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Numerical Analysis of the Mechanical Behavior on the Effect of the Geometric Interface of the Aluminum/Aluminum Plate Assembly

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Abstract: Adhesive joints are therefore often favored in the aerospace and automotive industries due to their advantages such as the formation of uniform stress distributions, the ability to join dissimilar materials, high fatigue resistance and impermeability. In this work, the use of texture manufacturing technology (Geometric shapes) to the assembly areas of Aluminum / Aluminum plates is explored. In order to improve the shear strength values of the single joint adhesive layer, it is necessary to model structural reinforcements at the interface of the bonded assembly. Through the Abaqus software; models will be developed to simulate the stress distribution along the region of interaction between the plates and the single joint adhesive layer. by an economic choice. The analysis of the dimensions of the lap length and the thickness of the adhesives are the main parameters to be modified to optimize the geometry of the assembly, because an increase in the resistance of the joint is accompanied.

Keywords: Adhesive, Single joint, Stress.

Introduction

Configurations of a single-lap joint have been studied for about more than sixty years and many analytical and numerical models have been developed. Volkersen (1938) proposed the first approach to analyze this type of structure. He considered only shear strain in the adhesive and axial deformations in the adherends. Demarkles (1955) improved the model including shear deformation of the adherends. These analyzes do not include the bending moment produced by the eccentric path of the load. The effect of the bending moment results in efforts normal to the plane of the adhesive, called peel stresses, which are important at the edges of the joint. Goland and Reissner (1944) were the first to analyze the effect of the eccentric path of the load by applying moments to the joint edges.

The most practical configuration is single-lap, which has been extensively studied, and several ideas have been proposed to improve their performance. The eccentricity of the load applied to the ends causes a significant stress concentration at the overlap ends, but minimal stresses at the core of the adhesive are noted. Several authors have tried to reduce these stress levels by using several methods. In general, there are two types of methods for reducing stress concentrations, namely changes in the material or the geometry of the adherend and adhesive. For example, introduction of notch, folding of the bonded surface or the use of corrugations at the covering ends of the adherends can reduce peel stresses at the overlap end.

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Different shapes of the adhesive edges have been studied to reduce the various stresses and ensure a better distribution in adhesive joints. Harris and Adams (1984) proposed the creation of adhesive fillet, however, Giovanni et al. (2002) modified the edges of the adherends by the presence of a chamfer. On the other hand, it is difficult to manufacture these adherends and to control their shape. Therefore, these methods are rarely relied upon in practice. McLaren and MacInnes (1958) studied a different method; they varied the bending moment factor by simply deforming the adherend at the end of the overlap length. The material modifications mainly optimize the properties of the adhesive and the adherends. Pires et al. (2003) have shown that the use of a bi-adhesive system is advantageous at the joint: when the adhesive is more flexible, the stress distribution is more uniform in the single-lap joint and the concentration is minimal.

Fitton and Broughton (2005) studied the effect of varying the modulus of adhesive as a method to optimize the performance of the joint. The results from the study of Sancaktar et al. (2000) showed that the use of a rigid adherend has made the stress distribution more uniform. The geometric modifications mainly include the corrugation, pre-folding of the adherend, chamfer and notch. Other authors (Lang & Mallick 1998) have used geometric modifications in the adherends at the level of the covering part and have concluded that if the size of the modified zone increases, then the stress concentration at the edges decreases. Avila and Bueno (2004) have shown that the use of corrugated sheets allows for a uniform stress distribution. Sancaktar and Nirantar (2003) have shown that if the angle of beveling of the adherends at the overlapping ends is important, the stresses on the joint are minimal and this is well demonstrated by Oterkus et a.l (2006).

The present work aims to study the Geometric shapes influence mechanical behavior at the interface of the adhesive joint used for the assembly of two aluminum adherends (2024-T3 alloy) and thus determine the stress distributions in the adhesive layer.

Geometric Model and Mechanical Properties

In this study, the geometric model for the single lap joint of the bonded adhesive used in joining two thin aluminum plates. In order to model the geometry presented in figure 1, we need their mechanical properties, for this purpose tensile tests were carried out on Aluminum 2024-T3; in the form of a plate; and on Adekit A-140 adhesive; in the form of standardized specimens; and which allowed to have the characteristics curves shown in Figure 2. From these two curves, one can determine the mechanical properties of the two materials shown in Table 1.

