Xi'an Shiyou Daxue Xuebao (Ziran Kexue Ban)/
Journal of Xi'an Shiyou University, Natural Sciences Edition
ISSN: 1673-064X
E-Publication: Online Open Access
Vol: 67 Issue 08 | 2024
DOI: 10.5281/zenodo.13365359

ANALYSIS OF THE EFFECTS OF DISBONDING ON SHEAR STRESSES IN BONDED ASSEMBLIES SUBJECTED TO MECHANICAL LOADS

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Abstract

This study examines the impact of delamination on shear stresses in bonded joints subjected to mechanical loads. The paper examines how different types and widths of delamination affect shear stress distribution in both the xz and zz planes, focusing on two common adhesive bonding configurations, simple overlap joints and end-to-end overlap joints. There is a notable increase in stress concentration as delamination width expands, according to experimental and simulated analyses. Longitudinal delamination also affects shear stresses, though to a lesser extent than transverse delamination. Maximum stress concentrations were observed in the presence of combined longitudinal and transverse delamination in the zz plane peeling stress, which is particularly sensitive to delamination effects. The study underscores the importance of considering delamination in the design and evaluation of bonded assemblies, highlighting how variations in delamination width and type can substantially impact structural performance. The study emphasizes how differences in delamination breadth and type can significantly effect structural performance, underscoring the need of taking delamination into account in the design and evaluation of bonded assemblies.

Index Terms: Delamination, Shear Stress, Bonded Joints, Mechanical Loads, Adhesive Bonding, Peeling Stress, Bonded Assemblies.

1. INTRODUCTION

Adhesives are used to link materials in bonded joints, which are widely used in many engineering applications because they can form robust connections with little mechanical or thermal turbulence. These joints are widely used in industries including construction, automotive, and aerospace because they provide a number of benefits, including improved performance, reduced weight, and flexible design. Nevertheless, despite these advantages, delamination—a serious problem when the adhesive layer separates from the substrate and may result in joint failure—can compromise the integrity of bonded joints. A lot of research has been done on the phenomenon of delamination. For instance, utilizing curved laminated FRP composite panels, Pradhan and Parida (2013) carried out a thorough investigation of delamination-induced damage in adhesive bonded lap shear joints [1]. Mishra, Pradhan, and Pandit (2016) further investigated delamination propagation in spar wingskin joints, highlighting its impact on structural performance [2].

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Similarly, Na Yahya and Safa Hashim (2014) explored stress distribution in steel/carbon composite double lap shear joints, emphasizing the importance of understanding shear stresses in bonded joints [3]. The work of Majid and Mohammad Reza (2018) on defect effects using cohesive zone modeling underscores the necessity for comprehensive analysis of joint quality [4]. Additionally, Marannano and Zuccarello (2022) optimized end double-lap bonded joints for GFRP composite sandwich panels, demonstrating practical approaches to enhancing joint performance [5]. Finally, Süsler, Avşar, and Türkmen (2023) illustrated the various effects of delamination on joint integrity by offering insights into the performance of repaired sandwich composite aeronautical structures under various stress circumstances [6].

Shear stresses have a direct impact on the structural integrity and functionality of adhesive assemblies, making them an essential component in the performance and dependability of bonded junctions. The importance of shear stress in a variety of applications has been brought to light by recent developments in its detection and management. As an example, Wintzheimer et al. (2019) showed how luminous shear stress sensors can offer comprehensive information on stress distributions, increasing the potential for mechanochromic detection and improving the performance of materials under load [7]. Similar to this, Blaeser et al. (2016) highlighted the significance of precisely managing shear stresses in 3D bioprinting to achieve optimal printing resolution and preserve stem cell viability [8]. This study's main goals are to: Examine how delamination affects shear stresses in bonded joints, paying particular attention to the various kinds and widths of delamination. Examine the effects of longitudinal and transverse delamination on the shear stress distribution in bonded joints in the xz and zz planes. To improve adhesive bond design and maintenance procedures, provide a thorough understanding of how delamination modifies stress distribution and joint integrity. This work offers a comprehensive analysis of the impact of delamination on shear stresses in bonded joints. In Section 2, the body of research is reviewed, important findings are summarized, and knowledge gaps are noted. The importance of shear stress analysis and how it relates to joint function are covered in Section 3. Shear stresses in bonded assemblies with overlap joints between two plates are examined in Section 5, while Section 4 concentrates on shear stresses in edge-to-edge bonded joints with a single overlap. A summary of the results and suggestions for more study to deepen our understanding of adhesive bonding under mechanical loads are included in the paper's conclusion.

2. LITERATURE REVIEW

Because adhesively bonded joint performance has important applications across a wide range of engineering domains, it is an important subject of research. Several factors, such as the type of adhesive, surface texture, and the presence of environmental chemicals, affect the mechanical performance and durability of these junctions. The effect of various adhesives on joint strength has been investigated in recent research. The impact of carbon and glass fiber reinforced composite adhesives on the strength of bonded joints

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was examined by Akpinar and Akpinar (2023) [9], who discovered that joint performance is highly dependent on the kind of reinforcement. The relevance of adhesive qualities in automotive applications is highlighted by de Queiroz, Banea, and Cavalcanti (2021) in their evaluation of adhesively bonded joints in both natural and synthetic fiber-reinforced polymer composites [10]. Another important factor in the mechanical performance of bonded joints is surface texture. In their analysis of surface texture's influence on joint performance, Naat and al. (2021) emphasized how surface preparation techniques can significantly affect the joints' mechanical strength [11]. This is in line with research by Gualberto, do Carmo Amorim, and Costa (2021), which examined the connection between environmental agents and design elements and showed how these elements affect adhesive performance under various circumstances [12]. Many studies have also been conducted on the behavior and strength of bonded joints under varied loading circumstances. In order to better understand how new manufacturing processes impact joint qualities, Spaggiari and Denti (2021) investigated the mechanical strength of joints made using polymeric additive manufacturing [13]. Comparably, Boretzki and Albiez (2022) examined the hybrid bonded-bolted joints' static strength and load-bearing characteristics, yielding insightful experimental and numerical information on joint performance [14].

