



Tensile Properties of Scarf Method GFRP Composite Repair using Hand Lay-Up and Vacuum Bagging Process

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Abstract. The use of composite materials in a structure needs to be followed by a repair method in case damage occurs in the structure. The standard methods for repairing glass fiber reinforced composite in aircraft structures is mentioned in the AC 43.13-1B document. One of them is the scarf method, which is a composite repair method by making a scarf side connection between the base material and the patch. In this study, the repair process is carried out using two techniques, hand lay-up and vacuum bagging. The comparison of strength between the repairs by hand lay-up and vacuum bagging is sought by conducting a tensile test on each specimen according to the ASTM D3039 standard. The test results showed that the average tensile strength of the vacuum bagging specimen is 20% to the average tensile strength value of the hand lay-up specimen. This trend is also shown in the tensile strain and elastic modulus of the vacuum bagging specimen, which respectively have values of only 51.5% and 38% of the hand lay-up specimen.

Keywords: Scarf Method Repair, Tensile Strength, Glass Fiber Reinforced Polymer, Hand Lay-Up, Vacuum Bagging.

1 Introduction

An aircraft is designed to have sufficient structural strength to withstand their operational loads while at the same time must also be lightweight to achieve the desired flight performance. Optimizing the weight of the airframe has become one of the critical issues in the aircraft development. Nowadays, the use of composite materials become one solution to obtain the optimum structural weight because it has better strength to weight ratio than metal structure. Composite materials are materials formed from several materials that are combined to get the best properties of the constituent elements, where the chemical and physical properties of each material are different from each other, and remain different in the final product of the composite material [1].

The type of composite material often used in many structural applications is the fiber-reinforced composites. Carbon fiber and glass fiber are examples of widely used fibers to build the structure not only limited for aircraft but also for other things, such as automotives, boat, sport goods, bicycle, building, and others. Several studies have been conducted to determine the characteristics glass fiber composite materials [2-9], as well as their use for various vehicles [10-13]. Many studies start to use natural fibers combine with glass fiber as the main reinforcing materials [14], for example using coconut fibers [15,16] and bamboo fibers [17]. The increasing use of composite materials in aircraft structures requires manufacturers and authorities to prepare recognized standards for the maintenance and repair of composite structures. Aircraft structures will experience damage during the operation and strength degradation as their age increases. Therefore, improvements and repairs are needed to restore the performance of the structures to their original design.

Various repair methods are designed to overcome several types of composite structure damage. The composite repair methods recognized by FAA are stated in the AC 43.13-1B document [18], in which it contains the methods and techniques for inspection and repair that are permitted to be implemented on civil aircraft without a pressurization system if there are no maintenance or repair instructions from the aircraft manufacturer. There is a chapter in AC 43.13-1B mentioning the repair of fiberglass composites used for aircraft parts that do not receive the main load, such as fairings and covers. There are 2 main repair methods for this type of structures, namely the scarf and lap methods with schematics as shown in Fig. 1 [19].

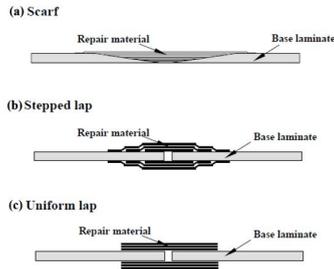


Fig. 1. Schematic of Composite Damage Repair Methods [19]

The scarf method is a composite repair method for damage that have diameter of less than 3 inches, the damage can be removed with sandpaper [18]. This method repairs composite panels by producing a joint with a slanted side. This method is used when there is a wide and deep damage on the composite panel that requires a strong and durable repair. The damaged part of the composite panel is removed from the base material and then repaired by applying a patch, as shown in Figure 1(a) [19].

In the Lap method, patch material can be applied on one or both sides of the base material around the damaged area. There are two types of lap repair methods, which are the uniform lap where each patch layer has the same length and the stepped lap where the length of each patch layer increases, starting from the shortest near the base surface to the longest one on the outermost layer [19]. Uysal [20] has conducted a study to determine the mechanical strength of laminate composite repair. The material used in the research is a glass-epoxy composite. Several tensile specimens were made to compare their strength, the first is the original specimen without damage and patch, second is the two-stepped patch, and the last is the three-stepped patch. The results showed that the three stepped patch specimen has better strength compared to the two-stepped patch specimen.

