Production and Mechanical Characterization of Ballistic Thermoplastic Composite Materials

D. Korsacilar, C. Atas

***Abstract*—**In this study, first thermoplastic composite materials /plates that have high ballistic impact resistance were produced. For this purpose, the thermoplastic prepreg and the vacuum bagging technique were used to produce a composite material. Thermoplastic prepregs (resin-impregnated fiber) that are supplied ready to be used, namely high-density polyethylene (HDPE) was chosen as matrix and unidirectional glass fiber was used as reinforcement. In order to compare the fiber configuration effect on mechanical properties, unidirectional and biaxial prepregs were used. Then the microstructural properties of the composites were investigated with scanning electron microscopy (SEM) analysis. Impact properties of the composites were examined by Charpy impact test and tensile mechanical tests and then the effects of ultraviolet irradiation were investigated on mechanical performance.

***Keywords*—**Ballistic, Composite, Thermoplastic.

I. Introduction

BECAUSE they provide a number of benefits, polymer matrix (thermoset or thermoplastic) composite materials, according to conventional metallic materials, are used extensively in engineering applications nowadays. A lot of studies have been concerning thermoset composites, while quite limited studies have been interested in thermoplastic composites. Due to thermoplastic composites have superior features such as recyclability, toughness (good impact and damage resistance), high strength/weight and modulus/weight ratios, sufficient corrosion resistance, excellent thermal and acoustic insulation properties, their interests, in composites structures, are increasing with each passing day. Furthermore, the composites are also used as ballistic materials because of their superior shock damping features.

Previous research has been carried out regarding the mechanical behavior of composite materials. Sarikanat et al. [1] investigated the impact behavior of glass fiber reinforced high-density (HDPE) and low-density polyethylene (LDPE) composite. They found that directions of the fibers were an important parameter for the tensile test of composite materials. Andrady et al. reported that exposure to ultraviolet irradiation caused fading of the polymer samples [2]. Another groups [3]-[5] obtained that the tensile strength and notched impact strength were impressed by the ultraviolet irradiation (UV). Cuong et al. [6] focused on polypropylene (PP) composites reinforced with aramid fabric and the effects of impregnation time and compression molding pressure on mechanical properties. Karger-Kocsis [7] investigated the effects of anisotropy on aramid fabric/PEEK (polyetheretherketone) and aramid fabric/PET (polyethylene terephthalate) strength of composites. In another study, they [8] fabricated polyamide laminates reinforced with woven glass fiber using a combination of woven fabrics and compression molding.

The aim of this study was to investigate the effects of glass fiber preimpregnated with a polyethylene resin, namely, thermoplastic prepreg, on mechanical properties, and the effects of fiber configuration on anisotropic behavior of the composites. For comparison, prepregs were stacked in different directions. Composite laminates were manufactured by using the vacuum bagging technique, and specimens in direction of 0^o were cut out from these laminates. The ultraviolet irradiation was applied to determine its effects on the mechanical properties of the composites. Tensile and Charpy impact test were utilized for determination of mechanical properties and all results have been presented in tabular and graphical forms. Scanning electron microscope (SEM) was used for describing the morphological features of fractured surfaces of glass/polyethylene composites.

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II. Experimental

A. Materials and Methods

“Prepreg” is the common term for a reinforcing fiber which has been pre-impregnated with a resin system. This system includes the suitable curing agent. Hereby, our prepregs were ready to lay into the formwork without the addition of any more resin. For the prepreg sheet to cure, combination of heat and pressure is necessary.

Unidirectional (UD) prepreg sheets (glass fiber and HDPE embedded), as shown in Fig. 1, provided by Fibre Glast Developments Corporation (Brookville, OH) were utilized for this study. The glass fibers were made of, as specified by the suppliers, 7781 E-Glass. Prepregs contain 30-35% resin. The properties of High-density polyethylene are S 0452, 0,950–0,956 g/cm^3 (at 23^{o}C). Thermoplastic composites were fabricated by the vacuum bagging technique as shown in Fig. 2. This technique is a composite manufacturing process in which vacuum pressure is used during the resin cure cycle.

