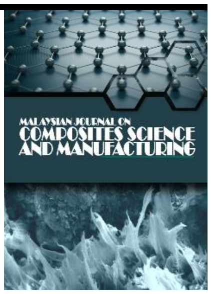
Penerbit
Akademia Baru

Malaysian Journal on Composites Science
and Manufacturing

Journal homepage:
https://www.akademiabaru.com/submit/index.php/mjcsm/
ISSN: 2716-6945



# Effect of Adhesive Type on the Adhesively Bonded Stepped Joint: A Numerical Investigation

Open Access

Md Sayed Anwar[1,*], Md Ahatashamul Haque Khan Shuvo[1], Md Manirul Islam,[1] Md Mehedi Hasan Ziad[1], Md Ariful Hasan[1]

[1] Department of Mechanical Engineering, Faculty of Science and Engineering, Sonargaon University, Dhaka-1215, Bangladesh

**ARTICLE INFO**

***Article history:***
Received 9 September 2023
Received in revised form 26 November 2023
Accepted 12 December 2023
Available online 30 March 2024

**ABSTRACT**

Single-lap joints are by far the most widely used adhesive joints and have been the subject of considerable research over the years. It is used in the automobile and aerospace industry where bolted or riveted joints are impossible. The joint strength in adhesively bonded joints depends on the adhesive and adherend properties and adherend geometry. In this paper, both the adhesive property and adherend geometry are considered. Two types of adhesives, i.e., SBT9244 (flexible) and DP460 (stiff), and three types of adherend geometry, Single Lap Joint (SLJ), One Step Lap Joint (OSLJ), and Three Step Lap Joint (TSLJ) are considered, and the effect of these are investigated by using a commercially available software Abaqus. The maximum peel stress occurs in a lap joint towards the edges of the joint and is minimum around the center region. The maximum peel stress is responsible for the failure of the joints, and the objective of this research was to reduce the peel stress, i.e., provide a more uniform stress distribution. Soft adhesive maximum peel stress and shear stress occur in [Type-I] 8.6 MPa and 6.4 MPa, respectively. Similarly, stiff adhesive maximum peel stress and shear stress occur in [Type-I] 37.14 MPa and 20.44 MPa, respectively. It is found from this investigation that if a relatively soft adhesive (SBT9244) is used in the joint, then the stress distribution reduces compared to a stiff adhesive (DP460). On the other hand, if steps are introduced in the bonded region, the stress distribution becomes more uniform and increases the bond strength.

***Keywords:***
Adhesively bonded joint, Stepped joint, Peel stress, Failure strength.

---

* *Corresponding author.*
*E-mail address: msanwar413246@gmail.com (Md Sayed Anwar)*
*E-mail of co-authors: mahskhan.khan@gmail.com, manirulislam2444@gmail.com, mehedihasanziad100@gmail.com, jacksprotik@gmail.com*

https://doi.org/10.37934/mjcsm.13.1.8297

## 1. Introduction

This paper focuses on the stress distribution in a stepped joint with a different number of steps and the stress distribution with varying adhesive thicknesses. Bonded composites have played a significant role in the aerospace and defence industries since the 1940s and 50s. The widespread use of composite materials, especially in aerospace and defence applications, began to gain attraction in the latter half of the 20th century. Still, it was not until the 1960s and 1970s that those composite materials started to see significant adoption [1]. Indeed, using composites for retrofitting structures is a relatively newer approach than traditional methods like steel jacketing, which have been employed for decades. While steel jacketing and other conventional retrofitting methods have a long history of use and are well-established, composites offer distinct advantages that make them an attractive choice, especially in certain situations [2]. Adhesively bonded joints are indeed preferred in various applications due to their numerous benefits, enabling improved performance, durability, and versatility in various applications [3]. The bonded joint is used in many industries, including automotive, aerospace, and construction [4]. In addition to the single-lap joint, double-lap and scarf joints can be bonded with adhesives, each with unique benefits and challenges. Regardless of the specific joint type, it is important to carefully design and execute the bonding process to ensure optimal strength and durability of the joint [5]. In many engineering applications, Advanced composite materials have indeed revolutionized various industries due to their remarkable characteristics and versatility [6].

In adhesively bonded joints, the distribution of peel stresses along the edges of the overlap region in adhesively bonded single-lap joints under static tensile loads significantly influences joint damage. This impact involves either decreasing stress levels at the overlap edges or redistributing these stresses towards the central [7] part of the overlap area, increasing the joint's strength. Stress concentration can occur at the edges of the overlap area, and this phenomenon can significantly impact the strength and performance of the joint. When using adhesive bonding techniques to create joints, it's important to consider the distribution of stresses within the bonded area. One critical factor to address is the reduction of stress concentrations at the free edges of the bonding area. Various types of joints can be bonded using adhesives. Adhesives are versatile materials that can join a wide range of materials together. Single-lap joints are indeed commonly used. This joint involves overlapping two pieces of material and then joining them together. Composite materials, made by combining different materials to create a material with enhanced properties, require specific joint configurations to maintain their structural integrity and strength, which are taken from previous studies [8-9].

Increasing the strength of adhesively bonded joints and reducing the effect of peeling stresses is crucial for ensuring the reliability and durability of bonded [10]. Various methods and techniques are used in different industries and applications to enhance the strength of joints and reduce stress concentrations, such as adhesive bonding, fasteners, welds, and more. One of these methods is the spew fille technique [11,12]. Design analysis for the adhesively bonded joint approach ensures that the adhesive can function effectively and that the overall bond meets the required specifications from previous studies [13,14]. Proposed notching of the adherends is a technique used in adhesive bonding to control and shift the location of damage initiation from the adhesive to the adherends (the bonded materials) [15]. This process involves creating small notches or grooves in the adherends near the bond line. Notching aims to improve the bonded joint's overall strength and durability by promoting more controlled and predictable failure modes. Tapering of the adherend termini is a well-known engineering method used to increase the strength of lap joints in various applications, particularly in structural engineering and material science. This technique is often employed when two materials or components need to be joined together to create a strong and durable connection [16]. Pre-bending of adherends is indeed an ingenious method to increase the strength of lap joints in certain applications, especially in the realm of aerospace and structural engineering. This technique involves curving or pre-forming the adherends (the overlapping materials being joined) before bonding [17]. The concept of variable flexibility and strength along the overlap length in adhesive joints is important in structural engineering and materials science. This idea suggests that an ideal adhesive joint should possess varying levels of flexibility and strength along its length to optimize its performance under different loading conditions [18]. It concluded that in a mixed-adhesive joint where both ductile and brittle adhesives are used together, the joint strength can be higher than when either adhesive is used individually. This conclusion appears to be based on some experimental or theoretical analysis comparing the joint strengths of these adhesive combinations [19].

The mechanical properties of different joints subjected to tensile loading with the same bonding area, such as single lap joints (SLJ), one-step lap joints (OSLJ), and three-step lap joints (TSLJ), various factors come into play that can influence their performance. These factors include stress distribution, load-carrying capacity, and failure modes. In the production of numerical samples, an aluminium alloy of AA2024-T3 was used as an adherent, and flexible adhesive SBT9244 and stiff adhesive DP460 were employed as adhesives. A comprehensive analysis involving different joint types, where stress analyses are performed using a three-dimensional finite element method. The analysis considers both geometric and material non-linearities in the adhesive and adherent materials. Experimental studies are often conducted to validate the results of finite element analysis (FEA). Experimental validation helps ensure that the FEA results are reliable and representative of real-world behaviour [20]. Adhesive bonding has become more prevalent recently across many industries due to its benefits over traditional joining processes in several areas, including fatigue resistance, design flexibility, damage tolerance, high strength-to-weight ratio, etc. Many applications include automobile, aerospace, marine, and railway coaches and boat fabrication.

