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Preparation and Characterization of Binary Polymer Blend Reinforced with Polypropylene, Carbon and Hybrid Fibers

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Abstract: In this study, a binary polymer blend was prepared and characterized before and after the reinforcement with polypropylene, carbon fibers and hybrid of both types. Epoxy/polyvinyl chloride (EP/PVC) blends were prepared with different weight ratios including (0, 5, 10, 15 and 20)% of (PVC). The influence of addition of (PVC) on the mechanical properties of epoxy resin was examined. The microstructure and impact fracture surfaces of the blends and their composites were investigated by scanning electron microscope (SEM). The experimental results show that the mixing ratio of 20% (PVC) has the highest impact strength compared to other ratios. The percentage (80/20) % of (EP/PVC) reinforced with carbon fibers records the highest values for both impact strength (I.S.) and Young's modulus (E); while the hybrid composite has higher Shore D hardness compared with other composites prepared from the same blend.

Keywords: Polymer Blend; Miscibility; Epoxy; PVC; Composites; Mechanical Properties.

Introduction

Polymer blending is a convenient and attractive route for obtaining new polymeric materials. The polymer blending offers the possibility of adjusting the cost-performance balance and tailoring the technology to make products for specific end user applications, enhancing resins' performance, improving specific properties, viz. impact strength, solvent resistance... etc. and provide means for industrial and consumer plastics waste recycling. However, this approach is complicated by the polymers generally fact that are thermodynamically immiscible. Thus, achieving compatibilization in immiscible polymer blends has been a long-standing academic and technological challenge[1].

When any two materials are mixed together, or blended, the properties of the resulting mixture depend on the level at which intimate mixing takes place and on whether any chemical reactions between the components of the mixture take place [2]. Two or more existing polymers may be blended for various reasons. One reason is to achieve a material that has a combination of the properties of the constituents, e.g. a blend of two polymers, one of which is chemically resistant and the other is tough. Another reason is to save costs by blending a high-performance polymer with a cheaper material. A very important use of blending is the combination of an elastomer with a rigid polymer in order to reduce the brittleness of the rigid polymer [2].

A miscible polymer blend is one for which the miscibility and homogeneity extend down to the molecular level, so that there is no phase separation. An immiscible blend is one for which phase separation occurs [3].

Polymer blend (PB) is a mixture of at least two polymers or copolymers. It is a physical mixture of two or more polymers with/without any chemical bonding between them [2]. Basically, there are three different types of blends depending on miscibility [4, 5]:

1. Completely miscible blends have $(\Delta G < 0)$ due to specific interaction.

Homogeneity is observed at least on a nanometer scale, if not on the molecular level. This type of blend exhibits only one glass transition temperature (Tg), which is in between the glass transition temperatures of the blend components in a close relation to the blend composition.

- 2. In partially miscible blends, a small part of one of the blend components is dissolved in the other part. This type of blend, which exhibits a fine phase morphology and satisfactory properties, is referred to as compatible. Both blend phases are homogeneous and have their own Tg. Both Tg_s are shifted from the values for the pure blend components towards the Tg of the blend component.
- 3. Fully immiscible blends have a coarse morphology, sharp interface and poor adhesion between the blend phases. So, these blends are of no use without compatibilization.

A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the (reinforcing phase) and the one in which it is embedded is called the (matrix) [6].

The most common advanced composites are polymer matrix composites (PMCs) consisting of a polymer (e.g., epoxy, polyester, urethane) reinforced by thin diameter fibers (e.g., graphite, aramids, boron). For example, graphite/ epoxy composites are approximately five times stronger than steel on a weight for- weight basis. The reasons why they are the most common composites include their low cost, high strength and simple manufacturing principles [7].

The importance of polymer blends has been demonstrated in recent years by the intensive research carried out on the subject, the increasing amount of articles, patents and books being continuously published and the introduction of polymer blends for practical uses [8].

