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Finite Element Analysis of an Adhesively Bonded Single Lap Joint

Hafiz TA
Department of Mechanical Engineering Sciences, Faculty of Engineering and Physical Sciences, University of Surrey, Guildford, Surrey, GU2 7XH, UK

Khaliq A
Faculty of Engineering and Industrial Sciences, High Temperature Processing Group, Swinburne University of Technology, Victoria 3122, Melbourne, Australia

Abstract **- Finite element analysis (FEA) is applied to analyse a single lap adhesively bonded metallic joint. Three different parameters namely adhesive thickness, adherend thickness and crack length are selected and their effect on x-component of displacement and stress, vector sum displacement, Von Mises stress and crack opening displacement is studied. Results for each entity are discussed and hence presented. Different behaviour of x-component, vector sum and crack opening displacement for adhesive and adherend are noted. Finally overall conclusion is made.**

Keywords **- Adhesively Bonded Metallic Joint, FEA, Parametric Study.**

I. Introduction

FEA provides a cost effective way to explore the performance of products or processes in a virtual prototyping. With this technique, user repeats various scenarios to optimize the product before the manufacturing of the product is started. This study is for the same purpose. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces called elements. Number of boundary conditions and load conditions are applied to a node of an element/ group of elements. The FEA set up stiffness and load matrices and finally solve them to produce an equilibrium situation, therefore, generating results for each element. However, FEA results should not be used blindly. The results should be verified to well establish mathematical relationships and real world-experiences. FEA attributes lies in its ability to show complex engineering problem in a visually helpful manner. It is also well known that different materials in bonded structure influence the accuracy of numerical calculations. These changes in mechanical properties results in discontinuity of stresses acting at the adhesive-adherend interface. The discontinuity becomes important as the adherend-adhesive stiffness variation increases. Singularities generate at the free edges of the interface. To get accurate results for stress distribution, 3-D model is quite useful. But in the present analysis 2-D analysis is used as it simplifies the model and reduces computing time. Computations of 24-noded element type were generated using the ANYS 9.0 which is general-purpose FEA software.

II. Finite Element Model

2.1 In-put Data

A 2-D model of the object is constructed for the present analysis of single lap joint although 3-D model can also be presented but it is avoided due to complexity in analysis. In the present case, the thickness of adhesive was taken as 0.5mm whereas 2 mm thickness of adherend or substrate is taken in the basic model. Over-lap length of 70mm was taken and the crack length was 0.5mm. Poison’s ratio which is dimensionless quantity as being the ration between lateral to longitudinal strains is 0.4 and 0.3 for adhesive and adherend respectively in our present case. The model is then tested using the work plane co-ordinate system within ANSYS.

This is the basic model programme that was analyzed in the ANSYS. After the verification of the model, a number of changes in adhesive, adherend and crack length are assumed for studying the effect of these parameters on the overall results.

2.2 Material Properties

For the existing part, a library of the adhesive and adherend materials is defined. The adhesive was made up of epoxy material, FM73M while aluminium was selected for adherend/substrate. Hence from the composition of adhesive and adherend, it is reasonable to realize that the adhesively bonded metallic joint is used for the analysis.

2.3 Mesh Generation

At this point ANSYS understands the makeup of the part. At this point there is a need to define the process that how the modelled system should be broken down into finite pieces.

2.4 Boundary conditions

In order to define the problem correctly and to obtain a proper solution, it is necessary to use appropriate boundary conditions. Therefore, the following conditions are applied:

- The clamping is modelled by fixing the nodes in both longitudinal and transverse directions i.e. X and Y directions respectively.
- The loading is imposed by the application of a horizontal tension force, *F*. This load will be uniformly distributed along the normal surface.
- The displacements of the nodes in the transverse direction, *y*, are nill (zero).

2.5 Loading

Once the system is fully designed, the last task is to load the system with constraints, such as physical loadings or boundary conditions. In our present case a force of 100 Newton in the longitudinal direction is assumed.

