 1.25 and 1.5mm). Fig. (4) shows photographs of the notched impact test samples.
The value of fracture toughness (Kc) is calculated by the following equation [11]:

$$Kc = \sqrt{E\, Gc} \quad \ldots.. (6)$$

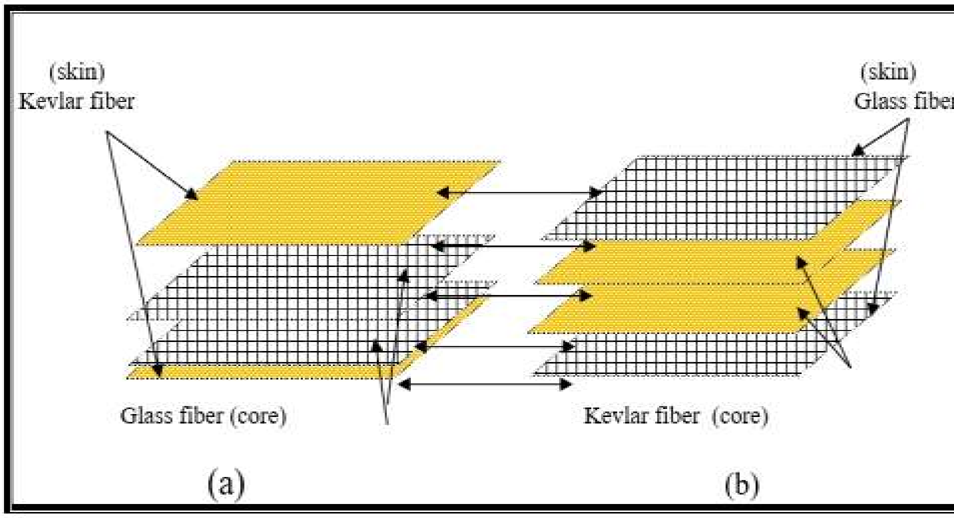
Shore D hardness instrument (digital, type TH210, Italy) was used to measure the hardness values of the specimens.

It is necessary to show that all the samples of bending and impact tests were cut according to standard specifications of (ASTM-D790 and ISO-179) respectively. The hardness test was carried out on the surfaces of impact test samples themselves.

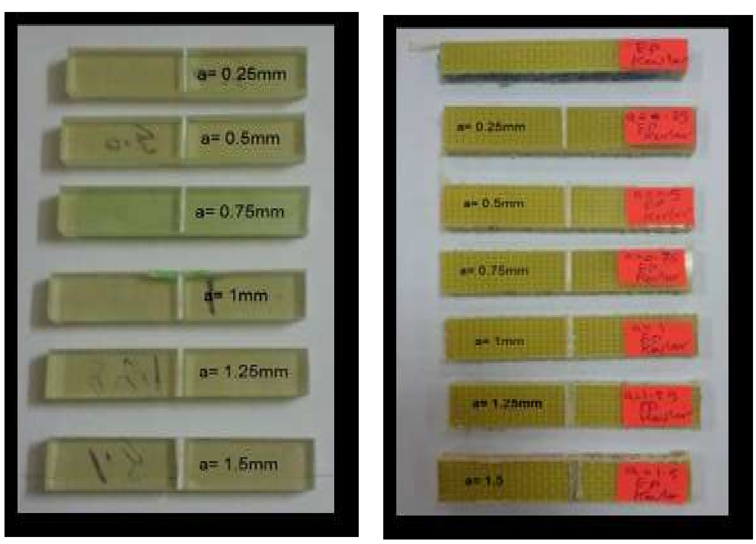
Figure (1): PC pellet and its solvent (a) PC pellet (b) Chloroform (c) PC pellets after dissolving.



Figure(2): (EP/PC) polymer blend sheets with different weight ratios of PC.



Figure(3): Scheme for sequence of the hybrid layers (glass and Kevlar fibers).



