# THREE DIMENSIONAL GEOMETRICAL NONLINEAR FINITE ELEMENT ANALYSIS IN ADHESIVELY BONDED JOINTS

Viresh G Patil
*Assistant Professor, Department of Mechanical Engineering, Medak College of Engineering & Technology Siddipet, Hyderabad, Telangana, India*

## ABSTRACT

*In this work, a numerical study is performed to evaluate the feasibility of different geometric changes in single-lap aluminium joints under tension loads bonded with an araldite adhesive. Three dimensional finite element modeling of single lap joint subjected to uniformly distributed forces and investigated the stress distribution over the overlap area. Further, two types of cases are considered having identical and non-identical adherends. The finite element model of the joint is obtained using isoparametric three dimensional elements having eight nodes with three degrees of freedom each. The stress components and their distributions both on adhesive surface and on metallic elements are given in dimensionless form using three dimensional graphics. This paper presents a new model for three-dimensional finite element analysis of adhesive joints. The model considers geometric and material nonlinearities and uses solid brick elements as well as specially developed interface elements.*

**Keyword : -** *Adherend, Adhesive, Non- linear Analysis, Finite Element Analysis and Adhesively bonded joints.*

## 1. INTRODUCTION

Adhesive joints have come to be widely used in the fields of aeronautics, spacecraft's and the significant improvement in the strength of adhesive joints. In the paper by Erdogan and Ratwani [1], the stress distribution in plates bonded through stepped joints is analyzed. A similar study is carried out by Chang and Muki [2]. The three-dimensional nature of the state of deformation in a single-lap test specimen is investigated by Tsai and Morton [3] in a linear elastic finite element analysis in which the boundary conditions account for the geometrically non-linear effects. In this study two kinds of adhesively bonding joint problem are numerically investigated. These are bonding of identical and nonidentical metallic adherends. Ali Kaya and Mehmet Tekelioglu [4] investigated the three dimensional stress analysis in adhesively bonded joints with identical and non-identical adherends.

A three dimensional schematic of adhesively bonded single-lap joint is shown in **Fig.1**. For the geometric parameters, *c* is the length of the overlap, *a* is the length of the outer adherend, *t* is the thickness of the adhesive, *b* is the width of the plate and *h* is the thickness of adherend. The numerical parameters are given in **Table.1**. Three degrees of freedom are used in the model. The degrees of freedom are the displacements u, v, and w in the direction of *x*, *y*, and *z* axis respectively.

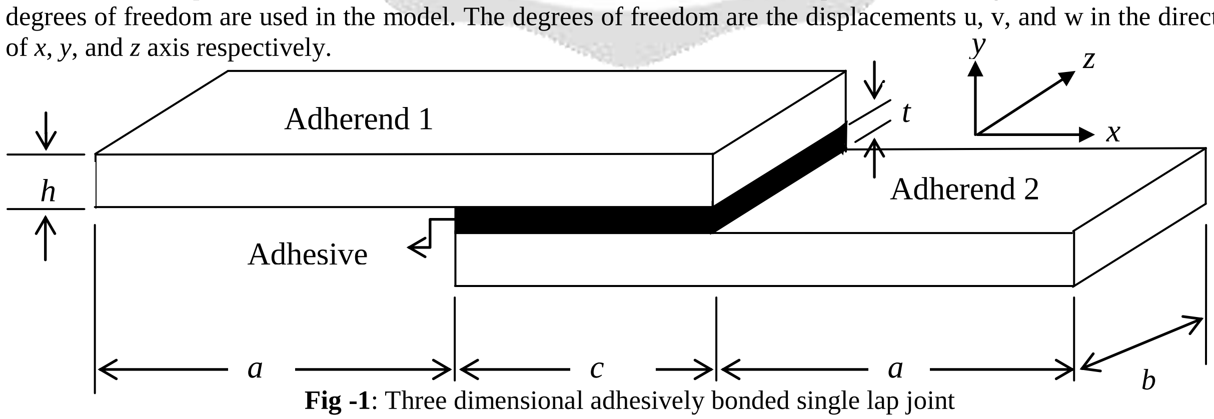


**Fig -1**: Three dimensional adhesively bonded single lap joint

**Table -1:** Parameters of the single lap joint

| | | | | | |
|---|---|---|---|---|---|
| *P = 9.81 MPa* | *l = 16 mm* | *b = 20 mm* | *t= 0.32 mm* | *h = 1.6 mm* | *a= 32 mm* |

## 2. FINITE ELEMENT MODEL

In three dimensional finite element analysis the materials are assumed to be isotropic and homogenous aluminum. Adhesive is also modeled as an isotropic material. Finite element model of the problem is shown in **Fig. 2**. The meshes in the adherends and adhesives were relatively fine also shown in figure**.** The boundary conditions are given in **Fig.3**. Ten elements were used through the thickness of the adherend, and four elements through the thickness of the adhesive layer. The analysis is performed using ANSYS software [5], utilizing 8-noded quadrilateral elements (SOLID45) used for both adherend and adhesive materials. An adhesively bonded lap joint between aluminum adherends. Adherends are considered to be reinforced utilizing araldite adhesive. The properties of the adherend and adhesive are appeared in **Table. 2**.

