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TENSILE STRENGTH AND FAILURE BEHAVIOUR OF CLINCHED JOINT IN CROSS-TENSION SPECIMENS OF SIMILAR ALUMINIUM ALLOY SHEETS

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Abstract

This research investigates experimentally the tensile strength and failure behaviour of clinched joints in cross-tensile specimens made of similar aluminium Al5457-H22 alloy sheets. The cross-tensile specimens were joined by clinching using different tool geometry parameters, and the tensile strength behaviours of the joined sheets were investigated under various tool geometry parameters. Meanwhile, the influence of the tool geometry parameters on the tensile strength was recorded experimentally. Additionally, the failure mechanism was studied under static loading conditions. As a result, macroscopic observation showed that clinched joints' pull-out failure mode with a circumferential direction crack was observed on a punch fillet radius of 0.3 mm and a punch angle of 2^o, which mainly failed due to kinked cracks through the upper sheet thickness. Thus, the cross-tensile specimen test can be an excellent method to analyse the failure behaviour of the clinched joint of aluminium sheets subjected to pure tension.

Keywords: *clinched joint, cross-tension, failure, aluminium, macroscopic*

1. Introduction

Recently, the automotive industry has been focused on reducing fuel consumption and improving the durability of their vehicles. To achieve these goals, they have started using lightweight materials to produce components, resulting in weight reductions of up to 10% in the latest vehicle models (Tekkaya et al., 2020). Joining lightweight materials can often pose a challenge. It's crucial to employ dependable techniques that preserve the material's strength and safety (Makelainen et al., 1999). Inadequate joining methods may lead to inferior performance and potential hazards. As such, joining methods are vital to guarantee the reliability and safety of lightweight materials.

In the automotive industry, various joining methods are used to join thin-walled structures such as doors, bumpers, pillars, engine compartments, etc. Several joining techniques such as brazing, rivet and clinching have been developed and implemented for lightweight materials that are dissimilar, coated, or difficult to weld (Makelainen et al., 1999). Among these techniques, clinching has emerged as a preferred method for sheet metal joining due to its merit of low cost of production. Extensive research has been conducted to develop clinching technology (Hammers, 2009; Abe et al., 2018) and as a result, numerous studies have investigated the experimental and numerical aspects of the clinching process for lightweight material (Babalo et al., 2018; De Paula et al., 2007; Lei et al., 1019).

In a joint sheet, various forces can influence its strength. These forces, such as tension, compression, shear, and peel, can impact the joint differently depending on their orientation and magnitude. As a result, various failure modes have been observed (Lei et al., 1019). Numerous research has explored how tool geometry parameters affect the strength and failure behaviours of clinched joints of metal sheets.

Cross-tensile analysis is a comprehensive technique that studies the strength and failure behaviours of sheets joined by a clinching process. This method examines the mechanical properties of the joint and analyses how the joint responds to pure tension. The cross-tension test is a crucial technique the automotive industry utilises to ascertain a vehicle's utmost load-carrying capacity in the event of collisions and assess its dependability. This method is highly favoured for its effectiveness. This research explored the tensional and failure characteristics of cross-tension samples created from aluminium alloy sheets joined by clinching under different tool geometry parameters.

2. Methods and materials

2.1. Materials characterisation

The material used for the study was Al5754-H22 aluminium alloy which are widely used in engineering materials in the automotive industry. The mechanical characterise was conducted in the University Miskolc material laboratory and the recorded material properties are shown in *Table 1*.

Table 1. *Mechanical property of Al5754-H22*

Ultimate Tensile strength (MPa)	Yield Strength (MPa)	Elongation (%)	Modulus of Elasticity (GPa)	Poisson ratio	Thickness (mm)
281	166	0.87	72	0.3	1

2.2. Test specimens

In this investigation, cross-tension specimens were made from Al5754-H22 aluminium alloys as per the EN ISO 14273 standards for cross-tension testing. The test specimen sheets' dimensions were 100 mm in length (L) and 30 mm in width (W) with a thickness of 1 mm. The cross-tension sample was joined by a clinching with different tool geometry parameters as shown in ***Hiba! A hivatkozási forrás nem található.***. The design of the cross-tension sample is presented in *Figure 1*.

