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Mechanical Properties of Liquid and Solid Repaired on Damaged Model of Glass Fiber-Reinforced Polymer Composites

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Abstract

This study has investigated the effect of repair method on mechanical properties of Glass Fiber-Reinforced Polymers (GFRP). Composite materials are primarily damaged by mechanical loads. In this study, a damaged composite was repaired by liquid filling and solid filling methods. The damaged composite was modeled by drilled composites specimen with 5 mm drill. The specimen than repaired in the form of the same fluid and solid mixture of epoxy resin composite. The tensile and impact properties of damaged and repaired composites were observed. The results show the increase of tensile and impact strength in each additional glass fiber in both liquid and solid repair. Also, solid repair data show the better and the increase of tensile and impact strength than the liquid repair. They are 23, 40 and 46 MPa for tensile strength of solid repair with 10%, 20% and 30% of additional glass-fiber respectively. Moreover, the impact strength data of solid repair show 0.86, 1.00 and 1.99 J/mm^2 with 10%, 20% and 30% of additional glass fiber respectively. Fractography study shows the fracture of Repaired Solid Hollow Glass-Fiber Reinforced Polymers (RSHGFRP) 30% composite located in the circle of repaired area. Solid repair shows higher mechanical properties than liquid repair.

Keywords: impact strength; liquid repair; solid repair; tensile strength; GFRP.

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1. Introduction

Polymer-Matrix Composites (PMC) has been known as the highest application of composites in everyday life. It consists of polymer resin as its matrix and fiber as its reinforcement. It is light, widely used quantities, easy of fabrication and less cost. Glass Fiber-Reinforced Polymer (GFRP) has been used as the replacement of metals in many industries application due to the formability, availability, mechanical properties and less corrosive properties [1]. Mechanical load and/or environmental conditions can damage composite. Cyclic load and impacted conditions can cause damage in fiber reinforced composites. Damage occurs in various forms such as matrix cracking, fiber/matrix debonding, surface micro buckling, delamination and fiber breakage. It can also yield the different forms of damage that affect the various laminate properties to different degrees [2]. It provides stress concentration and/or reduces the mechanical properties of composites [3]. It has become the prior damage to the ultimate failure of laminated fiber reinforced composites. Damages or cracks have to be repaired in order to avoid their propagation and catastrophic failure. The damage and/or crack in composites can be diminished from the composites by reparation on the damaged area [4]. There are two choices to tackle this problem, repaired the damaged area or replaced the component. Replacing the damaged component is not recommended when it comes to the big size of the component and of high level of integration. Therefore, the repair technique is a viable solution. The restoration of damaged areas must pay attention to some factors, for instance, the damaged location, thickness, aerodynamics requirements, operation conditions, such as pressure; temperature; and moisture, weight, mechanical property requirements and the damaged area or extent damage [5,6]. Adhesive bonding can use to repair of the damaged area of composite. The external patch is considered to be a temporary solution in order to keep the part in use. One of the issues of using this technique is the decision of the size of the patch. If the length and thickness of the patch is overlap or the length of the bond is too short, the entire adhesive layer suffers from high shear stress [6]. Unfortunately, it is complicated in designing suitable geometry such as length, size and thickness as well as surface preparation. The damaged area can be filled with liquid filling. This filling will flow into the crack area and filled the whole area to restore the connection between the defective materials. Resin is commonly used as the healing agent. Additionally, the addition of fiber-glass concentration increases the tensile strength, impact strength and flexural strength [5-10]. Damaged composite can be repaired by scarfing repair and injection repair. Scarfing repair requires the removal of the damaged area. A repair patch is inserted into the parent material. The patch can either come in the form of a hard or soft patch. The injection repair method has been done by injected of resin into the damaged composite part [11]. The damaged composite plates can be repaired by external circular patches. The performance of repaired composites under tensile loading depends on patch inplane stiffness and the patch stacking sequence (i.e. fiber orientation of the layer adjacent) [12]. The repair of damaged composite by adhesive bonding offers a better load transfer compared with mechanical fastening methods. Step/scarf joints repaired methods produce higher mechanical properties on damaged laminated composite [13]. Localized damage of composite can be repaired by cut and disposed of defective composite then patch the hole of the damaged area. The aim of this paper is to investigate the effect of repair damaged of glass fiber reinforced polymer (GFRP) by liquid and solid filling on tensile and impact strength of GRFP. The experimental procedure modeled of GFRP damaged with drilled GFRP specimen. It provides hollow GFRP by drilling the parent material on the center of specimens to produce Hollow Glass Fiber Reinforced Polymer (HGFRP). HGFRP is repaired by liquid filling made of epoxy resin and the same amount of glass fiber and by solid filling of the same composition of parent material was glued by epoxy resin.

