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THE INFLUENCE OF GEOMETRIC PARAMETERS AND MECHANICAL PROPERTIES OF ADHESIVE ON STRESS ANALYSIS IN ADHESIVELY BONDED ALUMINUM SINGLE LAP JOINT

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Summary

The aim of this study was to investigate adhesively bonded joints, and the influence of geometric parameters and mechanical properties of the adhesive in single lap aluminum structures under tensile load. A finite element model has been constructed in the ANSYS FE package and the effects of adhesive thickness, rigidity, strength and geometry have been studied in order to adjust peel stress. Various paths have been defined and obtained along the length of the adhesive and aluminum joint overlap. The results indicate that by increasing the adhesive thickness, the stress concentration decreases in the areas prone to yielding if a flexible adhesive is used instead of a rigid one, and effective stresses along the overlap length are also reduced. In addition, for a given tensile force, three different adhesive area geometries are defined. Considering the variation of peel and shear stress along the corners, the amount of adhesive used according to the introduced geometries is saved without sacrificing joint strength.

Key words: *adhesive bonding, single lap aluminum joint, stress concentration, peel and shear stress*

1. Introduction

Nowadays, adhesively bonded joints have found a wide variety of applications in industry. Due to their favorable properties including simplicity of bonding and low weight, adhesives have been applied in aerospace, automotive and construction industries. Adhesively bonded joints have uniform stress and load distribution as well as better fatigue performance compared to bolted and riveted joints. Altering the geometry of a bonded joint will invariably cause changes in the stress and strain distribution. These differences can also have a profound effect on the stress concentrations and consequently the load capacity and long-term performance of the joint. In adhesive bonding, the load is transmitted from one adherend to another smoothly through the adhesive layer in the overlap region, i.e. the adhesive serves as a medium for load transmission. Over the years, single lap joints have been the most widely used adhesive joints and the subject of many research studies. Simplicity and service efficiency of the single lap design are also exploited for determining mechanical properties of adhesive joints and adhesives [1].

A number of theoretical, numerical and experimental studies have been carried out in this field. Preminilary analyses such as the ones performed by Volkerson [2] and Goland and Reissner [3] had unrealistic simplifications. A large number of Finite Element (FE) models have been used for analysis of single lap joints. One of the first FE models was introduced by Wooley and Carver [4]. They used a 2-D model and plane stress case for elements. Khalili [5] conducted a 3-D modelling of composite materials with elastic linear behavior. Reis et al. [6-7] investigated the effect of aluminum stiffness on shear strength of these joints and found that by increasing aluminum stiffness, the rotation angle of joint under the load is reduced and it would result in better distribution of stresses within adhesive layers. Castagnetti [8] expanded the FE techniques for stress analysis. Sheppard [9] introduced a damaged area for the analysis of yielded elements within the adhesive layer. Lucić et al. [10] conducted a study to find an optimum overlap length ensuring the settled bearing performance of the adhesive bonded joint. Solmaz and Turgut [11] experimentally and numerically examined the failures and strengths of joints bonded by a Neoxil CE92 N8 adhesive at different overlap lengths and different taper angles. He [12] reviewed recent work relating to the finite element analysis of adhesively bonded joints, in terms of static loading analysis, environmental behaviours, fatigue loading analysis and dynamic characteristics of adhesively bonded joints. He concluded that the finite element analysis of adhesively bonded joints will help future applications of adhesive bonding by allowing system parameters to be selected to give as large a process window as possible for successful joint manufacture. This will allow many different designs to be simulated in order to perform a selection of different designs before testing, which would currently take too long to perform or be prohibitively expensive in practice. Ozer and Oz [13] investigated the bi-adhesively bonded double lap joint by using three dimensional finite element methods. They concluded that the stress component decreases in hybrid adhesive joints compared with those in which single adhesives were used over the full length of the bond line and also stress components can be optimized by using an appropriate bond-length ratio. Xu and Wei [14] studied the strength and interface failure mechanism of adhesively bonded single lap joints subjected to tensile loading, focusing on the effects of various system parameters including the fracture energy of the adhesive layer, the overlap length and adhesive layer thickness on the load bearing capability of joints. They showed that the overlap length and the adhesive fracture energy have combined influences on the load-bearing capability. On the other hand, a preliminary damage analysis of the adhesive layer was carried out, considering the situations when loads reach peak values.

