The Simulation of Notch Length on the Stress Distribution in Lap Zone of Single Lap Joint with a Centered Notch

Yan Zhanmou[1], You Min[1†], Yi Xiaosu[2], and Zheng Xiaoling[1]

[1]College of Mechanical and Material Engineering, China Three Gorges University, Yichang443002, China
[2]National Key Laboratory of Advanced Composites (LAC/BIAM), PO Box 81-3, Beijing 100095, China
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Abstract: The influence of the notch length on the stress distribution of mid-bondline and adherend was investigated using elasto-plastic finite element method. The results from the simulation showed that peak stress of mid-bondline decreased markedly as adherend with notch in the middle of lap zone, and the stress in the middle of joint with low stress originally increased evidently. All the peak stresses decreased firstly and increased again as the length of notch increased. The relative higher peak stress appeared at the point near the notch of adherend where might be failed previously during the loading procedure.

Keywords: *adhesive, aluminium alloy, single lap joints, stress distribution, finite element stress analysis, notch*

1. Introduction

Adhesion is applied in aeronautics and astronautics industry widely as a result of high strength-weight ratio, and adhesively bonded single lap joint is one of the most common joint. But single lap joint presents geometrically nonlinear due to the noncollinear load path, inducing the magnitude of eccentricity, and serious stress concentration takes place at the ends of lap zone, where the cracks initiate generally. All of the above are harmful to the strength of joint [1]. Pires *et al*. [2] showed the results that the more flexible the used adhesive, the more uniform the stress distribution of single lap joint, the smaller the stress concentration. The results of Broughton [3] were that the use of rigid adherend made the stress distribution uniform. The study of Lang *et al*. [4] showed that the larger the fillets size and angle, the lower the peak stress. It was also reported that the existence of metal component in the fillets increases the strength of single lap joint from the authors' work [5]. The results of Avila [6] through the experiment and numerical simulation showed that the stress distribution was more uniform by wave shape processing at lap zone, and the strength was higher. Sancaktar *et al*. [7] reported that the smaller the taper angle of adherend at the ends of lap zone, the higher the strength of joint. Belingardi [8] used the finite element method show that the smaller the inner chamfering angle in the unload ends of adherend, the lower the peak stress of single lap joint, and it is more advantageous. The results obtained by Sancaktare *et al*. [9] showed that the top notch and bottom notch at the ends of lap zone increase the strength of joint. The influence of notch at the middle of lap zone on the reduction of stress concentration may be evident. The influence of notch at the middle of lap zone on the stress distribution of adhesively bonded single lap joint was studied using elasto-plastic finite element method in this work.

2. Finite Element Model and Mesh

The model and mesh are built using the ANSYS finite element software. Adherend uses GB7124-86 "the measuring method of adhesive tensile shearing strength (metal to metal)". The bondline thickness of the specimen (100 mm^L × 25 mm^W × 2 mm^T) was 0.2 mm as shown in Figure 1. A couple of notches located in opposite sides of the adherend in the middle of lap zone. Bondline was divided into four layers along thickness direction, and the smallest element length of fillets and

†Corresponding author: e-mail: youmin@ ctgu.edu.cn

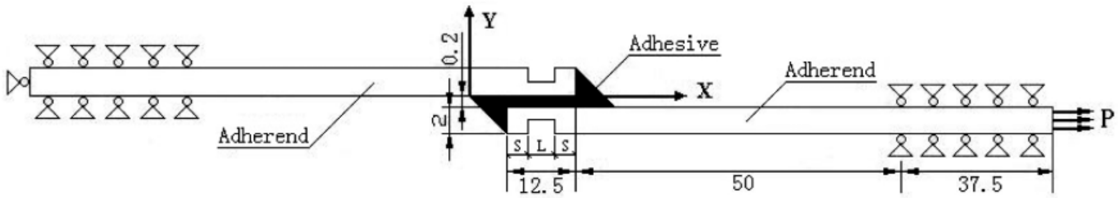

Figure 1. Finite element model.