Fig. 1 The prepreg sheet and composite plate sample

Thermoplastic prepreg sheets, approximately 0,15 mm thick, were cut to the size of 80 mm by 130 mm in the direction of the fibers. 30 ply prepregs were stacked on the horizontal pattern as unidirectional (all layers in the same direction) and biaxial (by turns one prepreg layer 0^o, other one 90^o) as shown in Fig. 3. Fig. 4 shows the cure cycle used for the autoclave vacuum bag degassing molding process. The specimen thickness were varies in the range of 4,75–5,38 mm depending on the quantity of embedded material, with the average value of 5 mm. After the manufacturing process, the composite plates were cut for the Charpy impact test, tensile mechanical test and SEM analysis. For each kind of composite panel, ten samples have been tested.

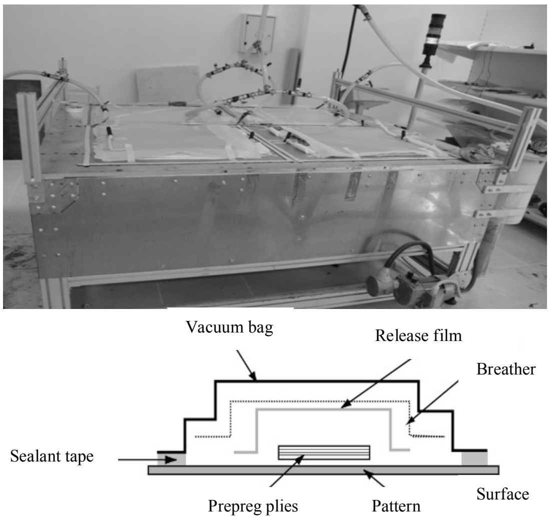

Fig. 2 Photographic and schematic representation of the vacuum bagging technique

B. Testing

1. Scanning Electron Microscopy

Scanning electron microscopy (SEM) analyses were performed on composites plates with a JSM–6060 JEOL. All sample surfaces were coated with gold layer before the analysis to obtain a conductive surface.

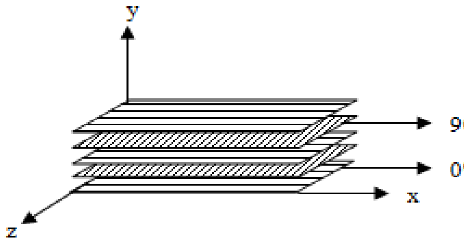

Fig. 3 Schematic model of prepreg layers (0^o+90^o)

2. Ultraviolet Irradiation of PE Composites

The ultraviolet irradiation was performed at light intensity of $114 W/m^2$ in air by an ultraviolet lamp manufactured by UVP (Canada) with wavelength in the range of 340–370 nm. The standard composites were named as GF+PE and ultraviolet irradiated PE composites for 40 min. and 80 min. were denoted as uv40PE and uv80PE, respectively.

3. Charpy Impact Test

The impact energy absorption tests were conducted by GF+PE ($0^o/0^o+90^o$), uv40PE ($0^o/0^o+90^o$) and uv80PE ($0^o/0^o+90^o$), on a Charpy impact tester (AOB Lab Pendulum Impact Tester, DT 300 EN, Turkey). Dimensions of the thermoplastic composite specimens were 5x10x55 for all test directions. Charpy specimens were prepared as notch-free because the notch effect was known to be insignificant for composite specimens [9]. The impact speed was fixed at the constant loading rate of 5.35 m/s since it is known that glass fiber-reinforced composites are sensitive to the rate of loading [10] and the employed hammer mass and drop angle were 20.59 kg and 140^o, respectively. The force transducer was mounted on the tup section with 1,5 mm nose radius. The energy absorption backgrounds with respect to time were measured.

