THERMO-MECHANICAL STRESS ANALYSIS OF ADHESIVELY BONDED DOUBLE LAP JOINT

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ABSTRACT

The purpose of this paper was to design a joint which can withstand low to high temperature, to achieve that strength mixed adhesive technique has been used. Brittle adhesive used for high temperature and ductile material used for low temperature. The use of such kind of joint is essential for supersonic aircraft and space related equipment. Hart-Smith had described this mixed modulus concept at very beginning. For different temperature loading brittle adhesive has been used in the middle and ductile adhesive in the ends. The finite element method has been used for numerical analysis. Stress distribution has been analysed for titanium/titanium single and double lap joints. It has been seen that mixed adhesive concept is more successful than single adhesive.

Keywords: Adhesives, Double lap joint, Finite element analysis, joint design, Properties of adhesive and titanium.

I. INTRODUCTION

Adhesive bonding is a material joining process in which an adhesive placed between the adherend surfaces solidifies to produce an adhesive bond. Adhesive bonded joints have advantage over other joining methods through lower structural weight, lower fabrication cost and improved damage tolerance. Now a days adhesives are used in many industries, for example, aerospace, automobile, electronics and Defence. Many of them manufacture products which have work under very different environmental conditions. Temperature variation is one of the biggest parameter. So therefore, to overcome with such problem development of adhesive joints which can withstand different temperature gradients are very necessary. Adhesives which can operate at high temperature are usually brittle at low temperatures, on the other hand for low temperature adhesives used are ductile in nature. Ductile adhesive has low strength at high temperature and brittle adhesive has low strength at low temperature. To overcome this situation mixed adhesive technique has been used. In present scenario, we don't have such adhesive which can operate from -55ºC to more than 200ºC without failure. Adhesive joints used in aerospace needs to withstand low and high temperature. For example, if a supersonic aircraft flies at

Mach 2.7, the air friction at this speed would generate a surface temperature of about 232ºC. A theoretical analysis of the adhesive shear stress distribution has shown by Lucas F.M. da Silva and R.D. Adams [1] that the mixed adhesive joints allows operation from low to high temperatures with the combination of a LTA and a HTA. Compared to a joint with HTA or LTA alone, the mixed adhesive joint decreases the stresses in the HTA at low temperature and LTA at high temperature. Hart and Smith [2] proposed a simple analytical model by considering that the adhesive layer has perfect elasto-plastic behaviour. He could show the maximum load that an adhesively bonded joint can transfer depends on the shear deformation energy of the adhesive layer, regardless of the stress-strain curve. This approach allows a better prediction of the mechanical behaviour of ductile adhesive layer.

Halil Özer and Özkan Öz [3] have performed finite element analysis for four different bond-length ratios (0.2, 0.4, 0.7 and 1.3) on a 3D model of a double lap joint. From the results, it can be predict that the stress components can be optimized using appropriate bond length ratios. Lucas F.M. da Silva and R.D. Adams [4] have experimentally shown that, for a joint with dissimilar adherends, mixed adhesive provides better performance over the temperature range than a high temperature adhesive alone. Elena M. Moya-Sanz et al. [5] have evaluated the effect of variations in the geometry of the adherends and the adhesive on the mechanical strength of a single lap joint subjected to uniaxial tensile load. Different geometries of joints have been studies, like adherends recessing and chamfering of the adhesive and adherends. Vertical displacements, peak stress and the failure load of the adherends have been analysed. Lucas F.M. da Silva and R. D. Adams [6] have described techniques to reduce the peel stresses in the composite and to increase the strength at low temperature. To achieve that, an internal taper and adhesive fillet arrangement can be use, if the thermal stresses are not important and adhesive has a high tensile strength. In this paper model geometry and meshing have been validated through Numerical analysis by using ABAQUS software. After validation, I have changed loading and boundary conditions. Analysis has been done for Supersonic Aircraft at Mach 2.7. The purpose of this analysis to design a joint which can operate at different temperature loading.

