EXPERIMENTAL STUDY OF COMPOSITE BONDED SKIN-STIFFENER SPECIMENS

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Abstract

Debonding failure characteristics of the composite skin-stiffener specimens were experimentally investigated. The influences of bonding methods, types of stiffener shape and various secondary bonding parameters were evaluated. The specimens with an open type stiffener had lower bending stiffness and larger failure displacement than those with a closed type stiffener. Secondary bonding and co-curing with adhesive had better failure strength than co-curing without adhesive film. Secondary bonded specimens failed by adhesive failure and co-cured specimens failed by delamination failure. As the bondline thickness was thinner, the skin-stiffener specimens had higher failure strength. The fillets had no influence on failure strength of the specimens. The influence of the surface roughness was shown according to types of stiffener shape.

1 Introduction

The composite stiffened panels with high postbuckling strength are good candidate structures for aerospace vehicle in which weight saving is important. The composite stiffened panels are usually manufactured by bonding the skin and stiffeners. In the bonding process, there are many bonding methods and parameters which influence the skin-stiffener adhesion strength.

In the previous study [1], the postbuckling strength of the composite stiffened panels was influenced by the skin-stiffener adhesion strength and the debonding failure. It indicated that the earlier skin-stiffener debonding failure, the lower the postbuckling strength. So, it is important to find the good bonding conditions to prevent the skin-stiffener debonding failure and improve the postbuckling strength. For this purpose, the skin-stiffener debonding failure behaviors need to be examined.

Most of the previous studies on the bonding joints deal with simple geometry, for example, single or double lap joints [2-5]. It is difficult to examine the skin-stiffener debonding failure behaviors with these lap joint specimens. It is also undesirable to use the testing of the composite stiffened panels due to the high cost and time consuming process. So, the simple skin-stiffener joint specimen needs to be manufactured and tested to evaluate the skin-stiffener debonding failure characteristics. This specimen is also useful to conduct an experimental parametric study.

There are some previous studies on the skin-stiffener specimens [6, 7]. But in these studies, as the skin-stiffener specimen was simplified to skin-flange type configuration, it is difficult to evaluate the influence of the stiffener section shape.

In this study, the debonding failure characteristics of the skin-stiffener specimens were experimentally investigated. The influences of bonding methods, types of stiffener shapes and various bonding parameters were also evaluated.

2 Test Specimens

The configuration of the skin-stiffener specimens is shown in Fig. 1. The specimen corresponds to a minimum part cut from the composite stiffened panel in Ref. [1] and consists of a skin and a stiffener with hat section.

The specimens were manufactured by secondary bonding or co-curing considering the following parameters.

- Bonding method: co-curing with and without adhesive film (FM73, Cytec Industries Inc.) and secondary bonding methods.
- Stiffener section : open and closed type (refer to Fig. 1)

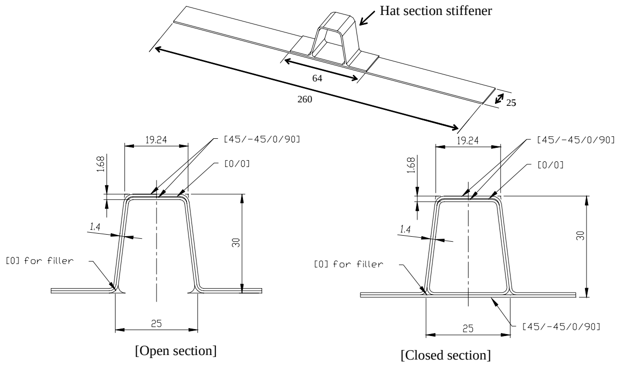


Fig. 1. Geometry of the composite skin-stiffener specimens

For the co-curing method, a skin and a stiffener were laid up and cured simultaneously at a temperature of 126°C and a pressure of 40psi. For the secondary bonded specimens, a skin and a stiffener were laid up and cured separately. After curing, the skin and stiffener were adhesively bonded together by using paste adhesive, Hysol EA9309.3NA. The bonding parameters considered in the secondary bonding process are as follows:

- Contact pressure: 1, 2 and 3 psi were applied for the variation of bondline thickness.
- Surface roughness: 220, 320 and 400 of mesh no. of abrasive papers were used for the variation of surface roughness on the bonding surface.
- Fillet: specimens with and without fillets were considered.

