Mechanical Property Comparison of Continuous Carbon Fiber Reinforced Epoxy and Polyamide - 6 Matrix Composite Laminates Manufactured by Tailored Fiber Placement Technology

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***Abstract*— *In today's industry, the need for multifunctional designs and products is increasing. In addition to the high-performance requirements expected from the products, environmentalist approaches such as environmental impact, suitability for recycling and reuse, and the existence of compelling industrial constraints have begun. Due to these and such similar factors, composite products and solutions are increasingly becoming more important in all industries. In the light of industrial and functional expectations, raw material types and production technologies can be shown among the main variables that ensure the features expected from a product to be obtained with optimized outputs. Tailored fiber placement and commingled hybrid fiber technology are the selected sample production techniques. The main advantage of this techniques is that fiber placement angles and product design can be tailored to resist to the multi-directional loads expected from a product because this is not possible with traditional manufacturing techniques. The stitching fiber placement technique is an innovative method that can be preferred in advanced engineering designs and applications in terms of high performance, low weight, low cost, and the optimized product.*

***Keywords*— *Tailored Fiber Placement, Thermoplastic Composite, Carbon Fiber, Hybrid Fiber, Commingled Fiber.*

I. INTRODUCTION

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 [1].

Due to the advancing technology, changing and developing needs, and the versatile and multifunctional features expected from engineering materials in the 21st century, the needs for new product and raw material solutions and the nature of the needs are increasing and changing. Especially in line with the developing technology, advanced engineering studies and designs; industrial expectations may differ and expect versatile functions from engineering products. While some of these expectations may be related to their mechanical properties, others consist of a combination of thermal or chemical properties. Composite product solutions are the most suitable material group that can meet these differing expectations. Both industrial and academic studies on composites are increasing and diversifying day by day.

Composite materials are used in a wide range of fields due to their characteristics of high strength, high elastic modulus, and light weight (low density) [2].

Production methods are as equally important as the raw materials used for the final product properties. Especially continuous fibre reinforced structures, fibre positions, angles, lamination are the main aspects of the mechanical properties. Tailored Fiber Placement method is the unique technology for positioning and fixing the fibre in a structure and it allows to reinforce the structure where needed. There are a lot of academical studies to point out TFP technology advantages. There are several studies focusing on fiber path and placement optimization based on load conditions and FEA analysis. TFP processes can be used for advanced component production [3].

TFP production technology can also be used for local 3D reinforcement for the structures by changing the stitch density and stitching materials. This option can be used for optimization [4].

TFP Technology could also allow to create the parts and structures with high physical and mechanical properties [5].

Apart from the advantages on product and part optimization, TFP technology allows production flexibility, maximizing properties by specialized fiber placement, design freedom, local reinforcement, waste and cost reduction opportunities, weight lightening and more sustainable production [6] [7].

II. METHODOLOGY

A. Material

In this study, two types of material and/or sample group have been determined to compare mechanical properties. The first group of samples was manufactured with PA6 thermoplastic matrix reinforced by continuous carbon fibre and the second group was manufactured by epoxy matrix reinforced by continuous fibre system.

Hyosung - H2550 type 12K carbon fibre [8] was selected as the reinforcement member for both groups. In sample group 1, thermoplastic PA6 matrix has been manufactured by using Basf – Ultramid B27-12 [9] as a multifilament continuous form. In sample group 2, epoxy matrix system samples have been produced by using Hexion Epicote Trac 06150 [10].

B. Production Methods

1) Commingled Fibre Production

For sample group 1, commingled fibre (carbon fiber + PA6) has been used for TFP sample production operations.

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Commingling operation was completed by spreading reinforce and matrix fibers and by combining them as homogeneous as possible. The scheme of the operation is given in the Figure 1. below and commingled Carbon Fiber – PA6 is shown in Figure 2.