## 2. Computational Modeling

### *2.1 Materials*

DP460 stiff adhesive and SBT 9244 soft adhesive were used as adhesives in this study. AA2024-T3 is a well-known aluminium alloy used in the aerospace and automotive industries for its favourable combination of properties, including a good strength-to-weight ratio, corrosion resistance, and excellent fatigue resistance taken from previous studies [7].

**Table 1**
Material properties of the adherend and adhesives

| Material | AA2024-T3 | SBT9244 | DP460 |
|---|---|---|---|
| E (MPa) | 72400 ± 530 | 82 ± 4 | 2077 ± 47 |
| V | 0.33 | 0.35 | 0.38 |
| $\sigma_t$ (MPa) | 482 ± 12 | 20.9 ± 0.7 | 44.6 ± 1.2 |
| $\varepsilon_t$ (mm/mm) | 0.1587 | 0.945 | 0.0428 |

## 2.2 Methodology

### *2.2.1 Three-dimensional finite-element modeling (3-D FEM)*

Samples of three different joint types (Type-I, Type-II, and Type-III) used in the numerical studies were modeled three-dimensionally using the Abaqus CAE geometry parameter shown in Figure 1. Performing stress analyses in adhesively bonded joints using a non-linear finite element method is a common practice in engineering and materials science to understand the behaviour of such joints under various loading conditions. The dimensions of the samples and boundary conditions used in the numerical study were the same as those used in the previous studies [7,21] experimentally study.

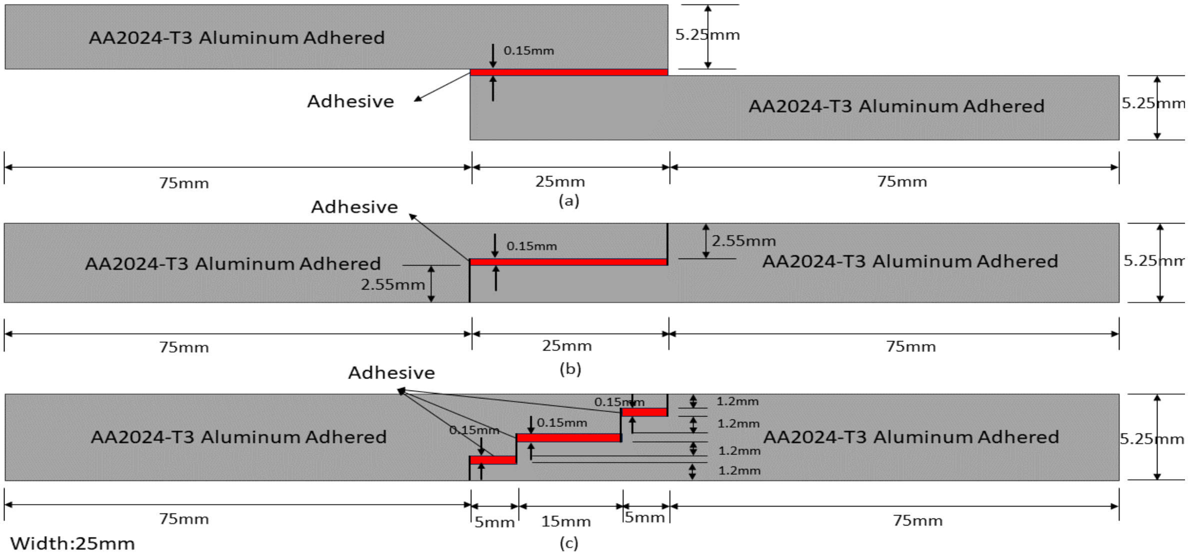


**Fig. 1.** Dimensions of the adhesively bonded joints: (a) single lap joint (Type-I), (b) one-step lap joint (Type-II), (c) three-step lap joint (Type-III)

Figure 2 shows that samples of all six examined with different types of joints. The part was instanced to be a dependent (mesh) on the part instance before setting any boundary conditions or meshes. There have been two steps created. The first is the initial step, and the second is the loading step. The boundary condition was applied in the initial step, and the load was applied in the loading step. The time period for the loading step is 6-11. At first, we created three sets (Left Face, Right Face, and Reference Plane (RP) and one surface (Right Surface). A boundary condition was applied to the left face, and load was applied to the reference plane. We find the maximum failure load in this section.

