The FEM Analysis of Recessing Location on the Stress Distribution in Aluminum Double Lap Joint

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Abstract: The elasto-plastic finite element method (FEM) was used to investigate the effect of off-center recessing location (8 mm length) on the stress distribution in the lap zone of adhesively bonded aluminium double lap joint. The results from simulation showed that the effect of off-cent recessing in bondline of double lap joint in the mid-bondline is not evidently to stress distribution in mid-bondline but the peak stresses both in mid-bondline and in the interface near the adherend side of the joint may increase markedly when an 8 mm length recessing was arranged symmetrical to the point of x =18 mm. When shifting an 8 mm length recess from near left end to the right end of the lap zone, all the highest peak stresses in the mid-bondline occurred under the condition of recess arranged symmetrical to the point of x = 6 mm.

Keywords: *aluminium, off-center recessing, double lap joint, stress distribution, FEM*

1. Introduction

Bonding technology is applied widely today in almost all the industry of the world accounting for its high strength-weight ratio, low cost and high efficiency and one branch of it named intermittent bonding appeared in recent years [1,2]. It is defined as a joint bonded by intermittent adhesive layer so that there is at least one gap (or more gaps, several recesses) in the adhesive layer. In general, the studies related to the recessing in bondline on the mechanical properties of adhesively bonded joint was in a viewpoint of treating the recessing as defect in the joint and mainly focused it on single lap joint [3-5]. Olia [3] reported that the effect of recess on the peak stresses of peel stress and shear stress in single lap joint under bending was little, unless it was sufficiently close to the end of lap zone. Lang [4] discussed the result using FEM that the effect of recess on the peak stress of joint under tensile load could be negligible. Results of De Moura [5] from experiment and numerical simulation showed that the influence of recess length and width on the nominal strength of joint was little. In our studies the intermittent (or recessed) bonding was considered as an advanced technology and showed that reasonable intermittent layer may increase the actual strength through experiment and FEM [1,2]. It was known that the use of double lap joint is broadly today in aeronautical industry [6] for avoiding the great eccentricity of stress in single lap joint. Up till now, there is scarcely literature related about double lap joint with recess. In this work the authors have investigated the effect of intermittent bonding on the stress distribution of double lap joint through elasto-plastic FEM.

2. Finite Element Model and Mesh

The model and mesh were built using the ANSYS finite element software. The aluminium specimen (100 $mm^L \times 25\ mm^W \times 2\ mm^T$) was prepared in accordance with GB7124-1986 as shown in Figure 1 and bonded with 0.2 mm-thick epoxy adhesive. The generalized plane strain element PLANE183 was used for both adherend and adhesive. The bondline was divided into four layers along the direction of thickness, and the element length of fillets and the neighboring adherend is set as 0.05 mm. Fillets were divided into triangular element while the others divided into quadrilateral one as shown in Figure 2. The load applied was taken as 150 MPa

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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	300	240
Epoxy resin XH-11	2.875	0.42	90	500

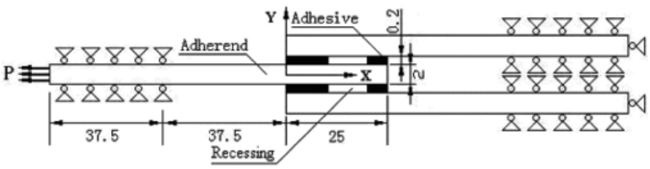

Figure 1. Finite element model.

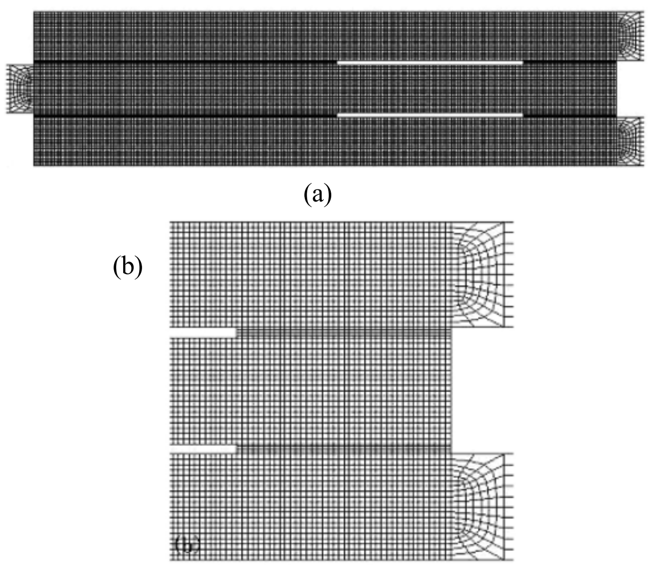

Figure 2. Finite element mesh: (a) overlap and (b) detail.