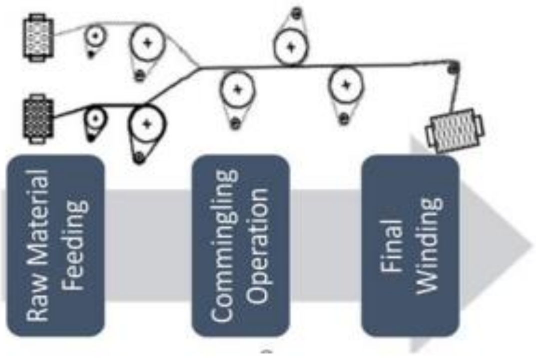

Fig. 1. Commingling Operation process flow

Fig. 2. Commingled Carbon Fiber – PA6 sample

2) Tailored Fiber Placement (TFP)

Tailored Fiber Placement methods have been used for fiber placement in both sample groups. Preform designs, based on international tensile and 3 point bending test specimen definitions, have been completed. Figure 3. and Figure 4. describe TFP equipment and TFP production mechanism.

Fig. 3. TFP machine

3) Test Plate Production

As the first step of sample production, TFP design files have been generated by using the following formulation to determine the specific design and TFP machine parameters.

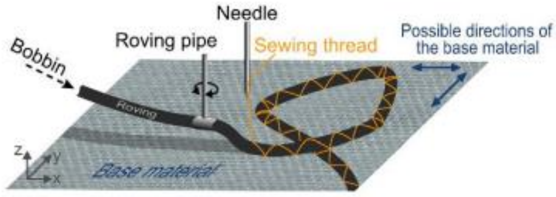

Fig. 4. TFP running mechanism [11]

$$Layer\ Area\ Density = Tex \div Layup\ (Stitching\ Width)$$

$$Total\ Area\ Density = Laminate\ Thickness\ x\ FVF\ x\ Fiber\ Density$$

$$Layer\ Amount\ = Total\ Area\ Density\ \div Layer\ Area\ Density$$

The main machine parameters that need to be calculated and/or determined are “stitch width” and “stitch length”. Details are given in Figure 5.

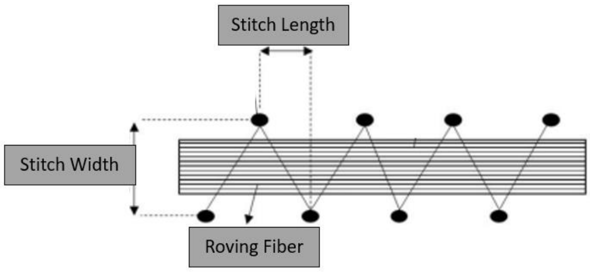

Fig. 5. TFP Machine and Design parameters

Unidirectional preform designs have been completed (Fig. 6) for both material groups and both test methods - Tensile and 3 Point Bending.

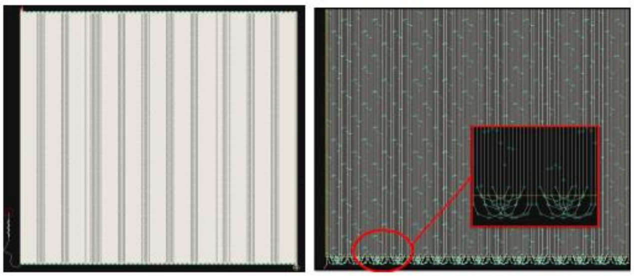

Fig. 6. TFP Preform Design

Figure 7. shows two material group preforms that will be used for molding & consolidation operation. Figure 7.a represents the preforms manufactured for material group -1 and Figure 7.b represents the preforms manufactured for material group -2.

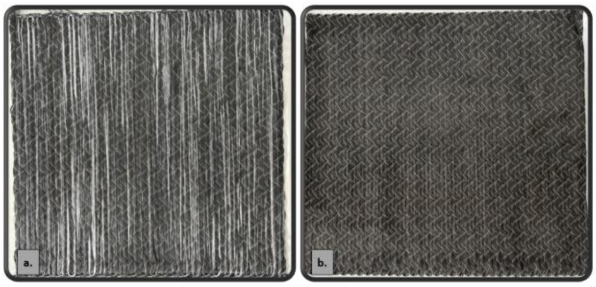

Fig. 7. (a) commingled fiber used preform for Group -1, (b) dry carbon fiber used preform form Group -2

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Manufactured preforms produced for "Group 1" were designed to theoretically reach 49% FVF (Fiber Volume Fraction) and molded under hot press unit by using following parameters;

- 280˚C
- 12 min dwell
- 120 kN (1.33 MPa)

Manufactured preforms for "Group 2" were also designed to reach theoretically 49% FVF. FVF adjustment has been completed by measuring the weight of resin and fiber. Epoxy resin has been applied manually. The following hot press parameters have been used for consolidation;

- 120˚C
- 5 min dwell
- 120 kN (1.33 MPa)

C. *Test Methods*

AGS-X series 100kN capacity Shimadzu equipment have been used for all mechanical tests. Test specimens extracted from molded panes by using 3 axis CNC rooter according to the related test standards.

