Fabrication and characterization of e-glass composites cylindrical tubes using three different methods.

K. Ganesh Kumar\textsuperscript{1,2}, Z.L.Lau\textsuperscript{1}, M.M.H. Megat Ahmad\textsuperscript{2}, M Y Yuhazri\textsuperscript{3}

\textsuperscript{1} Faculty of Engineering & Technology (FET), Multimedia University, Jalan Ayer Keroh Lama, 75450, Melaka, Malaysia.
\textsuperscript{2}Department of Mechanical Engineering, Faculty of Engineering, National Defence University of Malaysia, Sungai Besi Camp, 57000, Kuala Lumpur, Malaysia.
\textsuperscript{3}Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, 76100, Melaka, Malaysia.

ganesh.krishnan@mmu.edu.my

Abstract. The mechanical properties of the composites might have variations due to their manufacturing methods. In this paper, the glass fiber reinforced epoxy composite tubes are fabricated by using three different methods which are hands lay-up, vacuum bagging, and compression molding. The tensile properties such as the tensile strength, Young modulus, and the tensile response of thermal spiking were determined by carrying out the tensile testing. The test was conducted according to ASTM D3039 standard. The specimens were undergone heat treatment with 50°C, 100°C, and 150°C before undergoing the test. All the results were compared with the untreated specimen at room temperature. The untreated compression molding fabricated composite has obtained the highest tensile strength with a value of 273.518 MPa. The tensile strength of all types of specimens starts to reduce when the treatment temperature reaches to 150°C. The performance in terms of the specimen’s tensile properties shows that the compression molding method is the best approach.

1. Introduction
Nowadays, the implication of fibrous reinforced polymeric (FRP) composites tubes has been applied for an extensive variety of applications due to their exceptional combination properties. The composites tubes are widely used in the field of sporting goods, aerospace, structural, construction, and automobiles [1,2,3]. However, the effects of thermal spiking temperatures are encountered in real conditions which have highly affected the mechanical properties of the components. Aerospace components are always subjected to the thermal spike by exhaust fumes and different ranges of temperatures in the earth’s atmosphere. The changing temperature in the environment alters the mechanical behavior of FRP composites.

In many previous types of research, most of the researchers carry out the investigation on the failure mode of fiber composites polymer based on the interfacial adhesion effects as it will contribute to the stiffness and mechanical properties of the composites [4,5]. Kumar et al [6] have described that most of the aerospace composites failed under tensile loads. The effects of tensile behavior of composites will be affected due to the thermal spike of the changing temperature environment and this mechanical behavior is due to the interfacial adhesion effects of the composites [7]. Different composite fabrication methods will lead to the different mechanical properties of the composites which are mainly based on the interfacial adhesion effects of the composites as it controls the overall mechanical behavior of fiber-reinforced composites. Thus, an investigation about the tensile behavior of FRP based on the different manufacturing processes will be carried out which all of the specimens will go through the thermal spike to investigate the effects of interfacial adhesion on the components on the mechanical behavior of the composites tubes.
2. Materials and Experimental Procedure

The materials that had been selected to fabricate cylindrical composite tubes are epoxy and E-glass fiber supplied by Chemi-Bond from Selangor, Malaysia. The resin used in this project was Auto-Fix 1345 B hardener and Auto-Fix 1710 A epoxy. The epoxy and hardener are mixed by the ratio of 1:1 by weight as recommended by the supplier. Electric stirring was used in the mixing to reduced bubble formation. For E-glass fiber, it was cut in 200 mm in width and the length of the perimeter for the 50 mm inner diameter tube depending on the number of layers used. For the current study, composite with 1, 2, and 3 plies were investigated.

In the hand lay-up process, a 50 mm diameter steel mandrel was used. The mandrel was wrapped with PTFE plastic film and a release agent was applied. On the other hand, epoxy was applied to the E-glass fiber surface. The wetting of the glass fiber was rolled on the mandrel. At the same time, a steel roller was used to compress the fiber and it also helps to release bubbles form in between layers. After the fiber rolled on the mandrel, PTFE film again rolled on the mandrel against the fiber to produce a small compression force to hold the fiber in place. The composite was left to cure for 24 hours at room temperature. After curing, the composite was separated from the mandrel and cut to 100 mm in length as testing specimens.