This research will focus on the use of the scarf method for repairing Glass Fiber Reinforced Polymer (GFRP) composite panels. The Glass Fiber is a woven roving type mixed with SHCP resin. The strength of two scarf repair is compared, one batch of specimen implements the scarf repair by hand lay-up and the other use vacuum bagging methods. The basic difference between these two methods is the application of vacuum after the patch is placed on the base material. The strength comparison between the hand lay-up and vacuum bagging specimen has been assessed by other research [3,6,21], but for the normal specimen in a good condition, without any damage and repair. The research results found the same tendency, the specimens made by vacuum bagging method had better material properties than hand lay-up specimen.

There is a gap in determining which damage repair technique of scarf method that results in better strength. This research aims to find, between hand lay-up and vacuum bagging method, which process has better strength if the structure is repaired using scarf method. The results of this study can be an initial step in suggesting the repair method, especially for glass fiber-reinforced composite panels.

2 Research Method

This study uses a testing method on composite specimens made from a mixture of Fiberglass Woven Roving 200 and SHCP resin. There are 2 composite panels, each made by hand lay-up and vacuum bagging manufacturing methods. A hole is given to the cured composite panel to model the damage on the panel. The panel with hole is repaired using the scarf method, which is carried out by hand lay-up and vacuum bagging process. The repaired composite panels are then cut according to the geometry of the specimen referring to ASTM D3039. The strength of each specimen is identified by conducting a tensile test to obtain its tensile strength, maximum strain, and modulus of elasticity.

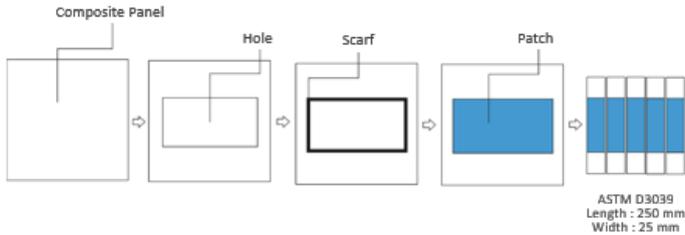


Fig. 2. Composite Specimen Repair Process

The process of making composite repair specimens is illustrated in Fig. 2. The initial composite panel as the base material is made with length, width, and height dimensions of 30 cm, 30 cm, and 0.3 cm respectively. Each panel is cut into 5 tensile test specimens. The holes for modeling damage in each composite panel are made in a rectangular shape to ensure that each specimen has the same patch size. The edges of the holes are made slanted or scarf with a slope length of 10 mm.

Table 1. Patch Size, Orientation, and Number of Patch Plies

Patch size	Fiber Orientation	Plies
3 x 8 inch	-45° / +45°	4
	0° / 90°	3
3,5 x 8,25 inch	-45° / +45°	4
	0° / 90°	3
4 x 8,5 inch	-45° / +45°	1
	0° / 90°	-

Patches are prepared in 15 layers for each composite panel. The weight ratio between glass fiber and resin is 50:50. The slanted edge of the hole in the base material is coated with resin first, then the glass fiber layers are laid out one by one and the resin is evenly applied to the entire area of each layer. The size and arrangement of the fiber orientation of each layer in sequence from top to bottom layer is shown in Table 1.

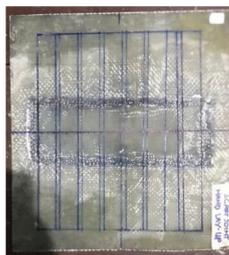


Fig. 3. Scarf Method Hand Lay-Up Composite Repaired Panel

The patch installation on first panel is carried out by hand lay-up process. After the patch lay-up process finished, the hand lay-up panel is pressed by putting a load on the top of the patch until the curing process complete. The curing process is carried out at room temperature, no heat treatment given to the composite panel. The repair area is then polished as needed to obtain a flat surface between the base material and the patch. The results of the composite panel repair with hand lay-up process can be seen in Fig. 3.