2. Materials and Methods

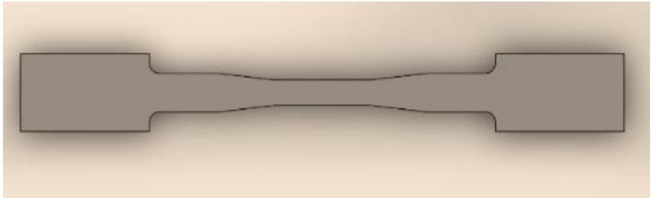
Yukalac 157 BQTN-EX epoxy-resin and fiberglass mat were used as matrix and reinforced of GFRP respectively. Glass fiber reinforced composites with a variation of % wt. fiber: 0 %, 10%, 20% and 30 were made by hand lay-up method and pressed. Wet disk cutting and CNC machining were conducted on composite plates to produced specimen tests. The dimension of tensile and impact specimens are prepared based on ASTM D 638 and ASTM D 6110 respectively. Damaged of composite material is modeled by drilled of each specimen at the center of the specimen with 5 mm drill as illustrated in **Figure 1.a** and **Figure 1.b**. The drilled epoxy resin and GFRP specimens are called Hollow Epoxy Resin (ER) and Hollow Glass Fiber Reinforced Polymer % wt. (HGFRP % wt) respectively. HER and HGFRP (10%, 20% and 30%) are repaired by 2 variation methods: liquid filling and solid filling. The liquid filling was done by mix epoxy resin with fiberglass, % wt. of fiberglass in the mixture fit with % wt. damaged composite. The blend of epoxy resin with 10%, 20%, 30 % additional glass fiber were filled the hollow of HGFRP 10%, 20% and 30% specimens. The solid filling method performed by make composite with % wt. fiberglass match with the damaged composite. The composite was cut and machined to make patch that fit with hollow. The dimension of patch is 10 % less than dimension of hollow. The patch filled into the hole and glued with epoxy resin. Named and description of variation of hole and repaired shows in **Table 1**.

Table 1: Name and description of variation GFRP and repaired composite

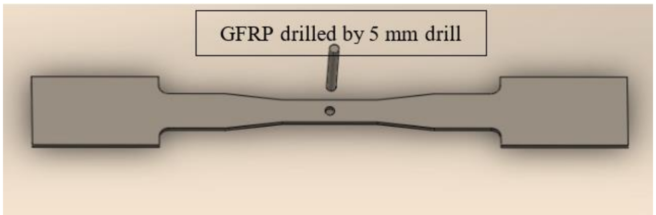
No	Description specimen	code
1	Epoxy resin, 0 % wt. glass fiber	ER
2.	Drilled epoxy-resin 0 % wt. glass fiber	HER
3.	Drilled epoxy-resin 0 % wt. glass fiber repaired by liquid filling	RLHER
4.	Drilled epoxy-resin 0 % wt. glass fiber repaired by solid filling	RSHER
5.	Glass Fiber Reinforced Polymer, 10 % wt. glass fiber	GFRP 10 %
6.	Drilled Glass Fiber Reinforced Polymer, 10 % wt. glass fiber	HGFRP 10 %
7.	Drilled Glass Fiber Reinforced Polymer, 10 % wt. glass fiber repaired by liquid filling	RLHGFRP 10 %
8.	Drilled Glass Fiber Reinforced Polymer, 10 % wt. glass fiber repaired by solid filling	RSHGFRP 10 %
9.	Glass Fiber Reinforced Polymer, 20 % wt. glass fiber	GFRP 20 %
10.	Drilled Glass Fiber Reinforced Polymer, 20 % wt. glass fiber	HGFRP 20 %
11.	Drilled Glass Fiber Reinforced Polymer, 20 % wt. glass fiber repaired by liquid filling	RLHGFRP 20 %
12	Drilled Glass Fiber Reinforced Polymer, 20 % wt. glass fiber repaired by solid filling	RSHGFRP 20 %
13.	Glass Fiber Reinforced Polymer, 30 % wt. glass fiber	GFRP 30 %
14.	Drilled Glass Fiber Reinforced Polymer, 30 % wt. glass fiber	HGFRP 30 %
15.	Drilled Glass Fiber Reinforced Polymer, 30 % wt. glass fiber repaired by liquid filling	RLHGFRP 30 %
16.	Drilled Glass Fiber Reinforced Polymer, 30 % wt. glass fiber repaired by solid filling	RSHGFRP 30 %

The illustration of solid repair process is depicted in **Figure 2.** Tensile and impact specimens are prepared based on ASTM D 638 and ASTM D 6110 shown in **Figure 2 and Figure 3**. There are 6 specimens for each variation.

