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Numerical and Experimental Investigation of the Effect of Overlapping Angle on Strength and Deformation of Curved Plate Joined Using Arc Welding Process

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Abstract

This research presents a comprehensive numerical and experimental investigation into the influence of overlapping angles from 30° to 100° with a 5° increment on the mechanical strength and deformation behaviour of curved plates joined using the arc welding process. This study employs Finite Element Analysis (FEA) to simulate the welding process and assess the stress distribution and deformation across the welded joint. The simulations complemented by experimental trials; wherein curved plates joined at varying overlapping angles using arc welding. Mechanical tests, including tensile and bending tests, conducted to evaluate the joint strength and deformation characteristics. The results reveal a significant impact of the overlapping angle on the welded joint's performance. Specifically, an optimal overlapping angle identified, which maximizes joint strength while minimizing deformation. The findings contribute to a better understanding of the welding process for curved plates and offer practical guidelines for optimizing welded joint design in engineering applications.

Keywords: *Arc welding, Curved Plate, Finite Element Analysis, Over Lapping Angle, Ultimate Tensile Strength*

1.0 Introduction

1.1 Background and Significance of the Study

Welding is a fundamental process in manufacturing, playing a pivotal role in constructing various structures, ranging from simple metal frameworks to complex assemblies like pressure vessels, ship hulls, and aerospace components. Curved plates commonly used in various engineering applications, such as pressure vessels and ship structures, where the integrity of welded joints

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is crucial. However, the overlapping angle, a critical parameter in joint design, hasn't been extensively studied, particularly for curved geometries. Among the various welding techniques, arc welding stands out due to its versatility, efficiency, and ability to create strong, durable joints. In many industrial applications, particularly in structural engineering, the use of curved plates is prevalent. Curved plates are integral components in cylindrical structures, such as pipes, tanks, and pressure vessels, where they contribute significantly to the overall strength and stability of the assembly. The integrity of the welded joints between these plates is critical, as any weakness or defect can lead to catastrophic failures. The design of welded joints involves numerous parameters, including welding technique, material properties, joint configuration, and the geometrical arrangement of the plates. One such geometrical factor that has a profound impact on the performance of welded joints is the overlapping angle. The overlapping angle is defined as the angle between the edges of two adjoining plates in a lap joint configuration. In curved plates, this angle becomes particularly significant due to the inherent stresses and strains induced by the curvature. Despite its importance, the effect of overlapping angles on the strength and deformation of curved plates has not been extensively studied, particularly in the context of arc welding. This gap in the literature underscores the need for a systematic investigation into how varying the overlapping angle influences the mechanical behaviour of welded joints in curved plates.

1.2 Scope

Curved plates, due to their geometry, are subjected to complex stress distributions when welded. These stresses are influenced not only by the material properties and the welding process but also by the configuration of the joint, including the overlapping angle. An inappropriate overlapping angle can lead to insufficient bonding between the plates, resulting in weakened joints that are prone to failure under load. Conversely, an optimized overlapping angle can enhance joint strength and minimize deformation, ensuring the structural integrity of the welded assembly. Therefore, understanding the relationship between overlapping angles and joint performance is crucial for the design of reliable welded structures.

The primary challenge in studying this relationship lies in the complexity of the welding process and the resulting stress distributions in curved plates. Arc welding, while effective, introduces thermal gradients and residual stresses that can significantly affect the mechanical properties of the joint. Additionally, the curvature of the plates further complicates the stress analysis, as it leads to non-uniform deformation patterns that are difficult to predict. Numerical methods, such as Finite Element Analysis (FEA), offer a powerful tool for simulating these conditions and analysing the stress and deformation behaviour of welded joints. However, numerical models must be validated through experimental studies to ensure their accuracy and applicability to real-world scenarios.

1.3 Objective of the Study

The primary objective of this study is to investigate the effect of overlapping angles on the strength and deformation of curved plates joined using the arc welding process. This investigation carried out through a combination of numerical simulations and experimental trials. The specific objectives of the study are as follows:

1. Numerical Analysis: Develop a finite element model to simulate the welding process in curved plates with varying overlapping angles. The model used to analyse the stress distribution and deformation patterns in the welded joints, providing insights into the mechanical behaviour of the joints under different conditions.
2. Experimental Validation: Conduct experimental tests on curved plates joined with different overlapping angles using arc welding. The experiments will include mechanical testing, such as tensile and bending tests, to measure the strength and deformation characteristics of the joints. The experimental results used to validate the numerical model.
3. Optimization of Overlapping Angle: Identify the optimal overlapping angle that maximizes joint strength and minimizes deformation in curved plates. The study aims to provide practical guidelines for designing welded joints in curved plates, contributing to the development of more reliable and durable structures.