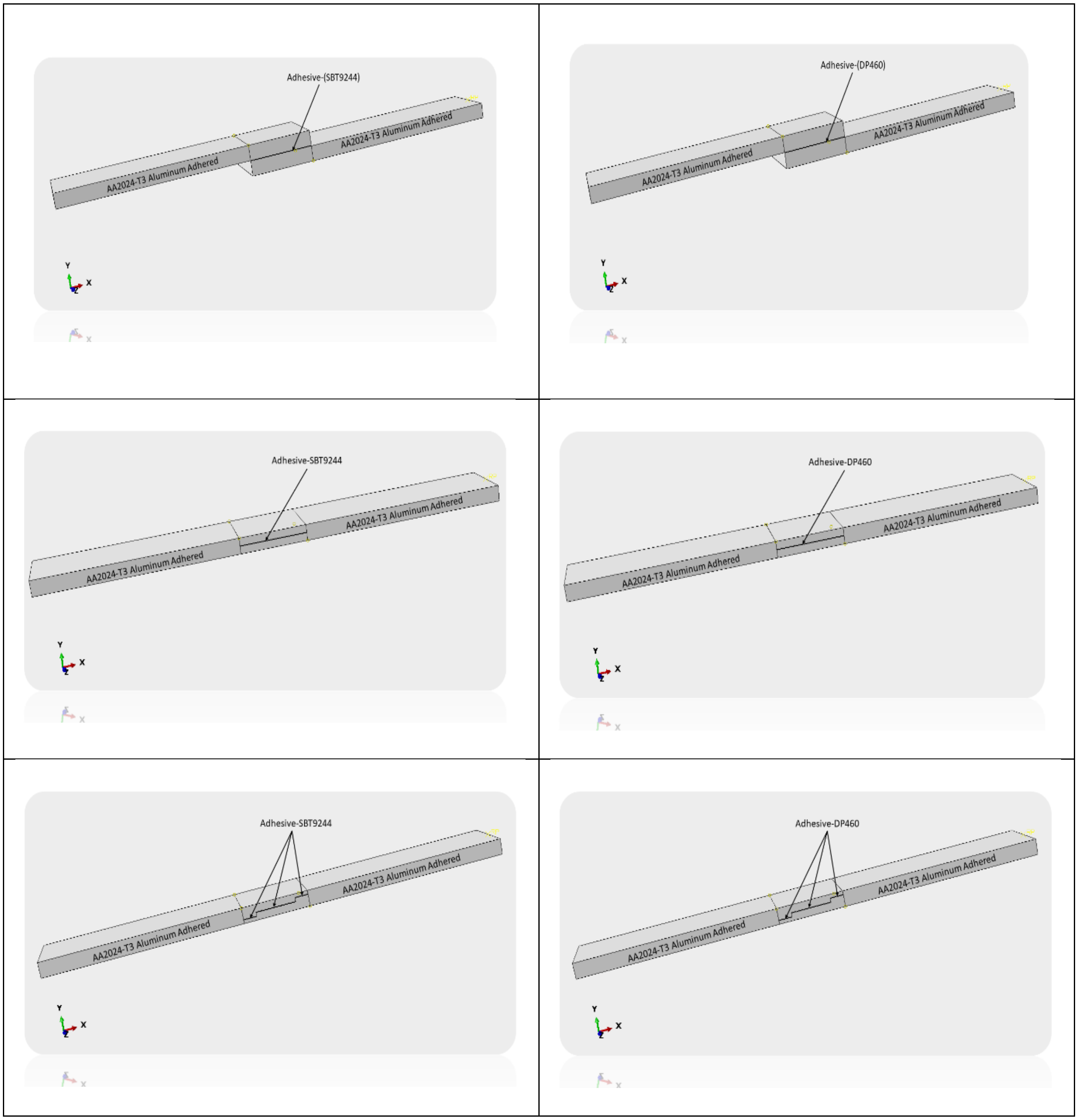


**Fig. 2.** Samples of all six examined with different types of joints

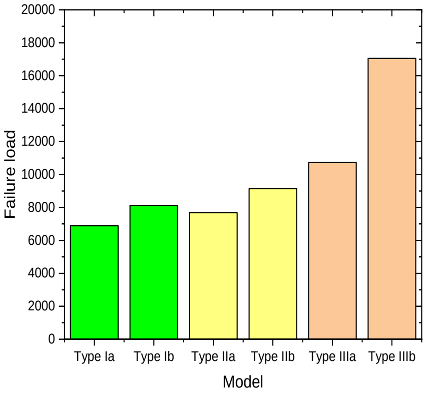


**Fig. 3.** Maximum Failure Load

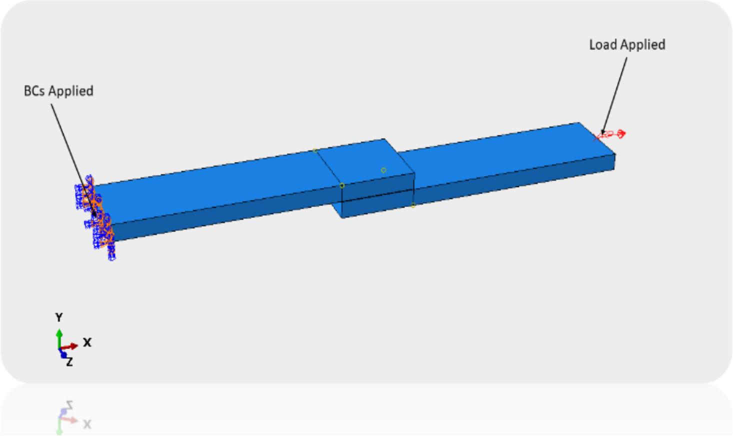


**Fig. 4.** Applying Load and Boundary Conditions

Figure 3 shows the maximum failure load of different types of joints [Type Ia and Type Ib SLJ, Type IIa and Type IIb OSLJ, and Type IIIa and Type IIIb TSLJ] with different adhesives and applying load and boundary conditions shown in Figure 4. In this process, we use part-by-part regions mesh and many element sizes to mesh the total part. We used several elements, 5 double biases of adhesive and adhered 0.2 double bias and 0.5 non-bias, and a total part element size of 1 non-bias, etc. Finally, the job was submitted for the analysis. The meshing element type is C3D8R linear hexahedral, i.e., the element is an 8-node linear brick with reduced integration with an hourglass control element. The total number of elements Type Ia is 63750, Type I 56250, Type IIa is 69875, Type IIb is 55275, Type IIIa is 54175, Type IIIb is 32550. Figure 5 shows a typical mesh model of the assembled part of the adhesively bonded joint TSLJ (Type-III).

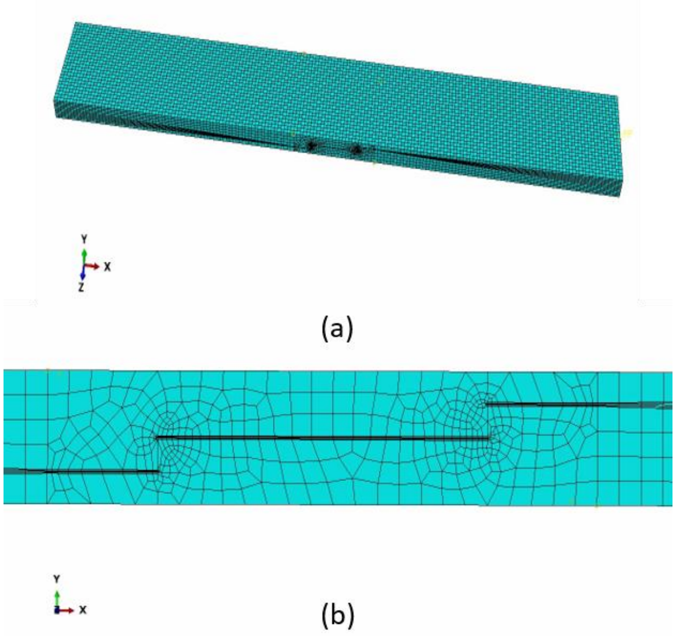


**Fig. 5.** Typical mesh model of the assembled part of the adhesively bonded joint (a) and (b) TSLJ (Type -III)

## 3.0 Results and Discussions

### *3.1 Model Validation*

Mesh dependency test of the analysis was performed using elements of six different sizes varying from the impact area. The elements were 1120, 2980, 16866, 66861, 77265 and 56250. For the dependency of the mesh, the von Mises stress vs overlap length curve was compared for different meshes. In the stress comparison curves in Figure 6, all numbers of elements are approximately the same. The maximum deviation of the no of element 77265 is also negligible. So, it is safe to assume the analysis is mesh-independent and can be performed using any element size. So, for the analysis, the region native mesh (the number of elements is 56250) was taken as average and minimum stress to get suitable results. The maximum stress value of SBT9244 Type-Ia is 10.5 MPa, and DP460 Type-Ib is 36.5 MPa. Approximate solutions are then merged to produce the outcome. The contours and graphical representations are illustrated and discussed below.

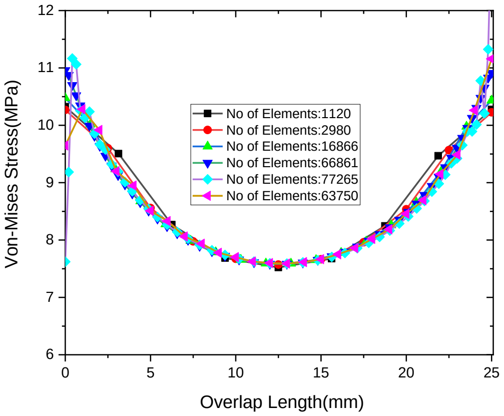


**Fig. 6.** Mesh sensibility analysis

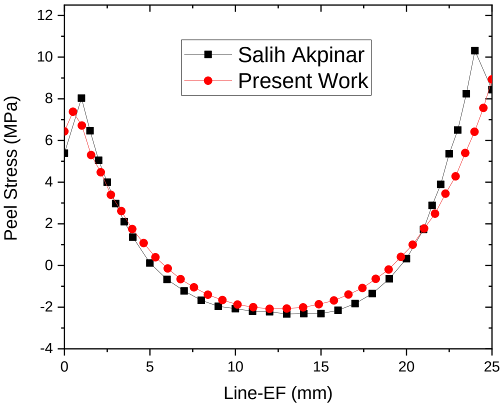


**Fig. 7.** Compare between the present study and previous research

Figure 6 shows a mesh sensibility analysis of SLJ (Type-I) lap joints. Single-lap joints are the most widely used adhesive joints and have been the subject of considerable research over the years, so we only show the SLJ Model comparison. Validation of this model is shown in Figure 7. The modeling used in this work was performed [7], and more research was taken from the previous studies [22-25]. A numerical simulation of adhesive-bonded joint composite material was carried out. Data from the previously mentioned research study was extracted using the origin software. Then, the simulation results were compared with those extracted from the research paper. Peel stress along the Y-axis, and overlap length along the X-axis are considered parameters for comparison. Figure 7 illustrates the comparison. The comparison shows that the error is quite minimal. Some deviation occurs at starting and ending points; the reason for the deviation may be the use of other simulation software. These results indicate that the simulation method is accurate.