Those specimens are tested by tensile test machine and Charpy impact test machine. Macrophotograph tests were carried out to evaluate fractographic images of tensile and impact tested specimens.



a. Tensile test specimens of GFRP



b. Modeled damaged composite (HGFRP)

Figure 1: Tensile specimen of composite and damage model

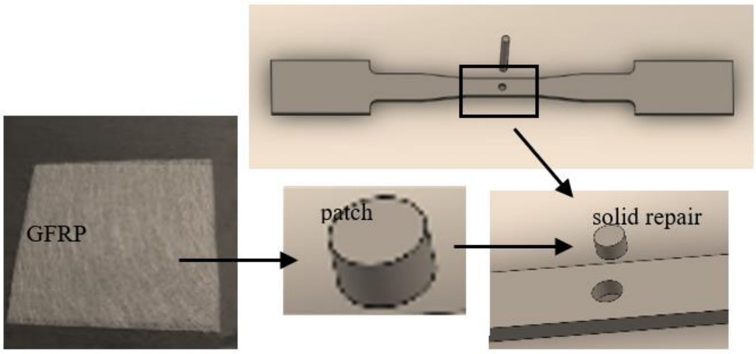


Figure 2: Solid repair of damage model composite

3. Results and Discussions

The tensile test of specimens was shown in **Figure 3.** It indicates that there is a decrease of tensile strength after the ER, GFRP 10%, GFRP 20%, and GFRP 30% were damaged. Decreases of tensile strength are lesser than what happens to ER specimen. It indicates that the additional glass fiber plays a role in supporting the tensile properties. It can be seen that adding glass fiber increases the tensile strength. The damaged specimens were repaired by liquid filling (RL). The results show that tensile strength increases along with the liquid repaired procedure even though it is not a significant increase. RL specimens' tensile strengths are higher than the damaged (HGFRP) and undamaged specimens (GFRP) but it does not show the same pattern for ER specimens that cannot achieve the value of undamaged ER. Tensile strengths of repaired by solid filling (RS) specimens soar up. They double from the value of HGFRP specimens except for HER specimens that cannot even reach a half of ER tensile strength. Tensile strength increments are clearly seen in the added glass fiber specimens. RSHGFRP 20% and RSHGFRP 30% escalate into twice value of HGFRP 20% and HGFRP 30%. Similarly, they reached two times of GFRP 20% and GFRP 30%. In conclusion, the tensile strength of solid repair is higher than the liquid repair. RSHGFRP with 30% addition of glass fiber proves the highest tensile strength about 46 MPa. The higher amount of glass fiber grows up tensile strength [6-9] regardless of undamaged, damaged, repaired by liquid filling and repaired by solid filling treatments.

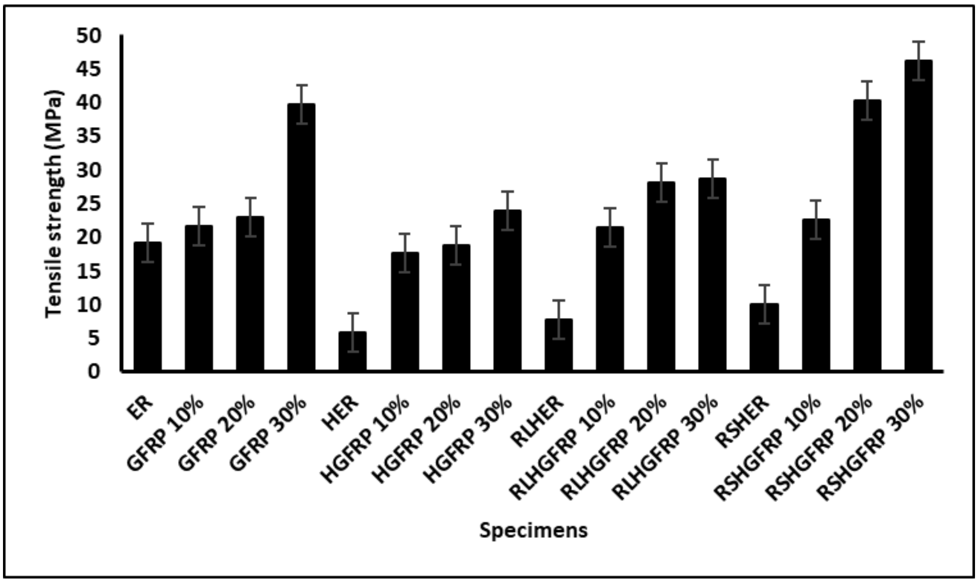


Figure 3: Tensile Strength of Composites, Damage model composites and Repaired Composites

