Journal of Materials Processing and Characterization 1(1), (2020) 14-21
DOI:
e-ISSN: 2716-1285, ISSN: 2714-9722

Tensile Strength of Carbon Fiber/Epoxy Composite Manufactured by the Bladder Compression Molding Method at Variable Pressure Levels

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Keywords
bladder compression moulding, epoxy, vacuum bagging.

Abstract

Composite materials uses have been increasingly ubiquitous due to their advantages, for example, in being strong, lightweight, and rust-resistant. Various composite manufacturing processes are designed to obtain composite products of better quality, including minimizing the number of pores or voids trapped within and increasing the fiber volume fraction until an optimal value is achieved. The method employed in this research was the bladder compression molding method, and the materials used were woven carbon fabric and epoxy matrix. According to previous research which used this method, the higher the pressure in the bladder, the better the product quality generated. The aim of this research was to investigate the effect of changes in the pressure level in the bladder (1, 2, 3, 4, 5, 6, 7, and 8 bar) on the mechanical properties of the composite produced. The test specimen was gained by cutting the composite product with a CNC router machine. The tensile test results indicate that the ultimate testing tensile strength was 604 MPa and that the optimal pressure in the bladder was 7 KPa. The conclusion of this research is that the composite product quality would increase with the progressive increase in the bladder pressure to the point of optimal pressure.

1 Introduction

Currently, uses of composite materials as alternatives to metal components in various equipment are omnipresent. This is inextricably linked to a number of important advantages of composite products over other preceding components. Composites' properties of being corrosion-resistant and strong but lightweight make them easy to be accepted as substituting components which increase their reinforced products' physical values (Callister Jr. and Rethwisch, 2014).

In general, composite fabrication is performed by combining reinforcing fiber and matrix. The constituents are applied one after another or as a mixture to the surfaces of a mold (Partridge, 2016). The requirement of a quality mold that ensures uniformity of the product's shape for repeated production processes puts composite fabrication into a relatively expensive category. Some prevailing composite fabrication processes are the result of constant upgrading carried out to obtain high-quality composite products and to achieve an increased efficiency to minimize the production cost. Each fabrication process has distinct advantages and disadvantages, both in terms of product quality (shape, surface quality, and mechanical properties) and in terms of process effectiveness and efficiency (process cycle time, energy need, and the impacts such fabrication process exerts on the environment).

The simplest composite fabrication processes generate products with relatively low fiber and resin density or relatively small fiber and matrix volume fractions (Partridge, 2016), for example, those using the hand lay-up and spray-up methods. The subsequent fabrication processes are developed in such a way that the composite products yielded have better quality. As such, the complexity of the processes and, at the same time, the costs for production also increase. Examples of such sophisticated methods include the vacuum bagging and autoclave methods.

It is also essential to pay attention to the bonding or joining of two composite-composed components. Often time, it is at this point that a construction design which involves composite materials is weak. Manufacturing of capsule-shaped objects for maritime and aviation purposes, for example, is often performed simply by joining two mold component pieces by gluing or riveting, while the water or air pressure such components receive is quite high. Risk of damage or leakage at the joint may lead to fatal consequences for the entire construction. The bladder molding composite fabrication method was developed for overcoming such problem, especially in meeting the need for composite products in jointless cylindrical shapes. Hi-tech products in the aviation field like unmanned aircrafts will find this method extremely helpful for their development. The bladder or balloon, which serves as the core of the mold, will be wrapped in the reinforcing fiber material along with the resin, then placed between two mold parts for the outer part formation. During the curing process, pressure is applied into the bladder to give better compactness to the composite product (Anderson and Altan, 2014). However, it has been hard to gain information regarding the ideal pressure needed to obtain a composite product with maximum density although such information will be very helpful for the composite fabrication process for specific purposes in the days to come.

This research, which employed the bladder molding method, was aimed to gain the optimum pressure value for the bladder and the ultimate strength of the composite products processed under this pressure.