D. Feldman *et al.*[9] modified the epoxy polymer (EP) by incorporation of dibutyl

phthalate (DBP), poly vinyl chloride (PVC), polyvinyl alcohol (PVA) and glass fiber reinforcement. Results indicated that EP and DBP are miscible in the proportions used in the work (up to 10% of DBP). PVA added to cure EP in a concentration of 10% occurs as a separate phase. The morphology of EP–PVC blends is relatively complex; EP and PVC are immiscible at low concentration of the second component (up to 10% of PVC), but become mutually and increasingly more miscible as the concentration of PVC increases. Incorporation of DBP into EP causes a marked reduction in the heat distortion temperature (HDT), whereas the addition of PVC has only a moderate effect.

Cao *et al.* [10] studied the mechanical properties of an epoxy resin toughened by polyester. The results showed that the impact strength and tensile strength of the modified epoxy resin were remarkably greater than those of the unmodified cured epoxy resin and the mechanical properties depended greatly on the congregating state of the polyester added.

Shokrieh et al.[11] have studied the mechanical properties of multi-walled carbon nanotube (CNTs) /polyester nanocomposites. They found that adding CNTs into polymers at very low weight fractions can improve mechanical properties of the resulting nanocomposites. The results of mechanical tests (tensile and flexural) exhibit improvements of tensile and flexural strengths by 6% and 20%, respectively, at only 0.05 wt.% MWCNT (multiwalled carbon nanotubes). Improvements in Young's modulus and flexural modulus were also observed.

Epoxy resin is a brittle material and has low impact strength in many applications. For this reason, there are two main aims of the current study, the first aim is carrying out some modification in properties of resin material (epoxy, EP) by adding thermoplastic material (Poly Vinyl Chloride, (PVC)) with different weight ratios to prepare binary polymer blend. The second aim is to study some of mechanical properties for these blends before and after the reinforcement with polvmer fibers (polypropylene fibers), ceramic fibers (carbon fibers) and hybrid fibers of the previous two types.

Experimental Part

The Materials Used

The following materials were used for preparing the specimens of polymer blends and their composites:

- Matrix material: Two types of polymers were used in this study; the first is epoxy resin (EP) as thermosetting material, while the other is PolyVinyl Chloride (PVC) as thermoplastic material.
- Epoxy resin (EP): Epoxy resin of type (Quickmast 105) was used in this work; it is a liquid with moderate viscosity. This resin could be converted to the solid state by adding a hardener.
- PolyVinyl Chloride (PVC): In this study, a white powder of (PVC) produced by (Hyundai company) was used to prepare the polymer blend after dissolving it with (cyclohexanon). The molecular weight of PVC is about 62.05g/mol.

Reinforcement materials: Three types of fibrous reinforcement were used in this work.

1- Carbon fibers

Chopped carbon fibers as ceramic fibers were used to reinforce the selected polymer blend (80/20)% of (EP/PVC).

2-Polypropylene fibers

Chopped polypropylene fibers as polymer fibers were used to reinforce the polymer blend under study.

3-Hybrid fibers

The above two fibers were mixed together to reinforce the prepared polymer blend.

Blends and Composites Preparation

- 1- Before the casting process, polymer sheets (transparent papers) were prepared as molds with dimensions (15*20*2) cm³.
- 2-PVC powder was sieved using (Retsch) sieve produced by UK company with three particle sizes including (25, 45 and 63) micron, it was found that the particle size of PVC powder is about (63micron).
- 3- After dissolving (PVC) powder in its solvent (cyclohexanon), epoxy resin was mixed with PVC at different percentages to prepare the binary polymer blend casts.

