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Influence of Plate Thickness on the Mechanical Behaviour of Mild Steel Curved Plates: An Experimental Study

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Abstract

This paper aims to investigate the influence of plate thickness on the strength, failure load and deformation behaviour of mild steel curved plates. Experimental tests were conducted on curved plates with varying thicknesses, subjected to static loading conditions. The ultimate load, deflection and failure modes were recorded and analysed. Results indicate a significant relationship between plate thickness and mechanical properties. Thicker plates exhibited higher load-carrying capacity and different deformation patterns than thinner plates.

Major Finding: *The findings provide valuable insights for designing and optimising curved plate structures in various engineering applications.*

Keywords: *Failure Load, Included Angle, Mild Steel, Plate Thickness, Tensile Strength*

1.0 Introduction

Curved plates are essential structural elements in various engineering applications, including pressure vessels, bridges and aircraft components. Their unique geometry provides enhanced structural integrity and load-bearing capacity compared to flat plates. However, the behaviour of curved plates under different loading conditions can be complex and influenced by various factors, such as material properties, curvature and boundary conditions.

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Among these factors, plate thickness plays a crucial role in determining the strength and deformation characteristics of curved plates.

The thickness of a curved plate significantly affects its mechanical properties and response to external loads. Thicker plates generally exhibit higher stiffness and load-carrying capacity due to their increased cross-sectional area. However, they may also be more susceptible to buckling or local instability under certain loading conditions. Conversely, thinner plates may be more flexible and prone to larger deformations but may also offer advantages in terms of weight reduction and manufacturing cost.

Understanding the relationship between plate thickness and mechanical properties is essential for the design and optimisation of curved plate structures. This knowledge enables engineers to select appropriate plate thicknesses to ensure structural integrity, safety and efficiency. Several studies have been conducted to investigate the effects of plate thickness on the behaviour of curved plates. These studies have employed both analytical and experimental methods to explore various aspects of the problem, including bending strength, buckling behaviour and deformation patterns.

Analytical methods, such as Finite Element Analysis (FEA), have been widely used to predict the response of curved plates to different loading conditions. FEA allows for detailed modelling of complex geometries and material properties, providing valuable insights into stress distributions, deflections and failure mechanisms. Experimental studies on curved plates have involved a variety of testing methods, including static loading, dynamic loading and fatigue testing. Static loading tests are commonly used to determine the ultimate load-carrying capacity and deformation behaviour of curved plates under monotonic loads.

2.0 Review of Literature

The findings from various research studies on welding distortion in curved plates and stiffened panels and the effects of plate geometry play a vital role in the strength and deformation of joints. Plate thickness significantly impacts strength and deformation. Thicker plates offer higher load capacity but are less prone to bending compared to thinner plates (Barsoum *et al.*, [1] Deng *et al.*,[2]). Curvature magnitude and aspect ratio influence buckling behaviour and post-buckling collapse (Park *et al.*,[3]). The curvature also affects the second moment of inertia, impacting elastic buckling strength (*Dang D et al.*[4]). The slenderness ratio plays a role in the ultimate strength of stiffened curved plates under axial compression (Jung *et al.*,[5]).

Welding, a ubiquitous process in modern manufacturing, often introduces residual stresses and distortions into the fabricated structures. These distortions can significantly impact the structural integrity and performance of components, particularly in complex geometries like curved plates and stiffened panels. FEA, a powerful computational tool, has emerged as a cornerstone for accurately predicting and mitigating these distortions.

Thermal-elastic-plastic FEA, in particular, is widely regarded as the most comprehensive approach for modelling welding-induced residual stresses and distortions. This method allows for a detailed representation of complex geometries, material properties and the intricate thermal and mechanical processes involved in welding. Researchers have leveraged FEA to investigate the influence of various factors on the ultimate strength and behaviour of curved plates.