For each kind of specimen with a different bonding method and bonding parameters, five specimens were manufactured using carbon/epoxy UD prepreg (HT145/RS1222, Hankuk Fiber Glass Inc., Korea) with ply thickness of 0.15mm. The stacking sequences of the specimens are shown in Fig. 1.

3 Test Setup

For the skin-stiffener specimens, three point bending tests were carried out as shown in Fig. 2. The skin-stiffener debonding failures are induced by postbuckling skin deformation which causes bending moment and peel stress at the skin-stiffener flange interface. The test setup reflects such a debonding mechanism of the composite stiffened panels.

The loading was applied in displacement control. The loading rate was controlled at 5mm/min. During the testing, the failure process such as crack initiation and growth were observed using on-line microscope and recorded using video camera. The load, stroke, and strain measurement data were also recorded.

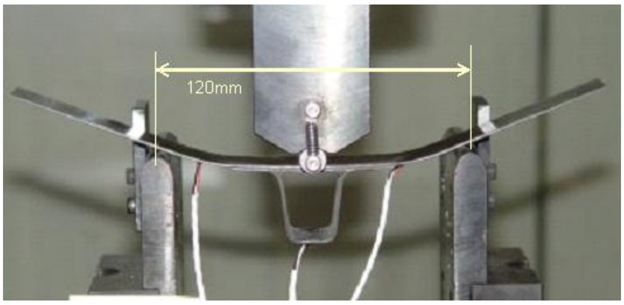


Fig. 2. Test setup of the skin-stiffener specimens

4 Results and Discussion

4.1 Load-Displacement Curves

Typical load-displacement curves are shown in Fig. 3. The early slope is linear and non-linearity appears as the load increase. The slope (that is, bending stiffness) in the load-displacement curves are different according to the stiffener section shape but not influenced by bonding methods and other parameters. The specimen with a closed type stiffener had 68% higher stiffness than the specimen with an open type stiffener.

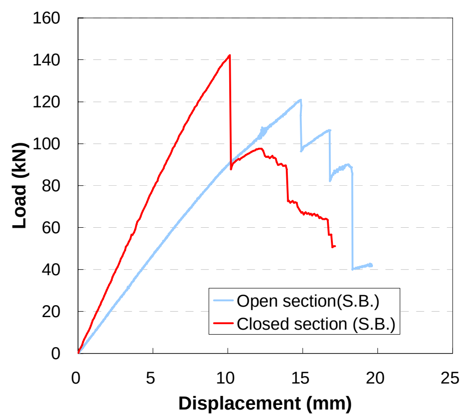


Fig. 3. Typical load-displacement curves of the skin-stiffener specimens

4.2 Failure Process and Mode

The typical failure process is shown in Fig. 4. The debonding failure was initiated at a stiffener flange tip. The initial failure propagated through the bondline and finally one side stiffener flange was separated suddenly as shown in Fig. 4. The load drops were also observed at the time of unstable crack propagation as shown in Fig. 3.

Failure modes are different with respect to the bonding methods and the stiffener types. The secondary bonded specimens failed by adhesive failure. In the co-cured specimens, the cracks growth into the skin and delamination failure appeared. The locations of delamination failure were different according to the stiffener section shape but not influenced by whether the adhesive layer exist or not. The debonding crack grew deeper in the specimen with an open type stiffener than the specimens with a closed type stiffener.