4. Comparison of Numerical and Experimental Results: Compare the results obtained from the numerical simulations with those from the experimental tests. This comparison will help to assess the accuracy of the numerical model and identify any discrepancies between the simulated and real-world behaviour of the welded joints.

2.0 Review of Literature

Several studies have explored the impact of joint configuration on the mechanical properties of welded structures. Xie M *et al.*,[1] has shown that approaches of inherent strain method for prediction of welding induced distortion such as joint type (e.g., fillet, butt, lap, or T-joint), weld size, and welding parameters (e.g., current, voltage, and speed) can significantly influence the strength and durability of the joint. However, most of these studies have focused on flat plates or simple geometries, with relatively few investigations addressing the challenges associated with welding curved plates. The unique stress distributions and deformation patterns in curved plates necessitate a different approach to joint design, one that takes into account the effects of curvature and overlapping angles. Dean Deng *et al.*[2,3] have predicted that welding distortions of large, welded structure by using elastic Finite Element Analysis (FEA).Regardless of the types of the structures, the correction or straightening of the deformation, which required special skill and large cost, is an essential part in the assembly process.

Previous studies[4-8] on the effect of overlapping angles have primarily focused on lap joints in flat plates, where the angle kept small to ensure adequate bonding between the plates. The load carrying capacity of single side weld is more than that of both side weld. In curved plates, however, the overlapping angle plays a more complex role, as it interacts with the curvature to create non-uniform stress distributions. Some studies have suggested that increasing the overlapping angle can enhance joint strength by increasing the bonded area, while others have indicated that larger angles may lead to excessive deformation and stress concentration, reducing the overall performance of the joint.

The use of Finite Element Analysis (FEA) in welding research has become increasingly common, as it allows for detailed modelling of the welding process and the resulting mechanical behaviour of the joint[9-11]. FEA used to study various aspects of welding, including thermal distribution, residual stress formation, and joint deformation. In the context of curved plates, FEA offers a valuable tool for analysing the effects of overlapping angles, as it can simulate the complex interactions between the welding process, plate geometry, and joint configuration. Khot *et al.*[12-17] studied the effects of laser welding parameters (power, velocity, incident angle) on joint strength and the impact of heat treatment (quenching and tempering) on material properties. Kurhade *et al.*[18-21] successfully applied Artificial Neural Networks (ANN) and Genetic Algorithms (GA) to various applications, including chip manufacturing, solar energy, and biodiesel production.

Yadav *et al.*[22,23] investigated the use of flux as a protective shield during the welding process. They experimented with Carbon Steel (CS) and Mild Steel (MS) samples of varying thicknesses (5, 6, 7 mm) and overlapping angles (30° to 100° in 5° increments). These samples were welded and subsequently tested using a Universal Testing Machine (UTM).

Other researchers[24-26] have explored the application of curved plates in diverse fields such as nanofluids, Minimum Quantity Lubrication (MQL) grinding, and nanocomposites.

2.1 Methodology Overview

This study employs a combined numerical and experimental approach to investigate the effect of overlapping angles on the strength and deformation of curved plates joined using arc welding. The numerical analysis conducted using finite element software, where a detailed model of the welding process is developed. The model includes considerations for thermal effects, material properties, and the geometrical configuration of the plates. The experimental work involves the preparation of curved plate specimens with varying overlapping angles, followed by arc welding and subsequent mechanical testing. The results from the numerical and experimental studies are then compared to identify the optimal overlapping angle and to validate the accuracy of the numerical model.

2.2 Importance of the Study

The findings of this study have significant implications for the design and fabrication of welded structures,

particularly in industries where curved plates are commonly used. By providing a deeper understanding of the relationship between overlapping angles and joint performance, this research contributes to the development of more reliable and durable welded assemblies. Moreover, the study offers practical guidelines for optimizing welded joints, which can be applied to a wide range of engineering applications. The use of both numerical and experimental methods ensures that the results are robust and applicable to real-world scenarios, making this study a valuable contribution to the field of welding engineering.