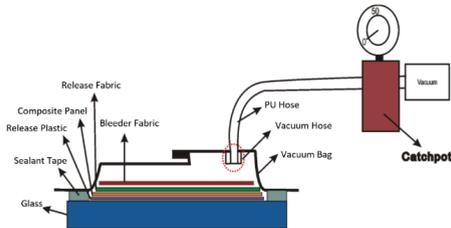


Fig. 4. Vacuum Bagging Schematic

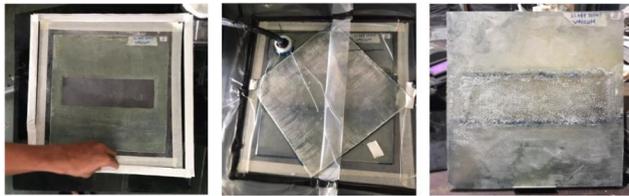


Fig. 5. Scarf Method Vacuum Bagging Composite Repaired Panel

The second panel is given a different curing treatment than the first panel. The vacuum process is applied to the second panel after the patch is completely installed over the entire hole area. The panel is left in the vacuum state until the curing process complete. The schematic of the vacuum bagging process is shown in Fig. 4, while the process of patch installation until the repaired panel finished are shown in Fig. 5. Similar to the first panel, the repair process is ended by polishing the repair area to make it even with the surface of the base plate.

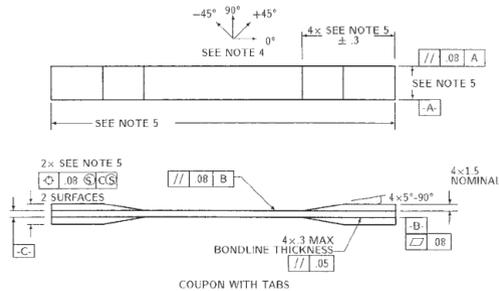


Fig. 6. Tensile Test Specimen according to ASTM D3039 [22]

The repaired composite panels are then cut according to the size of the tensile test specimen according to the ASTM D3039 standard (see Fig. 6). Each specimen has the same size of scarf repair patch area. Tensile test is carried out using a Zwick Roel Z020 tensile test machine as shown in Fig. 7. The tensile force is applied slowly at a constant speed of 6 mm/min and a grip distance of 150 mm. The specimen is pulled until it broke, the tensile force and deformation of the specimen are recorded to be calculated into tensile strength, maximum strain, and modulus of elasticity.



Fig. 7. Specimen Tensile Test

The tensile strength of specimen is obtained by measuring the maximum force divided by the initial cross-sectional area of the specimen, as shown in equation (1) where σ is the Stress in MPa, F is the maximum force in Newton, and A is the initial cross-section area in mm².

$$\sigma = F / A \quad (1)$$

The specimen strain, ϵ , is obtained from the measurement of specimen elongation ΔL divided by the initial length of the specimen L_0 , mathematically written in the equation (2).

$$\epsilon = \Delta L / L_0 \quad (2)$$

The specimen modulus of elasticity (E) can be obtained by dividing the stress in equation (1) with the strain calculation in equation (2), as written in the following equation (3).

$$E = \sigma / \epsilon \quad (3)$$

3 Results

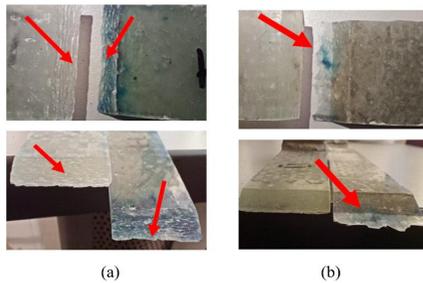


Fig. 8. Specimen Failure Mode (a) Hand Lay-Up and (b) Vacuum Bagging

The results of the specimens after tensile testing are shown in Fig. 8. Failure on all repaired composite specimens, whether using the hand lay-up or vacuum bagging methods, occurred at the joint between the patch and the base. The strength of the composite repair mainly depends on the resin bond strength between the patch and the base. By observing macroscopically, there is a presence of resin rising to the surface on the vacuum bagging specimens (see Fig. 8(b)). This occurs because during the application of vacuum, the resin which was initially only applied to the face of patch and base joint, is sucked to the surface. In the hand lay-up specimens, the resin remains only at the joint between the patch and the base, without any resin being sucked to the surface.

