Simulation-Based Evaluation of Joining Methods of Engineering Plastic Materials

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ABSTRACT

The reliability of joints in plastic assemblies depends strongly on the interaction between material behavior, joining technique, and loading conditions. In this study, Engineering components made from PMMA and PC-ABS were joined using two different methods: laser welding and adhesive joining. The objective is not a full comparative evaluation, but rather to understand the joint formation mechanisms and assess their mechanical response under typical service-level loading. This study primarily focuses on numerical simulation. However, experimental validation and fatigue behaviour analysis are recognised as scope for future research. Numerical simulations were carried out in LS-DYNA R12, where thermal and mechanical coupling were used to model the laser-welded interface, while a cohesive-zone approach represented the adhesive bond line. These models were used to predict pull strength and shear strength, capturing stress distribution, damage initiation, and failure progression for each joint type.

Indexterms—PMMA, PC-ABS, Laser welding, Adhesive joining, simulation results.

INTRODUCTION

Polymethyl methacrylate and Polycarbonate-Acrylonitrile Butadiene Styrene are widely adopted in the automotive industry, particularly for interior and exterior trim components, due to their balanced combination of mechanical strength, dimensional stability, and surface quality. PMMA offers excellent optical clarity and scratch resistance, making it suitable for decorative trims, light guides, and transparent covers. PC-ABS, on the other hand, provides high impact resistance and good thermal stability, which are essential for parts exposed to varying environmental conditions within the vehicle. Because these materials often appear together in automotive assemblies, understanding how to effectively join PMMA and PC-ABS is crucial for achieving reliable structural and aesthetic performance.

This study focuses on joining PMMA and PC-ABS components using laser welding and adhesive Plexus MA3940LH and evaluating their performance under pull and shear loading. While the work is not intended as a complete comparative assessment, it provides a useful understanding of how the two joining methods respond to mechanical stresses and how material properties influence joint performance. By integrating LS-DYNA simulations with the physical characteristics of the selected polymers, the research aims to support informed decisions regarding joining strategies for plastic assemblies in applications where reliability and structural performance are essential.

LITERATURE REVIEW

For the knowledge of various plastic joining methods, I have studied different research papers. The behaviour of the plastics and their properties are studied and analyzed. There are various joining methods available, such as Mechanical joining, Adhesive joining, and Welding processes.

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Grewell, D., Benatar, A. (2007), et al [1] provide information on the welding processes which are widely used in the current automotive market, such as Friction welding, Hot plate welding, ultrasonic welding, Laser welding, RF welding, and Hot gas welding.

Ries, M. (2024), et al [9] author discussed regarding the adhesive joint and modeling of complex behaviour of the polymeric adhesive. Molecular dynamics and continuum approach are employed to understand the complex behaviour of the polymer adhesive.

Demiral, M. (2025), et al [10] provided information regarding the demand and advances in the polymer adhesive technology. Also, stated the performance of polymer adhesives under tension, fatigue, creep, shear, fracture, impact and how the nanoscale mechanisms transform to macroscopic reliability. Takacs, L.,´ Szabo, F. (2020). et al [11] author analyzed the´ failure of adhesive joint of composite structure. Performed experimental and numerical analysis of glass fiber composite bonded with a methacrylate adhesive. Zhou, Z., Gao, X., Zhang, Y. (2022). et al [12] author discussed regarding the Laser joining of metals and polymers is gaining importance as a pathway to lightweight automotive structures.Also, emphasized methods to evaluate and regulate joint quality, focusing on interface bonding and mechanical reliability.

METHODOLOGY

An explicit analysis was performed to investigate the adhesive bond strength between two thermoplastic materials, Polymethyl methacrylate (PMMA) and PolycarbonateAcrylonitrile Butadiene Styrene (PC-ABS). The study was carried out using the CAE solver LS-DYNA R12, with HyperMesh 2022.2 as the pre-processor for geometry

