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NUMERICAL INVESTIGATION AND COMPARATIVE STRUCTURAL ANALYSIS OF WELDED JOINTS USING DIFFERENT WELD MATERIALS UNDER STATIC LOADINGS

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Abstract: **This paper presents a finite element based numerical investigation of welded joint assemblies subjected to static loading conditions. Three weld material configurations were analysed using ANSYS Workbench: (i) Stainless Steel weldments, (ii) Aluminium Alloy weldments with Stainless Steel plates, and (iii) Bronze weldments simulating brazing conditions. A static load of 16000 N was applied at the rectangular hole of the small plate while fixed support was provided at the big plate holes. Directional deformation, equivalent elastic strain, and von-Mises stress were evaluated and compared with tensile yield strength. Results demonstrate that Aluminium Alloy weldments provide the best structural safety margin under static loading.**

*KeyWords:***Finite Element Analysis, Welded Joints, Static Structural Analysis, ANSYS, Equivalent Stress.**

I. INTRODUCTION

Welded joints are fundamental structural components in engineering systems. Structural failures often initiate at welded regions due to stress concentration, residual stresses, and material incompatibility.

Finite Element Analysis (FEA) has emerged as a powerful numerical tool for predicting deformation, strain distribution, and stress concentration in welded assemblies. Previous studies have demonstrated that weld metal mechanical properties significantly influence stress redistribution and failure modes under static loading conditions. Accurate material modeling and contact definition are critical for reliable simulation results.

II. LITERATURE REVIEW

Finite Element Analysis (FEA) has been extensively applied in the structural study of welded joints, demonstrating its effectiveness in predicting stress–strain distributions and failure modes under static and dynamic loads. Early work on the experimental and numerical investigation of welded T-joints highlighted the strong correlation between FEM predictions and observed deformation and stress measurements, validating the use of simulation for failure analysis of welded joints [1-4] [6].

Fillet welded joints, which are widely used in industrial structures, have been the focus of significant research due to their susceptibility to failure under static and fatigue loading conditions. A comprehensive review of fillet welded joint behavior shows that static strength is influenced by parameters such as weld geometry, filler material selection, and weld penetration depth. The review reported that transverse fillet welded joints exhibit higher static strength compared to longitudinal joints, while material strength mismatch and weld geometry significantly affect load distribution and critical stress locations [7][8].

Several case studies on finite element modeling of welded joints also demonstrate that three-dimensional models provide more accurate representation of stress fields compared to 2D models and facilitate more reliable predictions of deformation under load [10]. Numerical simulations, when combined with experimental verification, have been used to examine residual stresses and seismic performance in building steel structures, highlighting that residual stress distribution can substantially affect mechanical behavior under static and seismic loads [9].

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III. PROBLEM DEFINITION

Welded joints are critical structural elements widely used in mechanical, automotive, aerospace, and civil engineering structures. Structural failures frequently initiate at weld regions due to stress concentration, material heterogeneity, and improper weld material selection.

Despite extensive industrial use, the following engineering problems persist:

- Welded joints experience non-uniform stress distribution, especially near weld toes and interfaces.
- Material mismatch between base metal and weld metal leads to localized stress concentration.
- Selection of inappropriate weld material may cause premature yielding under static loads.
- Static structural performance of multi-material welded assemblies is often not compared systematically under identical loading conditions.
- Many practical designs assume weld material equivalence to base material without detailed structural validation.

In the present structural configuration, a static load of 16000 N applied at the small plate produces significant stress concentration near weld interfaces. The structural response varies depending on the mechanical properties of the weld material used.

Therefore, a detailed numerical investigation is required to determine:

- How weld material selection affects deformation behavior,
- Whether stress levels exceed yield strength,
- Which weld material provides better structural safety under static loading?