II. FINITE ELEMENT ANALYSIS

2.1. Modeling of double lap joint

The double lap joint specimen considered for the present analysis is shown in Fig.1. The length of the joint is taken as L= 0.23m, top and bottom adherend thickness h_1 = 0.002m, main adherend thickness h_2 = 0.004m, thickness of adhesive layer t_a = 0.001m, width W = 0.025m, distance along the bond length (2a+b) = 0.05m.

All adherend are made up of isotropic material Titanium. The thickness of main adherend is taken as 0.004 m. Mechanical properties of titanium are given in Table I. Two types of adhesives are used in the present analysis. The first one is ductile adhesive (low modulus) and the second one is brittle adhesive (high modulus).

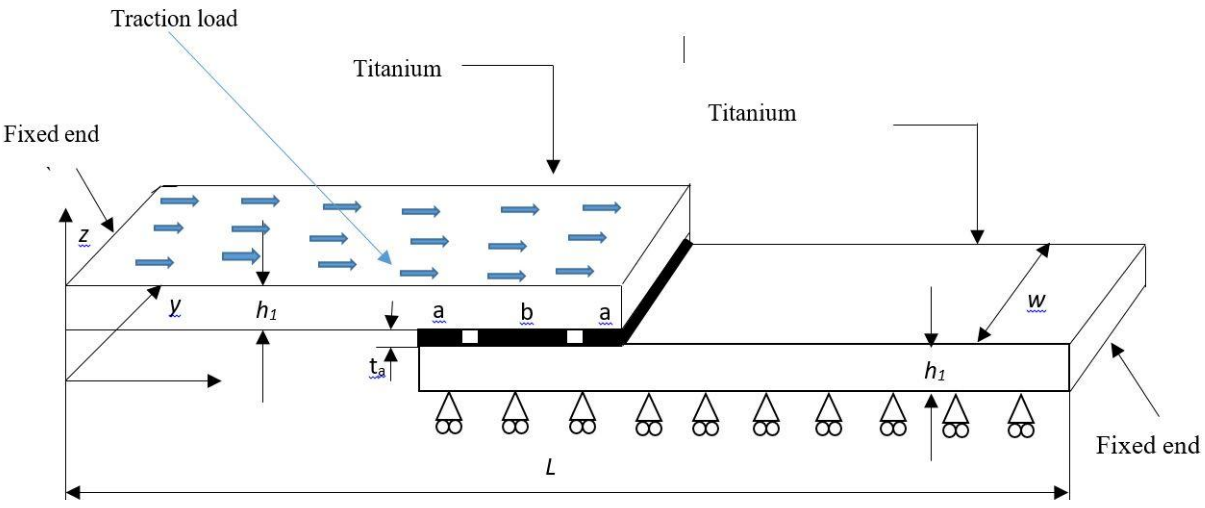

Fig.1. Double lap joint specimen Titanium.

Table I. Titanium (Ti-6Al-4V) adherend properties measured according to Lord [8]

Temp (ºC)	E (GPa)	Poisson's ratio, ν	σ_y (MPa)	CTE (1/°C)×10^{-6}
-55°C	110	0.33	1062	8.5
22°C	106.3	0.33	935	8.5
100°C	102.4	0.33	852	8.5
200°C	97.2	0.33	721	8.5

The possible failure modes considered here are:

(i) Shear yielding of the adhesive (centre line of adhesive layer)

(ii) Tensile yielding of the adherends at the overlap

The stiff or brittle adhesive HTA modelled in this investigation was Redux326 (Hexcel Composites), and the ductile or less stiff LTA was Supreme 10HT (Master Bond), which is modified epoxy. The brittle adhesive (Redux326) has a service temperature of up to 230ºC. The mechanical properties of the ductile and brittle adhesives given in Table II and Table III respectively. The glass transition temperature of supreme HT (low temperature adhesive) is 135ºC.

