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SIMULATION OF JOINT STRENGTH OF SINGLE LAP JOINT OF COMPOSITE PLATES BASED ON VARIATIONS OF PLATE THICKNESS AND OVERLAP LENGTH

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Abstract – In this study, finite element simulation of joint strength of single lap joint of composite plates based on variations of joint thickness and overlap length is presented by using ANSYS software. In the simulation, plate thickness and overlap length of the joint structure are varied. Based on the variations of plate thickness and overlap length, it is found that the largest joint strength is obtained at the values of plate thickness and overlap length of 2 mm and 55 mm, respectively. Also, it appears that the applied loading type will affect to the simulation results.

Keywords: Joint strength; single lap joint; adhesive; composite plate; optimum

1. Introduction

Composite is a combination of two or more materials on the macroscopic scale to produce a better new material with higher quality. Some properties that can be improved with composite materials are fatigue life, strength, stiffness, corrosion resistance and many others. The increase use of composite materials hence necessitates joining as well. Adhesive joint has succeeded in replacing conventional mechanical joint techniques using bolts and rivets because its ability to eliminate strength losses due to the presence of locations of stress concentration in the conventional mechanical joints. Adhesive joints are widely used for composite structures under static and dynamic loadings. The service life of adhesive joints is hence a major consideration in the composite structures because static and dynamic loads can cause local failure and fatigue in both adhesive and adherend materials. As a result, the static and dynamic characteristics of the adhesive joint become very important in its applications (Adams, 1989; Hart-Smith, 1973; Aydin et al., 2005; Gunes et al., 2007; Apalak and Yildirim, 2009).

In recent years, studies on strength of adhesively bonded joints have been an active research area. Raos et al. (2007) pointed out that increasing the overlap length of adhesively bonded joints makes the joint strength increases due to the increase in joining area. The effect of adherend thickness has been investigated by Lee et al. (2013). Furthermore, the effects of different overlap lengths and composite adherend thickness on the performance of adhesively-bonded joints under tensile and bending loadings have been discussed by Kadioglu et al. (2018). In another study, the behaviour of single lap joints under bending loading has been investigated by Karachalios et al. (2013). In addition, He (2012) presented numerical and experimental investigations of the dynamic response of bonded beams with a single-lap joint. Furthermore, Shishesaz and Hosseini (2018) presented an overview on the effects of joint geometry and material on stress distribution, strength and failure of bonded composite joints.

In this study, finite element simulation of joint strength of single lap joint of composite plates based on variations of joint thickness and overlap length is presented by using ANSYS software. In the simulation, plate thickness and overlap length of the joint structure are varied, from which the simulation results of the investigated joint strength are presented and discussed accordingly.

2. Materials and Method

2.1. *Adhesive Joint*

In engineering applications, adhesive has a high effect on the strength of joint structures (Campbell, 2010; Ebnesajjad, 2010). Moreover, the strength of joint with adhesive has the optimum value when the thickness of adhesive is in the range of 0.05 to 0.5 mm (Adams, 1989). Also, elastic analysis shows that the stress distribution of thin adhesives is more uniform than that of thick adhesives as thicker adhesives may contain defects such as voids and micro-cracks. Various loading types on a adhesively bonded joint are shown in Fig. 1.

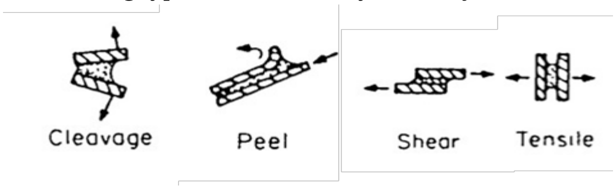

Fig. 1. Basic types of loading on a adhesively bonded joint.

Commonly, a lap shear stress test is carried out to evaluate and assess the strength of adhesive joint under the shear influence. This test is one of the most frequently used tests as it is inexpensive, easy to make and simple to do (Petrie, 2000). The standard used is ASTM D 3165. The lap shear stress is given by:

$$\tau = \frac{P}{bl} \tag{8}$$

where: P is the given load, b is the joint width, l is the overlap length and τ is the adhesive shear stress.

If the adherends are rigid, the stress distribution will be uniform, whereas if the adherends are elastic then the stress distribution will be non-uniform, as shown in Figs, 4(a) and (b). In the non-uniform case of stress distribution, the stress value at the joint ends will be higher and gradually decreases at the mid-overlap as illustrated in Fig. 2.