**Table -2:** Material properties of the single lap joint

| | |
|---|---|
| Elasticity modulus for adherend (Aluminum) | $E_1$ = 70 GPa |
| Elasticity modulus for adhesive | $E_A$ = 56.5 GPa |
| Poisson's ratio for adherend (Aluminum) | v = 0.33 |
| Poisson's ratio for adhesive | v = 0.34 |

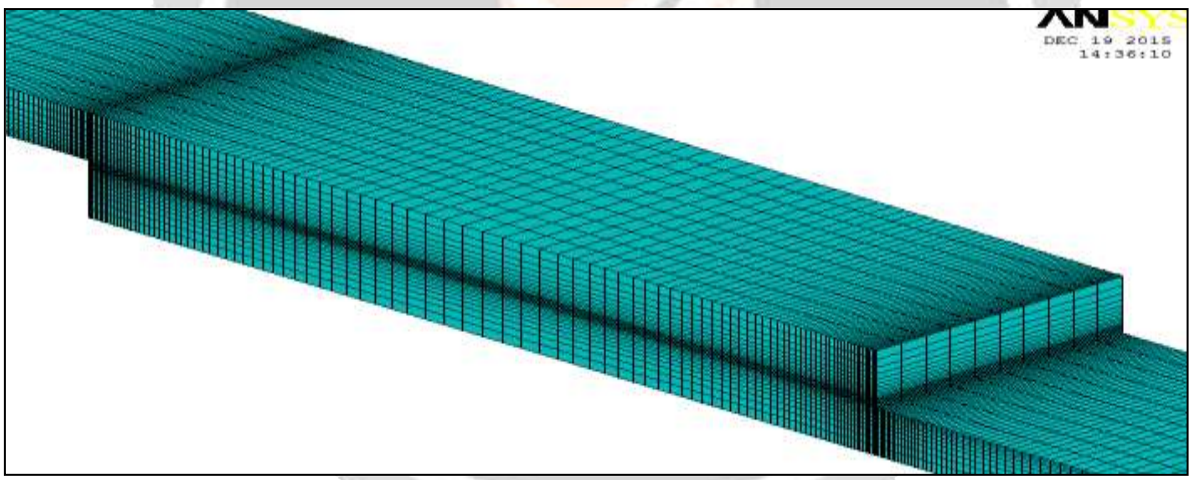


**Fig -2**: Three dimensional Finite element mesh in the adhesive region

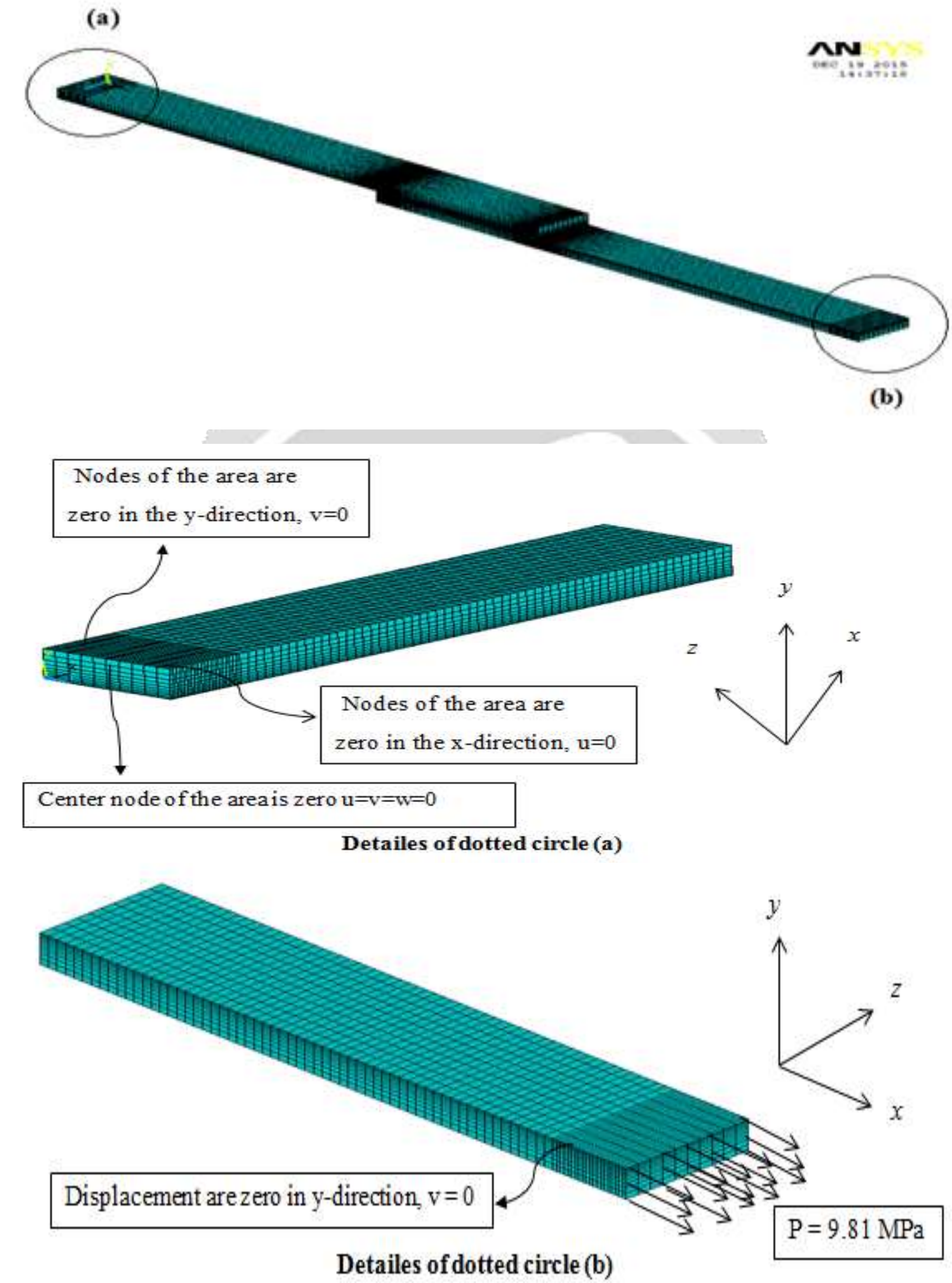


**Fig -3**: Boundary conditions and finite element model of the system

## 3. ADHESIVELY BONDED SINGLE LAP JOINT FOR IDENTICAL ADHERENDS

Joint geometry and physical parameters are demonstrated in the **Fig.1**. Adhesively reinforced single lap joint under axial tension force is appeared in **Fig.3**. The stress distribution components are not uniform through the width (z- axis). With these considerations, a three dimensional model is considered in the work varieties of the stresses along the width are investigated. The variety of stress components are plotted along the center plane of adhesive region. The stress components, normal stresses $\sigma_x$, and $\sigma_z$, peel stress $\sigma_{y,}$ shear stresses $\tau_{xy}$, $\tau_{yz,}$ $\tau_{xz}$ are investigated. The various stress components are plotted in **Fig. 4** and **Fig. 5**. And stress distributions are appeared in the non-dimensional directions, (x/c) in the x direction, (z/b) in the z direction.