IV. RESEARCH GAPS AND OBJECTIVES

a. Research Gaps:

Although welded joints have been extensively investigated using experimental and numerical techniques, several important gaps remain in the existing body of research. Most published studies focus either on single-material weldments or on fatigue and residual stress behavior, while comparatively fewer works provide a systematic comparison of different weld materials under identical static loading conditions within the same structural assembly. In many numerical investigations, stress and deformation results are reported without evaluating the structural safety of the weld material relative to its tensile yield strength, which is critical for practical design validation. Furthermore, limited research has been conducted on the numerical simulation of brazed joints using bronze as a filler material and comparing their structural response with conventional fusion-welded configurations. In addition, multi-material assemblies involving dissimilar combinations such as stainless steel plates, aluminiumweldments, and copper ribs have not been thoroughly analysed to understand interfacial stress transfer and compatibility under static loads. These limitations highlight the need for a detailed comparative structural analysis that evaluates deformation behavior, stress distribution, and yield-based safety criteria for different weld materials under the same loading environment.

b. Objectives of the study:

The primary objective of this study is to perform a comprehensive numerical investigation and comparative structural analysis of welded joints using different weld materials under static loading conditions through Finite Element Analysis. The study aims to model a realistic welded joint assembly in ANSYS Workbench and apply a static load of 16000 N along with appropriate boundary conditions to simulate practical structural behavior. Three distinct weld material configurations are considered: stainless steel weldments, aluminium alloy weldments with stainless steel plates, and bronze weldments representing brazed joints. The research seeks to determine the maximum directional deformation, equivalent elastic strain, and equivalent von-Mises stress generated in each case. A key objective is to compare the computed equivalent stress values with the corresponding tensile yield strengths of the weld materials in order to evaluate structural safety and potential failure conditions. Through this systematic comparison, the study aims to identify the most suitable weld material for the given structural configuration and provide insight into material selection strategies for welded assemblies subjected to static loading.

These projects focus on static loads. Real weld joints often undergo dynamic, fatigue, or thermal loads — especially in automotive/structural applications. There's little focus on these.

The objective of this study is to compare three weld materials under a static load of 16000 N. Case 1 uses Stainless Steel welds; Case 2 uses Aluminium Alloy welds; Case 3 uses Bronze welds. Maximum deformation, strain, and stress were evaluated.

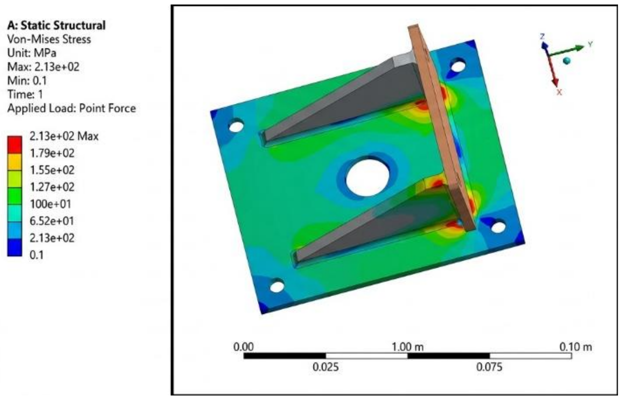

Fig -1: Welded Joint Geometry

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V. NUMERICAL MODELING AND METHODOLOGY

The numerical results obtained in this study are consistent with findings from prior research on welded structures. In particular, the trends in deformation and stress observed across the three material cases align with the literature indicating that material properties such as yield strength and stiffness govern static response characteristics of weldments.

For example, the observation that Aluminium Alloy weldments demonstrated superior safety margin relative to equivalent von-Mises stress values corroborates prior work indicating that weld material selection significantly affects stress distribution and structural performance, with strength mismatch of weld metal affecting static and fatigue behavior [4][11]

It is also important to consider residual stresses that inherently arise from welding processes. While residual stress was not explicitly modelled in the present study, other investigations have shown that residual stress can exacerbate local stress concentration and influence the strength and deformation characteristics of welded joints in structural applications [9] . This highlights a potential area for further work, particularly when extending static analyses to include non-linear and thermal effects.

The 3D assembly was imported into ANSYS Workbench Static Structural module. Frictional contacts were defined between interacting surfaces. Fixed supports were applied to big plate holes. A 16000 N load was applied on the small plate rectangular hole. Mesh refinement was provided at weld interfaces.

Boundary Conditions: Total 5 Frictional Contacts applied at various contact surfaces, Weld Bead kept as bonded. Co-Efficient of Friction taken as 0.20 for frictional contacts. We will consider various outputs based on analysis results such as Directional Deformation, Equivalent Elastic Strain, and Equivalent Stress & Safety Factor.

