MECHANICAL JOINING OF ALUMINIUM ALLOY SHEETS

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Modern lightweight car bodies are becoming more and more complex in comparison with previous constructions. Various materials are used in particular areas of car bodies, serving different purposes. Constructions made of aluminium alloy sheets are widely used in car body production to reduce the total car weight. However, resistance spot welding is not applicable for joining aluminium alloy sheets. Therefore, alternative joining methods are being developed. One of the alternatives is mechanical joining - clinching. The paper focuses on the evaluation of the properties of joints made by clinching. Aluminium alloy sheets EN AW 5754 of hardness H11, H22 and H24 and EN AW 6082 were used for experiments. The tensile test and a metallographic observation were used to evaluate the properties of the clinched joints. Clinching proved to be a suitable technique for joining the observed aluminium alloy sheets.

KEYWORDS

clinching, tensile test, metallography, aluminium alloy sheets

1 INTRODUCTION

Efforts to reduce car body weight and thus reduce car consumption and air emissions are constantly being pursued in the automotive industry. To achieve this goal, some lightweight materials, such as aluminium alloy, magnesium alloy and titanium alloy sheets are widely used on the automotive engineering [Chen 2017, Kaščák 2017].

The question is not only how to produce the parts, but also how to connect them into a functional structure. Resistance spot welding (RSW) is the oldest and the most common method used in the car body production. RSW is accomplished by passing electrical current through sheets via electrodes. The heat induced by the electrical current creates a molten nugget [Zhang 2006, Spišák 2011, Haghshenas 2020].

However, it is difficult or even impossible to join aluminium alloy sheets by RSW because of the natural surface oxide layer and high thermal conductivity [He 2014, Jiang 2015]. Therefore, new alternative joining methods are being developed. In recent years, mechanical joining methods such as clinching, clinch-riveting and self-piercing riveting have been utilized for joining metal sheets [Džupon 2017, Yan 2018].

Mechanical clinching is a technology that is developing rapidly, since the clinching process is very fast, simple, easy to automate and does not need additional joining parts, such as rivets. Unlike clinch-riveting and self-piercing riveting, the clinched joints do not increase the weight of the product, since no additional material is needed. Hence, the operating costs of clinching are also lower. Although the load-bearing capacity of clinched joints is lower than that of joints made by clinch-riveting, self-piercing riveting or resistance spot welding for the same material combinations, its fatigue performance is better because of the mechanical structure of the joints. In addition, the clinching process can be used to solve some problems related to joining dissimilar materials, plated materials, and multilayer material connections [Lei 2019, Chen 2020].

The aluminium alloy sheet has a good performance for plastic deformation which makes it suitable for the clinching process. Various aluminium alloy sheets have different mechanical and chemical properties, but the clinching technology can join them together quickly and effectively [Chen 2017].

The research focused on clinching aluminium alloy sheets AW 5754 as well as AW 6082 and the evaluation of properties of the resulting joints.

2 PRINCIPLE OF CLINCHING TECHNIQUE

Clinching is the one of the mechanical joining methods, that is increasingly used in the automotive industry. It is a high speed fastening method using punch and specially formed die do form a mechanical interlock between the joined materials. As the local plastic deformation of the joined materials is used to create a joint, the materials should have sufficient ductility to avoid cracking. Clinching does not require an extra fastener. A button is formed on the underside and provides an interlock between the materials [Israel 2013, Ge 2019].

The process of clinching is illustrated in Fig. 1. The process itself can be described as [Kaščák 2013]:

Phase 1: The punch and blank holder move downward, the sheets are clamped and fixed by applied force of the blank holder.

Phase 2: The sheets flow into the bottom die cavity forming a cup. No material is laterally drawn into the joint from surrounding area.

Phase 3: Finally, the thickness of the cup's bottom is reduced by upsetting and the material forced into the die groove and in lateral direction, forming the necessary undercut.

