THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 2 - 2022, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2022.2.03

EFFECT OF THE FIBER ORIENTATION OF GLASS FIBER REINFORCED POLYMER COMPOSITES ON MECHANICAL PROPERTIES

Rodica CHIHAI (PEȚU), Claudia UNGUREANU, Vasile BRIA
"Dunarea de Jos" University of Galati, Research and Development Centre for Thermoset Matrix Composites, Cross-Border Faculty, Galati, Romania
e-mail: claudia.ungureanu@ugal.ro; vasile.bria@ugal.ro

ABSTRACT

Fiber reinforced polymer (FRP) composites possess excellent specific strength, specific stiffness and controlled anisotropy for which these are extensively used in various engineering applications, like automobile industries, aerospace industries, marine industries, space industries, electronics industries and many more. Glass fibers (GF), carbon fibers (CF) and aramid fibers (AF) are common reinforcements for polymer matrix composites (PMCs). High mechanical properties and wear resistance behaviour of glass fiber reinforced composites are the premises for the current experimental research on the effect of fiber orientation on the tensile strength of the polymeric composite materials. The glass fiber reinforced epoxy resin composite was prepared by wet lay-up method, followed by thermal treatment.

KEYWORDS: glass fiber, orientation, mechanical properties, epoxy resin

1. Introduction

Developing new composite materials from existing materials is the real challenge for most of the material engineers. So, there are huge research endeavours emerging in the field of composites to develop new materials with upgraded mechanical, electrical and thermal properties [1]. Among these composites, fiber reinforced polymer (FRP) offers not only high strength to weight ratio, but it also reveals exceptional properties like high strength, flexibility, stiffness and resistance to chemical harm. These wide ranges of diverse features have led composite materials to find significant applications in a variety of fields such as construction, mechanical, automobile, aerospace, and many other manufacturing industries [2, 3].

In order to get the best characteristics of the composites, different methods may be used, such as using hard materials like glass mats, silicone or ceramics, chemical additives or making coating layer [4]. Glass fiber (fiberglass) is one of the promising materials that can be used in laminate composite production. Fiberglass offers excellent strength and durability, thermal stability, resistance to impact, chemical, friction, and wear properties [5]. Also, it was demonstrated the increase of the tensile strength of the composite properties due to the fiber content [6, 7].

The arrangement and orientation of fibers define the properties and structural behavior of composite material [8, 9]. The fiber orientation mainly depends on the melt flow characteristics during manufacturing, which depend on rheological properties of the melt (viscosity, viscoelastic properties), processing parameters (injection temperature, pressure), product complex geometry (tool complexity) [10]. Literature also shows that fiber orientation significantly affects the mechanical properties of the SFRP. If fibers are longitudinally oriented (parallel to the loading direction), mechanical properties are improved due to the efficient load transfer from matrix to fiber, whereas in the case of transversely oriented fibers (perpendicular to the loading direction), only a small or negligible increase in mechanical properties is observed compared to the non-reinforced (or neat) material [11, 12]. Thus, the fiber orientation and distribution are parameters that are difficult to predetermine, yet it needs to be considered during product design and manufacturing.

As far as it is known, there are limited information on the application of oriented reinforced glass fiber as per its improved tensile properties.

Because of the fact that it was determined that the polymer composites reinforced with fabrics and epoxy resins showed very good mechanical results during the research carried out over a long specific period of time [13-15], this paper aimed to analyse the behavior of the composite materials reinforced with glass fibers and homogeneous epoxy matrix.

2. Materials and methods

2.1. Materials

Epoxy resin has superior mechanical and electrical properties compared to other resins and it has good chemical and thermal resistance, but having high cross-linking, it sometimes suffers from brittleness and exhibits low impact properties, which can be improved by fabric reinforcement [16-20]. The experiments were carried out using the Epiphen system consisting of RE4020 (resin) and DE 4020 (hardener), with a 100:30 ratio [21, 22]. Generally, the producers give information regarding the natural polymerization at room temperature for 14 days, but to reach the best quality of the polymer, they also recommend thermal treatments. Glass fiber that has been used as reinforcement elements has a 280 g/m^2 specific weight and the thickness of 220 µm. This fiber has good reinforcement capability.

