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Studying the Effect of Reinforcement with Random Short Fibers and Temperature on the Impact Strength of an Epoxy/Polyurethane Blend Matrix

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Abstract: A polymeric blend consisting of epoxy resin and polyurethane was prepared as a matrix material with (88%) of epoxy and (12%) of polyurethane by weight fraction. It was reinforced with a random short whisker fibre of polypropylene (PP) and fibreglass (FG) with fractional volumes of 4, 8, and 12%. The impact strength before and after the reinforcement was done with temperatures of 25, 50, and 75 °C. The results showed that the reinforcement of matrix material with fibre has increased the impact strength from 3.4 kJ/m² to 16.9 kJ/m² at 12% vol. of the composite material of both fibre polypropylene with glass fibre and followed by the composite material with polypropylene fibre, and finally by the composite material of glass fibre. Also, the increase in temperature led to a rise in the impact strength, except for the polypropylene fibre-reinforced polymer mixture, as the increasing in temperature led to a decrease in the values of impact strength from 14.2 KJ /m² at 25 °C to 11.5 kJ/m² at 75° C.

Keywords: Polymeric blend, Epoxy resins, Polyurethane resin, Impact strength, Temperature effect, Volume fraction

1. Introduction

Polymers are used in a wide range of industrial applications because they possess special characteristics that other types of materials (metal and ceramics) do not. Polymers are noted for their light weight and ease of manufacturing. It is resistant to oxidation and corrosive solutions such as alkalines, acids, solvents, and rapid colouring [1]. Further scientific advances in polymers have made it possible to formulate new polymeric materials with desirable properties by physically mixing two or more polymers to form polymer blends. The resultant mixture has common features regarding the basic components, depending on the polymer quality and the mixing method. The polymer blends are binary, triple or quadrilateral depending on the number of polymers that form the mixture.

Fibre-reinforced materials are used for wide ranges of applications, such as gas turbine machines and other products undergoing vertical impact loads at the level of reinforcement. Plastic materials are subjected to external impacts during the impact strength test, which is a well-trusted method that grants descriptive and correct indications of the strength of the material and its resistance to fracturing under stress induced by high speeds [2]. Essentially, the impact strength is defined as the highest durability of the material for a sudden impact without fracture [3].

Many researchers were interested in studying the mechanical properties of composite materials in general, especially impact strength due to its great importance in determining the quality of a material that is suitable for various industrial applications.



In 1987, Malinconico et al studied the impact test by the Charpy method and with different temperatures of heat on pure polyester and polyester blended with different proportions of polybutadiene rubber. They concluded that certain percentages of the rubber in the polyester matrix yield much higher impact strength than the pure polystyrene. In essence, the polymer blends have better mechanical properties [4]. In 1992, Nasser studied the impact strength by Charpy method of polyester reinforced with glass fibre. He noted that impact strength increases with temperature [5]. In 2008, Hanaa studied the mechanical and thermal properties of hybrid composite materials consisting of epoxy as a base material and reinforced with Kevlar, glass, or Nylon fibres. The results showed the fibres enhanced mechanical properties [6].

The purpose of this study is to improve the impact strength of a polymeric mixture by reinforcing this mixture with fibres and to indicate the effect of temperature on the values of impact strength.

2. Experimental

2.1. Materials

2.1.1. Matrix material. In this research, epoxy resin (EP) was used, which is a liquid substance. Its specific gravity is 1.0 g/cm^3 and solidifies when the hardener was added, which is a transparent liquid. The hardener is added to the resin at a ratio of 1:3 by volume at room temperature. The type of epoxy is Quickmast 105 and is manufactured by Ayla Construction Chemicals (DCP Jordan). It has more distinct characteristics than other commercial epoxies, such as low viscosity, high adhesion, and low creep rate. Table 1 shows the specifications of epoxy used in this research.

Table 1. The specifications of epoxy at 25°C

Properties	Typical Results
Flexural Strength	$>45 \text{ N/mm}^2$
Compressive Strength	$>70 \text{ N/mm}^2$
Tensile Strength	$>25 \text{ N/mm}^2$
Young's Modulus	16 GPa

The polyurethane (PU) type is Nitofill UR63, which is manufactured by Fosroc Constructive Solutions UAE, which is in the form of a transparent liquid at room temperature. Its specific gravity is 1.07 g/cm^3 . The hardener added to it is also a transparent liquid, with a rate of addition (1:3). Polyurethane is characterized by its good resistance to most organic solvents, diluted acids, and alkaline. Table 2 shows the specifications of polyurethane rubber used in this paper.

