Crack analysis of Aluminium Steel butt weld for isotropic loads using Ansys

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Abstract:

Aluminium and steel are two different materials that not supposed to weld directly because of its material elements. Present work is a validation for weld of both materials using aluma steel weld electrodes. The methodology involved creating a detailed finite element model of the aluminium steel butt weld using Ansys software. The model was subjected to isotropic loads to simulate real-world conditions. Stress intensity factors were then calculated to evaluate the potential for crack initiation and propagation in the weld.The analysis is expected to reveal stress distribution patterns and potential failure points within the aluminium steel butt weld under isotropic loads. By using Ansys, can check the weld's performance and identify any critical areas that may require reinforcement. Ultimately, this will help in optimizing the weld design for improved durability and safety.

Key words: Butt weld, Crack analysis, Aluminium, Steel, ANSYS

1. Introduction

The analysis of cracks in welded joints, particularly in butt welds between aluminum and steel, is crucial for ensuring the structural integrity and safety of critical components under various loading conditions. Aluminum and steel, being dissimilar metals, present unique challenges in welding due to differences in their thermal expansion, mechanical properties, and welding behavior. Butt welding, a common technique used to join these materials, can lead to potential stress concentrations, particularly at the weld interface, which may result in crack formation under isotropic loading conditions. Isotropic loads, which apply equal stress in all directions, can exacerbate the development of cracks in these welded joints, making it essential to accurately assess the weld's performance. Finite Element Analysis (FEA) using advanced simulation software such as ANSYS provides a powerful tool for evaluating the crack behavior and predicting failure modes in these welded structures. By simulating the stress distribution, crack propagation, and potential fracture locations, engineers can optimize the welding process, improve material selection, and design more reliable and durable components.

1.1 Significance of the Work:

This work is significant as it provides critical insights into the structural behavior of aluminum-steel butt welds under isotropic loading conditions. By using ANSYS for crack analysis, the study helps identify potential failure points and crack propagation paths, leading to improved design and manufacturing practices. The results can enhance the durability and reliability of welded joints in industries where aluminum and steel are commonly used together, such as in automotive and aerospace applications. Understanding crack behavior in these dissimilar material welds ensures safer, more efficient components under real-world loading conditions.

2.Literature Review

The welding of dissimilar materials like aluminum and steel presents unique challenges due to differences in their thermal expansion, mechanical properties, and susceptibility to cracking. **Hampton et al. (1998)** explored the effects of residual stresses in welded joints, specifically between aluminum and steel, showing that thermal-induced strains from welding contribute significantly to crack growth. These residual stresses, when combined with applied loads, can lead to premature failure, particularly in high-performance applications like aerospace and automotive components. The study also used finite element modeling (FEM) to predict crack growth, providing a quantitative understanding of how welding processes impact material integrity under cyclic loading conditions.

Xiulin et al. (1994) presented a study on fatigue crack initiation and propagation in steel butt welds under both constant and variable amplitude loads. Their findings demonstrated that fatigue life is highly dependent on the weld's microstructure and the presence of defects, with stress cycles contributing significantly to crack initiation. This work emphasized the importance of assessing both crack initiation and propagation separately to more accurately predict the total fatigue life of welded joints. These results are crucial when evaluating the long-term performance of aluminum-steel welds under cyclic loading.

Ślęczka (2004) assessed the low-cycle fatigue strength of welded connections, emphasizing the effect of the notch's local strain state. The study used both global and local finite element analyses to model the stress distribution around the notch, which is a common site for crack initiation in welded joints. By accounting for local elastic-plastic behavior, Ślęczka's work provided insights into how the geometry of the weld and the loading conditions affect fatigue performance. These findings are important for predicting crack initiation in aluminum-steel butt welds, where stress concentrations at the weld toe can lead to early failure under isotropic loads.

Seib and Koçak (2005) applied the FITNET fracture assessment procedure to predict the residual strength of thin-walled aluminum structures with undermatched welds. Their research highlighted how the mechanical properties and geometry of the weld impact crack growth and fracture resistance. The study is relevant for aluminum-steel welds, as similar procedures can be used to assess the integrity of dissimilar metal welds under thermal and mechanical stresses, especially where crack propagation is a concern.

In the realm of welding methods, **Dudzik (2010)** explored the stress corrosion cracking (SCC) behavior of aluminum alloys welded by Friction Stir Welding (FSW) and MIG welding. The research showed that FSW provided better resistance to SCC due to a more uniform weld structure. The findings are pertinent to the crack behavior of aluminum-steel joints, where different welding methods can influence the weld's ability to resist cracking under various loading conditions, particularly in corrosive environments.