### *3.2 Stress*

Following the finite element analysis (FEA), values of Type-I, Type-II, and Type-III joints are given in (Figure 1). The numerical analysis study has revealed that the most vulnerable points where failure is likely to occur are situated at the interface between the adhesive layer and the upper adherend, specifically on the surface designated as ABCD (Figure 8). Finite element analyses (FEA) were conducted on three different joint types (Type-Ia, Type-IIa, Type-IIIa) using flexible SBT9244 adhesive with an identical bonding area, subjecting them to a tensile load of 3000 N. Similarly, FEA was carried out on three distinct joint types (Type-Ib, Type-IIb, Type-IIIb) employing stiff DP460 adhesive under a load of 4000 N. It's worth noting that the latter load corresponds to half of the minimum failure load observed in experiments for these specific joint specimens. Peel and shear are distinct stress types that can affect an adhesive bond. Peel stress occurs when a force is applied parallel to the adhesive bond line's surface, separating the adhesive from the substrate.

On the other hand, shear stress is when a force is applied to the adhesive perpendicular to the bond line, causing the adhesive to slide or shear along the substrate. In terms of effectiveness, it depends on the specific application and the materials being bonded. Both peel and shear stresses can be effective for certain types of bonds and can lead to varying stress patterns within the adhesive layer (at the EF line).

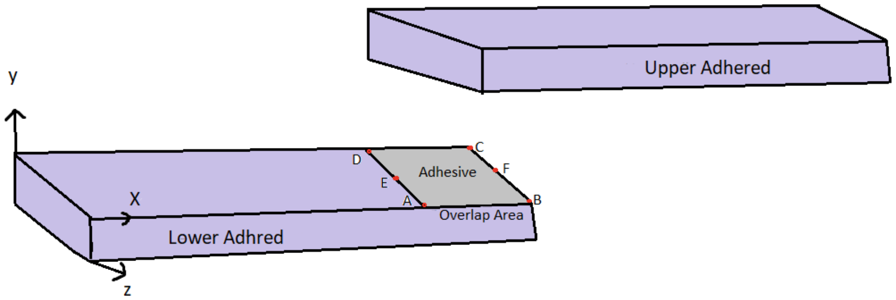
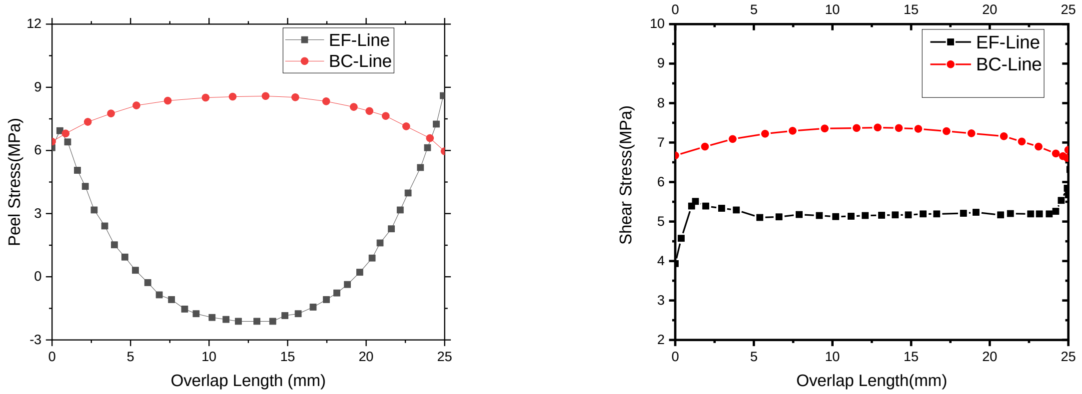


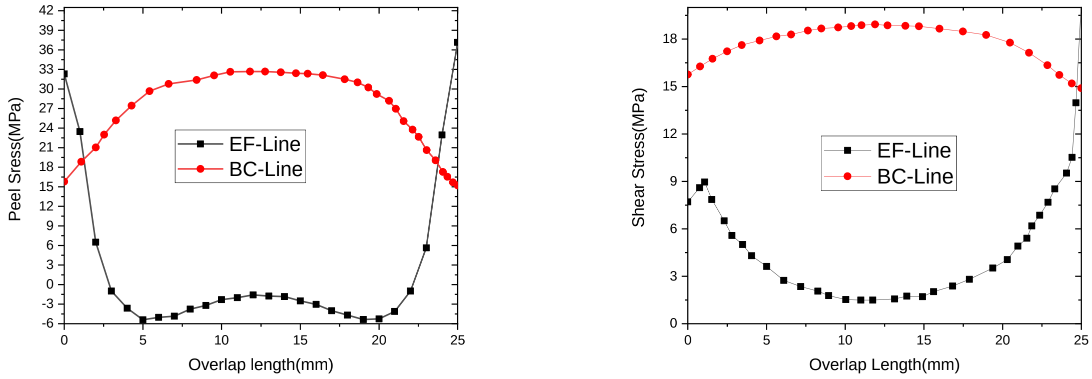
**Fig. 8.** Critical failure surfaces of the joint samples bonded with adhesive

Figure 9 and Figure 10 show the stress distributions of SLJ (Type-I). In single-lap bonded joints, stresses are maximum at the edges, where failure usually begins, while stresses are the minimum in the centre. Three samples of Type-Ia, Type-IIa, Type-IIIa, Type-Ib, Type-IIb, and Type-IIIb were subjected to tensile loading until failure. Type-Ia peel stress comparison shows that the error is quite minimal, and some deviation occurs at the starting and ending points. During the evaluation of these graphs, it is observed that stress concentrations manifest at the boundaries of the overlapping regions, reaching a peak magnitude at a specific location denoted as point F. The analysis of peel stresses in SBT9244 bonded joints, specifically for Type-I joints, reveals a distinct pattern. Peel stresses manifest tensile characteristics at the outer edges of the overlapping region, gradually diminishing as one moves toward the center. In regions nearer to the center, these peel stresses transition to become compressive. Since the influence of moments caused by extraneous loads in Type-Ia joints is reduced in Type-IIa joints, in such joints, the stresses developed near the center are almost zero.