The impact strength of composites is expressed in **Figure 4**. Impact strength reduces when the specimens damaged (hollow models). The reduction of impact strength is about 30% from undamaged composites. The hollow area suffers from stress concentration which declines impact strength on each material. Damaged repaired by liquid filling (RL) shows rise of impact strength on RLHER. It reaches the above value of the undrilled (RE) specimen. The Liquid filling (RL) on HGFRP 10 %, HGFRP 20%, and HGFRP 30% improves impact strength minimally. It goes the same with the repaired by solid filling (RS) specimens. Unlike solid filling repair on HGFRP, impact strength on solid repair of HER goes up slowly and shows a lower value than the liquid repair. The impact strength of solid repair is considered better than the liquid repair but it cannot be applied to HER. Due the transfer stress from matrix to the glass fiber, tensile strength of composites increases. The increasing weight fraction of glass fiber rises the impact strength of composite [6-8]. This study discovered 2 patterns of fracture on repaired tensile test and impact test as shown in **Figure 5** and **Figure 6** respectively. Fracture through holes was observed in HER specimens and RLHGFRP 10%, RLHGFRP 20%, and RLHGFRP 30%. It happened by the stress concentration in the hole area of the HER specimen and repaired area by liquid filling of HGFRP where the adhesion between the fiber and matrices is less strong. Consequently, stress concentration occurs in this area in the transverse direction [5]. The fracture at surrounding the repaired area was detected in RSHGFRP 10%, RSHGFRP 20%, and RSHGFRP 30% specimens. The pattern is not affected by the addition of glass fiber percentage. However, it is indicated that crack propagation is on the resin area of solid filling on the hollow specimens (HER and HGFRP). The propagation of cracks in this area is due to the fact that between parent material and repair material is attached only to epoxy resin which functions as a healing agent [3]. This epoxy resin fills empty holes which are initially occupied by fiber and pulled out due to the process of damage. The crack propagation is estimated to start from this area and propagates in the same position so that fracture formed around the repaired area.

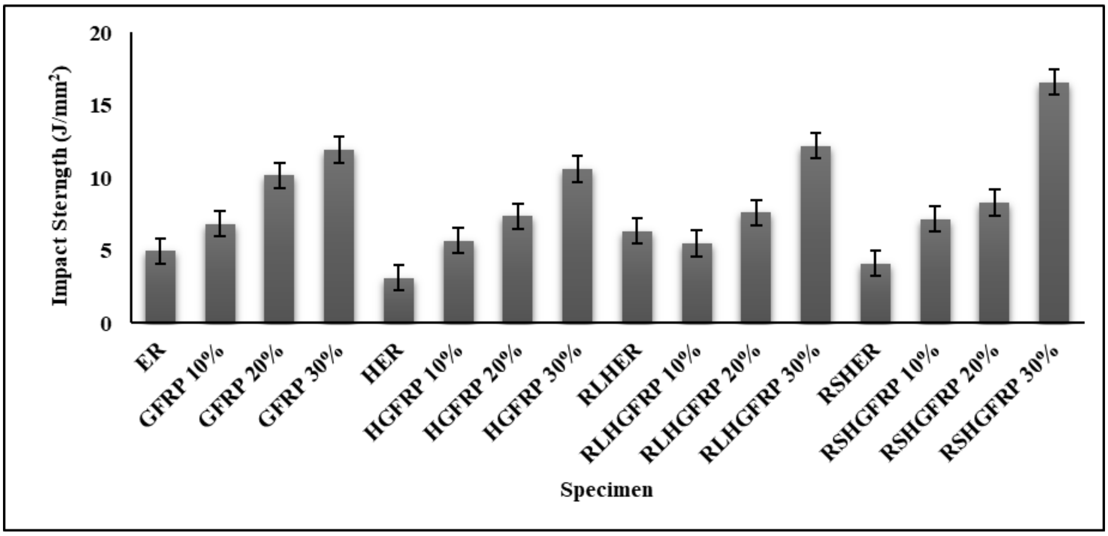


Figure 4: Impact Strength of Composites, Damage model composites and Repaired Composites