Table 1. Material property

Material	Elastic modulus E/GPa	Poisson's ratio γ	Yield strength σ_y/MPa	Hardening modulus E_r/MPa
LY12	71	0.32	320	240
Epoxy resin	1.89	0.33	50	50

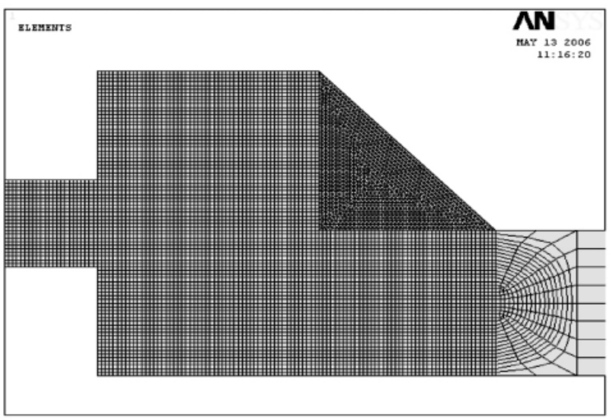

Figure 2. Mesh of lap zone.

the neighboring adherend was 0.05 mm. Fillets were divided into triangular element, and the others were divided into quadrilateral element, as shown in Figure 2. Considered the non-linear behavior, bilinear isotropic hardening plasticity option (BISO) was used to describe the elastic-plastic behavior of material, as shown in Table 1.

3. Finite Element Analysis

The finite element model was analyzed using elas-to-plastic finite element method. The load applied was taken as 60 MPa (3 KN) and the constraint of the model is also shown in Figure 1.

3.1. Influence of Notch

Figure 3 shows the effect of notch in adherends on the stress distribution of joint in the mid-bondline. The notch is 7 mm in length and 1.5 mm in depth. The joint was bonded by an epoxy resin adhesive. The peak stress of the mid-bondline (y = -0.1 mm) decreases markedly as adherend with notch (Figure 3c), and all the stresses in the middle part of joint with low stress originally increases evidently, especially for normal stress *Sx*, peel stress *Sy*, the first principal stress *S1* and von Mises equivalent stress *Seqv*, but the variety of all the stress near the ends is slight. The reason may be that destructible region is formed after the outside of adherend in middle of lap zone being processed into notch, increasing the extent of stress concentration greatly, and transferring peak stress from the corner near ends to the notch. Figure 4 gives the contour pattern of the stress distribution of the lap zone of the joint and it is clearly that peak stress in mid-bondline decreases but increased greatly in the adherend with notch.

Figure 5 shows the results of stress distribution in plane with coordinate of y = -0.25 mm. The stress distribution of normal stress and the first principal stress is similar to that of von Mises equivalent stress. All the stresses near the notch increase greatly, especially for peel and von Mises equivalent stress. The stress in the middle of joint with low stress originally increases when stress concentration of adherend transfers from notch to the mid-bondline, then the middle of joint takes on more load, and reduce the stress of corner between bondline and fillet, which means decreasing the peak stress of the mid-bondline. It is the same result as bi-adhesive joint [2]. The dangerous region may be formed after the joint subjected to loading and the failure may occur near the notch previously to that in bondline.