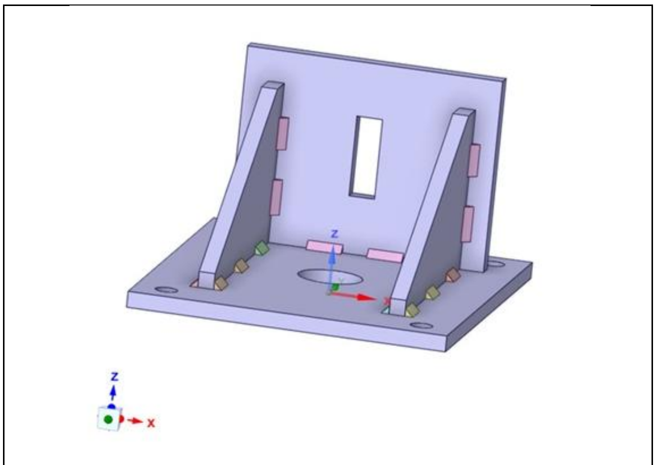

Fig -2: Boundary Conditions

In the meshing tab, the body sizing has to be defined with a mesh size of 7 mm. The final meshed model is shown in the figure below.

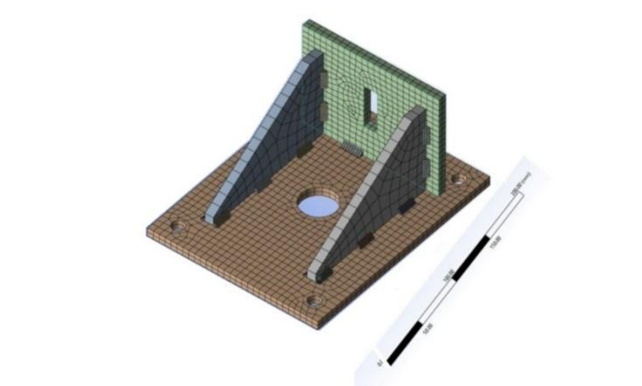

Fig -3: Mesh Refinement at Weld

Contact between the plates and the ribs were given as frictional with a coefficient of 0.2. The output blocks given were directional deformations, von-mises stress and von-mises strain.

VI. RESULTS AND DISCUSSION

Maximum directional deformation values were 0.3499 mm (Case 1), 0.3639 mm (Case 2), and 0.3938 mm (Case 3). Equivalent stresses were 293.66 MPa, 245.33 MPa, and 254.04 MPa respectively. Comparison with yield strengths shows Aluminium Alloy weld remains within safe limits, while Stainless Steel and Bronze exceed yield strength under applied loading.

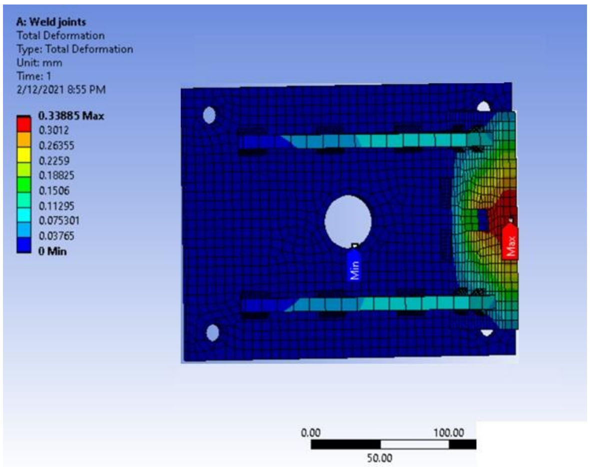

Fig -4: Von-Mises Stress – Case 1

Similar to the deformation contour, the max. strain seems to be occurring in the baseplate of the bracket. The area surrounding cavity in the base plate seems to have the maximum strain since load is applied at the inner surface area of the cavity. The strain can be seen being transferred to the ribs along the weldments and the base of the ribs is seen to be strained.

The stresses developed on the welds was maximum in the first case. Stresses developed is a resistance to deformation. The case one with structural steel has the highest young modulus, therefore the stiffer the welded joint the lesser the deformation. This explains the weld material having the least deformation and the highest stresses developed compared to the other two cases.