Table 2. The specifications of polyurethane at 25°C

Properties	Typical Results
Tensile Strength	25–45 N/mm^2
Elongation %	400–790
Hardness, Shore A	50–70

2.1.2. Reinforcement materials. In this study, two types of fibre were used to strengthen the polymeric mixture (the base material), Polypropylene whisker fibres were provided by Sika® Fiber (Turkey) with a length of 6 mm with a nominal fiber diameter of $18 \mu\text{m}$ and a specific gravity of 0.91 g/cm^3 . Table 3 shows the properties of polypropylene fibres as provided by the supplier.

Table 3. Mechanical properties of polypropylene fibers.

Properties	Typical Results
Elongation at Break %	45%
Tensile Strength	300 – 400 N/mm ²
Modulus of Elasticity	4000 N/mm ²
Specific Surface Area of Fibers	250 m ² /kg
Thermal Conductivity	Low
Melt Point	160 °C

The second is the glass whisker type E that was produced by URSA Uralita group –Turkey. It has a length of 6 mm and density of 2.54 g/cm³. It an individual fiber diameter between 6.1–7.7 µm. Table 4 shows some glass whisker properties as provided by the supplier.

Table 4 Mechanical and physical properties of Glass whisker

Properties	Typical Results
Tensile Strength	520 MPa
Modulus of Elasticity	75 GPa
Elongation at Break	4.8 %
Shear Modulus	30 GPa
Thermal Conductivity	1.35 W/m.K
Maximum Service Temperature	630°C

2.2. Sample preparation

Forming in place moulding method was used in the preparation of samples before and after fibre reinforcement because it is a common and a successful method in the preparation of polymeric compositions. The preparation of the samples has many steps which are:

2.2.1 Preparing polymer blend. Epoxy was gradually mixed with the hardener, then that mix was added to polyurethane and blended gradually and then Polyurethane hardener was added to the blend. The percentage of mixing blend was (88% EP /12% PU) by weight fraction. The density of the blend was determined by the law of mixture using the relation as in Equation (1) [7]:

$$\rho_m = w_1\rho_1 + w_2\rho_2 \quad (1)$$

Where

ρ_m : the density of the matrix (polymer blend).

ρ_1, ρ_2 : the density of the first and the second polymer respectively (g/cm³)

w_1, w_2 : the percentages of the first and the second polymer respectively.

2.2.2. Whisker fibre addition ratios. The composite materials were made with a volume fracture of 4, 8, and 12% by relying on the following relation as in equation (2) [7]:

$$\varphi = \frac{1}{(1 + \frac{1-\psi}{\psi} \frac{\rho_f}{\rho_m})} \quad (2)$$

Where:

φ : The volumetric fracture of fibres in the composite material.

ψ : weight fraction of fibres in the composite material.

ρ_f, ρ_m : The density of fibres and the polymer matrix, respectively, (kg/m³) .

The mixture of blended polymers and fibre whiskers are prepared by being poured in a glass mould made with dimensions $25 \times 25 \times 0.5 \text{ cm}^3$. Before pouring the composite mixture, the mould was thoroughly cleaned and dried. In order to ensure that the resin is not stuck to the mould, stickers of thick transparent film were placed on the inner walls of the mould to obtain a regular and smooth surface and for an easy extraction of the moulded material. After the completion of the solidification process for all composite castings (24 hours), the castings are extracted from the moulds, and are cured at 45°C for 2 hours to complete the chemical reactions.

The casts are then cut by using a special cutting device according to ISO 179:2010 standard dimensions ($3.5 \times 10 \times 55 \text{ mm}^3$) by using a HSM41 Charpy impact tester. It is worth mentioning that a special chamber was prepared for the samples in order to maintain the temperature of the samples during the tests. The chamber consists of an air blower, which can control the temperature of the intake air and the thermometer, where the hot air is blown into the room until the thermometer stands at 25°C , 50°C , and 75°C .

The impact strength test was performed on three samples of the same composite material at each temperature and labelled as follows (Table 5).

Table 5. Shortcut and its meaning that is used in this paper

Meaning	Label
Matrix Material (Polymer Blend).	BM
Polymer Blend Reinforced with polypropylene Fibres whisker	PP
Polymer Blend Reinforced with E-glass Fibres whisker.	GF
Polymer Blend Reinforced with Polypropylene and E-glass Fibre whiskers.	GPF

2.3. Mechanical Test

Some polymeric materials are ductile under the effect of static stresses. However, it seems that these samples were brittle when under the influence of rapid stresses [8]. Impact strength testing was performed by the charpy method, which is highly reliable for studying the behaviour of materials that are exposed to the effect of rapid impacts. This also represents a type of three-point flexure test known as a dynamic three-point flexure.