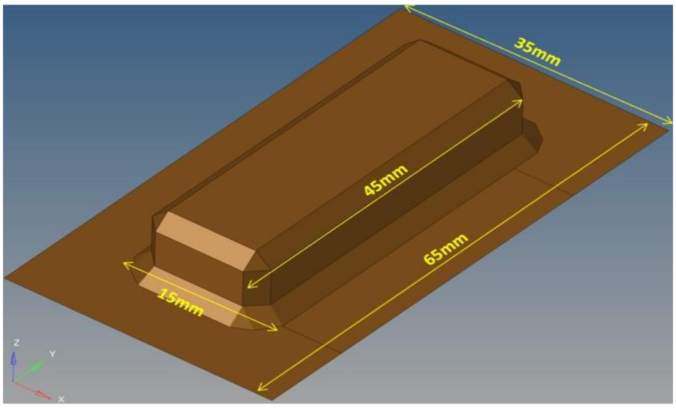

Fig. 1. Dimensions of the plastic component

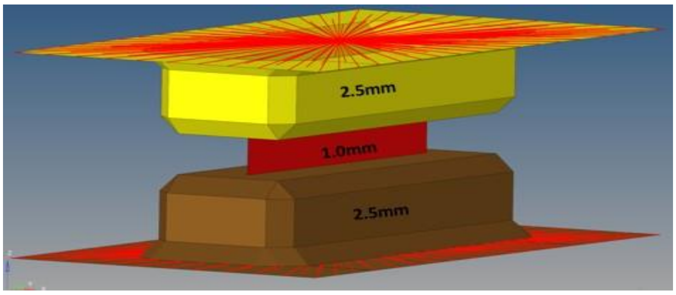

Fig. 3. Simulation test setup of Weld joint(Red color) between the two components

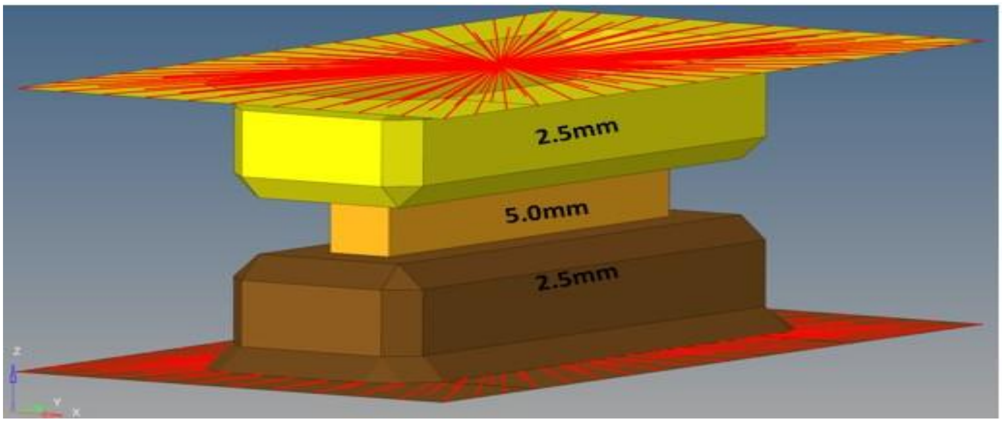

Fig. 2. Simulation test setup of Adhesive joint(yellow coloured) between the components

definition and meshing, and Hyperview 2022.2 was used as the post-processor for visualization and data interpretation. The material properties of both substrates and the adhesive were defined based on established values to ensure accurate representation of their mechanical behaviour. The adhesive interface was modelled to capture debonding and progressive failure under applied loading conditions. The results obtained from the simulation are presented, highlighting Force-Displacement responses and failure characteristics. In addition, graphs were plotted and shown to illustrate the comparative bond strength between PC-ABS and PMMA, providing clear insight into adhesive performance under the chosen loading scenario.

Both components are modelled as hollow cuboidal structures, as shown in Fig. 1. The Dimensions of each cuboid are 45 mm × 15 mm × 2.5 mm, with the PMMA block positioned at the bottom and the PC-ABS block placed directly above. In the simulation environment, the PMMA cuboid is constrained to the base to represent its attachment to the vehicle structure, whereas the PC-ABS cuboid is fixed to the top boundary.

