INVESTIGATION IN DELAMINATION BEHAVIOR OF COMPOSITE STIFFENER RUN-OUT UNDER TENSILE LOAD

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ABSTRACT

Tensile experimental and finite element simulation of stiffened composite panels with stiffener runout were performed to discuss to failure behaviors of the composite s. The results showed that there is high stress concentration at the stiffener cutouts, which interrupt the load path. The failure was initiated at the edge of the run-out and propagated across the skin-stiffener interface. A fracture mechanical approach could simulate the initiation and propagation of the debonding of the composite stiffened panels, the results is in good agreement with experimental values. It was verified that the modified stiffened plate is superior to the reference stiffened plate, and the influence of the geometrical parameter to the carrying capacity of the structure was discussed.

1. INTRODUCTION

Stiffened composite panels are successfully used in primary aircraft structures such as wings and fuselages. The stiffener design at run-out is very important part in wings' edge. Debonding between stringer and skin is easily initial subjected load carrying.

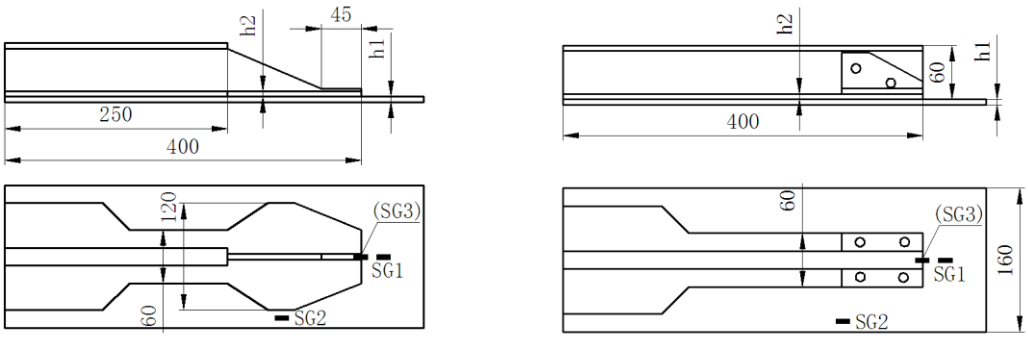
Recent efforts towards the development of the next generation of large civil and military transports have shifted this focus on the potential use of co-cured or adhesively bonded structures. Several studies about the skin stiffener failure have been carried out [1, 2]. The failure of stiffener run-outs loaded in the compression with different stacking sequences was investigated [3]. The most common approach that has been proposed to simulate the debonding is virtual crack-closure technique, either by post-procession finite element results, and cohesive finite elements [4]. However, a model that can be used to design structure with geometrical discontinuities, such as skin-stiffer run-out is still lacking. And the model was modeled with shell element or shell-solid modeling technique. And the range of the application of cohesive finite element was limited to structures with small fracture process zones confined to the crack tip.

The research in this paper focuses on composite stiffened run-outs loaded in tensile with optimal design of stiffener. Experimental and numerical investigations were performed to discuss the load carrying capacity of different design of the stiffeners at run-out. By all the specimens, failure was shown to occur at the skin-stiffer interface. 3D solid element and cohesive finite element were adopted in the finite element analysis to analyze the damage initiation and the crack propagation. Finally, the geometry parameters which influence the mechanical behaviors of the stiffened panels run-out region were discussed.

2. EXPERIMENTAL

2.1 Experimental method

Fuselage-representative panels consisting of a skin and single stiffener were tested. The ends of these specimens were machined parallel to ensure uniform loading. The specimen was aligned by careful measurement in the loading direction to avoid bending. In experimental testing, a set of data collection devices were applied which included strain gauges, video recordings. A CSS-WAW-600 testing machine was used for the tensile testing. The ends of these specimens were machined parallel to ensure uniform loading. In experimental testing, a set of data collection devices were applied which included strain gauges, video recordings. The locations of strain gauges are shown in Figure 1. SG1 and SG2 are affixed on the front of skin, but SG3 is affixed on the back of skin. Two types of stiffened panels consisting of a skin and single stiffener were shown in Figure 1. The bond between stringer and skin is adhesive joint only at Figure 1(a), but add rivet bond at end besides adhesive joint shown in Figure 1(b). The material used in these specimens was IM7/977-2. The stacking sequence of the skin is [45/-45/45/-45/0/0/90/0/0/45/-45/0]s, and [45/0/0/-45/0/0/45/0/0/-45/0/0/45/90/-45/90]s in the stringer.