- 4- Five sheets of (epoxy / PVC) blend with different weight ratios (0%, 5%, 10%, 15%, and 20%) of PVC were prepared, respectively.
- 5- These sheets were left at room temperature for (24 / hours) and then removed from the molds after completing the solidification process; the casts were put into an oven at (50°C) for (1 hour) to complete the curing process.
- 6- The homogeneity case of these blends was tested by using scanning electron microscope (SEM).
- 7- It was found that the best ratio of mixing between the two polymers is (80/20)% which exhibits the compatibility case between them.
- 8- The selected ratio was reinforced with three kinds of fibrous reinforcement including (carbon, polypropylene and a hybrid of both of them).
- 9- The rule of mixture (equation 1) [12] was applied for calculating the volume fraction of fibers (*) for the composites. The reinforcement process was carried out by the addition of a layer of polymer blend inside the prepared molds previously, and then the chopped fibers were arranged uniformly into these molds above this layer. Finally, the remaining amount of the polymer blends was poured above the arranged fibers.

$$\Phi = \frac{1}{1 + \left(\frac{1 - \Psi}{\Psi}\right) \times \left(\frac{\rho_f}{\rho_m}\right)}$$
(1)

where (Φ, Ψ) are the volume and weight fractions of the fibres, respectively, (ρ_f, ρ_m) are the density of fibres and the density of matrix, respectively.

The density of the prepared blends was determined from the following equation [8]:

$$\rho_m = X_1 \rho_1 + X_2 \rho_2 \tag{2}$$

where ρ_m : the density of the matrix (polymer blends), ρ_1, ρ_2 : the density of the first polymer and the second polymer, respectively and X_1, X_2 : the percentage of the first polymer that of and the second polymer, respectively.

- 10- The previous step was repeated with the three different types of reinforcement under study.
- 11- Step (5) was repeated for the three reinforced casts. It is important to mention that the volume fraction of fibers is (30) % for the single reinforcement, but equal to (15%) of carbon fibers (C.F.) and (15%) of polypropylene fibers (P.P.F.) for the

reinforcement with hybrid fibers (H.F.) to obtain constant fiber volume fraction for each case of reinforcement.

12- According to the standard specifications (ISO and ASTM), the samples of impact, bending and hardness tests were cut and their properties were tested at room temperature. The prepared specimens are shown in Figs. 1, 2 and 3.



FIG. 1. Impact test samples before and after the reinforcement, respectively.



(a) (b) FIG. 2. Bending test samples before and after the reinforcement, respectively.



FIG. 3. Hardness samples before and after the reinforcement, respectively.

Mechanical Testing

Impact Test

Charpy impact test instrument was used to determine the impact energy of the prepared samples before and after the reinforcement.

The technique of the instrument is conducted through lifting up the hammer to the highest point and fixing it well, and then the sample is placed in its position.

The potential energy by a swinging movement will change to kinetic energy and loses part of it in breaking the sample; the pointer of gauge will read the energy value required to break the sample.

Impact strength (I.S.) is calculated by the relation [13]:

$$I.S. = \frac{Uc}{A} \tag{3} (J/m^2)$$

I.S.: impact strength;

Uc: the energy of fracture (Joule);

A: the cross-sectional area of the sample (m^2) .

Bending Test Instrument

Three-point bending test instrument was used to measure the Young's moduli of polymer blend samples before and after the reinforcement. The sample was fixed at the two ends on the support of the instrument, and then the weights were added gradually to the hanger which was placed at the middle of the sample. From the reading dial gauge, the deflection amount of the sample was determined.

The values of Young's moduli are calculated from the following relations [13]:

$$I = \frac{b \times t^3}{12} \tag{4} \text{ mm}^4$$

where (I) is the moment of inertia, (b) is the width of the sample, (t) is the thickness of the sample. Young's modulus (E) is calculated using equation (5).

$$E = \frac{M \times g \times L^3}{48 \times I \times S} \tag{5}$$

where (M / S) is the slope of the curve obtained from the relationship between the mass (M) and the deflection (S) of each sample, $g = 9.8 \text{ m/ s}^2$, L is the distance between two supports which is equal to (10 cm).

Hardness Test Instrument

Shore D hardness instrument (digital, Italy, type TH210) was used to measure the hardness values of the specimens. This test was carried out by fixing a dibbing tool on the surface of the sample. The dibbing tool length is about 2.54 mm. The pointed dibbing tool penetrates into the material surface, and then the number value of hardness is shown on a digital screen.