Phase 4: The punch is retracted and the clamping force relieved.

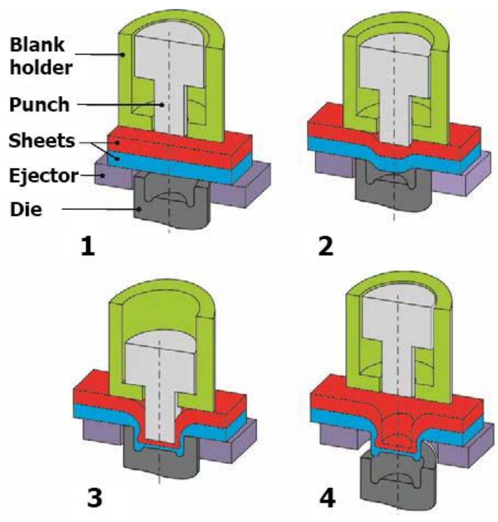

Figure 1. Principle of clinching [Kaščák 2013]

3 MATERIALS AND EXPERIMENTS

Aluminium alloy sheets were used for the experiments: three types of AW 5754 (H11, H22 and H24) with different mechanical properties and AW 6082; all with the thickness of 0.8 mm. AW 5754 sheets are non-hardenable type of Al alloy, so the H11 type is hardened by shaping processes, the H22 type is hardened by rolling then annealed to quarter hard and the H24 type is hardened by rolling and annealing to half hard. The chemical composition and the basic mechanical properties of the aluminium alloy sheets are shown in Tab. 1 and Tab. 2.

Table 1. Chemical composition of joined materials (wt%)

Material	Mg	Mn	Si	Fe	Cr	Zn	Ti
AW5754	3.6	0.5	0.4	0.4	0.3	0.2	0.15
AW6082	0.9	0.8	1.0	0.5	0.25	0.2	0.1

Table 2. Basic mechanical properties of joined materials

Material	$R_{p0.2}$ [MPa]	R_m [MPa]	A_{80} [%]
AW5754 H11	137	221	25
AW5754 H22	160	246	19
AW5754 H24	138	242	6
AW6082	313	341	12

The following tests were performed for evaluation of the properties of the joints: tension test and a metallographic observation. The samples with dimensions of 40 x 90 mm and 30 mm lapping according to standard ISO 12996 (Mechanical joining — Destructive testing of joints — Specimen dimensions and test procedure for tensile shear testing of single joints) were used for the experiments (Fig. 2).

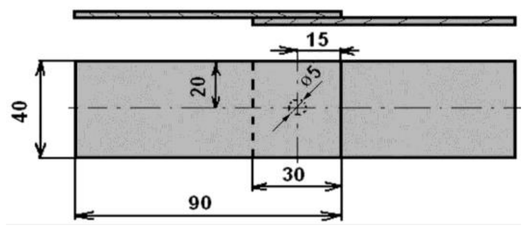

Figure 2. Dimensions of tested sample

Six samples were prepared for every aluminium alloy sheet. According to the principle of the clinching process, the cleaning of the surfaces of the joined materials was not necessary. The diameter of formed cup side was ø5 mm.

The load-bearing capacity of the clinched joints represented by maximum shearing force in failure F_{max} was evaluated according to above mentioned standard ISO 12996. A part of the evaluation of the tensile test is the assessment of the mode of joint failure as well. Typical failure modes of clinched joints are: pull-out, neck fracture, neck fracture with plastic deformation and pull-out with neck fracture – see Fig. 3.