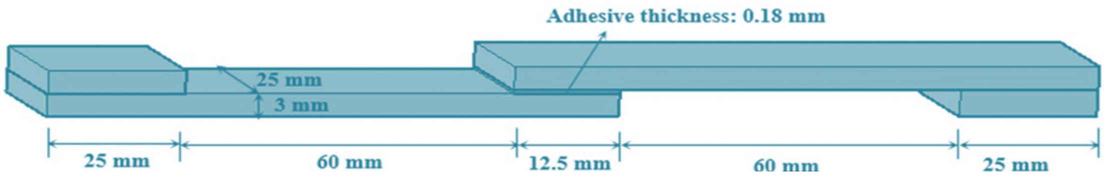
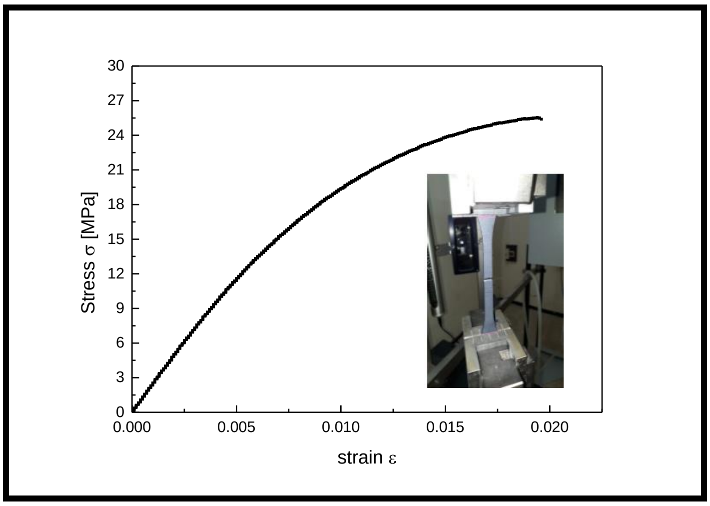


Figure 1. Geometric model of single lap joint bonded adhesive.



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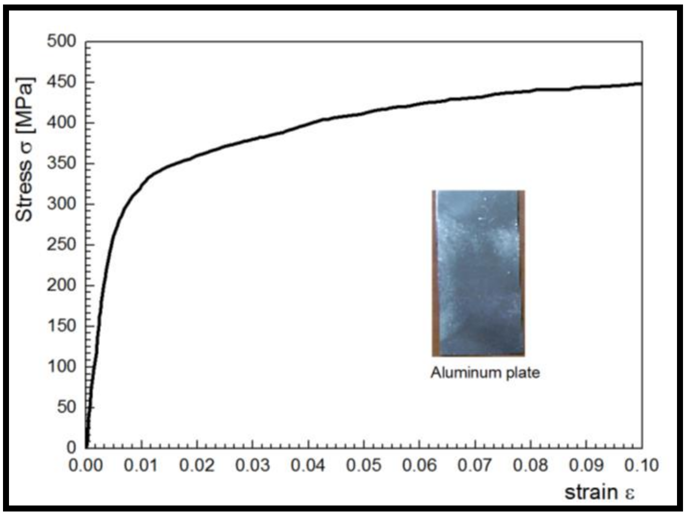

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Figure 2. Tensile stress–strain curve for: a)-Aluminum plate, b) - Adhesive Adekit A140 (Madani et al. 2010).

Table 1. Mechanical properties of the joint materials (Madani et al. 2010).

Property	Materials		Description
	Aluminum	Adhesive	
E (MPa)	69000	2690	Young's modulus
G (MPa)	26500	1120	Shear modulus
ν	0.3	0.3	Poisson's Ratio
σ (MPa)	220	14.9	Yield tensile strength
ρ	2,77	1,38	Density

