



## EXPERIMENTAL MANUFACTURING METHODS OF GLASS FIBER COMPOSITES CONSIDERING FLEXURAL BEHAVIOUR

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### ABSTRACT

*Fiber-reinforced plastic laminates (FRPL) and sandwich composites are excellent materials due to their mechanical properties (i.e., lightweight, low density, and high strength to weight ratio). These applications are widely used in the fields of aviation, automotive, and construction industries. The superior mechanical properties depend on the reinforcing materials, matrixes, and manufacturing processes. Therefore, this study proposes a comprehensive analysis of the mechanical properties of epoxy resin reinforced by glass fibers under different processes. Glass-fiber sandwich composites were manufactured by the hand lay-up process and cured in different methods (i.e., with and without vacuum bagging). Furthermore, the comparison between curing temperature and pressure is investigated using the vacuum bagging process to determine the mechanical properties under flexural tests. Also, Universal Testing Machines (UTM) are used to perform experimental test. Therefore, it is confirmed that the hand lay-up process affects the flexural stress, deflection and internal force of both fiber-reinforced plastic laminates and sandwich composites. At the high curing temperature, the vacuum bagging method significantly provides the greater flexural stress, deflection and load.*

### INTRODUCTION

Composite material structures such as fiber-reinforced plastic laminates and sandwich composites are widely used in the aerospace, engine turbine, and automobile industries due to their superior mechanical properties (i.e., lightweight, low density, and high strength to weight ratio) (Krzyhak et al. 2016). The material structure contributes to property enhancement. The types and processes should be considered while conducting the structure materials. Meanwhile, the types of material used (i.e., polymer matrix and fibers) provided a significant property when composites were fabricated under a manufacturing process, and the mechanical properties depend on the structure and the process of manufacture. Fiber-reinforced plastic laminates are composed of thin layer fibers embedded in a polymer matrix. Sandwich composite structures

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consist of many layers of fiber and a core material at the middle embedded in a matrix. Strength, density, and the ability to absorb the energy of the material are investigated to enhance. There are several types of fibers used in composite sandwich structures (i.e., glass fiber, carbon fiber, Kevlar fiber) (Zangana et al. 2020, Gustin et al. 2005). The main function of using fibers is to reinforce the material. Glass-fiber reinforced polymer matrix is widely used due to its cost and high abrasion resistance despite the high strength of carbon fiber reinforcement (Karlsson et al. 1997, Sathishkumar et al. 2014). In automotive and aeronautical industries, epoxy resins are commonly used as a polymer matrix to provide better mechanical and thermal properties (Hidalgo-Salazar et al. 2018). A lightweight core is embedded to improve the strength of the materials relative to their weight (i.e., PVC foam, Aluminum core, Aramid core, and Balsa lightweight core) (Hassan et al. 2012). Polyvinyl chloride (PVC) foam cores are used in several parts of the aircraft such as wings, lavatory door, compartment, and floor panels due to their high-performance weight ratio. The foam core sandwich composites have good impact resistance and have been used as sound and heat insulation (Dweib et al. 2004).

There are many techniques of the manufacturing process to enhance the mechanical property, and the hand lay-up is taken due to the cost consumption and the technical equipment required. In student UAVs, formula competitions, and hobbies, the hand lay-up process is the best choice in terms of cost and time consumption. This was conducted by placing the reinforcing fibers on the mold and then applying the coagulation accelerator resin (Tamilarasana et al. 2015, Belingardi et al. 2008) to invent the monocoque and semi-monocoque chassis or fuselage of Student formula and fixed-wing UAV respectively (Liang et al. 2021, Dalli et al. 2020). Furthermore, the composite molding of glass fibers and polyester polymer resins was studied for mechanical properties testing, and the maximum tensile strength and the flexural stress were 78.83 MPa and 119.23 Mpa, respectively (EL-Wazerya et al. 2017). Production by vacuum bagging technique is similar to hand lay-up, and the method can help in dissolving the resin. The technique is widely used in the manufacture of large, complex-shaped composite materials such as wind turbines (Javaid et al. 2006, Sutherland et al. 2004). In addition, the tensile properties of glass fiber composite materials and epoxy resins were studied using vacuum bagging. The strength of the material increased with the pressure value (Hoda et al. 2004). The same production method was studied, but the composite material was cured at different temperatures for one hour using a hot air oven. Furthermore, the strength of the material increased with the curing temperature (Uzay et al. 2017). The tensile properties of the reinforced fiber composite are directly related to the curing temperature during the manufacturing process. The composite materials are cured at room temperature because of work-to-production, and the increase in the curing temperature contributed to the mechanical properties compared to the composite curing at room temperature (Joshi et al. 2003, Cao et al. 2007).