2 Methodology

This research used twill weave carbon fiber fabric with weight per area of 240 g/m2 as the reinforcing fiber and bisphenol A-epichlorohydrin type epoxy resin mixed with cycloalipathic anine type EPH 55 epoxy hardener at 1:1 ratio as the matrix. A composite specimen was manufactured with the bladder molding method, aided with the hand lay-up method for the initial application of fiber and resin upon a pair of closed mold parts made from series 6 aluminum as shown in Figure 1.

Figure 1. Aluminum mold

Meanwhile, the bladder was manufactured from silicone rubber with RTV-blue catalyst as a hardening agent using the same mold before it is used for molding the composite.

All of the raw materials along with the technical data as listed in Table 1 (Li et al., 2015) were provided by the Mechanical Technology Laboratory, Department of Mechanical and Industrial Department, Universitas Gadjah Mada Yogyakarta, while the research was conducted at the Central Plastics Technology Laboratory, Politeknik ATMI Surakarta, using central compressor Ingersoll Rand type XK06-010-00512 at maximum pressure of 1 MPa.

Table 1. Fiber and matrix technical data

Technical data	Fiber	Matrix
Density [g/cm^3]	1.8	1.18
Tensile modulus [GPa]	18	3
Tensile stress [MPa]	4,900	67

The bladder was manufactured by mixing silicone rubber and the catalyst in a container at a weight ratio of 50:1, stirring the mixture well, then pouring it into the hole of each mold part. Over each pool was placed a piece of Styrofoam with a weight applied. Hence, after the curing process was complete, holey silicone rubber pieces were obtained (Figure 2).

The two bladder pieces were then glued together with a binder of the same material with an air tube previously fitted (Figure 3).

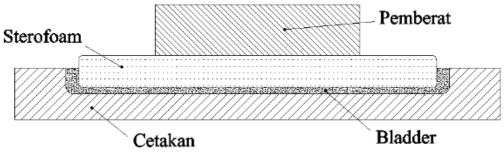

Figure 2. Bladder manufacturing

Figure 3. Bladder

The next step was preparing the fiber and matrix. The woven carbon was cut 170 x 325 mm2 in size, while the epoxy resin was mixed with the hardening solution in a container. The two mold parts were prepared near each other, then the cavities were smeared with wax for easy removal of the composite produced. Woven carbon was used for easy placement on the mold parts, especially for mold contour with an intricate shape (Hancock and Potter, 2006).

Resin was applied on the surface of the two mold parts over which wax was smeared, than one piece of woven carbon sheet was laid on each part. Resin was applied over the woven carbon sheet, and the next sheet was laid. This went on until there were six fiber layers on each mold cavity surface before finally concluded with resin smear. On the topmost layer was placed a perforated sheet of plastic (breather) which would let the excess resin flow from the composite arrangement. Then, a piece of white flannel fabric as the excess resin absorber was laid as a covering layer. The bladder was placed on the layers on the lower mold part, and the lower and upper mold parts, along with all of the filling layers, were closed together, causing the bladder to be sandwiched. The two mold parts were held together in place with 6 M12 imbush bolts. After the mold was clossed with bolts fastened, the air tube from the central compressor was connected to the air tube that run toward the bladder through a regulator as shown in the experimental setup in Figure 4.

Figure 4. Experimental setup

The air pressure from the XK06-010-00512 type Ingersoll Rand central compressor (Figure 5) was adjusted by the regulator, starting from p = 100 KPa. The process lasted for approximately 22 hours until the epoxy curing at room temperature was complete. The composite product was removed from the mold (Figure 6), which would be used for process repeats at different levels of pressure according to the data in Table 2.

