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AN EXPERIMENTAL INVESTIGATION ON BENDING BEHAVIOR OF REPAIRED POLYMER SANDWICH COMPOSITE PANELS

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ABSTRACT

The high cost of advanced polymer composite structures in aviation and the challenges in composite recycling have made the repair of sandwich composite structures more important. The purpose of composite repair is to make the strength of damaged structure as close as possible to the undamaged structures in terms of mechanical properties and to provide the most effective load transfer. In this study, Gillfab® 4505 polymer sandwich composite panel, which is used as cabin flooring panel structures for heavy duty use in Airbus aircraft models, are used. Perforation, delamination damages and matrix damage which are frequently encountered in these sandwich composite panels, are repaired and their quasi-static performances under bending loading are investigated experimentally in comparison with undamaged samples. In the guidance of an ASTM standard, three-point static bending test procedure is applied to test coupons that are manufactured by cutting from sandwich panel. Two different repair methods are compared to recover the strength. The load capacity is increased to 85% for filling repair method and 80% for core plug with patch repair method according to the bending test results of damaged and undamaged sandwich composite coupons.

INTRODUCTION

The bending dominated sandwich structures are widely used for various applications in aerospace industry. Besides the bending strength; they are structures that can meet special mechanical properties such as high bending stiffness, impact strength, corrosion resistance, fatigue resistance and low thermal and acoustic conductivity. A common in-service damage detection in sandwich structures is delamination caused by a low velocity impact effect. Delamination can occur in one of the sandwich faces or in the interface adhesion region between the face and the core which are bonded together. This phenomenon can effectively reduce the structural strength to withstand bending loading. Under the effects of in-plane tensile and compression loading conditions, cracks may become unstable and significant crack propagation even at very low stress levels can be occurred. The other in-service impact

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damage detections can be occurred as perforations on sandwich panels and core crushing which cause to be stress concentrations.

The high cost of newly manufactured advanced polymer sandwich composite structures and the challenges in composite recycling associated with environmental awareness make sandwich composite repair a useful option. In this way, the service life of sandwich products will not be only extended, but the operational cost will be also reduced and the environmental protection will be also held.

Repair of sandwich composite structures are generally performed with a composite layup patch application for the laminated faces as the main structure is not changed. There are different layup techniques. Attaching the patch with adhesive is one of the most common repair techniques applied in case of temporary or permanent repair. Adhesive bonding is preferred to replace the mechanical fastening in the repair process because of its useful advantages such as less stress concentrations, more uniform load distribution, and better fatigue properties. On the other hand, adhesive bonding of a small amount of honeycomb core material is applied for the repair of sandwich core section. Moreover, advanced epoxy adhesive as filling for aviation can be also used instead of layup composite patch techniques and the honeycomb core plug repair as it is a low cost and fast method.

Purpose

The purpose of composite repairs is to bring the damaged structure as close as possible to the undamaged structure in terms of mechanical properties and to provide the most effective load transfer. In this study, composite repair procedures are applied to the sandwich composite panel which is made of polymer honeycomb core and laminated composite surfaces and the panel is then subjected to bending loading. Gillfab® 4505 polymer sandwich composite panel, which is used as cabin flooring panel structures for heavy duty use in Airbus A318/A319/A320/A321/A330/A340 aircrafts, is used. Gillfab® 4505 panels are used in passenger aisle and galley areas and flight compartments of this aircrafts [The Gill Corporation, 2021]. It is clear that these panels are mostly under bending loading during in-service conditions. Moreover, these structures can tend to suffer from local damages, perforation or delamination damages as a result of low velocity impact and crushing.

The effect of repair procedures on the flexural strength and bending stiffness of the repaired sandwich panels are analyzed experimentally. The increase in load carrying capacity of repaired sandwich structures compared to impact damaged structures are investigated under quasi-static test loading conditions. So, it is examined that whether these repaired panel is able to maintain its operational tasks or not. For this purpose, three-point static bending tests, which can simulate the type of loading are applied to repaired panel.

Literature Review

Advanced composite materials, including sandwich composite materials, are replacing traditional metallic materials in aircraft structures due to their high specific stiffness and specific strength. At this point, there are many well-known examples of applications of metallic and polymer sandwich composite materials, including but not limited to Boeing 787, Airbus 350, F-35 and F-22 components, which require particularly high bending strength due to their bending-dominated properties. In spite of the increase in the use of sandwich composite materials in aviation, the fact that they still have high costs as raw materials and production processes and the polymer sandwich composite panels are especially insufficient relative to the impact or crash load. Thus, the repair of sandwich and layered composite structures has gradually attracted the attention of many researchers in recent years. However, if we do not include some research of commercial aviation company that require confidentiality, there appears to be limited work in the academic literature on the repair procedures of sandwich composite structures and comparative study of the mechanical behavior of repaired sandwich composite structures. It can be thought that studies related to the repair of laminated composite structures can also be a reference to sandwich repair studies. There are more studies about the repair of laminated composites. However, the inclusion of a core structure in the form of a thick honeycomb or foam between two thin surfaces and the bonded joint assembly technique in joining the surface and the core makes repair of sandwich composite structures more difficult. This difficulty increases as the depth (reaching to the core region and back surface) and the size of the impact damage area increases.

