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Research paper

Design and Fabrication of Laminated Composite Tube Using Modified Bladder Assisted Compression Molding Technique

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Abstract

Fiber reinforced composites especially polymer base fiber are finding increasing application due to their high specific strength and stiffness to weight ration. Several uses of composite material are including marine, aeronautical and piping applications. Even though, they are known for having specific strength and stiffness; lacking or limited fabrication methods specifically for tube shapes is a disadvantage. In this current paper, a new way of fabricating cylindrical composite tubes using modified bladder assisted compression molding (MBACM) was presented. Glass fiber reinforced composite tubes are fabricated with fiber content in a mat form which consists from 1 to 5 layers. This technique provides capability for producing tube specimens with an internal diameter around 50mm and lengths up to 300mm. The feasibility of this manufacturing method is demonstrated by fabricating laminated composite cylinder using multiple numbers of plies. To evaluate the mechanical properties of the fabricated composite tubes, quasi-static crushing test were conducted to assess crashworthiness and monitor crushing mechanisms corresponding to each layers. This present work confirms that cylindrical composite tube can be fabricated using MBACM technique and the increasing layer of E-glass fiber is significantly changing the mechanical properties to have higher performance in strength.

Keywords: *Composite material, Fiberglass, Manufacturing process, Mechanical properties, Tube.*

1. Introduction

In recent years, the increasing demand and use of composite materials are significant especially their use in aerospace, defence and automotive applications [1-3] Composite materials refer to the combination of matrix and reinforcement that are associated with each other to provide unique combination of properties. Composite materials have their inevitable physical, mechanical, thermal and corrosion resistance as well as dimensional stability [4, 5]. Even though its hold such a properties, there are still limitations on its manufacturing process availability and complexity[6]. Compression molding which is also known as matched-die molding is frequently used as processing technique that provides specific design to the forming process for plastic and polymer composite products[4] [7]. Since compression molding can be used to produce large automotive panels, it has become very famous among the automotive industry due to its high volume capabilities[8].Compression molding has its own advantages over other fabricating processes. It possesses higher stability of product quality when it is compared to hand lay-up method. Production efficiency of hand lay-up method is lower than compression molding because of the slower speed that causes longer production cycle. Labour costs for compression molding is also lower than hand lay-up method because the latter method is labor intensive mainly due to the manual application of reinforcements and resin materials. Compression molding also offers higher surface quality than filament winding. As compared to other processes which require tooling features, little material is wasted using compression molding process. Despite many advantages of compression molding, this conventional process has its disadvantages too. High initial investment for compression molding because of its expensive equipment and mold costs. Thus, it is relatively costly for small industries to operate and run compression molding process. Compression molding process requires a large yet fixed space to equip with its machines. It may suffer in terms of portability. The product fabricated using compression molding process is also limited to flat and moderately curved parts without undercuts. Literature survey shows that very limited studies have been reported on fabrication of cylindrical glass fiber reinforced composite tube using compression molding[2, 9-10]. For small industries, there is higher initial investment in compression molding due to its expensive equipment and mold. Thus, compression molding method is needed to be modified to efficiently support small industries. In addition, large and fixed place is required to allow the process of compression molding to be taken place. Compression molding method can be altered to become portable process that may be an innovation for the current compression molding. In order to verify the feasibility of the fabricated cylindrical glass fiber reinforced composite tube, a variety of mechanical tests shall be performed and the results will show the possibility of implementing the fabrication process[11-12]. In this current study, the glass fiber composites tube was manufactured using modified fabrication method of hands lay-up and compression bladder molding technique. The use of prepregs is desirable to achieve higher fiber volume fraction[11]. The step involves were given in details along with compression properties such as young modulus, maximum force and compression strength.

2. Materials preparations

The glass fiber reinforced composite tubes were fabricated using modified bladder assisted compression molding (MBACM). The resin system presented in this work was commercially available Auto-Fix 1345-B epoxy and Auto-Fix 1710-A hardener supplied from Chemi-Bond based in Selangor, Malaysia. E-glass woven roving fibers used for this research where it was obtain from Win-Fung Fiberglass Sdn Bhd.