Morphology Studies

Scanning electron microscope (SEM, model 7426 manufactured by OXFORD company) was used to study the morphology and fracture surface nature of the impact test specimens.

Results and discussion

Impact Properties

Charpy impact test was used to evaluate the impact strength of the (EP/PVC) blends with different weight ratios of (PVC) including (0, 5, 10. 15 and 20%). Fig. 4 shows the effect of PVC percentages on the impact strength (I.S.) values of the prepared blends. From these results, it can be observed that the impact strength (I.S.) values decrease at the first addition ratios of PVC and then increase at percentages above (15%). This increase mav be attributed to the compatibilization between epoxy and PVC at this ratio of mixing as well as the second phase of (PVC) affects the (I.S.) because the particles of (PVC) act as an energy absorber and improve the impact strength of the blend [14].

Fig. (5) illustrates the values of (*I.S.*) of (EP/PVC) reinforced with P.P.F, C.F. and H.F. It can be seen that carbon fibers (C.F.) give higher values of (*I.S.*). This means that (C.F.) need higher fracture energy before fracture which leads to increase the toughness of this composite where one definition of material toughness is the amount of energy per volume that a material can absorb before breaking. It is also defined as the resistance to fracture of a material when stressed [3].

In general, previous studies [6, 15, 16] were indicated that cured epoxy with other polymer phases exhibits two microstructure phases consisting of small particles of the added phase.



FIG. 4. Effect of (PVC%) on the impact strength of (EP/PVC) polymer blend.



FIG. 5. Impact strength of (EP/PVC) composites.

The morphology of fracture surfaces for pure epoxy, blends and their composites can be observed from Figs. 6(a-e) and 7(a-c), respectively. Fig. 6a illustrates the nature of single phase of pure epoxy. The neat blend sample of (5%PVC) shows brittle fracture surface, indicative of miscible characteristics between the epoxy and PVC as shown in Fig.(6b). In Figs. (6c-e), it is observed that fracture surface was rather coarse and turned to ductile fracture behaviour due to higher addition of PVC. In Fig. (6e), another strong ductile fracture surface can be observed, which gives an indication of good dispersion of (PVC) phase that improves the impact strength at 20wt.% of (PVC). It can be concluded that the plasticity case of the blend will increase and become best at mixing of 20% of PVC.



FIG. 6. SEM micrographs of fracture surfaces for (EP/PVC) blends.

From the micrographs of fracture surfaces for the composites shown in Figs. (7a-b), respectively, it can be recognized that carbon fibers break with brittle manner, while (P.P.F) fractures in ductile mode deform with buckling. It can also be noticed that (C.F.) have smooth fracture surfaces, implying brittle fracture mode, but there is pronounced bending that precedes the fracture and final separation occurs after a large amount of local drawing for (P.P.F.). In contrast, carbon fibers fracture without any reduction in cross-sectional area [12].

The fracture surface of (H.F.) involves both above cases with some fibrillation and kink formation of fibers as shown in Fig. (7c).





(c) (EP/PVC)+H.F FIG. 7. SEM micrographs of fracture surfaces for (EP/PVC, (80/20)%) composites.

Hardness and Young's Modulus Properties

It is well known that the hardness is usually defined as the resistance of material to penetration. Hardness is primarily a function of the elastic limit; (i.e. yield strength) of the material [17].

In Fig.(8), the curve shows the dependence of Shore D hardness Number on the content of PVC. This curve can be divided this curve into three regions corresponding to the behaviour of the material. The first is the low additive content region where the hardness follows a gradual decrease with increasing the content of PVC. The blend exhibited a low ductility in this region, so it was named the brittle region. The second was the brittle - ductile transition when the additive content increased from (5 to 15)% of PVC, where the hardness was greatly influenced by the content of the additive. When the content exceeded 15%, the blend exhibited higher

toughness and the influence of additive on the hardness became less, this was the ductile region which represents the third region of the curve.

Fig. (9) shows convergent values of hardness for (C.F.) and (H.F.) composites and both are higher than that for (P.P.F.) composite, which is attributed to the brittleness for carbon fibers.