The maximum peel stress values occur as $\sigma_y$ and maximum shear stress values as $\tau_{xz}$. In this study, adhesively reinforced joints are demonstrated utilizing three dimensional finite elements. The reinforced materials are identical and non- identical stress distribution in the adhesive layer demonstrates the stresses in adhesive layer, maximum stress at the end of the joint. It is inspected that the stress distribution along width (z- axis) is non-uniform. The stress components in the center plane (along z = 5 mm) is more prominent than the components at end plane. Typical stresses $\sigma_x$ and $\sigma_z$ are nearly the same for the identical and non-identical adhesively bonded joints. For sure the identical case gives somewhat more noteworthy qualities. **Fig.4** and **Fig.7**. Peel stresses ($\sigma_y$) and normal stress ($\sigma_x$) clearly shows the identical and non-identical adherend stress are investigated, it is seen that the stress values in free edges (that is in z = 0 and in z = 5 mm) are in the middle of 0 mm and 5 mm in center plane (that is in z = 2.5 mm).

### 3.1 Contour plots for identical adherends

The distribution of displacements and stress are shown in **Fig.6**. In X-component maximum displacement is 0.12 mm, for Y- component maximum displacement is 0.26 mm and Z-component maximum displacement is 0.000302 mm. The variation of maximum peel stress is 65.08 MPa, shear stress is 23.24 MPa and von Mises stress is 67.80 MPa. Compare to identical adherend in non-identical adherend, the maximum peel stress is reduced linearly by 5.63%, the maximum shear stress ( $\tau_{max}$) is reduced linearly by 3.27% and the maximum von Mises stress is reduced linearly by 4%.