Initial imperfections in the plate geometry, for instance, can have a profound effect on buckling behaviours. Jung *et al.*,[5] and *tran KL et al.*,[6] studied the effectiveness of different stiffener configurations in improving the structural performance of curved plates. Residual stress, a direct consequence of the welding process, plays a critical role in determining the stress-strain behaviour of the material. *Zhao H et al.*,[7] highlighted the potential for stress concentration due to residual stresses, which can compromise the structural integrity of welded components. Welding conditions, such as preheat temperature, also influence the distribution of residual stresses. Jiang *et al.*,[8] investigated the impact of preheat temperature on residual stress patterns in welded joints.

The angle of loading on a fillet weld is another factor that can affect its ultimate strength. Lesik *et al.*,[9] and Miazga *et al.*,[10] explored the relationship between the loading angle and the strength of fillet welds. Welding distortion can lead to dimensional inaccuracies and increase fabrication costs. Miazga *et al.*,[10] and Peric *et al.*,[11] emphasised the

importance of accurate prediction and reduction of welding distortion to ensure high-quality welds. Root gaps and misalignment between parts to be welded can also contribute to distortion. Deng *et al.*,[12] studied the effects of root gaps and misalignment on welding distortion in curved plates. Park *et al.*[13] demonstrated that even minor imperfections can significantly reduce the load-carrying capacity of curved plates. Stiffeners, on the other hand, can enhance the ultimate strength of curved plates under axial compression.

In conclusion, this review provides a concise overview of the research on welding distortion in curved plates and stiffened panels. By understanding the effects of various factors, engineers can design and fabricate structures with minimal distortion and improved structural performance. FEA, as a powerful computational tool, plays a pivotal role in predicting and mitigating welding distortion, ensuring the reliability and safety of welded components. Previous research[14-20] has revealed that plate thickness can significantly influence the strength and deformation of curved plates. Kurhade *et al.*[21-24] investigated the use of nanofluids in different applications, highlighting their impact on understanding a fluid's strength behaviour. Yadav *et al.*[25-28] focused on the importance of welding in designing and analysing electric bikes. Their work covered Body-in-White (BIW) fixtures, leaf springs (both composite and metal) and chassis used in Light Commercial Vehicles (LCVs). Khot *et al.*,[29,30] delved into laser welding, specifically optimising its process parameters to achieve improved strength. Finally, Kurhade *et al.*[31-36] explored heat transfer performance under various conditions, including the use of Corrugated Twisted Tape, recycled aluminium cans, electronic cooling technology, biodiesel blends and wind tunnels. Thicker plates have been shown to exhibit higher ultimate loads and lower deflections compared to thinner plates. However, the specific relationship between plate thickness and mechanical properties can vary depending on the loading conditions, curvature, and material properties. In this study, experimental investigation of the effect of plate thickness on the strength and deformation of mild steel curved plates. Mild steel is a commonly used material in structural applications due to its good mechanical properties and relatively low cost. By conducting a series of static loading tests on curved plates with varying thicknesses, we will quantify the relationship between plate thickness and ultimate load, deflection, and failure mode. The findings of this study will contribute to a better understanding of the behaviour of curved plates and provide valuable guidance for the design and optimisation of structures incorporating these elements. The results may also apply to other materials and loading conditions, providing a broader framework for the design of curved plate structures in various engineering fields.

3.0 Experimental Methodology

3.1 Test Specimen Dimensions and Variations

The curved plate is considered with material properties as shown in Table 1. The actual components in CAD fire and 2D wire-frame model are as shown in Figure 1.

The plates selected for testing were specifically designed with the following dimensions:

A non-curved length of 50 mm.

An innermost radius of 62.5 mm.