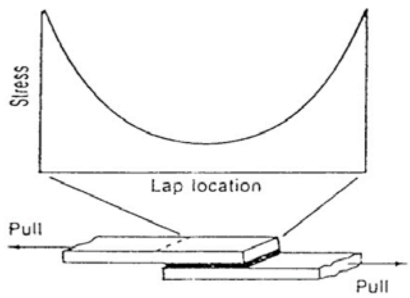

Fig. 2. Stress distribution in the adhesive region when the stress is on the shear.

2.2. *Micromechanics*

Composite micromechanics can be used to predict the properties of a composite by using rule of mixtures (Chawla, 1998; Jones, 1999), as given by the following equations:

$$E_1 = E_f V_f + E_m V_m \tag{1}$$

$$E_2 = \frac{E_f E_m}{E_f V_m + E_m V_f} \tag{2}$$

$$G_{12} = \frac{G_f G_m}{G_f V_m + G_m V_f} \tag{3}$$

$$v_{12} = v_f V_f + v_m V_m \tag{4}$$

$$\rho = \rho_f V_f + \rho_m V_m \tag{5}$$

$$\frac{v_{21}}{E_2} = \frac{v_{12}}{E_1} \tag{6}$$

where: E_1 is the longitudinal elastic modulus, E_2 is the transverse elastic modulus, G_{12} is the shear modulus, v_{12}, v_{21} are the Poisson ratios (major and minor), and ρ is the density.

In this study, the composite material used is unidirectional laminate composite (IM-6/3501-6) made of IM-6 (graphite fiber, Hexcel) and 3501-6 (epoxy, Hercules) with a lamina thickness of 0.1335 mm and the direction of unidirectional fibers [0^o] with V_f = 0.635 (Apalak and Yildirim, 2007). The mechanical properties of graphite fiber, epoxy resin and lamina are shown in Table 1. Also, the adhesive thickness is set to be 0.2 mm and the length L of the composite plates is taken as 250 mm. Other parameters can be seen in Table 2.

Table 1. Mechanical properties of graphite fiber, epoxy resin and lamina

Property	Fiber	Epoxy Resin	Lamina
ρ (kg/m3)	1743.834	1264.972	1552.289
E_{11} (GPa)	259.105	4.344	157.218
E_{22}=E_{33} (GPa)	13.927	4.344	9.309
G_{12}=G_{13} (GPa)	50.952	1.597	5.723
G_{23} (GPa)	8.274	1.597	3.475
v_{12}= v_{13}	0.26	0.36	0.3
v_{23}	0.33	0.36	0.34

Table 2. Variations of plate thickness and overlap length

	Plate thickness *t* (mm)	Overlap length *c* (mm)
Model 1	2	55
Model 2	2	60
Model 3	2	65
Model 4	2.27	55
Model 5	2.27	60
Model 6	2.27	65
Model 7	2.54	55
Model 8	2.54	60
Model 9	2.54	65

3. Results and Discussion

In this study, the load is given in the form of displacement of 1.5 mm. From Fig. 4, it is seen that stress concentration sites occur at the joint ends, from which delamination failure would be likely to begin.