A thorough analysis has been conducted on the fatigue and impact resistance of bonded joints. Understanding fatigue behavior is crucial for joint design, as demonstrated by Jalali et al.'s (2021) study on the impact fatigue's impacts on adhesively bonded joints' residual static strength [15]. This is in addition to study conducted by Yousefi Kanani et al. (2020) on adhesively bonded and hybrid joints with differing adherends, which examined the effects of various joint configurations on overall performance in a critical manner [16]. The field is also being advanced by newly developed materials and design strategies. A novel epoxy film adhesive with block copolymers and nanoparticles was presented by Ghaderi, Semnani, and Moini Jazani in 2024 [17]. This adhesive improves the mechanical, adhesion, and thermal properties of aluminum bonded joints. Akhavan-Safar, Carneiro Neto, Sampaio, Simões, Vignoli, & da Silva, 2024) also examined creep behavior in bonded joints, offering a thorough summary of how time-dependent deformation impacts joint endurance [18]. Nespě\ný, Vaněk, and Pěnčík (2024) added insightful information on joint performance under shear stresses, which advanced our understanding of shear testing in cement and fiber composite materials [19].

This paper offers a comprehensive investigation of these impacts. It closes a significant knowledge gap by concentrating on different delamination scenarios and provides a more thorough understanding of the mechanics underlying adhesive joint failures. This work integrates a new analytical tools to expand the field of shear stress analysis by using cutting-edge techniques, such as sensor technology and computational models. These methods improve the accuracy and dependability of the results by allowing a more accurate assessment of shear stress distributions and the effect of delamination. The results of this study will have more applicable in different domains as: construction, automobile, and aerospace, where bonded joints are widely used.

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3. SHEAR STRESS ANALYSIS AND ITS IMPORTANCE IN BONDED ASSEMBLIES

Shear stress analysis involves determining the shear forces acting on a structure or material. This entails measuring the tensions and deformations in a specific cross-sectional area, as well as evaluating the internal forces within the material. The results of shear stress analysis are used to ascertain whether a material or structure can withstand the shear forces that may occur during its use. Engineers can use mathematical models to simulate shear forces and stresses in different types of structures or materials, aiding in the design and material selection for various projects, from bridge construction to aerospace engineering. Shear stress in bonded assemblies is a force that acts when two materials are bonded together, and a perpendicular force is applied to their contact interface. This force can cause deformations and stresses in both the adhesive and the bonded materials. Shear stress resistance is a crucial factor in the design of bonded assemblies, as it determines the assembly's ability to withstand shear stresses that may occur during its use.

Engineers can use shear tests to measure the assembly's resistance to shear stress and employ mathematical models to simulate the stresses in different types of bonded assemblies. This helps in choosing appropriate materials and bonding methods for specific applications. It's important to note that shear stress resistance depends on numerous factors, such as the nature and properties of the bonded materials, the quality of adhesive application, and the usage conditions of the assembly. Therefore, tests and analyses must be conducted to determine shear stress resistance in each individual case.

In this work, we analyze the shear stresses in adhesives for different types of bonded assemblies: bonding between two plates with an overlap joint and edge-to-edge bonding with a single overlap. The first step involves analyzing the effect of plate thickness. Next, we analyze the effects of longitudinal delamination, transverse delamination, and mixed delamination (longitudinal and transverse) for different shear planes. We also examine the effect of peeling shear stress.

Peeling stress is a force acting on an adhesive or bonded surface in a direction opposite to the bonded surface. This force is perpendicular to the bonded surface and can often be measured by performing a peel test, which involves pulling an adhesive bonded to a substrate and measuring the force required to detach it. Peeling stress is crucial in adhesion applications as it can determine the durability and resistance of adhesives. Factors such as temperature, pulling speed, and bonding surface all influence peeling stress and must be considered when designing adhesive structures.

Figure 1 shows that the shear stress τxz is more significant compared to the stress recorded in the xy plane. It is essential to control shear stress concerning the xz plane. This means monitoring the force applied perpendicularly to the contact interface between the two materials and parallel to the xz plane's surface, and conducting shear stress resistance tests to assess the assembly's ability to withstand shear forces that may occur during its use.

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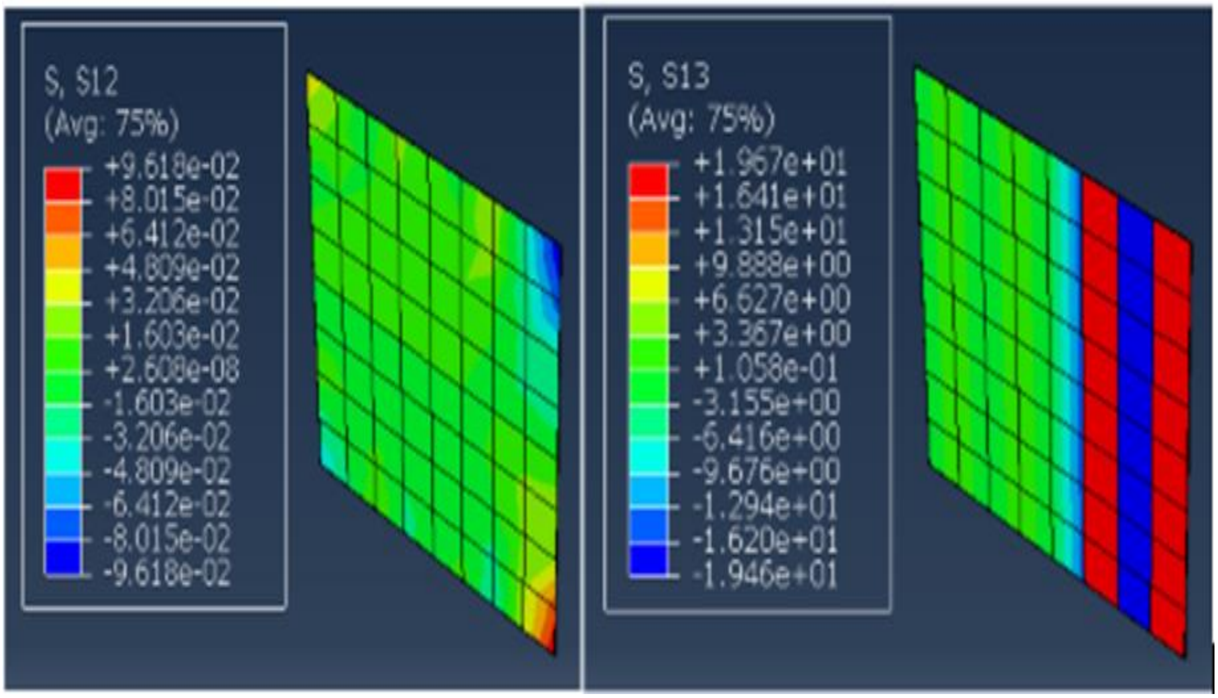