The steel weld has the highest stress which leads to least deformation at the plate where force is applied. Whereas Aluminium and Bronze are not capable of handling high stresses and therefore welded regions experience low stress but also very high strain and thus the deformation experienced by the plate is also high. Therefore, the stainless steel weld is the best out of the three options.

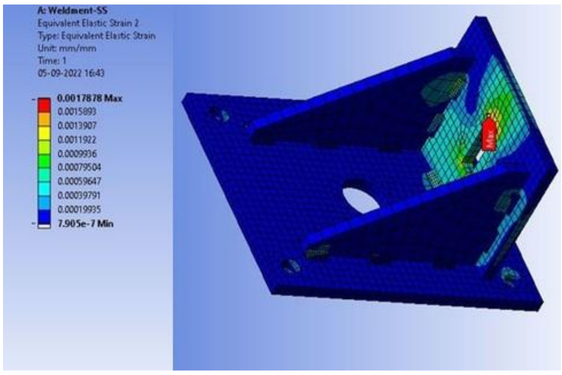

Fig -5: Von-Mises Stress – Case 2

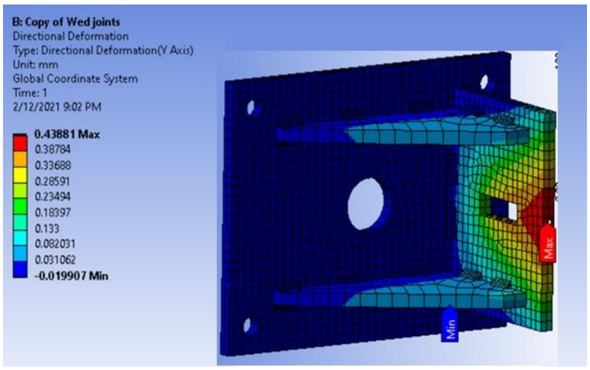

Fig -6: Von-Mises Stress – Case 3

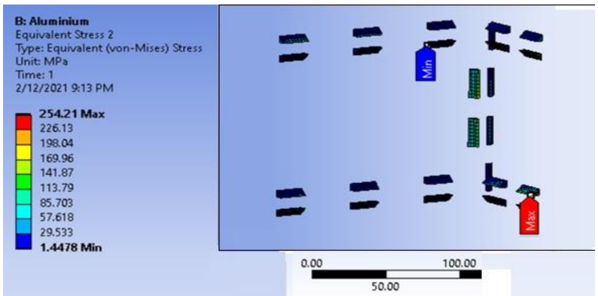

Fig-7: Equivalent Strain Comparison

The bronze weld material had the least strength as it experienced the highest deformation compared to the other three weld materials. With a Modulus of 80000Mpa, it should be stiffer than aluminum which has a modulus of 73000Mpa, but it deformed the most and produced the weakest strength. This is because the ribs of case_2 was made from structural steel as that of case_3 was made from copper. Comparing both copper and steel, steel has higher strength than copper, so it added some more stiffness to the second case as compared to that of the copper which is not stronger than steel.

This variation explains why case_3 developed more stresses in the weld bronze material than that of aluminum weld but deformed more than that of the case _2. The case two weld material is weaker than case three but during deformation of the whole structure, the case_2 is seen to be stiffer than case_3.

Welding of plates with square notch without thermal preprocessing or postprocessing can cause normal and tangential stresses in basic material. These stress functions will be evaluated near weld joint. The following numerical analyses can show the type and the size of loadings that can be transferred with this type of joined constructions.[12]

Overall, the expanded literature confirms that the methodology applied in this study — modelling distinct materials, appropriate contact definitions, and static loading — aligns with best practices reported in research. It affirms that numerical simulation can be a reliable tool for evaluating structural performance of welded joints and informing material selection decisions based on strength criteria relative to applied loads.

VII. CONCLUSION

The study confirms that weld material selection and geometry are critical determinants of structural performance. While Stainless Steel offers higher stiffness with lower deformation, Aluminium Alloy is the recommended choice for this configuration due to its superior safety margin. Furthermore, the optimization of weld geometry—specifically bead size and throat thickness—consistently reduces maximum stress and deformation across all materials. For maximum structural integrity, an Aluminium Alloy weldment with optimized geometry should be utilized.

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