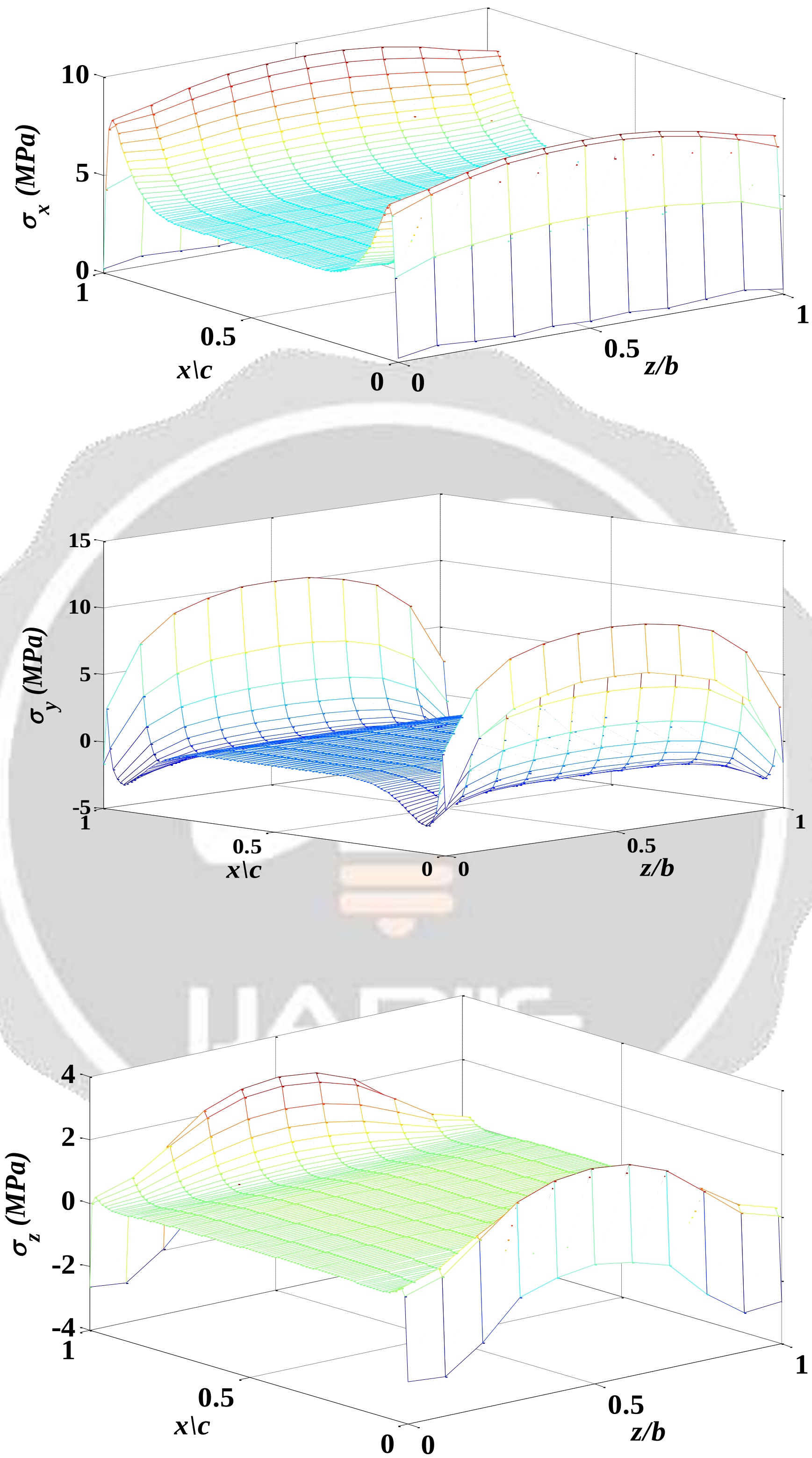


**Fig -4**: Variation of normal and peel stresses for identical adherends [6]

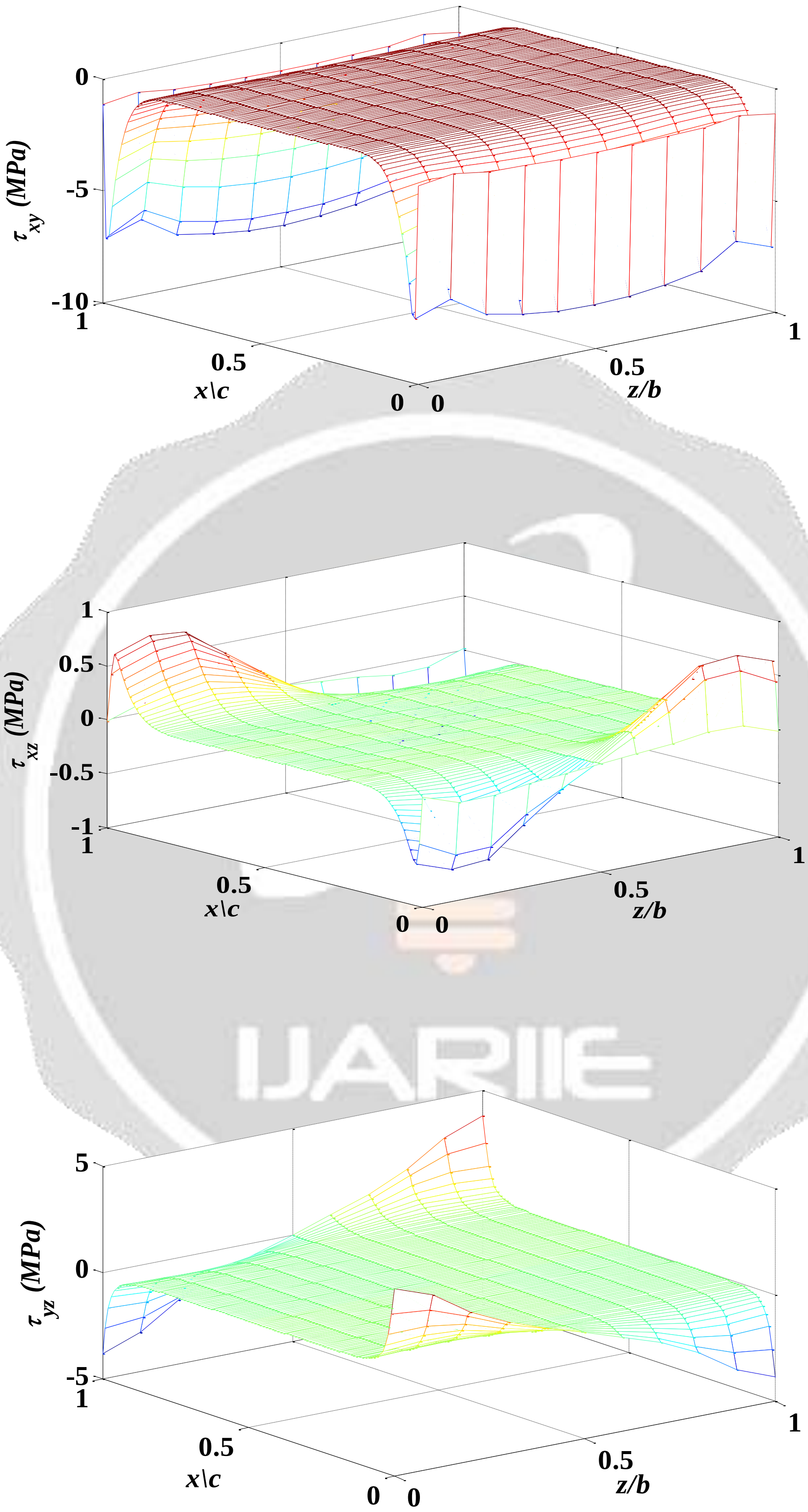


**Fig -5**: Variation of shear stresses for identical adherends [6]

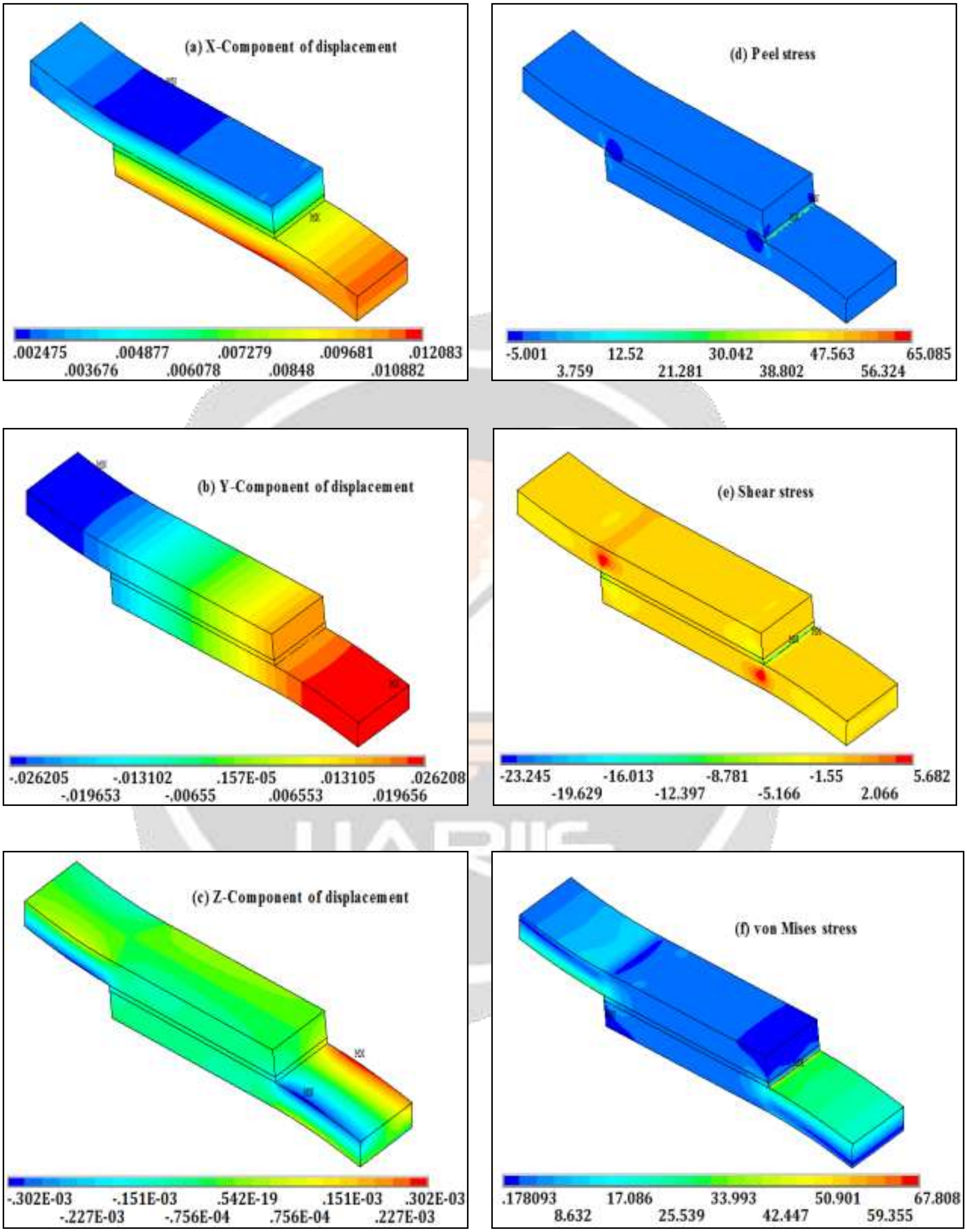


**Fig -6**: Contour plots for displacements and stresses for identical adherends

## 4. ADHESIVELY BONDED SINGLE LAP JOINT FOR NON-IDENTICAL ADHERENDS

In addition of the adhesive bonding has several advantages; aluminum and steel are chosen as various materials for the present study. The details of adhesively bonded joint are the same as in **Fig.1**. The parameters of the adhesively bonded joint are same as in **Table.1**. The material properties are given in **Table.3**. The cross section utilized for this study is the same as the identical materials. The results for this case are given as previous case (identical adherend).