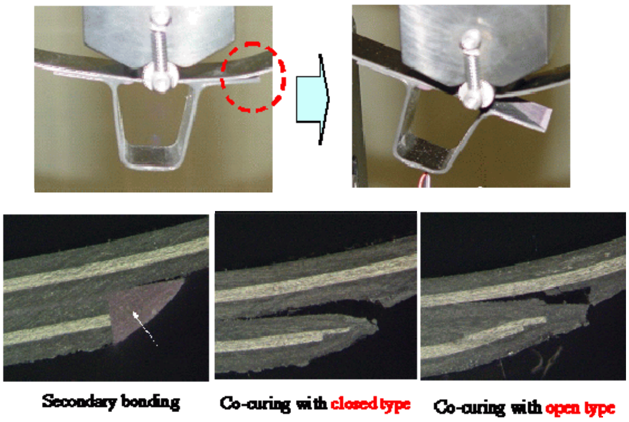


Fig. 4. Failure process of the specimens

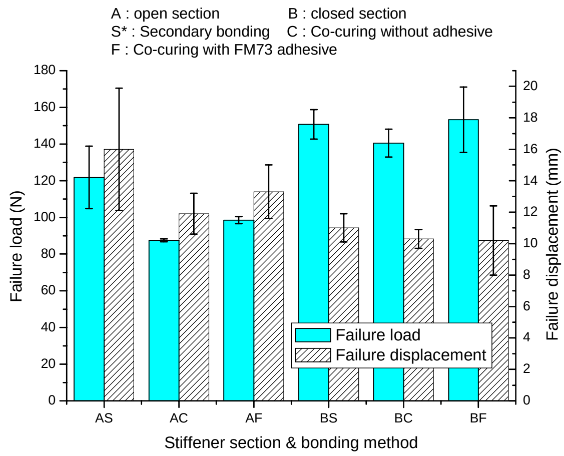
4.3 Failure Strength

4.3.1 Influence of stiffener type and bonding method

Fig. 5 shows the failure strength of the specimens with respect to the bonding methods and the stiffener section types. Both of the failure load and the failure displacement are presented in Fig. 5. In this figure, the difference between open and closed type stiffeners can be easily found. While the specimens with an open type stiffener had larger failure displacement, those with a closed type stiffener had higher failure load for the same bonding method. This is related with the difference of the bending stiffness between both specimens as shown in Fig. 3. As the specimens with an open type stiffener have lower bending stiffness than those with a closed type stiffener, the former have larger deformation and failure displacement than the latter.

About the bonding methods, it can be seen that the secondary bonding and the co-curing with adhesive film had better failure strength than the co-curing without adhesive film. But the influence of the bonding method was less clear than the stiffener section type. So, if one of the failure load and the failure displacement need to be increased, it is better to change the stiffener section type than the bonding method.

The previous experimental study [1] showed that the composite stiffened panels with an open type stiffener had higher postbuckling strengths than those with a closed type stiffeners because the skin-stiffener debonding failure did not appear in the former. The present experimental results are consistent with the previous one [1]. That is, it can be seen that the open type stiffener with less lateral bending stiffness is advantageous to increase the postbuckling strength of the composite stiffened panels by prevention of the skin-stiffener debonding failure.



* Secondary bonding parameter : sandpaper no. 300, contact pressure 3psi

Fig. 5. Failure process of the specimens

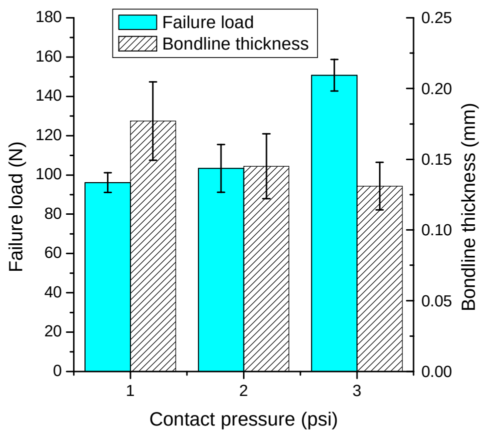


Fig. 6. Failure strength of the closed type specimens according to bondline thickness (mesh no. of abrasive paper = 320)

4.3.2 Influence of bondline thickness

Fig. 6 shows the influence of bondline thickness on the failure strength of the specimens with a closed type stiffener. This figure shows that the bondline thickness and the failure strength are different with respect to the contact pressure. Consequently, the failure strength increases as the bondline thickness decreases in the range of 0.13~0.18mm.

4.3.3 Influence of surface roughness

The influences of surface roughness on the failure strength are shown in Fig. 7 and 8. From the Fig. 7 and 8, it can be seen that the influences of surface roughness are different according to the stiffener types. For the open type stiffener, the failure load increases as the average arithmetic surface roughness increases within the range of 0.88~1.5μm. For the closed type stiffener, the average surface roughness of 1.14μm corresponds to the best failure strength within the range of 0.94~1.78μm. So, the influence of the surface roughness seems to be different according to geometry of the bonded specimens and the detail stress state in the bondline interface.