For the material preparation, epoxy and hardener were mixed in the ratio of 1:1 by weight. The hardener was poured into an empty plastic cup and then mixed the same amount of epoxy. They were stirred properly and it was ensured that the epoxy-hardener mixture was fully blended until a milky form was reached. The reinforcement used in this work was unidirectional E-glass fibers as shown in Fig. 1.

Fig. 1: E-glass fibers in mat form

3. Methodology

The design of the experiment has to be planned accordingly to ensure proper process flow and wastage of material is kept to minimum. Fig. 2 is an idea on how the methodology process is to be carried out is shown on the flowchart.

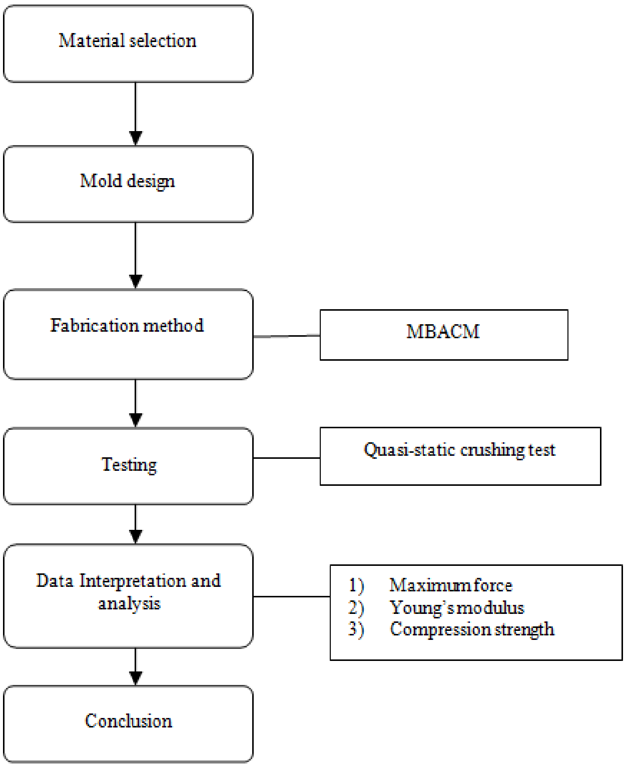

Fig 2: Flowchart of the methodology

3.1. Mold of MBACM

The material chosen for the mold was aluminium as it contributes a better accuracy compared to wood. As shown in Fig. 3, the mold was designated into two parts which were upper mold half and lower mold half. The mold which has a dimension of 340mm x 100mm can form a circular shape with outer diameter of 50mm. Without utilizing G-clamp, the upper mold half has 6 screws that are used to clamp the mold in a proper way. In addition, there were 8 screws acted as detaching tool for the upper mold after curing reaction. As highlighted in Fig. 4, the dowel pins were used to alignment both half of the mold during closure.

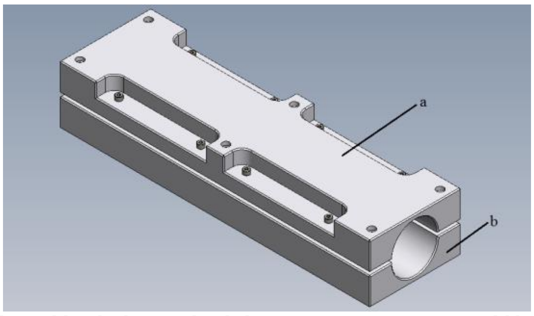

Fig. 3: Isometric view of the molds which were divided into two parts: (a) upper mold half and (b) lower mold half