In addition, patterns of impact tests were found in 2 places. Firstly, fracture passing through the middle of the repaired hole were commonly found in the HER, RLHER, RLHGFRP specimens that allow the method of liquid filling. The bond between fiber and matrices is less strong so that stress concentration occurs in this area [5]. While the fracture surrounding the repaired hole was found in RSHER and RSHGFRP specimens. Similar to tensile test specimens, the crack propagates in this area because of the parent material with the solid filling is adhered only by epoxy resin. The epoxy resin bonds empty holes that were initially occupied by fiber and the fiber were pulled out because of the drilling process. The crack propagation is initially started in this area and grows in the same position. As a result, fracture bordering the solid repaired area cannot be denied [3].

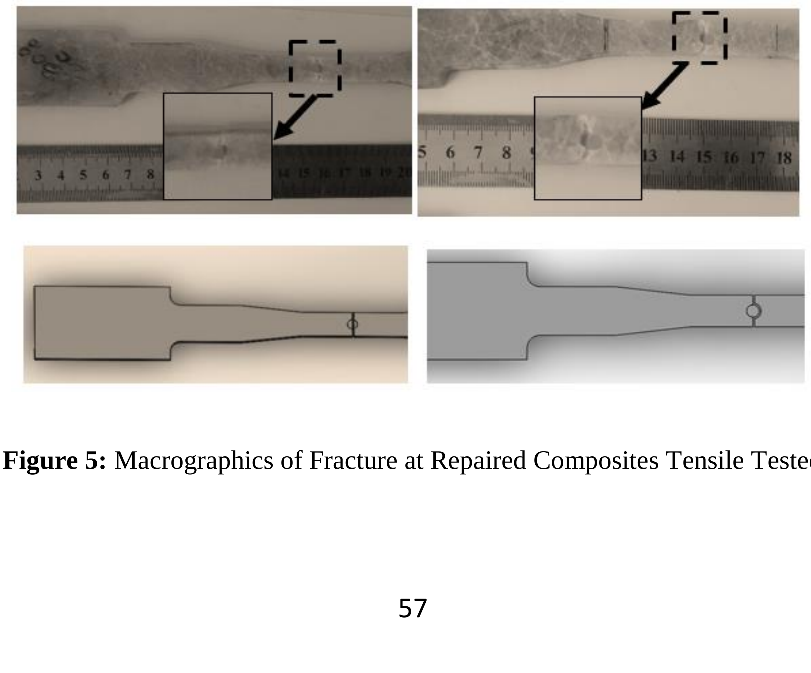


Figure 5: Macrographics of Fracture at Repaired Composites Tensile Tested

Figure 6: Macrophotograph of Fracture at Repaired Composites Impact Tested

4. Recommendations

The results showed that the damaged composite could be repaired by removing the damaged area and patching it. The hole patching can be conducted by liquid filling made of epoxy resin and the same amount of glass fiber and by solid filling of the same composition of parent material was glued by epoxy resin. the solid filling method provides a higher tensile and impact strength compared to the liquid filling method. For further research, it is recommended to examine variations in the hole size and thickness of the damaged area composite.

5. Conclusions

Comparing the result of repaired procedures, it can be concluded that:

1. The process of damaging/treating holes in HER and HGFRP specimens show a sharp decrease in tensile strength and 30 % decrease of impact strength on the undamaged specimens of ER and GFRP.

2. Along with the repaired by liquid and solid filling process (RL and RS) in the HER and HGFRP, it shows an increase in tensile and impacts strength. The significant increase is found on solid filing (RS) and it exceeds the tensile and impact strength of ER specimens at GFRP 30%.

3. The addition of glass fiber to the epoxy resin material will increase 2 times of its tensile and impact strength in compare between GFRP 30% and ER specimens

4. In the tensile and impact test, it was found 2 patterns of fracture: fracture through the repaired area is found in HER specimens and RLHGFRP 10%, 20%, and 30%. The fracture circling the repaired hole is found in RSHGFRP specimens 10%, 20%, and 30%.

5. The fracture pattern is not affected by the addition of glass fiber percentage. However, fractures are caused more by the different methods of repairing hollow specimens by liquid and solid filling in HER and HGFRP. This analysis is also supported by SEM testing on ER specimens and RSHGFRP 30%. The fracture in the ER specimen shows brittle fracture and large void appears as the origin of the crack. Whereas, in RSHGFRP 30% specimen shows no void and attaching epoxy resin as a sticking media between solid filling and parent

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