TABLE I Meshing Parameters for the Adhesive Joint and Weld Rib

	Adhesive layer	*weld Rib*
Element Type	Hexa 3D	Shell 2D
Element Formulation	1	16
Mesh size(mm)	4 × 5 × 2.5	4 × 2.5
Layers	2	2
Joining method	Tied Constrained	Nodal Connectivity
Material Type	MAT100	MAT24

TABLE II Meshing Parameters for The Plastics Pmma And Pc-Abs Materials

	PMMA (base plate)	*PC-ABS(Top plate)*
Element Type	Shell 2D	Shell 2D
Element Formulation	16	16
Mesh size(mm)	4 × 4	4 × 4
Material Type	MAT24	MAT24

A 1 mm gap is maintained between the two components. This gap represents the space where the joint is formed, either through Adhesive bonding or Laser welding, depending on the joining process being evaluated. In the first stage, the gap is filled with an industrial adhesive [4], 35 mm × 5 mm × 5 mm, and adhesion is analysed using LS-DYNA as in Fig. 2. The simulation incorporates appropriate material models for both plastics and the adhesive to capture joint behaviour under load. In the second stage, the same geometric configuration is used, but the components are assumed to be joined by laser welding 35 mm × 5 mm × 5 mm, as in Fig. 3. The welded interface is modelled according to the expected fusion characteristics of PMMA and PC-ABS under laser energy. This configuration is again simulated in LS-DYNA to evaluate its mechanical response.

For both joining methods, only tensile (pull) strength and shear strength are considered. Loads are applied to the PC-ABS component while the PMMA base remains fixed, enabling the study of joint performance under controlled boundary conditions.

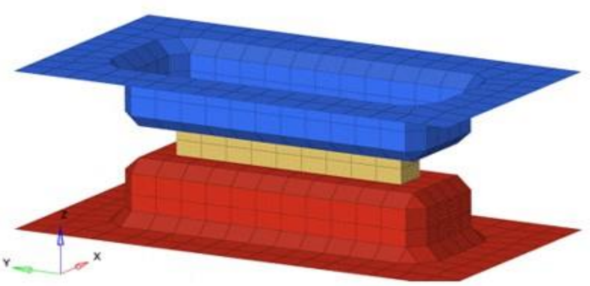

Fig. 4. Tensile load simulation results of Adhesive-bonded PMMA and PCABS Plastics

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The material properties of both Polymethyl methacrylate and Polycarbonate-Acrylonitrile Butadiene Styrene are listed in Tables 3 and 4, while the properties of adhesive Plexus MA3940LH are referred to.[8]

TABLE III Properties Of Polymethyl Methacrylate

S. No	*PMMA Property*	*value*
1	Material	Thermoplastic
2	Density	1180-1190 kg/m^3
3	Ultimate Tensile Strength	72 MPa
4	Yield Tensile Strength	54-73 MPa
5	Ultimate Compressive Strength	72-124 MPa
6	Young's Modulus	3.036 GPa
7	Flexural Modulus	2.24 - 3.17 GPa
8	Melting Point	45 °C
9	Thermal Conductivity	0.17 - 0.19 W/m-K
10	Specific Heat Capacity	1450 J/Kg-K

TABLE IV Properties of Polycarbonate-Acrylonitrile Butadiene Styrene

S. No	*PC-ABS Property*	*value*
1	Material	Thermoplastic
2	Density	1050 – 1020 kg/m^3
3	Melting Temperature	250 °C
4	Tensile strength	40 - 60 MPa
5	Flexural Strength	78.5 MPa
6	Poisson's Ratio	0.392
7	Elastic Modulus	2 - 2.6 GPa

RESULTS AND DISCUSSION

Tensile load simulation test results of adhesive joint areshown below in Fig. 4 and graphical values in Fig. 5. Also, the Tensile load simulation results of the welded joint are shown in Fig. 6 and graphical values in Fig. 7.

DISCUSSION

The tensile test results show a major difference in joint performance, with the adhesive bond reaching 1516.8 N. (Fig. 5) while the weld joint withstands 4073.1 N (Fig. 7).