The bagging process starts with a 50mm outer diameter hollow cylindrical tube that was prepared as a mold as same as the hand layup fabrication process. A layer of wrapping paper was wrapped around the mold. After that, the coated laminate fabric was wrapped around the shape of the mold. Another layer of wrapping paper acts as the release fabric was wrapped around the mold to separate the bleeder layer laminate fabric. After that, the thick type of wrapping paper with its length longer than the mold was acting as the vacuum bag. The vacuum bag was then covered over the mold which acts as a membrane to protect the laminate and facilitate the air sucking process. The sealing tape was used to seal the vacuum bag to prevent the air from flowing in. The mold pipe was then connected from the vacuum bag to the resin trap to prevent the extra resins from flowing into the vacuum pump. Another flexible tube was connected to the vacuum pump to allow the air sucking process. The connecting point was also sealed with industrial clay and double side tape to prevent void which causes the air to flow in. After the set-up of the vacuum bagging process is done, the one-sixth horsepower vacuum pump was allowed to operate to suck the air out from the setup for about 45 minutes. The vacuum pump was then turned off and the laminate is cured for at least six hours.

Unlike hand layup and vacuum bagging fabrication processes, the fabrication process does not require the cylindrical tube as a mold. The mold for the compression molding was a true close-set molding with an inflatable flexible bladder. The mold was first designed and fabricated with the dimension of 320mm x 100mm x 100mm rectangular solid box with a hollow cylindrical shape in the middle. The mold was made with aluminum 6061. An inflatable bladder was used to allow the inflation to the desired consolidation pressure so that the prepreg can be fully inflated in the hollow cylindrical shape. The overall setup was shown in figure 1.

![Figure 1. a) Hands layup process b) Vacuum bagging arrangement c) bladder assisted compression molding](image)

3. Results and Discussion

3.1 Tensile properties

In this section, the comparison will be made based on different fabrication methods and the analysis will be carried out to determine the causes. The microscopic view of the void content will be shown in the
The strength of the mechanical properties of the composites will be highly dependent on the internal structure especially the void content between the matrix and fiber layer [8]. Through a simple observation on the diagram, it can be observed that the hand lay-up specimen had a very high void content area which was distributed along with the internal surface. The void content of the vacuum bagging specimen has a better void content distribution than the hand lay-up specimen while the compression molding specimen had a very low void content distribution. More details of the microscopic view with the use of an optical microscope will be shown in section 3.2.

The experiment data shows that different fabrication methods led to different mechanical properties of the specimen. The curing or treated temperature also brings some affection to the mechanical properties. The data comparison between the Hands lay-up (H1), Vacuum bagging (V1), and Compression molding (C1) specimen with its corresponding temperature (RT= Room Temperature), (50=50°C), (100=100°C), and (150=150°C) was shown in table 1 to table 3.

From figure 2, it can be observed that the C1 specimen had the highest tensile stress, followed by the V1 and H1 specimens with the value of 273.518 MPa, 266.789MPa, and 180.874 MPa. The variation of the tensile stress between the 3 fabrication methods might be due to the void content [9]. The C1 specimen had the lowest void content percentage while comparing to the H1 and V1 specimens. The individual void that is present in the specimen will cause a high-stress concentration limited to a small neighbourhood of the void which will decrease the interlaminar stress between the matrix and fiber phase [10]. However, the void with a smaller area will not have much effect on the laminate. The laminate strength will depend on the size of the area over where it exists. From the observation, the H1 specimen has a very large void content thus the laminate strength between the matrix and fiber phase decrease, leading to the low tensile stress. Besides, the was only a small variation of the tensile stress between the V1 and C1 specimens. The void content area of V1 was slightly better than the H1 specimen but still higher than the C1 specimen.

From figure 2, it can be easily observed that the tensile stress of all types of specimens increases gradually with the 50°C and 100°C treated temperature. The improving effect of the heat treatment depends on the improvement in the fiber-matrix interfacial shear strength. When the specimens had undergone the heat treatment, the crystallinity increased significantly which cause the new arrangement

| Specimens | Max Load (N) | Max Tensile Stress (MPa) | Max Strain | Young Modulus (GPa) |
|-----------|-------------|---------------------|------------|-------------------|
| H1_RT     | 1510.300    | 180.874             | 0.0312     | 5.789             |
| H1_50     | 1566.250    | 187.575             | 0.0325     | 5.732             |
| H1_100    | 1707.525    | 204.494             | 0.0407     | 5.028             |
| H1_150    | 1494.790    | 179.017             | 0.0362     | 4.944             |

| Specimens | Max Load (N) | Max Tensile Stress (MPa) | Max Strain | Young Modulus (GPa) |
|-----------|-------------|---------------------|------------|-------------------|
| V1_RT     | 2004.920    | 266.789             | 0.0331     | 8.060             |
| V1_50     | 2123.390    | 282.554             | 0.0358     | 7.898             |
| V1_100    | 2397.577    | 319.039             | 0.0401     | 7.956             |
| V1_150    | 2145.840    | 285.541             | 0.0326     | 8.759             |