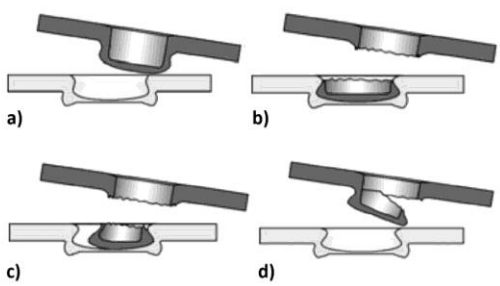

Figure 3. Failure modes of clinched joints: a) pull-out, b) neck fracture, c) neck fracture with plastic deformation and d) pull-out with neck fracture

The tensile test was carried out on the metal strength testing machine TIRAtest 2300 produced by VEB TIW Rauenstein, with the loading speed of 8 mm/min. The metallographic observation was performed on the light optical microscope Keyence VHX-5000.

4 ANALYSIS OF RESULTS

Tensile test was performed under displacement control conditions on the samples with aluminium alloy sheets to characterise the static behaviour of the clinched joints. The shearing force-displacement curves obtained from tensile test for all the tested samples with clinched joints are shown in Fig. 4-7. The clinched joints with aluminium alloy sheets AW 5754 H11 reached the value of shearing force F_s approximately of 570 N, with a displacement value approximately of 0.2 mm (Fig. 4).

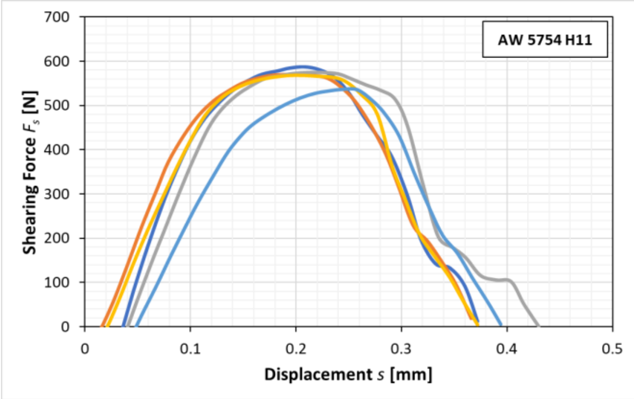

Figure 4. Shearing force-displacement curves of clinching joints for AW 5754 H11

The clinched joints with AW 5754 H22 reached the value of shearing force F_s approximately of 520 N, with a displacement value approximately of 0.18 mm (Fig. 5). When sheets AW 5754 H24 were joined, the value of shearing force F_s significantly decreased to the value approximately of 270 N, with a displacement value approximately of 0.18 mm (Fig. 6).

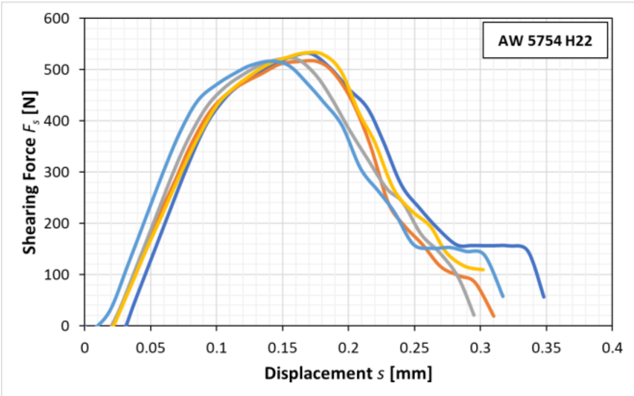

Figure 5. Shearing force-displacement curves of clinching joints for AW 5754 H22

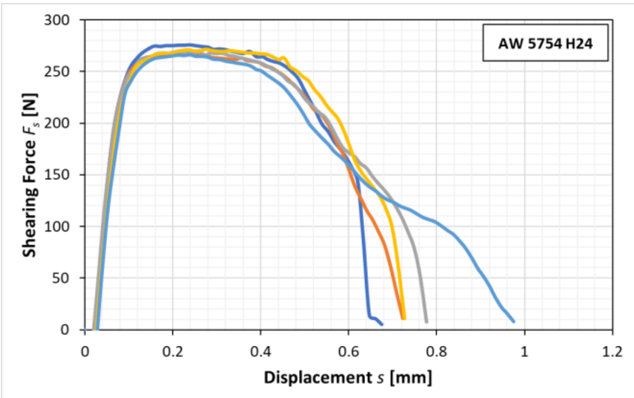

Figure 6. Shearing force-displacement curves of clinching joints for AW 5754 H24

The clinched joints with aluminium alloy sheets AW 6082 reached the highest values of shearing force F_s, approximately of 790 N. A displacement value was approximately of 0.28 mm (Fig. 7).