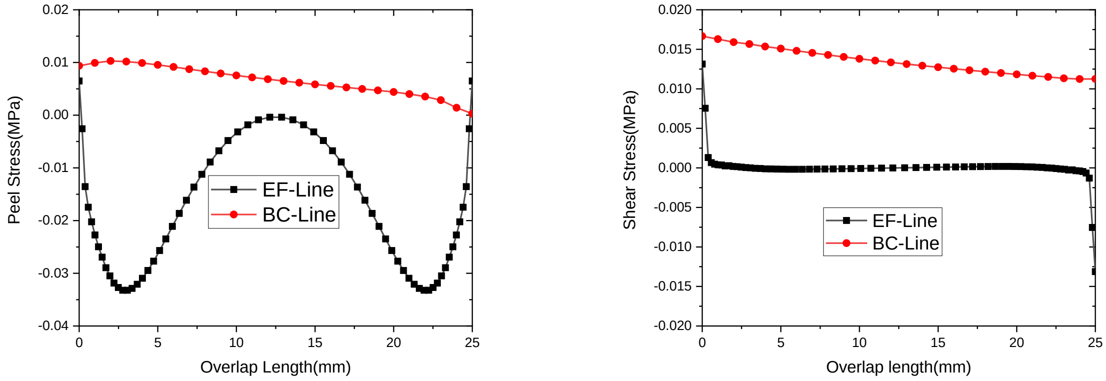
(a) (b)

**Fig. 9.** The stress distributions in the adhesive layer along EF and BC Line for SLJ joint bonded with SBT9244 adhesive (a) peel stress ($\sigma_y$) and (b) Shear Stress($\tau$)



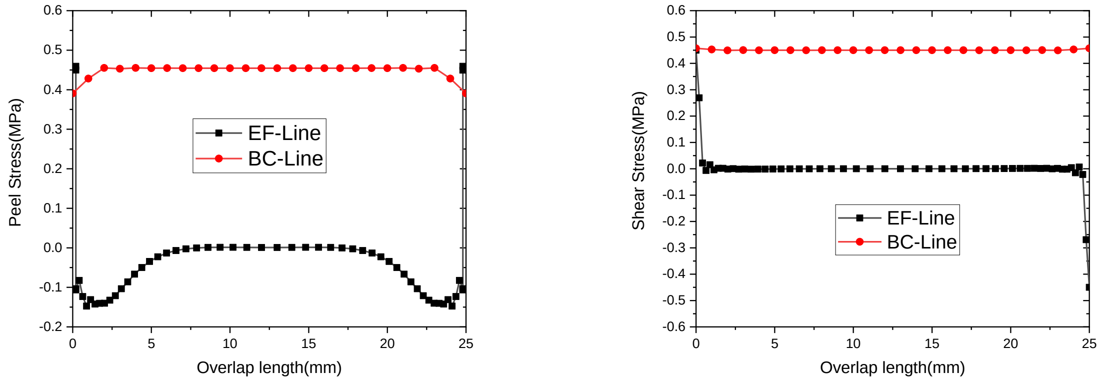
(a) (b)

**Fig. 10.** The stress distributions in the adhesive layer along EF and BC Line for SLJ joint bonded with DP460 adhesive (a) peel stress ($\sigma_y$) and (b) Shear Stress($\tau$)



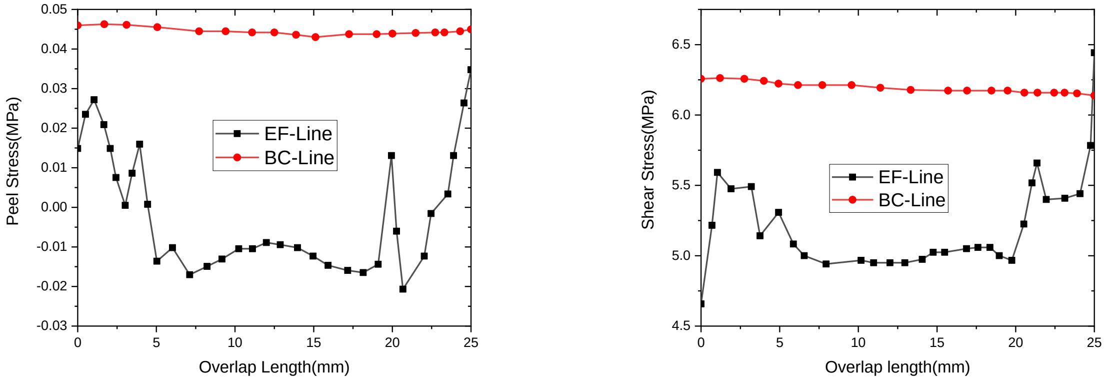
(a) (b)

**Fig. 11.** The stress distributions in the adhesive layer along EF and BC Line for OSLJ joint bonded withSBT9244 adhesive (a) peel stress ($\sigma_y$) and (b) Shear Stress($\tau$)



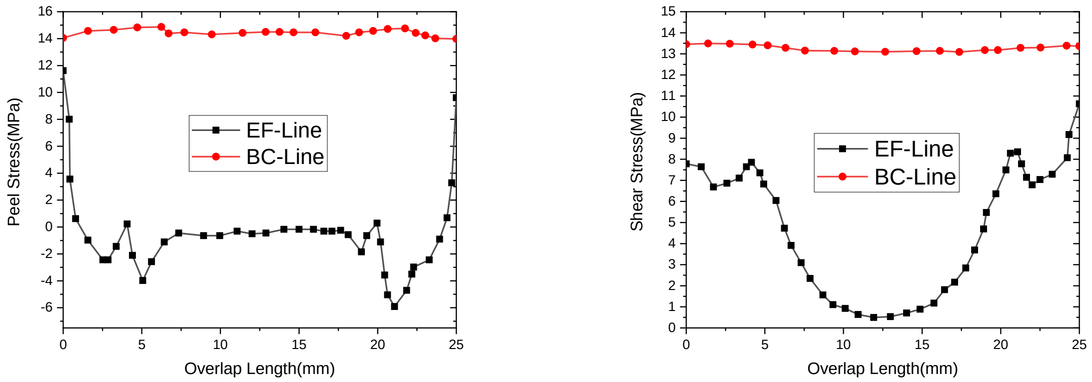
(a) (b)

**Fig. 12.** The stress distributions in the adhesive layer along EF and BC Line for OSLJ joint bonded with DP460 adhesive (a) peel stress ($\sigma_y$) and (b) Shear Stress($\tau$)



(a) (b)

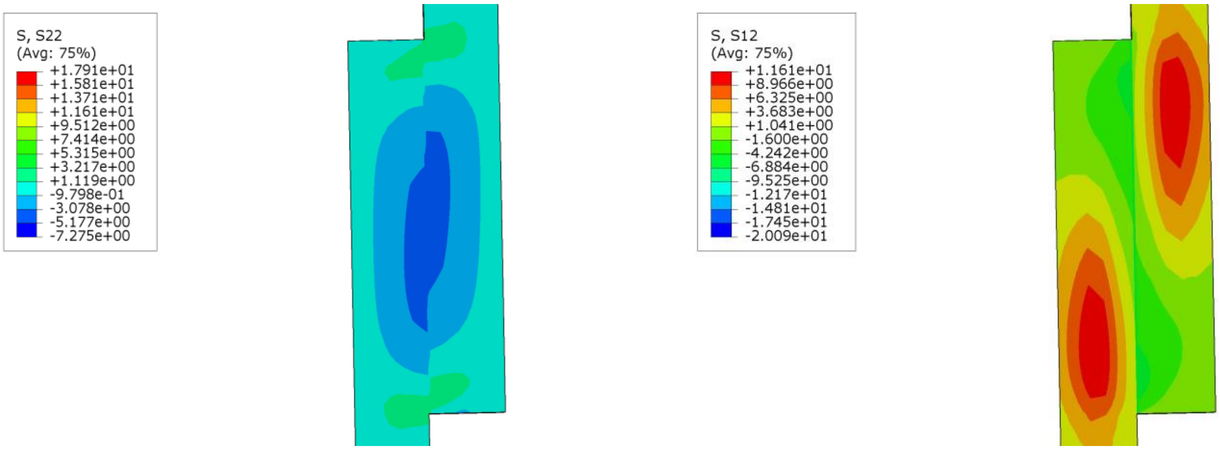
**Fig. 13.** The stress distributions in the adhesive layer along EF and BC Line for TSLJ joint bonded with SBT9244 adhesive (a) peel stress ($\sigma_y$) and (b) Shear Stress($\tau$)