This indicates that the Laser-welded interface creates a much

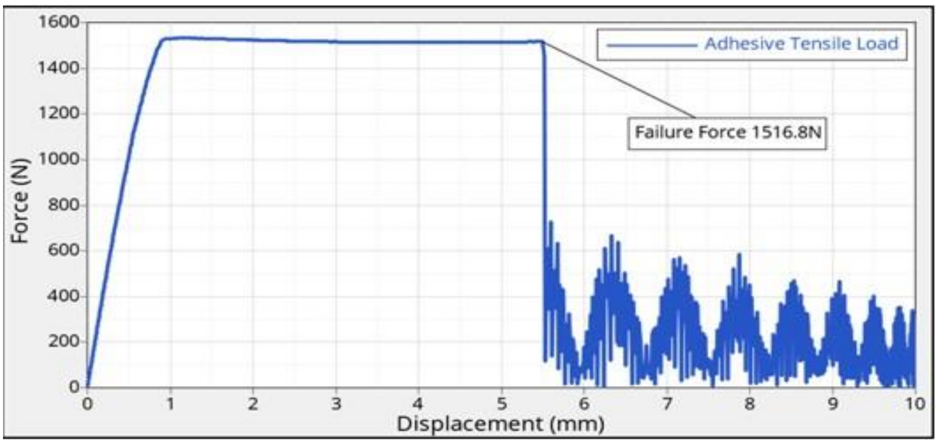

Fig. 5. Tensile Force(N) vs Displacement (mm)

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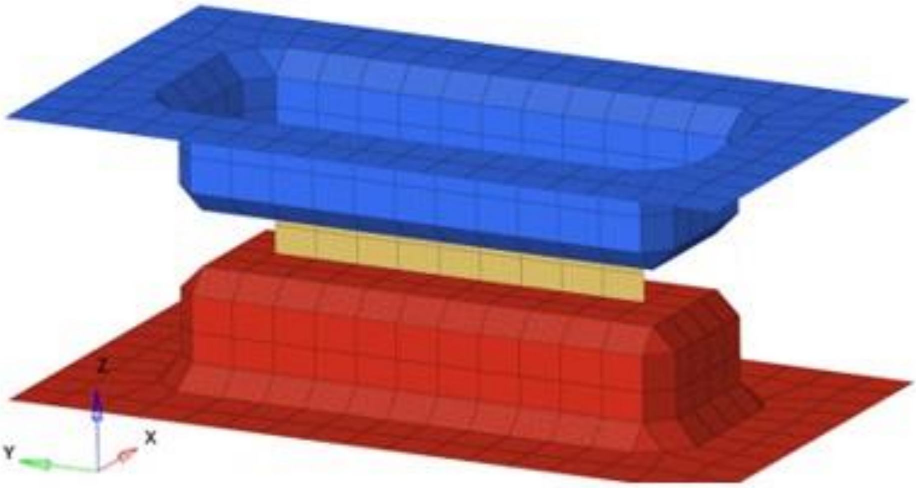


Fig. 6.Tensile load simulation results of Laser-welded joined PMMA and

PC-ABS Plastics

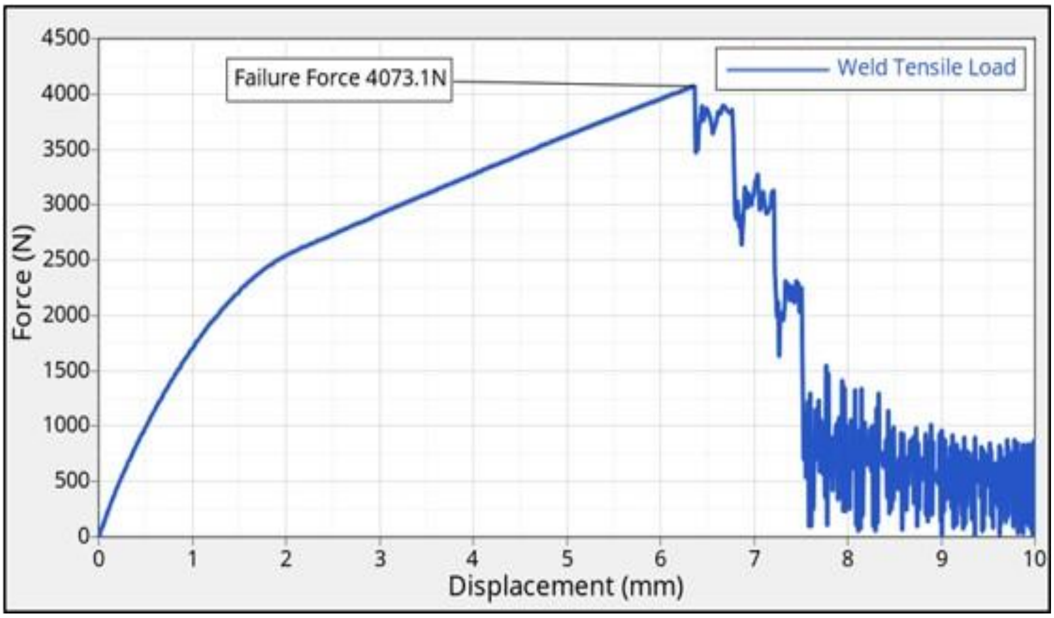


Fig. 7. Tensile Force(N) vs Displacement (mm)

