

Hole Introduction Effect on The E-Glass WR 185 Fibre Reinforcement Polyester

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Abstract. Challenge to use a light structural material for aero vehicle could be answered by fibre reinforced polymer composite. This composite has high ratio of strength to weight. In application this composite should be in mechanical assembling such as bolt. So that, investigation of hole introduction on the composite integrity and behaviours are needed. In this study, E-glass WR 185 fibres used as reinforcement in polyester BQIN EX 157 matrix. The composite made by hand lay-up methods; in which 13 layers of E-glass fibres were laminated one by one layer with polyester resin. After dried up, composite was cut off to made specimen for density, tensile and compression test. Some of tensile and compression specimens were drilled (marked as “open hole specimen”) in their centre. The result showed density of 1.12 g/cm³, maximum strength of 178 MPa (tensile) and 130 MPa (compressive). Introducing an open hole reduced strength to 119 MPa (tensile, decreased ~33%), and to 112 MPa (compressive, ~14%). Reducing strength is well confirmed with change of failure type; from lateral at grip top (LAT) to lateral gage middle (LGM). LGM of the open hole specimen means crack starting from the hole to both of lateral direction.

Keywords: polymer, composite, reinforcement, fibre, polyester resin

1. Introduction

Global warming due to change in earth atmosphere especially in ozone. The ozone breakdown is triggered by glass house gasses likes CO and CO₂. There are many sources of the gasses in the atmosphere likes forest firing, coal and gasoline vehicles [1]. Environment saving articles demand as low as gas emission from the vehicle. That could be achieved through higher efficiency of petroleum, and weight reducing of the vehicles. Mechanically, weight reducing should be with no or less sacrifice on mechanical properties of vehicle material. Introducing lightweight metal or composite material might satisfy the requirement. Among them, composite seemed more flexible in physical and mechanical properties [2] and kind of green or recyclable material [3]. So that composite be more familiar in some structural purposes' material like in aero plane vehicles.

CFRP, a carbon fibre polymer composite can be found in aeroplane body or in unmanned aircraft vehicle, UAV. The lighter body of vehicle means longer travel time and more covered area can be achieved. UAV or drone is useful to surveillance purposes likes mapping of forest, farming and disaster mitigation [4]. In polymer matrix composite, lightweight refer to polymer-based matrix, in which mechanical strength source from fibre material and bounding between fibre and matrix [2]. Fibre material usually made from carbon, Kevlar, or ceramic material such as fibre glass. E-glass fibre is widely used because high mechanical strength, and good insulator. Polyester has good dimension



stability, and high modulus that comparable to epoxy. Both of these two materials are easily to find in our national market. In this study, e-glass fibre namely WR 185 introduced into matrix of polyester resin. In our previous study, 40% volume of WR185 in polyester matrix provides best mechanicals performance in the composite. This work tries to understand the composite characteristics when open hole presence. That may be useful information prior to applied for floating material of small amphibian aircraft vehicle.

2. Methodology

2.1. Material and specimen

Composite was made from polyester resin and e-glass fibre. A woven fabric e-glass fibre WR 185 with thickness of 0.11 mm was cut off in size of 400 x 450 mm. ASTM standard demand composite thickness of 3.5 mm. Fibre volume fraction of 40% means 0.4 of total composite thickness is thickness of the fibres (1.4 mm). So that, one composite needs 13 plies of e-glass fibre in total. The other part of composite was occupied by unsaturated polyester resin Yukalac BQIN-EX 157. In order to accelerated curing of resin, certain volume of catalyst was added, in ratio of 1:100, then manual stirred for about 45 minutes or till homogenous mix.

Making of composite was started with introduced wax on bottom surface (glass material) of die, to prevent resin sticking. Followed by introducing a layer of resin with brush, and one sheet e-glass fibre was carefully put on resin, then flattened with touch up method to ensure resin filled the pores of the fibre. It is one set of resin and e-glass fibre. For the next set, a layer of resin followed with a sheet fibre again. In total, one composite panel has 13 layers of fibre and 14 layers of resin. Last layer of fibre was covered with a last thin layer of resin as well as first layer of resin. Fully dried up composite had achieved after 24 hours. Then composite surface was mechanically smoothed with sand paper to remove some surface defects and to achieved thickness of 3.5 mm.