Mesh Description

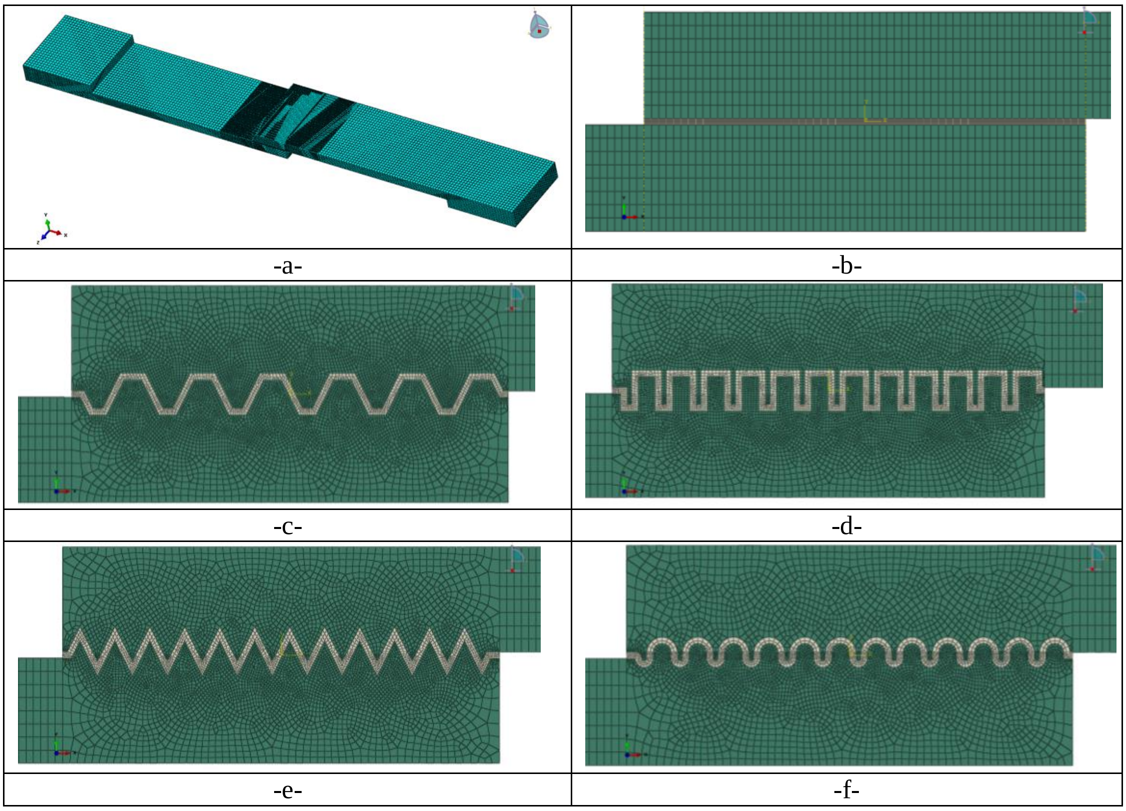


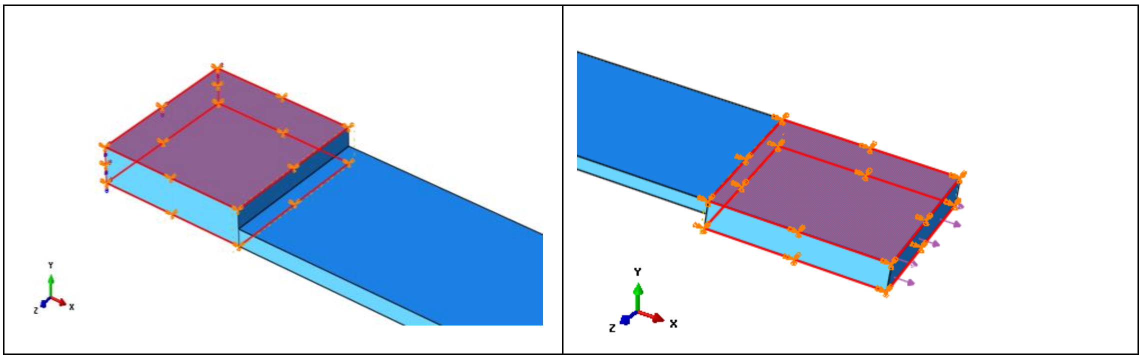
Figure 3. Mesh of the assembled structure; a) Assembly model, b) Simple single-lap joint, c) Trapezoidal shape, d) Rectangular shape, e) Triangular shape, f) Circular shape.

The numerical analysis was performed by using the Abaqus calculation software using a non-linear static analysis, the Green-Lagrange strain formulation and three-dimensional modeling. The adhesive layer was modeled in the form of a third layer in order to introduce its real mechanical properties through its traction curve. This three-layer modeling technique has been used by several authors (Elhannani et al., 2015, Kaddouri et al., 2019, Medjdoub et al.,2022).