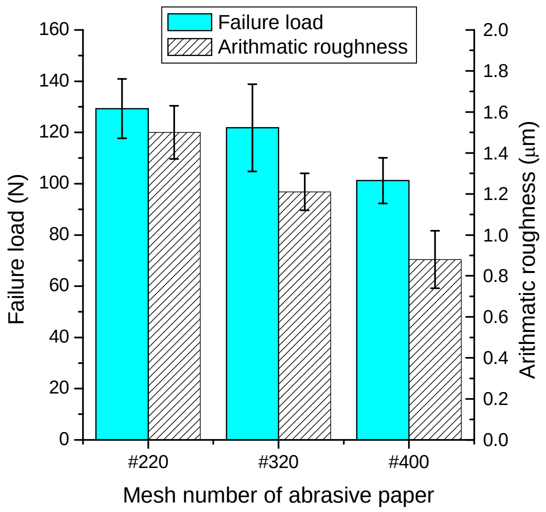


Fig. 7. Failure strength vs. arithmetic average surface roughness of the open type specimens

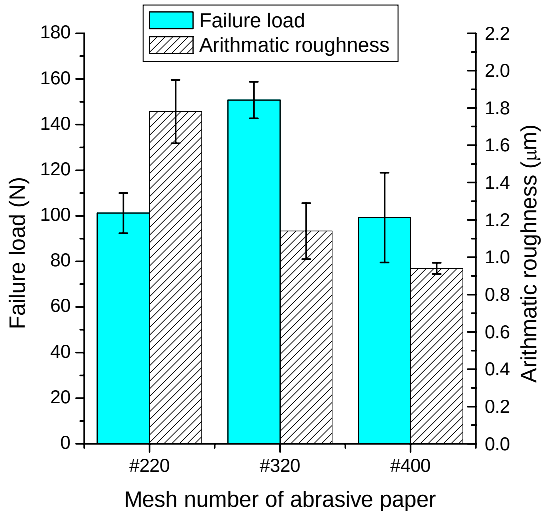


Fig. 8. Failure strength vs. arithmetic average surface roughness of the closed type specimens

4.3.4 Influence of fillets

The fillets are located at the stiffener flange tip as shown in Fig. 4. It is known that the fillets are very beneficial for the increase of the joint strength in the single lap bonded joint [2, 4]. But the fillets did not have influences on the failure strength of the skin-stiffener specimens as shown in Fig. 9.

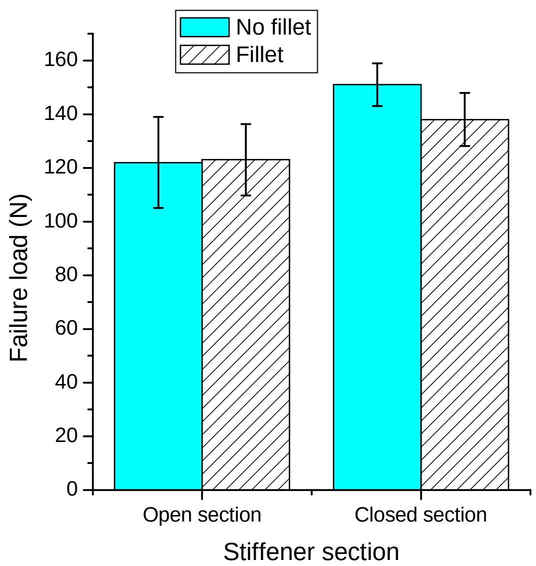


Fig.9. Influence of the fillets on failure strength

4.3.5 Comparison with single lap joints

The present results regarding the influences of various bonding parameters were compared with the results of single lap joints [2]. The influence of the bondline thickness was the same. That is, as the bondline thickness decreases, the joint strength increases. But the surface roughness, fillets, and the bonding methods had different influences on the joint strength according to whether the joint configuration is single lap or skin-stiffener types.

5 Conclusions

Debonding failure characteristics of the composite skin-stiffener specimens were experimentally investigated. The influences of the bonding methods, types of stiffener shape and various secondary bonding parameters were evaluated. The specimens with an open type stiffener had lower bending stiffness and larger failure displacement than those with a closed type stiffener. So, it can be seen that the stiffener with less bending stiffness is advantageous to increase the postbuckling strength of the composite stiffened panels. Secondary bonding and co-curing with an adhesive layer had better failure strength than co-curing without adhesive film. The secondary bonded specimens failed by adhesive failure and the co-cured specimens failed by delamination failure. As the bondline thickness was thinner, the skin-stiffener specimens had higher failure strength. The fillets had no influence on failure strength of the specimens. The influences of the surface roughness were different according to types of the stiffener shape.

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