Mechanical Properties of 2D Cross-Ply E-Glass Fiber Reinforced Thermoplastic Laminated Composite Materials

Murat Yazici, Hakkı Özer, İdris Karen, Yücel Can, Cengiz Torçuk

Abstract*— In accordance with the basic demand of the automotive industry, like reducing weight, lower emission values and fuel economy, researchers are working on Thermoplastic Composites (TPC) in the fields of developing, producing and recycling. The main reason of this is that Thermoplastic Composites have a lower density, higher toughness and higher impact strength besides thermoformability. Furthermore, Automotive Industry has focused attention on thermoplastic composites as a consequence of the importance of recyclable materials were risen. Cross ply [0/90]$_5$ continuous glass fiber reinforced Polyamide (PA), Polyethylene (PE) and Polypropylene (PP) laminated composites were produced. The mechanical properties of these materials were obtained by appropriate tests.

Keywords: Thermoplastic Composite Materials, Mechanical Properties, Damage Mechanisms

I. INTRODUCTION

In recent years, researchers in the automotive industry have focused on improving the strength of existing parts and producing lightweight parts which cause lower CO_2 emissions. Studies showed that composite materials can be an alternative to conventional engineering materials because of their higher specific strength and lower density [1,2]. Composite materials can be different characteristic due to used reinforcement and matrix materials. TPC materials are preferable than Thermoset Composite materials because of having advantages like being recyclable and re-formability at specific temperatures. Also, those structures have some more advantages as high fracture toughness and high damage tolerance [3,4].

Sorrentino et al. [7] presented an interlaminar strength study to obtain the best compatibility between fiber and matrix. They showed that; increasing compatibility between fiber/matrix improved the impact energy absorption. Parabhakaran et al. developed the TPC materials with PA6 matrix, by commingled yarns and prepreg methods. Their study showed that as TPC materials produced by the commingled yarns method have higher strength properties. However, the TPC materials produced by prepreg method have higher strength properties in compression test [8].

Researchers carried out studies on developing TPC materials, using TPC materials in automotive industry and obtaining high strength TPC structures by lamination techniques. Then they investigated, influences of the different matrix and reinforcement materials used in various production methods on mechanical properties are analyzed [5, 9-11].

In this study, three type of TPC materials were produced which consist of continuous E-glass fiber compatible with thermoplastic as reinforcement and PA, PE and PP as a matrix, by lamination techniques. Composite production was carried out placing from [0/90]$_5$ laminate orientations in a hot press for a while. To determine the mechanical properties of TPC materials Tension, Compression, Shear and Charpy impact tests were made according to standards. For Finite Element damage analysis, the experimental failure data of the TPCs and elastic constants are needed. In this study elastic constants and critical stress values were obtained experimentally.

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II. MATERIALS AND METHODS

In this study, composite structures, consist of continuous glass fiber reinforcement and a thermoplastic matrix, was produced by lamination techniques. PA, PE and PP are chosen as the thermoplastic matrix materials and E-Glass fiber in the size of 0.3K is used as the reinforcement material. Table 1 shows mechanical properties of used matrix and reinforcement materials.

TABLE 1. FIBER AND THERMOPLASTIC MATRIX MATERIAL PROPERTIES

Materials	Density (g/cm^3)	Tensile Strength (MPa)	Compression Strength (MPa)	Charpy Impact Strength (kJ/m^2)	Poisson Ratio
Polyamide	1,07-1,14	60-70	70-90	15-25	0,39
Polyethylene	0,92	20-28	15	12	0,4
Polypropylene	0,90	23-33	110	14	0,45
E-Glass Fiber	2,55	1550	-	-	-

A. Production of the Thermoplastic Composites

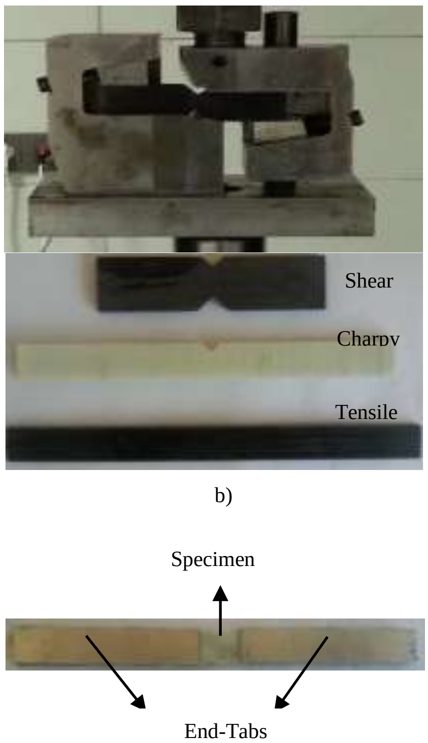
Production of TPC materials are made by film stacking method. The composite materials can be produced with different layers by thickness in demand. The most imported advantage of this method is that operating temperature range can be adjusted due to the type of matrix materials.