Figure 1: Shear Stresses in the xy and xz Planes

4. ANALYSIS OF SHEAR STRESSES FOR AN EDGE-TO-EDGE BONDED JOINT WITH SINGLE OVERLAP

In this section, when discussing an assembly with a single lap joint, it refers to a bonding method where the materials are held together using a simple lap joint. This method does not provide sufficient resistance to shear stress but can be used for expansion joints or assemblies not subjected to significant forces.

It is important to follow the manufacturer's instructions when using this assembly method and to consider the shear stresses that may occur during its use. Generally, it is preferable to use more robust assembly methods for joints subjected to significant forces.

Figure 2 presents the shear stress in the xz plane relative to the applied load, comparing different plate thicknesses. From this figure, it is clear that the recorded stress increases with the applied load.

It can be noted that the maximum recorded stress increases with the applied load. For different types of loading, a plate with a thickness of 5mm shows a stress concentration increase of about 78% compared to a plate with a thickness of 3mm, due to the higher applieds

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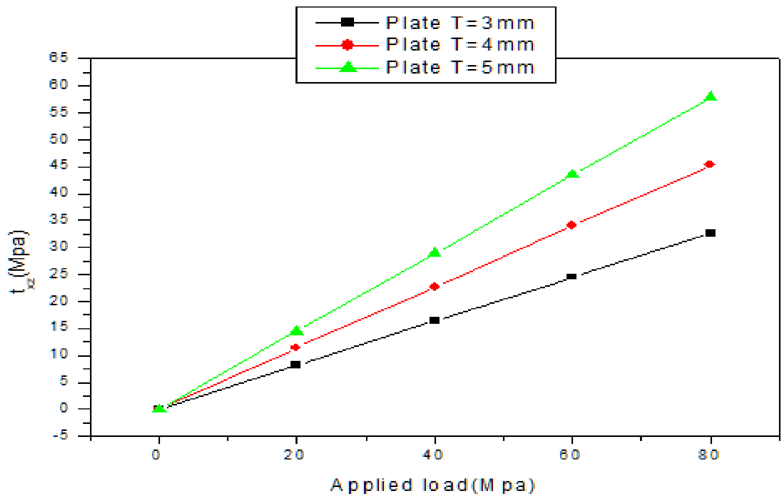

Figure 2: Shear Stresses in the xz Plane Influenced by Plate Thickness

Figure 3 presents the peeling shear stress in the zz plane relative to the applied load. From this figure, it is clear that the recorded stress increases with the applied load. It can be noted that the maximum recorded stress increases with the applied load. The peeling stresses are less significant compared to the shear stress in the xz plane.

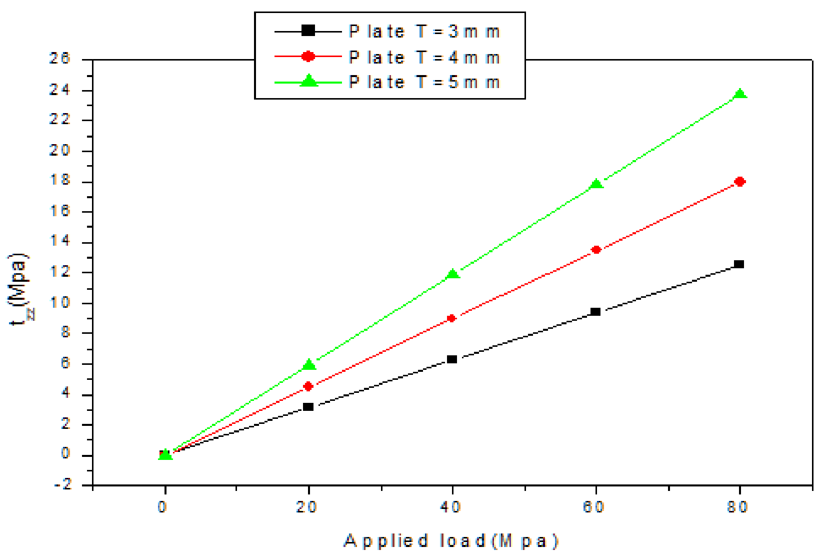

Figure 3: Shear Stresses in the zz Plane Influenced by Plate Thickness

Transverse delamination of the adhesive on both sides has a significant influence on the bonded assembly, as shown in Figure 4. This is because the transmission of stresses through the transverse planes means that the width of delamination does not have a significant impact. Therefore, a delamination width of 6mm increases the shear stresses by 11% compared to a delamination width of 2mm.

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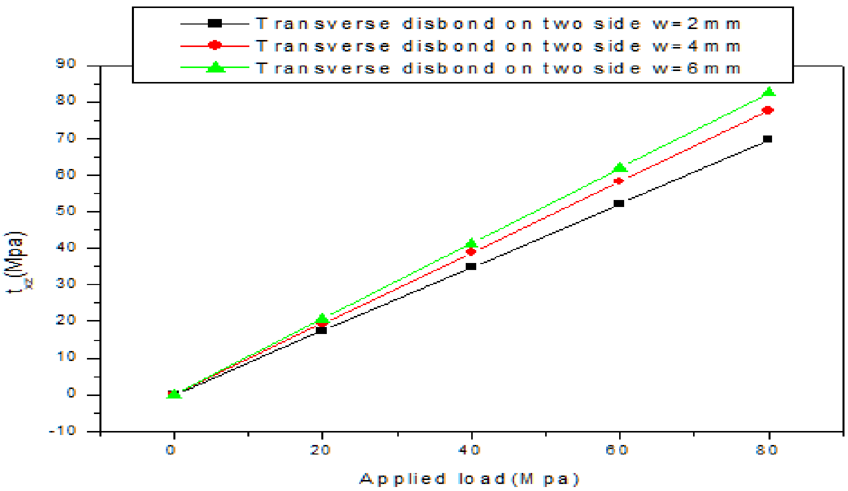