4. Tensile Mechanical Test

Tensile mechanical tests were performed by using a Shimadzu AG-50 kNG testing machine on samples that were cut from the composites panels, at room temperature. For each kind of composite panel, ten samples were tested and the average values were calculated from the received data.

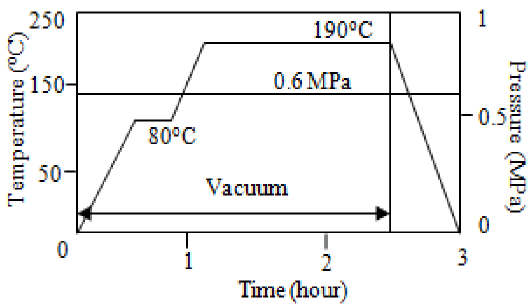

Fig. 4 Cure cycle

III. Results

In this section, the results of our tests were presented and the influence of ultraviolet irradiation on the morphology of the composite plates was analyzed; furthermore, the effects of both the morphology and direction of prepregs on the mechanical properties of composites were discussed.

A. Mechanical Properties

The mechanical properties of GF+PE ($0^o/0^o+90^o$), uv40PE ($0^o/0^o+90^o$) and uv80PE ($0^o/0^o+90^o$) composite were listed in Table I. First of all, compared with that in GF+PE (0^o) and GF+PE (0^o+90^o) composites, the resistance of prepreg layers in GF+PE (0^o+90^o) composite greatly improved. At that rate, the tensile strength and the impact energy absorption of GF+PE (0^o+90^o) composite increased. The tensile stress and the impact energy absorption of GF+PE (0^o) and GF+PE (0^o+90^o) composites (uv40PE) increased with the increasing irradiation time. The tensile stress and the impact energy absorption of GF+PE (0^o) and GF+PE (0^o+90^o) composites (uv80PE) first increased with the increasing irradiation time, reached a maximum value after irradiated for 40min, and then decreased with further increasing irradiation time because of fulsome degradation of the molecular chains of PE. The graphics of tensile properties of composite were given in Fig. 4.

TABLE I
MECHANICAL PROPERTIES OF COMPOSITE PLATES

Composites	Irradiation time (min.)	Tensile stress (MPa)	Impact strength (J/m)
GF+PE(0^o)	0	29,1	35
GF+PE(0^o+90^o)	0	38,4	41
uv40PE(0^o)	40	33,6	38
uv40PE(0^o+90^o)	40	42,5	45
uv80PE(0^o)	80	28,4	33
uv80PE(0^o+90^o)	80	36,7	40

B. SEM Analysis of Composites

The SEM photographs of liquid nitrogen frozen fractured surface of GF+PE (0^o) composite and GF+PE (0^o+90^o) composite were shown in Fig. 5. The smooth fiber surfaces can be the evidence of low adhesion force. Fiber pull-out observed in the form of GF+PE (0^o) composite pointed out clearly to the adhesive failure (Fig. 5 (a)). Narrow grooves, at high magnification, obviously seen in the GF+PE (0^o+90^o) composite indicated the increased adhesive force (Fig. 5 (b)). When the micrographs of the uv40PE (0^o+90^o) composite were examined, fibers were found to be clinging more together tightly (Fig. 5 (d)). On the other hand, in the form of uv80PE (0^o+90^o) specimens (Fig. 5 (c)), fiber surfaces were almost completely devoid of matrix material, indicating interfacial failure. These results may suggest that the ultraviolet light caused to break the bonds between fibers and matrix for uv80PE specimens whereas the ultraviolet light improved the mechanical and physical properties for the uv40PE composite.