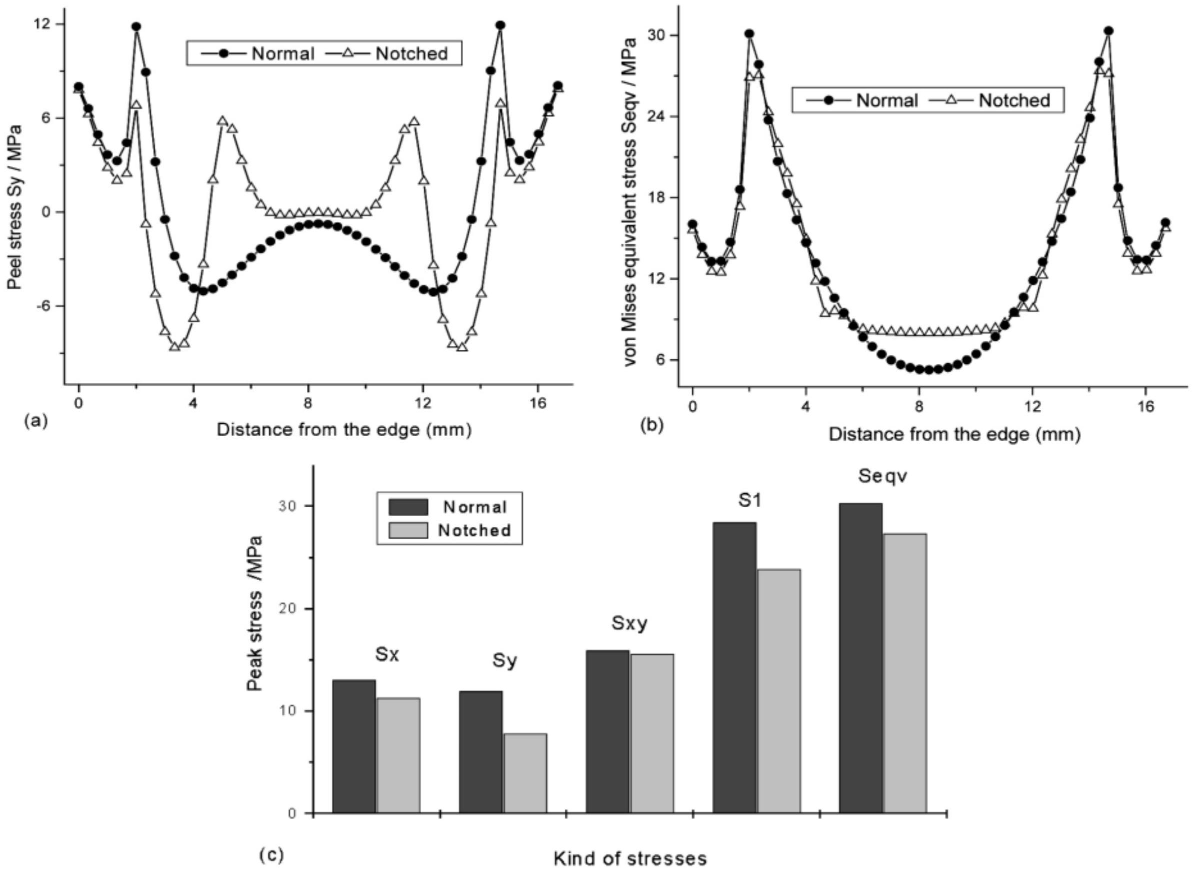

Figure 3. The influence of notch on the stress distribution of joint in the mid-bondline: (a) peel stress *Sy*; (b) Von Mises equivalent stress *Seqv*; (c) peak stresses.