The samples used in this investigation were prepared using wet-lay-up technique and the concept of fiber orientation in the composite was equally adopted in this work in order to study the influence of the orientation of glass fiber on the tensile strength of the composite materials [23, 24]. The wet lay-up forming method is the most suitable when it is about forming particular fabric reinforced polymer composites, especially when the pot-time of the polymer is long enough to ensure a good penetration of the pre-polymer in-between the fiber threads.

It was formed of two composites made of 29 layers, which were denoted in this paper as M1 and M2. The M1 represents the materials where all the layers are orientated in the same direction and the layer configuration of the composite material M2 with the fabric orientation at various angles is presented in Table 1.

After the introduction of all layers, the mould was closed and placed in a horizontal position to ensure the quality of the structure and surfaces of the formed materials. For the formed materials, thermal treatment was applied (8 hours at 60 °C, 2 hours at 80 °C and 1 hour at 90 °C) after the natural polymerization of polymer matrix of reinforced composites.

Table 1. *Orientation of the layers in the composite material*

No. layer	Orientation	No. layer	Orientation
1	0°	**16**	-30°
2	30°	**17**	0°
3	45°	**18**	30°
4	60°	**19**	45°
5	90°	**20**	60°
6	-60°	**21**	90°
7	-45°	**22**	-60°
8	-30°	**23**	-45°
9	0°	**24**	-30°
10	30°	**25**	0°
11	45°	**26**	30°
12	60°	**27**	45°
13	90°	**28**	60°
14	-60°	**29**	90°
15	-45°		

2.2. Tensile test

Tensile properties of the composites were performed according to ASTM D638-03. The tensile tests were done on Instron Universal Testing Machine with a maximum loading capacity of 100 kN. The tests were set for a loading speed of 5mm/minute and the stop condition was set at 50% drop of force or 50 mm displacement of grip. The standard tensile samples were extracted after the thermal treatment using a high-pressure water jet cutting machine. The specimen has the following dimensions: 57 mm in length X 13 mm of width X mm of thickness (Figure 1a).

THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
Nº. 2 - 2022, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2022.2.03

a

b

Fig. 1. *a - The tensile test samples; b - Tensile test specimen holding in the Instron machine*

Figure 1b., shows the holding of a tensile test specimen on an *Instron* machine. For each composite panel, a set of five sample specimens were manufactured and tested. For post processing of the experimental results, a statistical analysis was performed based on the arithmetic mean with a negligible standard deviation.

3. Results and discussion

In the current study the composite material tensile strength was defined as the ultimate strength for which the total fracture of the known dog-bone specimen occurs.

Similar to other literature studies, as described by [25], the increase of the fiber content determined high mechanical properties as tensile, impact and flexural tendencies fiber on the reinforced polymer composites. As described by [26], the improving of the mechanical properties of fibre reinforced polymeric composites may be preferred to metal for some engineering applications.

In order to ensure the mechanical strength of the composite material in all directions, a special architecture was formed, namely the layers of fabrics in the formed composite were distributed at different angles fabric for the M2 material.

If we want to form a composite landmark, a landmark that presents a certain behavior in different directions, this behavior can be imprinted on the composite material from the design phase, by establishing the optimal architecture.

Figure 2-5 shows the tensile properties of the formed materials composite.

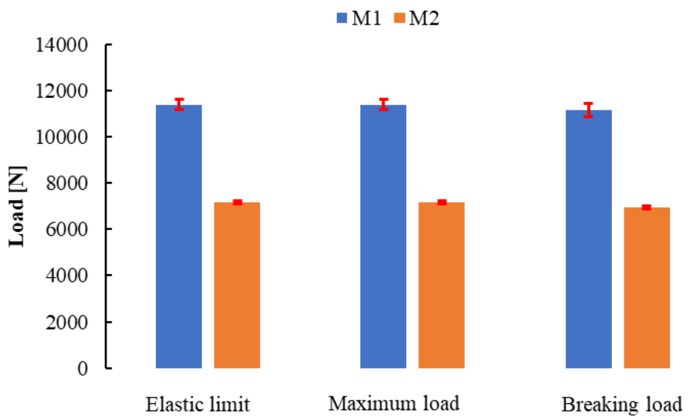

Fig. 2. *Maximum tensile load of formed materials*

THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 2 - 2022, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2022.2.03