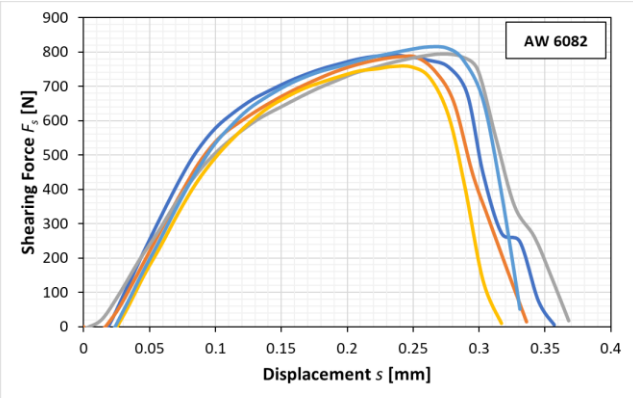

Figure 7. Shearing force-displacement curves of clinching joints for AW 6082

The maximum values of shearing force F_s of clinched joints for all tested aluminium alloy sheets are shown in Fig. 8. The highest values of shearing force F_s were obtained from the shearing curves of the tested samples with aluminium sheets AW 6082. This material is of higher alternative yield point $R_{p0.2}$ and ultimate tensile strength R_m in comparison to the other aluminium alloy sheets (Tab. 2).
On the other hand, the lowest values of shearing force F_{max} were obtained from the shearing curves of the tested samples with material AW 5754 H24. This material is of the lowest values of $R_{p0.2}$, R_m as well as elongation at fracture A_{80}. The values of F_{max} of clinched joints for materials AW 5754 H11 and H22 were approximately at the same level which corresponds to their mechanical properties, as shown in the Tab. 2.

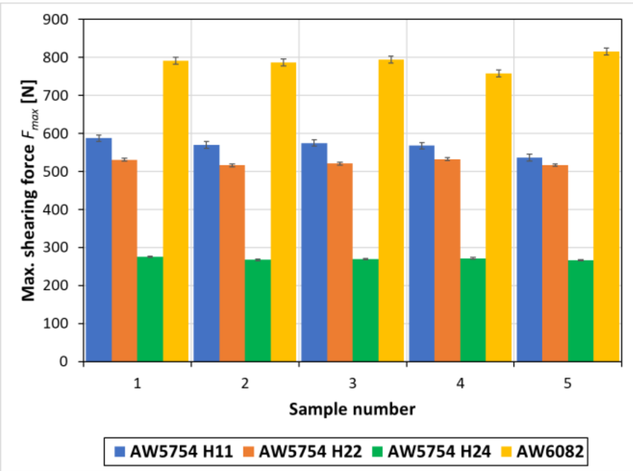

Figure 8. Maximum shearing force F_{max} of clinched joints

The same mode of joint failure – neck fracture occurred in all the tested samples (Fig. 9). The top punch sided sheet was cut off in the neck area and get locked in the die sided sheet.
The metallographic observation confirmed the formation of clinched joints of all observed aluminium alloy sheets with characteristic mechanical interlock (Fig. 10). No inner defects such as micro-voids or micro-fractures zones in the clinched joints occurred.

