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THE PERFORMANCES OF MULTIAXIS NON-INTERLACE E-GLASS/POLYESTER PREFORMS FOR COMPOSITES

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ABSTRACT

The aim of the research is to develop non-interlace preforms and describe the mechanical properties of them. For this purpose, the preforms were produced and consolidated where high modulus and high strength E-glass and polyester matrix were used. The E-glass/polyester composites were investigated with regard to fiber linear density, packing density (tight and loose) and fiber orientations. The effects of these parameters on the tensile and bending strength and modulus of the composites were experimentally investigated. Generally, the tightly wound preforms show better mechanical performance compare to that of the loosely wound preform due to the high fiber volume fraction. Fiber orientation in the preform could affect the properties of the composite in where the properties of the composites could be homogeneous. It is found that the damage mode in the structure under the tensile and bending load is mainly due to the delamination (Mode I).

Key Words: E-Glass/Polyester composites; Multiaxis fabrics; Mechanical properties of composites; Tight and loose preforms; Tensile and bending strength and modulus.

1. INTRODUCTION

Tensile properties of unidirectional E-glass/polyester composites were studied. Damage mechanism of the composite showed non-linear behavior and initiated at the interface fiber-resin region. The strain rate effect on the weft directional composite is significant on threshold stresses [1]. The effect of different densities of woven fabric and number of stacking laminate on the properties of woven fabric reinforced epoxy was studied. The results showed that a further increase of the fiber content increases the flextural properties of the composites. Also, the flextural strength and modulus increase with the increasing number of ply used in the laminate structure [2]. Fracture mechanics of cross-ply E-glass/epoxy composite under tensile loading were investigated experimentally. At large inner-ply thicknesses, the samples showed uniform transverse cracking, and at very low inner-ply thickness, this transverse cracking could be suppressed completely prior to total specimen failure. It is also reported that the cracking constraint observed can be accounted for using the laminate theory [3]. Fiber waviness has been shown to play a major role in compressive strength and fatigue endurance [4]. Mode I and Mode II fracture mechanics test on unidirectional E-glass/epoxy composite were conducted. Both mode-I and mode-II tests have revealed a high sensitivity to the fiber/matrix interface quality [5]. E-glass/nano silicate-epoxy nonwoven composite was studied. Flextural testing of the composites showed that the nano-layers improve the modulus and the strength considerably [6]. Multiaxis 3D woven preforms were developed with five yarn sets: bias(+), bias(-), warp, filling, and z-yarns. The orientation of the yarns on the five axis have improved the mechanical properties of the preform. The yarns of the preforms, which were made of polyacrylonitrile (PAN)-based carbon fibers, were consolidated with an epoxy resin. These preforms were tested and compared with the 3D orthogonal woven carbon composites. It was found that the in-plane shear strength and modulus of multiaxis 3D woven composite were higher than that of the 3D orthogonal woven composite. However the bending strength, bending modulus, and the interlaminar shear strength of the multiaxis 3D woven composite were slightly lower than that of the 3D orthogonal woven composite because of the orientations of bias yarns on both surfaces of the multiaxis 3D woven structure. The failures of both woven samples were also analyzed for the assessment of their mechanical behaviors. The unit cell of the multiaxis 3D woven preform was described.

Depending on the unit cell geometry, some relationships were developed to predict the volume fraction of each yarn set in the preform and these predicted results were also compared with the measured values [7]. The aim of this study is to determine tensile and bending properties of developed multiaxis non-interlaced E-glass/polyester composites by considering packing density of preforms and linear density of E-glass fibers used.

2. MATERIALS AND METHOD

2.1. Multiaxis Non-Interlaced E-Glass/Polyester Composites

Multiaxis non-interlaced and multilayered preform was developed. It had four yarn sets as bias (±θ), warp (0°), and filling (90°). These four yarn sets were all wound around each other to form the structure where first warp (0°) was wound and later on the filling (90°), the bias(+) and the bias(-) yarns were wound. The winding procedure was carried out one time to make a 4-layers structure. They were all positioned the in-plane direction of the preform structure without any interlacement with each other. After each layer was wound, an adhesive plaster was used to hold the all yarn ends around the structure to provide structural integrity during fabrication with a manually driven prototype flat winder [8]. The unit cell and preforms are seen in Figures 1 and 2.