Table II. Supreme 10HT (Low temperature adhesive) properties measured according to Lord [8]

Temp (ºC)	E (GPa)	ν	τ_y (MPa)	CTE (1/°C)× 10^{-6}
-55°C	4.89	0.36	45.0	58
22°C	3.45	0.36	33.0	58
100°C	2.18	0.36	21.1	58
200°C	0.04	0.5	2.7	58

Table III. Redux326 (High temperature adhesive) properties measured according to Lord [8]

Temp (ºC)	E (GPa)	ν	τ_y (MPa)	CTE (1/°C)× 10^{-6}
-55°C	5.50	0.35	39.3	50.6
22°C	4.44	0.35	36.6	50.6
100°C	3.56	0.35	29.3	50.6
200°C	1.24	0.35	19.7	50.6

2.2. Meshing of double lap joint

A good meshing has been developed of a 2D model in ABAQUS software. Element size for part instance and edge instance have been taken 2 mm and 1 mm respectively.

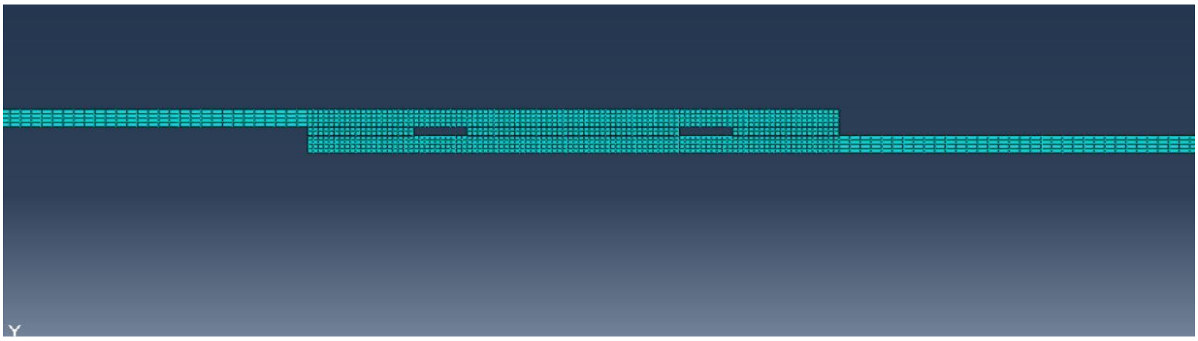

Fig.2. Finite element mesh of double lap joint

III. RESULTS AND DISCUSSIONS

Two dimensional finite element analysis have been carried out on the double lap joint made of Titanium/Titanium adherends. Shear Stress vs overlap length graph have been plotted. Validation of model geometry and meshing have been done with published work by Lucas F.M. da Silva and R. D. Adams [1]. A comparison has been done between published work (Fig.3) and present work (Fig.4). Graph has been plotted against each other to verify results.

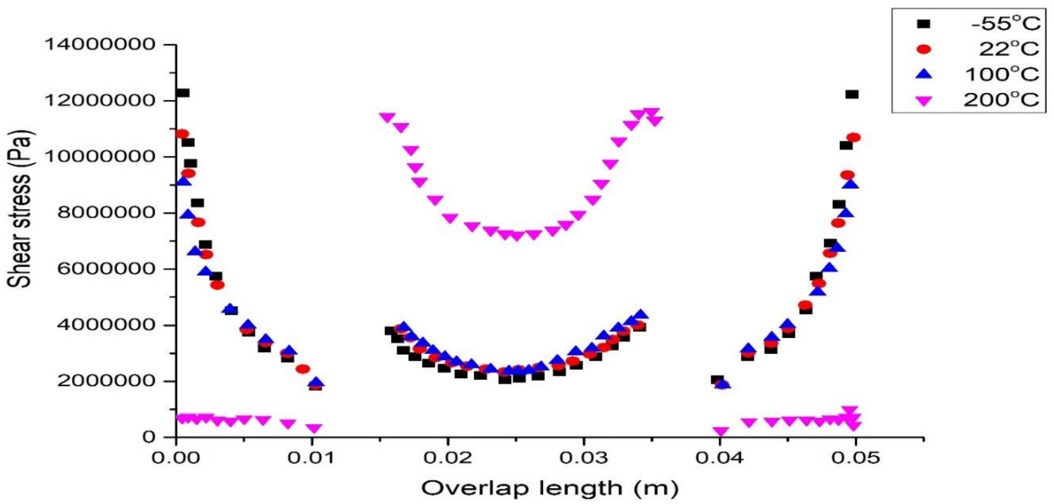

Fig.3.