| Specimens | Max Load (N) | Max Tensile Stress (MPa) | Max Strain | Young Modulus (GPa) |
|-----------|-------------|---------------------|------------|-------------------|
| C1_RT     | 2055.490    | 273.518             | 0.0368     | 7.433             |
| C1_50     | 2235.550    | 297.537             | 0.0369     | 8.063             |
| C1_100    | 2523.730    | 335.826             | 0.0401     | 8.191             |
| C1_150    | 2041.220    | 271.619             | 0.0399     | 6.811             |
of the molecules that adjacent to the fiber to a more compact way, thus reduce the void content in the interface. The decreasing of void content in the interface further leads to the increasing of interfacial shear stress between the fiber and matrix phase. Thus, the H1, V1, and C1 specimens were able to withstand more force and thus increase the tensile strength.

However, the tensile stress started to drop when the treated temperature comes to 150°C as shown in figure 2. From the research of Jeng-Shyong Lin [11], he experimented on the effect of heat treatment on the glass fiber reinforced polypropylene. The results show that the polypropylene started to melt when the temperature comes to 120°C. Due to the similar results with the researcher, it might be concluded that the epoxy molecules start to melt between the 100°C and 150°C which the interfacial bonding between the interface was weakened. By observation, the tensile stress of the specimen with 150°C treated temperature was even lower than the specimen with untreated temperature.

![Graphs showing tensile stress versus strain for H1, V1, and C1 specimens with different treated temperatures.]

**Figure 2.** Average (AVG) comparison of tensile stress versus strain curve with room temperature, treated at 50°C, 100°C and 150°C temperature for a) H1, b) V1 and c) C1 respectively.
From figure 3, just focusing on 100°C it can be observed that the C1 specimen had the highest tensile strength, followed by V1 and H1. C1 is a manufacturing method that reflects that integrated highest pressure throughout the process compares to the other two processes. Pressure implied has led to a lower up amount of void in the material. The pressure inside the mold is to clear out and air gap and between the fiberglass and epoxy during the curing process. By doing this, the material is well compressed within the mold surface area which imparts greater strength. It is also evident in the structure of the C1 specimen which has less void percentage compares to the other two processes.

![Graph](image)

**Figure 3.** Average (AVG) comparison of tensile stress versus strain curve for H1, V1, and C1 at 100°C

### 3.2 Microstructural

Using an optical microscope, the void content of each sample was analyzed under 40x magnification. The location of each measurement was chosen without discrimination and in approximately the same locations for each of the samples. The void content of the four pipes was measured using image analysis[12]. From figure 4, it can be observed that the H1 specimen had a large area of void content percentage on the interface compare to the other 2 specimens. The V1 specimen had a better void content percentage while the C1 specimen had only a few void contents on the interface. As mention, the void content had a significant effect on the interlaminar shear stress between the matrix and fiber interface[13]. The tensile strength of the composite was then affected by the interlaminar shear stress between the laminar. The results explained that why the C1 specimen has the highest tensile strength, followed by the V1 and H1.
Figure 4. Void content in a) H1 b)V1 and c)C1 specimens

Figure 6 shows the surface failure of the V1 specimen. In figure 6 a) it can be observed that the fiber pull out might not only be due to the pulling force, it might also be due to misalignment of the fiber. The misalignment might be due to the error in the composite preparation process or the curing process. All the V1 specimens were failed under the fiber pull-out as it was the main reason for the tensile failure. From observation, the semitransparent area in figure 6 d) might be due to the molecules of matrix melting and cracking. It had the same condition as Figure 5 d) for the H1 specimen.

The microstructure of surface failure of the C1 specimen was shown in figure 7. The failure was similar to the H1 and V1 specimens. All the C1 specimen meet failure due to the fiber pull out. By observation, figure 7 c) shows a semitransparent area. By comparing Figure 5 d) and Figure 6 d), it might be the matrix melting area. It was observed that the matrix phase of the C1 specimen had started to melt at 100 degrees Celsius. From all the figures and data above, it can be agreed that the reduction of tensile strength of the composite under the treatment temperature was due to the melting of matrix molecules.

