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The Stress-Strain State of Ti/Al Composites with Elliptical Defects and Soft Interlayers under Tensile Loading

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Abstract

In this study FEM simulation was applied to assess the impact of defects and the thickness of the soft interlayer on the stress-strain state of laminated Ti/Al-alloy composites with soft Al interlayers. Johnson-Cook models were utilized to describe the behavior of materials plasticity and rupture. The tensile force was applied transversely to the interface between bonded metals.

Keywords: Ti, aluminum, soft interlayer, FEM, laminated composite

1 Introduction

The strength of plain shape parts is usually higher than of complex form components. Such feature is a result of the micro and macro defects, formed during materials fabrication and maintenance.

In order to assess the impact of the defects on the behavior of materials, tensile tests of specimen with stress concentrators are performed [1]. Ultimate strength in this case is a fraction of the ultimate load before fracture by the specimen transection in the region with the concentrator. FEM allows simulation of laminated composites with defects of various shapes and sizes. Thus the study [2] presents results of the hole stress concentrators in Al interlayers of Ti/Al alloy composite evolution.

Soft interlayers are installed in laminated composites as plasticity buffers [3, 4]. Due to contact hardening effect the interlayers contribute to the plasticity and elongation of the material bond area.

The aim of the present study was to investigate the influence of Al interlayer thickness on the stress-strain state of flat Ti-Al alloy composites with elliptical holes.

2 FEM Simulation

FEM simulation of the deformation and rupture of laminated Ti alloy-Al-Al alloy composite during tensile tests was carried out using Abaqus software. The cross section size of Ti alloy-Al-Al alloy composite was 5x10mm. The interlayer thickness was 1.25-5 mm. The interlayer had elliptical hole concentrator with 2 and 0.5 mm axis length values.

In order to consider the impact of transverse deformations on the stress-strain state FEM simulation of the 3d bodies was performed. The hardening of materials was simulated using Johnson-Cook plasticity model [5]. The model utilizes the deformation - yield strength curves at various temperatures and deformation speeds:

$$\sigma_Y = \left(A + B \cdot \epsilon_p^n\right) \times \left(1 + C \cdot \ln \frac{\dot{\epsilon}_p^n}{\dot{\epsilon}_0}\right) \times \left[1 - \left(\frac{T - T_r}{T_m - T_r}\right)^m\right], \tag{1}$$

where ϵ_p - accumulated plastic strain, $\dot{\epsilon}_p$ - plastic strain rate, $\dot{\epsilon}_0$ - reference strain rate, T - current temperature, T_r - room temperature, T_m - melting temperature, A, B, C, n and m - model constants.

The ultimate deformation of the material at which rupture of Al alloy or pure Al interlayer happened was described by Johnson-Cook failure model [6]. The destruction of the finite element model cell occurred when D was equal to 1:

Table 1: Johnson Cook constitutive model parameters for materials used in this study

Material	Johnson Cook constitutive model parameters [7]						
	A, MPa	B, MPa	m	n	$\dot{\epsilon}_0$, s^{-1}	T_m, K	T_r, K
Al-alloy plate	218.3	704.6	0.93	0.62	1	873	293
Al interlayer	60	6.4	0.859	0.62	1	933	293
Ti plate	420	52	1	0.48	1	1940	293

$$D = \frac{1}{\epsilon_f} \sum_i \Delta\epsilon_p^2, \tag{2}$$

where $\Delta\epsilon_p^i$ – denotes the increment of equivalent plastic strain which occurs during an integration cycle, ϵ_f - the equivalent strain to fracture:

$$\epsilon_f = \left[D_1 + D_2 exp\left(D_3 \frac{p}{\sigma_{ef}}\right)\right] \times \left(1 + D_4 ln \frac{\epsilon_p}{\epsilon_0}\right) \times \left(1 + D_5 \frac{T - T_r}{T_m - T_r}\right), \tag{3}$$

here $D_1 \ldots D_5$ – table parameters of the investigated materials, σ_{ef} – effective stress, p – pressure in the considered FEM cell. The model parameters for materials used in this study are provided in tables 1 and 2 [6, 7] (rupture of Ti layer was not considered).