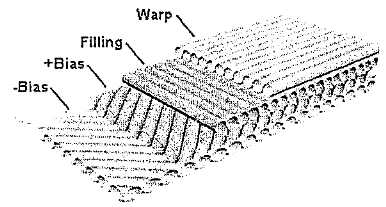

Fig. 1 Schematic views of the non-interlaced multiaxis preform unit cell [8]

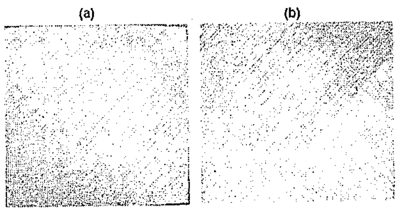

Fig. 2 Top view of the multiaxis non-interlaced preforms, linear density 600 tex (a), and linear density 2400 tex (b).

High strength and high modulus E-Glass (CE-WR) produced by Cam Elyaf Inc., Turkey was used to form the unit cells. The fiber and resin properties are shown in Table 1.

Table 1. Properties of E-glass fiber and resin used in composite structures

Fiber/material type	Fiber diameter (μ)	Density (g/cm^3)	Tensile strength (GPa)	Tensile modulus (GPa)	Elongation at break (%)	Melting point (C°)
E-Glass						
E-glass fiber (Cam Elyaf Inc., Turkey)	16 (600 tex) 22.5 (2400 tex)	2.56	3.5	76	4.8	841
Resin						
Polyester Resin (Orthophtalic, Cam Elyaf Inc.)	-	1.17	0.055	3.4	2.1	490

The density of the fiber was 2.56 g/cm^3, filament diameter was 16 micron for 600 tex and 22.5 micron for 2400 tex yarns, and the ultimate elongation was 4.80 %. Tensile strength and modulus of the fibers were 3445 MPa and 76 GPa, respectively. Fibers were compatible with polyester matrix and sized for winding and weaving to improve the handling characteristics [9]. Multiaxis non-interlaced preforms were consolidated to produce composites. Tensile strength and modulus of polyester resin (CE 92 N8, Cam Elyaf Inc., Turkey) were 55 MPa and 3.4 GPa, respectively. Resin density was 1.17 g/cm^3. A hand lay–up technique was used to consolidate the preforms. Polyester resin (CE 92 N8, 98.7%), catalyst (Cobalt, 0.3%) and hardener (Methyl ethyl ketone peroxide, 1%) were mixed and applied to the preforms at atmospheric conditions.

Packing density of the preforms is considered as tight and loose. The performs produced by using 2400 tex E-glass fiber were separated into two groups as tight (25 ends/10 cm) and loose (14 ends/10 cm) while the performs of 600 tex E-glass fiber have two forms as tight (47 ends/10 cm) and loose (25 ends/10 cm). The specifications of the multiaxis non-interlaced preforms and composites are presented in Table 2. Density of composite was determined by ASTM D792-91 [10]. The composite volume fraction and void content were also determined by ASTM D3171-99 and ASTM D2734-91, respectively [11, 12].

Table 2. Specifications of performs and composite structures

		Structure Types			
		PI-T	PI-L	PII-T	PII-L
		[0/90/±45]^1		[0/90/±45]^1	
Preform Structure	Linear density (tex)	600		2400	
		Tight	**Loose**	**Tight**	**Loose**
	Packing density (ends/10 cm)	47	25	25	14
	Warp yarn (0°)	1 layer	1 layer	1 layer	1 layer
	Filling yarn (90°)	1 layer	1 layer	1 layer	1 layer
	+ Bias yarn (+45°)	1 layer	1 layer	1 layer	1 layer
	– Bias yarn (–45°)	1 layer	1 layer	1 layer	1 layer
	Total number of layer	**4 layers**	**4 layers**	**4 layers**	**4 layers**
	Cross section	Rectangular		Rectangular	
	Thickness (mm)	0.73	0.42	2.05	1.07
Composite Specifications	Matrix type	Polyester (CE 98 N8)		Polyester (CE 98 N8)	
	Impregnation technique	Hand lay-up		Hand lay-up	
Composite Structure	Volume fraction-V_f (weight base, %)	47.86	41.19	60.86	51.47
	Void content (%)	0.37	5.75	0.22	1.84
	Density (g/cm^3)	1.574	1.423	1.743	1.593
	Thickness (mm)	1.86	1.30	2.73	1.45

2.2. Tensile Tests

The tensile strength tests of composite structures were performed on Zwick Z010/TN2A tester according to ASTM D3039. Tensile testing speed was 2 mm/min. The test dimensions were 25.4×227 mm which had 50 mm gauge length for both bottom and the top of the specimen. The tab parts of the samples were made by using the same sample piece and epoxy resin was used as adhesive. The sample orientation was bias(-), bias(+), filling and warp respectively and applied tensile load was parallel to the warp directions. Figure 3 shows the dimension of a tensile test specimen and, tensile and bending testers are shown in Figure 4.