Specimen for density, tensile and compressive test was machined cut off from the composite plate. Density testing specimen has dimension of 10x10 mm² with composite thickness. Density test was repeated for 10 times. Tensile testing specimen was made according ASTM D3039; with total length of 250 mm, width of 25 mm and thickness of accordingly to composite. The compressive testing specimen made according to ASTM D6641; total length of 140 mm, and width of 13 mm. Both of testing and compressive specimen is rectangular shape material.

Half of tensile and compressive specimens were drilled to get an open hole. As above explanation, joining composite by bolt will results an open hole on composite. This study investigated effect of an open hole on the composite. According ASTM, ratio of width-to-diameter should be equal to 6. So that, tensile and compressive test specimen would have hole diameter of ~4 mm (25/6) and ~2 mm (13/6), respectively.

2.2. Experimental

Measuring density was conducting 10 times using densitometer machine. Specimen was weighed before and during immersion in water that put on the plate of densitometer. Condition for density test are at room temperature 24.5°C and relative humidity of 38.8%. Tensile testing conducted on UTM Tensilon RTF-2410 with condition of travel speed of 2 mm/min, at room temperature of 22 ± 2°C and relative humidity of 47 ± 10 %. Compressive testing also on UTM Tensilon with condition equal to tensile testing. Setting for compressive test is shown in Figure 1. All the mechanical tests were done for 7 times.

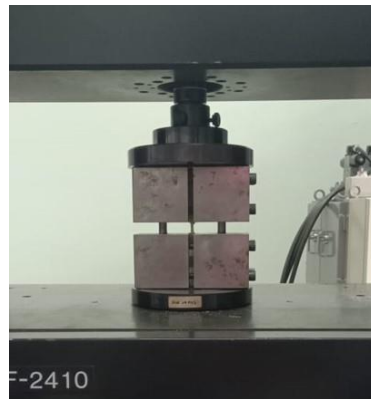


Figure 1. Setting for a compressive test.

3. Results and Discussion

Densitometer showed density of the composite on its monitor at the end of testing. Density of specimen varied from 0.94–1.62 g/cm³, with average of 1.12 g/cm³. This value is less than GFRP WR 185 laminates with lycal resin that reported by K Abdurrohman et al [5]. This value is also less than density of lightweight metal that widely use in aero industry such as aluminium alloy (~2.7 g/cm³) or magnesium alloy (~1.7 g/cm³). However, variety of value density implies that hand lay-up technique is not quite good to result homogenous composite.

Tensile strength of composite decreased with introduction of hole at centre of specimen as shown in Figure 2. With no hole composite has tensile strength in average of 178 MPa, meanwhile with open hole specimen only provided tensile strength of 119 MPa. These value is lower than reported by Ilhamdi et al with stacking sequence 0°, 90°, 0° [6], but higher than reported by S.M. Kumar et al [7]. By number, introducing hole at the centre of specimen had weakened composite about 33%, lost strength about 59 MPa.

Other tensile parameter is strain at failure that showed in Figure 3. Tensile strain of no hole composite varied from 3.48% to 4.79%, while open hole composite has 2.68% to 3.64%. Different among 7 repetitions is quite closed each other, implies that composite has good homogeneity in tensile strain. No hole composites seemed have higher strain compare to open hole ones. However, the different between these two kind composite is about 1% in average, 4.2% of no hole composite and 3.2% of open hole composite.

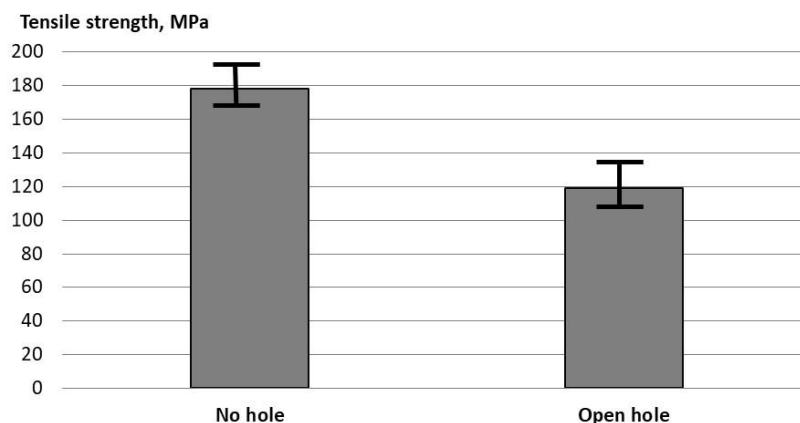


Figure 2. Tensile strength of the composite.

