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Mechanical Properties Analysis of Patch Repaired Composite Structures with Debonding Flaw

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Abstract. Increasing use of composite structures in transport industry puts forward new requirements for its maintenance and repair. However, bonding repair process will produce inevitable debonding flaws, and there will also be debonding damage during use service. In this paper, mechanisms properties of compression failure of patch repaired composite structures were explored, and effects of flaws on the properties were analysed. The results showed that buckling of patch repaired structures first occurred in compression process and then failed. Patch repaired structures broke at the damage hole. Under compression load, debonding flaw of patch repaired composite structures would be expanded, which caused the patch and the parent laminates to be detached earlier, and compression bearing capacity became weaker.

1. Introduction

The application of composite materials on aircraft structures is increasing dramatically in the recent years, and it is becoming more important to develop bonding techniques for composite structures. Adhesively bonding technology provides advantages such as weight reduction over traditional mechanical joining methods. Adhesively bonding technology can reduce stress concentrations and thus increase fatigue and damage resistance of bonded structural assemblies. Bonding technology is usually applied to reinforcement and repair. Bonded repair methods include patch repair method, scarf repair method and injection repair. The advantage of patch repair method is that the process is simple and high-efficiency, and the damage to parent laminates is small.

Recently, the mechanical properties of ideal flaw free bonding structures and repair structures have caused widely public concern. Hu F Z et al. [1] examined the compressive behaviour of bonded external patch repairs. The problem of a laminate plate with an elliptical hole repaired by elliptical patches under in-plane and/or bending load is investigated by Engels H [2]. Liu X et al.[3] studied the tensile behavior of open-hole composite plates bonded with external composite patches, experimental tests and developed a 3-D progressive damage model. Three types of final failure modes of these repaired structures subjected to tensile loads are concluded, with each corresponding to a different damage progression process. Cheng P C et al. [4, 5] examined the tensile behaviour of

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composite structures repaired by bonding external patches. Guo X et al. [6] studied the tensile behavior of composite laminate containing penetrated damage and the optimization of repair designing parameters after being flush repaired on double-sided. Soutis C et al. [7] examined the compressive behaviour of bonded external patch repairs; the compression loading mode is more severe than the tensile mode owing to the instability of delaminated plies. Jiang Y P et al. [8] investigate the efficiency of repaired panels in this paper, and then modeling of the mechanical behavior of the repaired composite panel under compression static load is conducted by using of the finite element method.

However, bonding process will produce inevitable debonding flaws, and there will also be debonding damage during the use process. At the same time, many scholars have also studied the mechanical properties of two dimensional adhesive joints with flaws.

Kan H P et al. [9] developed a stress analysis technique for load transfer in metal-to-composite adhesively bonded step-lap joints with bondline flaws. Rossettosetal J N et al. [10] developed an analytical model to compare the effects of voids and debonds on the interfacial shear stresses between the adherends and the adhesive in simple lap joints. Cheuk P T et al. [11] analyzed the effect of cracks embedded in strap adherend on the lap shear joints. The failure loads and failure modes of specimens with different length of cracks are determined in the experimental study. de Moura M F S F [12] evaluated the influence of strip flaws on the mechanical behaviour of composite bonded joints. It was verified that specific strength of the joints was not affected by the size of the flaw. Wang C H [13, 14] conducted experiments on scarf joints containing disbonds of varying lengths. The results showed that the load-carrying capacity of scarf joints decreases with the size of the bondline flaw at a faster rate than the reduction in the effective bond area. The author of this article has carried out an investigation into the effects of debond flaws on the mechanical properties of adhesively bonded single lap joints and composite scarf joints [15, 16].

However, under the action of compression load, the research on the defect propagation mechanism of 3D bonded repair structure is very scarce. Therefore the compression characteristics of patch repaired composite structures were studied in this paper. The mechanism of compression damage expansion was analyzed and the relationship between strength and flaws was discussed.