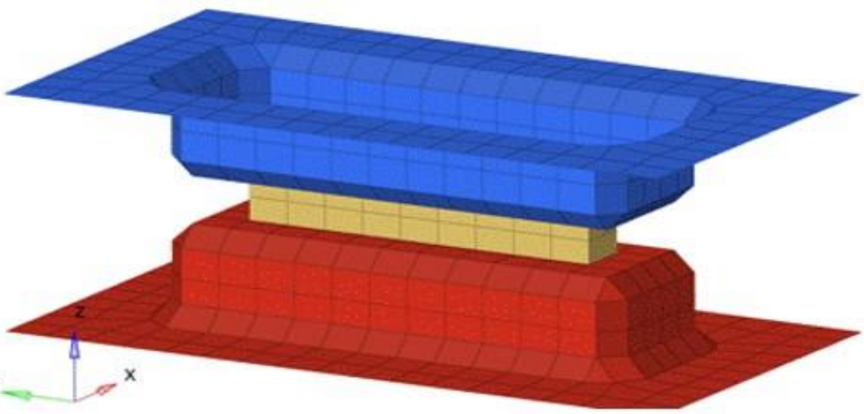
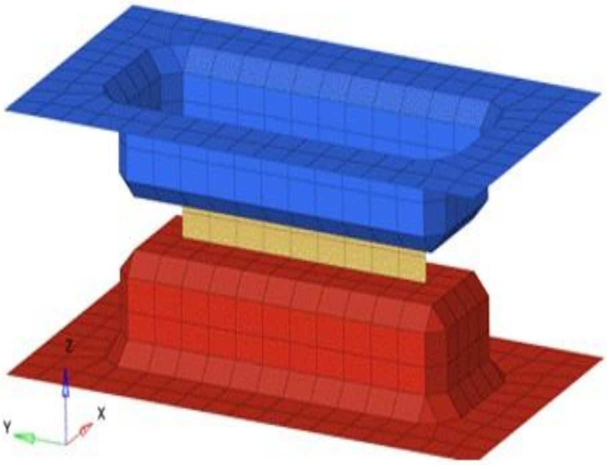


Fig. 8. Shear load simulation model for adhesive-bonded PMMA and PCABS plastic components along X-direction

Fig. 9. shear Force(N) along X-direction vs Displacement (mm)



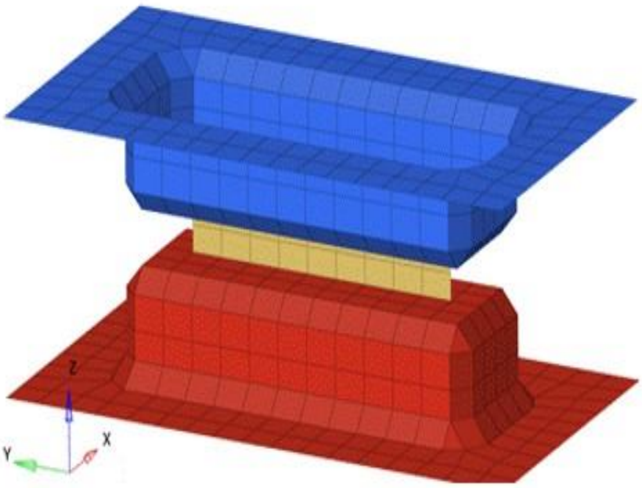
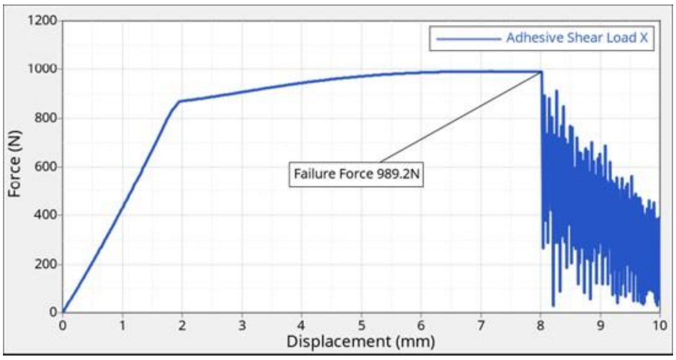
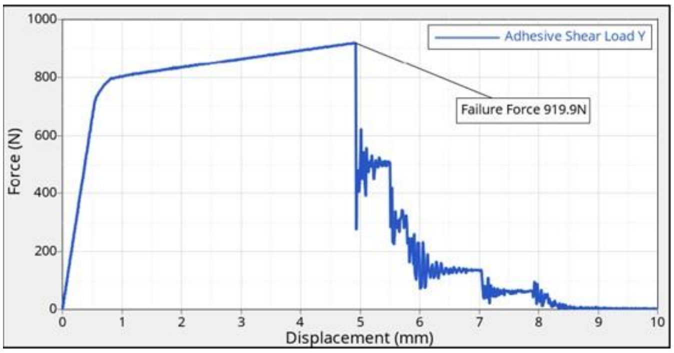