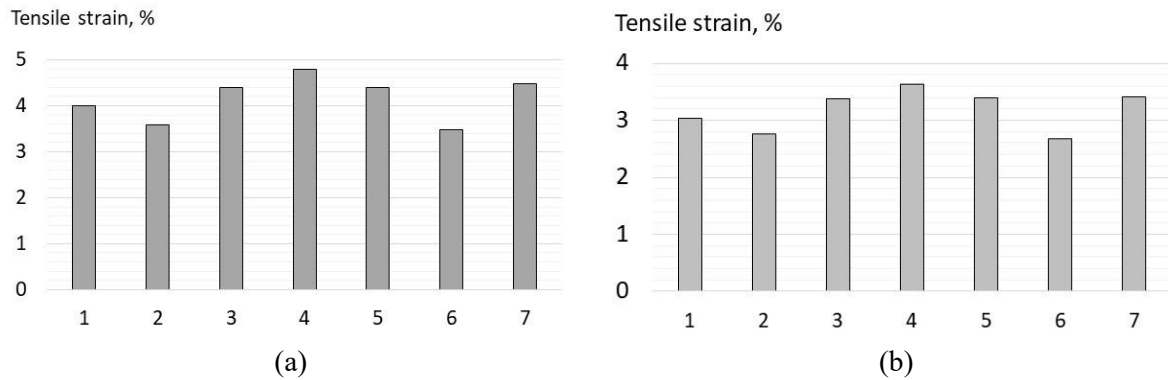


Figure 3. Tensile strain of composite for 7 repetition test; (a) no hole, (b) open hole.

Note: Horizontal dash line is average value.

Compressive strength of composite also decreased with introduction of open hole at centre of specimen as shown in Figure 4. In average, compressive strength reduced from 136 MPa to 119 MPa. These value is much lower than reported by Ilhamdi et. al. [6] and M Tanoglu et. al. [8] that used ply-lay up in plane direction technique in making composite. Introducing hole weakened composite about 12%, lost compressive strength about 17 MPa. Deviation in compressive strength is larger than tensile strength. But, coincidentally minimum compressive strength both of two condition composite is rather equal at 106 MPa. Other impact of open hole introduction on composite is enabling composite achieved more deformation during compressive test i.e. compressive strain increased almost two times from 0.75% to 1.13%, as shown in Figure 5. Empty area in hole might allow composite deformed larger before broken.

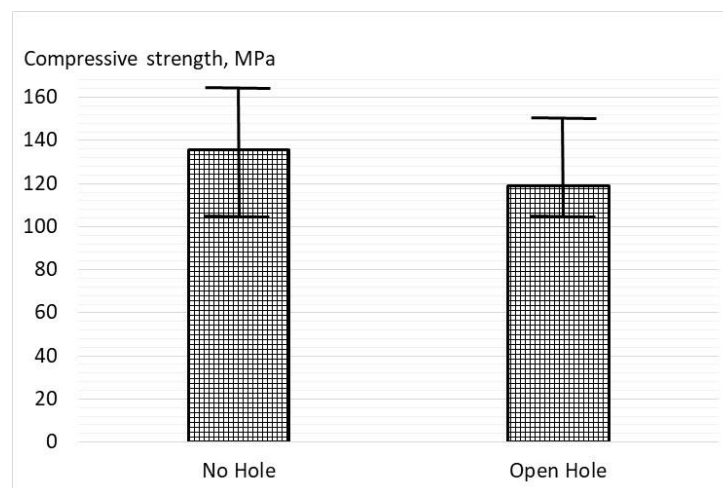


Figure 4. Compressive strength of the composite.