(a) (b)

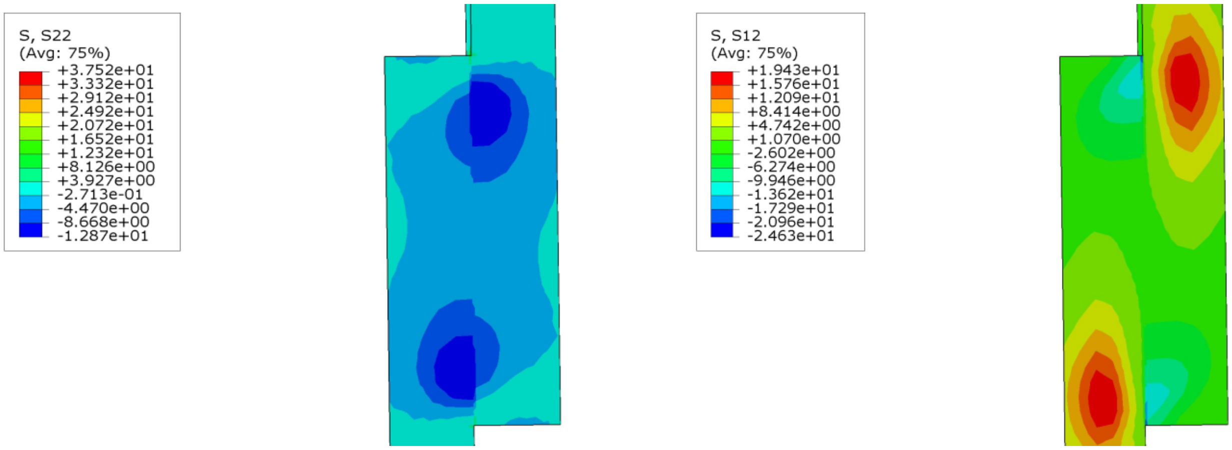
**Fig. 14.** The stress distributions in the adhesive layer along EF and BC Line for TSLJ joint bonded with DP460 adhesive (a) peel stress ($\sigma_y$) and (b) Shear Stress($\tau$)

The stress distributions of OSLJ (Type-ll) are shown in Figures 11 and 12. In addition, when approaching the amplitude of the overlap region in Type-III joints, a reduction in peel stresses occurring at the edge of the overlap area is noted. This reduction in peel stresses at the edge, which plays a critical role in damage initiation, is effectively redirected toward the center of the overlap area (as depicted in Figures 13 and 14). Simultaneously, along the length of the lap joint (at line EF), the shear stress reaches its maximum at point F and its minimum at point E. For Type-II hinge height joints, a notable distinction in stress values at the edges is clear. Further, the Type III-a connection exhibits a more uniform distribution of stress values, with reduced dissimilar at its edges.



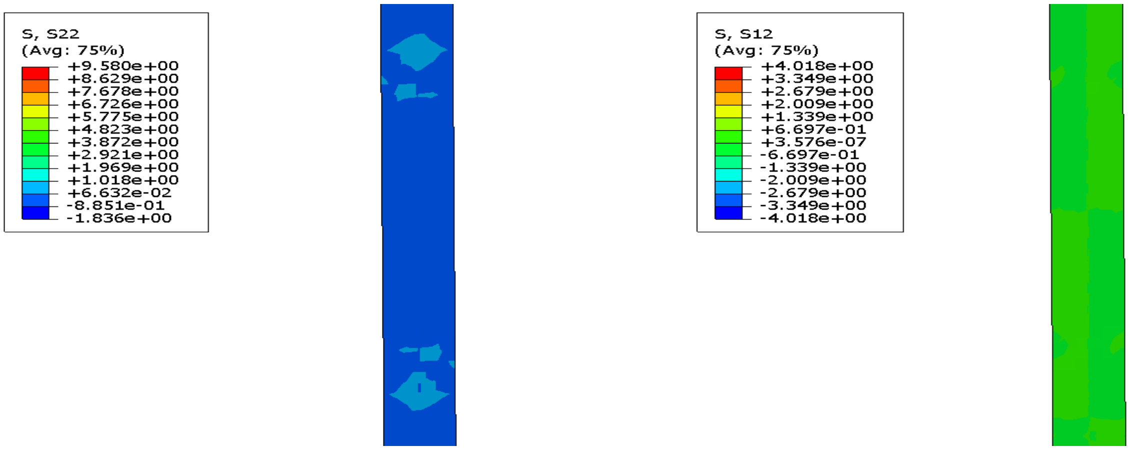
(a) (b)

**Fig. 15.** Contour map under unit tensile loading of Type-Ia with adhesive SBT9244 (a) Y direction peel stress and (b) XY direction Shear stress



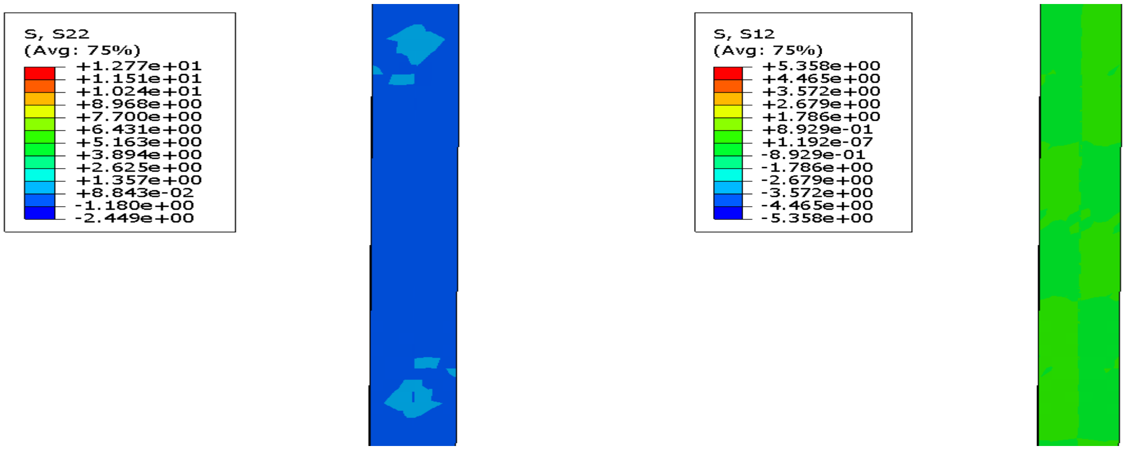
(a) (b)

**Fig. 16.** Contour map under unit tensile loading of Type-Ib with adhesive DP460 (a) Y direction peel stress and (b) XY direction Shear stress