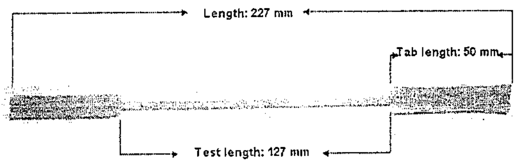

Fig. 3 Tensile test specimen dimensions

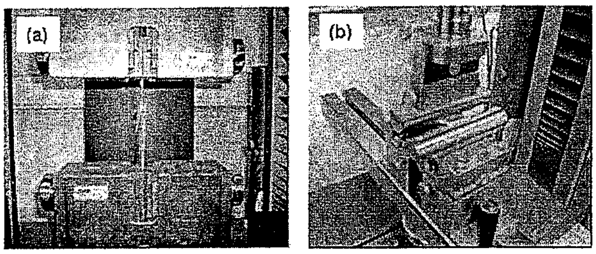

Fig. 4 Tensile (a) and bending (b) testers.

2.3. Bending Tests

3-point bending tests of composite structures were performed on Zwick Z010/TN2A tester according to ASTM D790. The test dimensions, support span length and testing speed were determined considering the composite thickness and given in Table 3. The sample orientation was bias(-), bias(+), filling and warp respectively and applied bending load was perpendicular to the bias(-) direction.

Table 3. Bending test conditions

	Structure Types			
	PI-T	PI-L	PII-T	PII-L
	[0/90/±45][1]		[0/90/±45][1]	
Linear density (tex)	600		2400	
Packing density	**Tight** (V_f: 47.86)	**Loose** (V_f: 41.19)	**Tight** (V_f: 60.86)	**Loose** (V_f: 51.47)
Thickness (mm)	1.86	1.30	2.73	1.45
Dimensions (width × length, mm)	25×54	25×50	25×69	25×50
Support span length (mm)	30	22	44	23
Testing speed (mm/min.)	0.87	0.7	1.14	0.74

3. RESULTS AND DISCUSSION

3.1. Tensile Results

Tensile test results of composite structures are presented in Table 4. The tensile strength values versus tensile elongations and tensile modulus values of composite structures were plotted and given in Figure 5 and 6, respectively.

Table 4. Tensile test results of composite structures

	Structure Types			
	PI-T	PI-L	PII-T	PII-L
	[0/90/±45][1]		[0/90/±45][1]	
Linear density (tex)	600		2400	
Packing density	**Tight** (V_f: 47.86)	**Loose** (V_f: 41.19)	**Tight** (V_f: 60.86)	**Loose** (V_f: 51.47)
Tensile strength (MPa)	119.1	87.2	123.2	115
Tensile modulus (GPa)	13.4	13.8	18.7	11.1
Tensile elongation (%)	1.74	1.06	2.03	2.21