Two different devices are used in the manufacturing. The first one is temperature set screw press and the second one is 40- ton hydraulic press. As the first stage stretched glass fibers placed between matrix plates then all of them kept in screw press at 180-200°C temperature about 8 minutes to ensure penetration of matrix into fibers. The resulting composite layers were placed in $[0/90]_5$ fiber orientation and pressurized under 10 tons at 180-200°C temperature about 8 minutes and then left to cooling. The specimens as Tension, Compression, Shear and Charpy impact were obtained from the produced TPC materials by water jet cutting according to ASTM standards.

In tension and compression tests, some deformations can begin in the specimens because of the acting pressure between grips and to avoid this deformation alumina end-tabs prepared and bonded. End-tabs were bonded by acrylic based adhesives 3M DP8010 and 3M DP8005. Fracture surfaces and failure regions were examined by Insize ISM-PM200S Digital Microscope as a post-mortem analysis.

B. Mechanical Characterization

Tension, Compression and Shear Test were performed according to ASTM D3039 (140x12x2.6 mm), ASTM D3410 (140x12x2.6 mm) and ASTM D5379 (76x19x4 mm) standards respectively. In all experiments, crosshead speed of the device was a constant speed of 10 mm/min. The displacements were measured by video extensometer in Tensile tests. The shear tests performed by an apparatus that produced via ASTM D5379 standard shown in Figure 1a.



c)

Fig.1 a) Shear test apparatus b) Water jet cut composite specimens for Shear, Charpy and Tensile c) End-tabbed composite specimen with PA matrix for Compression tests.

The purpose of Charpy impact test is to determine the energy absorption capacity of the materials against to dynamic forces. The stress concentrations in the specimens constitute artificially in the tip of the notch while impact. Test specimens were prepared according to ASTM D6110 (127x12.7x5 mm).

III. RESULTS AND DISCUSSION

Tensile, compression, shear and notched impact tests of continuous glass fiber reinforced PA, PE and PP composites were performed.

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In tensile experiments due to cross ply laminated composites brittle failure were obtained. The post mortem pictures of the failure regions showed fracture of the fiber and matrix (Figure 2). That means good interface bonding occurred between fiber and thermoplastic polymer composites. The tensile strength of continuous glass fiber reinforced PA, PE and PP composites is respectively 231 MPa, 117.82 MPa, 190.2 MPa was obtained which shown in Figure 3 . The results show that the highest tensile strength was seen on the PA matrix TPCs.

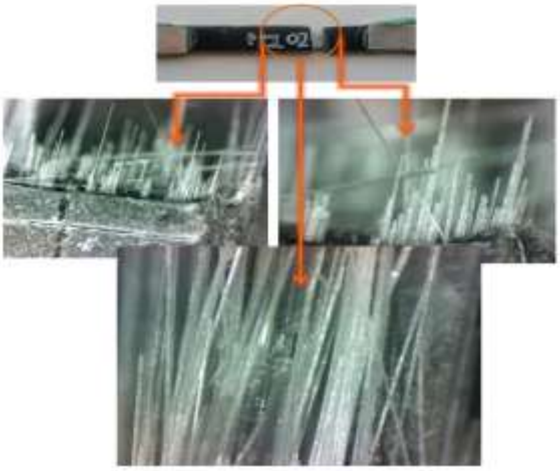


Fig.2 Rupture area of PP matrix TPC material.