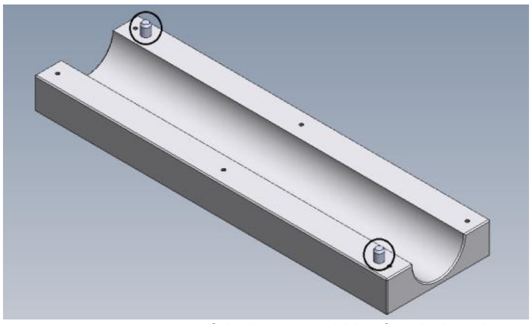

Fig. 4: Isometric view of the lower mold half with dowel pins

3.2. Process of MBACM

The valve of the bladder was attached to a pump and the bladder was pumped until it was fully expanded. Fig. 5 shows the closed molds that were needed to be left overnight for curing reaction to perform. After curing reaction, the upper mold half was detached from the lower mold half by unscrewing the screws. Fig. 6 displays the fabricated composite tube with a plastic wrapping paper wrapping around it. The processes were repeated from one layer to five layers of E-glass fibers. Three tubes would be fabricated for every layer. The tubes with different layer were fabricated and shown Fig. 7. Each tube fabricated has at least a length of 300mm

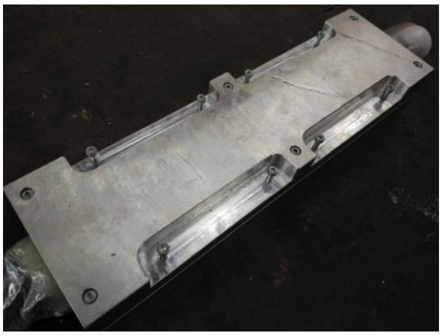

Fig. 5: The closed mold

Fig. 6: Final product with plastic wrapping

A bladder was employed together with the mold to obtain hollow part in the tube. The bladder was made of rubber tube. The rubber tube was cut into a length of approximately 450mm. In order to seal both ends of the rubber tube, polyethylene rod was cut into two small rods with each 60mm long and they were machined using turning machine into approximate diameter of 28mm to 30mm for easier stuffing into the rubber tube. The rod being stuffed into the rubber tube then was applied with epoxy-hardener mixture the make sure there will be no air leakage in the bladder later on. The bladder was left to cure overnight in the room temperature. After completing the sealing process, the bladder was wrapped with plastic wrapping paper which to protect the surface of bladder from to have direct contact with the prepreg.

To achieve resin impregnation, the epoxy-hardener mixture was distributed evenly on the E-glass fibers. After removing the excess resin by using spreader, the prepreg was wrapped around the bladder. Thus, the bladder was again wrapped with plastic wrapping paper to avoid the contact from prepreg to the lower mold half because it might be harder to detach the upper mold half if there was direct contact between the prepreg and mold. After the wrapping process, the bladder with the prepreg was put on the lower mold half which was then closed with upper mold half. Allen key was used to tighten both mold halves together.

3.3. Specimen Preparation

The tubes fabricated were needed to be in specific size in order to proceed with the mechanical test. Thus, the tubes were cut by using vertical band saw machine. For quasi-static crushing, the tube was cut into a specimen with length of 100mm. The fiber angle is set constant for all at longitudinal (0°). Quasi-static crushing test was performed in reference to ASTM D695-15 using universal testing machine (Shimadzu, AG-I) with a constant crosshead speed of 1.3mm/min.

Table 1: Fabricated tube dimensions

Specimen	Inner Diameter, D_i (mm)	Outer Diameter, D_0 (mm)	Wall Thickness, t (mm)	Length, L(mm)
1 layer	52	53	1	300
2 layers	51.5	54.5	3	300
3 layers	50	56	6	300
4 layers	49	57.5	9	300
5 layers	47	59	12	300

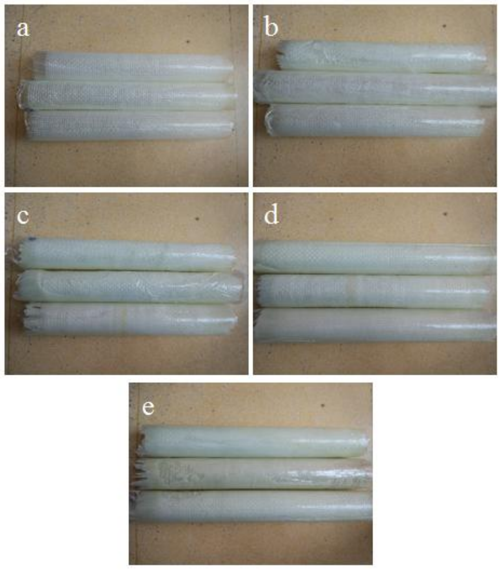

Fig. 7: The fabricated tubes with different layer of E-glass fibers: (a) one layer; (b) two layers; (c) three layers; (d) four layers and (e) five layers