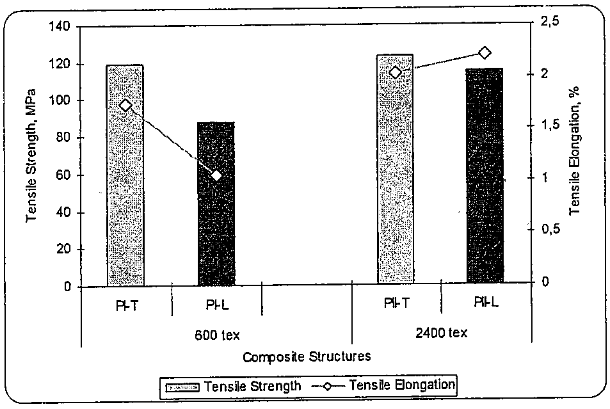

Fig. 5 Tensile strength and elongation values of composite structures

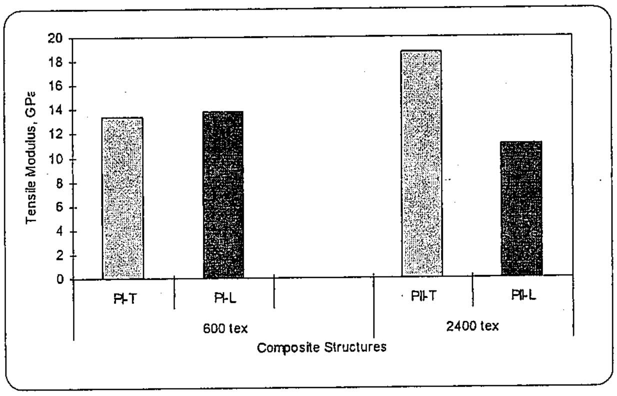

Fig. 6 Tensile modulus of composite structures

As seen in Figure 5 and 6, liner density of E-glass yarn affects the total volume fraction of E-glass/polyester composite. The higher the linear density is, the higher the volume fraction of multiaxis E-glass preforms. It is found out that the tensile strength and modulus of E-glass/polyester composites are proportional to their total volume fraction. The high volume fraction of the E-glass preforms results high tensile strength of the E-glass/polyester composites. The tensile elongations of the composites PI-T and PI-L is low compared to those of composites PII-T and PII-L due to the high matrix content.

After the tensile and bending tests were applied to the developed composite structures, the structures were examined by an optical microscope (Olympus SZ61-TR). Optical views of selected composite structures after tensile test are shown in Figure 7.

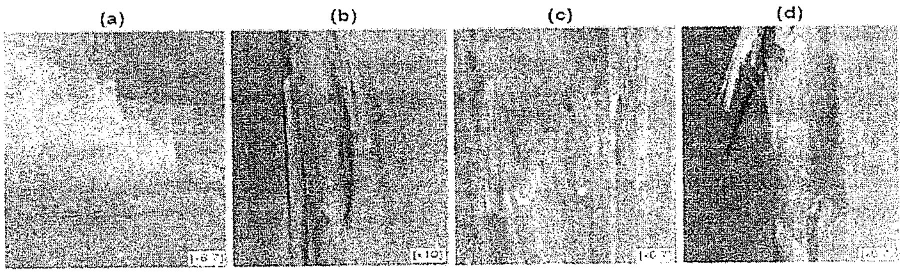

Fig. 7 Optical views of composite structures after tensile test, 600 tex-loose surface (PI-L) (a); 600 tex-loose cross section (PI-L) (b); 2400 tex-tight surface (PII-T) (c); 2400 tex-tight cross section (PII-T) (d).

Surface of the composite PI-L has local matrix and filament breakages under the tensile load as seen in Figure 7 (a). Also, there is severe delamination between layers warp and bias(-), and has local splitting between filling and bias(+) seen in Figure 7 (b). In Figure (c), it is observed that the composite PII-T has matrix and fiber breakages. But crack in the surface of the PII-T propagated to the off-axis direction. In Figure (d), there is severe delamination between the layers. This indicated that the developed structure has weakness to the out-of-plane directions due to no reinforcement.

3.2. Bending Results

Bending test results of composite structures are presented in Table 5. The bending strength and bending modulus values of composite structures were plotted and given in Figure 8 and 9, respectively.

Table 5. Bending test results of composite structures

	Structure Types			
	PI-T	PI-L	PII-T	PII-L
	$[0/90/\pm45]^{1}$		$[0/90/\pm45]^{1}$	
Linear density (tex)	600		2400	
Packing density	**tight** (V_f: 47.86)	**loose** (V_f: 41.19)	**tight** (V_f: 60.86)	**loose** (V_f: 51.47)
Bending strength (MPa)	295.10	162.70	390.7	370.1
Bending modulus (GPa)	4.87	3.27	5.1	5.1