Fig. 10. Shear load simulation model for Laser welded joint between PMMA and PC-ABS plastic components along X-direction





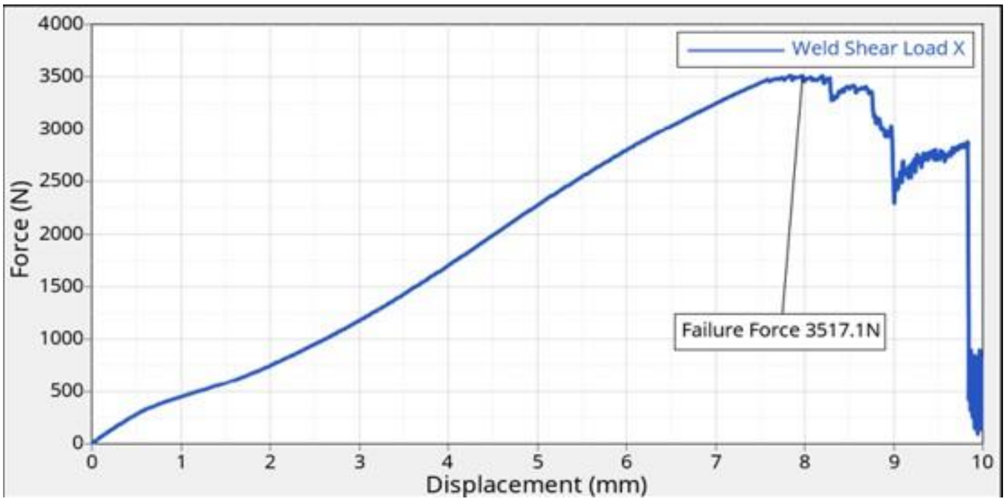


Fig. 11. shear Force(N) along X-direction vs Displacement (mm)

Fig. 12. Shear load simulation model for adhesive-bonded PMMA and PCABS plastic components along the Y-direction

Fig. 13. shear Force(N) along Y-direction vs Displacement (mm)

Fig. 14. Shear load simulation model for Laser welded joint between PMMA and PC-ABS plastic components along Y-direction

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stronger load-bearing connection compared to the adhesive layer.

In the shear test along the X-direction, the adhesive joint holds 989.2 N (Fig. 9), whereas the welded joint holds 3517.7 N (Fig. 11). The large gap between these values suggests that welding provides better resistance against lateral sliding forces.

The Shear performance along the Y-direction follows the same trend, with the adhesive joint failing at 919.0 N(Fig. 13) and the welded joint resisting up to 2494.8 N (Fig. 15). This confirms that the welded interface is structurally more robust