Figure 4: Shear Stresses in the xz Plane Influenced by Transverse Delamination of the Adhesive Layer

Peeling stresses are very significant in the case of transverse delamination, as shown in Figure 5. A delamination width of 6mm increases peeling shear stresses by 29% compared to a delamination width of 2mm

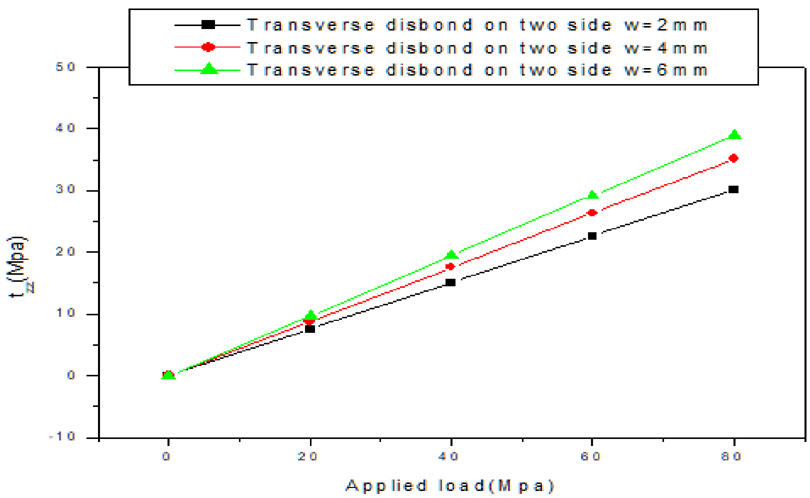

Figure 5: Shear Stresses in the zz Plane Influenced by Transverse Delamination of the Adhesive Layer

Longitudinal delamination of the adhesive layer occurs when the applied shear force on a section of the adhesive exceeds its ability to bond to the surface it is adhered to. Figure 6 shows that longitudinal delamination is less significant compared to transverse delamination. The width of delamination does not have a major influence; thus, a delamination width of 6mm increases shear stresses by 10% compared to a delamination width of 2mm.

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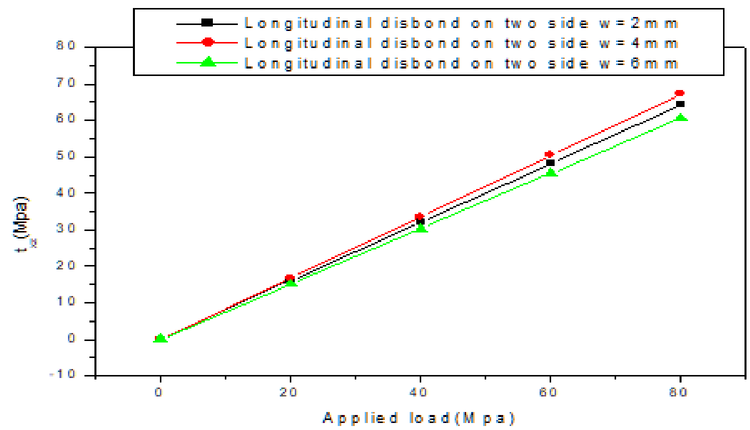

Figure 6: Shear Stresses in the xz Plane Influenced by Longitudinal Delamination of the Adhesive Layer

As shown in Figure 7, longitudinal delamination of the adhesive layer affects peeling shear stresses less than transverse shear stresses. The width of delamination does not have a significant impact; therefore, a delamination width of 6mm increases peeling shear stresses by 9% compared to a delamination width of 2mm.

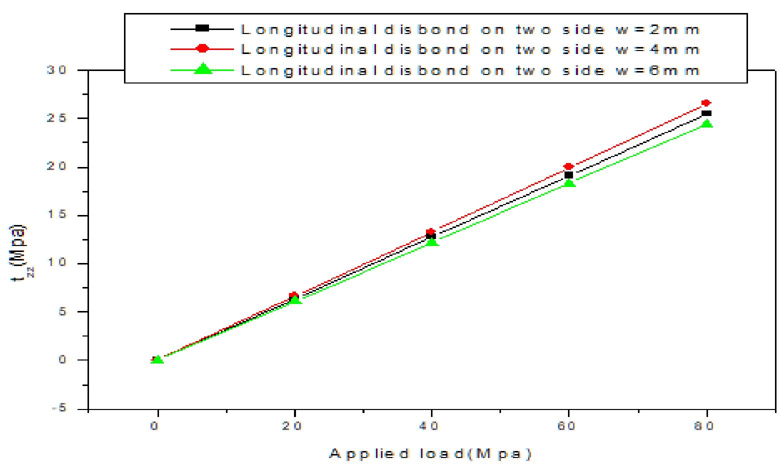

Figure 7: Shear Stresses in the zz Plane Influenced by Longitudinal Delamination of the Adhesive Layer

Figure 8 shows the shear stress of the adhesive in the xz plane as a function of the applied load. It is evident from this figure that the extent of shear stress increases with the applied load because a higher applied load leads to significant stress transmission at the adhesive layer, resulting in greater shear stresses. Additionally, it is observed that the width of delamination has a considerable impact on the distribution of stresses across the adhesive layer; therefore, a delamination width of 6mm increases shear stresses by 63% compared to a delamination width of 2mm

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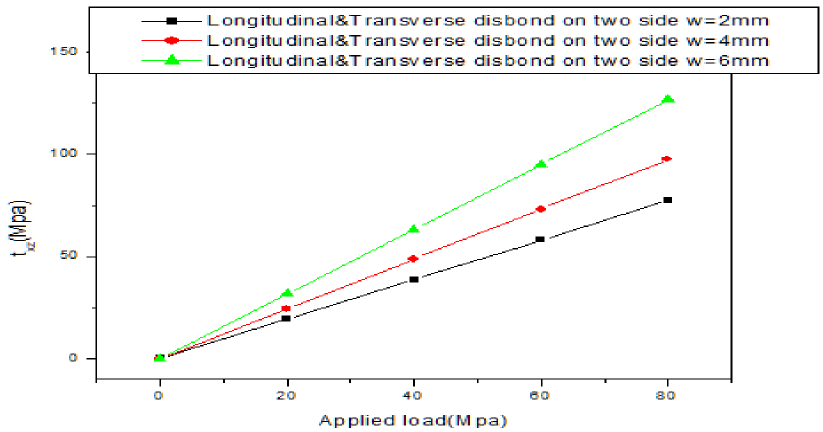