In our study, the single joint model is the basic model that allows us to compare it with other assembly models from the mechanical resistance point of view. We have represented five 5 different geometric models are used in the adhesive / plate interface: the simple shape, the trapezoidal shape, the rectangular shape, the triangular shape and the circular shape (Figure 3). The structure was meshed with linear hexahedral C3D8R elements (bricks), The total number of elements generated for the model was 224750. The adhesive layer is homogeneous, elastoplastic, isotropic and deforms under shear and peel stress. In the finite element model, the nodes are common between the aluminum plate and the adhesive layer so that there is continuity of deformation and stress.

Loading and Boundary Conditions

One of the joint edges is clamped, while the other extremity of the second plate is subjected to an applied normal stress of σ=10 MPa. The faces at each extremity of the two plates at the level of the heels are blocked. At the level of the embedded extremity the two faces are blocked in U1=U2= UR1=UR3=0 (Figure 4. a). On the other hand, on the level of the faces at the loaded extremity the two faces are blocked in U2= UR1=UR3=0 (Figure 4. b).



-a- -b-

Figure 4. Boundary conditions; a) at clamped side, b) at loaded side.

Results and Discussion

The results represent the distribution of von Mises, shear and peel stresses in the five different single lap joint models used in our study: the simple shape (Basic), the trapezoidal shape, the rectangular shape, the triangular shape and the circular shape.The von Mises stress level in assembly for the simple single lap joint is shown in figure 5.a. Where it is clearly seen there is a stress concentration near the assembly zone. In figure 5.b, we show that the high stress area increases in the adhesive surface, thus relieving the high stresses at the edges. On the other hand, the core of the adhesive becomes more and more active. According to this figure we note that there is a high stress concentration at the extremity of the adhesive and it decreases in the center of this layer. The comparison of the maximum von Mises stresses between the different models (Figure 5.b.c.d.e.f) shows that the circular shape has the lowest level of stress.

Figure 6 represents the effect of adhesive layer shape on the distrubtion of von Mises stress. We note that all the modifications of the shape assembly reduce the von Mises stress in the center of the layer adhesive compared to the simple shape. But, the level of the von Mises stress for different geometries at the extremities exceeds that of the simple shape. Which, it is bad for the assembly. By comparing the different configurations assembly, the lowest von Mises values were recorded in the center and both ends of layer adhesive in the circular shape. In the circular case the reduction ratio of the maximum von Mises stress compared to the simple form is 25%; which it is beneficial.