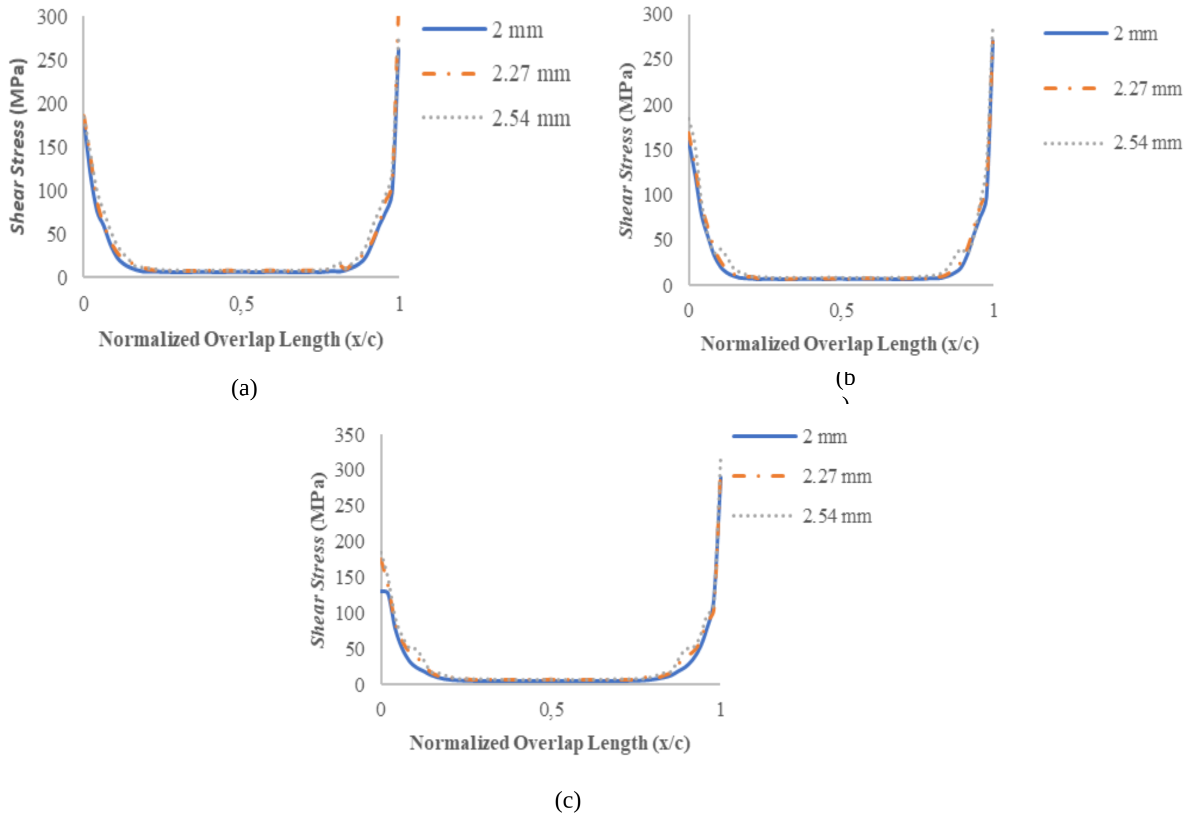

Fig. 4. Distribution of shear stress along the joint length with the variation of overlap length: (a) 55 mm, (b) 60 mm, and (c) 65 mm.

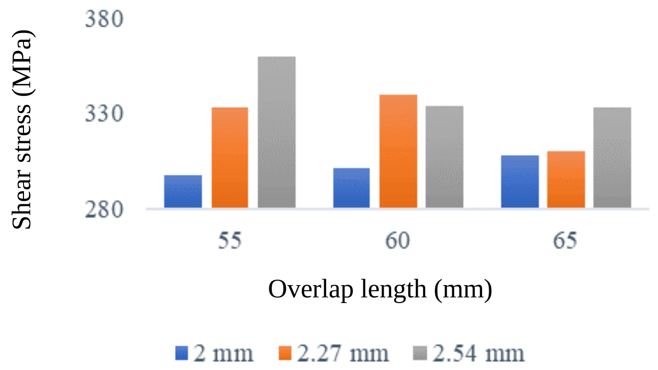

Fig. 5. Shear stress of the joint structure due to the effect of plate thickness for different overlap values.

From Fig. 5, the shear stress is lowest if the plate thickness of 2 mm is used for all values of overlap length. However, the shear stress increases as the overlap length is increased for the plate thickness of 2 mm. The same does not hold for the thickness values of 2.27 and 2.54 mm, respectively.

It is also shown that the joint structure will tend to be more rigid if the plate thickness is increased, as shown in Fig. 5 and 6. In the present study, the strength of the joint structure decreases if the thicker plates of 2.27 mm and 2.54 mm are used, respectively. For the thickest plates of 2.54 mm, the increase in the overlap length could reduce the value of shear stresses in the joint length. However, the trend does not hold for the thickness value of 2.27 mm, in which the value of shear stress fluctuates as the overlap length increases. Thus, the increase in the overlap length does not give significant effect in reducing the stress level for certain values of plate thickness. It appears that this may be due to the applied loading which is in the form of constant displacement, rather than in the form of force. Optimization study seems to be interesting as subject of further investigation, including dynamic aspects as well, especially by using soft computing techniques like neural networks and evolutionary algorithms (Hidayat and Yusoff, 2009; Hidayat, 2015). Moreover, investigation on the static and dynamic aspects of single lap joint of composite plates by using other numerical methods such as meshless methods (Hidayat et al., 2016; Hidayat et al., 2018; Hidayat et al., 2020) will be also interesting for further research study.