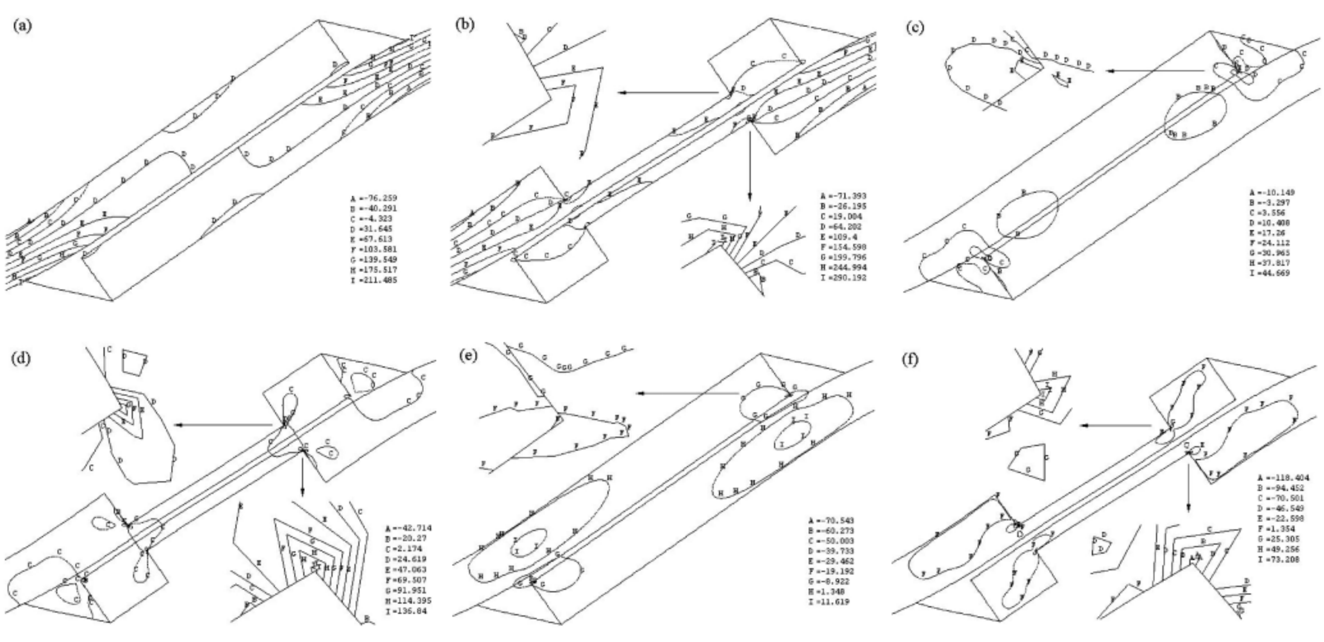

Figure 4. Stress distribution in the lap zone: *Sx* in (a) normal and (b) notched; *Sy* in (c) normal and (d) notched; *Sxy* in (e) normal and (f) notched joint.

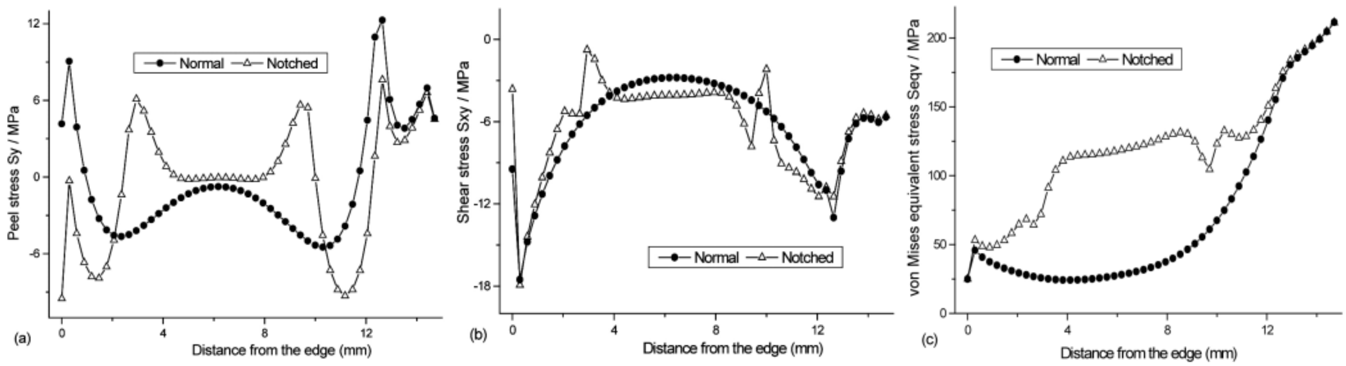

Figure 5. The effect of notch on the stress distribution of adherend (y = -0.25 mm): (a) peel stress *Sy*; (b) shear stress *Sxy* and (c) Von Mises equivalent stress *Seqv*.