SLJ adhesive shear stress distribution for a 5 KN load [1]

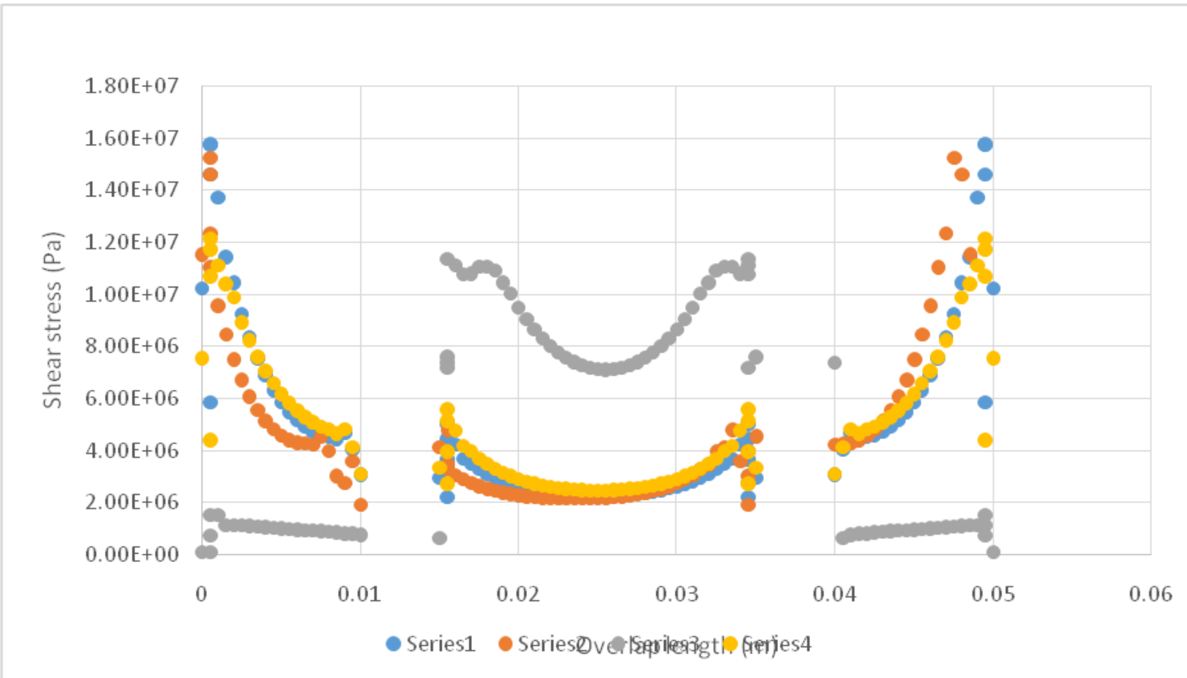

Fig.4. SLJ adhesive shear stress distribution for a 5 KN load

Series 1, 2, 3 and 4 are used for 22ºC, -55ºC, 200ºC and 100ºC respectively.

From the above graphs it can be seen that model geometry and meshing are used have given good results. So it can be used for further study.

Now I have changed my loading and boundary conditions in my present study and analysis has been performed under different temperature loading conditions. Analysis has done for Mach 2.7 (926.1 m/s). At this Mach no, surface temperature of plate would be 232ºC due to air friction and surface load will be 2.57E3 due to air traction. Results have been plotted below.