2.6 Solution

This is very critical step, in this step ANSYS is directed within what state (steady state, transient… etc.) the problem must be solved. Once there is message in ANSYS that solution is done, then selecting general postprocessor and then deformed shape , user have option to analyse the solution whether only in deformed shape or deformed plus un-deformed shape etc. There are various options available for analysis and to plot results in different ways.

III. Results and Discussions

There are many ways to present ANSYS' results, any option can be selected from the many options such as tables, graphs, and contour plots. Only four options from the number of available parameters were selected for the present study. The following table of values was obtained during working on the basic model. The basic model interpretation is shown with the graphical representation. The changes in the model and their effects are presented in the appendix.

3.1 Basic Model

These are the graphical representation obtained from finite element programme ANSYS, along each figure it has been shown with the effect of the respective parameters.

Keeping the above model as basic, a number of changes were made and the results for each specific change in the basic model keeping others unchanged were noted. The detailed discussion can be found in the following sections.

3.2 Effect of Adherend thickness

Five parameters namely crack opening displacement, displacement in X-direction, vector sum displacement, stress along X-axis and Von Misses stress were selected. Adherend thickness change of 1, 1.5, 3 and 4 *mm* were made in the basic model. The effect of each change on each parameter was noted and presented. Graphical presentation for each parameter is attached in the appendix.

The figures show the maximum stress in the X-component and Von Misses stresses as a function of the adherend thickness. It is apparent that for thin adherends, the stresses increases. This is very likely due to high geometric deformations experienced by the thin adherends (low stiffness). For high thicknesses, the stiffness of the adherend increases and the geometric deformations become negligible. Thus, the stresses decrease significantly and the load transfer is improved. One may then conclude that there exists a thickness at which the Von Misses stresses reach a maximum, as shown in the figure.

Figure 6 was used to show the response of adherend thickness on the X-component of displacement as well as on the vector sum displacement. It is quite clear that there exist an inverse relationship between displacement and the adherend thickness i.e. when the adherend thickness gets thinner the related displacement get larger. The main reason is that specimen used for adherend was of Aluminium alloy of 70 MPa Young Modulus. Hence a very stiff material was used for the present case of FE analysis. Therefore this stiffer material as gets smaller in thickness allows for larger displacement and similarly when there is gradual increase in thickness of the adhesive then gradual decrease in displacement for both selected parameters is obvious from the figure. It would be interesting to note the same parameters effect in case of adhesive.

Similarly the effect of crack opening displacement was noted and observed that as the thickness gets larger, crack opening displacement also gets smaller which is clearly shown in Figure (7). Hence to keep COD minimum (which is needed in any case) stiffer adherend are preferred.

3.3 Effect of Adhesive thickness

Like the effect of adherend change section, similar five parameters are presented for adhesive thickness. Adhesive thickness change of 0.1, 0.2, 0.3 and 0.4 *mm* were made in the basic model. The effect of each change on each parameter was noted and presented.

Although it seems logical that increase in the bond-line thickness improves the joint strength. However, Figure (8) shows that this is not correct because an optimum bond-line thickness, for which the maximum stresses are reduced to minimum values, exists. Therefore, for that adhesive thickness, the strength of the adhesive joint is the maximum. For the present case, in the basic model of 0.5 mm and 2 mm thickness adhesive and adherend respectively, the maximum stress in x-component of stress and Von Mises stress are 481.42 and 316.96 MPa respectively. But at 0.3 mm thickness of adhesive, keeping other parameters unchanged, the maximum decrease in stresses was observed to 481.18 and 319.43 MPa respectively. On the other hand, for many applications, the manufacturers recommend an adhesive thickness usually between 0.1 and 0.2 mm for maximum joint strength.

Figure (9) is plotted using adhesive thickness against the X-component of displacement as well as vector sum displacement.

Figure (9) shows that there is a direct relationship between adhesive thickness and displacement in the present case. The adhesive material was very flexible not stiffer as in the case of adherend hence the relationship shown varies from that shown in the case of adherend.