Table 2. Variable pressures

Process Pressure		Process Pressure	
1	100 MPa	5	500 MPa
2	200 MPa	6	6`00 MPa
3	300 MPa	7	700 MPa
4	400 MPa	8	800 MPa

Figure 5. Central compressor

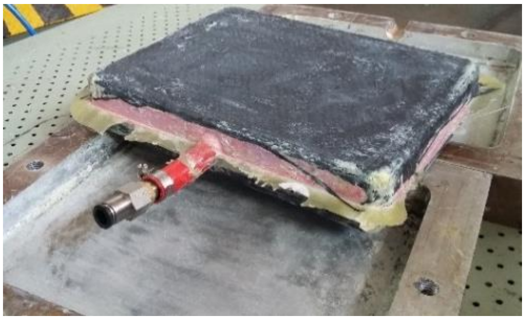

Figure 6. Composite produced

The composites produced were removed from the bladder and mold, then cut with an end mill cutter 4 mm in dimension for tensile testing using a CNC Router machine. From each composite piece produced at different bladder pressure, five tensile specimens were taken according to ASTM D638 in shape and dimension as shown in Figure 7.

Figure 7. Tensile Test Specimen

The specimens were tested using Universal Testing Machine Zwick Roell type N020 with maximum tensile strength of 20 kN (Figure 8) after measurement of the fracture section of each specimen using a 0.01-mm-accuracy 0–25 mm Mitutoyo outside micrometer.

The maximum stress values of the five tensile test specimens for each process were averaged and then compared with each other so that the optimum pressure value for the woven carbon fiber/epoxy resin composite manufacturing process by the bladder molding method as well as the maximum tensile strength of the product could be obtained.

Figure 8. Tensile test process

3 Results and Discussion

The tensile test results, including the maximum force required, tensile strength until point of fracture, tensile modulus, and fracture stress, are outlined in Table 3.

Table 3. Tensile test results

No.	Pressure [KPa]	Force [N]	σ_M [MPa]	E_T [GPa]	ε [%]	Thickness [mm]	Width [mm]	Area [mm^2]
1	100	12,078.49	435.457	51.422	0.89	2.26	12.25	27.74
2	200	11,298.39	500.027	47.691	1.05	1.81	12.53	22.65
3	300	13,190.27	500.144	41.756	1.20	2.12	12.49	26.46
4	400	11,892.40	510.582	41.226	1.24	1.86	12.50	23.29
5	500	10,950.81	493.169	41.153	1.20	1.77	12.59	22.24
6	600	10,748.90	457.273	41.652	1.10	1.86	12.63	23.55
7	700	12,816.77	604.948	56.290	1.08	1.69	12.53	21.20
8	800	11,550.51	520.817	44.172	1.18	1.78	12.51	22.29