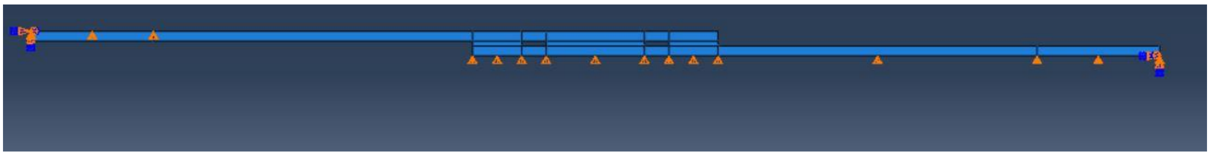

Fig.5. Basic model geometry of DLJ with boundary conditions

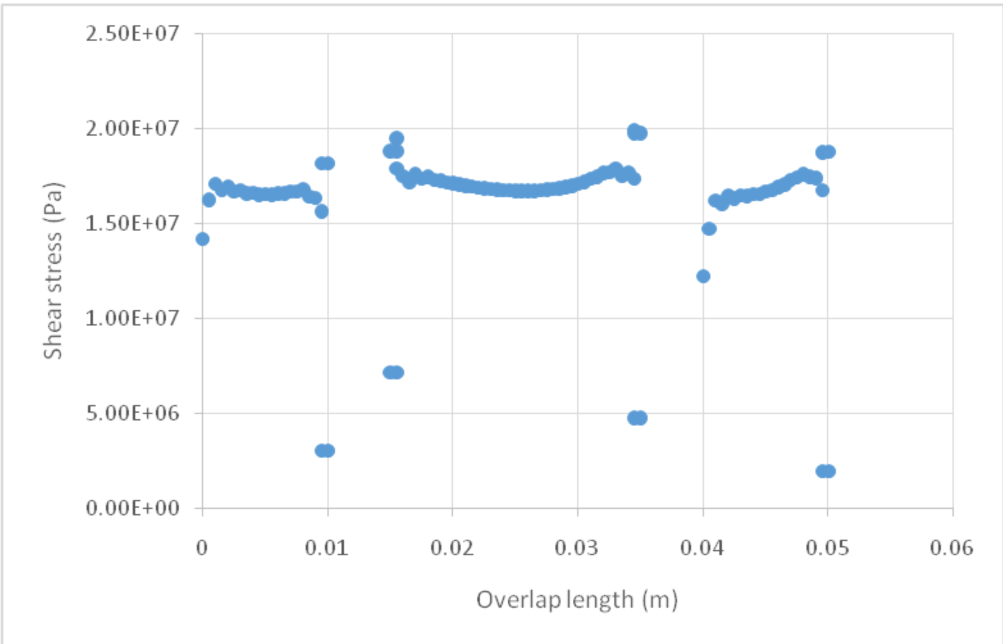

Fig.6. DLJ adhesive shear stress distribution for a 7.397 N load at 232ºC

As we can see from the above results, traction load is very less compared to previous analysis but still shear stress is very high due to high temperature loading. So we can't ignore temperature effect during analysis. It can be observe, if we use low temperature adhesive (less stiff) in place of mixed adhesive. Joint will fail at high temperature because of its low strength at high temperature. There have been some discontinuity found in adhesive gap and those can be rectify by improving the joint design.

IV. CONCLUSION

A numerical analysis of adhesive stress distribution has shown that the mixed adhesive joint allows operation from low to high temperatures with the combination of a ductile adhesive and a brittle adhesive. The joint will have better strength with ductile adhesive alone at low temperature or brittle adhesive alone at high temperature but vice versa is not possible. For that we need mixed adhesive, so we can operate at low as well as high temperatures. From Fig.3 and Fig.4, I have validated my geometry and meshing. Results have been compared with published results (Fig.3). After fully comparison, I have changed my loading and boundary conditions. Now analysis of supersonic aircraft at mach 2.7 with surface skin temperature 232ºC has been done. Graph has been plotted between shear stress and overlap length. In future, experimental analysis can be perform and validation can be done.

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