(a) (b)

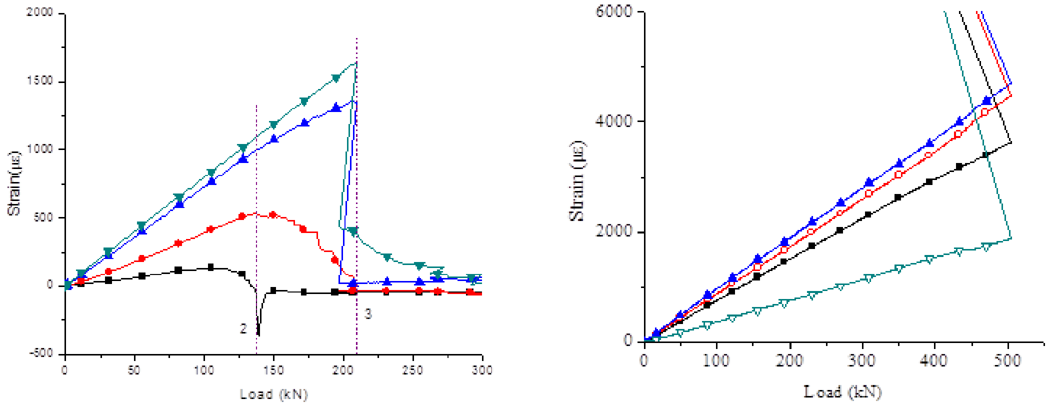
Figure 1: Stiffened composite panel design at run-out (a) adhesive only (b) adhesive and rivet bond

2.2 Experimental results

Breakage phenomena of stiffened composite panels are shown in Figure 3. The fracture patterns of the stiffened panel are characterized by debonding and fiber fracture in skin, which are shown in Figure 2. Under the tensile load, the damage initials at edge of interface. The delamination between skin and stiffener starts when the tensile load reaches F_d. The skin breaks at the maximum tensile load F_{max}. The experimental results are shown in Table 1. Take one of adhesive only specimens for example, the strains in the skin of strain gauges change with load shown in Figure 3, and the strains in the stiffener shown in Figure 3. In experiment loading the first loud noise was at the load of 135 kN, which was considered the start of the debonding. The debonding between stiffener and skin extend totally at a load of 209 kN.

(a) (b)

Figure 2: Breakage phenomena of stiffened panels (a) adhesive only (b) adhesive and rivet bond



(a) (b)

Figure 3: Strain-load curves of strain gages

	Joint type		F_d[kN]	F_{dc}[kN]	F_{max}[kN]
Experimental	adhesive		135	209	383
	adhesive and rivet bond			182	506
Numerical	wide range of stringer	30mm	107	207	
		60mm	122	229	
		90mm	147	246	
	thickness of skin	4.56mm	107	207	
		6.08mm	137	268	

Table 1: Experimental and numerical results

3. NUMERICAL ANALYSIS

3.1 Model details

Finite element simulation of the parametric study was carried out in ABAQUS. The main model has three different parts, the skin, the stiffener and the adhesive between them. The skin and stiffener have been modeled by the 8-nodes 3D layered solid reduced integration elements, while the interface between the stiffen and skin has been modeled by 8-nodes 3D cohesive elements to predict the delaminating propagation. The finite element model is shown in Figure 4. Under mixed-mode loading, the damage onset may occur when any of the stress components reach their respective tolerance. One group of the models changes the size of width of stiffener with 30mm, 60 mm and 90mm, the other group changes the stiffener thickness from 4.56 to 6.08mm.

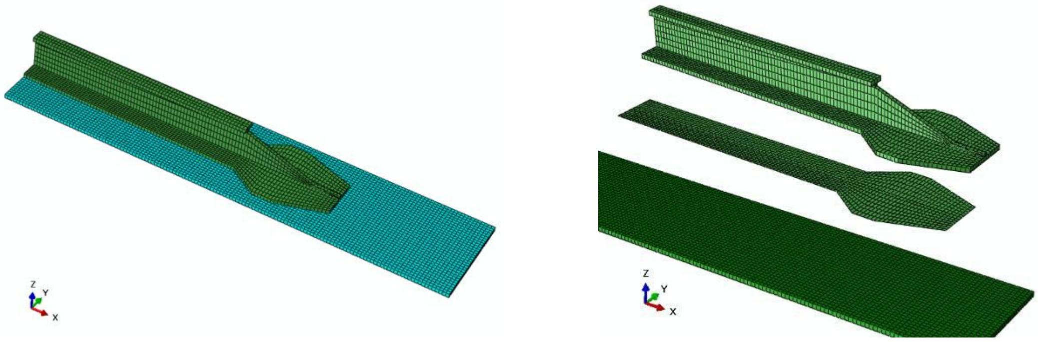


Figure 4: Finite element model of adhesive stiffened panel

3.2 Failure criterion

The cohesive law for single mode loading with linear elastic-linear softening model, which is the simplest to implement, and is the mostly commonly used. Under mixed-mode loading, damage onset may occur before any of the stress components involved reaches their respective tolerance. Therefore, it is assumed that debonding initiation can be predicted using the quadratic failure criterion as follows

$$\left\{\frac{\sigma_n}{\sigma_n^0}\right\}^2+\left\{\frac{\tau_s}{\tau_s^0}\right\}^2+\left\{\frac{\tau_t}{\tau_t^0}\right\}^2=1 \tag{1}$$