Table 2: Fracture constants for materials used in this study

Material	Fracture constants [6]							
	D_1	D_2	D_3	D_4	D_5	$\dot{\epsilon}_0$, s^{-1}	T_m, K	T_r, K
Al-alloy plate	0.178	0.389	-2.246	0	0	1	873	293
Al interlayer	0.071	1.428	-1.142	0.0097	0	1	933	293

Due to the low value of the speed (lower than 0.0025 s^{-1}) of deformation, its impact was not considered.

Cubic mesh with 0.25 mm side length was mainly applied to the simulated body. The elliptical hole contained 100 Hex-cells on its perimeter, while the Al interlayer was covered by 40 longitudinal layers of mesh cells.

The model contained the following boundary conditions: the upper boundary of Al alloy layer was fixed; the lower boundary of Ti alloy layer was being displaced at the speed of 1 mm/s. The simulation was running until the initial FEM cells ruptured.

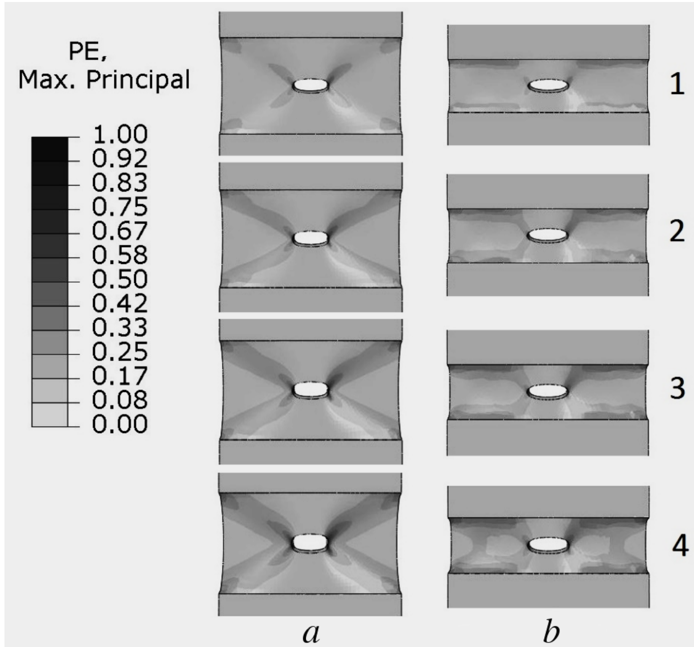

Figure 1: Distribution of the plastic deformation in Al interlayer with the thickness value of (a) 5 mm; (b) 1.25 mm at the relative interlayer deformation value of: I – $\epsilon = 5\%$; II – $\epsilon = 6.5\%$; III – $\epsilon = 7.8\%$; IV -- $\epsilon = 10\%$

3 Results and Discussion

The simulation revealed the plastic deformation across the Al-interlayer to be non-uniformly distributed at the initial deformation stages. The initial plastic deformation in the 5 mm thick Al interlayer was observed in adjacent to the interface with base materials parts of the elliptical hole arcs (fig. 1 a). The subsequent specimen elongation contributes to the localization of deformation along diagonal planes.

Plastic deformation in the specimens with lower interlayer thickness value (fig. 1 b) occurs near the larger arc of the elliptical hole as well as along the interface with base materials. In all simulated cases the initial rupture of FEM cells was observed near the larger arc of the elliptical hole.

The shapes of the absolute axial deformation of the specimen - applied force curves are similar to each other in the whole range of investigated interlayer thickness values (fig. 2). However the decrease in the interlayer thickness value resulted in the growth of the maximum force at which the necking began.