Figure 5. The microstructure of surface failure of H1 specimens; a) H1_RT b) H1_50, c) H1_100 and d) H1_150
Figure 6. The microstructure of surface failure of V1 specimens; a) V1_RT, b) V1_50, c) V1_100 and d) V1_150

Figure 7. The microstructure of surface failure of C1 specimens; a) C1_RT, b) C1_50, c) C1_100 and d) C1_150
4. Conclusion

The glass fiber reinforced epoxy composites tubes were fabricated through three different manufacturing processes as Hands lay-up, Vacuum bagging, and Compression molding methods. The comparison of the composites showed that the C1 specimen had the highest tensile strength and young modulus among all other specimens while the H1 specimen had the lowest tensile properties. The observation showed that the C1 composites had the lowest void content percentage, followed by the V1 and H1 composites. The void content had a significant effect on the tensile strength of the composites as the void will reduce the interlaminar shear stress between matrix and fiber interface thus reducing the tensile properties of composites. The experimental data showed that the tensile strength of the composites increases generally and gradually with the increased temperature up to 100°C as the interlaminar shear stress or interface bonding force between the matrix and fiber layer improved. However, the tensile strength of the composites started to decrease when the treatment temperature come to 150°C. In conclusion, the overall performance of C1 composites was better than the V1 and H1 composites in terms of their mechanical properties and the tensile response towards the treatment temperature. The results show that the glass fiber reinforced composites had a strong tensile strength which was able to withstand a larger tensile load. Thus, the glass fiber reinforced composite was suitable for applications such as large as bridge hangers and smaller like a fishing rod in terms of their strong tensile strength and response towards the thermal spiking.

Acknowledgments

The authors acknowledge the assistance provided by Multimedia University (MMU) for financial and equipment aid.

References

[1] Babazadeh J, Rahmani K, Hashemi S J, and Sadooghi A, 2021 Effect of glass, carbon, and kevlar fibers on mechanical properties for polymeric composite tubes produced by a unidirectional winding method Mater. Res. Express 8 45301
[2] Saffar A, Darvizeh A, Ansari R, Kazemi A, and Alitavoli M 2020 Damage analysis of fiber–metal laminate patches as a repair system for surface defects of steel pipelines: Proc. Inst. Mech. Eng. Pt. L Mater. Des. Appl. 235 4 868–879
[3] Koli D K, Agnihotri G, and Purohit R, 2014 A Review on Properties, Behaviour and Processing Methods for Al- Nano Al2O3 Composites Procedia Mater. Sci. 6 567–589
[4] Rahmani K, Wheatley G, Sadooghi A, Hashemi S J, and Babazadeh J 2021 The experimental analysis of creep and corrosion properties of polymeric tube reinforced by glass, carbon and Kevlar fibers Mater. Res. Express 8 65307
[5] Wu W, Xie L, Jiang B, and Ziegmann G 2013 Simultaneous binding and toughening concept for textile reinforced pCBT composites: Manufacturing and flexural properties Compos. Struct. 105 279-287
[6] Mahato K K, Dutta K, and Ray B C, 2018 Effect of Thermal Spike Conditioning on the Tensile Behavior of Glass/Epoxy Composites Mater. Today Proc. 5 12109–12114
[7] Wang W et al., 2020 Surface Modification of Flax Fibers with Isocyanate and Its Effects on Fiber/Epoxy Interfacial Properties Fibers Polym. 21 12 2888–2895
[8] Lekube B M, Hermann W, and Burgstaller C, 2020 Partially compacted polypropylene glassfiber non-woven composite: Influence of processing, porosity and fiber length on mechanical properties and modeling Compos. Part A Appl. Sci. Manuf. 135 105939
[9] Mehdikhani M, Gorbatikh L, Verpoest I, and Lomov S V, 2019 Voids in fiber-reinforced polymer composites: A review on their formation, characteristics, and effects on mechanical performance J. Compos. Mater. 53 12 1579–1669
[10] Zhang A Y, Li D H, Zhang D X, Lu H B, Xiao H Y, and Jia J, 2011 Qualitative separation of the effect of voids on the static mechanical properties of hygrothermally
conditioned carbon/epoxy composites  Express Polym. Lett. 5 8 708–716

[11] Lin J S , 2003 Effect of Heat Treatment on the Tensile Strength of Glass Fibre Reinforced Polypropylene: 11 369–381

[12] Harris W , Soutis C , Gresil M , and Atkin C , 2020 Pressure response and life assessment of filament-wound composite pipes after impact Int. J. Light. Mater. Manuf. 3 365–375

[13] Van De Werken N , Tekinalp H , Khanbolouki P , Ozcan S , Williams A , and Tehraní M , 2019 Additively manufactured carbon fiber-reinforced composites: State of the art and perspective Additive Manufacturing 31:100962

[14] Viel Q , Esposito A , Saiter J M , Santulli C and Turner J A 2018 Interfacial characterization by pull-out test of bamboo fibers embedded in Poly(lactic acid) Fibers 6 1