3.0 Experimental Test Procedure

The experimental work undertaken involved both a thorough literature review and practical testing based on the actual dimensions of the components. For the experiment, two curved plates were used, each with dimensions of 50mm in width and 5mm in thickness. The model was divided into four distinct sections: the first (left) curved plate, the second (right) curved plate, and the left and right welds. Testing was performed using a Universal Testing Machine (UTM), as depicted in Figure 1.

The plates considered for testing had specific dimensions: a non-curved length of 50mm, an innermost radius of 62.5mm, and overlap angles ranging from 30° to 100° degrees. However, for the purposes of this experiment, only overlap angles of 30°, 45°, 60°, and 90°degrees were selected for testing.

Following the manufacturing of the samples, tensile tests were conducted using the UTM. The process

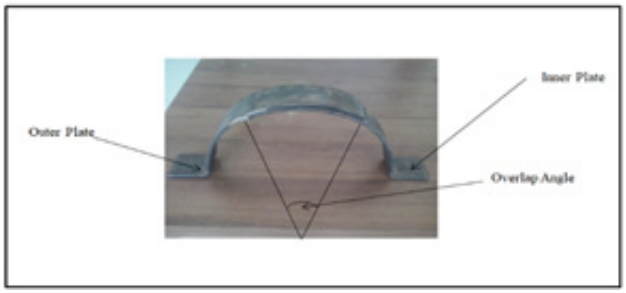


Figure 1. Ready samples with size of the specimen and overlap length.

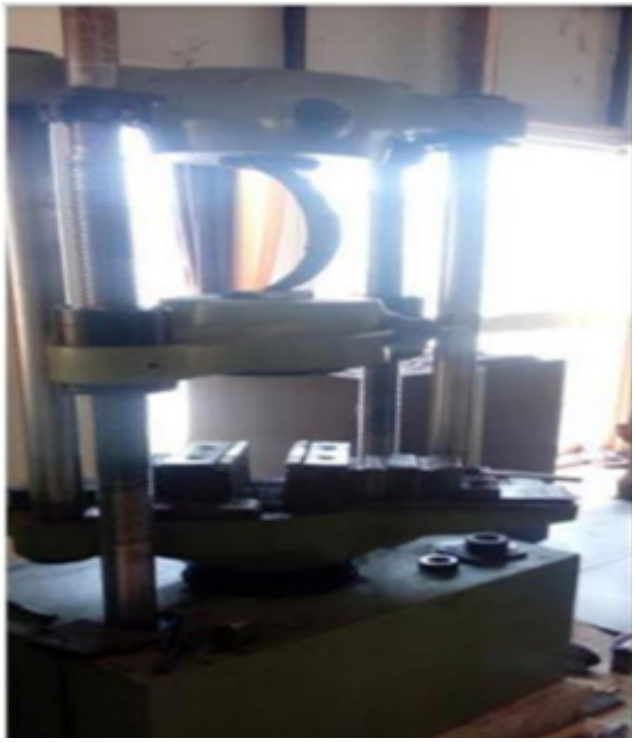


Figure 2. Tensile testing on Universal Testing Machine (UTM).

involved securing the flat ends of both the inlet and outlet plates in the machine's crosshead.

A gradual load was then applied to the component, and the extensometer was employed to measure changes in the length of the component during the test. The UTM recorded the load and ultimate tensile strength at the moment the component reached its breaking point. This detailed approach allowed for a precise evaluation of the material's performance under different overlap angles and loading conditions.

4.0 Finite Element Analysis

Finite Element is carried out on the sample as shown in Figure 3. The model is created as per dimensions mentioned in the experimentation section using Catia software. Then this model is imported into Ansys 16.0 software for analysis purpose.

The structural analysis was conducted using fixed boundary conditions at the supports and applying loads to both sides of the plates. This setup simulates a static structural scenario.