Figure 8: Shear Stresses in the xz Plane Influenced by Longitudinal and Transverse Delamination of the Adhesive Layer

Figure 9 shows the shear stress of the adhesive in the zz plane as a function of the applied load. It is clear from this figure that an increase in the applied load leads to a significant rise in the adhesive shear stress. The presence of delamination on both sides notably increases the recorded shear stresses. Additionally, the width of delamination greatly impacts the stress distribution across the adhesive layer; thus, a delamination width of 6mm increases shear stresses by 185% compared to a delamination width of 2mm.

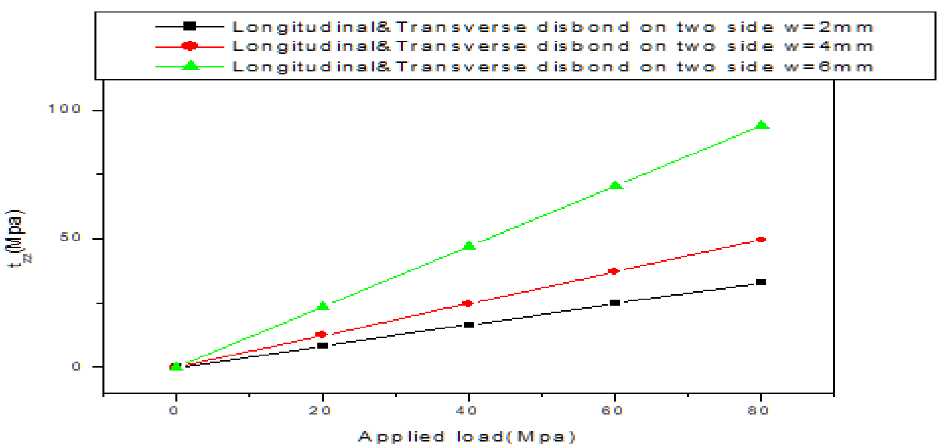

Figure 9: Shear Stresses in the zz Plane Influenced by Longitudinal and Transverse Delamination of the Adhesive Layer

Figure 10 shows the variation in shear stress across the adhesive layer in the xz plane under varying loads for different types of adhesive layer delamination. It is observed that transverse delamination has a slightly greater effect compared to longitudinal delamination, but the difference is substantial in the case of delamination on both transverse and longitudinal sides. Longitudinal delamination increases shear stresses by 16% compared to a non-delaminated bond, transverse delamination increases shear

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stresses by 42% compared to a non-delaminated bond, and delamination on both longitudinal and transverse sides increases shear stresses by 118% compared to a non-delaminated bond.

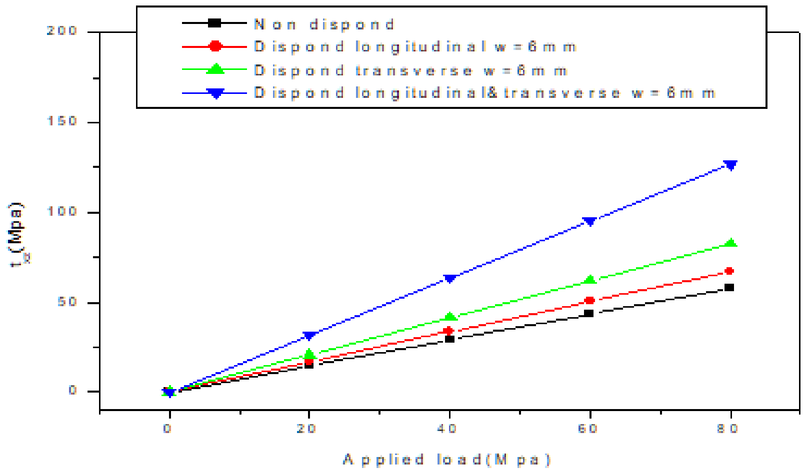

Figure 10: Comparison of Shear Stresses in the xz Plane for Different Forms of Adhesive Layer Delamination

Figure 11 represents the variation in shear stress across the adhesive layer in the zz plane under varying loads for different forms of adhesive layer delamination. Longitudinal delamination increases shear stresses by 12% compared to a non-delaminated bond, transverse delamination increases shear stresses by 64% compared to a non-delaminated bond, and delamination on both longitudinal and transverse sides increases shear stresses by 296% compared to a non-delaminated bond.

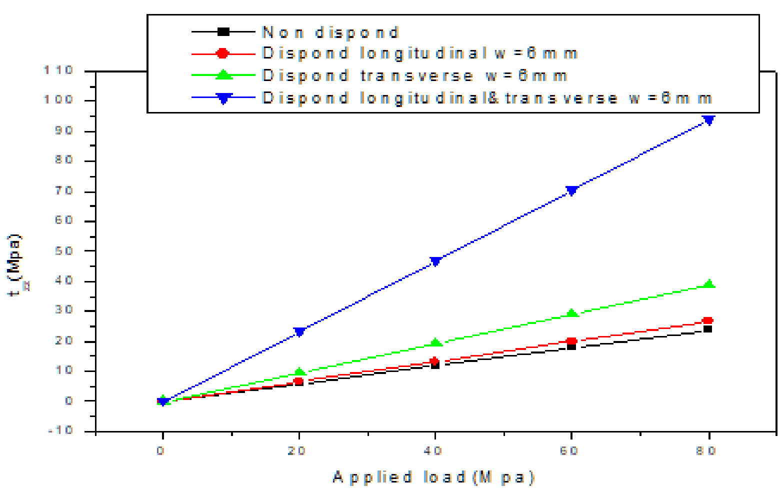

Figure 11: Comparison of Shear Stresses in the zz Plane for Different Forms of Adhesive Layer Delamination

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5. ANALYSIS OF SHEAR STRESSES FOR A BONDED ASSEMBLY WITH OVERLAP JOINT BETWEEN TWO PLATES

In this section, a bonded assembly between two plates with an overlap joint involves using two overlapping plates that are held together with an adhesive or glue. This method is often used to achieve a tight and strong bond between the two plates. Overlap joints are commonly used for plate repairs, for joining two plates end-to-end, or to create airtight joints on flat surfaces. Figures 12 and 13 show the variation in shear stress across the adhesive layer in the xz and zz planes under varying loads, comparing different plate thicknesses. It is observed that the shear stress recorded in the peeling shear type is higher compared to the stress in the xz plane. For peeling shear, different loading types indicate that a plate with a thickness of 5mm increases stress concentration compared to a plate with a thickness of 3mm by approximately 148%. This increase is due to the higher applied stress.