(a)Blend (b) composite

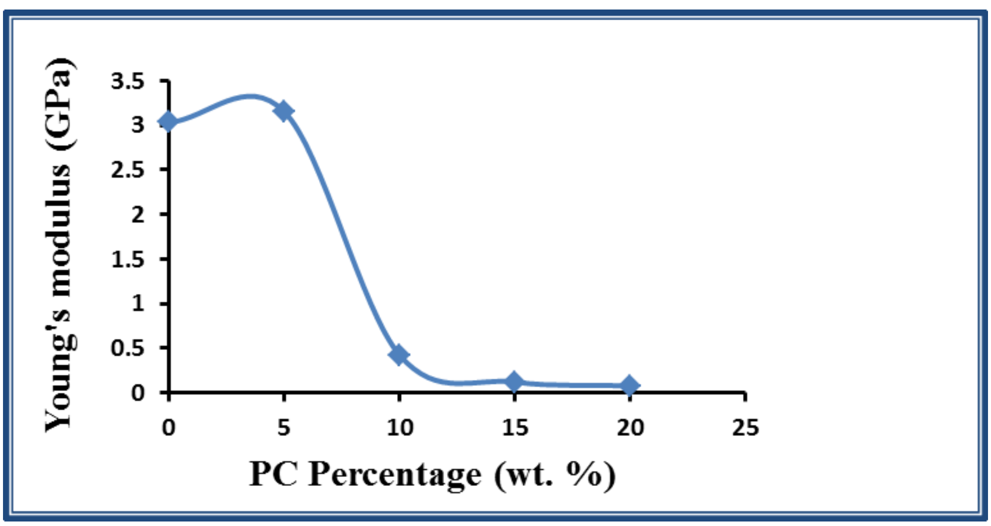
Figure(4): Photographic images of impact samples (blend and composites with different notches).

Results and Discussion

This research discusses the effect of blending ratio on the values of Young's modulus, impact characteristics and hardness as well as it explains the role of reinforcement with different fibers arranged on these values. Fig.(5) shows the effect of PC percentages (wt.%) on the Young's modulus (E) values of the polymer blend. It can be noticed that the values of (E) of the binary blend decrease at ratios higher than 5% of PC. This means that the rigidity of material gradually decreases after blending the epoxy resin with PC. This phenomenon happens due to formg semi interpenetrating polymer network after blending epoxy with PC which gives an indication that there is no complete crosslinking between the two polymers then leading to decrease the rigidity and Young's modulus.

This means that the material at the ratio of (5%wt.) of PC behaves as rigid and stiff material whereas it becomes flexible at higher content of PC. This result agrees with the study [12].

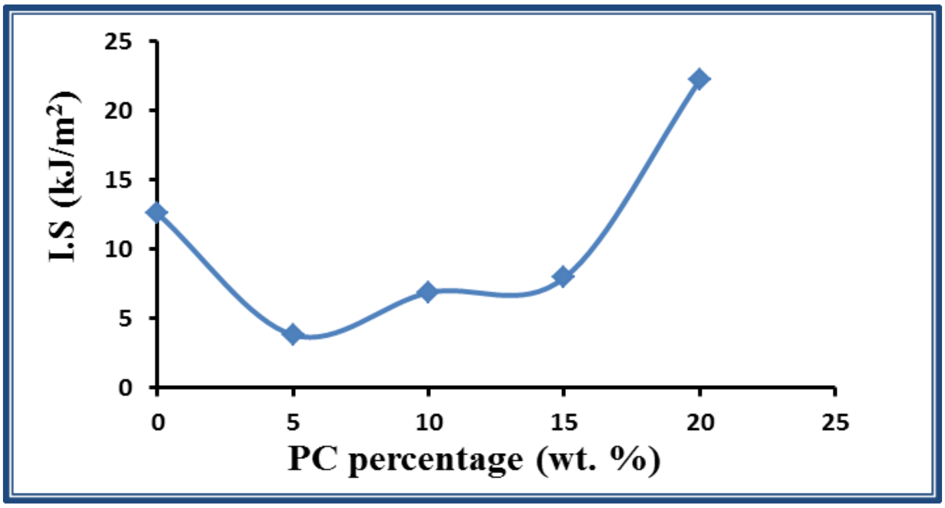
Tables (1and 2) list the values of (E) of single and hybrid composites when the matrix is pure epoxy or blend respectively. It can be concluded that the epoxy or blend reinforced with glass fibers (G.F) has recorded the highest values of (E) due to presence of the glass fibers which have higher value of (E) compared with Kevlar fibers, beauae (E) is equal to 72.4GPa and 62.05GPa for glass and Kevlar fibers respectively [13]. It can be observed that the values of (I.S, Gc and Kc) are higher for blend matrix composites compared with epoxy matrix composites reinforced with the same type of reinforcement. In contrast, the values of Young's modulus and hardness of blend composites are lower than that of corresponded composites.