Whereas studies on the repair of sandwich composite structures can be categorized into some topics for differentiating as the composite repair methods, the change and the effect of parameters in a repair procedure, various types of repaired materials or the effect of the damage type; it firstly seems more useful to categorize the academic literature by the performance of the repaired sandwich composite structure under various types of loadings. From this point of view, the mechanical behavior of the repaired composite structures analyzed in the literature has been investigated under low-speed impact, tensile, compression (mostly for buckling effect) and bending loads.

The conventional repair method is used to be mechanical joints using bolts and rivets, which can cause stress concentration and increase the weight of the structure. Adhesive repair technique has become an attractive option due to its low weight and superior structural efficiency. For this reason, it is seen that research on the development of efficient adhesive repair techniques has become widespread in the last decade. Among these methods, scarf repair, or taper sanded repair, achieves a more uniform stress distribution and is often used when a smooth surface is needed to meet aerodynamic and latent requirements. Other methods are the step sanded method, which is the non-angled layout of scarf repair, overlap method and patch method. In addition, the method of filling with materials such as epoxy or putty is also used. In terms of sandwich repair methods, depending on the thickness of the damage through the sandwich, whether a filling method can be applied in the damaged honeycomb core region or a filling method with honeycomb bonding is among the other parameters that should be taken into account. In general, repair of damage caused by the impact in sandwich structures may be important in order to protect the structural integrity. Since sandwich structures are mostly designed to overcome bending loading, it is essential to investigate the behavior and performance of repaired sandwich structures under bending loading. There are limited studies on the comparative analyses of the performance of various repaired sandwich structures under bending loading.

In these previous limited studies, the four-point bending test procedure was used for testing the bending performance of repaired sandwich structures. In one of last studies, the effect of stepped-scarf repair on circular zones for the polymer composite sandwich panels was investigated numerically and experimentally [Ghazali et al., 2018]. The repair area was chosen as the middle of the beam in length. The four-point bending test method is effective to analyze the centrum of the beams. It is shown that the repair can recover up to 95% of the pristine value under four-point bending loads while the recover decreases 85% for compressive loads.

In another study [Arıkan et al., 2018], although the three-point bending test method was selected, the damaged and repaired zone was also applied to the middle of the span length, as in the previous four-point bending studies. Loading fixture can coincide with this area. It is possible to make more effective repair application and analyze its performance between support and loading fixtures by using three-point bending method. In addition to this, foam material was used for the sandwich core in that study. This core material doesn’t represent an advanced sandwich core material in aerospace industry like the aramid honeycomb.

METHOD

Gillfab® 4505, which has high strength and rigidity with light weight, is a hybrid composite sandwich panel reinforced with woven fiberglass and unidirectional carbon fiber bonded to a Gillcore® HD meta-aramid honeycomb core. Its applications are used for heavy duty use in passenger aisle and galley areas and flight compartments for Airbus A318/A319/A320/A321/A330/A340 aircrafts. Phenolic is used for facings resin system and epoxy is used for bonding adhesive [The Gill Corporation, 2021]. Figure 1 shows Gillfab® 4505 sandwich panel and the application in passenger aisle of an Airbus model. The dimensional properties of the panel are detailed in Table 1.

Figure 1*: Gillfab® 4505 sandwich composite panel and the application of flooring panel [The Gill Corporation, 2021]*

Table 1*: Dimensional properties of a Gillfab® 4505 panel [The Gill Corporation, 2021]*

Thickness	9.5 mm
Length	Maximum 1.52 m
Width	Maximum 3.66 m
Facing Thickness	0.5 mm

A favorable ASTM standard [ASTM C393/C393M-16, 2016] is used for all dimensions of the coupons and three-point bending test procedures. For the preparation of test samples which have the properties of 200 mm (length) x 75 mm (width), the cutting process is made from sandwich panels shown in Table 1. The span length is 150 mm and the test speed is 2 mm/min. A steel loading block is used which has the properties of 25 mm (length) x 75 mm (width) and 6 mm thickness under the loading cylinder located as an intermediate layer between the cylinder and the sample. In this way, local core crushing is prevented at the loading point, which may cause an unexpected damage type. The bending test are done by using MTS® universal test machine. The test speed for cross head displacement is 2 mm/min to produce failure within 3 to 6 min. The load and displacement data are stored and the calculations about bending properties are executed by using ASTM standard [ASTM C393/C393M-16, 2016]. The comparison of results that are belong to undamaged and repaired coupons is analyzed and commented. Force-displacement curves are examined. Damage modes are observed. Core shear ultimate stresses and facing stresses which are important for shear performance are calculated by using the following equations, respectively [ASTM C393/C393M-16, 2016]. *d* is the sandwich thickness while *c* is the core thickness. *b* is the sandwich width and P_{max} is the measured maximum force before failure. *n* is the nominal facing thickness and *S* is the span length in the next equations.