Overlapping angles varying from 30 to 100 degrees in increments of 5 degrees

To ensure a comprehensive evaluation, samples were prepared with overlapping angles ranging from 30 to 90 degrees in steps of 5 degrees. Additionally, the plate

Table 1. Material properties of mild steel (IS2062)

Sr no	Properties	Value
1	Ultimate Tensile Strength (MPa)	350-450
2	Yield Tensile Strength (MPa)	240
3	Poisson's Ratio	0.27-0.30
4	Density (kg/m^3)	7850

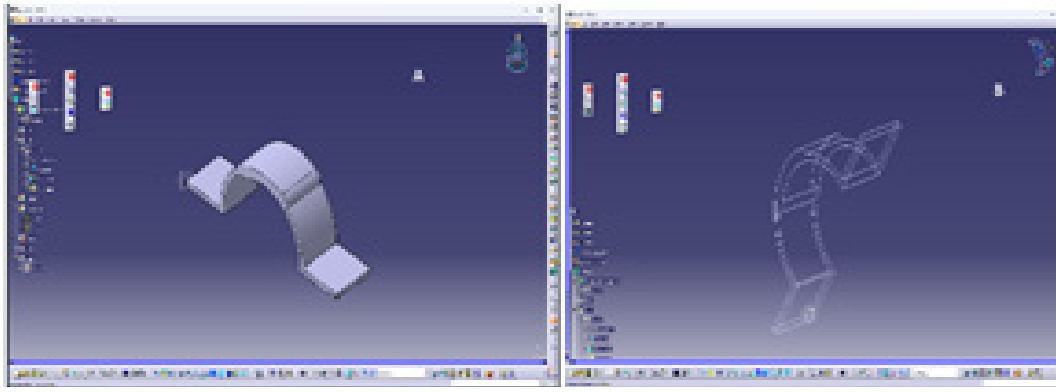


Figure 1. **(A)** CAD modelling of the test specimen. **(B)** Wire frame model of the sample.

thickness was varied to include 5mm, 6mm and 7mm thicknesses, further expanding the scope of the testing.

3.2 Tensile Testing Procedure

Tensile testing was conducted on the plate samples using a Universal Testing Machine (UTM) as shown in Figure 2. The UTM employed in the testing process boasted a high degree of accuracy, with load readings precise to within ±1% from 2% to 100% of its maximum capacity. The machine's load-carrying capacity ranged from approximately 100kN to 2000kN, providing ample capacity for testing the various plate configurations.



Figure 2. The experimental set-up for tensile testing on the UTM machine.

In tensile tests, the machine recorded both deformation and failure load data. These readings were meticulously captured and analysed to assess the mechanical properties of the plate samples under different conditions.

4.0 Result and Discussion

In this session, the different parameters are elaborated as overlapping angle, plate thickness and correlated with deformation and failure load.

4.1 Deformation

The relationship between plate thickness and deformation, as depicted in Figure 3, reveals a clear trend: thinner plates (e.g., 5 mm) exhibit higher deformation, while thicker plates demonstrate greater stiffness and resistance to deformation.

The influence of overlap angle on deformation, however, is more complex. In the case of 7mm plates, the deformation of the respective joints increases progressively in a nearly linear manner. For 6 mm plates, the deformation pattern follows a similar trend, but with two noticeable dips occurring at 65 and 85 degrees. The 5mm plates exhibit a unique deformation behaviour. The

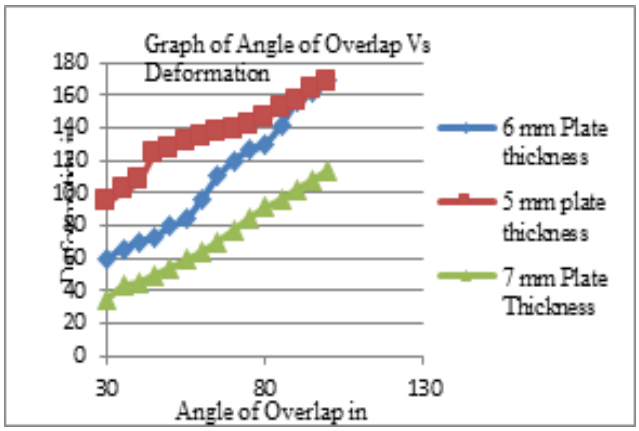


Figure 3. Graph of overlapping angle with deformation of joint for different thickness.

for all three plate thicknesses (5 mm, 6 mm and 7 mm) indicate a consistent relationship between these variables. The high R-squared values of approximately 0.99 for each curve demonstrate a very good fit between the quadratic regression model and the experimental data. This implies that the overlap angle is a significant predictor of failure load.