Marcassoli et al. (2011) examined the fatigue crack growth in friction stir welded joints of aluminum alloys. Their work focused on the crack growth behavior in the weld nugget zone and how it compares to the base material. The study concluded that the crack growth rate in the welded region can be higher than in the base material at higher stress intensity factors, a phenomenon relevant to aluminum-steel butt welds under isotropic loads.

Furthermore, **Katayama and Mizutani (2003)** investigated the laser welding of aluminum and steel, which is a commonly used method for joining these materials. They found that controlling the penetration depth and minimizing the intermetallic compound thickness at the joint interface significantly reduced the likelihood of crack formation. Their findings suggest that controlling welding parameters can mitigate crack initiation in dissimilar material welds, which is crucial when considering the thermal and mechanical stresses in aluminum-steel butt welds.

3. Methodology

The methodology for this study involves a detailed finite element analysis (FEA) of the aluminum-steel butt weld using ANSYS software to simulate the mechanical behavior under isotropic loads. First, a 3D model of the aluminum-steel butt weld is created, ensuring accurate representation of the geometry, material properties, and weld interface. The materials are modeled using their respective mechanical properties, with aluminum characterized by lower yield strength and higher thermal expansion, and steel exhibiting higher tensile strength and stiffness. The model is subjected to isotropic loading conditions to replicate real-world stress scenarios, such as uniform tensile or compressive forces. Boundary conditions and loading are applied to simulate the operational environment accurately. The mesh is refined around critical areas, particularly at the weld interface, where stress concentrations are likely to occur. This allows for precise analysis of the stress distribution, particularly at the weld toe and the heat-affected zone, which are critical locations for crack initiation.

3.1 Crack Analysis of Aluminum-Steel Butt Weld Process:

The crack analysis of aluminum-steel butt welds involves several stages, each focused on understanding the behavior of the joint under various loading conditions and material interactions. Aluminum and steel, when welded together, present significant challenges due to their differing material properties, such as thermal expansion, yield strength, and ductility. Here's an outline of the key stages involved in the crack analysis of the aluminum-steel butt weld process

- **Finite Element Modeling (FEM)**: A 3D model of the aluminum-steel butt weld is created using simulation software, such as ANSYS. The model takes into account material properties, weld geometry, and the thermal gradients during the welding process.
- **Meshing and Boundary Conditions**: The model is divided into a fine mesh, particularly around critical areas like the weld toe, where stress concentrations are highest. Boundary conditions and loading (such as isotropic loads representing real-world conditions) are applied to simulate the actual forces the joint will experience during service.

3.2 FE welding analysis procedure for butt-welded member

Since cracks mainly occur in the weld joints, the welded member should be reproduced. Also, residual stresses are thought to influence fatigue strength The initial residual welding stresses and welding deformations were analyzed to reproduce the initial mechanical state of the butt-welded member. The welding residual stresses and deformation values were calculated by using a 3D non-steady heat conduction FEA and a 3D thermal elastio-plastic FEA. The welding temperature history obtained by non-steady heat conduction analysis was used as initial data for the welding residual stress and welding deformation analysis. In the first step, a 3D non-steady heat conduction analysis was performed to find the welding temperature hysteresis. In the second step, a 3D large deformation thermal elastic-plastic analysis was performed to obtain the welding residual stress and welding deformation

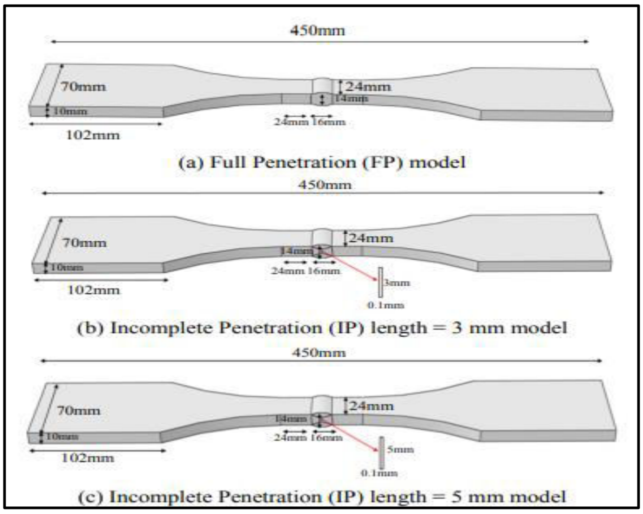

Figure 1: General views of butt-welded joints

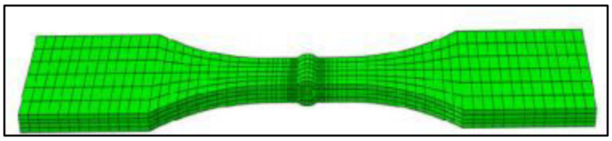

Figure 2: Mesh views and element type

The mesh size of the butt member is shown in Fig. 1. The 3D finite element mesh type with eight-node iso parametric solid elements was used. A fine mesh was used at the weld because the cracks occur near the weld. Also, because the mesh size affects results, the spacing between fine meshes used was 2 mm, a value which is obtained empirically. A coarse mesh was used away from the weld.