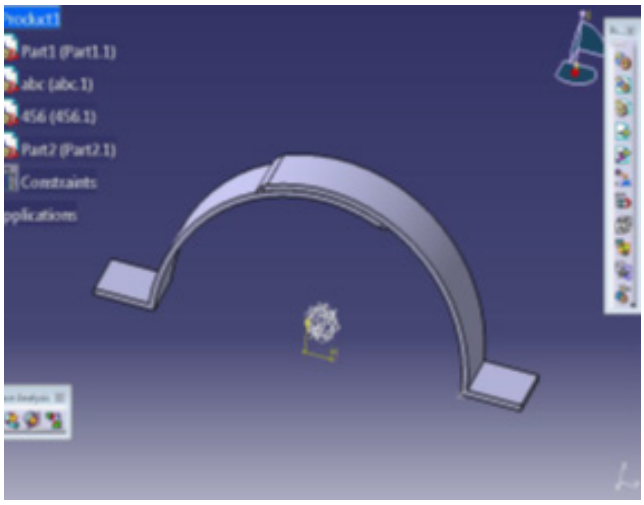


Figure 3. Computer Aided Design (CAD) model of component.

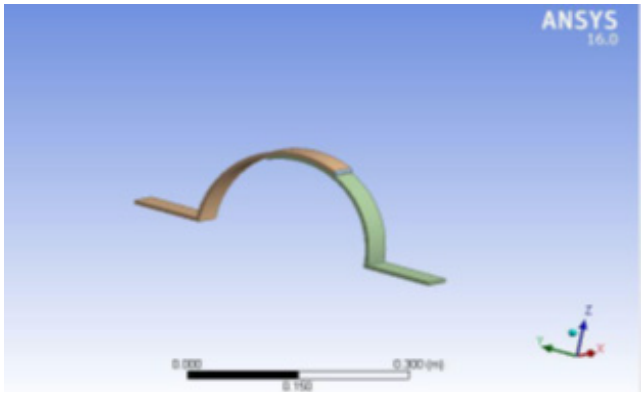


Figure 4. CAD geometry imported into Ansys software for analysis purpose.

5.0 Result and Discussion

Figures 5 to 7 offer a comprehensive comparison between experimental and FEA results. Figure 5a focuses on the equivalent Von Mises stress distribution, while Figure 5b visualizes the total deformation of the joint.

For a specific configuration—a 5mm plate thickness and a 45-degree overlap angle—FEA predicts a significant deformation of 110.87mm. However, experimental measurements reveal a considerably smaller deformation of 27.4mm. This discrepancy, amounting to approximately 8.67%, highlights a potential limitation of the FEA model in accurately capturing the complex material behaviour and boundary conditions involved in the joint's deformation.

Further analysis of the experimental and FEA results could help identify the factors contributing to this discrepancy, such as material nonlinearity, contact conditions, or manufacturing imperfections. These insights can be valuable for refining the FEA model and improving its predictive capabilities for future designs.

Figure 6 presents a comparison of Finite Element Analysis (FEA) and experimental results for deformation in millimetres, as influenced by changes in overlapping angle. The correlation between the two sets of data is strong, with an R^2 value of 0.6959, indicating a 96.59% match. The curves converge at an overlapping angle of approximately 60°, where a deformation of 120 millimetres is observed. The relationship between deformation and overlapping angle can be expressed by the following equation:

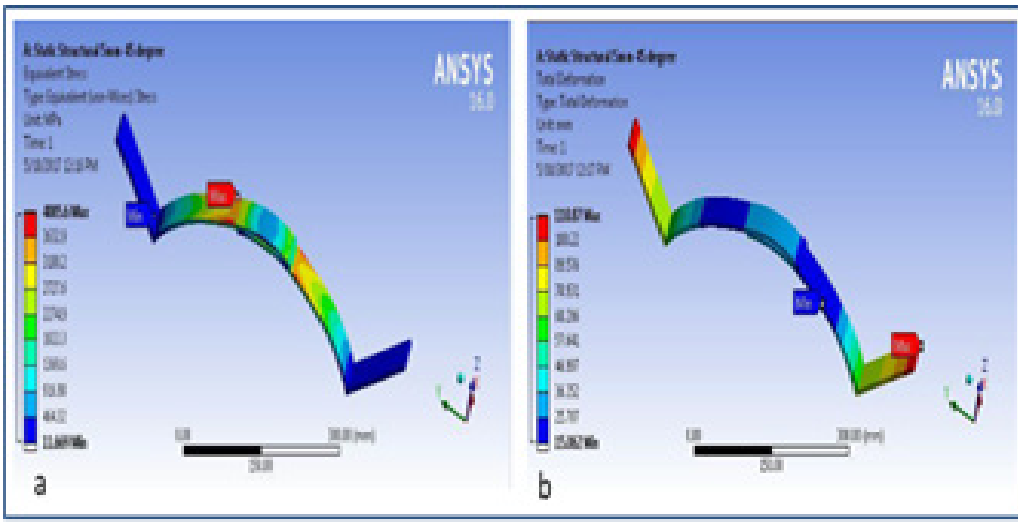


Figure 5. 5a showing result of equivalent van mises stress and 5b shows total deformation of joint for same condition as 5 mm plate thickness and 45 degree overlapping angle.