(7.5 KN) and the boundary conditions of the model are also shown in Figure 1. All the stresses data were obtained from mid-bondline y = 1.1 mm.

3. Finite Element Analysis

2.1. Influence of Recess

The effect of recess on the stress distribution in the mid-bondline of the joint is shown in Figure 3 where 8 mm length recess located symmetrical to the point x = 18 mm. From Figure 3 it can be seen the effect of recess on the peak stress in the mid-bondline of the joint was very small but the stress at the edge of recess increased evidently. The peak stresses of double lap joint appeared at the ends of lap zone and the maximum stress at the left while the stresses in the middle of lap zone were very small so that almost to equal zero. So the effect of recess could be negligible. Where there is no adhesive (the gap existed), there is no any stress component at all in the mid-bondline. The peak stresses of double lap joint appear at the ends of lap zone, and the maximum is on the left, while the stresses in the middle of lap zone, offsetting to right, are very small, almost equal to zero, bearing little load. So the effect of gap could be negligible. From Figure 3(f) to Figure 3(j) the same tendency of the stress in the adherend along the lap zone is shown and relative higher value of peak stress (over 60 MPa) appears in the curve represented the stress distribution of *Sx*, *S1* and *Seqv*. In Fig. 3(f) the normal stress at the point x = 14.5 mm has increased by 140.7% and at the right edge of the end (x = 25 mm) increased by 6.6%. For the stress distribution of *Sy* and *Sxy* in adherend corresponding to the gap in adhesive layer the stress is below the one of no gap existed in the adhesive layer and the peak value of stress appears at the point near the edge of the gap. From Figure 3 it is clearly that the load bearing ability of the double lap joint should not be affected by an 8 mm length gap arranged symmetrical to the point x = 18 mm. In other words, the effect of the gap under such condition may be negligible.

2.2. Influence of Recess Position

When the recess length kept as 8 mm the effect of recess position on the stress distribution was investigated. The distribution of the normal stress *Sx,* peel stress *Sy*, shear stress *Sxy*, 1st principal stress *S1* and von Mises equivalent stress *Seqv* in the mid-bondline of double lap joint is shown in Figure 4. The peak stress of *Sxy*, *S1 or Seqv* increased markedly when the recess located closely to the left end of lap zone (location: x=2 to 10 mm). When shifting the 8 mm length recess from near left end to the right end of the lap zone, all the highest peak stresses occurred under the condition of recess arranged symmetrical to the point of x = 6 mm. The va-