This study is focused on a manufacturing process of fiber-reinforced plastic laminates and sandwich composites based on glass fibers and PVC foam cores, and the hand lay-up and vacuum bagging processes at room temperature are performed. Furthermore, a comparison of the vacuum bagging process between the room and the curing temperature at 80 °C conditions was conducted. The flexural stress of specimens fabricated by different processes was investigated using a Universal Testing Machine (UTM).

## **RESEARCH METHOD**

### **Materials preparation**

In this experiment, 100 g/m<sup>3</sup> glass fiber (1x1 plain weave) was used as a reinforcing material while ER550 Epoxy resin and hardener were used as a matrix for both laminates and sandwich composites. The two materials were mixed at a weight ratio of 100:35, and polyvinyl chloride (PVC) was prepared for the fabrication of sandwich composites.

Table 1. Mechanical properties of glass fiber for experimental study

Fiber type	Density (g/cm <sup>3</sup> )	Tensile strength (GPa)
Glass fiber <sup>a</sup>	1.6	0.74

<sup>a</sup>(Compositesplaza, 2013)

## Experiment preparation

### 1. Hand Lay-Up.

The prepared glass fiber was properly cut by the angle of 0 degrees (size: 20 x 20 cm<sup>2</sup>) for 4 pieces and one piece of PVC foam was cut by the area of 20 x 20 cm<sup>2</sup>. Furthermore, a polymer matrix was produced by mixing the thermoset epoxy resin and hardener at a ratio (MR) of 100:35 after the fiber and the core material were prepared. The hand lay-up process was conducted on the aluminum plate by placing the first layer of fiber and pouring the mixed matrix over the area. The whole process was repeated on the second layer of fiber. Fiber-reinforced plastic laminates were fabricated using 5 layers of glass fiber [GF/GF/GF/GF/GF] in the directions of [0°/0°/0°/0°/0°] (Figure 1) respectively. Sandwich structures (Figure 2) are impregnated and laminated by the hand lay-up technique on an aluminum plate with 4 layers of fiber and one layer of foam core (i.e., [GF/GF/PVC/GF/GF] by the orientation of [0°/0°/0°/0°/0°]). To place the PVC foam core material, before laying the other two layers on top, the mixed epoxy resin needs to work as an adhesive film between the PVC and fiber layers.

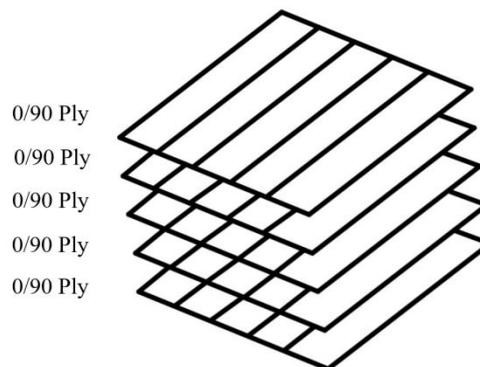


Figure 1. Fiber-reinforced plastic laminates

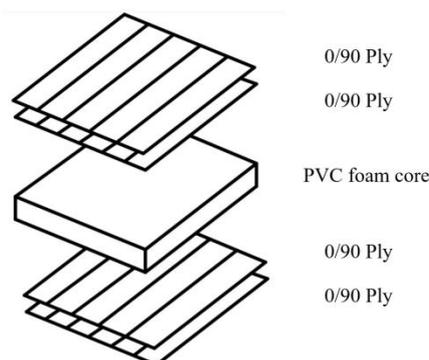


Figure 2. Sandwich composites

### 2. Vacuum bagging

After the hand lay-up process (Figure 3), the vacuum bagging process (Figure 4) should be performed by varying the curing temperature, and a peel ply layer is used to absorb the excessing resin. Furthermore, a release film is then applied over the area to constraint the direction of resin drain-out. A breather layer is placed above the plies to absorb resin and ensure that the vacuum was distributed evenly throughout the bag. The vacuum bag is sealed around