In this paper, a 2-D model of a single-lap aluminum joint is presented and the effects of different thicknesses of the adhesive layer, various geometric models of this layer, distribution of stresses in the center of the adhesive layer, the aluminum-adhesive interface and Young's modulus of the adhesive on the stress distribution along specified paths are investigated.

2. Volkerson's and Goland and Reissner's analytical models

Classical studies on adhesively bonded joints were first carried out by Volkerson and by Goland and Reissner. Volkerson's assumption was based on the deformation of the adhesive and aluminum only due to shear and tensile loads, respectively. Maximum stresses occur in the initial and final overlap points and therefore, yield begins at these points. Goland and Reissner took the effect of the bending moment in bonded joints into account and analyzed stresses in the center of the adhesive layer by testing Volkerson's sample model (Fig. 1) [15]. The defects of the classical studies are:

- The stress variation along the adhesive length was ignored, especially at the interface between adhesive and other material.
- Maximum shear stress occurs at overlapping corners, but we should greatly reduce it at the corners. This significant reduction can be seen in Fig. 2.
- Aluminum was considered as a thin beam and the effect of shear and peel deformations along the thickness was ignored.

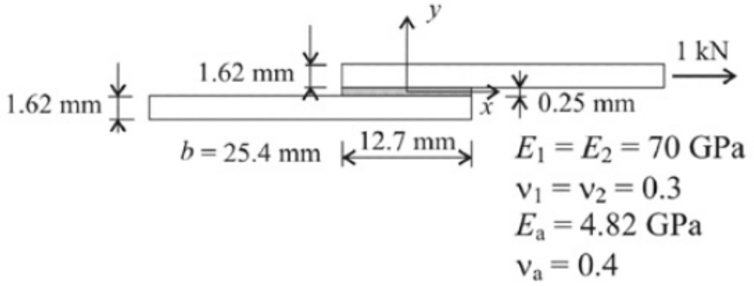
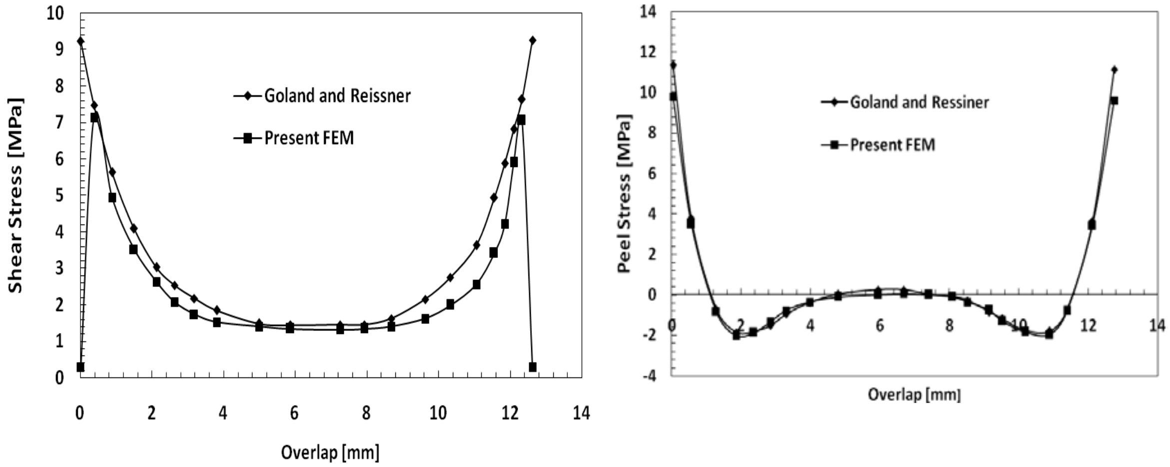


Fig. 1 The sample case of Goland and Reissner [15]



(a) (b)

Fig. 2 Stress distribution along the overlapping length of the Goland and Reissner sample case; a) shear stress, b) peel stress

3. Finite element modelling

Single lap aluminum joint consisting of two plates made of aluminum 7075-T6 of equal thickness of 5 mm and, epoxy adhesives (flexible and rigid), 0.2, 0.3 and 0.4 mm thick, are modelled in ANSYS. Mechanical properties of the used adhesives are shown in Table 1 [16]. The overlap length in all models was 50 mm and constant. Fig. 3 illustrates dimensions of the plates and the geometry of the single lap joint model.