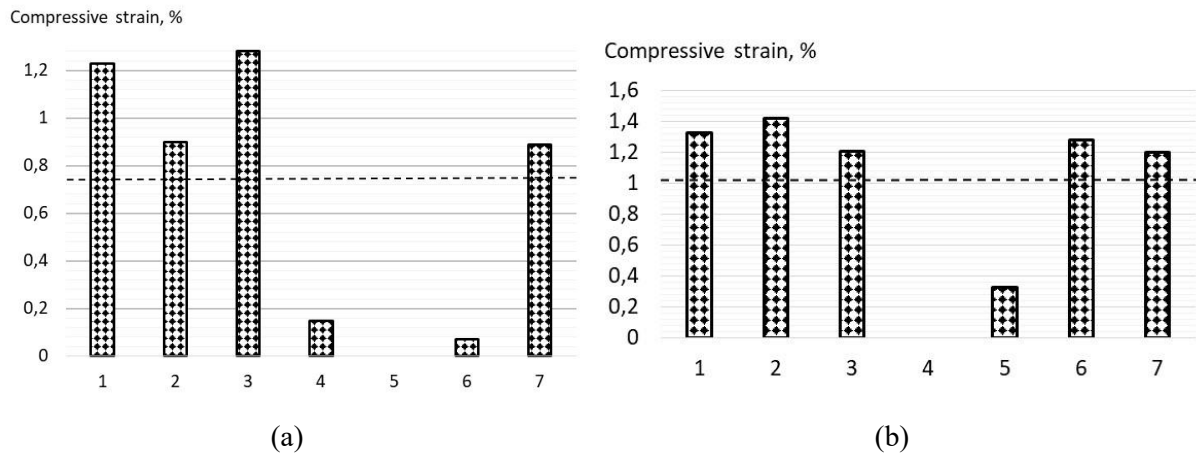


Figure 5. Compressive strain of the composite for 7 repetition test; (a) no hole, (b) open hole. Note: specimen number 5 of (a) and 4 of (b) are failed. Horizontal dash line is average value

Introduction of hole on the composite also change failure mode tensile testing specimen, as shown in Figure 6. According to ASTM, no hole specimen revealed lateral at grip top (LAT) failure mode, where fracture happened at the end of examination area that closed to grip. Total different failure mode presence on open hole specimen in which fracture lines cross the hole geometry. It is known as lateral gage middle (LGM). Both of specimen condition showed pull out fibres from their matrix.

The same failure modes also revealed on compressive testing specimens with identical condition as shown in Figure 7. No hole specimen of compressive test showed LAT mode while open hole compressive test had LGM mode. The only difference compressive specimen from tensile specimen is no pull out fibre was exposed after testing. Fracture line on compressive test was marked as blur-like grey line in examination area.

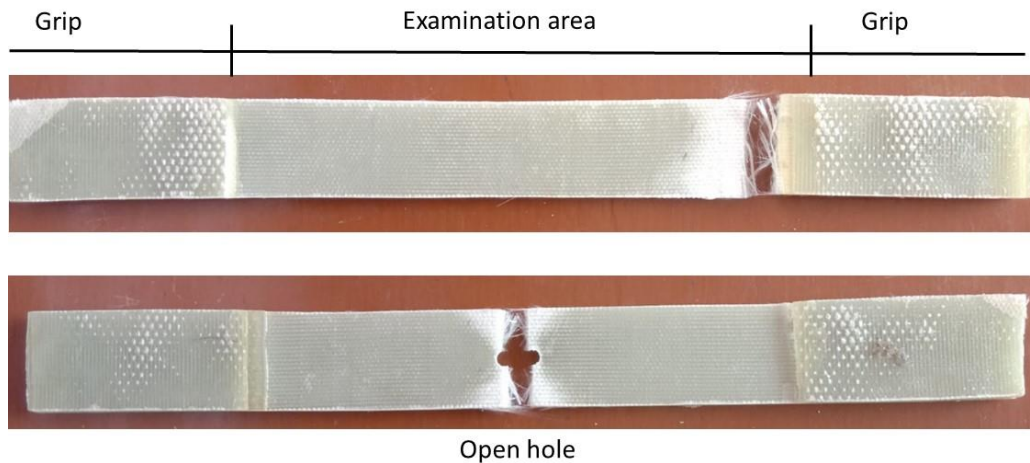


Figure 6. Fracture appearance of tensile test specimen; (above) no hole, (below) open hole.