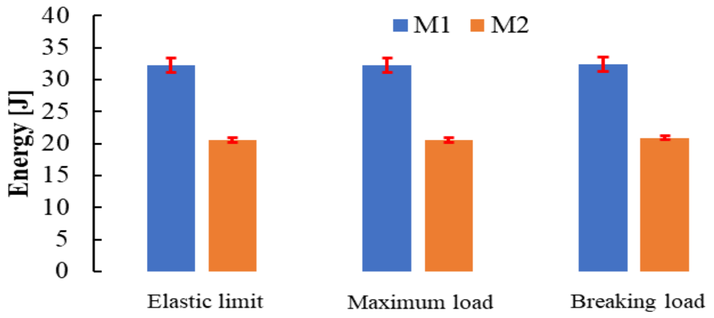

Fig. 3. *Energy to break of formed materials*

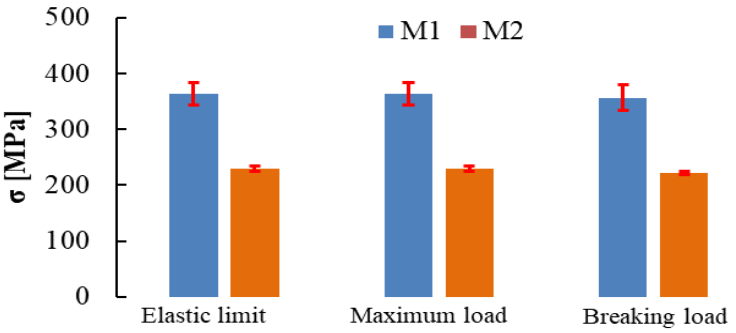

Fig. 4. *Tensile strength of formed materials*

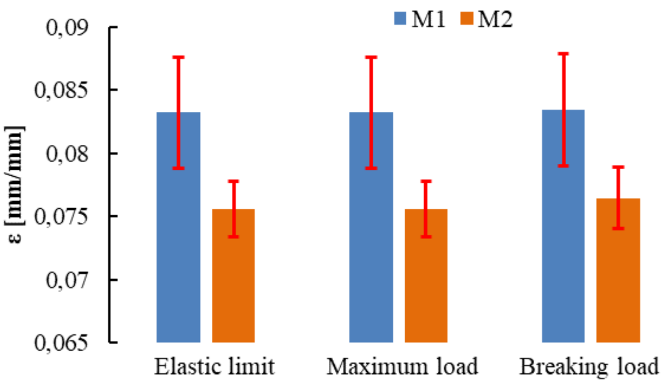

Fig. 5. *Tensile deformation*

From the error bars that represent the standard deviation, it denotes the fact that the values obtained from the 5 specimens are close. The difference between M1 and M2 can be explained by the ones described above, namely: only 28% of the fibers make the effort in the test direction.

From the graphs, it can be seen that M2 has a strength greater than 28% compared to M1, this indicates that the fibers oriented at 30º, 60º take on a full-length part of the force.

It can also be seen that the parameters shown on the graph for the 3 zones show approximately the same values, which indicates that the evolution of the force on the move is constant (linear). Therefore, the material exhibits identical mechanical behavior to tensile stresses.

Many studies have studied the effect of the reinforced glass fiber on the bulk mechanical properties of polymer composites [27-29]. It is widely acknowledged that the glass fiber, as the reinforced phase of the composites, bears more external load than the matrix does under the uniaxial tension. Specimens images after the test are shown in Figure 6.