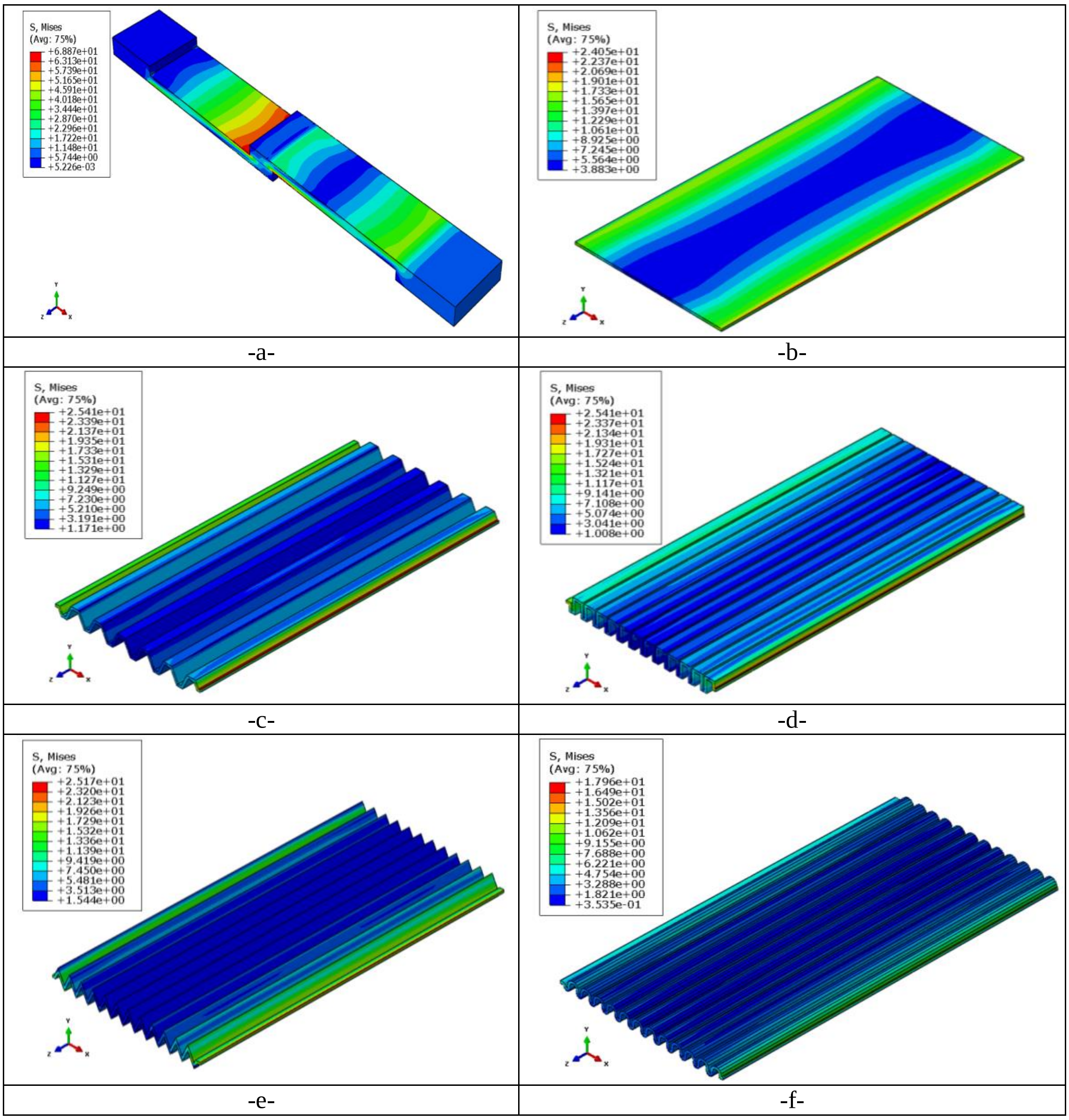


Figure 5. von Mises stress level in the adhesive joint a) The assembly b) Simple single-lap joint, c) Trapezoidal shape, d) Rectangular shape, e) Triangular shape, f) Circular shape.

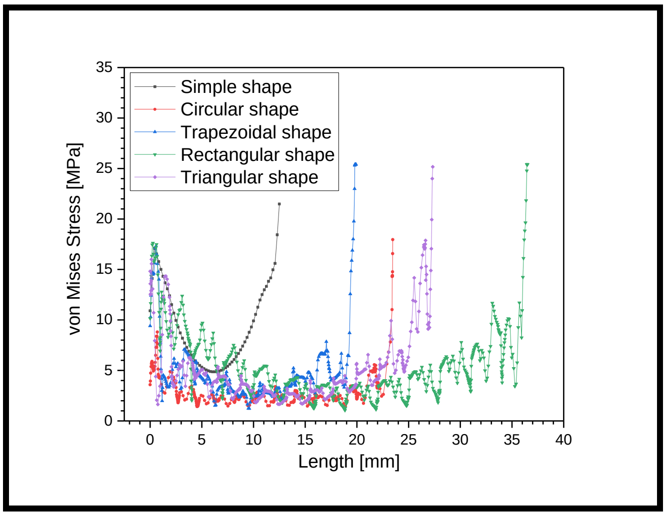


Figure 6. Distribution of von mises stress in the length of the cover joint for different shape.