Table 1 Mechanical properties of Aluminum7075-T6 and Adhesive Neoxil CE92 N8 [16]

No.	Materials	Mechanical properties
1	Aluminium	E = 71.5 GPa , $\nu = 0.33$
2	Adhesive	E_1= 2.50 GPa , $\nu = 0.25$ E_2= 4.82 GPa , $\nu = 0.25$

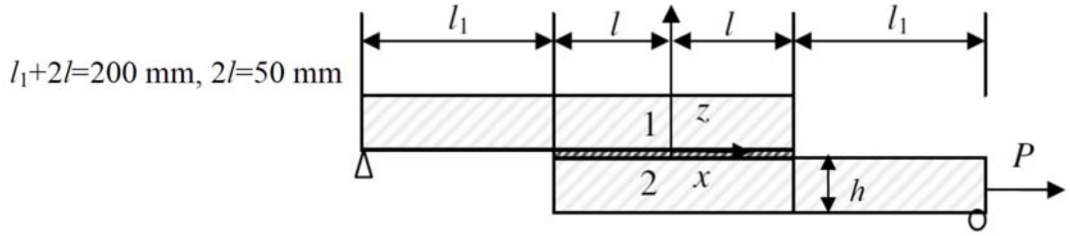


Fig. 3 The single lap joint model [16]

Regarding the stress concentration on the sides of the adhesive areas and the possibility of yielding and for the purpose of achieving higher accuracy of the analysis and the free boundary conditions, the mesh of the overlapping area was considered finer compared to other parts (Fig. 4). PLANE 82 element was used for the meshing of aluminum and adhesive and they are considered to have elastic behavior. The upper edge ending was fixed in all directions and the lower edge was under constant tensile load in all models.