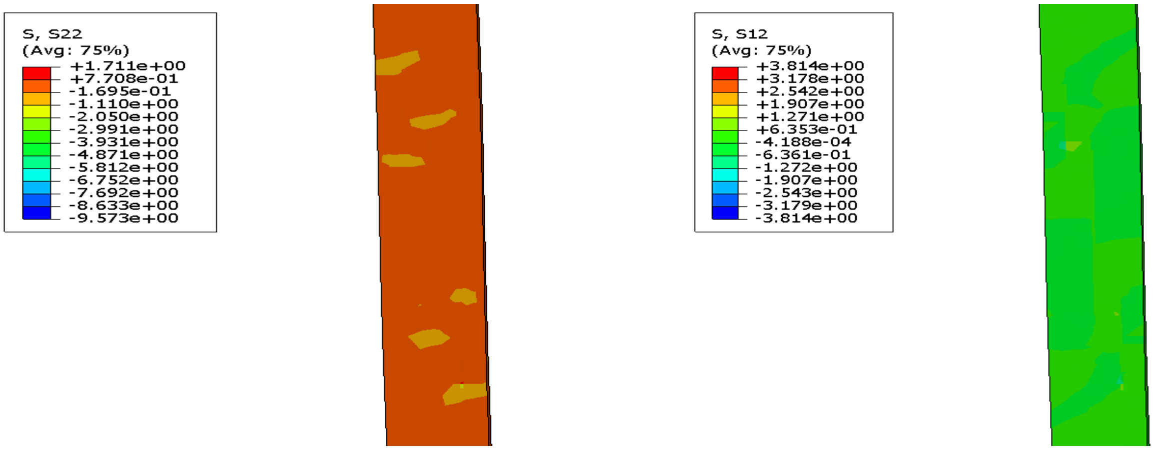
(a) (b)

**Fig. 17.** Contour map under unit tensile loading of Type-IIa with adhesive SBT9244 (a) Y direction peel stress and (b) XY direction Shear stress



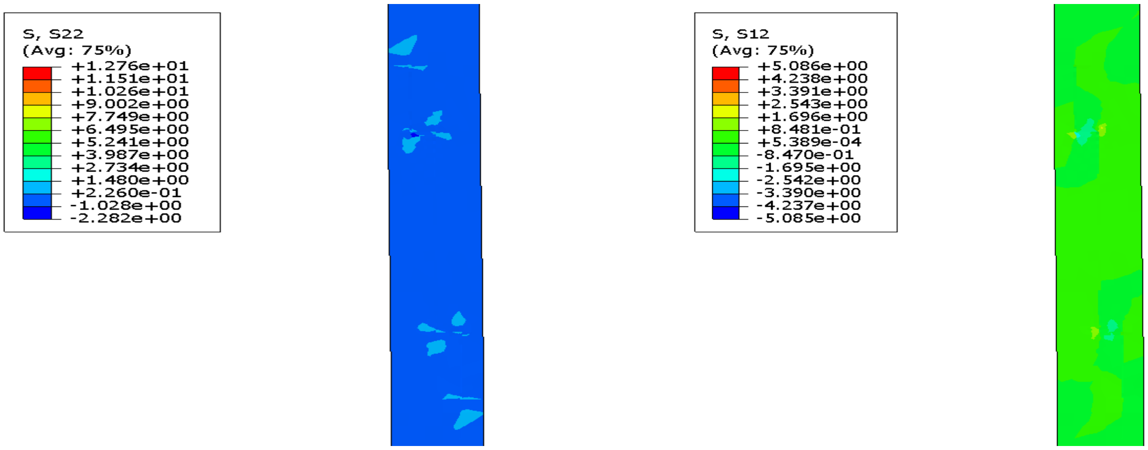
(a) (b)

**Fig. 18.** Contour map under unit tensile loading of Type-IIb with adhesive DP460 (a) Y direction peel stress and (b) XY direction Shear stress



(a) (b)

**Fig. 19.** Contour map under unit tensile loading of Type-IIIa with adhesive SBT9244 (a) Y direction peel stress and (b) XY direction Shear stress



(a) (b)

**Fig. 20.** Contour map under unit tensile loading of Type-IIIb with adhesive DP460 (a) Y direction peel stress and (b) XY direction Shear stress

Figures 15-20 show contour maps of all six examined samples with different types of joints. An examination of peel stress distribution reveals a distinct pattern in the context of bonding three different joint types using DP460 adhesive. Specifically, when the adhesive possesses a higher hardness level, stress concentration becomes evident at the amplitude of the overlap region, with the stress magnitude reaching its peak at point F. On the other hand, peel stress exhibits compressive properties. The peel stress is close to zero in the Type-Ib joint in the middle of the overlapping region in the Type-IIb and Type-IIIb joints. At the same time, the shear stress distribution along the overlapping length (line EF) does not exhibit uniformity for any of the types examined. In all cases, the shear stress is most obvious at point F and is at its lowest within the central portion of the overlapping region.

Finally, the shear stress generated in Type-IIIb is transferred from the edge of the overlapping region to the inner region. For Type I joints, the peel stresses are tensile at the edges of the overlapping region. Moving towards the center, these stresses transition to a compressive state, eventually approaching zero in the vicinity of the central region. When assessing the distribution of peel stress and shear stress within the adhesive layer along the line BC, it is evident that the stress values for Type I joints are not evenly distributed along this line. Specifically, they reach their maximum at the midpoint (point F) and their minimum values at the edges (points B and C). Additionally, stress values are significantly dissimilar between the central region and the edges. In the case of Type-II connections, there is a noticeable reduction in the dissimilar between stress values at the center and the edges along the width direction. Meanwhile, the stress values display an almost negligible difference for Type-III connections, indicating a remarkably uniform distribution. An important observation is that at point F, where the peel stress becomes a critical parameter for initiating adhesive layer damage, Type-II and Type-III connections exhibit lower peel stress values than Type-I connections. Type-II and Type-III connections exhibit reduced peel stress and decreased shear stress. However, it's worth noting that the extent of stress reduction varies between Type-II and Type-III joints, with Type-III joints experiencing the most significant reduction. This reduction in stress levels plays a pivotal role in enhancing the load-carrying capacity of the connection.

## 4.0 Conclusions

In this Numerical Study, the mechanical behaviours of three different joint types (SLJ, OSLJ, and TSLJ) subjected to tensile loading were investigated numerically. By employing a linear material model and considering non-linear geometry, along with utilizing measurements that are approximated but very close to accuracy, emulating boundary conditions accurately, and ensuring a validated mesh density, it becomes possible to make reasonably precise predictions regarding the deformation of a single-lap joint during a tensile test while minimizing errors. These errors can be mitigated by adopting a more precise material model, finer measurements, a more rigorous testing comparison, and an optimized testing setup. Alternatively, it's important to recognize that the geometry of the bonding area, whether employing Single-Lap Joints (SLJ), Overlap Single-Lap Joints (OSLJ), or Tapered Single-Lap Joints (TSLJ), has a profound influence on the formation of stress concentrations within the adhesive joint and ultimately impacts the load-carrying capacity of the joint.

Comparing the load capacity of the joints bonded with DP460 rigid adhesive showed that OSLJ (Type-IIb) and TSLJ (Type-IIIb) carried higher loads than SLJ (Type-Ib) by 12.56% and 73%, respectively. For joints bonded using SBT9244 flexible adhesive with the same bonded area, OSLJ (Type-IIa) and TSLJ (Type-IIIa) carried higher loads than SLJ (Type-Ia) by 11.4% and 55.7%, respectively. In the case of Type-II and Type-III joints, the shear and peel stress distributions exhibit uniformity when assessed along the width (BC line). However, this distribution pattern takes a different form for Type-I joints, with stress levels peaking in the middle of the width and assumedly reaching their minimum at the edges. This variation in stress distribution resulted in significant differences between stress values at the center and the edges.

There is an enormous area for further development. Future work can be carried out by changing the layer thickness and seeing how it influences the behaviour of the structures. To understand the effect, varied material and geometric parameters directly impact the critical point stresses. One varies more than one parameter at once to understand how each parameter interacts with the other. It is suggested that the understanding of the failure of adhesively bonded lap joints be extended, increasing the accuracy of the experimental finite element model.