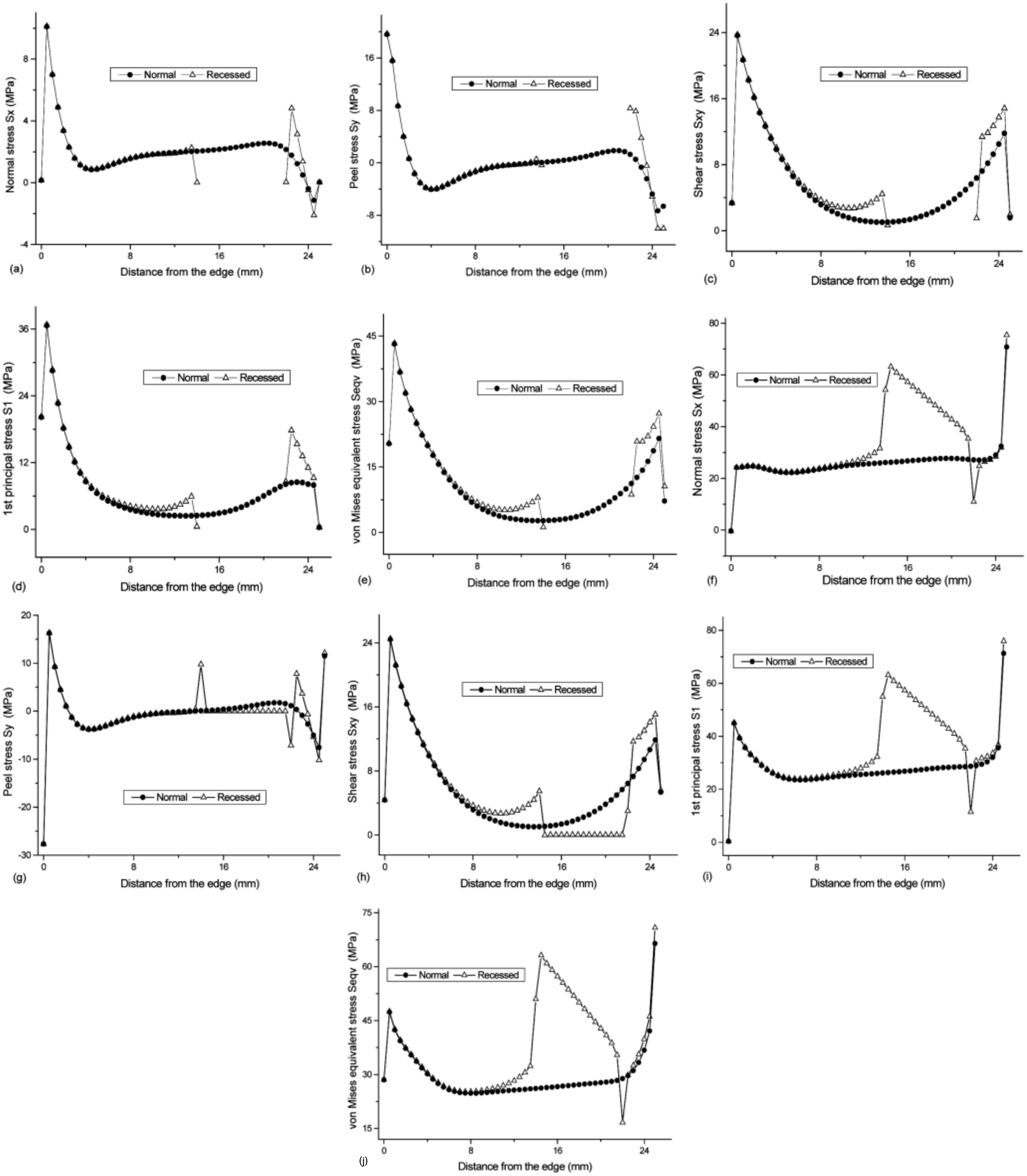

Figure 3. The effect of 8 mm length gap centered at x= 18 mm on the stresses distribution in double lap joint: normal stress Sx in (a) mid-adhesive and (f) adherend; peel stress *Sy* in (b) mid-adhesive and (g) adherend; shear stress *Sxy* in (c) mid-adhesive and (h) adherend; 1st principal stress *S1* in (d) mid-adhesive and (i) adherend and von Mises equivalent stress *Seqv* in (e) mid-adhesive and (j) adherend.