the edges with sealant tape, and the bag is connected to a pump to press the resin at 0.8 bar pressure. Curing temperatures at room temperature and 80 °C are shown in Figure 5 while Table 2 showed the specimens with a different process.

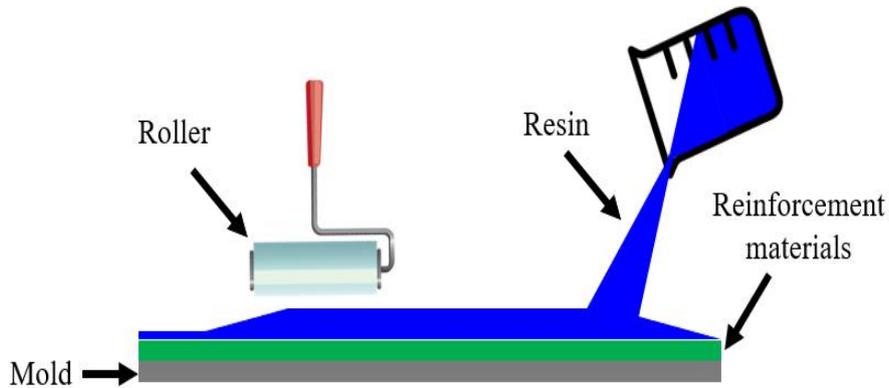


Figure 3. Hand lay-up technique

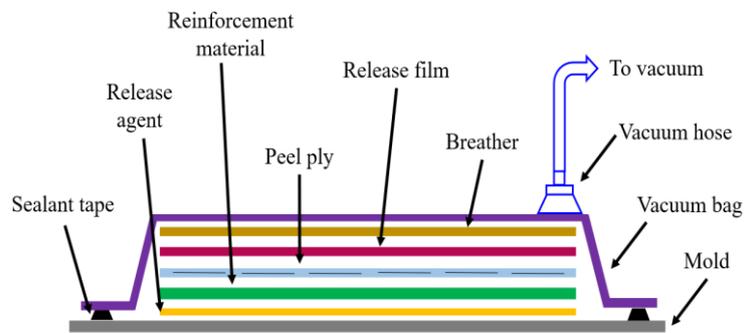


Figure 4. Vacuum bagging process

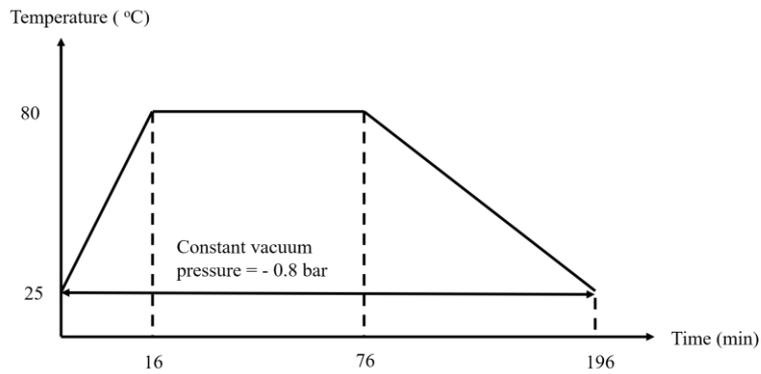


Figure 5. Temperature profile utilized during the curing process.