In Figure (10) adhesive thickness was plotted against the crack opening displacement (COD). It is crystal clear that as the thickness of adhesive gets smaller the related COD gets smaller too and vice versa. Hence this also suggests that why the thinner adhesive is preferred over thicker adhesive. One reason is of course to keep crack opening displacement minimum because COD is not a positive factor favouring any advantage in analysis of structures rather negative and needs to keep small.

3.4 Effect of Crack Length

Like the adherend and adhesive, set of five similar parameters were considered. Crack length change of 0.25, 1, 2 and 2.5 *mm* were made in the basic model. The effect of each change on each parameter was noted and presented. It is interesting to note that when crack length was less, the stresses were higher in the region but these starts to decrease when crack increases as at this point less stresses would propagate the crack to failure.

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It was observed that when the crack length decreases, the stresses are increased and vice versa. To show the effect of crack opening displacement on the crack length, Figure (11) is quite helpful. This depicts that there is a direct relationship between crack length and crack opening displacement. Hence the need comes that the crack length should be kept less in case to avoid larger CODs.

It is worth to note from the above discussion of the parametric study of the analysis that crack length and adhesive thickness are directly proportional to the x-component, vector sum as well as crack opening displacements. Hence the adhesive thickness and crack length should be small to avoid lager displacements which will ultimately lead to faster crack growth. It is also obvious from the above results that adherend thickness show inverse proportion to the displacement hence favouring in minimizing crack growth rate. Therefore it is recommended that stiffer adherend with proper thickness should be utilized.

IV. Conclusions

Finite element studies has been applied to single lap joint and it has been found through FEA results that stiff and more strengthen adherendS are preferable over less stiffer ones because the former would minimize the crack opening displacement which is the ultimately required to have crack propagation minimum. It was also interesting to note that thinner adhesives and smaller crack length will also favour in minimizing crack opening displacement as well as vector sum displacement.