Table 2. *Geometrical parameters*

Joints	Tool geometry parameters			
	Punch		Die	
	Radius (r) (mm)	Angle (α) (°)	Diameter (D) (mm)	Depth (h) (mm)
A	0.3	5	6	1.3
B	0.1	5	6	1.3
C	0.5	5	6	1.3
D	0.3	8	6	1.3
E	0.3	2	6	1.3
F	0.3	5	6	1.5
G	0.3	5	6.5	1.3

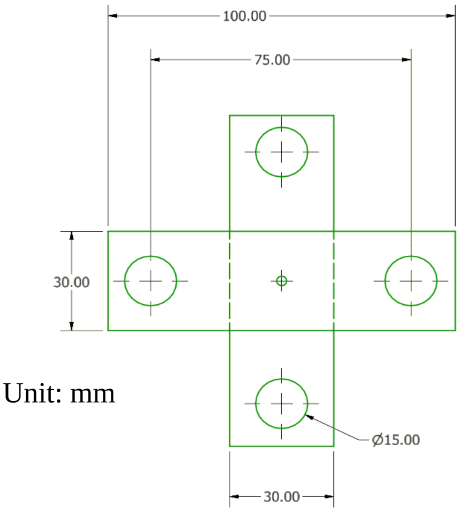


Figure 1. *Dimension of Cross tension Specimen*

As shown in *Figure 2* cross-tension tests were performed under a MTS universal electro- hydraulic testing machine with a constant strain rate of 0.02 mm/s to determine the mechanical properties of the clinched samples. Macroscopic observation analysis was carried out using digital camera to investigate the failure mode of the clinched joint of the cross-tension specimens.

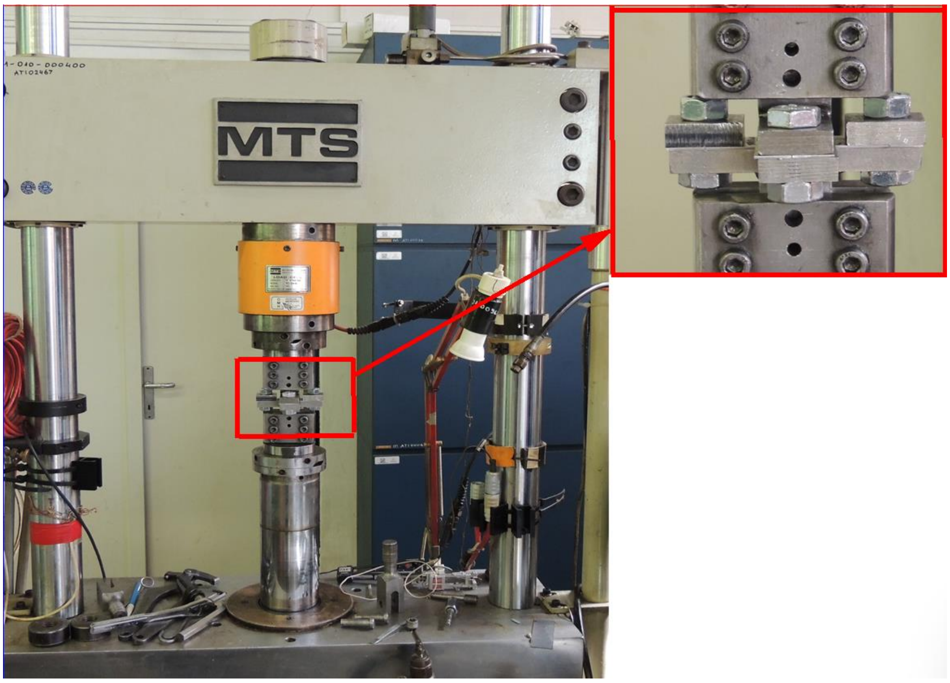


Figure 2. *Experimental setup*

3. Results and discussion

3.1. Effects of punch fillet radius on the failure mechanism

This study investigated the impact of punch fillet radius on the failure mode of cross-tension joints by experimental methods. *Figure 3* displays pure tension versus displacement for varying punch fillet radii with a punch angle of 5^0 degrees. The cross-tension joints were created with a constant punch angle and punching fillet radii of 0.5 mm, 0.3 mm, and 0.1 mm. We used five specimens for each tool process parameter and the failure mode and pure tensile strength of the clinched joints were investigated. As depicted in *Figure 3*, the maximum tensile load is decreased as the punch fillet radius increased, with the highest load occurred at a punch fillet radius of 0.1 mm. Consequently, the failure mode for three fillet radii were a pull-out failure without any crack around the button as shown in *Table 2*.