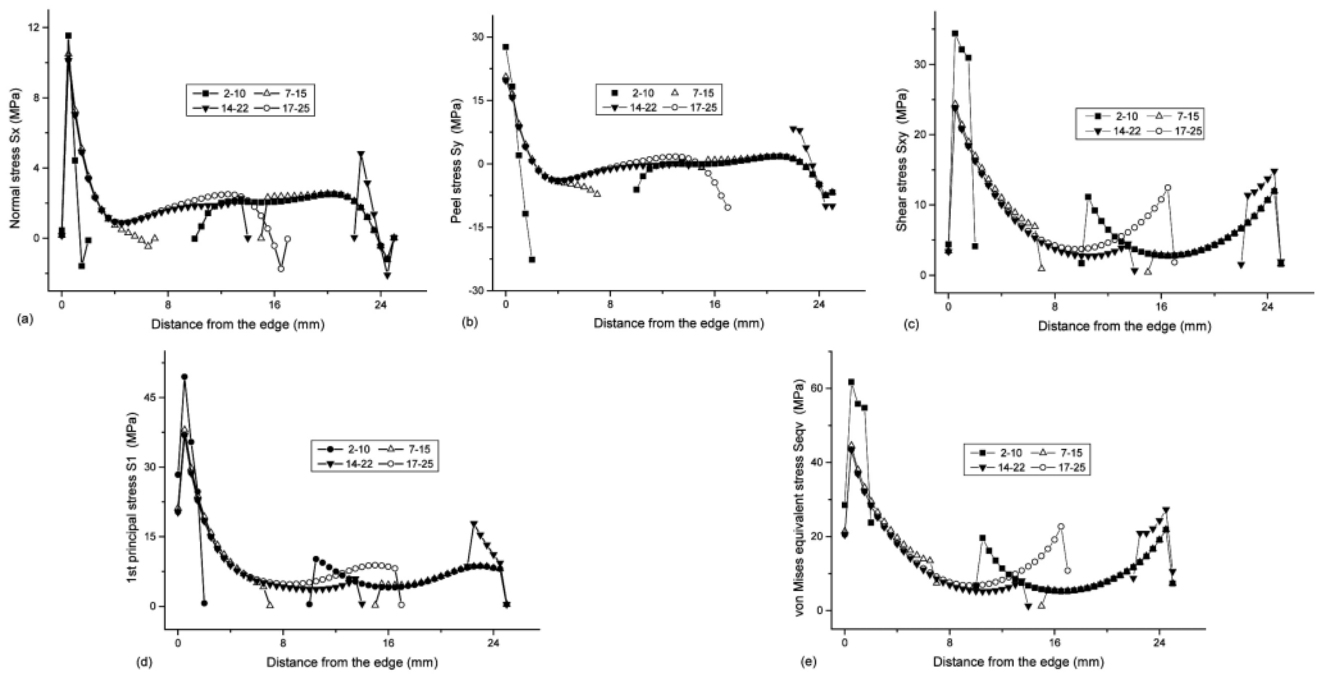

Figure 4. The effect of position of recess on the stress distribution in double lap joint within the mid-bondline: (a) normal stress *Sx*; (b) peel stress *Sy*; (c) shear stress *Sxy*; (d) 1st principal stress *S1* and (e) von Mises equivalent stress *Seqv*.

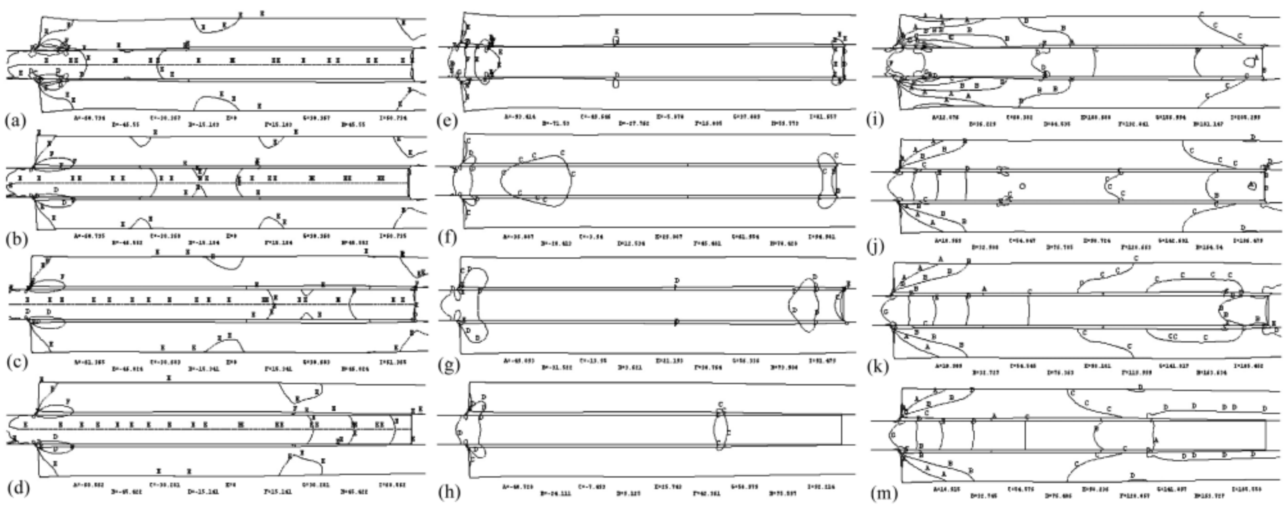

Figure 5. The effect of 8 mm length recess position on the stress distribution in double lap joint from left to right: shear stress *Sxy* of 2～10 mm (a), 7～15 mm (b), 14～22 mm (c) and 17～25 mm (d); peel stress *Sy* of 2～10 mm (e), 7～15 mm (f), 14～22 mm (g) and 17～25 mm (h); von Mises equivalent stress *Seqv* of 2～10 mm (i), 7～15 mm (j), 14～22 mm (k) and 17～25 mm (m).