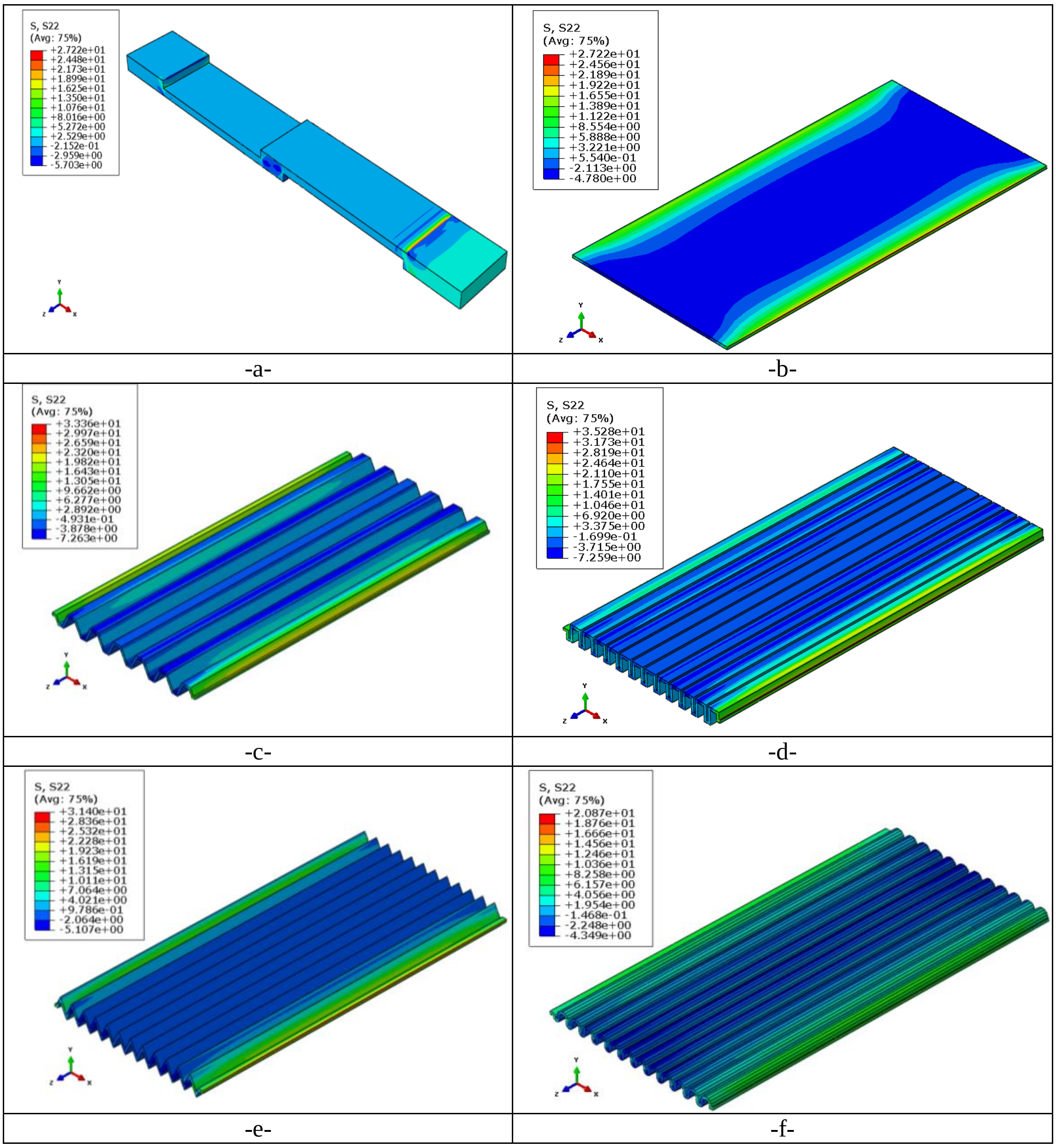


Figure 7. Peel stress level in the adhesive joint a) The assembly b) Simple single-lap joint, c) Trapezoidal shape, d) Rectangular shape, e) Triangular shape, f) Circular shape.

The figure 7 show the level of peel stress distribution at the assembly and the different shapes of the plate/adhesive interface. It is noted that is a low value of the peel stress in the center of adhesive layer for all the shape configurations. In this figure its shown a strong increase at the extremity of the adhesive layer. Also, the circular shape provides the lowest level of peel stress compared to the different geometries.

The figure 8 represent the variation of the peel stress for the different models. This figure show clearly that the circular shape significantly reduces the peel stress at the center and the ends of the adhesive layer compared to the simple shape by a rate of 23%. which is very advantageous in terms of performance and efficiency. It's very interesting to see that the geometry modification of the interface increases the surface contact between the plate and the adhesive by 65% for the same length of 12.5mm in the simple case. This promotes increasing the distribution of peel stresses over a larger surface and decreasing the concentration of these stress in the center of the adhesive layer. The effect of changing the interface geometry between the plates and the adhesive on the shear stress distribution is shown in figure 9. It can be seen that the distribution of shear stress represent a maximum at the ends of the different shapes of the adhesive layer (Figure 9.b.c.d.e). Then it starts to decrease from the extremities to have the minimum of the stresses in the center. In the same figure we record the minimum value of the shear stresses in the circular model, which confirms the effectiveness of the circular geometry.