The use of a quadratic equation to model the relationship suggests a non-linear dependence of failure load on the overlap angle. This could be attributed to factors such as stress concentration, material properties and geometric effects that become more pronounced as the overlap angle increases.

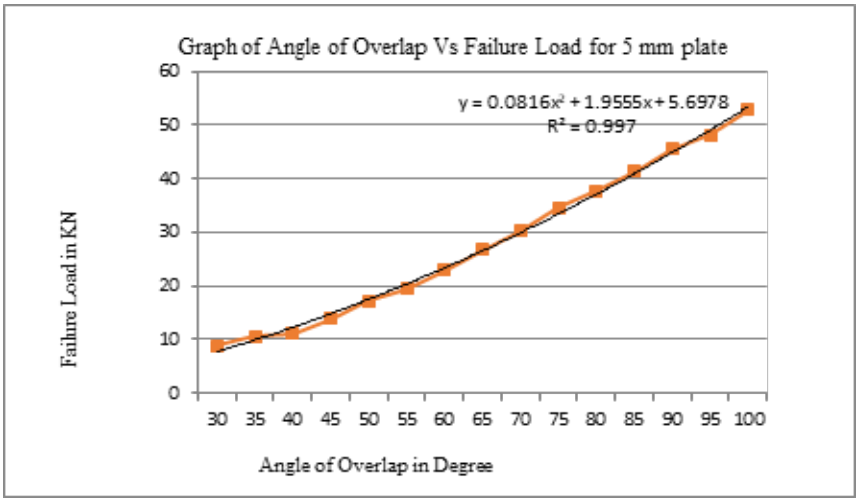


Figure 4. Graph of overlapping angle with failure load for 5mm plate thickness.

deformation starts at 45 degrees and continues to increase gradually until reaching 100 degrees. Beyond this point, the deformation pattern shifts to a more linear trend. These findings underscore the interplay between plate thickness and overlap angle in determining the overall deformation characteristics of the joints. Understanding these relationships is crucial for optimising the design and performance of structures fabricated from these materials.

4.2 Failure Load

The data provided suggests a strong correlation between failure load and overlap angle for plates of varying thicknesses. The similar patterns observed in the curves

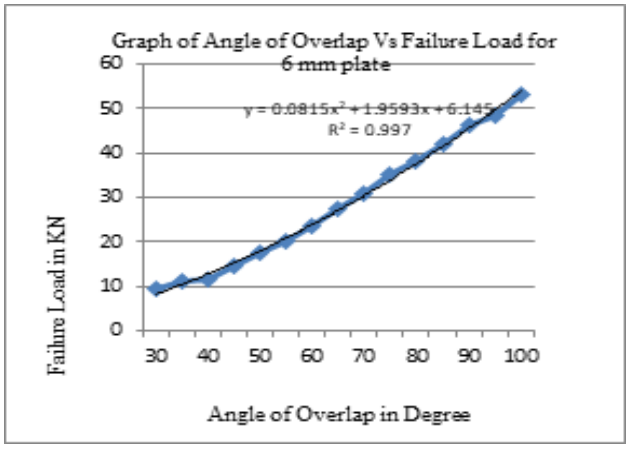


Figure 5. Graph of overlapping angle with failure load for 6mm plate thickness.