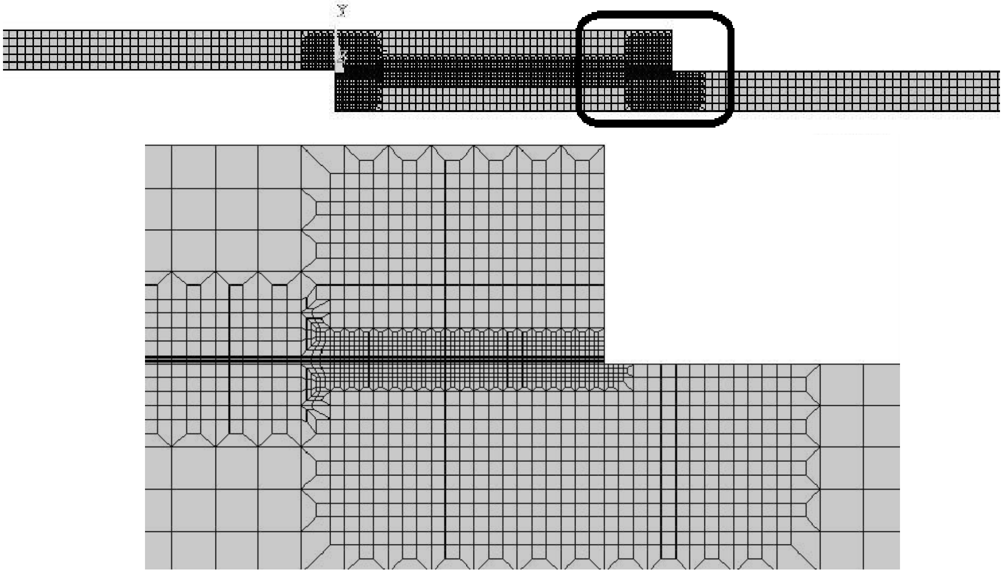


Fig. 4 FE model of adhesive joint under tensile load

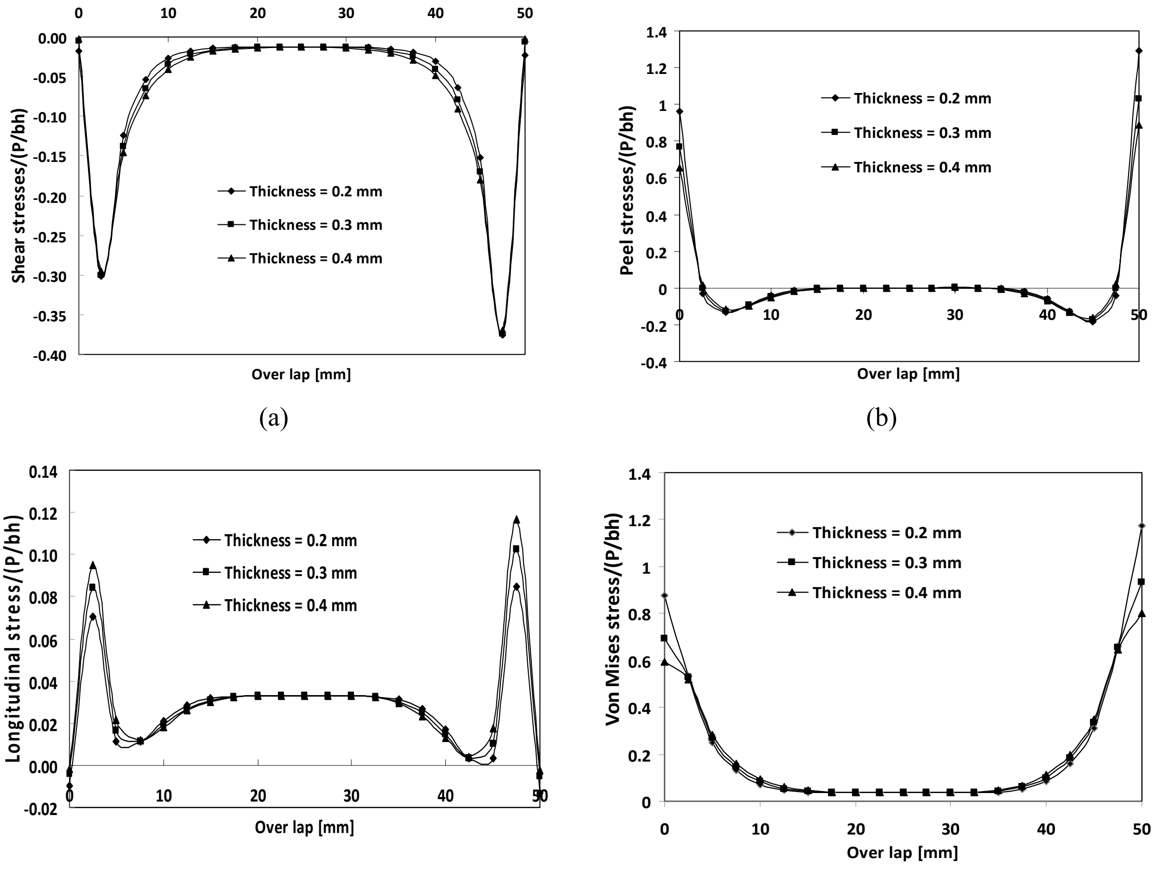
4. Results and discussion

4.1 Validation

In the analysis of adhesives used in mechanical joints, the shear and peel stresses have a significant role. For the validation of the FE solution of the adhesive joints, the obtained results for shear and peel stresses are compared with those of the Goland and Reissner sample case (Fig. 1). As can be seen in Fig. 2, there is a good agreement between them.

4.2 Effects of adhesive thickness on stress distribution

Fig. 5 shows the effect of adhesive thickness on the distribution of shear, peel, longitudinal and Von Mises stress in the center of the adhesive layer developed by the FE model. It is obvious that by increasing the adhesive thickness, stresses decrease and the effects of shear and peel stresses are more significant along the loading direction and in the center of the adhesive layer compared to the longitudinal stress. As evident from Fig. 5 the maximum difference between the stresses occurs at the edge of the overlapping area which can lead to a sharp increase in the stress concentration in these areas. These results are consistent with the ones achieved by Kawashita et al [17].