2. Experiment Setup

2.1. Specimens

Specimens of patch repaired composite structures are fabricated with X850 prepreg material. Ply sequence of parent laminates is $[45/0/-45/90]_{2s}$. Diameter of the preset pierce hole is 20mm. Diameter of the repair patch is 80mm. Ply sequence of the patch is $[45^o/0^o/-45^o/90^o]_s$.

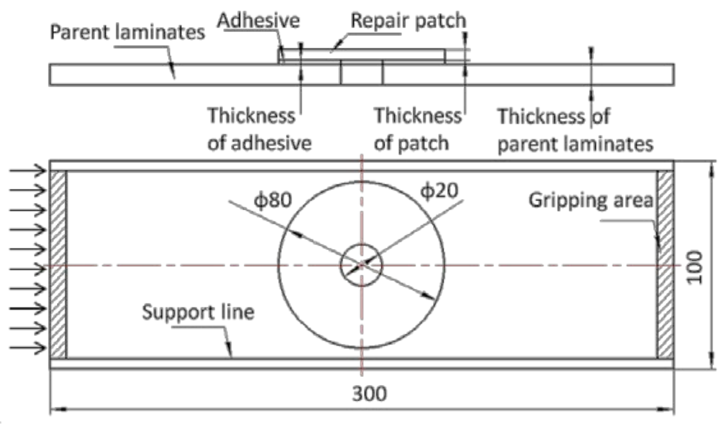


Figure 1. Schematic diagram of compressing specimen for patch repair structures (Unit: mm).

The parent laminates and the repair patch were bonded together with each other by J116B adhesive film. Schematic diagram of repair patch and parent laminates are shown in figure 1. In the sample processing stage, pieces of teflon films are inserted between the adhesive layer and the patch to form a preset debonding flaw. The flaws are located at the middle point of the long axis and the middle point of the short axis, as shown in figure 2.

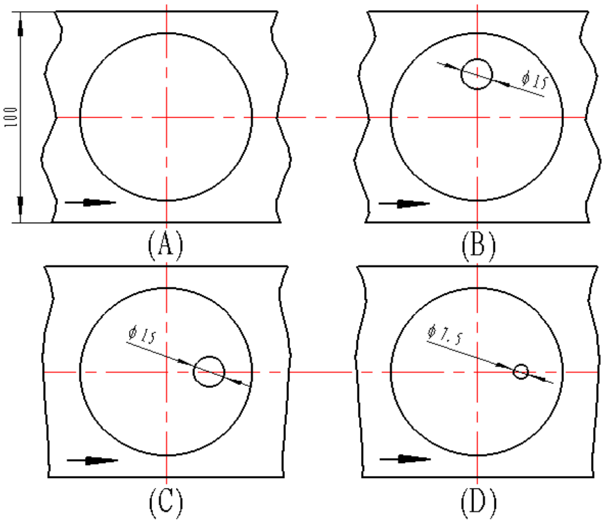
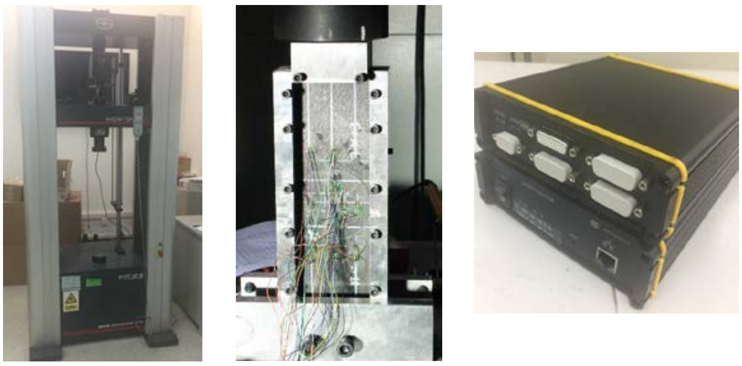


Figure 2. Schematic diagram of flaw location (Unit: mm).