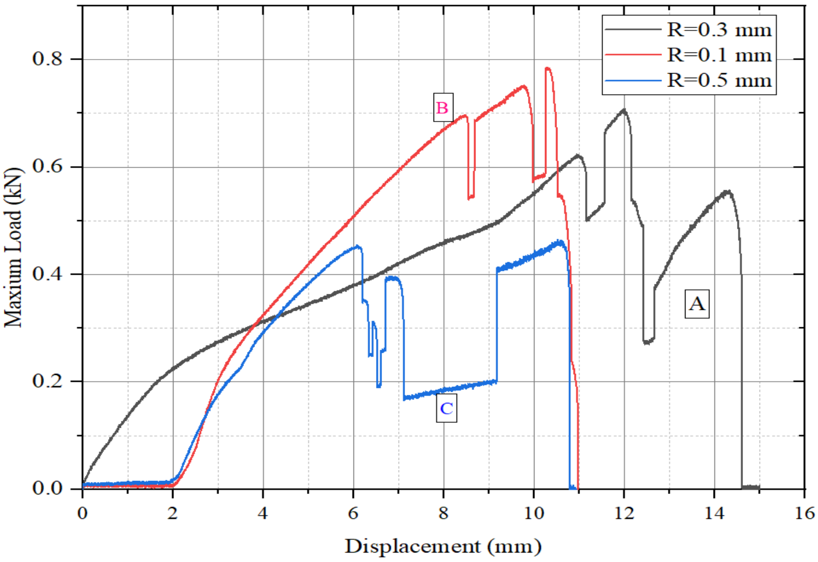
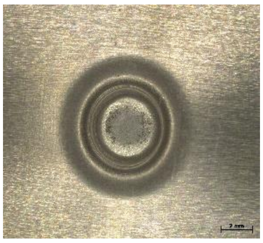
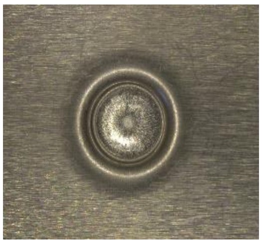
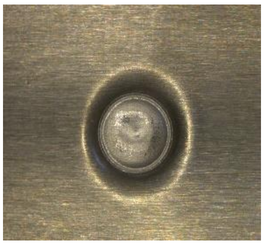


Figure 3. *Pure Tensile load- displacement with varying punch fillet radius*

Table 2. *Pure Tensile load- displacement with varying punch fillet radius*

	R = 0.5mm	*R = 0.3 mm*	*R = 0.1 mm*
Bottom sheet			

Top Sheet			

3.2. *Effects of punch angle on the failure mechanism*

The impact of punch angle on the tensile and failure behaviours of cross-tension specimens was depicted in *Figure 4* and *Table 3*, respectively. It is observed that as the punch angle increased, the pure tensile strength of the clinched joint of sheet metal decreased. This finding highlights the significance of punch angle in determining the overall strength of the joint and necessitates careful consideration in the joining of lightweight materials. Based on, the analysis of *Table 3*, it has been observed a specific type of failure occurred when the punch angles are 2^0 and 5^0 degrees. This failure mode are pull-out which happened without cracks in the circumferential joint area. On other hand, at a punch angle of 8^0, a small portion of the top button is attached to the bottom sheet.