Where, σ_n is the transverse normal tensile stress, τ_{sn},τ_{tn} are the transverse shear stresses, $\sigma_n^0,\tau_s^0,\tau_t^0$ are the maximum stresses. The onset of damage propagation criterion can be determined using the B-K damage criterion based on the energy [5] as

$$\frac{G_n+G_s+G_t}{G_n^c+(G_s^c-G_n^c)(\dfrac{G_s+G_t}{G_n+G_s+G_t})\eta}=1 \tag{2}$$

Where G are the strain energy release rates in the modes I, II and III, G^c are the fracture toughness values, and η is a curve fit parameter found from mixed-mode test data.

3.3 Numerical Results

It was found that the failure load was greatly influenced by change of geometric feature of the specimens. The structural response of the modified stiffener design was investigated for wide range of stringer and thickness of skin. The results are shown in Figure 5 (a) and (b). The load value of interface delaminating completely is defined as F_{dc}. The computational results are listed in Table 1.

Take the wide 60mm model as example. It can be seen from Figure 5 (a) the debonding occurs at the load of 122 kN, this is because the damage arisen. When the load is to 229kN, the debonding is unstable growth at that time, ribs and skin separated completely. When the stiffener is terminated, the load must be transferred to the skin, making the design of the run-out region vital, hence improved design is required. These sections are analyzed using a parametric study to optimism the design of the run-out. The tensile strength increases as the size w increases from 30mm, 60 mm and 90mm. But the tensile strength decreases as the size b increases from 4.56 to 6.08mm.

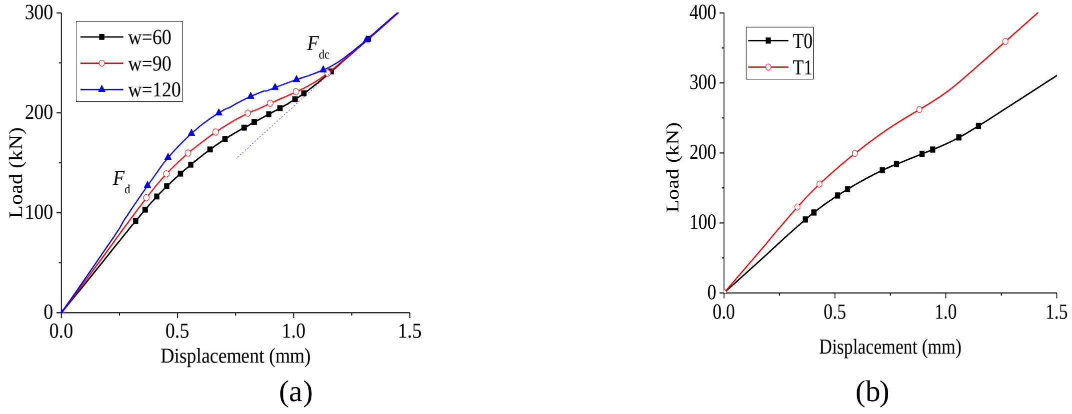


Figure 5: Load versus displacement of different models (a) different wide of stringer (b) different thickness

4. CONCLUSION

The skin-stiffener separation of the composite panel subjected to tensile was studied by using experimental method and computational fracture mechanics analysis. The shear load resulted skin-stiffener separation initiating at the end of cutout. The results are as follows:

1) The failure modes of different pieces were obtained, the strains in different parts were recorded and analyzed, thus the deformation of different locations and bearing capacity were obtained.
2) The adhesively bonded composite panels with stiffener runout, the failure was initiated at the edge of the run-out and propagated across the skin-stiffener interface, and the skin and stiffener debonding completely, then the skin bearded independently.
3) The failure modes of composite stiffener panels with the adhesive and the ashesive-rivet joint are different. The initial debonding load can be greatly increased by the acting of the rivet joint.
4) The cohesive element in nonlinear finite element software ABAQUS was used to simulate the interface between the skin and stiffener. The process of damage initiation, as well propagation and catastrophic failure, of the stiffened composite panels was simulated by the proposed technique. The finite element analysis result is well agreed with the experiment data. growth characteristics for each specimen.
5) By simulating the modified composite stiffened plate in the experiment and the referenced one in terms of the finite element analysis, the failure mechanism and bearing capacity were compared. It was verified that the modified stiffened plate without any increase in weight is superior to the referenced one. Then, the influence of the geometrical parameters web length D and skin thickness T to the initial debonding load, complete debonding load and the buckling load of the structure was discussed in details. It is of significance to design the composite stiffened plate in optimization.

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