1) *Tensile Testing*

Manufactured test specimens from "Sample Group 1" and "Sample Group 2" were carried to tensile test according to ISO 527 – 5 [12] requirements.

2) *3 Point Bending Test*

Manufactured test specimens from "Sample Group 1" and "Sample Group 2" were carried to 3 point bending test according to ISO 14125 [13] requirements.

III. Results and Analysis

A. *Tensile Property Evaluation*

Tensile properties have been measured according to ISO 527-5 and the graphs below have been generated by using Excel for further evaluation.

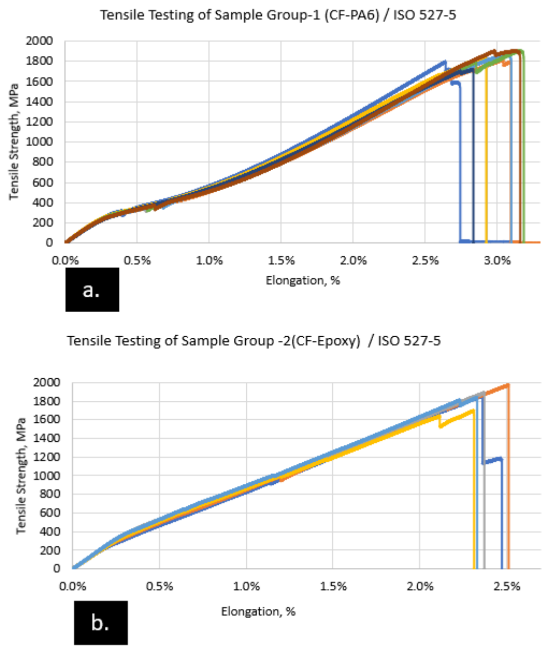

Fig. 8. (a) Group -1 Tensile Test Result, (b) Group -2 Tensile Test Result

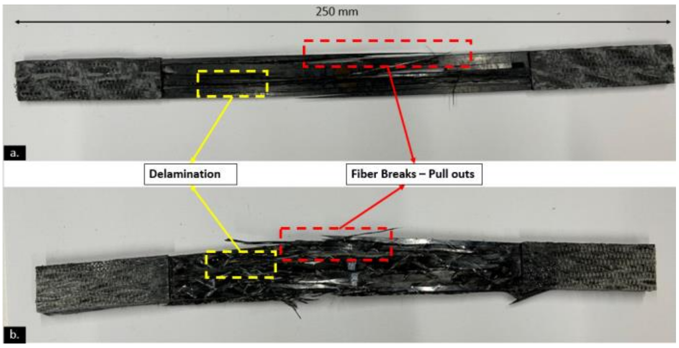

Fig. 9. (a) Group -1 Tested Tensile Test Specimen, (b) Group -2 Tested Tensile Test Specimen

In accordance to test results shown in Figure 8. (a) – 8. (b) – 9. (a) and 9. (b);

- In Sample Group 1, tensile strength averagely reached 1830MPa level and average elongation 2.8% occurred.
- In Sample Group 2, tensile strength averagely reached 1850MPa level and average elongation 2.4%.

B. *3 Point Bending Property Evaluation*

3 Point Bending properties have been measured according to ISO 14125 and the graphs below have been generated by using Excel for further evaluation.