(a) (b)

(c) (d)

Fig. 5 Effect of adhesive thickness on: a) shear stress, b) peel stress; c) longitudinal stress, d) Von Mises stress

4.3 Checking gap existence within the adhesive layer

By observing the stress distribution within the adhesive layer and the existence of the minimal stress distribution in the central areas and the concentration of a large part of created stresses within the adhesive layer in the overlap edges, it is possible to remove a part of the adhesive used in low-stress areas. For this purpose, three arrangements for the boundary layer are created according to Fig. 6, as the normal case is the case without a gap. The second case (H1) is the case in which a half of the used adhesive is removed form the edges close to the loading and in the third case (H2) the length of the adhesion area is divided into two parts (12.5 mm) and each part is placed at the edges of overlapping. The influences of the adhesive layer arrangement in the center of the adhesive layer and the aluminum-adhesive interface on the distribution of shear, peel, longitudinal and Von Mises stresses are shown in Figs. 7 and 8, respectively.

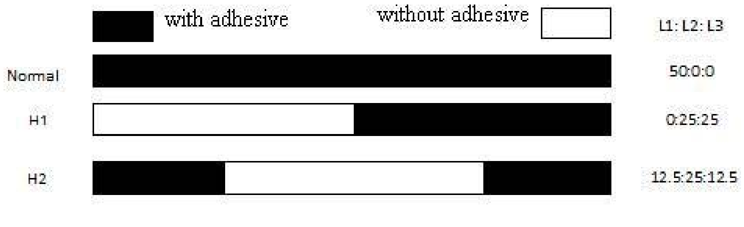
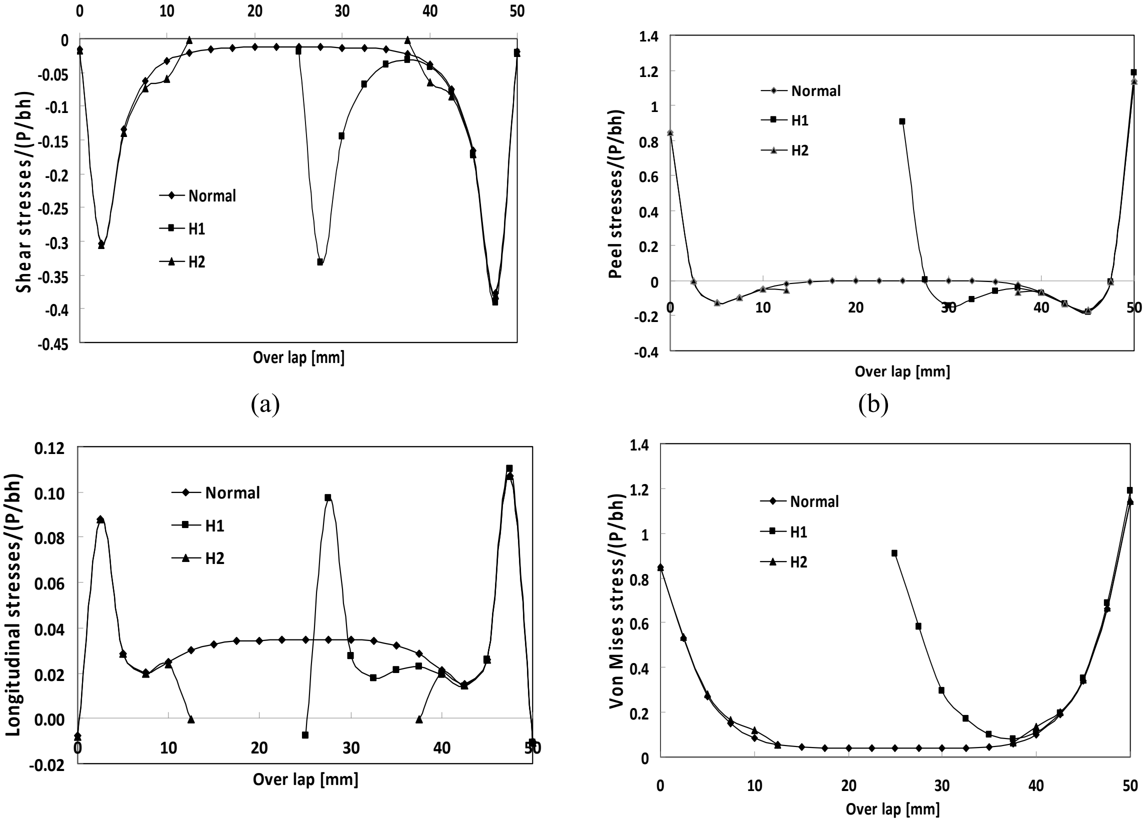