The increase in the ultimate strength value of metal composites caused by the reduction of soft interlayer thickness is due to the contact hardening effect at which plastic deformation in the interlayer is constrained by stronger adjacent metals. Shear stress occurs and increases on contact boundaries between

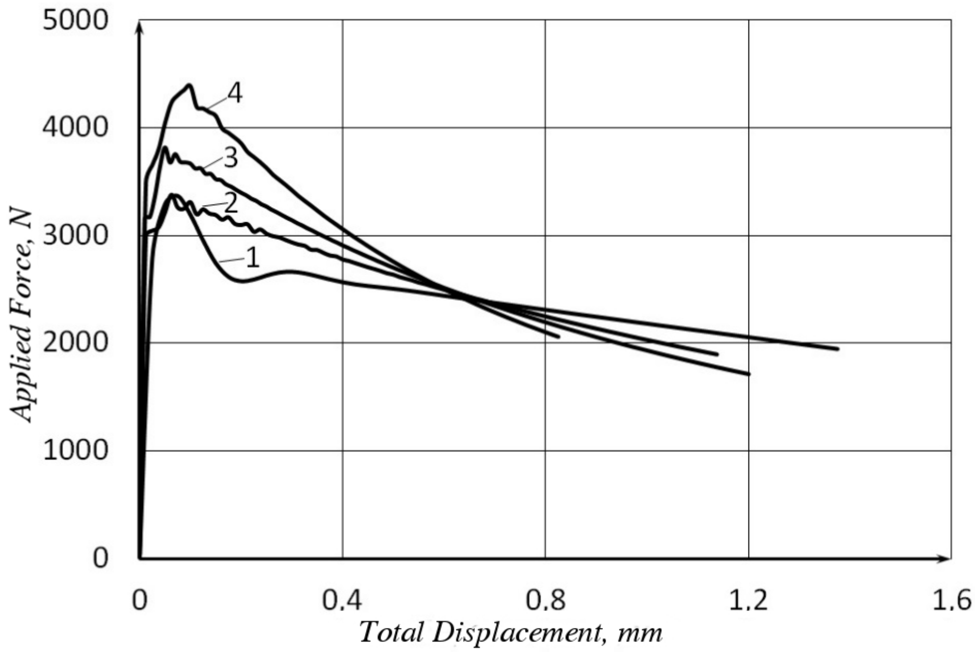

Figure 2: Absolute axial deformation of the specimen - applied force curves for the simulated interlayer thickness values: 1 — 5 mm; 2 – 2.5 mm; 3 – 1.8 mm; 4 – 1.25 mm

the interlayer and base materials. Thus the interlayer stress state becomes triaxial and non-uniform which cause the growth in strength.

The decrease in the specimen area in the necking zone contributed to the drop in tensile force. Such drop was more intense for specimens with low values of soft interlayer thickness. As a result at absolute deformations of 0.6 mm the loads required for subsequent specimen elongation with low interlayer thickness values are smaller than of the specimens with high-width interlayers. Von Mises stress and total deformation distributions for specimens with various interlayer thickness values at the moment of the first FEM cell rupture are presented in figures 3 and 4.

The maximum values of Mises stress were observed in Al-alloy and Ti-alloy layers near the interface between corresponding plates and the interlayer. The stress values are located outside of the hole plane and reach up to 150 MPa.

Maximum local total deformation up to 280% concentrated in Al interlayer near the arc surface of elliptical hole (fig. 4). The deformation increases with the growth of the distance from the specimen free boundary. The reduction of Al interlayer thickness contributes to plastic deformation of the whole volume of Al-alloy base layer.