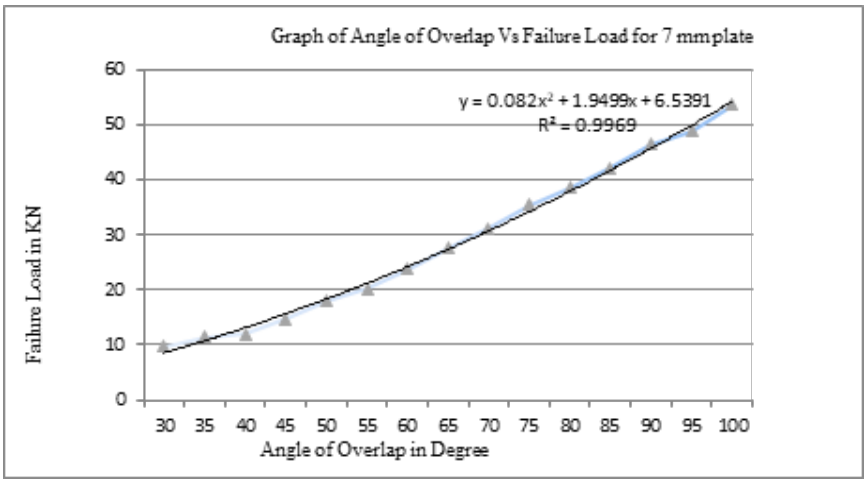


Figure 6. Graph of overlapping angle with failure load for 7mm plate thickness.

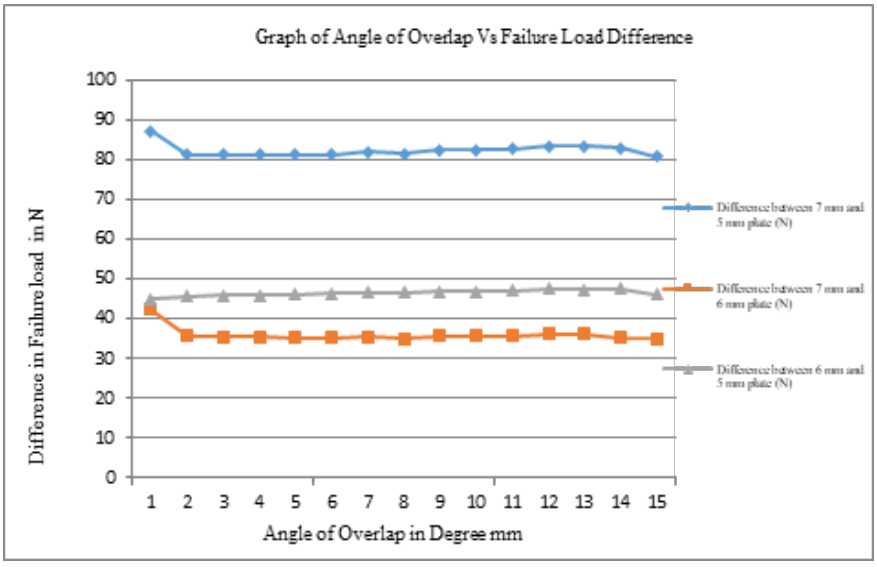


Figure 7. Graph of angle of overlap with failure load differences between 7, 6 and 5 mm.

y=0.0816x^2+1.9555x+5.6978 1

y=0.0815x^2+1.9555x+6.145 2

y=0.082x^2+1.9499x+5.5391 3

Figure 4 visually demonstrates the relationship between plate thickness and failure load. The data reveals a clear trend: as plate thickness increases from 5 mm to 7 mm, the failure load also increases. Specifically, the difference in failure load between a 7 mm and a 5 mm plate ranges from 87.3N to 80.8N as shown in Figure 5 and Figure 6.

This is a significant increase compared to the difference between 7mm and 6mm plates, which range from 42.5N to 34.8N. Similarly, the difference between 6mm and 5mm plates is smaller, ranging from 45N to 47.6N as shown in Figure 7.