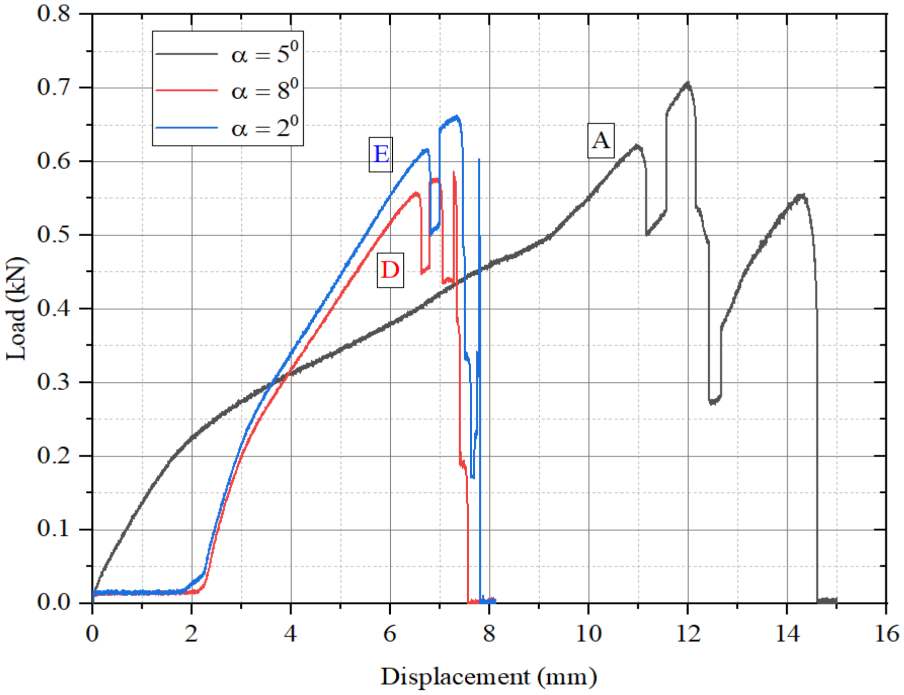
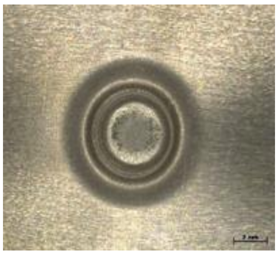
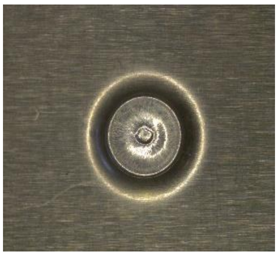
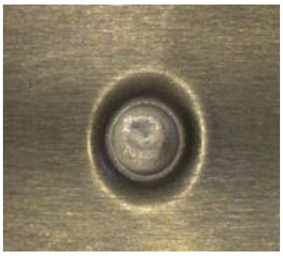


Figure 4. *Pure Tensile load- displacement with varying punch angle*

Table 3. *Macroscopic images for different punch angle*

Punch angle	8°	5°	2°
Bottom sheet			
Top sheet			

3.3. Effects of die depth and diameter on the failure mechanism

The effect of die depth on the pure tensile strength of the aluminium sheets joined by clinched is shown in *Figure 5* and *Table 4*. As shown in *Figure 5(a)*, the pure tensile strength of the clinched joint was increased as the die depth decreased. At the die depth of 1.3 mm, the pure tensile strength of 0.65 kN was recorded as twice the strength of a clinched joint of a die depth of 1.5 mm which is 0.34 kN. Additionally, as the diameter increased, the pure tensile strength of the clinched joint is decreased significantly as shown in *Figure 5(b)*. At the die diameter of 6.5 mm, the pure tensile strength of 0.3 kN was recoreded which twice less than the pure tensile strength of the 6 mm die diameter of the clinched joint. Meanwhile, the failure behaviours of the cross-tension joint are affected by both the die depth and die diameter of the clinched joint. In *Table 4*, at a depth of 1.3 mm in the joint area, a complete crack around the button is observed. Whereas, with the die diameter of 6.5 mm, the failure behaviours are initiated at the opposite side of the button. Finally, a small portion of the joint is pitted around the circumferential of the clinched joint.