## Acknowledgement

First and foremost, we would want to show our profound thankfulness to Almighty Allah for His bountiful blessings on our research work. We would also like to convey cordial honour, respect, and gratitude to our honourable supervisor, Md. Ahatashamul Haque Khan Shuvo, Department head Md. Mostafa Hossain and our honourable VC Prof. Dr. Md. Abul Bashar Sonargaon University, We would specially thankfulness to Prof. Dr. Md. Shariful Islam, Department of Mechanical Engineering, Khulna University of Engineering & Technology for the guidance, helpful instructions, advice, and corrections during various stages of the research work as well as, friendly cooperation throughout this research paper.

## References

[1] L. D. R. Grant, Robert D. Adams and Lucas FM da Silva, "Experimental and Numerical Analysis of Single-Lap Joints for the Automotive Industry," International Journal of Adhesion and Adhesives 29, no. 4 (2009): 405-413. https://doi.org/10.1016/j.ijadhadh.2008.09.001

[2] Lucas FM da Silva, R. D. Adams and M. Gibbs, "Manufacture of Adhesive Joints and Bulk Specimens with High-Temperature Adhesives," International Journal of Adhesion and Adhesives 24, no. 1 (2004): 69-83. https://doi.org/10.1016/S0143-7496(03)00101-5

[3] R. L. Patrick, "Structural Adhesives with Emphasis on Aerospace Applications," Treatise on Adhesion and Adhesives 4 (1976).

[4] L. J. Hart-Smith, Analysis and Design of Advanced Composite Bonded Joints (NASA Langly Contract Report, NASA CR-2218, 1973a).

[5] Onur Sayman, Volkan Arikan, Akar Dogan, Ibrahim F. Soykok and Tolga Dogan, "Failure Analysis of Adhesively Bonded Composite Joints under Transverse Impact and Different Temperatures," Composites Part B: Engineering 54 (2013): 409-414. https://doi.org/10.1016/j.compositesb.2013.06.017

[6] Suong V Hoa. Principles of the Manufacturing of Composite Materials. (Pennsylvania: DEStech Publications, Inc, 2009).

[7] S. Akpinar, "The Strength of the Adhesively Bonded Step-Lap Joints for Different Step Numbers," Composites Part B: Engineering 67 (2014): 170-178. https://doi.org/10.1016/j.compositesb.2014.06.023

[8] Recep Gunes, M. Kemal Apalak, Mustafa Yildirim and Ismail Ozkes, "Free Vibration Analysis of Adhesively Bonded Single Lap Joints with Wide and Narrow Functionally Graded Plates," Composite Structures 92, no. 1 (2010): 1-17. https://doi.org/10.1016/j.compstruct.2009.06.003

[9] Robert Uscinowicz, "Impact of Temperature on Shear Strength of Single Lap Al–Cu Bimetallic Joint," Composites Part B: Engineering 44, no. 1 (2013): 344-356. https://doi.org/10.1016/j.compositesb.2012.04.073

[10] R. D. Adams and J. A. Harris, "The Influence of Local Geometry on the Strength of Adhesive Joints," International Journal of Adhesion and Adhesives 7, no. 2 (1987): 69-80. https://doi.org/10.1016/0143-7496(87)90092-3

[11] X. Zhao, R. D. Adams and L. F. M. Da Silva, "Single Lap Joints with Rounded Adherend Corners: Experimental Results and Strength Prediction," Journal of Adhesion Science and Technology 25, no. 8 (2011): 837-856. https://www.tandfonline.com/doi/abs/10.1163/016942410X520880

[12] John S. Tomblin, Chenxuan Yang and P. Harter, Investigation of Thick Bond Line Adhesive Joints. No. DOT/FAA/AR-01/33. Office of Aviation Research, US Federal Aviation Administration, 2001.

[13] L. J. Hart-Smith, Analysis and Design of Advanced Composite Bonded Joints (NASA Langly Contract Report, NASA CR-2218, 1973b, 1973c, 1973d, 1973e).

[14] L. J. Hart-Smith, Analysis and Design of Advanced Composite Bonded Joints (NASA Langly Contract Report, AFWAL-TR-81-3154, 2 Vols, 1982a).

[15] Erol Sancaktar and Sean R. Simmons, "Optimization of Adhesively-Bonded Single Lap Joints by Adherend Notching," Journal of Adhesion Science and Technology 14, no. 11 (2000): 1363-1404. https://doi.org/10.1163/156856100742258

[16] Erol Sancaktar and Prasad Nirantar, "Increasing Strength of Single Lap Joints of Metal Adherends by Taper Minimization," Journal of Adhesion Science and Technology 17, no. 5 (2003): 655-675. https://doi.org/10.1163/156856103321340796

[17] Erol Sancaktar, "A Comparison of Linear With Non-Linear Viscoelastic Solutions for Shear Stress Concentration in Double Lap Joints," The Journal of Adhesion 34, no. 1-4 (1991): 211-220. https://doi.org/10.1080/00218469108026515

[18] Lucas FM da Silva and Maria Joao CQ Lopes, "Joint Strength Optimization by the Mixed-Adhesive Technique," International Journal of Adhesion and Adhesives 29, no. 5 (2009): 509-514. https://doi.org/10.1016/j.ijadhadh.2008.09.009

[19] Şemsettin Temiz, "Application of Bi-Adhesive in Double-Strap Joints Subjected to Bending Moment," Journal of Adhesion Science and Technology 20, no. 14 (2006): 1547-1560. https://doi.org/10.1163/156856106778884262

[20] Salih Akpinar, Murat Demir Aydin and Adnan Özel, "A Study on 3-D Stress Distributions in the Bi-Adhesively Bonded T-Joints," Applied Mathematical Modelling 37, no. 24 (2013): 10220-10230. https://doi.org/10.1016/j.apm.2013.06.008

[21] M Durmus and S. Akpinar, "The Experimental and Numerical Analysis of the Adhesively Bonded Three Step-Lap Joints with Different Step Length," *Theoretical and Applied Fracture Mechanics 105 (2020) 102427.* https://doi.org/10.1016/j.tafmec.2019.102427

[22] Adnan Ozel, Betul Yazici, Salih Akpinar, Murat Demir Aydin and Şemsettin Temiz, "A Study on the Strength of Adhesively Bonded Joints with Different Adherends," Composites Part B: Engineering 62 (2014): 167-174. https://doi.org/10.1016/j.compositesb.2014.03.001

[23] Simay Bayramoglu, Kübra Demir and Salih Akpinar, "Investigation of Internal Step and Metal Part Reinforcement on Joint Strength in the Adhesively Bonded Joint: Experimental and Numerical Analysis," Theoretical and Applied Fracture Mechanics 108 (2020): 102613. https://doi.org/10.1016/j.tafmec.2020.102613

[24] Salih Akpinar, Muhammet Onur Doru, Adnan Özel, Murat Demir Aydin and Hamed Ghaffarzadeh Jahanpasand, "The Effect of the Spew Fillet on an Adhesively Bonded Single-Lap Joint Subjected to Bending Moment," Composites Part B: Engineering 55 (2013): 55-64. https://doi.org/10.1016/j.compositesb.2013.05.056

[25] Kürsat Gültekin, Salih Akpinar and Adnan Özel, "The Effect of the Adherend Width on the Strength of Adhesively Bonded Single-Lap Joint: Experimental and Numerical Analysis," Composites Part B: Engineering 60 (2014): 736-745. https://doi.org/10.1016/j.compositesb.2014.01.022