**Table -3:** Material properties of the adhesively bonded single lap joint (non-identical adherends)

| | |
|---|---|
| Elasticity modulus for adherend (Aluminum) | $E_1 = 71\ GPa$ |
| Elasticity modulus for adherend (Steel) | $E_2 = 200\ GPa$ |
| Elasticity modulus for adhesive | $E_A = 56.5\ GPa$ |
| Poisson's ratio for adherend (Aluminum) | $v = 0.33$ |
| Poisson's ratio for adherend (Steel) | $v = 0.33$ |
| Poisson's ratio for adhesive | $v = 0.33$ |

**Fig.7** and **Fig.8** demonstrates stress components for the center plane of adhesive layer. The examination of plots reveals that there were no much differences in stress values for the identical and non-identical cases. The examinations of the identical and non- identical adherends are appeared in **Table.4**.

**Table -4:** Comparison of identical and non-identical adherends

| **Stresses** | **Identical adherends (MPa)** | **Non-identical adherends (MPa)** |
|---|---|---|
| $\sigma_x$ (Normal stress) | 9.47 | 8.19 |
| $\sigma_y$ (Peel stress) | 10.26 | 9.24 |
| $\sigma_z$ (Normal stress) | 2.75 | 3 |
| $\tau_{xy}$ (Shear stress) | 8.09 | 9 |
| $\tau_{xz}$ (Shear stress) | 0.73 | 0.61 |
| $\tau_{yz}$ (Shear stress) | 3.82 | 4.75 |

### 4.1 Contour plots for non-identical adherends

The distribution of displacements and stress are shown in **Fig.9**. In X-component maximum displacement is 0.009 mm, for Y- component maximum displacement is 0.004 mm and Z-component maximum displacement is 0.000284 mm. The variation of maximum peel stress is 61.41 MPa, shear stress is 22.48 MPa and von Mises stress is 64.99 MPa. Compare to identical adherend in non-identical adherend, the maximum peel stress is reduced linearly by 5.63%, the maximum shear stress ($\tau_{max}$) is reduced linearly by 3.27% and the maximum von Mises stress is reduced linearly by 4%.