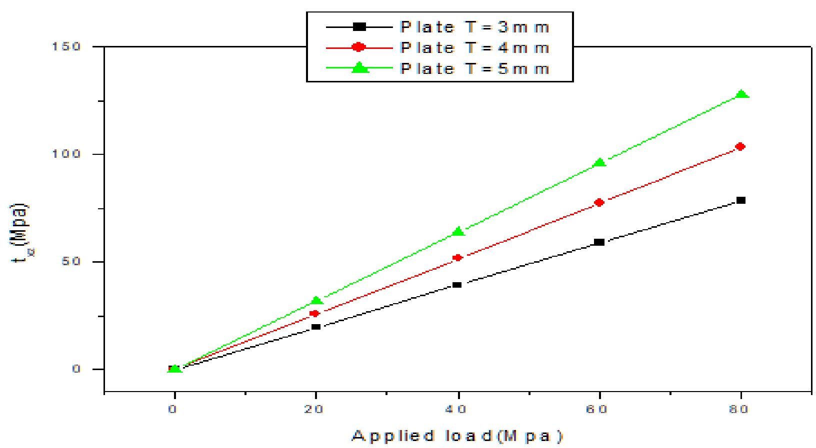

Figure 12: Shear Stresses in the xz Plane Influenced by Plate Thickness

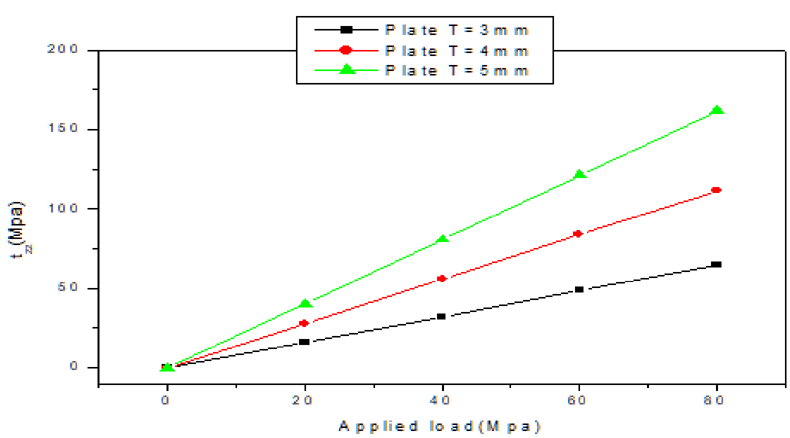

Figure 13: Shear Stresses in the zz Plane Influenced by Plate Thickness

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Figures 14 and 15 show shear stresses in the xz and zz planes relative to the applied load under the effect of longitudinal delamination in the adhesive layer. It is clear that the width of delamination significantly affects the propagation and distribution of peeling shear stresses, unlike shear stress in the xz plane. For peeling shear, different loading types indicate that a delamination width of 6mm increases stress concentration by approximately 51% compared to a delamination width of 2mm.

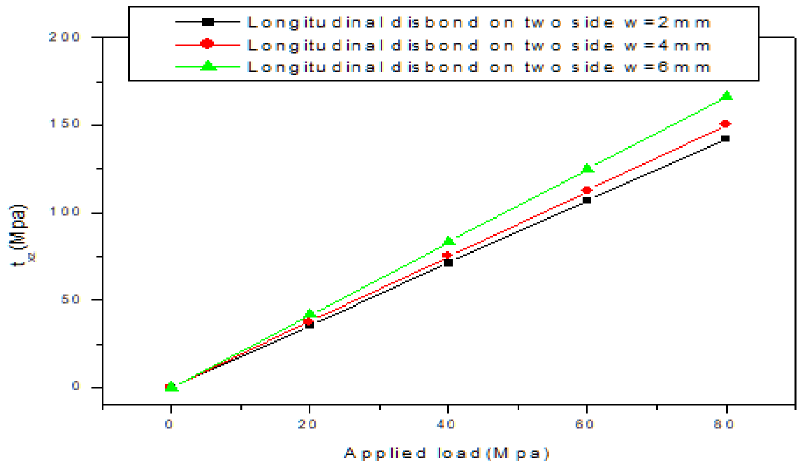

Figure 14: Shear Stresses in the xz Plane Influenced by Longitudinal Delamination of the Adhesive Layer

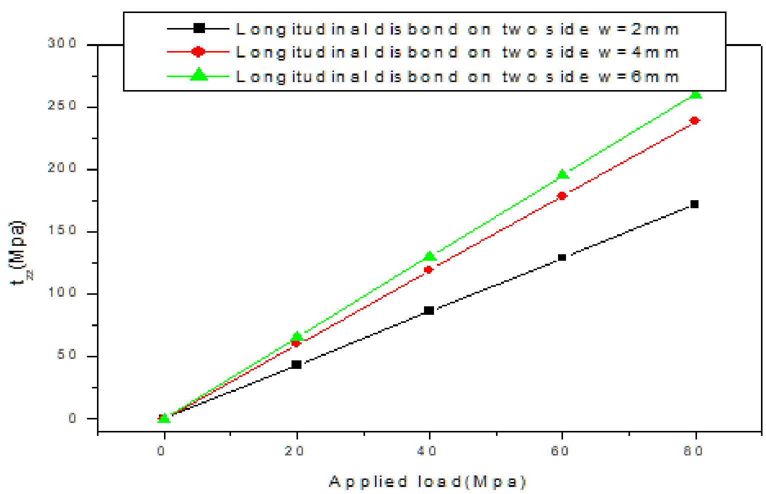

Figure 15: Shear Stresses in the zz Plane Influenced by Longitudinal Delamination of the Adhesive Layer

Figures 16 and 17 show shear stresses in the xz and zz planes relative to the applied load under the effect of transverse delamination in the adhesive layer. It is clear that the width of delamination has a very significant influence on the propagation and distribution of peeling shear stresses, unlike shear stress in the xz plane. For peeling shear, different

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loading types indicate that an assembly with a delamination width of 6mm increases stress concentration by approximately 47% compared to a delamination width of 2mm.