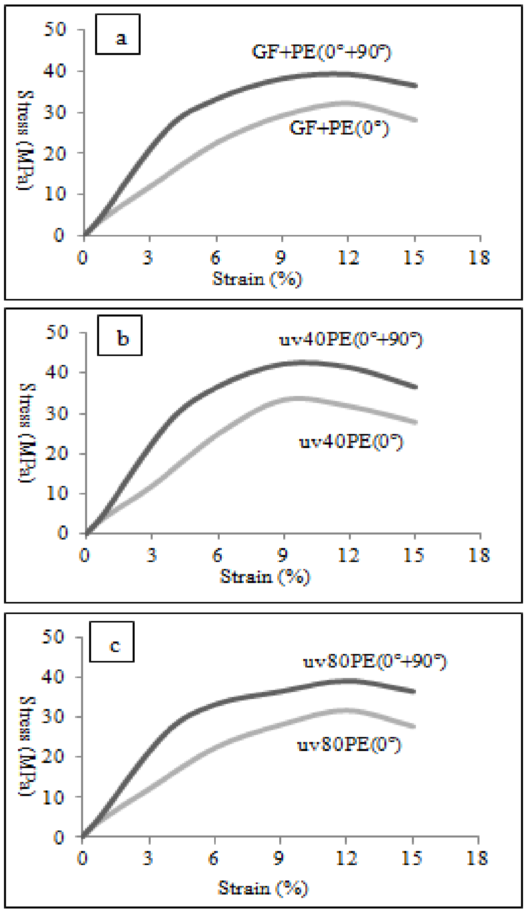

Fig. 4 The graphics of tensile properties of composites (a) GF+PE(0^o) and GF+PE(0^o+90^o), (b) uv40PE(0^o) and uv40PE(0^o+90^o), (c) uv80PE(0^o) and uv80PE(0^o+90^o)

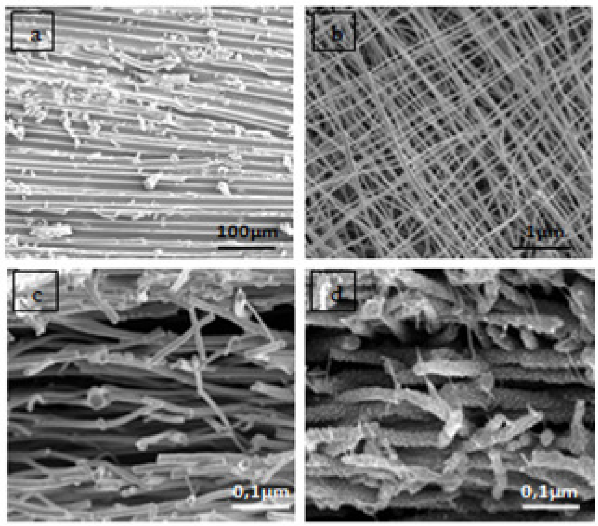

Fig. 5 The SEM images of composites (a) GF+PE(0^o), (b) GF+PE(0^o+90^o), (c) uv80PE(0^o+90^o) and (c) uv40PE(0^o+90^o)

IV. Conclusion

GF+PE(0^o) and GF+PE(0^o+90^o) composites were developed by stacking of 30 ply prepregs as unidirectional and biaxial, respectively. All composites were producted by the vacuum bagging technique. The ultraviolet irradiation was applied to state its effects. Tensile and Charpy impact, test were conducted o determine the mechanical and morphological features of materials. As a result of these tests;

- When we compared to GF+PE (0^o) with GF+PE (0^o+90^o), the resistance of GF+PE (0^o+90^o) composite was found at higher value.
- Whereas the tensile stress and the impact energy absorption reached a maximum value after irradiated for 40min.
- Narrow grooves, at high magnification, of GF+PE (0^o+90^o) composite indicated the higher adhesive force than GF+PE(0^o).
- When the micrographs of the uv40PE (0^o+90^o) and uv40PE (0^o+90^o) composites were examined, fibers of the uv40PE (0^o+90^o) were found to be clinging more together tightly.

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