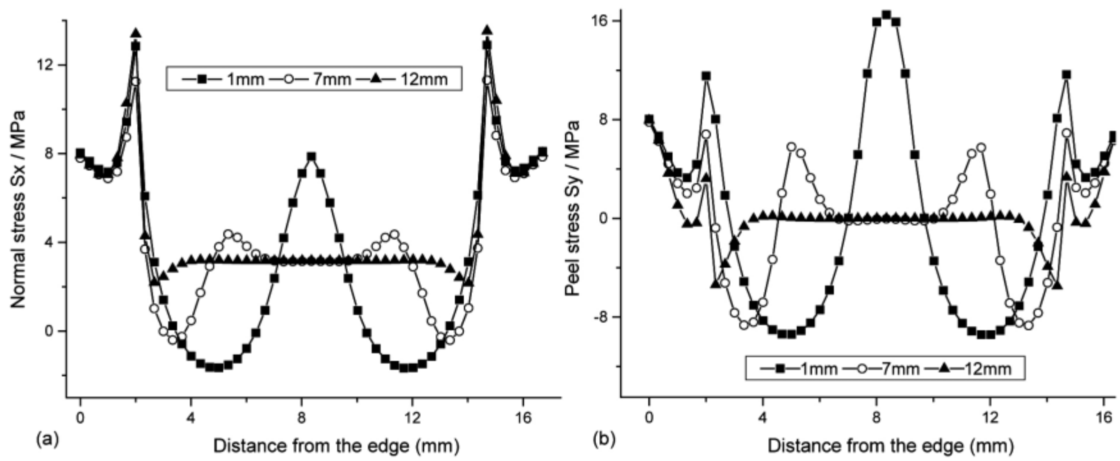

Figure 6. The effect of notch length on stress distribution in the mid-bondline: (a) *Sx* and (b) *Sy*.

3.2. Influence of Notch Length

While keeping notch depth as a constant of 1.5 mm, the notch length L was set as 1 mm, 7 mm and 12 mm respectively. With regard to the normal stress in the mid-bondline, as the notch length L increases, the peak stress and stress near notch reduce, and the peak stress achieves minimum when L = 7 mm approximately. The influence of notch length on shear stress, the first principal stress and von Mises equivalent stress is similar to that of normal stress, as shown in Figure 6, and the used adhesive is epoxy resin adhesive. When notch length increases further, reaching the corner between bondline and fillet, then each peak stress increases instead. The reason is that great stress concentration exists in the corner originally, and stress concentration becomes more serious when notch reaches the corner, then the peak stress increases. But for peel stress, as the notch length increases, the peak stress and stress near notch reduce all the time. Figure 7 shows the effect of notch length on stress distribution along whole joint. The peak stress of *Sx* in adherend with 12 mm notch occurs near the point in the interface opposite to the free end of another adherend (Figure 7a) and in the adherend with a shorter length of 1 mm the peak stresses occur not only in the interface but also at the corner of the notch (Figure 7d). The peak stress of *Seqv* in Figure 7c (L = 12 mm) is much higher than that one in Figure 7f (L = 1 mm). Comparing them with the *Seqv* in Figure 4e (L = 0 mm) and Figure 4f (L = 7 mm) it is obviously that notch in the adherends may bring the adherend to an adverse state although the peak stress in mid-bondline should decrease evidently.