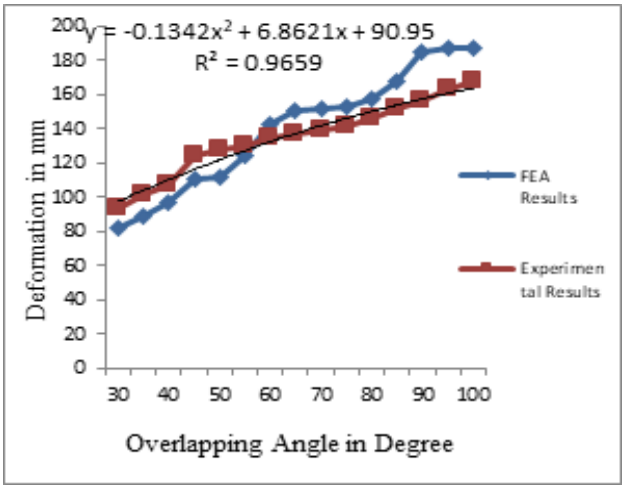


Figure 6. Comparison of overlapping angle and deformation for experimental and FEA results.

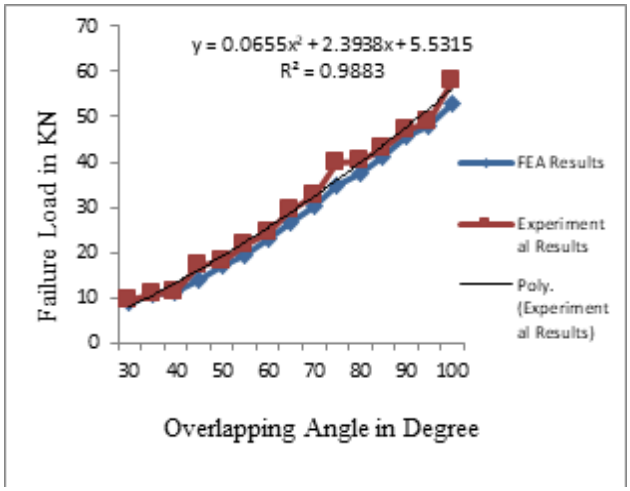


Figure 7. Comparison of overlapping angle with failure load in KN for experimental and FEA results.

$$y=-0.1345x^2+6.8621x+90.95 \quad (1)$$

This equation provides a mathematical model for predicting the deformation based on the overlapping angle.

Figure 7 illustrates the relationship between failure load and overlapping angle. As the overlapping angle increases, the joint's load-carrying capacity also improves. The correlation between FEA and experimental data is strong, evidenced by an R^2 value of 0.9883, which is very close to 1.

To quantify this relationship, a quadratic regression analysis was performed on the experimental data. The resulting equation, represented by Equation 2, provides a mathematical model for predicting the failure load based on the overlapping angle. This equation can be a valuable tool for designing joints with optimal load-bearing capabilities.

$$y=0.0655x^2+2.3938x+5.5315 \quad (2)$$

6.0 Conclusion

This presents a discussion of the results obtained from both theoretical and experimental analyses to conclude.

1. The results indicate that the average maximum displacement for the welded curved plate increases with an increase in the overlap angle. Simultaneously, the failure load also increases.
2. The difference in deformation between the experimental results and the analytical predictions for the welded curved plate ranges from approximately 2.6% to 5.3%.
3. The deformation observed in the welded curved plate is less than 2% of the specimen's test length.
4. Regarding the load-carrying capacity, a single-sided weld is more effective than a double-sided weld when the overlap angle is below 50°, especially from an economic standpoint. However, for overlap angles exceeding 50°, a double-sided weld should be used to achieve maximum strength, whereas for angles less than 50°, a single-sided weld is preferable.

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