Figure(5): Young's modulus values (E) of polymer blend (EP/PC) as a function of PC content (wt.%).

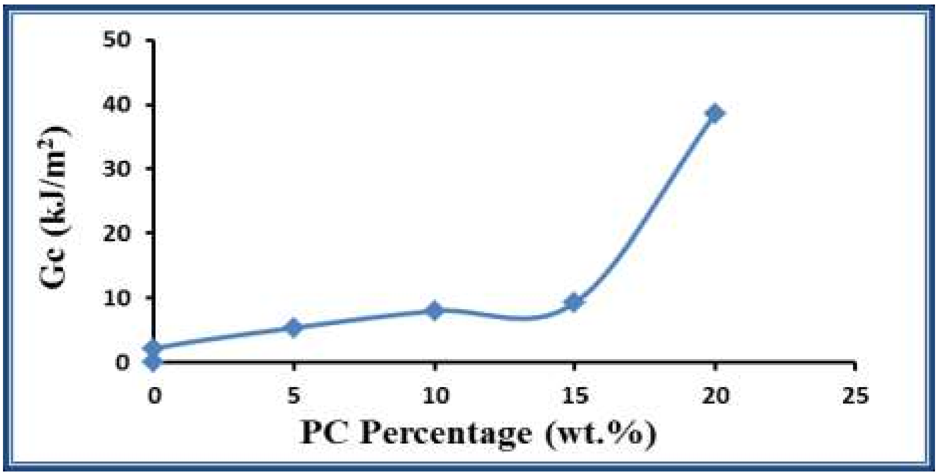
Charpy impact test was carried out on all polymer blends samples (notched and un-notched). Fig.(6) demonstrates the relation of the impact strength values (I.S) with PC content (wt.%) of the blend. It can be noted that the percentage of 20% PC has the highest value of (I.S) compared with lower percentages. The reason behind this is the increasing of material ability to absorb more energy before fracture which makes the material behave as ductile material.

This means that PC can act as a modifier of epoxy properties because it is well known that epoxy behaves as brittle material and suffers from embrittlement behavior during impact loading with poor resistance to crack growth [14]. The increment ratio of impact strength after blending epoxy resin with 20wt.% PC is equal to (76.59%) compared with its value of pure epoxy.



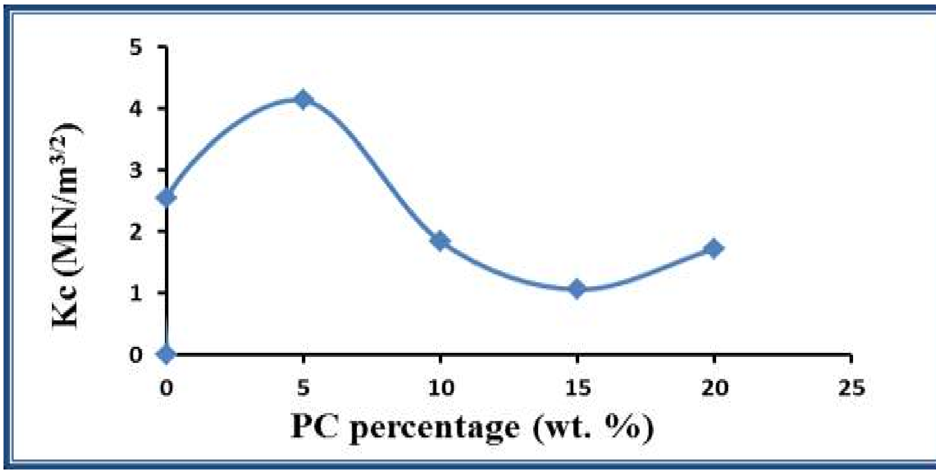
Figure(6): Impact strength values (I.S) of polymer blend (EP/PC) as a function of PC(wt.%).

Fig.(7) illustrates the values of material toughness (Gc) as a function of blending percentages of PC. It is clear that the value of Gc increases from (2.142 to 38.6) kJ/m^2 after blending epoxy resin with 20 wt.% of PC. This means increasing the absorbed energy by the material before final failure. It also can be concluded that Gc values are close at the percentages (5, 10 and 15) % of PC and all of them are lower than that Gc of (20%).