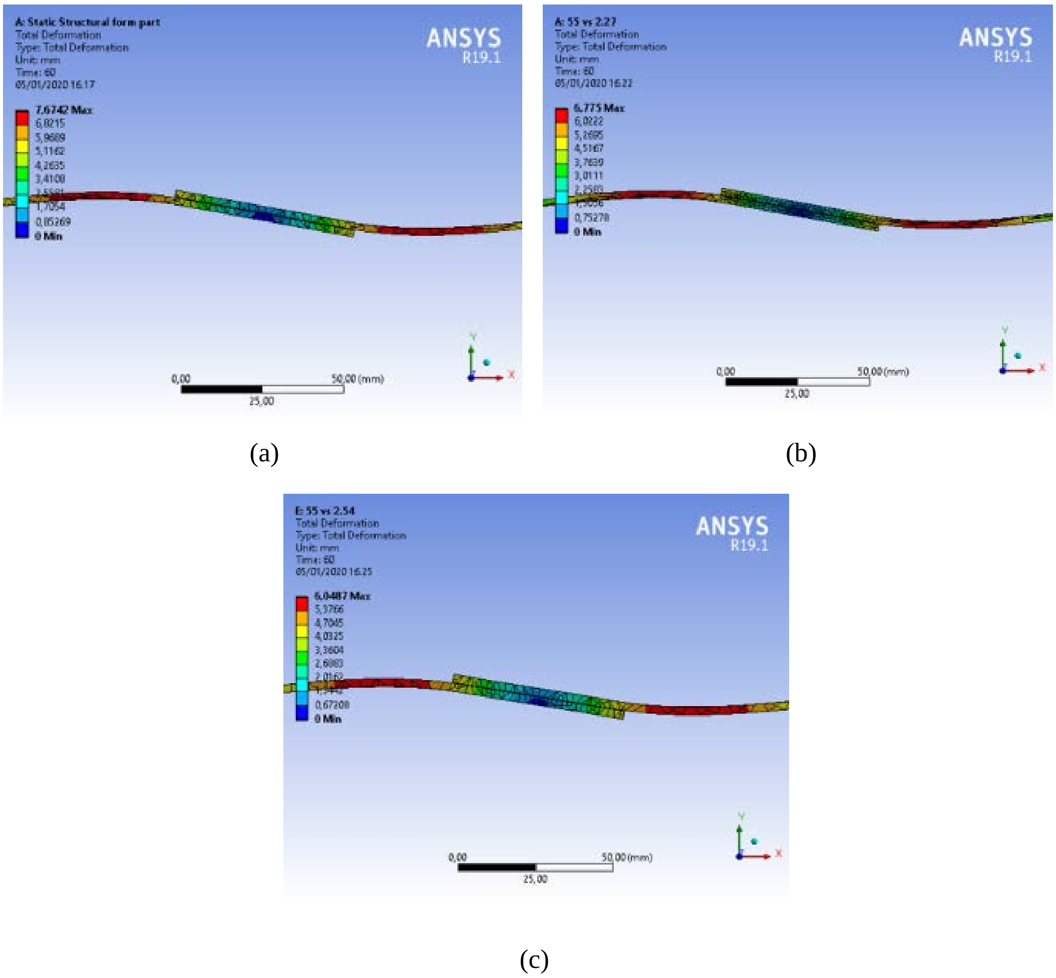

Fig. 6. Distribution of displacement in the joint structure with the variation of plate thickness: (a) 2 mm, (b) 2.27 mm, and (c) 2.54 mm (the overlap length is 55 mm).

4. Conclusions

In this paper, simulation and analysis of joint strength of single lap joint of composite plates has been presented. Based on the variations of plate thickness and overlap length, it is found that the largest joint strength is obtained at the values of plate thickness and overlap length of 2 mm and 55 mm, respectively. Also, it appears that the applied loading type will affect to the simulation results.

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