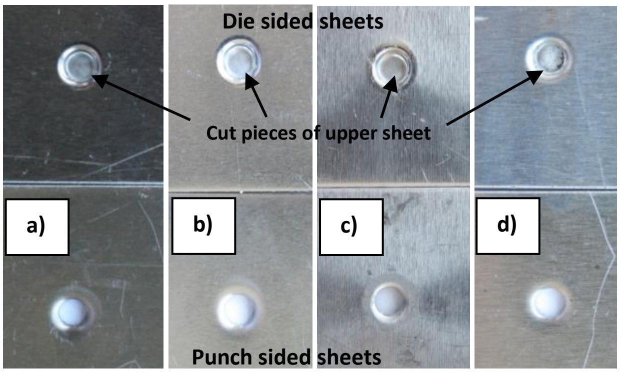

Figure 9. Clinched joints after tensile test: a) AW 5754 H11, b) AW 5754 H22, c) AW 5754 H24 and d) AW 6082

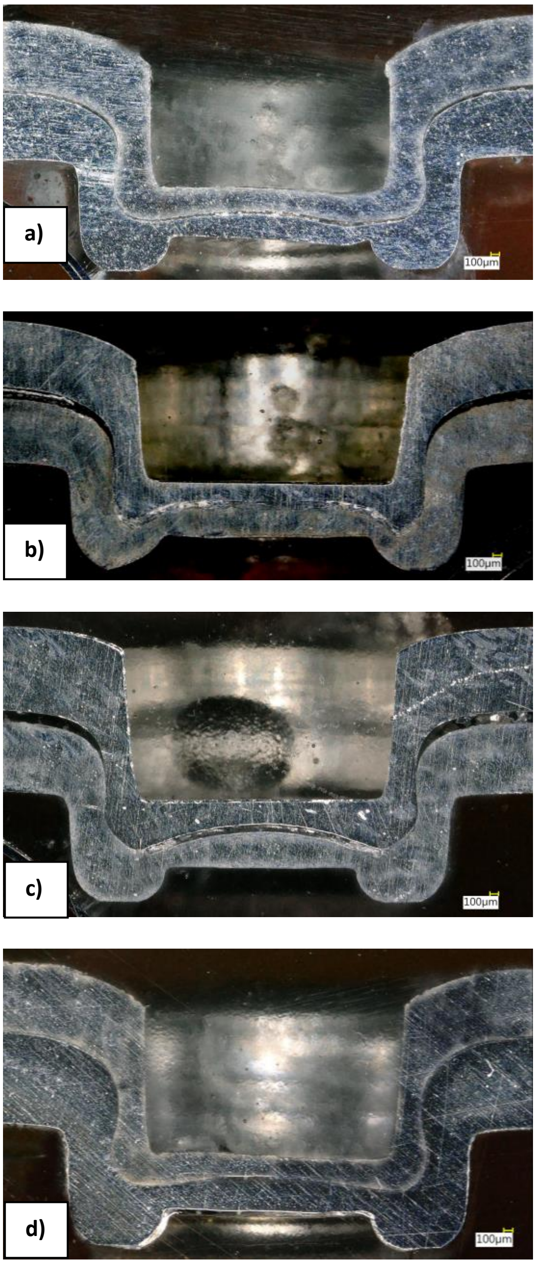

Figure 10. Macrostructure of clinched joints: a) AW 5754 H11, b) AW 5754 H22, c) AW 5754 H24 and d) AW 6082

5 CONCLUSIONS

Clinching technique is increasingly used not only in automotive industry, but also in building and electrical industries for joining various grades and thicknesses of materials. Low running costs, no need for fasteners, no thermal effects on the clinched joint and no coating breakage on joined materials are the main advantageous of this type of mechanical joining.
In this study, the clinching of aluminium alloy sheets AW 5754 (H11, H22 and H24) and AW 6082 was investigated. The shearing test confirmed the suitability of clinching process as a technique for joining observed aluminium alloy sheets. The high-quality clinched joints were created, that was confirmed by metallographic observation. No cracks or failures occurred during the clinching process.
The experiments show significant effect of mechanical properties of joined aluminium alloy sheets on the load-bearing capacity of the clinched joints.

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