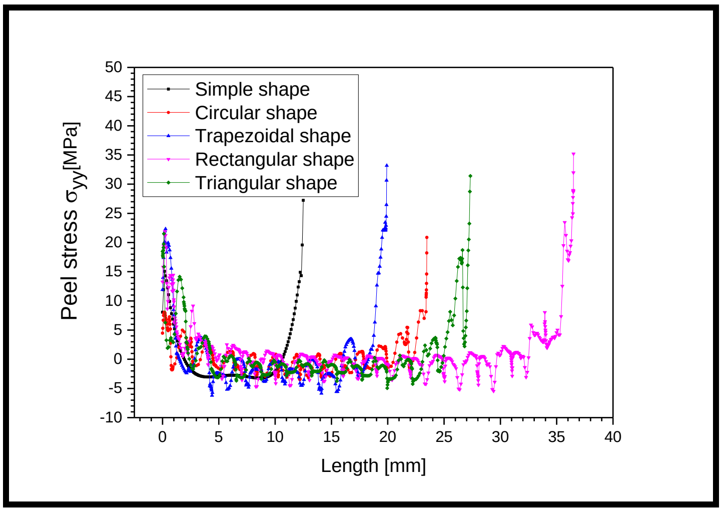


Figure 8. Distribution of peel stress in the length of the cover joint for different shape.