2.2. Test Equipments

All the specimens were subjected to longitudinal compression loads on a 10 ton electric testing machine as shown in figure 3(a). Strain measurement and data acquisition were carried out by DH3821 static strain test system developed in Donghua as shown in figure 3(c).



(a)WDW-100E (b) Test fixture (c)DH3821

Figure 3. Test equipment and fixture.

Compression test standards for adhesive bonded repair structures have not been established. Compression tests for composite bonded repair structures referred to the standard of compression test CAI for laminates with impact damage, which is ASTM D7137"Standard Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates"[17]. A test fixture was designed according to the compression test fixture after impact as shown in figure 3(b). The two sides of fixture were used to constrain the side deformation and prevent the overall buckling of the specimens.

3. Discussions and Results

3.1. Patch Repaired Composite Structures without Flaws

The compression strength of patch repaired composite structures without flaws is 257.94MPa, and the dispersion coefficient is 6.02%. The failure modes are the repair patch peeled off, and first layer of the parent laminates stripped at first. Then the parent laminates crushed along the hole edge, as shown in figure 4.

The load displacement curve of the specimen is shown in figure 5. The slope of the load displacement curve is equivalent to the compression stiffness of the structure. In order to analyze the variation of the compression stiffness during loading, a straight line was drawn along the initial slope of the load displacement curve. It can be seen that the slope of the curve decreases obviously when the load reaches 58kN. The reduction of the structure stiffness means that the structure began to buckle from this point. When the load increased to 75kN after buckling, the whole structure failed. Post buckling stages of the structure was relatively short.

Figure 4. Failure modes.

In order to monitor the progressive damage process of the specimens, strain gauges were pasted at the corresponding positions on both sides of the specimens, as shown in figure 6. The positive and negative sides of the strain gauge were arranged symmetrically. The strain gauge x1 ~ x12 were arranged on the patch side of the specimens, and the strain gauge x101 ~ x112 were arranged on the other side of the specimens.

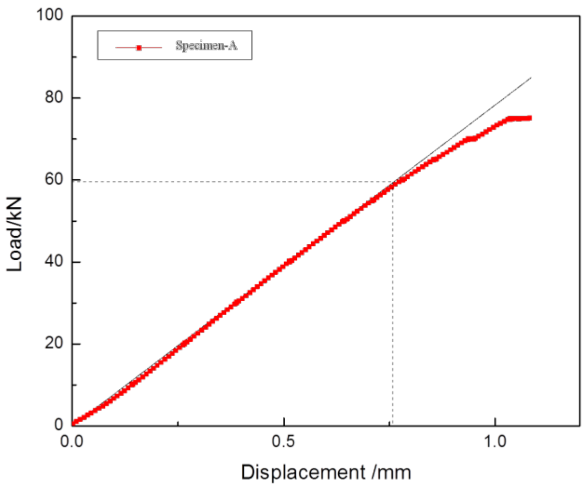
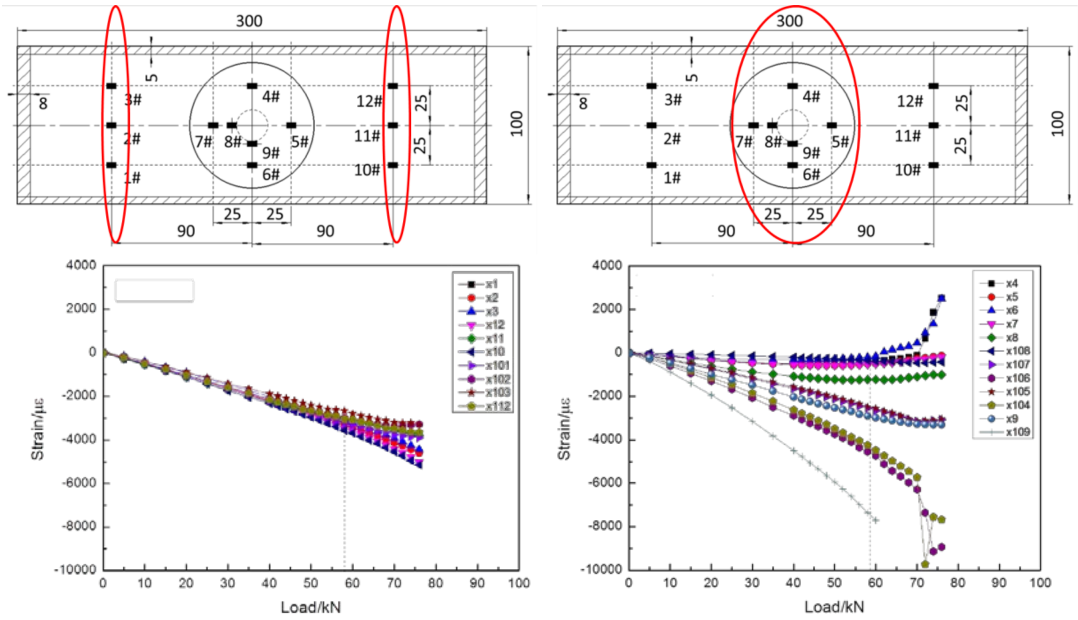