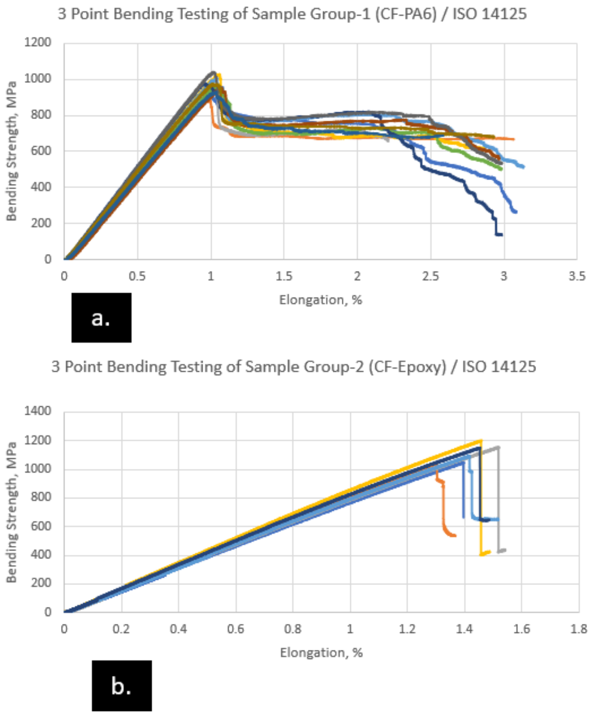

Fig. 10. (a) Group -1 Bending Test Result, (b) Group -2 Bending Test Result

In accordance to the test results shown in Figure 10. (a) - 10. (b) – 11. (a) and 11. (b);

- In Sample Group 1; bending strength averagely reached 890MPa level and 20% drop observed around in 1% elongation level but the structure continued to carry the load until 3% elongation level.
- In Sample Group 2; bending strength averagely reached 1100MPa level and average elongation 1.4%.

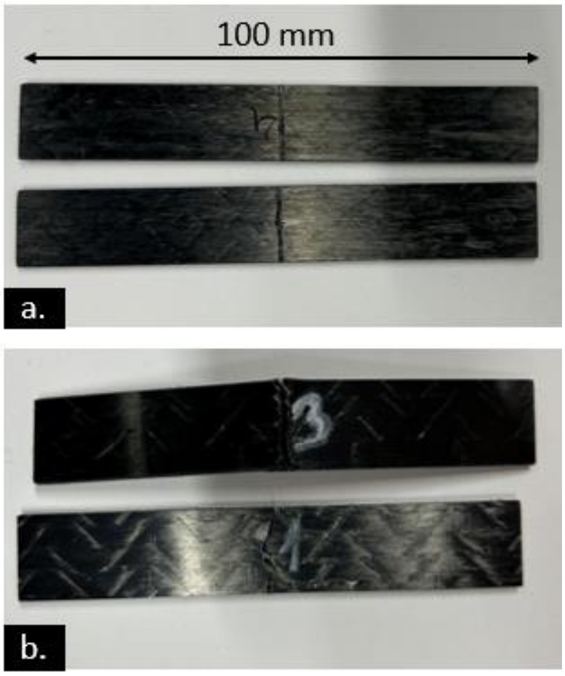

Fig. 11. (a) Group -1 Bending Test Result, (b) Group -2 Bending Test Result

IV. Conclusion

This study aims to carry out a deep evaluation and comparison between thermoset and thermoplastic composite laminate mechanical properties manufactured by Tailored Fiber Placement technology. The TFP and Commingled fiber approach could be considered as a key innovative method for this study.

The results of the applied tests are as follows:

TABLE 1. Tensile and 3 Point Bending Test Results

	Carbon Fiber + PA6 Sample Group- 1		Carbon Fiber + Epoxy Sample Group- 2	
	Result	Standard Dev.	Result	Standard Dev.
3P Bending Strength, MPa	878.90	79.12	1114.77	62.55
Bending Modulus, GPa	91.79	7.25	83.61	4.85
Tensile Strength, MPa	1831.58	56.83	1850.52	88.62
Tensile Modulus, GPa	106.44	3.71	114.59	2.86