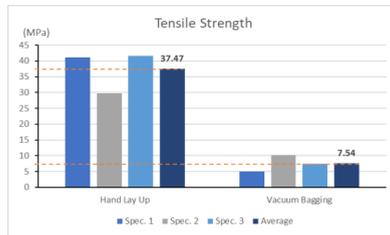


Fig. 9. Tensile Strength Result

The comparison of the average maximum tensile stress between the hand lay-up and vacuum bagging specimens is shown in Fig. 9. The average maximum tensile stress in composite panel repair using the hand lay-up method is higher than the vacuum bagging method. Hand lay-up specimens have an average tensile strength of 37.54 MPa, while the vacuum bagging specimens have a much lower average tensile strength of 7.54 MPa, or only 20% of the tensile strength of the hand lay-up specimens. The bond between the patch and the base plays a crucial role in determining the tensile strength of composite panel repairs. In the vacuum bagging method, the resin that should bind the patch and the base is drawn to the surface, making the joint weaker compared to the hand lay-up method.

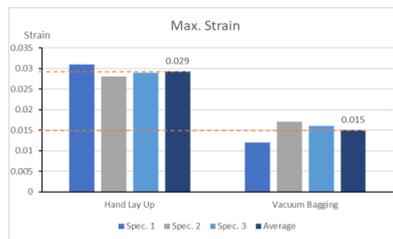


Fig. 10. Maximum Strain Result

The average maximum strain between the hand lay-up and vacuum bagging specimens shows the same trend as the average maximum stress results. The average tensile strain results are shown in Fig. 10. The hand lay-up specimens are able to stretch 51.7% more than the vacuum bagging specimens, with values of 0.029 compared to 0.015.

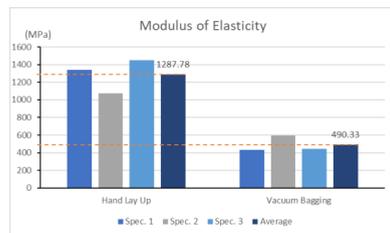


Fig. 11. Modulus of Elasticity

Fig. 11 shows the comparison of the average modulus of elasticity between the hand lay-up and vacuum bagging specimens. The modulus of elasticity for each specimen is calculated by dividing the stress by the strain within the elastic zone. The values of all specimen's modulus of elasticity are then averaged to obtain the average modulus of elasticity for the hand lay-up and vacuum bagging specimens. The results show that the hand lay-up specimens have a modulus of elasticity of 1287.8 MPa, while the vacuum

bagging specimens have a modulus of elasticity of 490.3 MPa, or only 38% of the modulus of elasticity of the hand lay-up specimens.

The tensile material properties of the specimen repaired by hand lay up shows higher value than vacuum bag specimen. The tendency is different compare with non-repaired glass fiber reinforced polymer composite properties from other research [3, 6, 21] which shows that the specimen made by vacuum bagging have higher properties than hand lay up specimen. This study gives recommendation for the scarf repair of glass fiber composite structure to put more attention to the behavior of the resin system. For low viscosity resin like SHCP used in this research, the use of vacuum may result in the resin suction to the surface. This will cause a weaker bond between the base structure and the patch. In this case, the hand lay-up process is preferred over the vacuum bagging process.

4 Conclusion

The repair of glass fiber composite panels and SHCP resin is conducted using the scarf method with hand lay-up and vacuum bagging processes. The tensile strength of these two repair specimens is identified by tensile test. The results showed that the hand lay-up method exhibited greater tensile properties compared to the vacuum bagging specimens. The average tensile strength of the vacuum bagging specimens is only 20% of that of the hand lay-up specimens. The tensile strain and modulus of elasticity of the vacuum bagging specimens are also lower than those of the hand lay-up specimens, by 51.7% and 38%, respectively. Macro photos of the fractured tensile test specimens show that the resin can effectively bond the patch and base sides in the hand lay-up specimens, whereas in the vacuum bagging specimens, some part of the resin is sucked to the surface, resulting in a weaker bond between the patch and base.

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