4. Experimental results and discussion

4.1. Process design

Comparing to the conventional compression molding that implement hydraulic press for producing large parts and with high volume production, the present work involves compression molding that could be portable and easily used for fabricating cylindrical composite tube. The very first draft of the molds is showed in Fig. 7. At first, the material chosen was wood due to cost effectiveness. The plate that is pointed by an arrow in Fig.7 was decided to be used as tightening mechanism of the upper mold half and lower mold half. It could be used to do alignment as well. The hole circled in Fig. 7 was planned to do detaching the upper mold half from the lower mold half as the cured resin might stick closely to the mold. However, the design is not choose due to several limitations.

4.2. Compression properties

From quasi-static crushing, maximum force, Young's modulus and compression strength were determined. Table 2 shows one of the tabulated data and Fig. 8 show plotted data.As shown in Fig. 9 to Fig. 11, the comparison of maximum force, Young's modulus and compression strength between the specimens with different layer of E-glass fiber in quasi-static crushing are displayed. From the figures, specimen with five layers of E-glass fiber has the highest value of Young's modulus and compression strength which are 1830.5211MPa and 59.2566MPa respectively. In addition, it holds the highest maximum force which is 22.4679kN amongst all the specimens. For specimen with four layers of E-glass fiber, it has second highest compression properties which are 1461.8186MPa for Young's modulus and 50.5431MPa for compression strength as well as 15.699kN for maximum force. Next, third highest average value of compression properties is from specimen with three layers of E-glass fiber. It has Young's modulus at 1231.4085MPa and compression strength at 41.6513MPa as well as maximum force at 8.1229kN. Specimen with two layers of E-glass fiber has the second lowest value of Young's modulus and compression strength which are 1091.5169MPa and 31.86MPa. The lowest average value of compression properties for specimen with one layer of E-glass fiber are 561.0457MPa from Young's modulus and 25.8051MPa from compression strength as well as 2.775kN from maximum force.

Table 2: Result of quasi-static crushing using specimen with 4 layers of E-glass fiber (Test 2)

Number of Test	Maximum Force (kN)	Young's Modulus (MPa)	Compression Strength (MPa)
1	14.8375	899.5289	37.2315
2	15.1719	1166.461	44.9904
3	17.0875	2319.766	69.4074
Average	15.6990	1461.9186	50.5431

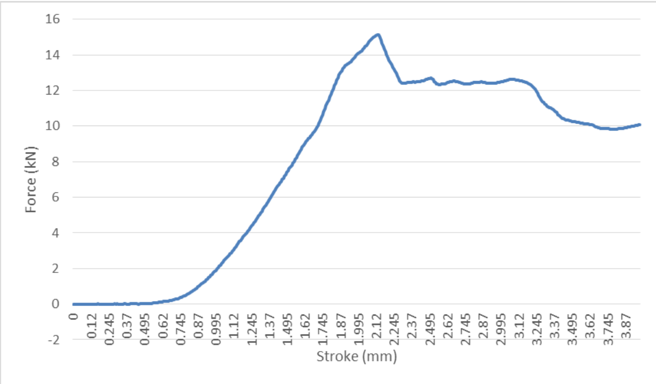

Fig. 8: Graph of Force versus Stroke for 4 layers of E-glass fiber (Test 2)

When there is an addition in the layer of E-glass fiber, compression properties such as maximum force, Young's modulus and strength shows increasing in value. This may be due to the changes in fiber content as more resin were needed to be used in the fabrication of composite tube when the fiber content increased. Catastrophic failure together with abrupt decrease after reaching a maximum value was occurred in all specimens. It can be observed that some specimens showed minor delamination and buckling behaviour. From the data comparison, the energy absorption capability was strongly dependent on the number of ply used to fabricate to composite tube.