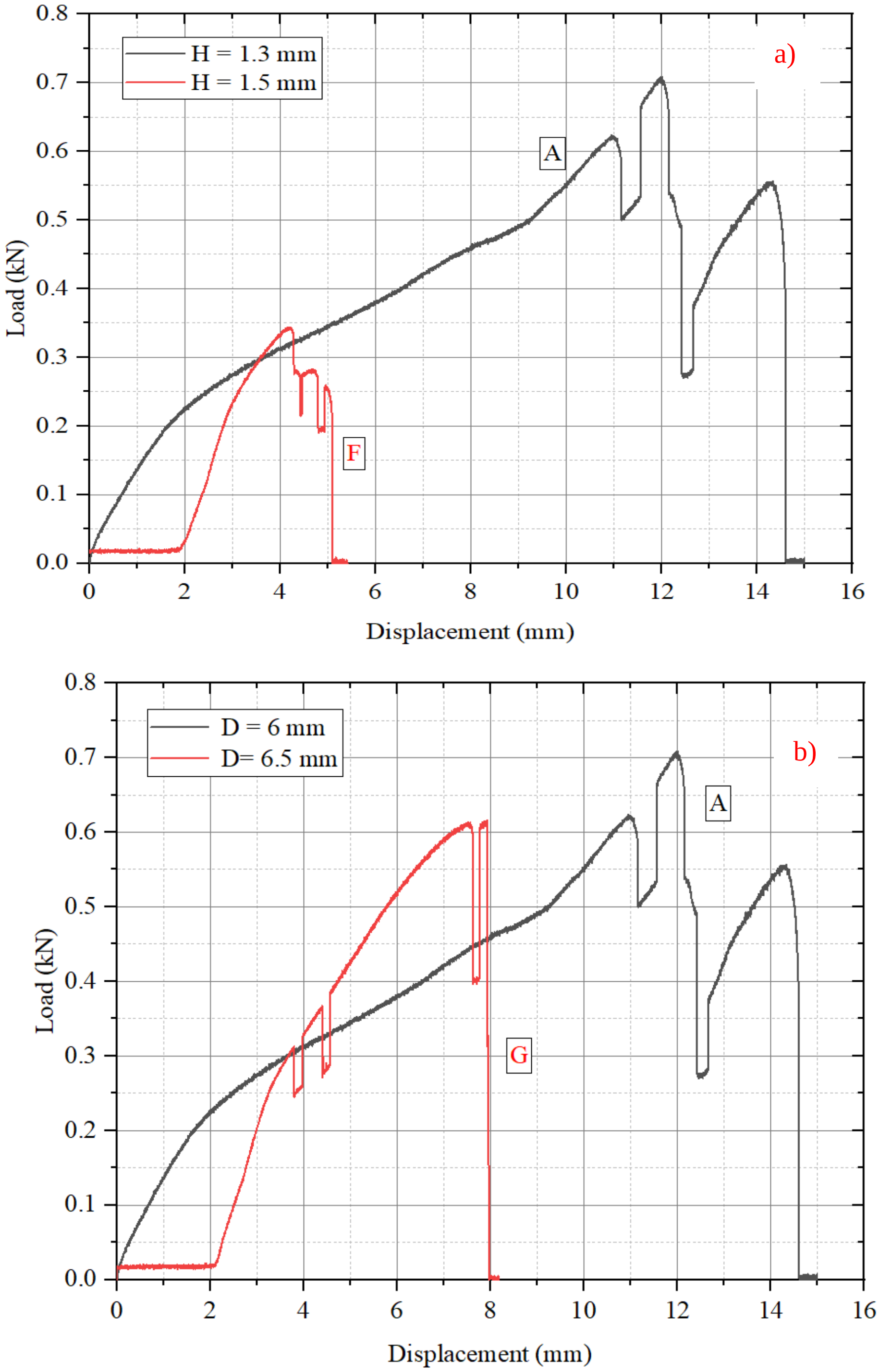
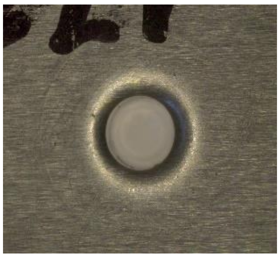
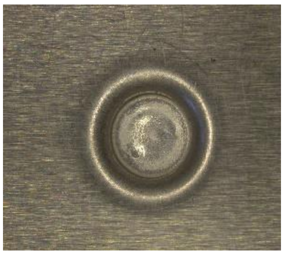


Figure 5. *Pure Tensile load- displacement a) varying die depth b) die diameter*

Table 4. *Macroscopic images for different die diameter and die depth*

	Dia = 6 mm & H = 1.3 mm	Dia = 6 mm & H = 1.5 mm	Dia = 6.5 mm & H = 1.3 mm
Bottom sheet			
Top Sheet			

4. Conclusion

This paper investigated the influence of tool geometry parameters on the tensile and failure behaviour of cross-tension aluminium alloy sheets joined by clinching. The influences tool geometry parameters on the strength of the joints were investigated using MTS universal electro- hydraulic testing machine. By macroscopic observation after the cross-tension test, the pull-out mode of failure with a circumferential direction crack was observed at a die diameter of 6 mm and die depth of 1.5 mm. On other hand, for other tool geometry parameters the failure mode was pull-out without any crack around the clinched joint. As the neck thickness is reduced, the crack is started around the circumferential of the top sheets joint. Therefore, the tool geometry parameters are vital when joining similar sheets. It can be important to optimise the tool geometry parameters to enhance the pure tensile strength. Additionally, the failure behaviours also affected by the tool geometry parameters.

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