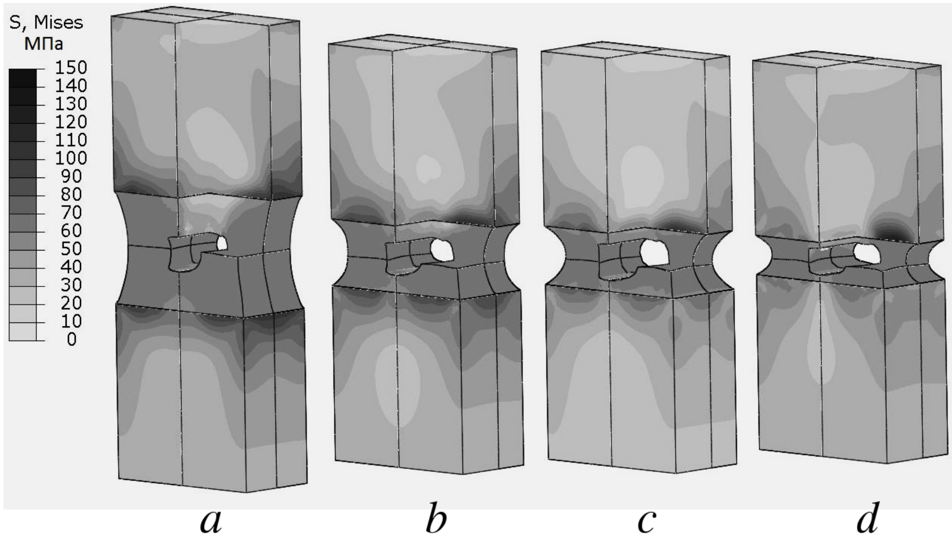

Figure 3: Von Mises stress distribution in the simulated specimens with various thickness values of Al interlayer at the moment of initial FEM cell rupture: 1 — 5 mm; 2 — 2.5 mm; 3 — 1.8 mm; 4 — 1.25 mm

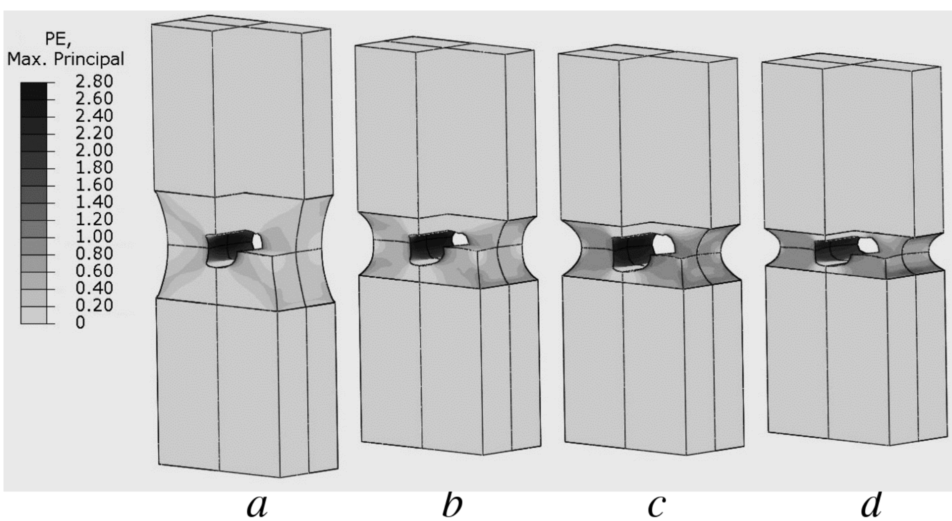

Figure 4: The total deformation distribution in the simulated specimens with various thickness values of Al interlayer at the moment of initial FEM cell rupture: 1 — 5 mm; 2 — 2.5 mm; 3 — 1.8 mm; 4 — 1.25 mm

4 Conclusion

1. The relation between Von Mises stress as well as the deformation distribution and the interlayer thickness of Al-alloy-Al interlayer-Ti alloy composite during tensile loading was identified. The interlayer contained an elliptical hole in its structure.

2. The shapes of the absolute axial deformation of the specimen - applied force curves are similar to each other in the whole range of investigated interlayer thickness values, however the reduction of the interlayer thickness increased the maximum load value due to contact hardening effect, which subsequently leads to necking and rupture at lower deformation values.

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