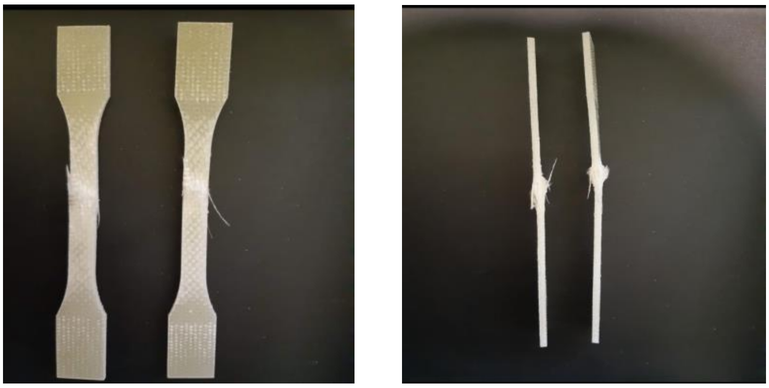

Fig. 6. *Specimens after the tensile test*

4. Conclusions

By subjecting a piece of fabric-reinforced composite material to physical stress, it is largely taken up by the fibers of the fabric. As the fibers in the fabric are oriented perpendicularly, it is obvious that the maximum strength of a fabric-reinforced composite landmark will be in both directions, warp and beat. If the composite material is formed by the overlapping of several equally oriented fabric starts, the maximum strength of the material will be in both directions.

In the case of material M2, the mechanical behavior is below the maximum values obtained, then in the case of material M1, it shows an approximately identical behavior in all directions, whereas material M1, although it has comparatively higher mechanical strength, this behavior is manifested only in both directions, beating and warping.

The parameter values in the case of material M1 are valid only in the 2 directions (0º, 90º), and on directions (30º, 60º, 45º) of the same material which has weak mechanical properties. However, this cannot be noticed in the case of the M2 material, which has significant amounts of fiber in those directions that can take over the tensile stress.

Acknowledgements

This research study was performed in the frame of Research and Development Center for Thermoset Matrix Composites (CCDCOMT).

References

[1]. Watt W., Perov B. V., *Handbook of Composites*, vol. 1, Strong Fibres, 1985.

[2]. Sherif G., Chukov D., Tcherdyntsev V., Torokhov V., *Effect of formation route on the mechanical properties of the polyethersulfone composites reinforced with glass fibers*, Polymers, 11 (8), 1364, 2019.

[3]. Vallittu P. K., Närhi T. O., Hupa L., *Fiber glass-bioactive glass composite for bone replacing and bone anchoring implants*, Dental Materials, 31 (4), p. 371-381, 2015.

[4]. Mohammed L., Ansari M. N., Pua G., Jawaid M., Islam M. S., *A review on natural fiber reinforced polymer composite and its applications*, International Journal of Polymer Science, 2015.

[5]. Neşer G., *Polymer based composites in marine use: history and future trends*, Procedia engineering, 194, p. 19-24, 2017.

[6]. Ahmad I., Baharum A., Abdullah I., *Effect of extrusion rate and fiber loading on mechanical properties of Twaron fiber-thermoplastic natural rubber (TPNR) composites*, Journal of reinforced plastics and composites, 25 (9), p. 957-965, 2006.

[7]. Zaini N. A. M., Ismail H., Rusli A., *Tensile, thermal, flammability and morphological properties of sepiolite filled ethylene propylene diene monomer (EDPM) rubber composites*, Iranian Polymer Journal, 27 (5), p. 287-296, 2018.

[8]. Agarwal B. D., Broutman L. J., Chandrashekhara K., *Analysis and performance of fiber composites*, John Wiley & Sons. Inc, New York, NY, 1990.

[9]. Ahivhare P. R., Bhalavi T., *Natural fibre reinforced polymer composite materials - A review*, Polym. Renew. Resource, 8, p. 71-78, 2017.

[10]. McNally D., *Short fiber orientation and its effects on the properties of thermoplastic composite materials*, 1977.

[11]. Nciri M., Notta-Cuvier D., Lauro F., Chaari F., Zouari B., Maalej Y., *A viscoelastic-viscoplastic model for short-fibre reinforced polymers with complex fibre orientations*, In EPJ Web of Conferences (vol. 94, p. 04008), EDP Sciences, 2015.

[12]. Notta-Cuvier D., Nciri M., Lauro F., Delille R., Chaari F., Robache F., Maalej Y., *Coupled influence of strain rate and heterogeneous fibre orientation on the mechanical behaviour of short-glass-fibre reinforced polypropylene*, Mechanics of Materials, 100, p. 186-197, 2016.