$$F_s^{ult} = \frac{P_{\max}}{(d+c)b} \quad \textbf{(1)}$$

$$\sigma = \frac{P_{\max} S}{2t(d+c)b} \quad \textbf{(2)}$$

Two different repair methods are applied, namely filling repair and core plug with patch repair. In both repair methods, the level of impact damage and the repaired area and volume which are prepared during the repair are important in terms of making a healthy comparison. At this point, although it may be difficult to damage each sample at the same energy value, it is sufficient that the repaired surface area and the thickness to be formed during the preparation of the impact damage area in samples belonging to both types of repair methods are aimed to be have the same dimensional properties. Therefore, in both repair methods, controlled impact damage is applied to each sample so that the same size of repair can be applied. Damaged upper sandwich face and honeycomb core structure are removed by using suited abrasives. Since there is no damage to the lower face of the sandwich, this face is not included in the repair process. After removing contamination and burrs, the circular repair area of each sample is smoothed to 50 mm in diameter and nearly 9 mm in thickness.

In the filling repair method, repair and filling with advanced reinforced filling epoxy adhesive for aviation is used after cleaning the repair area. The curing process is then applied for a certain time. After curing, the filling is lightly abraded until the repair area is flush with its surroundings. The relevant area is cleaned and the repair is completed. In the core plug with patch repair method, repair has a two-stage process. First, the damaged core area replaced with the new core material by bonding process to main structure. Then, the patch method is applied to make a top coating on the repair honeycomb core. Honeycomb core direction, patch diameter, curing temperature, vacuum and curing time are critical parameters for this repair method.

RESULTS

Two different repair methods are compared to recover the strength by also considering the bending test results of undamaged and unrepaired coupons. Eight coupons were tested for each type and twenty-four coupons were tested in total. The three-point bending test results of Gillfab® 4505 panel are listed in Table 2. *R* represents the reference coupons for specimen code. *D* represents coupons which had repaired by filling paste while *Y* defines that the coupon is repaired by patch repair. The average values and standard deviations of each bending properties are also shown in Table 2.

The reference coupons which are undamaged and unrepaired have the maximum average core shear ultimate stress and maximum average facing stress as expected. All average results have good standard deviations. The load capacity is increased to 85% with filling paste repair and 80% with scarf patch repair method according to the bending test results of damaged and undamaged sandwich composite coupons. However, filling the hole with paste will increase the weight and density more than filling the hole with honeycomb. So, if we look from the viewpoint of specific strength, the difference of 5% between two repair methods is acceptable.

Table 2*: Three-point bending coupon test results of Gillfab® 4505 panels*

Specimen Code	Core Shear Ultimate Stress (MPa)		Facing Stress (MPa)	
R-C-1	3.564	Average (MPa)	534,560	Average (MPa)
R-C-2	3.250		487,447	
R-C-3	3.354	3.371	503,086	505.584
R-C-4	3.278		491,663	
R-C-5	3.541	Standard Deviation	531,177	Standard Deviation
R-C-6	3.370		505,475	
R-C-7	3.444	0.131	516,586	19.685
R-C-8	3.165		474,675	
D-C-1	2.893	Average (MPa)	434,018	Average (MPa)
D-C-2	2.725		408,814	
D-C-3	3.236	2.871	485,461	430.586
D-C-4	2.759	***85%***	413,915	***85%***
D-C-5	2.876	Standard Deviation	431,335	Standard Deviation
D-C-6	2.995		449,296	
D-C-7	2.595	0.180	389,278	27.009
D-C-8	2.884		432,572	
Y-C-1	2.699	Average (MPa)	404,917	Average (MPa)
Y-C-2	2.611		391,659	
Y-C-3	2.862	2.691	429,267	403.667
Y-C-4	2.817	***80%***	422,532	***80%***
Y-C-5	2.520	Standard Deviation	378,046	Standard Deviation
Y-C-6	2.609		391,404	
Y-C-7	2.797	0.114	419,528	17.146
Y-C-8	2.613		391,985	

References

Arıkan, V., Karakuzu, R. and Alpyıldız, T. (2018) *Improvement of Load Carrying Capacity of Sandwich Composites by Different Patch Repair Types*, Polymer Testing, Vol. 72, p: 257-262, DOI: 10.1016/j.polymertesting.2018.10.039.

ASTM C393/C393M-16 (2016) *Standard test method for core shear properties of sandwich constructions by beam flexure*, West Conshohocken, PA: ASTM International.

Ghazali, E., Dano, M.L., Gakwaya, A., Amyot, C.O. (2018) *Experimental and Numerical Studies of Stepped-Scarf Circular Repairs in Composite Sandwich Panels,* International Journal of Adhesion and Adhesives, Vol. 82, p: 41-49, DOI: 10.1016/j.ijadhadh.2017.12.008.

The Gill Corporation, *Gillfab® 4505 Product Data Sheet*, https://www.thegillcorp.com/datasheets/Gillfab_4505_Panel.pdf, Mar 2021.