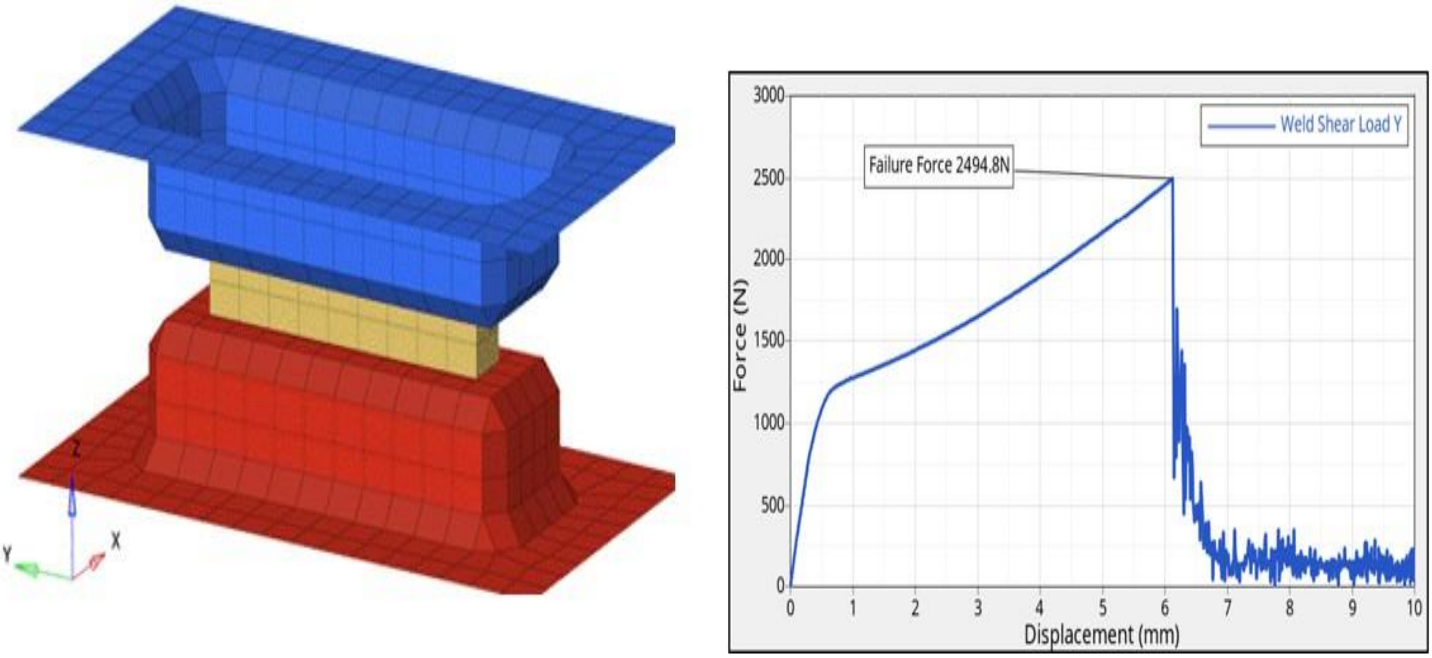

Fig. 15. shear Force(N) along Y-direction vs Displacement (mm)

across multiple shear orientations.

Across all loading modes, the adhesive bond consistently shows lower strength compared to the weld joint. This difference likely results from the continuous material fusion achieved during welding, which eliminates the weakness of an additional interlayer. Overall, the simulation results clearly demonstrate that laser welding gives superior tensile and shear strength for PMMA and PC-ABS joints. These findings can help guide material joining decisions in automotive applications where durability and load capacity are critical.

CONCLUSIONS

This numerical investigation highlights the strong influence of the joining technique on the structural performance of PMMA and PC-ABS assemblies. The simulated tensile response shows that the Laser-welded joint sustains a higher load of 4073.1 N than the adhesive joint (1516.8 N), indicating a substantially greater capacity to transfer axial forces across the interface.

A comparable trend is observed under shear loading. In the X-direction, the welded configuration withstands 3517.7 N, exceeding the adhesive joint strength of 989.2 N. In the Y-direction, the welded joint supports 2494.8 N, compared with 919.0 N for the adhesive-bonded joint. The consistency of these results across multiple loading modes demonstrates that the welded interface provides improved mechanical stability.

The enhanced performance of the Laser-welded joints is primarily associated with the formation of a continuous fusion zone, which promotes efficient stress transmission and reduces interfacial discontinuities. By contrast, adhesive bonding relies on a distinct intermediate layer whose mechanical characteristics and interfacial adhesion limit the load-carrying capability of the assembly.

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In summary, the simulation outcomes indicate that laser welding offers superior strength and reliability for PMMA and PC-ABS joints under both tensile and shear conditions. These findings provide a useful computational basis for selecting appropriate joining strategies in polymer component design, particularly in engineering applications where structural integrity and load resistance are critical.

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