Figure(7): Material toughness values (Gc) of polymer blend (EP/PC) as a function of PC(wt.%).

Fig.(8) shows the relation between fracture toughness values (Kc) and PC percentage (wt.%). From this figure, it can be found that the percent 5% of PC records the highest value of Kc compared with other percentages. This result is due to the value of Young's modulus (E) of 3.15GPa for this percent which is higher than other values (E) of another percent. This result agrees with that obtained by the researchers in their study on advanced epoxy resins with enhanced toughness for demanding applications [15].



Figure(8): Fracture toughness values (Kc) of polymer blend (EP/PC) as a function of PC(wt.%).

The values of (I.S), (Gc) and (Kc) of epoxy and blend composites as a function of composite type respectively are listed in Tables (1and 2). It can be concluded that epoxy or blend reinforced with Kevlar fibers has the highest value of (I.S) compared with other composites under study. This result is due to presence of Kevlar fibers which have higher impact energy compared with glass fibers, these fibers play the important role in improving the impact characteristics as indicated by many previous studies [16,17]. Fig.(9) illustrates the optical micrographs for epoxy and its blends in different weight ratios of PC. From these micrographs it can be observed the nature of fractured surfaces of all blends which exhibit the brittle and ductile fracture behavior.

After carrying out the hardness test, it is found that the hardness values of the prepared polymer blend decrease with increasing the ratio of PC from 5% to 20% but return to increase after the reinforcement of the matrix with the laminate of glass fibers in single and hybrid type (K/G/K).

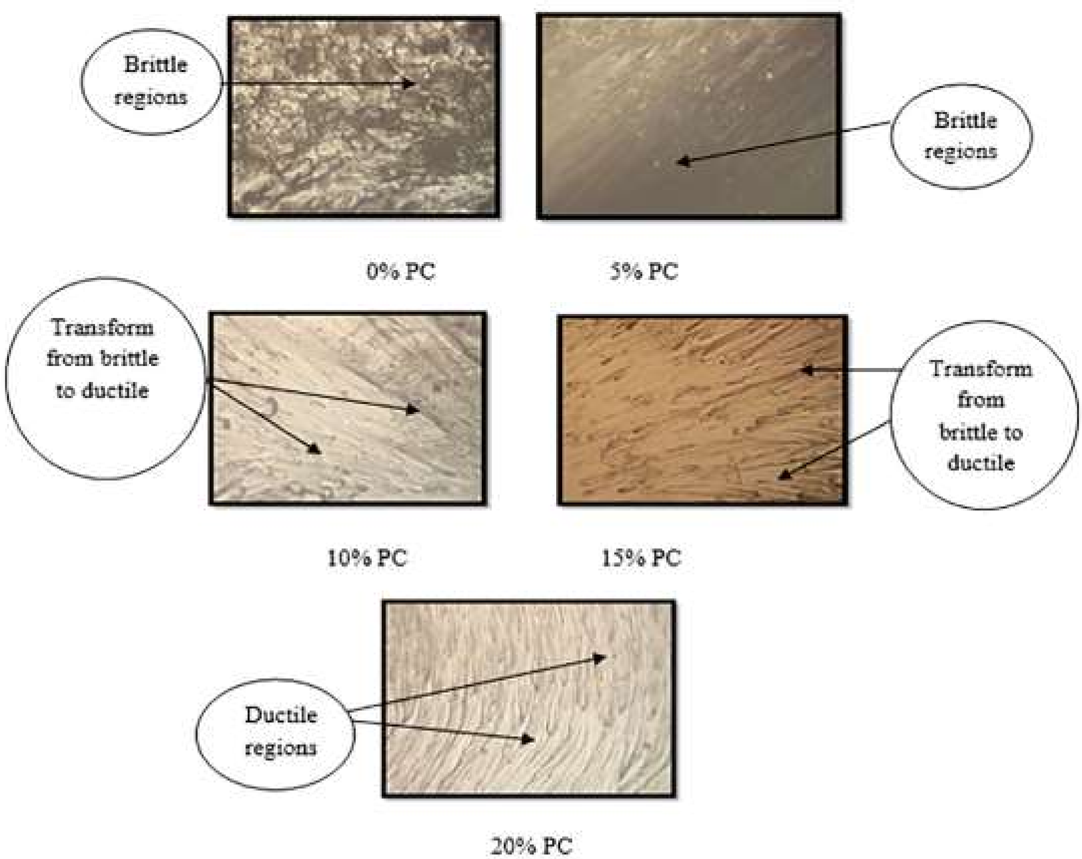
Fig.(10) represents the relation between Shore D hardness number and the content of PC percentage. From this figure it can be concluded that there is some change in the values of hardness and the ratio of decreasing of about 21% of the sample that contains 20% of PC compared with the pure sample. Also, this curve can be divided into three regions. The first is from 0% to 5% of PC in which the material behaves as brittle matter while in the middle region from 5% to 15% of PC, there is some transformation from brittle to ductile behavior and then finally the material becomes flexible in the third region and behaves as ductile at 20% content of PC. The values of Shore D hardness are listed in Tables (1 and 2). From these tables, it can be concluded that the samples (EP+G.F and blend+G.F) record the highest values of hardness compared with other composites.