Figure 5. Load displacement curve of patch repaired composite specimen without flaws.

The strain gauges outside the repair area were monitored and used to adjust the load uniformity of the two sides to reduce the bending effect, as shown in figure 6(a). When the load was greater than 58kN, the strain difference of those strain gauges in figure 6(a) increased gradually. This indicates that the structure started to buckle, which caused local bending.

From figure. 6 (b), it can be observed that the compression strain values of 105# and 107# on the parent laminates side are not increased with the increase of 104# and 106# when the load is greater than 58kN. The compression strain values of 5# and 7# on the patch side are not increased with the increase of 4# and 6# when the load is greater than 58kN. At the same time, the value of strain gauge on the patch side was found to increase gradually to positive, while the value strain gauge on the other side continue to decrease, as before. The deformation on the long axis was smaller than that of the short axis. It can be explained that the buckling of the patch also occurred, and the external surface bears tensile action.

After buckling, when the load reached 70kN, the strain difference between 4#, 6# and 9# increased sharply, indicating that the patch and parent laminates were detached.



(a) Strain gauges outside the repair area (b) Strain gauges in the repair region

Figure 6. Strain load curve of patch repaired composite specimen without flaws.

The above results show that the structure buckled during the loading process of the repaired structure. The repair structure is weak in resistance to buckling, and then the overall failure occurs quickly.

3.2 Patch Repaired Composite Structures with Flaws

The failure strength of all the compression specimens are shown in figure 7. When flaw is located at the long axis position, the flaw size has small effect on the compression properties of the structure. When the flaw is located at the short axis, the failure path of the structure will exceed the flaw, which will aggravate the failure of the structure.

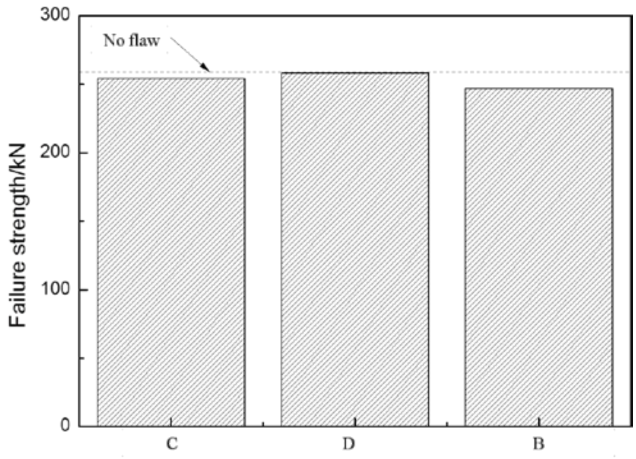


Figure 7. The failure strength of all the compression specimens.