[13]. Wentzel D., Sevostianov I., *International Journal of Engineering Science*, 130, p. 129-135, https://doi. org/10.1016 /jijengsci.2018.05.012, 2018.

[14]. Forintos N., Czigány T., *Multifunctional application of carbon fiber reinforced polymer composites: Electrical properties of the reinforcing carbon fibers – A short review*, Composites Part B: Engineering, doi: 10.1016/j.compositesb.2018.10.098, 2018.

[15]. Peters S.-T., *Handbook of Composites*, 2, Ed. Green Gate Publishing Services, Tonbridge, England, p. 1-1052, ISBN 0-412-54020-7, 1998.

[16]. Ma R., Li W., Huang M., Feng M., Liu X., *The reinforcing effects of dendritic short carbon fibers for rigid polyurethane composites*, Composites Science and Technology, 170, p. 128-134, 2019.

[17]. Alam P., Mamalis D., Robert C., Floreani C., Brádaigh C. M. Ó., *The fatigue of carbon fibre reinforced plastics-A review*, Composites Part B: Engineering, 166, p. 555-579, 2019.

[18]. Morampudi P., Namala K. K., Gajjela Y. K., Barath M., Prudhvi G., *Review on glass fiber reinforced polymer composites*, Materials Today: Proceedings, 43, p. 314-319, doi: 10.1016/j.matpr.2020.11.669, 2021.

[19]. Sahu N. P., Khande D. K., Patel G. C., Bohidar S. K., Sen P. K., *Study on aramid fibre and comparison with other composite materials*, International Journal for Innovative Research in Science & Technology, 1 (7), p. 303-306, 2014.

[20]. Vedrtnam A., *Novel method for improving fatigue behavior of carbon fiber reinforced epoxy composite*, Composites Part B: Engineering, 157, p. 305-321, 2019.

[21]. ***, http://www.polydis.ro/wp-content/uploads/2014/08/Epiphen-4020.pdf.

[22]. Jin F.-L., Li X., Park S.-J., *Synthesis and application of epoxy resins: A review*, Journal of Industrial and Engineering Chemistry, 29, 1-11, doi: 10.1016/j.jiec.2015.03.026, 2015.

[23]. Shekar K. C., Singaravel B., Prasad S. D., Venkateshwarlu N., *Effect of Fiber Orientation on the Flexural Properties of Glass Fiber Reinforced*, Epoxy- Matrix Composite, Materials Science Forum, 969, p. 502-507, doi: 10.4028/www.scientific.net/msf.969.502, 2019.

[24]. Prasanth S. I., Kesavan K., Kiran P., Sivaguru M., Sudharsan R., Vijayanandh R., *Advanced structural analysis on e-glass fiber reinforced with polymer for enhancing the mechanical properties by optimizing the orientation of fiber*, Proceedings of advanced material, Engineering & Technology, doi: 10.1063/5.0019378, 2020.

[25]. Chen R. S., Muhammad Y. H., Ahmad S., *Physical, mechanical and environmental stress cracking characteristics of epoxy/glass fiber composites: Effect of matrix/fiber modification and fiber loading*, Polymer Testing, 96, 107088, 2021.

[26]. Bahl S., *Fiber reinforced metal matrix composites - a review*, Materials Today: Proceedings, doi: 10.1016/j.matpr.2020.07.423, 2020.

[27]. Xian G., Guo R., Li C., *Combined effects of sustained bending loading, water immersion and fiber hybrid mode on the mechanical properties of carbon/glass fiber reinforced polymer composite*, Composite Structures, 281, 115060, 2022.

[28]. Babazadeh J., Rahmani K., Hashemi S. J., Sadooghi A., *Effect of glass, carbon, and kevlar fibers on mechanical properties for polymeric composite tubes produced by a unidirectional winding method*, Materials Research Express, 8 (4), 045301, 2021.

[29]. Wang C., Zhang Y., Yi Y., Lai D., Yang J., Wang W., *Thermal, morphological and mechanical properties of glass fiber reinforced star-branched polyamide 6*, Polymer Composites, 2022.