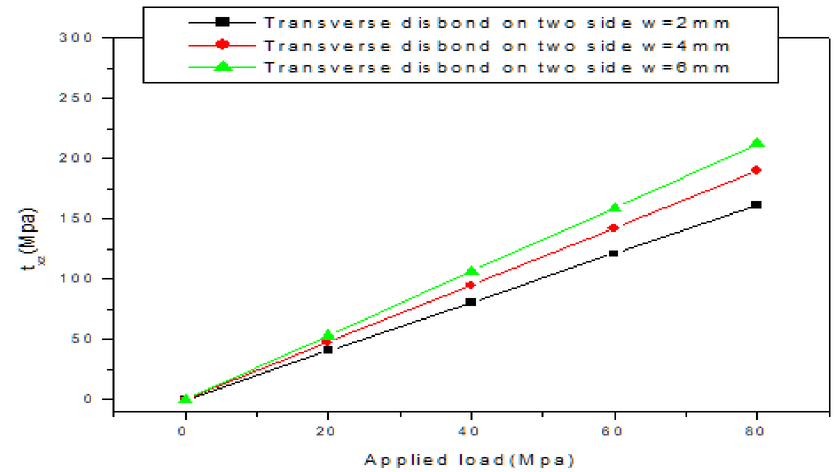

Figure 16: Shear Stresses in the xz Plane Influenced by Transverse Delamination of the Adhesive Layer

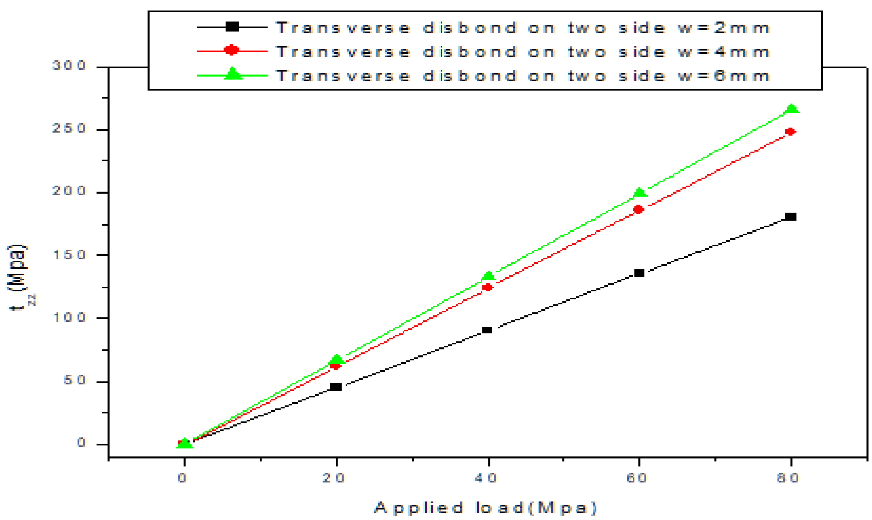

Figure 17: Shear Stresses in the zz Plane Influenced by Transverse Delamination of the Adhesive Layer

Figures 18 and 19 show shear stresses in the xz and zz planes relative to the applied load under the effect of both transverse and longitudinal delamination simultaneously in the adhesive layer. It is clear that the width of delamination has a significant influence on the propagation and distribution of shear stresses across both planes, with maximum stresses recorded in the zz plane. For peeling shear, different loading types indicate that an assembly with a delamination width of 6mm increases stress concentration by approximately 88% compared to a delamination width of 2mm.

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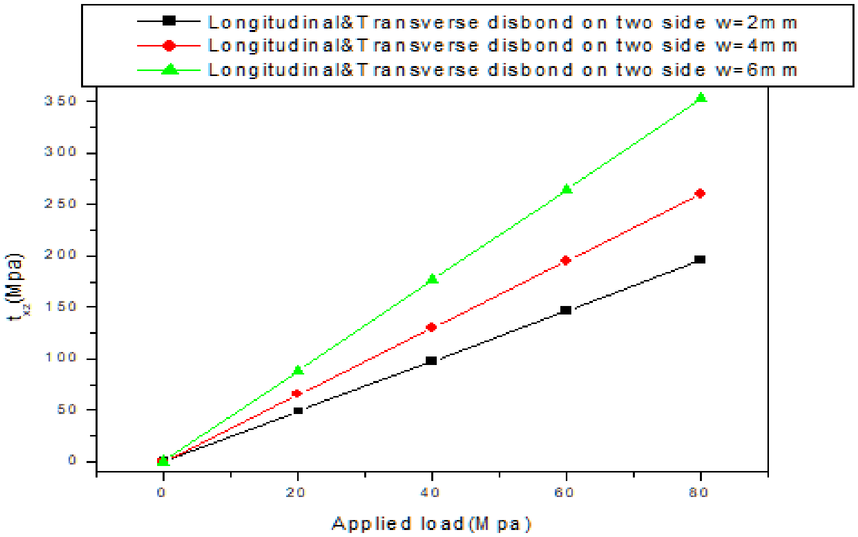

Figure 18: Shear Stresses in the xz Plane Influenced by Both Longitudinal and Transverse Delamination of the Adhesive Layer