V. Appendix

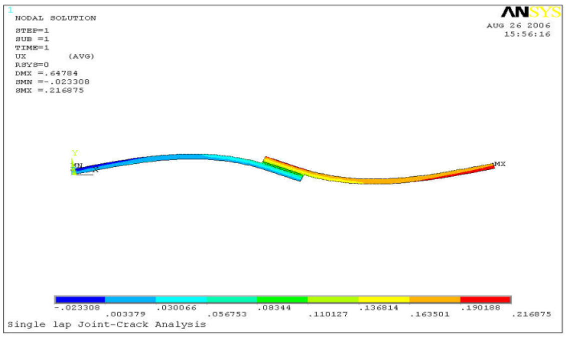

Fig.1. Basic Model Effect of X-Component of displacement

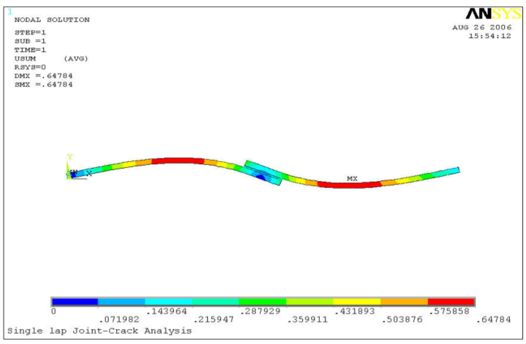

Fig.2. Basic Model: Effect of Vector Sum Displacement

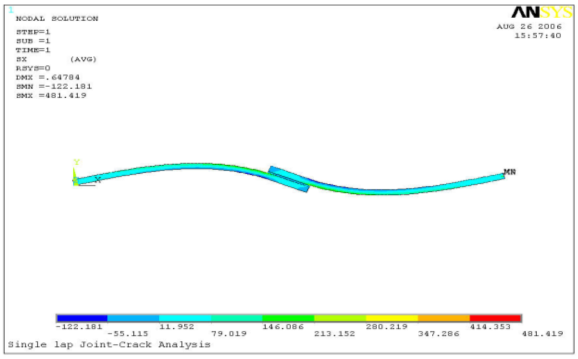

Fig.3. Basic Model: Effect of X-Component of Stress

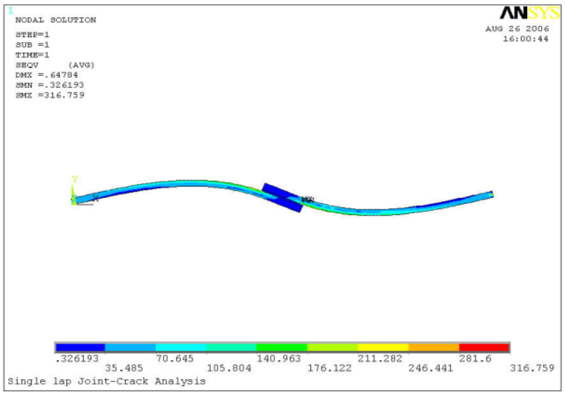

Fig.4. Basic Model: Effect of Von Misses Stress

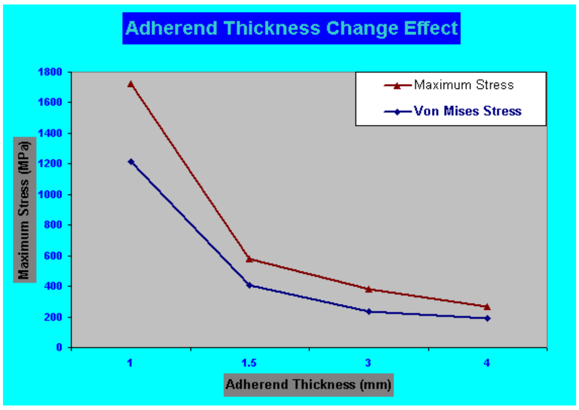

Fig.5. Effect of Adherend Thickness on Stress

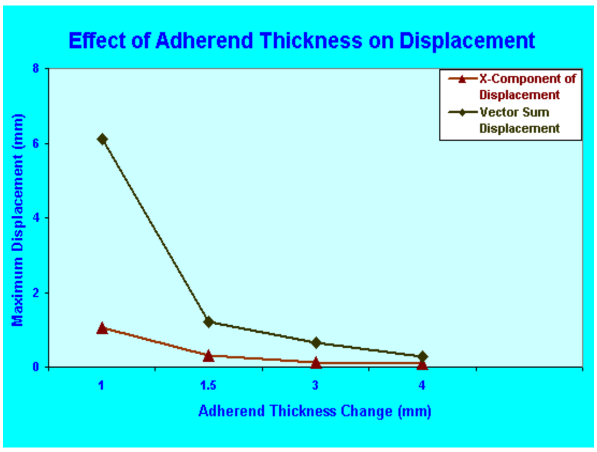

Fig.6. Effect of Adherend Thickness on Displacement

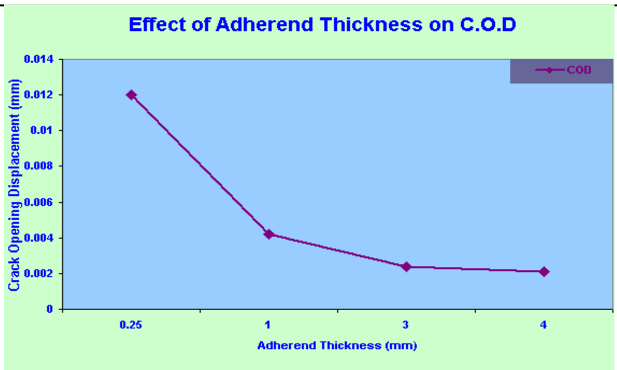

Fig.7. Effect of Adherend Thickness on C.O.D

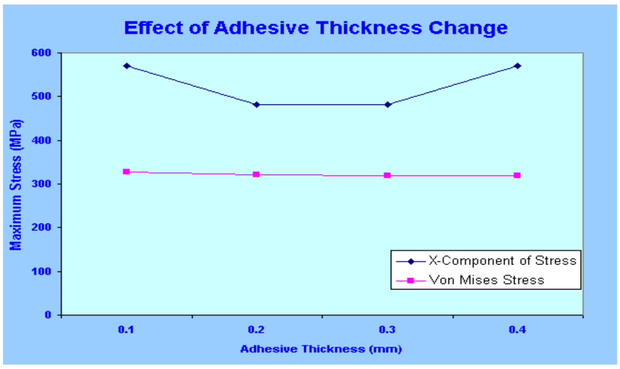

Fig.8. Effect of Adhesive Thickness on Stress

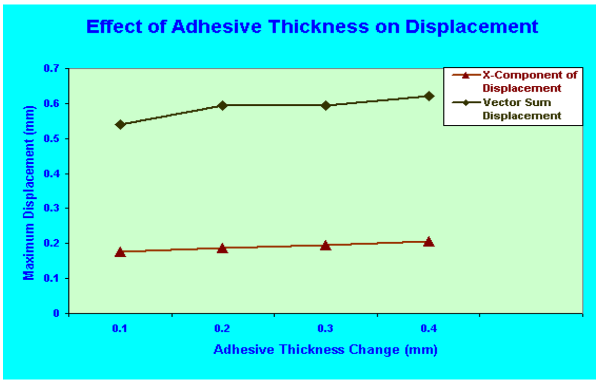

Fig.9. Effect of Adhesive Thickness on Displacement

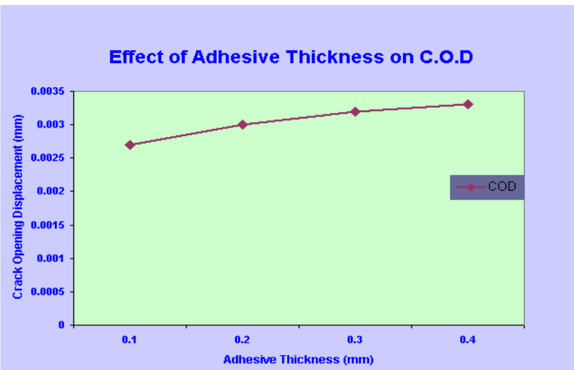

Fig.10. Effect of Adhesive Thickness on C.O.D

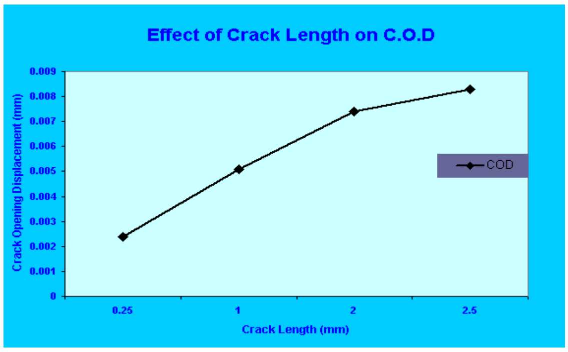

Fig.11. Effect of crack length on C.O.D

AUTHOR'S PROFILE

Dr. Hafiz Ali

completed his B.Sc. with Honours in Industrial and Manufacturing Engineering (IME) from University of Engineering and Technology(UET) Lahore, Pakistan in 2004. He then secured MSc with Merit in Advance Manufacturing Management and Technology (AMMT) from University of Surrey, UK in 2006 and PhD in 2011 from the same University.

Hafiz is currently working on an EU funded consortium involving developing nonlinear ultrasonic techniques to allow the determination of bond strength in composite structures. The key research challenges are interpreting the complex nature of the transmitted nonlinear signal and optimizing the operating point selection for thin specimens. Main challenges include: Experimental demonstration of various nonlinear ultrasonic techniques in thin specimens, Development of models to allow easy selection of a guided wave operating point for inspection of thin components and Usage of nonlinear guided wave inspection techniques to investigate the levels of nonlinearity present in thin composite specimens of varying bond strength.