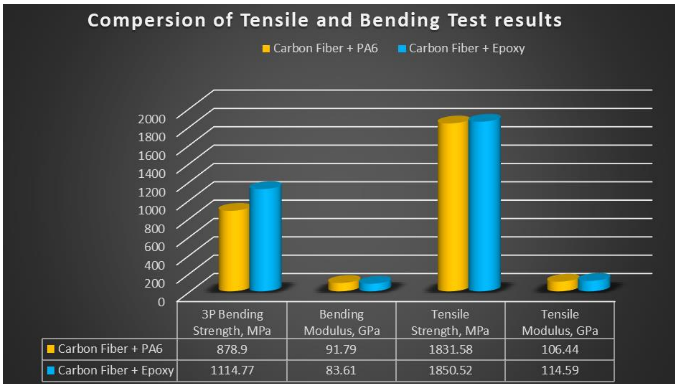

Fig. 12. Test results comparison for Sample Group – 1 and Sample Group – 2 for Tensile and 3 Point Bending test

Based on the test results of the research;
for Tensile Properties,

- Tensile properties resulted in similar level strength and modulus for both groups.
- By considering the elongation properties, Epoxy system was observed more resistant to deformation.
- The sample group 2 with epoxy matrix system also represented more brittle behaviors compared to the sample group 1 with PA6 matrix system.

for 3 Point Bending Properties,

- Used matrix types were more effective on the bending properties compared to the tensile properties.
- Thermoplastic PA6 matrix system had more failure tolerance compared to the Epoxy system based on tested specimens max. strength and elongation results.
- Thermoplastic matrix system reached lower ultimate bending strength compared to the Epoxy system.
- Thermoplastic system had higher toughness than Epoxy system.
- Epoxy system was more resistant to load until it broke.

References

[1] A.K. Kaw, "Mechanics of Composite Materials, Florida": Taylor & Francis Group, LLC, 2006.
[2] Ono, M.; Yamane, M.; Tanoue, S.; Uematsu, H.; Yamashita, Y. Mechanical Properties of Thermoplastic Composites Made of Commingled Carbon Fiber/Nylon Fiber. Polymers 2021, 13, 3206, September 2021
[3] K. Gliesche, T. Hübner, H. Orawetz," Application of the tailored fibre placement (TFP) process for a local reinforcement on an ''open-hole'' tension plate from carbon/epoksi laminates", Composites Science and Technology 63 (2003) 81–88.
[4] P. Mattheij, K. Glische, D. Feltin," 3D reinforced stitched carbon/epoksi laminates made by tailored fibre placement", Composites: Part A 31 (2000) 571–581.
[5] N. V. Aleksandrovich, P. I. Aleksandrovich, B. S. Sergeevich, O. M. Andreyevich, S.V. Igorevich," TFP Technology As The Advanced Method Of Manufacture Of 3D Reinforced Preforms From Polymer Composite Materials", Vol.12 No.5 (2021), 84- 91, Turkish Journal of Computer and Mathematics Education.
[6] A. Spickenheuer, C. Scheffler, L. Bittrich, R. Haase, D. Weise, D. Garray, G. Heinrich1, "Tailored Fiber Placement in Thermoplastic Composites", Technologies for Lightweight Structures 1(2) (2017), pp. 114–127.
[7] E. G. Koricho, A. Khemonko, T. Fristedt, M. Haq, "Innovative tailored fiber placement technique for enhanced damage resistance in notched composite laminate", Composite Structure 120 (2015) 378-385.
[8] http://www.hyosungadvancedmaterials.com/en/business/carbon_material.do
[9] https://chemicals.basf.com/global/en/Monomers/polyamide_intermediates/polya mide_for_extrusions.html
[10] https://www.hexion.com
[11] E. Richter, K. Uhlig, A. Spickenheuera, L. Bittricha, E. Mader, G. Heinrich,“ Thermoplastic Composite Parts Based On Online Spun Commingled Hybrid Yarns With Continuous Curvilinear Fibre Patterns", Eccm16 - 16 Th European Conference On Composite Materials, Seville, Spain, 22-26 June 2014
[12] ISO 527-5 - Determination of tensile properties of plastics
[13] ISO14125 - Fibre-reinforced plastic composites — Determination of flexural properties

K.Coban Gokhan and Kaboglu Cihan, "Mechanical Property Comparison of Continuous Carbon Fiber Reinforced Epoxy and Polyamide - 6 Matrix Composite Laminates Manufactured by Tailored Fiber Placement Technology," *International Research Journal of Advanced Engineering and Science*, Volume 8, Issue 1, pp. 65-68, 2023.