4. Conclusion

The peak stress of the mid-bondline decreases mark-

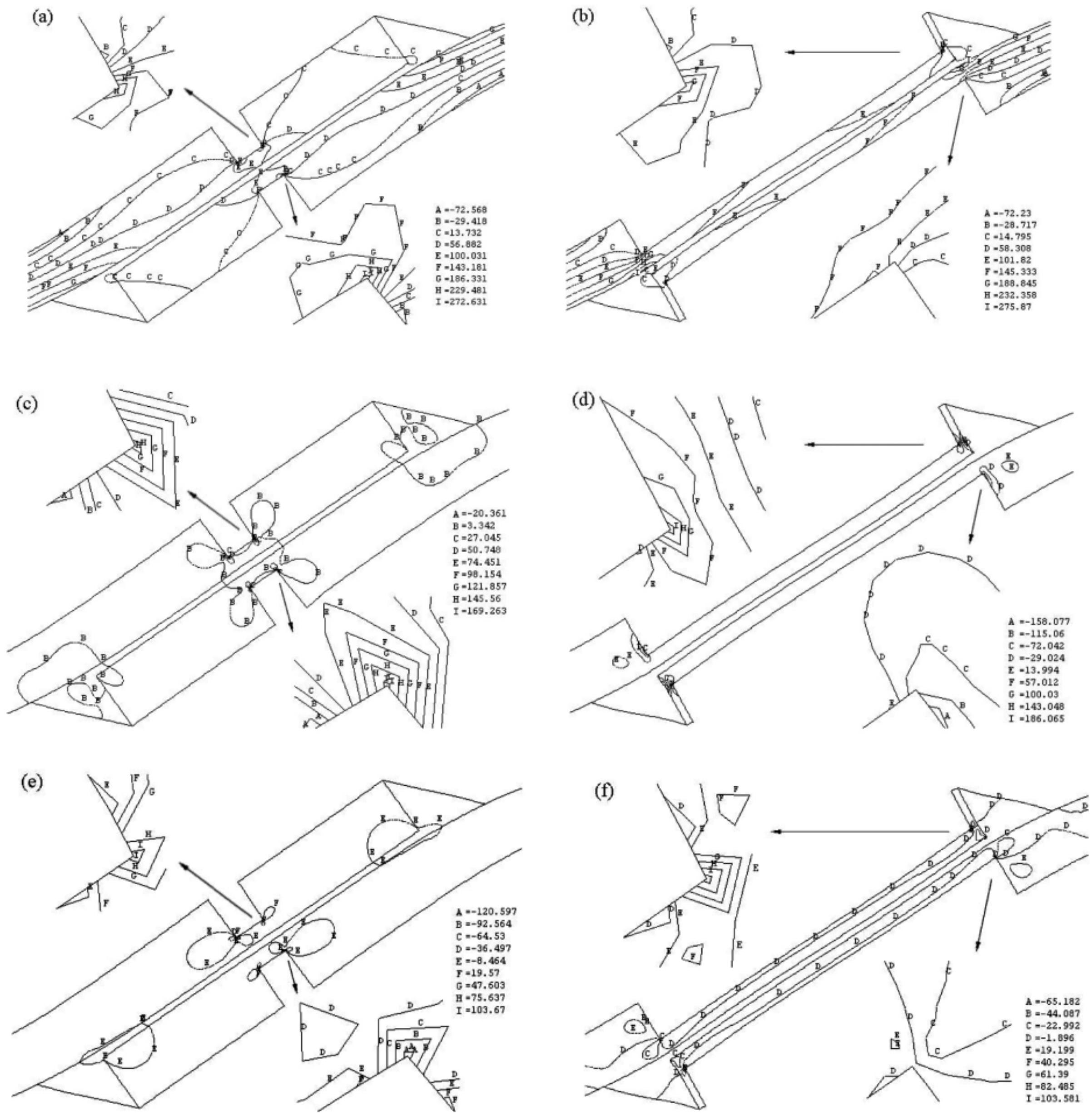

Figure 7. The effect of notch length on the stress distribution in the joint: *Sx* in 1 mm (a) and 12 mm (b); *Sy* in 1 mm (c) and 12 mm (d); *Sxy* in 1 mm (e) and 12 mm (f) length notched joint.

edly as adherend with notch, and nearly all the stress in the middle part of lap zone increases evidently, but the variety of each stress in the ends is slight. Serious stress concentration occurs at the edge of notch where the failure of joint may originally take place instead of bondline. Along the orientation of thickness, the nearer adherend away from notch, the higher the peak stress.

As the notch length increases, the peak stress in the mid-bondline decreases. When it increases further to reaching the corner between bondline and fillet, the peak stress increases instead while peak stress of *Sy* decreases all the time.

Acknowledgments

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