riety of peak stresses was very small as the recess transferred in a wide range from the left part to the right end of lap zone in other three cases. For understanding the effect of recess position better the contour diagrams presenting the distribution of the stress *Sy*, *Sxy* and *Seqv* were shown in Figure 5 and the detail contour diagram of peel stress *Sy* in the left part of lap zone shown in Figure 6. In Figure 4(a) the normal stress *Sx* at the point x = 0.5 mm the peak value was about 34.4 MPa for a recess from x = 2 mm to x = 10 mm (recess symmetrical to the point x = 6 mm) as at least 41.6% higher than the other three peak values (recess

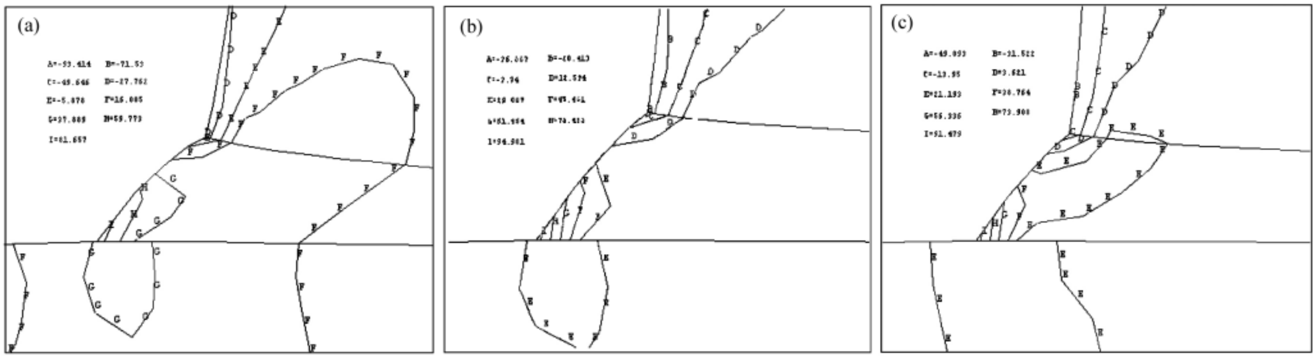

Figure 6. The detail contour diagram of peel stress *Sy* in the left part of lap zone: (a) 2～10 mm, (b) 7～15 mm and (c) 17～25 mm.

symmetrical to the point x = 11 mm, x = 18 mm and x = 21 mm respectively). From Figure 5 it could be seen the contour lines are more complex for the condition of the recess located near the left end of the lap zone in Figure 5(a), Figure 5(e) and Figure 5(i). But in Figure 6 the highest values of peel stress *Sy* (about 94.3 MPa, recess symmetrical to the point x = 11 mm) appeared at the toe of the right fillet in Figure 6(b) and the lower one (about 81.7 MPa, symmetrical to the point x = 6 mm) occurred in Figure 6(a). When the recess located at the right end of lap zone (recess symmetrical to the point x = 21 mm) there is no adhesive at all in the right part of lap zone, which means to reduce the lap length of the joint.

4. Conclusion

The effect of 8 mm length recess and its position on the stress distribution in the adhesively bonded aluminium double lap joint has been investigated using elasto-plastic finite element method and the following conclusions have been drawn:

The effect of 8 mm length off-center recess (arranged symmetrical to the point x = 18 mm) is not evidently on the peak stresses of double lap joint in the mid-bondline and the ultimate load of the joint might not be decreased markedly.

The peak stresses decrease gradually first and then increase a little again when the 8 mm length recess transfers from near the left end of lap zone to right one and the variety of peak stress is negligible. All the peak stresses reach their lowest values when an 8 mm length recess was arranged symmetrical to the point of x = 18 mm, and the peak stresses increase markedly when recess was located closed to the left end of lap zone (arranged symmetrical to the point of x = 6 mm).

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