Table 2. Designed method for experimental study

Production method	Specimens	Temperature (°C)	Vacuum pressure (bar)	Type of Specimens
Hand lay-up	S1	25	-	FRPL
	S4	25	-	Sandwich
Hand lay-up and vacuum bagging at room temperature	S2	25	-0.8	FRPL
	S5	25	-0.8	Sandwich
Hand lay-up and vacuum bagging at a higher temperature	S3	80	-0.8	FRPL
	S6	80	-0.8	Sandwich

**Flexural test**

Sandwich composite and fiber-reinforced plastic specimens were prepared with the size of 191 x 20 x 7.2 mm<sup>3</sup> and 191 x 20 x 1 mm<sup>3</sup> respectively. The flexural test was performed under three-point bending mode following the standard of ASTM D790M-03 [22] with a crosshead speed of 1.2 mm/min and support span length of 100 mm.

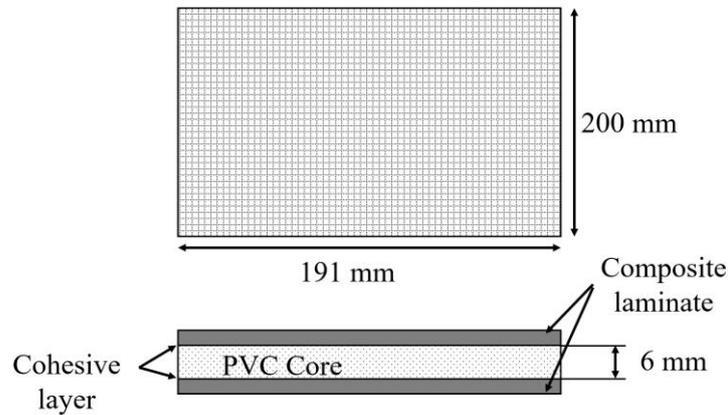


Figure 6. Geometry of laminates

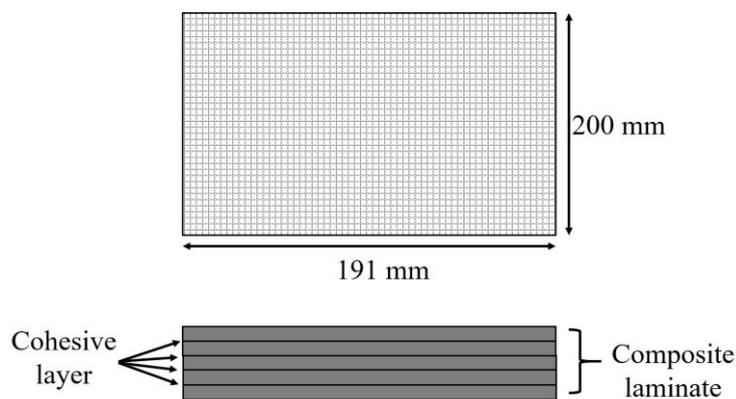


Figure 7. The geometry of sandwich composites

## RESULTS AND DISCUSSION

Figure 8 presents the flexural stress and strain characteristics under the three-point bending mode. The beginning of the sandwich composite tests showed the increased stress when subjected to the load and then slightly changed into nonlinear. The specimens are slightly deflected before the fracture when it is closed to the maximum stress. In contrast, the composite laminates showed extremely higher stress when subjected to the load but can be slightly deflected below the sandwich composites. The greatest flexural strength is in vacuum bagging. After the curing is conducted at a temperature of 80°C, hand-lay-up sandwich composites are produced due to the formation of a greater amount of resin between the fibers and vacuum bag at room temperature. The specimens showed an adequate bonding between layers without delamination failure. Meanwhile, fracture displacement and skin failure are observed when the specimens are subjected to the strength at the load stamp.

The pressure and temperature of the flexural stress of laminates and sandwich composites were improved by the curing process, and the bonding between fiber and matrixes was also improved after conducting the vacuum bagging process. The applied load initially contacts the surface of the matrix and was transmitted to the fibers during the testing. The stiffnesses of laminates and sandwich composites were enhanced because of the reinforcing fibers.

Flexural laboratory results of fiber-reinforced plastic laminates are shown in Figure 8(A) where the highest flexural stress was found by composite curing at 80°C. The material was given increased flexural stress, followed by hand-lay-up forming.