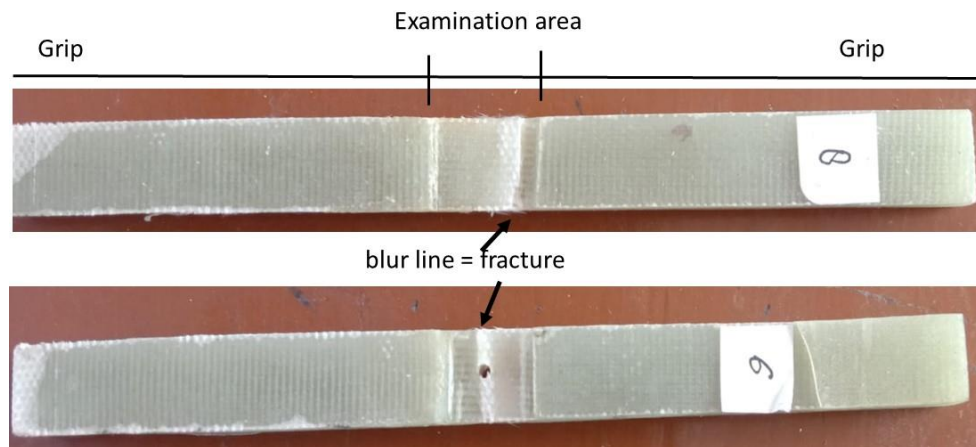


Figure 7. Fracture appearance of compressive test specimen; (above) no hole, (below) open hole.

Effect of open hole introduction at centre of composite could be resumed in Table 1. Open hole change fracture behaviour of composite from lateral at top grip into lateral gage middle. This change might be enabled by fact that hole reduces actual solid cross section area of the specimen. So that, when equal applied force with no hole specimen occurred, specimen will experience higher stress. However, results showed that tensile stress of open hole specimen is lower than of no hole specimen. It is should be another reason for this change.

Table 1. Results resume of open hole effect on composite.

	UTS	TS	UCS	CS	TFM	CFM
No hole	178	4.2	136	0.75	LAT	LAT
Open hole	119	3.2	119	1.13	LGM	LGM

Note: UTS = ultimate tensile strength, MPa. TS = tensile strain, %. UCS = ultimate compressive strength, MPa. CS = compressive strain, %. TFM = tensile failure mode. CFM = compressive failure mode

Hole in the composite could be treated as geometry defect. Because hole made by drilling on composite. The material flow could be said break off by that cutting process, and no change in mechanical strength by deformation. Fortunately, circle shape of hole made no stress concentration around. However, when external tensile force applied on composite, tensile stress will raise. When stress conquer a local yield strength, a little plastic deformation will be promoted at two ends of hole. This deformation made hole change from defect to crack starter, that also induced stress concentration increasing [6]. Further applied stress will open crack at the two ends of hole, then crack propagated perpendicular to applied stress direction, as indicated in Figure 6. It is seemed that crack that started from open hole is easier to nucleated than specimen with no hole. It is reasonable for failure mode change. It became clear that not smaller area that made hole dangerous for structure integrity, but when hole experienced small plastic formation does.

4. Conclusions

Polyester resin e-glass fibre (40% vol.) reinforced composite is a kind of lightweight material with density of 1.12 g/cm³. This value is much smaller than lightweight metal alloys such as aluminium or magnesium base. Introducing open hole has negative effect on mechanical properties of composite; reduced tensile strength, tensile strain and compressive strength, but increased compressive strain. Tensile strength significantly dropped from 178 MPa to 119 MPa, weakened about 33%. Tensile strain is only reduced about 1%, dropped from 4.2% to 3.2%. Compressive strength dropped from 136 MPa to 119 MPa, weakened about 12%. Existence of hole enables a larger compressive strain, up to 1.31%.

Open hole existence made a total change in nature of composite fracture. When no hole happened on the specimen of tensile and compressive, LAT mode failure always occurred. But, open hole would have resulted LGM failure mode on these two tests. Tensile and compressive fracture could be easily distinguished by exposed pull out fibre on tensile and grey blur line fracture on compressive, respectively.

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