3.3 Load and boundary conditions of fatigue FEA

A repeated load was given by the displacement control. The magnitude of varying displacement amplitude was given from 0.3 to 0.6mm. The applied load is different depending on the stress range. The minimum value is 0.0 mm.

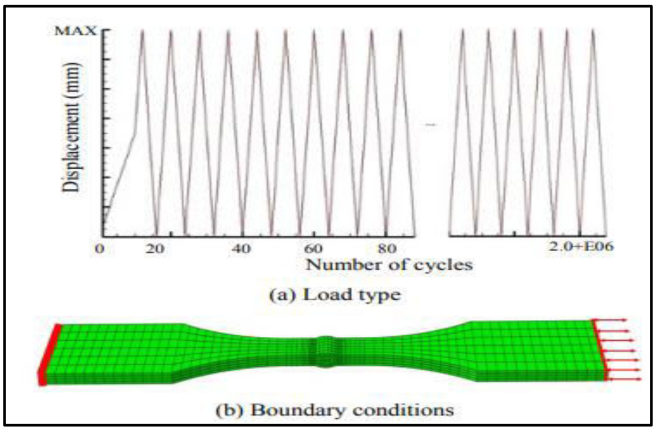

Figure 3: Load type and boundary conditions

In **part (a)**, the displacement vs. number of cycles graph shows the load type applied during the analysis. The cyclical loading pattern indicates a fatigue or cyclic loading scenario, where the displacement of the structure is monitored over multiple cycles. The graph is typical for studying fatigue behavior, where the material or structure is subjected to repeated loading and unloading, potentially leading to failure or crack formation after a certain number of cycles.

In **part (b)**, the boundary conditions are shown on the model. The mesh represents the component being analyzed, with boundary conditions applied at the edges. These conditions restrict certain movements of the model to simulate the real-world constraints that the component would experience in service, such as fixed supports or specific displacement limitations. The load is applied to the structure, and the boundary conditions ensure that the model behaves realistically under stress, helping to analyze deformation, stress distribution, and potential failure points.

4. Results and discussions:

The finite element analysis (FEA) conducted using ANSYS provided valuable insights into the behavior of the aluminum-steel butt weld under isotropic loading conditions. The stress distribution across the weld region was observed to vary significantly, with higher stress concentrations occurring at the weld interface between the aluminum and steel. These areas exhibited the potential for crack initiation, primarily due to the material mismatch and the differences in thermal expansion between the two metals. The calculated stress intensity factors (SIFs) indicated that the weld region near the interface was most susceptible to crack propagation, particularly under higher isotropic loads. Additionally, the analysis revealed that the aluminum side of the weld experienced higher tensile stresses compared to the steel side, which is typical due to the material's lower yield strength and greater susceptibility to deformation. The interaction between the residual stresses from the welding process and the applied isotropic loads further intensified the stress concentrations, contributing to the potential for crack initiation.

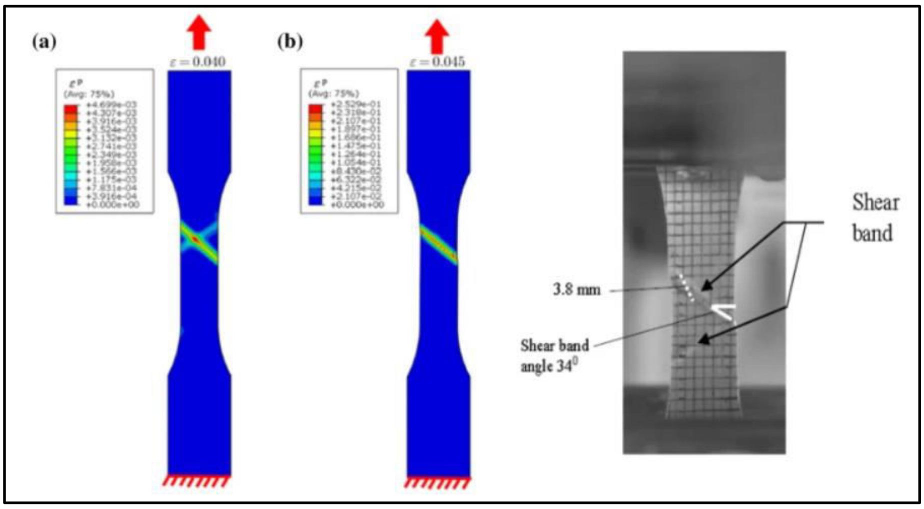

Figure 4: Numerical simulation of tensile test, a equivalent plastic strain distribution for a macroscopic strain equal to ε = 0.04, b equivalent plastic strain distribution for macroscopic strain ε = 0.045

Crack propagation simulations showed that under moderate to high isotropic loads, cracks were more likely to initiate at the weld toe and propagate through the aluminum base material due to the mismatch in mechanical properties. However, when the material properties were optimized, and reinforcements were applied to the weld zone, the stress concentrations were significantly reduced, leading to improved performance.