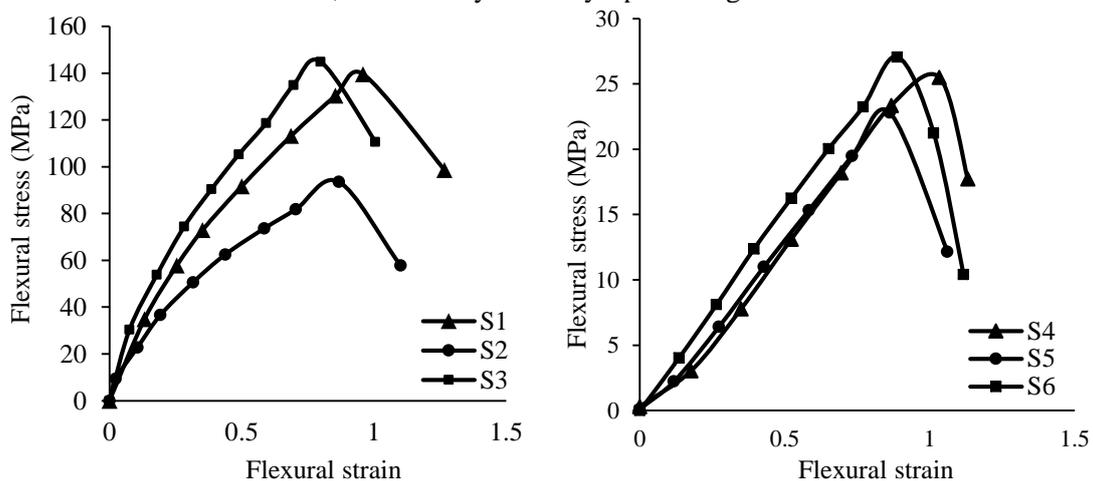


Figure 8. The relationship between flexural stress and strain: (A) fiber-reinforced plastic laminates (FRPL) and (B) sandwich composites

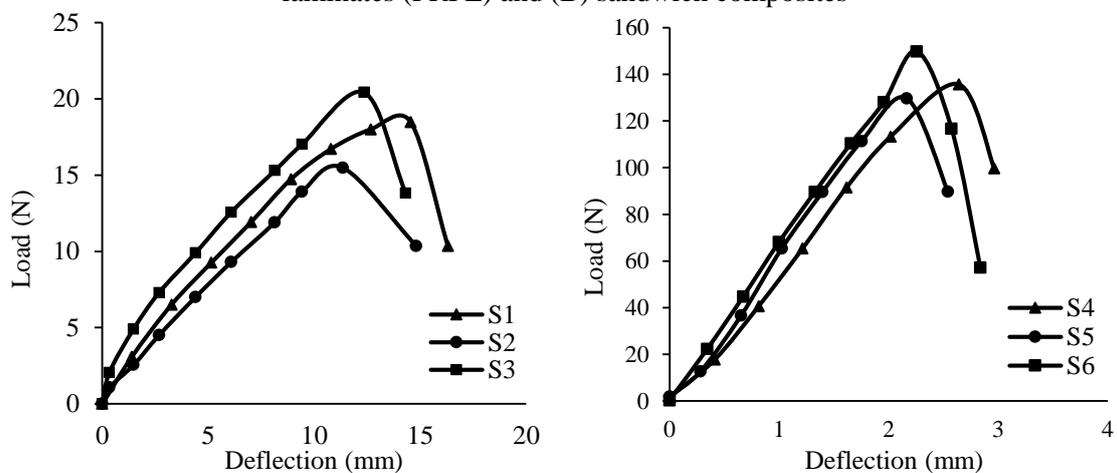


Figure 9. The relationship between load and deflection: (A) fiber-reinforced plastic laminates (FRPL) and (B) sandwich composites

Figure 10(A) showed that the fiber-reinforced plastic laminates and sandwich composites had the highest bending stresses in vacuum bagging with 80°C curing, followed by hand lay-up and vacuum bagging at room temperature.