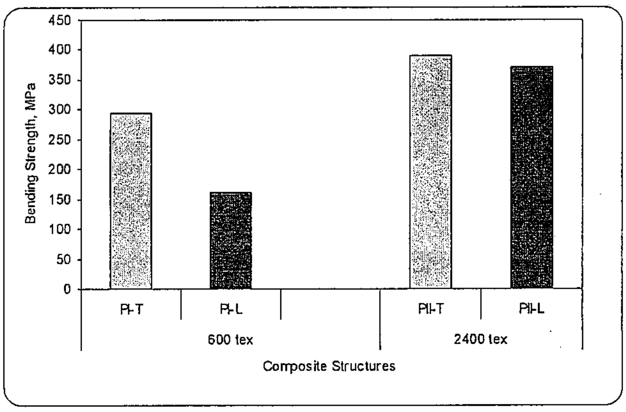

Fig. 8 Bending strengths of composite structures

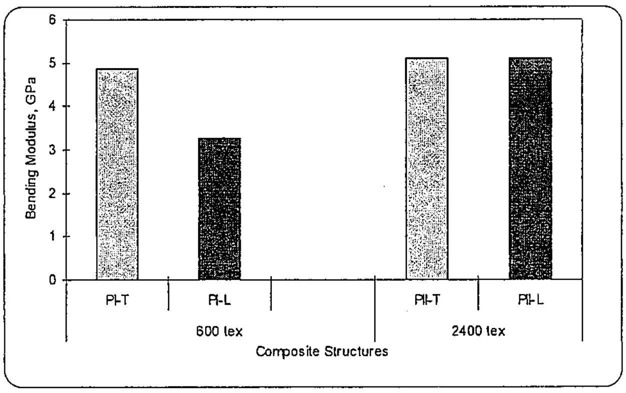

Fig. 9 Bending modulus of composite structures.

As seen in Figure 8 and 9, the flextural strength and modulus of the E-glass/polyester composites are proportional to their total volume fraction. The high volume fraction of the E-glass preforms results high flextural strength and modulus of the E-glass/polyester composites. Optical views of selected composite structures after bending test are shown in Figure 10.

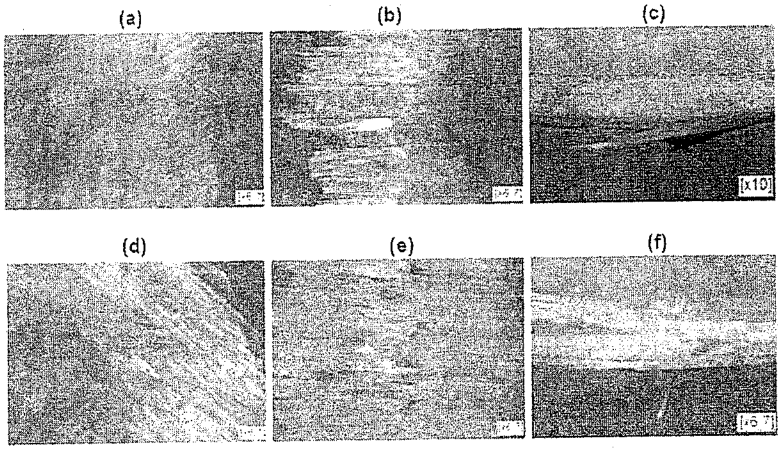

Fig. 10 Optical views of composite structures after bending test, 600 tex-tight (PI-T); bending direction, top surface (a), reverse of bending direction bottom surface (b), cross section (c); 2400 tex-tight (PII-T); bending direction (d), reverse of bending direction (e), cross section (f)

It is observed that the top surface of the composite PI-T has local matrix and filament separation under the bending load as seen in Figure 10 (a), whereas bottom surface of the PI-T has multiple fiber breakages and fiber-matrix splitting especially between warp and filling layers as seen in Figure 10 (b). Also, there is a local delamination between warp and filling layers in seen in Figure 10 (c). The top surface of the composite PII-T has matrix and fiber breakages, and has some intra-fiber separation between bias(-) and bias(+) layers as seen in Figure 10 (d), whereas bottom surface of the composite PII-T has warp fiber breakages across the length direction of the structure as seen clearly in Figure 10(e). The PII-T has a local delamination on top of the layers between bias(-) and bias(+), and bottom of the layers warp and filling. In addition, fiber and matrix were sheared to the out-of-plane direction of the structure as seen in Figure 10 (f). The dominant failure mechanism based on Mode-I as a form of separation and matrix-fiber breakages. This is because no reinforcement introduced to the out-of-plane direction of the structures. The future research will be conducted on multiaxial testing of composites to identify the directional properties.

4. ACKNOWLEDGEMENT

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[11] Fiber volume fraction (Burn-off test ASTM D3171-99).
[12] Void content in composite (ASTM D2734-91).

BIOGRAPHIES

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