This gradual increase in failure load can be attributed to the enhanced load-carrying capacity of thicker plates. The additional material provides greater resistance to

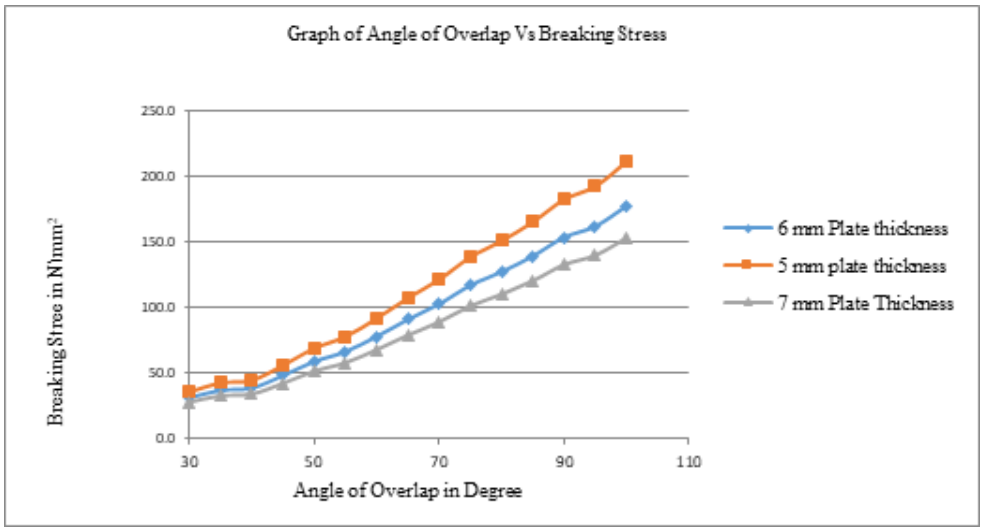


Figure 8. Graph of angle of overlap with failure load differences between 7, 6 and 5 mm.

deformation and fracture, allowing the joint to withstand higher loads before failure.

4.3 Breaking Stress

The strength of a joint is directly influenced by its effective cross-sectional area. This study investigates the relationship between overlap angle and breaking stress in joints of varying thicknesses. The breaking stress, as depicted in Figure 8, is highest in the 5mm plate and lowest in the 7 mm plate. All three plates exhibit similar trends, with maximum stress occurring at a 100-degree overlap angle and minimum stress at a 30-degree overlap angle.

The 5mm plate, despite being the thinnest, demonstrated the highest breaking stress of 211.2 N/mm². In contrast, the 7mm plate, despite being the thickest, exhibited the lowest breaking stress of 35.16 N/mm². This unexpected result suggests that other factors, such as stress distribution or material properties, may also play a significant role in determining joint strength. The average difference in breaking stress between 7mm and 5mm plates was significantly higher than that between 7 mm and 6 mm plates. Specifically, the difference was 29.8 N/mm² for 7mm and 5mm plates, compared to 12.6 N/mm² for 7mm and 6mm plates. The average difference in breaking stress between a 6mm plate and a 5mm plate thickness is 17.2 N/mm².

5.0 Conclusion

This experimental study comprehensively investigated the influence of plate thickness on the mechanical behaviour of mild steel curved plates. Through a series of controlled tests, it was determined that plate thickness significantly affects the load-carrying capacity, deflection and stress distribution in these structures.

1. Thicker plates exhibited higher load-carrying capacities compared to thinner plates, indicating that increasing thickness can enhance the strength and structural integrity of curved plates.
2. Thinner plates demonstrated greater deflection under the same applied loads, suggesting that they are more susceptible to deformation than thicker plates.
3. For overlap angles below 50°, single-sided welds in 7mm plates were found to be economically advantageous. However, for overlap angles exceeding 50°, double-sided welds were recommended to achieve maximum strength.
4. The average increase in breaking stress for a 5mm plate compared to a 7mm plate is approximately 36%, while for a 6mm plate compared to a 7mm plate, it is around 15%.

These findings provide valuable insights for the design and optimisation of curved plate structures, enabling

engineers to make informed decisions regarding plate thickness and weld type selection based on specific loading conditions and economic constraints.

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