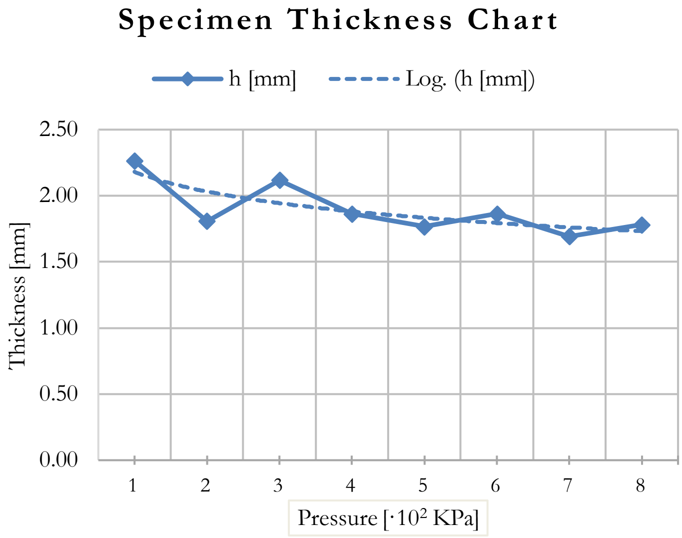

Figure 9. Specimen thickness chart

Table 3 shows that the higher the pressure was exerted to the bladder, the lower the thickness of the composite products (Anderson, et al., 2013). The trend line logarithmically presented in Figure 9 provides an illustration for that trend. The flannel fabric placed between the perforated plastic (breather) and the bladder functioned well. The bladder's pressure forced the excess resin out from between the woven carbon fabric layers through the small holes of the breather. The excess resin was absorbed well by the flannel fabric. Thus, after the completion of the process, the bladder looked as though wrapped in a film. This film was the resin-absorbing flannel fabric which indirectly protected the bladder against the sharp edges of the tools used to remove the composite product from the mold cavities. Besides, the ring set between the mold parts when closed kept a space between the mold surfaces, giving a room for the excess resin unabsorbed by the flannel fabric to flow. The excess resin that was unabsorbed by the flannel fabric dried during the curing process on the mold surfaces, making it easy for removal.

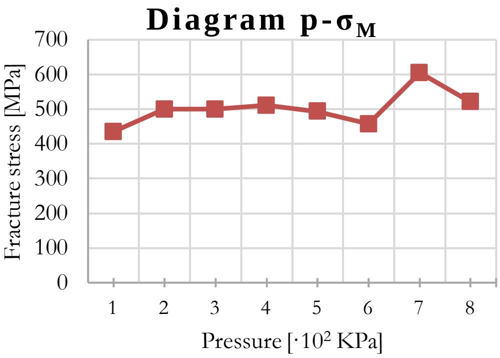

Figure 10. Pressure-fracture stress chart

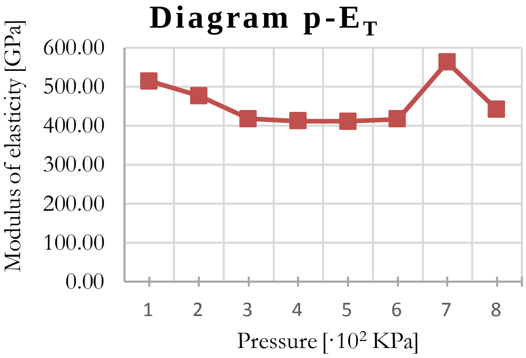

Figure 11. Pressure-tensile modulus chart

The values of fracture stress compared to the bladder pressure during the tensile test in respective units (pressure in KPa, fracture stress in MPa) are shown in Figure 10. It can be observed that the specimens' fracture stress values would increase if the bladder pressure levels also increased. Thus, the maximum fracture stress value of 604.948 MPa was reached at bladder pressure of 700 KPa. The fracture stress values at bladder pressure levels 500 KPa, 600 KPa, and 800 KPa were outside the expectation area. This was presumably caused by the difference in thickness and stiffness of the woven carbon fiber materials used in this research, which was accepted in several deliveries, as shown in Figure 12. Another possible cause was that the area of the flannel fabric prepared for absorbing the excess resin differed from process to process and from process level to another.

Figure 12. Difference in stiffness and thickness between pieces of woven carbon fabric

The same was the case in the tensile modulus. As can be observed in Figure 11, the tensile modulus values (in MPa) were compared to the bladder pressure levels (in KPa). At bladder pressure 70 KPa, the tensile modulus reached the highest value, namely 562.9·102 MPa. This value is higher than when the bladder pressure was at 800 KPa. In this case, the difference in the stiffness of the raw materials, especially woven carbon fiber, tended to have a significant effect (Gibson, 2012).

4 Conclusion

From this research, a number of conclusions were drawn:

1. The maximum fracture stress value of the composite material produced using the bladder compression molding was 604.948 MPa, which was reached at bladder pressure 700 KPa.
2. The maximum tensile fracture value of the composite material produced using the same method was 56.29 GPa, also at bladder pressure 700 KPa.
3. The composite material produced would tend to be thinner when the bladder pressure also increased, with the potential of decreased resin content or increased fiber volume fraction in the composite.
4. A further study with bending and density tests on the composite manufactured by this method is deemed necessary to gain more detailed information regarding the mechanical properties of the composite.

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