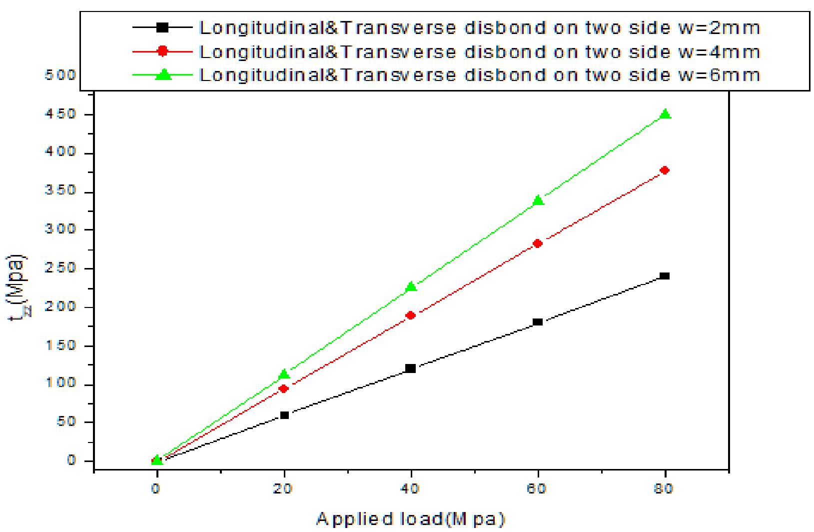

Figure 19: Shear Stresses in the zz Plane Influenced by Both Longitudinal and Transverse Delamination of the Adhesive Layer

Figures 20 and 21 illustrate shear stresses in the xz and zz planes relative to the applied load for various forms of adhesive layer delamination. It is evident that the effects differ between the xz and zz shear planes. In the xz plane, longitudinal and transverse delamination are nearly identical, while the differences are more pronounced in the zz plane.

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In the xz plane, longitudinal delamination increases shear stresses by 29% compared to a non-delaminated bond, transverse delamination increases shear stresses by 65%, and delamination on both longitudinal and transverse sides increases shear stresses by 157% compared to a non-delaminated bond. In the zz plane, longitudinal delamination increases shear stresses by 60%, transverse delamination increases them by 64%, and delamination on both longitudinal and transverse sides increases shear stresses by 178% compared to a non-delaminated bond.

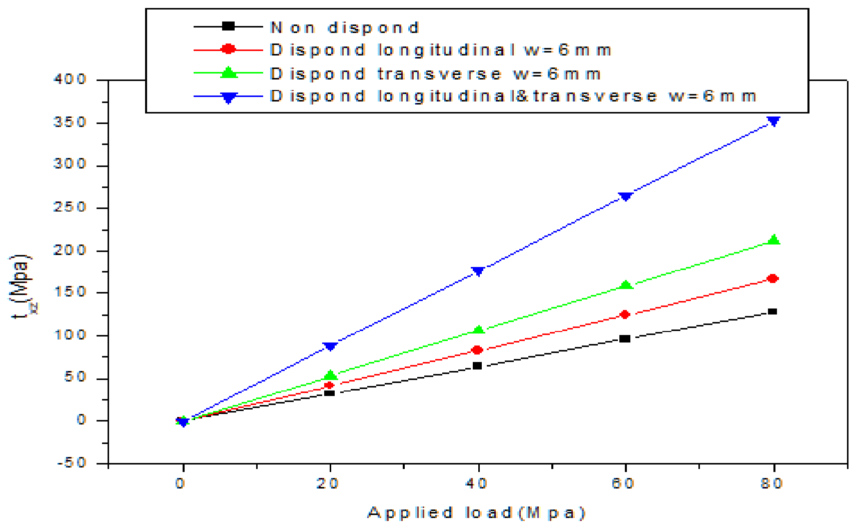

Figure 20: Comparison of Shear Stresses in the xz Plane for Different Forms of Adhesive Layer Delamination

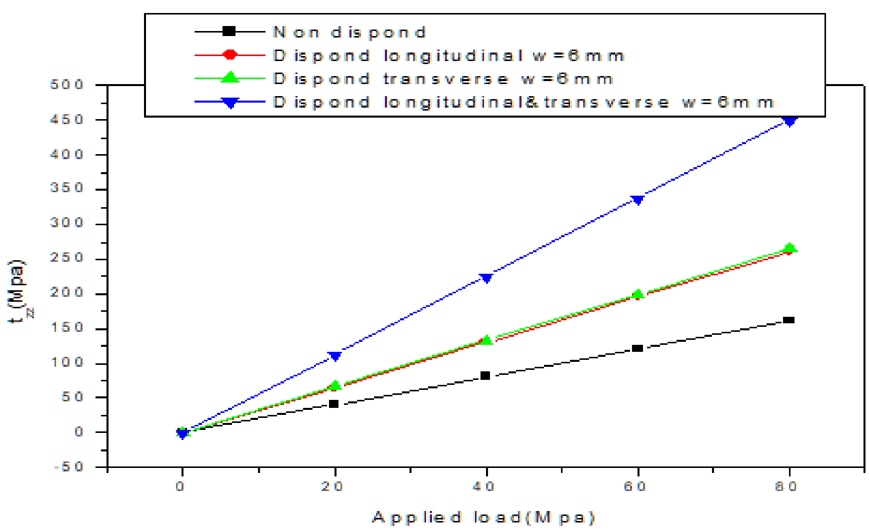

Figure 21: Comparison of Shear Stresses in the zz Plane for Different Forms of Adhesive Layer Delamination

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ISSN: 1673-064X
E-Publication: Online Open Access
Vol: 67 Issue 08 | 2024
DOI: 10.5281/zenodo.13365359

6. CONCLUSION

This study was conducted with the aim of analyzing the effects of delamination in different types of bonding. It was shown that for an edge-to-edge bonded joint with a single overlap, shear stresses recorded on the xz plane were higher compared to other planes and the maximum shear stresses were recorded for transverse delamination. This is because the transmission of stresses through the transverse planes, the width of the delamination did not obviously affect single delamination (transverse or longitudinal). On the other hand, it is noted that the width of the delamination greatly influences the stress distribution across the adhesive layer when there is both transverse and longitudinal delamination at the same time.

Conversely, for a bonded joint between two plates with overlap, the peeling shear stresses (the stresses recorded on the zz plane) were higher compared to other planes. This is because the deformation of the two bonded plates significantly affects the adhesive part (the bonding area located in the overlap section). It can be clearly seen that the effect of the delamination width clearly affects the propagation and distribution of peeling shear stresses. We also note that the width of the delamination greatly influences the stress distribution across the adhesive layer when there is both transverse and longitudinal delamination at the same time compared to single delamination (transverse or longitudinal).

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