The principle on which this test is based is that some of the primary energy (potential energy) of the hammer is absorbed from the sample before fracturing. The impact strength is calculated from the following relation as in Equation (3) [9]:

$$a_{cU} = \frac{E_{cU}}{b \times h} \quad (3)$$

Where

a_{cU} : Charpy notched impact strength (kJ/m^2)

E_{cU} : impact energy absorbed in breaking an unnotched specimen.

h : specimen thickness

b : and specimen width

This absorptive energy depends on the nature of the components involved in the manufacture of the composite material, and its ability to resist the external stress imposed on it [10].

3. Results and Discussion

3.1. Volume Fraction Effect

The results obtained for prepared samples with different fiber types and volume fraction in the research are displayed in Table 6 and indicate that the values of the impact strength significantly had increased more than in the case of the unreinforced matrix material (polymeric blend) with varying degrees from one substance to another depending on the type and weight fraction of the fibre used.

Table 6. The values of the impact strength

Volume Fraction	PP	GF	GPF
BM = 0%	3.4	3.4	3.4
4%	9	5.4	11.5
8%	11.2	7.9	14.35
12%	14.2	9.6	16.9

The failure resulting from the impact test for unreinforced polymeric mixture occurs through the growth of initial cracks induced by the impact stresses resulting from the separation of the bonds or polymeric forces.

However, if the polymeric mixture is reinforced with fibres, these fibres will bear the greatest portion of the imposed load compared with the polymeric mixture. Therefore, the fibres work to distribute the stress over a larger area and reduce the possibility of concentrating stress on a particular area; most of the elastic strain energy of the composite material will be stored in them [11, 12].

According to Table 6., the highest impact strength in the laboratory conditions at a temperature of 25 °C was for the GPF samples GPF, followed by the PP samples and GF samples, respectively.

The impact strength depends on the nature of the matrix material (polymer mixture), the reinforcement materials as well as on the interface between them as the interface forces play a major role in increasing the impact strength values of the composite material. This is observed experimentally on fracture surfaces, where the fibres themselves have fractured but have not separated from the base material.

When the composite material is exposed to the impact stress perpendicular to the orientation of the reinforcement, the crack extends through the matrix, the interface, and then to the fibres. If the imposed stress and the absorbed energy is greater than the adhesion energy between the fibre and the matrix material, the crack makes its way through the fibre and grows toward the second nearest fibre and then the absorbed energy during the fracture is large enough to exceed the cohesive energy.

3.2. Temperature Effect

Table 7 shows the values of impact strength with volume fraction 12% with the increase of the temperature. It can be seen that increasing the temperature led to the increasing of impact strength and for all models except for the composite material (PP).

Table 7. The values of impact strength with volume fraction 12% with the increase of the temperature

Temperature °C	GPF	GF	PP	BM
25	16.9	9.6	14.2	3.4
50	19.6	9.9	13.4	5.2
75	16.8	11.4	11.5	6.9

This is due to the loosening of the bonds between the molecules of the material and its sliding motion, which gives it greater potential to absorb the energy of the impact, leading to an increase in the energy needed for the fracture [13].

The reason behind the loosening of the bonds is the presence of some minor bonds between the chains of the base material (the polymer mixture) that weaken with high temperature while the primary bonds do not (at least at the same extent) [14].

In addition, the increase in impact strength values of the composite materials can be attributed to glass fibre whiskers with a random orientation that are characterized by their symmetrical properties in all directions as well as the high hardness, good durability, and high modulus of elasticity of GF [15].

While the reduction of the values of the impact strength for the composite material (PP) with the increase in temperature is due to changing the behaviour of the matrix material and polypropylene fibres, the polymer materials exhibited softening behaviour.

Increasing the temperature increases the movement of the monomer units of the molecular chains and the loosening of the bonds between them softens the matrix and the interface with the fibres and thus weakens the impact strength of the composite [16].

4. Conclusions

1. Fibre reinforcement has led to a significant increase of impact strength for all models.
2. Increasing the temperature also increased the impact strength for all models, except for the composite material which was reinforced with polypropylene fibres whisker.
3. The presence of PP fibres with fibreglass whiskers in the composite materials increased the impact strength.

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