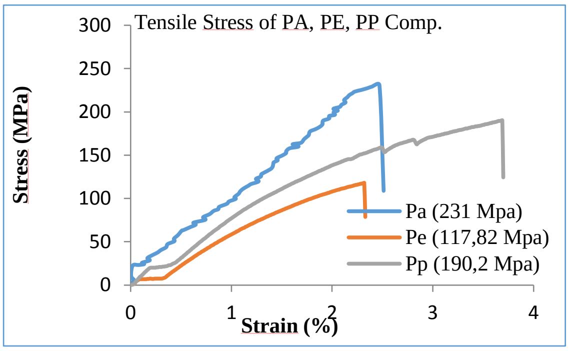


Fig.3 Results of Tensile tests of the TPC materials

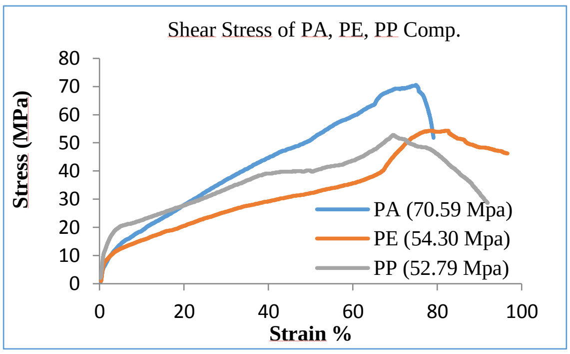


Fig.4 Results of Shear tests of the TPC materials

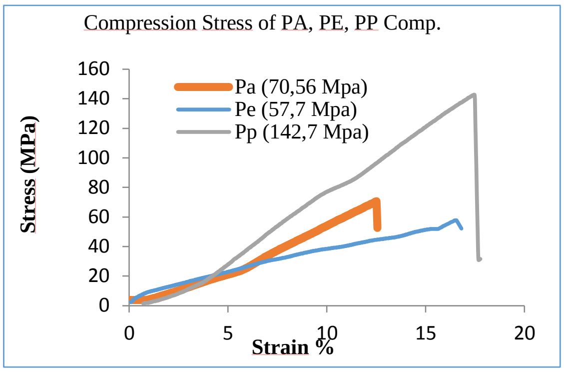
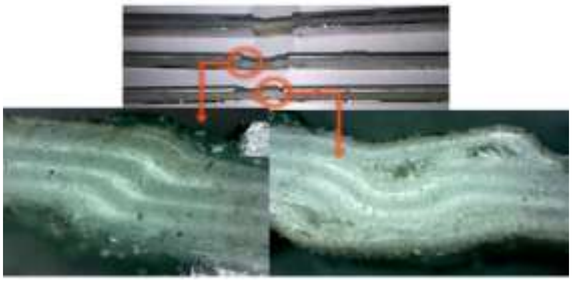


Fig.5 Results of Compression tests of the TPC materials



a)

b)

Fig.6 Post-mortem. images around Compression damaged regions of the TPCs: a) PA matrix b) PE and PP matrix

In compression, experiments showed different failure mechanisms than the Tensile. Delamination and buckling were obtained in PA matrix composite laminates. In Figure 6a, delaminations and fiber buckling in shear mode occurring was seen when to examine the failure regions of PA matrix TPC specimens after Compression tests.

In compression experiments, the PE and PP matrix thermoplastic composite specimens were failed as shear mode damages (Figure 6b).

Compression tests results were given in Figure 5 which having more brittle characterization of PE and PP than PA matrix TPC materials.

Shear tests were conducted for determining the shear characterization of stratification TPC materials. Samples of TPC materials were damaged after the %80 deformation. Deformation of the shear specimen under loading condition was given in Figure 7.

Fig.7 Deformation of the PP TPC material during the shear test.

The results of the shear experiments were given in Figure 4. The results show that PA matrix TPC material has the highest shear strength of 70.59 MPa.

The Charpy impact tests results show that PA and PE have the higher energy absorption than the PE matrix case that given in Table 2.

The results which were obtained from all experiments are presented in Table 2. The tests results show that PA and PP matrix composites have better mechanical properties than PE matrix composite specimens.

TABLE 2. OBTAINED RESULTS OF PA, PE AND PP THERMOPLASTIC COMPOSITES.

Mechanical Properties	Materials		
	PA	PE	PP
Tensile Stress(MPa)	231.00	117.82	190.20
Compression Stress(MPa)	70.56	57.70	142.70
Charpy Impact Energy (j/cm^2)	28.08	26.96	17.83
Shear Stress (MPa)	70.59	54.30	52.79

IV. CONCLUSIONS

As a result of tensile tests, TPC materials including PA and PP matrix showed an excellent performance with the highest tensile strength. TPC material with PA matrix has the higher specific strength and lower density than the most of the steels. Therefore, it is supposed to be an alternative material instead of steel materials in the automotive industry.

It is seen that during the compression experiments that shear damage and fibre buckling occurred in TPC experimental samples including PE, PP and PA matrixes.

As a result obtained from the TPC material experiments including PA, the matrix has higher shear stress than the PP and PE matrix TPC.

Charpy notch impact tests showed that PA matrix case has the highest energy absorption properties.

V. ACKNOWLEDGEMENTS

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