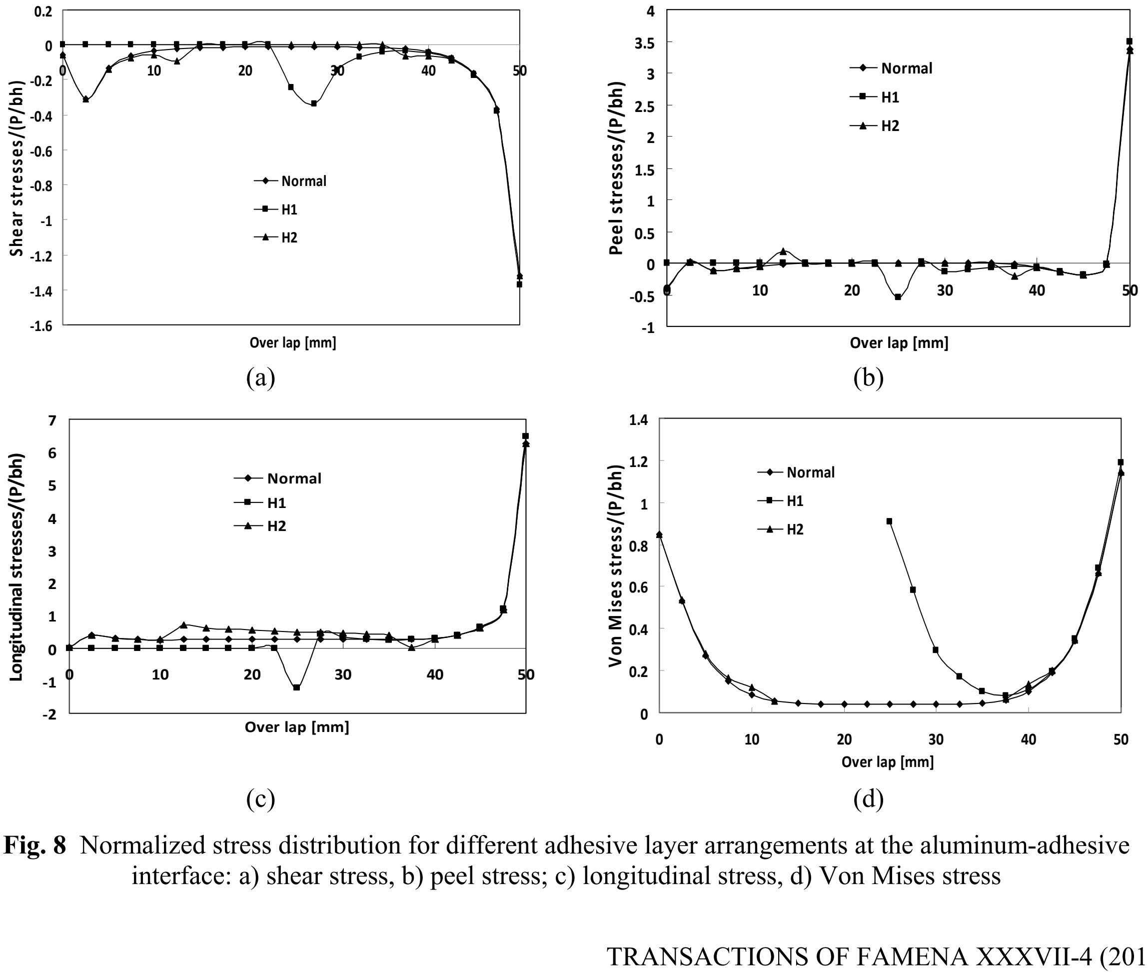
Fig. 6 Arrangement of adhesive layer along overlap length