Figure 9 showed the load and deflection characteristics acquired during a three-point bending. The curve started as an ascending linear function and then transitioned to a slightly decreasing curve. The specimen failed when the load reached its maximum value, and the type of function changed to nonlinear accompanied by a quick drop in load value.

The force acting on the specimen was bent, resulting in flexural stress and strain. In addition, the flexural stress increased because the curing temperature affected the strength value when considering the forming method. Heat curing can coordinate fiber and matrix production as well as the adsorption of epoxy resin. The deflection phase results in increased fracture of the specimen with more flexural stress as shown in Figure 9.

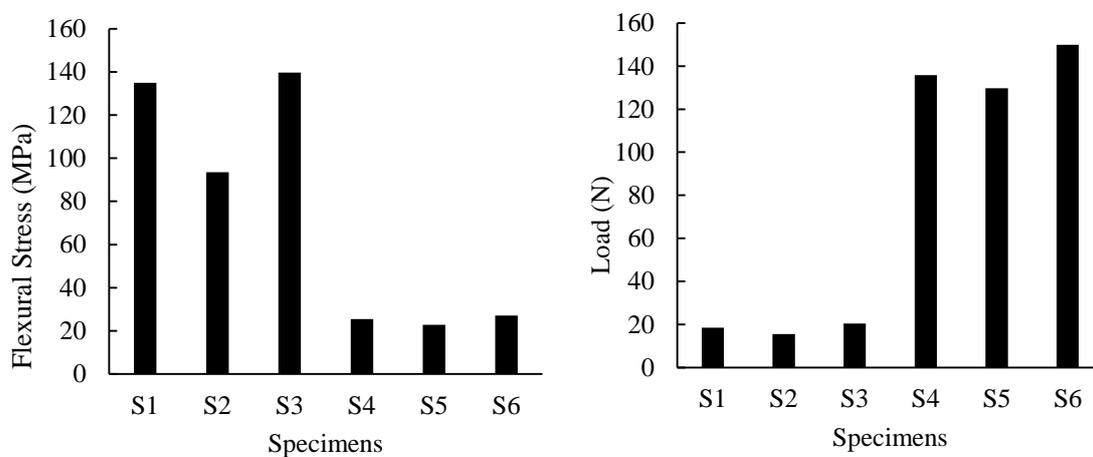


Figure 10. (A) The flexural stress against the type of specimens and (B) the relationship between load and type of specimens

Figure 10(B) showed that the fiber-reinforced plastic laminates and sandwiches possessed the highest load vacuum bagging with 80°C curings, followed by hand lay-up and vacuum bagging at room temperature.

## CONCLUSIONS

The experimental study of the composite forming method showed that manufacturing affects the mechanical properties of the materials. The different forming method results in flexural strengths, internal forces, and deflections. In this study, the composite laminates and sandwich composites under the vacuum bagging process at 80°C showed an outstanding property. The foam core sandwich panels subjected the composite to a higher load while the fiber-reinforced plastic laminates provided a greater flexural strength than the sandwich composites due to the small cross-section area of the load. The fiber layer of the vacuum bagging is compressed on the cross-section area during the process. However, curing temperature presents brittle laminates and sandwich panels. The capability of materials subjected to loads, flexural stress, and deflection relatively depends on the laminating and bonding between fibers and core. Meanwhile, the curing temperature is considered with the vacuum bagging to provide an enhanced mechanical property and also to strengthen the materials.