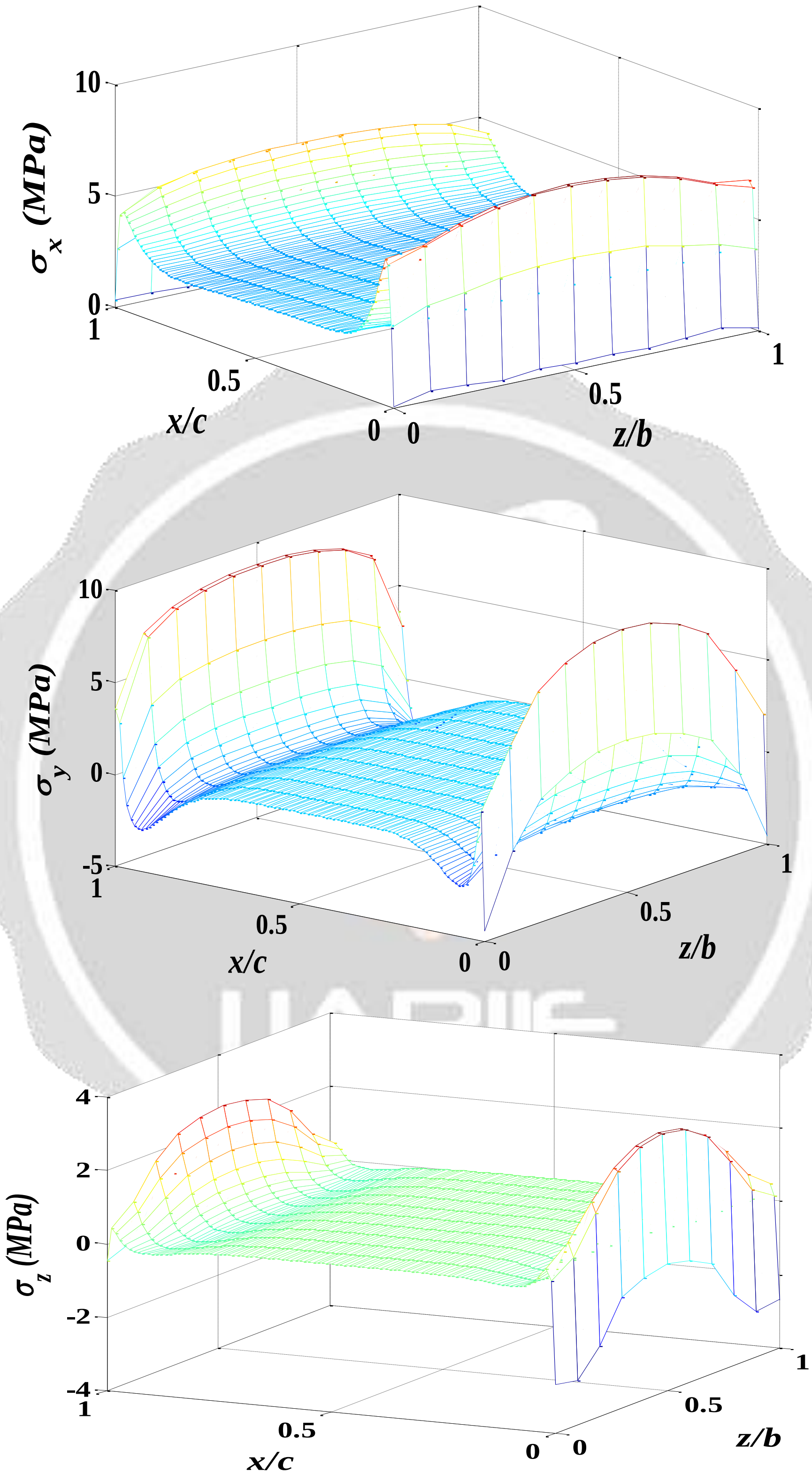


**Fig -7**: Variation of normal and peel stresses for non-identical adherends [6]

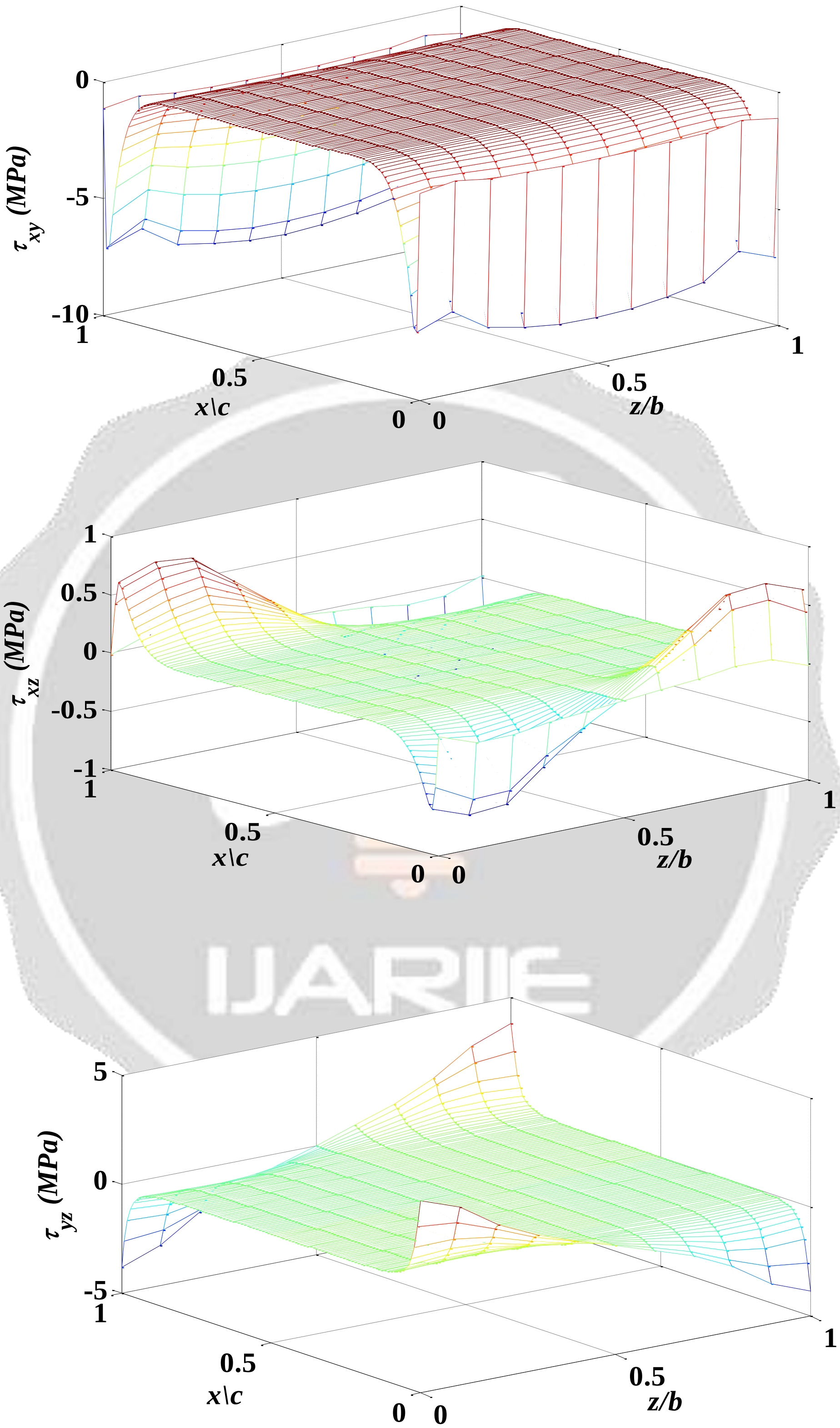


**Fig -8**: Variation of shear stresses for non-identical adherends [6]

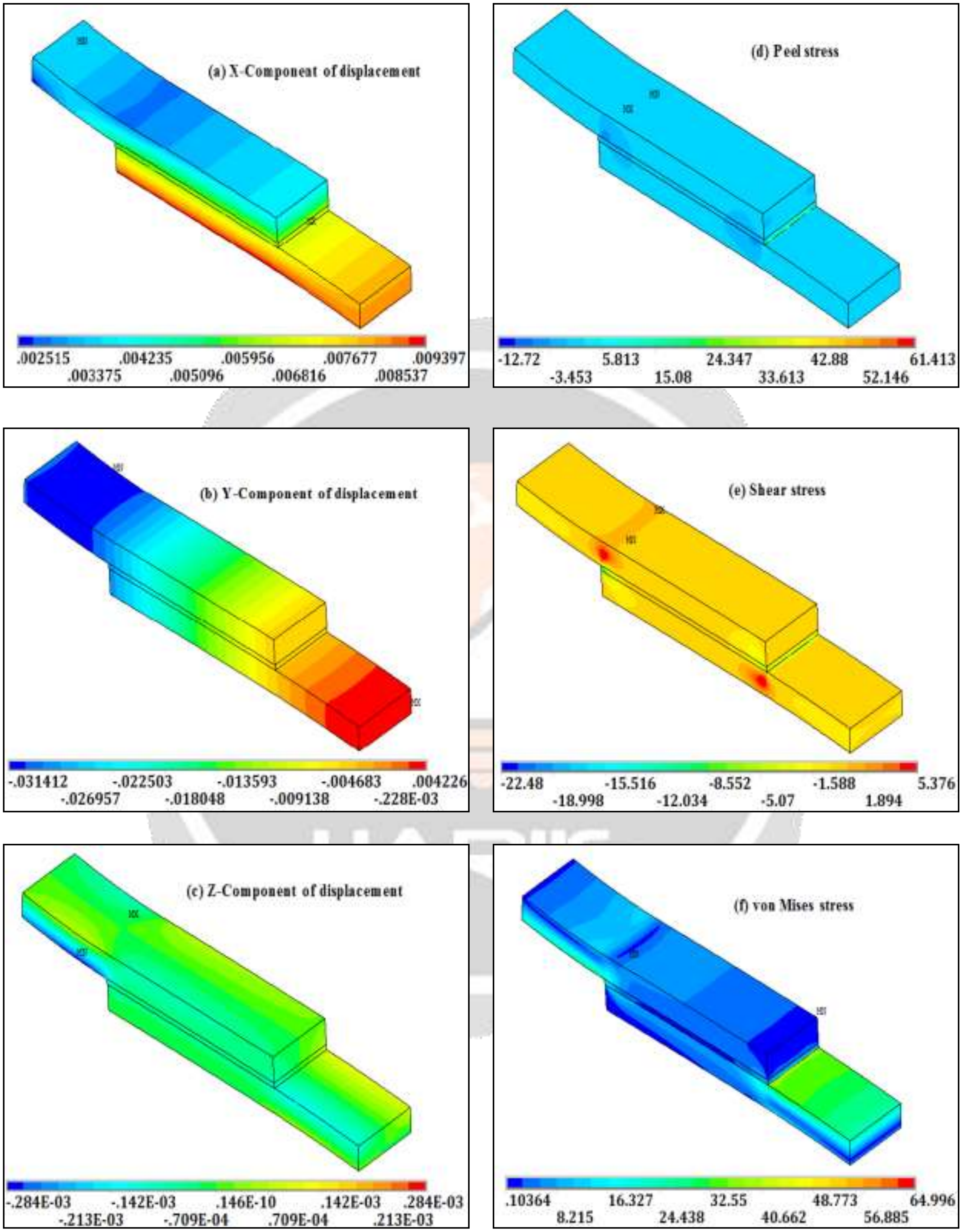


**Fig -9**: Distribution of displacements and stresses for non-identical adherends

## 5. CONCLUSIONS

The results from the 3D FE analysis were taken from the transverse middle plane of the joint. The examination of plots reveals that there aren't much important differences in stress values for the identical and non-identical cases. Normal stresses $\sigma x$ and $\sigma_z$ are nearly the same for the identical and non-identical joints. Indeed the identical case gives slightly greater values. It is important to observed that the prediction of the normal stress along the thickness direction is not possible using 2D FE model (plane stress or plane strain). But the present study indicates that through the thickness direction normal stresses are important because of their significant values.

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