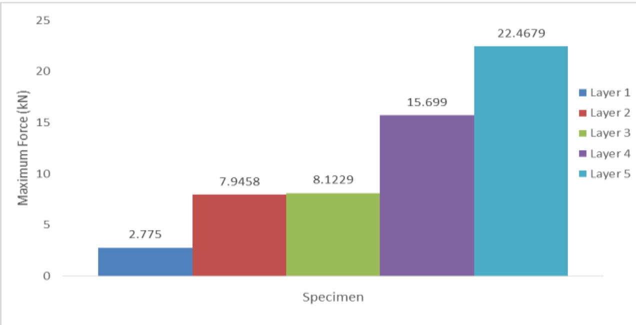

Fig. 9: Comparison of maximum force between the specimens with different layer of E-glass fiber in quasi-static crushing

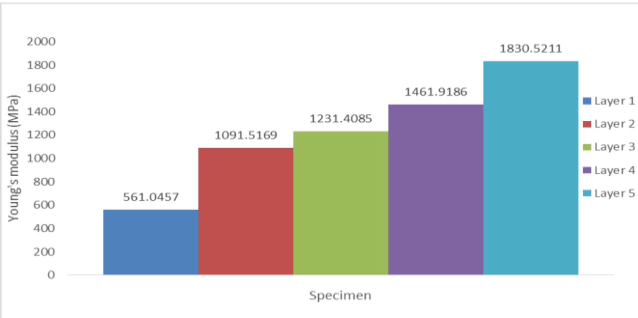

Fig. 10: Comparison of Young's modulus between the specimens with different layer of E-glass fiber in quasi-static crushing

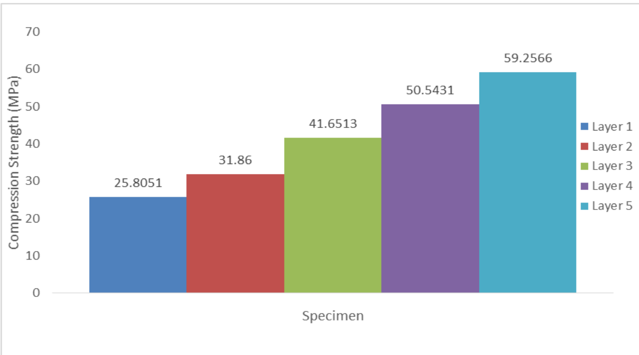

Fig. 11: Comparison of compression strength between the specimens with different layer of E-glass fiber in quasi-static crushing

5. Conclusion

In this experimental work, a new cost-effective manufacturing process, MBACM was presented. Cylindrical composite tubes in this study were made of different layer of E-glass fiber and epoxy resin. A variety of mechanical tests was performed on the fabricated composite tubes and compression properties are presented in this paper. The mechanical properties increase from specimen with one layer of E-glass fiber to specimen with five layers of E-glass fiber. The specimen with five layers of E-glass fiber has the highest mechanical properties amongst all the tubes fabricated. However, it was observed that it has a flaw showed from the edge area of the fabricated tubes. The edge area of the fabricated tubes was observed that the edge area were not smooth for tubes with one layer of E-glass fiber to three layers of E-glass fiber. In comparison of the edge area of tubes with four layers and five layers of E-glass fiber, tubes of four layers of E-glass fiber has better surface of edge area. To sum it all, although specimen with five layers of E-glass fiber has the highest mechanical properties among all the tubes fabricated but four layers of E-glass fiber shows better aspect in edge area. In addition, tubes with four layers of E-glass fiber have second highest mechanical properties among all the tubes. Hence, the optimum option for fabricating a composite tube is with four layer of E-glass fiber. The proposed process was shown to produce composite cylinder in a more cost effective manner as a viable alternative to processes which are more expensive and complicated such as filament winding and pultrusion. For future studies the process can be used to fabricate more geometrically complex structural component using variety of prepreg and by modifying the bladder.

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