## REFERENCES

- ASTM. (1970). D790-03. Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials. West Conshohocken: ASTM Int' l
- Belingardi, G., Cavatorta, P.M., Paolino, S.D., (2008). Repeated impact response of hand lay-up and vacuum infusion thick glass reinforced laminates. *Impact Engineering*, 35, 609 - 619
- Cao, Y., Cameron, J., (2007). The Effect of Curing Conditions on the Properties of Silica Modified Glass Fiber Reinforced Epoxy Composite. *Reinforced Plastics and Composites*, 26
- Compositesplaza. (. ( 2 0 1 3 EGWFPL125 . 1 0 0 -Technical data sheet. Netherlands: Compositesplaza BV.
- Dalli, D., Varandas, F.L., Catalanotti, G., Foster, S., Falzon, G.B., (2020). Assessing the current modelling approach for predicting the crashworthiness of Formula One composite structures. *Composite*, 201
- Dweib, M.A., Hu, B., O'Donnell, A., Shenton, H.W., Wool, R.P., (2004). All natural composite sandwich beams for structural applications. *Composite Structures*, 63, 147–157
- EL-Wazerya, S.M., EL-Elamya, I.M., Zoalfakarb, H.S., (2017). Mechanical Properties of Glass Fiber Reinforced Polyester Composites. *Applied Science and Engineering*, 14(3), 121-131
- Gustin, J., Joneson, A., Mahinfalah, M., Stone, J., (2005). Low velocity impact of combination Kevlar/carbon fiber sandwich composites. *Composite Structures*, 69, 396–406
- Hassan, Z.M., Cantwell, J.W., (2012). The influence of core properties on the perforation resistance of sandwich structures – An experimental study. *Composite*, 43, 3231–3238
- Hidalgo-Salazar, A.M., Correa, P., (2018). Mechanical and thermal properties of biocomposites from nonwoven industrial Figue fiber mats with Epoxy Resin and Linear Low Density Polyethylene. *Results in Physics*, 8, 461-467
- Hoda, K., Seyed, A.S., Bob, M., Melanie, V., (2004). Effects of variation in autoclave pressure, temperature, and vacuum-application time on porosity and mechanical properties of a carbon fiber/epoxy composite. *Composites Material*, 46, 1985–2004
- Javaid, U., Khan, K.Z., Khan, B.M., Bassyouni, M., Abdel-Hamid, S.M.S., Abdel-Aziz, H.M., Hasan, W.S., (2016). Fabrication and thermo-mechanical characterization of glass fiber/vinyl ester wind turbine rotor blade. *Composite*, 19
- Joshi, C.S., Lam, C.Y., Tun, W.U., (2003). Improved cure optimization in pultrusion with pre-heating and die-cooler temperature. *Composite*, 34, 1151-1159
- Karlsson, F. K., Astrom, T. B., (1997). Manufacturing and Application of Structure Sandwich Components. *Appl. Sci. Manu*, 28, 97-111
- Krzyhak, A., Mazur, M., Gajewski, M., Drozd, K., Komorek, A., Przybyl, P., (2016). Sandwich Structured Composites for Aeronautics: Methods of Manufacturing Affecting Some Mechanical Properties. *Aerospace Engineering*, 2016, 10
- Li, T., Wang, L., (2017). Bending behavior of sandwich composite structures with tunable 3D-printed core materials. *Composite Structures*, 175, 46–57
- Liang, C. Y., Chin, C.P., Sun, P.Y., Wang, R. M., (2021). Design and Manufacture of Composite Landing Gear for a Light Unmanned Aerial Vehicle. *Applied Sciences*, 11
- Sathishkumar, TP., Satheeshkumar, S., Naveen, J., (2014). Glass fiber-reinforced polymer composites – a review. *Reinforced Plastics and Composites*, 33(13), 1258–1275
- Sutherland, S.L., Soares, G.C., (2006). Impact behaviour of typical marine composite laminates. *Composite*, 37
- Tamilarasana, U., Karunamoorthy, L., Palanikumar, K., (2015). Mechanical Properties Evaluation of the Carbon Fibre Reinforced Aluminium Sandwich Composites. *Materials Research*, 18(5), 1029-1037
- Uzay, C., Boztepe, H.M., Bayramoglu, M., Geren, N., (2017). Effect of Post-Curing Heat Treatment Process on Mechanical Properties of Fiber Reinforced Polymer (FRP) Composites. *Materials Testing. Vol 59*, 366-372

Zangana, S., Epaarachchi, J., Ferdous, W., Leng, J., (2020). A novel hybridised composite sandwich core with Glass, Kevlar and Zylon fibres – Investigation under low-velocity impact. *Impact Engineering*, 137