The 4#, 5#, 6# and 7# strain differences between the parent laminates and the patch were taken to analyze the effect of the flaws, and the strain load curve was drawn as shown in figure 8. The strain differences values of 5# and 7# on the long axis are smaller than the strain differences values of 4# and 6# on the short axis. It is indicated that the strain value differences on the long axis is smaller than those on the short axis. After 70 kN, the strain difference on the short axis increased sharply, which indicates that the break onset position of the patch and the parent laminates was located next to the short axis. After 70 kN, the slope of the strain differences load curve on the long axis did not change much. This shows that there is no separation between the patch and the motherboard at the long axis.

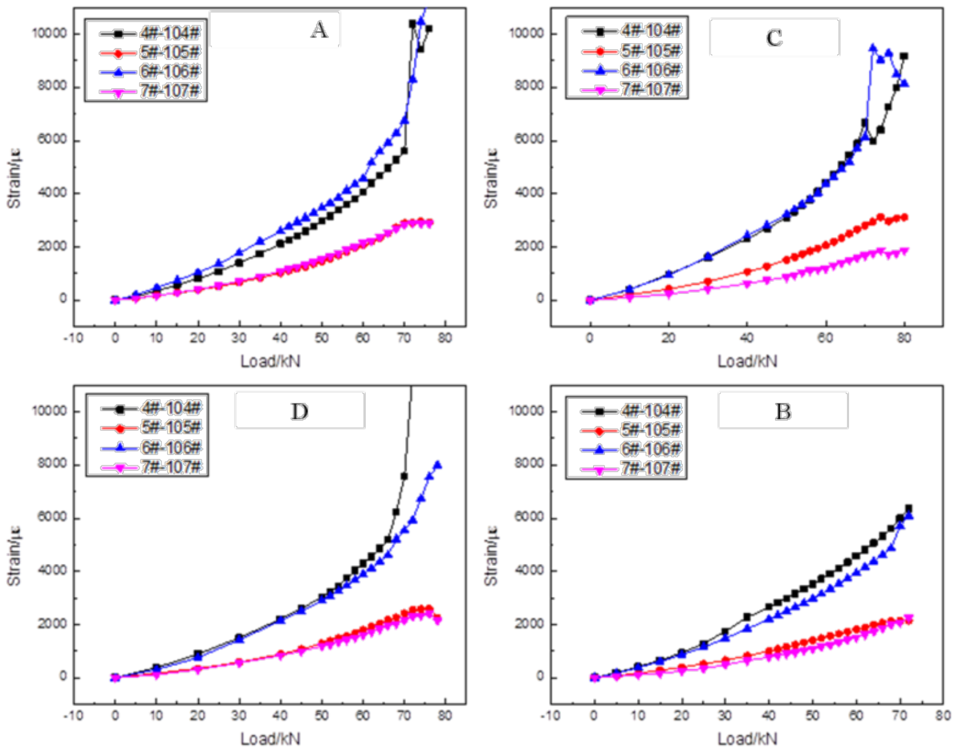


Figure 8. Strain loading curve for all the compression specimens.

4. Conclusions

In view of the compression properties of composite bonded repair structure, experimental study was carried out to explore the failure mechanism under compression load. At the same time, the influence of different locations of debonding flaws on the compression properties of patch repaired composite structures was studied, and the mechanism of flaw influence and the mechanism of flaw expansion were grasps. Flaw is located at the long axis position of the repair structure, and the debonding size has smaller effect on the compression properties of the structure. When the flaw is located at the short axis, the influence on the structure properties is greater. The flaw located at the path of damage extension speeded up the damage propagation of repaired structures. The debonding flaw may expand under the compression load, which causes the patch of the repair structure to be separated from the parent laminates earlier, and the compression bearing capacity becomes weaker.

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