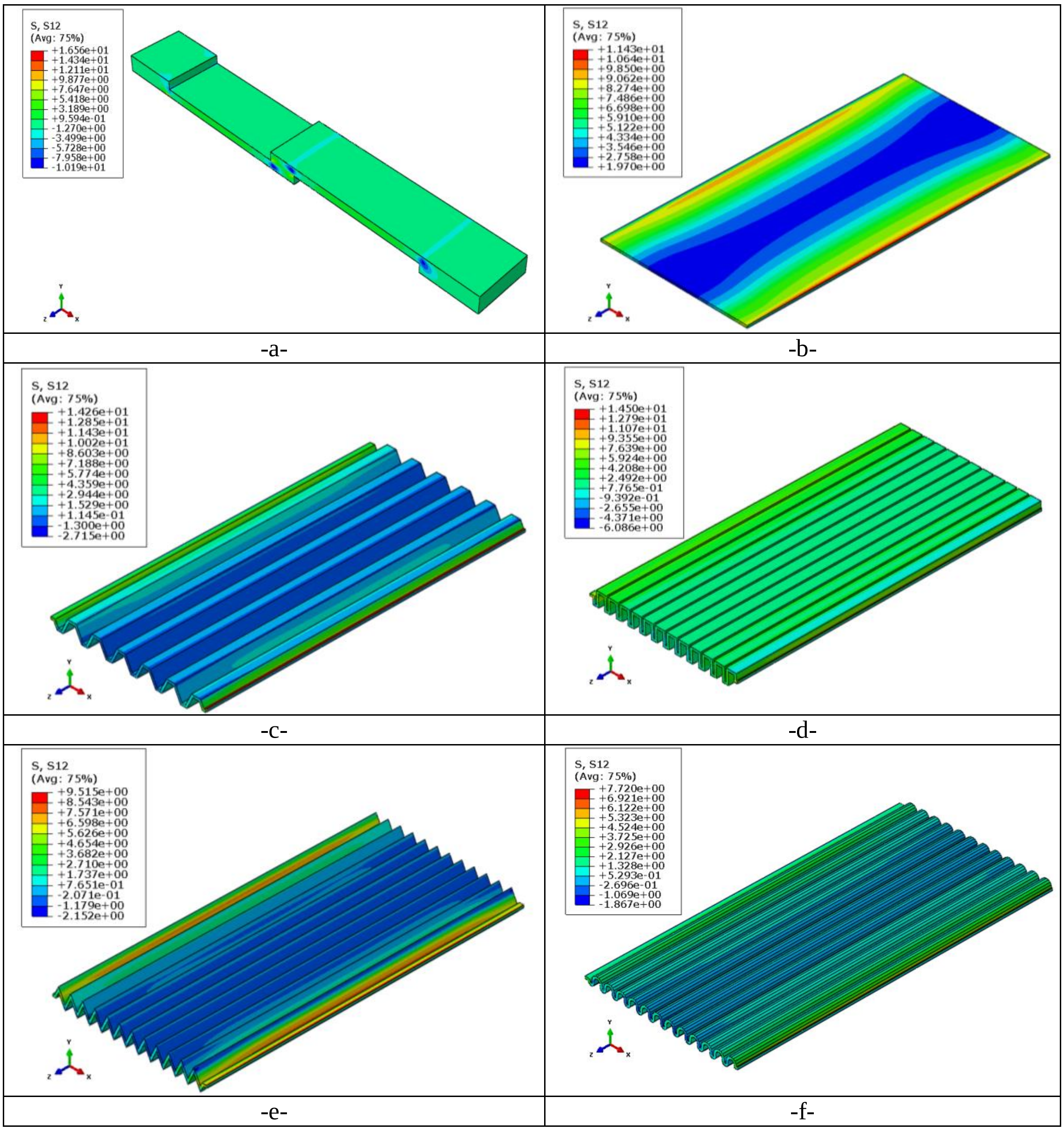


Figure 9. Shear stress level in the adhesive joint a) The assembly b) Simple single-lap joint, c) Trapezoidal shape, d) Rectangular shape, e) Triangular shape, f) Circular shape.

The evolution of shear stress along the length of the adhesive layer is illustrated in Figure 10. It is noted that the level of the shear stress of the various shapes are low at the center of the adhesive compared to the simple case. Because the length of geometric shapes (Trapezoidal, Rectangular, Triangular and Circular) promotes the distribution of shear stresses. Finally the minimum shear stress value is recorded in the circular form and this is validates the results obtained previously by reducing the shear stresses by 32%.

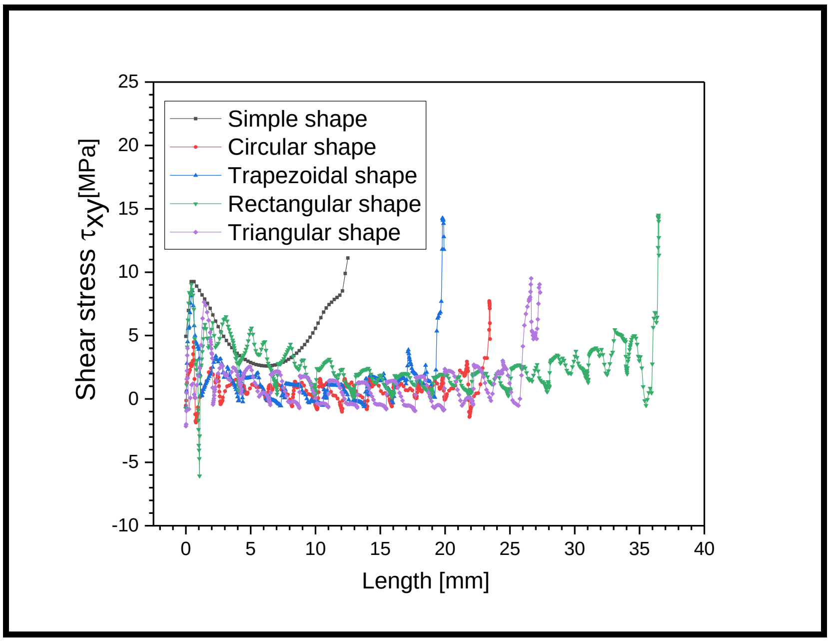


Figure 10. Distribution of shear stress in the length of the cover joint for different shape.

Conclusion

From the numerical analysis of the stress distribution in bonded assemblies, based on tensile tests carried out on different shape of adhesive layer, the following conclusions can be drawn: A geometrical modification in the interface reduce considerably the stress intensity in the center of adhesive layer.The distribution of von Mise, peel and shear stress represent a maximum at the ends of the different shapes of the adhesive layer. The circular shape assembly has the lowest stress values (von Mises, peel and shear stress), which is advantageous for the life of the structure in service.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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