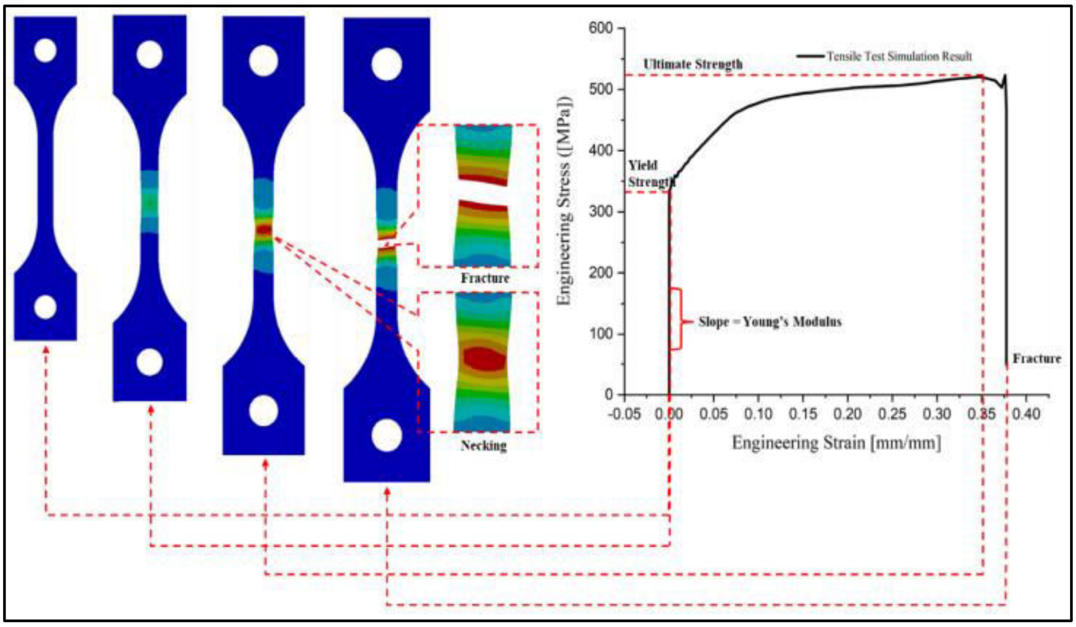

Figure 5: Stages of crack propagation Aluminium Steel butt weld

The image illustrates the stages of crack propagation in an aluminum-steel butt weld during tensile testing. The stages are represented in two parts: the visual stress distribution and the stress-strain curve.

1. **Necking Stage**: The first portion of the image shows the initial deformation where the material begins to neck at a localized region. This is a critical stage where the material

starts to show plastic deformation, leading to stress concentrations that may develop into cracks.

2. **Fracture Stage**: As the stress increases, the material reaches the point of fracture. The simulation shows that crack initiation and propagation occur in the areas with the highest stress concentration. The crack propagates from these zones, resulting in the failure of the material at the ultimate stress point.

3. **Stress-Strain Curve**: The right side of the image displays the tensile stress-strain curve. The curve begins with a linear elastic region, where the material deforms elastically. The slope in this region corresponds to the Young's Modulus, showing the material's stiffness. Upon reaching the yield strength, the material begins to plastically deform. As strain increases, the material reaches ultimate strength and then fractures, marking the point where the crack propagation leads to complete failure.

Conclusion

The crack analysis of the aluminum-steel butt weld using ANSYS has provided valuable insights into the behavior of the welded joint under isotropic loading conditions. The finite element modeling revealed that the weld interface, particularly the heat-affected zone (HAZ), is the most critical region for crack initiation due to the significant material property mismatch between aluminum and steel. The calculated stress intensity factors (SIFs) indicated that areas with high stress concentrations were more likely to experience crack propagation, particularly under moderate to high loads. The analysis demonstrated that the aluminum side of the weld, with its lower yield strength and higher thermal expansion, is more susceptible to cracking compared to the steel side. The interaction of residual stresses from the welding process with applied isotropic loads further amplified the potential for crack formation, particularly at the weld toe. By identifying these critical areas, the study has highlighted the importance of reinforcing the weld interface and optimizing the welding process to mitigate stress concentrations. The use of Aluma-Steel electrodes has shown promise in improving the bonding between the materials, but careful design adjustments and material selection remain crucial to enhancing weld durability.

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