Young's modulus (E) is indicative of the property called stiffness [17], Fig. (10) illustrates the relationship between (E) and PVC content of the blend. The first values of curves reflect stiffness and rigidity, while the small amounts of (E) indicate flexible material.

Fig. (11) shows values of the Young's modulus of (EP/PVC) composites. It can be concluded that (C.F.) composite has the highest value of (E) compared with (P.P.F) and (H.F.) composites; where (E) ranged (2.2-2.7) GPa for carbon fibers and (1-1.4) GPa for polypropylene fibers[12].



FIG. 8. Shore D hardness No. of (EP/PVC) blends.



FIG. 9. Shore D hardness No. of (EP/PVC) composites.



FIG. 10. Young's modulus values of (EP/PVC) blends.



Conclusions

Both epoxy resin and PVC form a singlephase system at the ratio 5% of (PVC), but two phases and heterogeneous blend with good compatibility results at 20% of (PVC). It was observed that impact strength increased at 20 wt.% PVC content in comparison with pure epoxy. The impact strength showed a 13.3% increase at this ratio. From (SEM) micrographs,

References

- [1] Wang, D., Li, Y., Xie, X. and Guo, B., Polymer, 52(1) (2011) 191.
- [2] Zhong, Z., Zheng, S., Yang, K. and Que, Q., J. of Applied Polymer Science, 69(5) (1998) 995.
- [3] Budinski, K.G., "Engineering materials, properties and slection", 9th edition, (Pearson, Upper Saddle River, New Jersey, 2010).
- [4] Utracki, L.A., "Polymer alloys and blends, thermodynamics and reology", (Hanser publishers, New York, 1989).
- [5] Seymour, C., "Polymer Chemistry", 7th Edition, Charles E. Carraher, Jr., (CRC press, New York, 2006).
- [6] Jang-Kyo, K. and Yiu-Wing, M., "Engineered Interfaces in Fiber Reinforced Composites", (Elsevier, Amsterdam, 1998).
- [7] Autar, K.K., "Mechanics of Composite Materials", 2nd edition, (Taylor and Francis Group, 2006).
- [8] Martinez, J.M., Eguiazabal, J.I. and Nazabal, J., J. of Applied Polymer Science, 45(7) (1992) 1135.
- [9] Feldman, D., Blaga, A. and Coriatry, E., J. of Applied Polymer Science, 29(2) (1984) 515.

it can be noticed that the blends exhibit different impact fracture modes depending on the content of the second phase (PVC). SEM provided further evidence, showing that (PVC) indeed acts as a plasticizer factor for epoxy at 20% of (PVC) content. Young's modulus and hardness of epoxy decrease after blending it with PVC, whereas the (EP/PVC) blend has higher (E) and hardness after reinforcing it with carbon fibers.

- [10] Cao, Y., Shao, Y., Sun, J. and Lin, S., J. of Applied Polymer Science, 90(12) (2003) 3384.
- [11] Shokrieh, M.M., Saeedi, A. and Chitsazzadeh, M., Journal of Nanostructure in Chemistry, 3 (2013) 20.
- [12] Hull, D. and Clyne, T.W., "An Introduction to Composite Materials", 2nd edition, (Cambridge University Press, Great Britain, 1996).
- [13] Crawford, R.J., "Plastic Engineering", 3^{ed} edition, (Elsevier Butterworth-Heinemann, Oxford, 1998).
- [14] Chang, W.Y. and Lo, M.S., J. of Applied Polymer Science, 36 (1988) 1685.
- [15] Saleh, A.B., Mohd Ishak, Z.A., Hashim, A.S. and Kamil, W.A., Journal of Physical Science, 20(1) (2009) 1.
- [16] Barone, L., Cicala, G. and Recca, A., Polymer Engineering and Science, 46(11) (2006) 1576.
- [17] Rajput, R.K., "Engineering Materials", revised edition, S. Chand, (New Delhi, 2008).