Table (1): Mechanical properties of epoxy composites

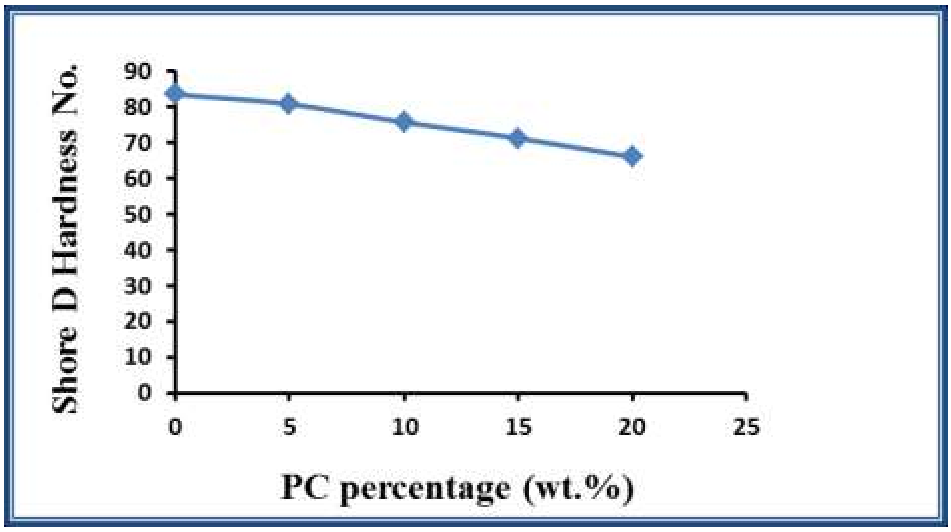
sample	E(GPa)	I.S(kJ/m^2)	Gc(kJ/m^2)	Kc(MN/m$^{3/2}$)	Hardness No.
EP+K.F	3.594	139.23	120	13.723	82.53
EP+G.F	7.215	101.398	108.6	27.99	87.58
EP+K/G/K	3.984	145.655	23.9	9.758	81.34
EP+G/K/G	5.891	121.201	19.2	10.635	89.78

Table (2): Mechanical properties of blend composites

sample	E(GPa)	I.S(kJ/m^2)	Gc(kJ/m^2)	Kc(MN/m$^{3/2}$)	Hardness No.
blend+K.F	2.154	160.405	398	29.279	67.5
blend+G.F	4.291	128.381	217.7	30.564	77.1
blend+K/G/K	1.182	151.88	120.5	11.929	71.75
blend+G/K/G	3.843	129.719	119.4	21.421	75.8



Figure(9): Optical micrographs of polymer blends (EP/PC) with different (wt%) of PC and 100×



Figure(10): The hardness values of polymer blend (EP/PC) as a function of PC (wt.%)

CONCLUSIONS

1-It is possible to obtain homogenous polymer blend by mixing epoxy with polycarbonate.
2- There is modification of the epoxy properties during preparation of the binary blend (EP/PC).
3- The impact strength and material toughness of epoxy increase after blending it with 20wt.% of polycarbonate content.
4- After blending the epoxy with PC, a new material with low cost, easy fabrication and improved toughness can be obtained.
5- It is found that the skin and core layer sequence of hybrid composite play an important role in obtaining the balanced stiffness and toughness properties.

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