(a) (b)

(c) (d)

Fig. 7 Normalized stress distribution for different adhesive layer arrangements in the center of adhesive: a) shear stress, b) peel stress; c) longitudinal stress, d) Von Mises stress



(a) (b)

(c) (d)

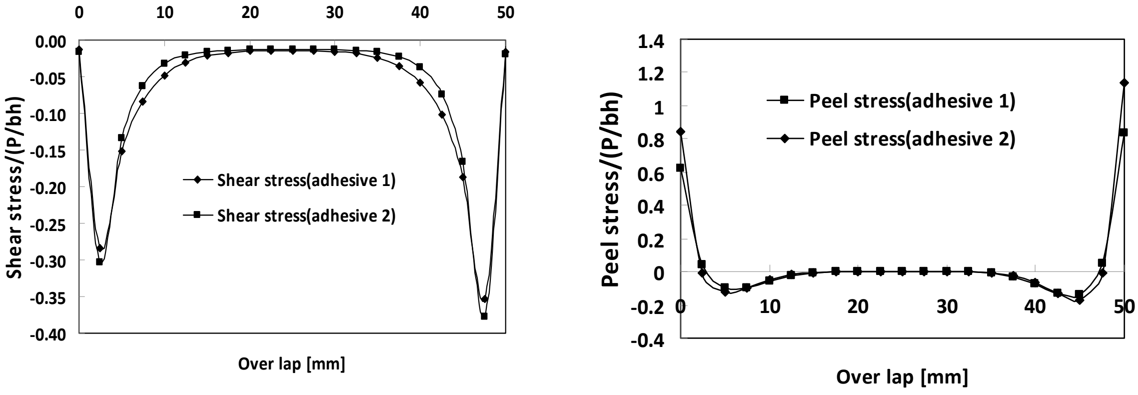
Fig. 8 Normalized stress distribution for different adhesive layer arrangements at the aluminum-adhesive interface: a) shear stress, b) peel stress; c) longitudinal stress, d) Von Mises stress

As can be seen in Figs. 7 and 8, despite the amount of the used adhesive, stress levels along the overlap length vary slightly and it is a very interesting result. In the case of no gap, the overlap edges have minimum stress concentration in sensitive areas. Maximum stress concentration occurs in the "H1" case. In the "H2" case, the amount of stress concentration is between the previous concentrations. Consequently, to save on the amount of the used adhesive, as well as to maintain the joint strength, the "H2" arrangement can be used according to the FE model.

To study the yielding of these joints, typically the adhesive yield patterns can be used for the prediction of the service life of joints [9]. In this area, especially in the overlapping corners due to joining of two nonhomogeneous materials, there will be a sudden increase in stress as shown in Fig. 8. The stress values on the left hand side corner of the overlapping area increase steeply indicating that most of the stresses resulted from the peel stress. Behavioural patterns of the stresses in this part are consistent with the patterns in Ref. [18].

4.4 Effect of elasticity modulus on peel and shear stresses

Two types of adhesive are used to investigate the effect of the adhesive's modulus of elasticity on the distribution of shear and peel stresses along the overlap length. The adhesive properties are given in Table 1. Fig. 9 shows the distribution of shear and peel stresses. In the case of constant tensile load and the utilization of adhesive with a high modulus of elasticity, these stresses have higher values compared to the flexible adhesive in the overlap corners, and hence the stress concentration will be higher in these areas.



(a) (b)

Fig. 9 Effect of adhesive's modulus of elasticity on distribution of: a) shear stress, b) peel stress

5. Conclusions

In this study, the effects of geometric parameters and mechanical properties of the adhesive in single lap aluminum structures under tensile load have been investigated. The finite element package ANSYS was used for modelling and analyzing the effects of adhesive thickness, type of adhesive, its geometry and modulus of elasticity on the shear and peel stresses along the overlap length. The obtained results show that by increasing the adhesive thickness, the effective stresses along the overlap length were reduced and by utilizing the flexible adhesive instead of the rigid one, stress concentration was reduced in areas prone to yielding. Moreover, taking into account the variation of peel and shear stress along the overlap corners, the amount of the adhesive used according to the introduced geometries was saved without sacrificing the joint strength.

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