CLINCHING HOT-DIP GALVANIZED STEEL COMBINED WITH ALUMINIUM ALLOY

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Abstract
Combination of steel sheets and aluminium alloys in components are widely used in various industrial areas because of their high performance. At times it is not possible to join this material combination utilizing conventional joining techniques, especially welding methods, therefore other alternative techniques are developed. One of the alternatives are mechanical clinching as a cold joining process. The paper evaluates the properties of clinched joints. The following materials utilized in automotive industry in car body production were used in the joining process: hot-dip galvanized steel sheet H220PD (thickness of 0.8 mm) and aluminium alloys EN AW 5754 (0.8 mm). The following tests were performed to evaluate the properties of the clinched joints: tension test – to determine the load bearing capacities and the force-elongation diagrams; microhardness test – to determine the changes in the materials joined by clinching; and a metallographic analysis observing the clinched joints' structures. Clinching proved to be suitable methods for joining the observed combination of hot-dip galvanized steel and aluminium alloy.

Keywords: clinching, aluminium alloys, hot-dip galvanized steel, tension test, metallography, microhardness test

1 Introduction

Currently, mass production of lightweight assemblies in automotive industry focuses on the systematic utilization of lightweight materials, such as aluminium alloys, magnesium alloys or a combination of materials, such as the combination of steel and aluminium alloys, steel and magnesium alloys [1,2]. Some research was focused on suitability of mechanical clinching of titanium sheets [3], even suitability of mechanical clinching of hybrid metal–polymer joints [4,5]. The optimization of a vehicle in terms of cost and performance can be achieved only by using different materials in different positions of the vehicle in order to exploit the peculiar characteristics of each different material optimized to specific use conditions [6]. Resistance spot welding is the most used joining technique in car body production, especially when joining galvanized steel sheets [7]. The resistance spot welding process bonds contacting metal surfaces via the heat obtained from resistance to an electrical current flow. And in comparison with other welding methods, no filler metals are used [8]. But some of these materials are difficult or even impossible to join with conventional resistance spot welding and so considerable effort has gone into developing new joining methods suitable for joining these materials [9]. Clinching is an alternative to resistance spot welding as a new, rapidly developed branch of mechanical joining

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[3]. The clinching process is a combination of drawing and forming that locks together steel sheets. A die and a punch are the active parts of clinching tool joining the sheets. The sheets are plastically deformed and the shape of the tools remains theoretically unchanged during the clinching processes. The force needed for the joining process depends on the thickness and the strength of the materials to be joined, the size of the tools and friction coefficient [10-12]. The research of the effect of sheet thickness on mechanical behaviours of joined materials used in automotive industry was published in [13-14].

The other methods of mechanical joining of various materials in car body production are clinch riveting and self-piercing riveting [15-17]. Taking into consideration that aluminium alloys are increasingly being used in the construction of car bodies, more research is needed into the joining of these alloys, or the combination of aluminium alloys and metals. The effects of process parameters on the joint characteristics of advanced high-strength steel and aluminium alloy sheet in mechanical clinching process using finite element analysis was investigated in [18]. Joining range of aluminium alloy with high-strength steel is small because of the different ductility between advanced high-strength steel and aluminium alloy. The clinching process should be optimized to join dissimilar sheet metals without defects in the mechanical clinching process [18].

Aluminium alloys are used in the industry because of their advantageous properties. They can be employed in numerous automotive structures, including chassis, powertrain and car body. Utilizing of aluminium alloys can significantly reduce the weight of an automobile body. Aluminium body structure can be designed and manufactured in two ways; one method is similar to the steel construction using stamping process and the other method involves processes of casting, extrusions, and stamping welded together, known as a space frame [19-20]. The extensive utilizing of aluminium alloys in automotive industry owing to the high strength to weight ratio requires to develop new joining processes due to the low weldability of such materials [5].

Dissimilar joining between steel and aluminium alloy has been investigated intensively but achieving satisfactory quality of these joints is the challenge including distinct differences between steels and aluminium alloys, such as thermal expansion coefficient, temperature of melting, mechanical properties and others [21-22].

The research was focused on the evaluation of properties of the clinched joints of material combination of steel H220PD and aluminium alloy EN AW 5754 (AlMg3).

2 Experimental materials and methods

Mechanical clinching is a high speed cold joining process in which two or more sheets are joined by local hemming with a punch and a die [15]. No additional elements are needed in this process. It is used for joining materials of 0.5 mm to about 3 mm in thickness, up to a total joint thickness of about 10 mm [1-4]. As the joints are made by local plastic deformation of the sheets, the materials should have sufficient ductility to avoid cracking [23]. The mechanism of clinched joint creation is shown in **Fig. 1**.

The combination of hot-dip galvanized steel sheet H220PD with the thickness of 0.8 mm with three types of aluminium alloy EN AW 5754 (H11, H22 and H24) with the thickness of 0.8 mm were analysed. The basic mechanical properties of materials used for mechanical clinching ($Rp_{0.2}$ – yield strength, Rm – ultimate tensile strength, A_{80} – elongation) are shown in **Table 1**. The chemical composition of these materials are shown in **Table 2**. The diameters of the clinching tool was ø5 mm of the die and ø3.6 mm of the punch.

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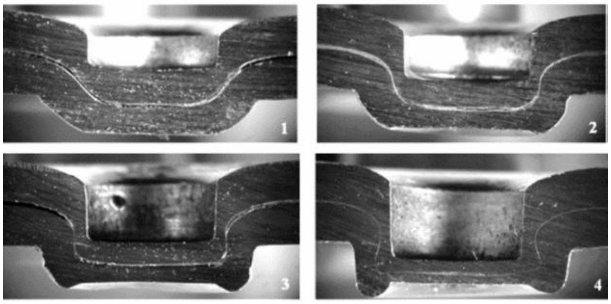


Fig. 1 The mechanism of joint creation in mechanical clinching

Table 1 Basic mechanical properties of joined materials

Material	**$Rp_{0.2}$ [MPa]**	**Rm [MPa]**	**A_{80} [%]**
H220PD	238	382	36
EN AW 5754 H11	137	221	25
EN AW 5754 H22	160	246	20
EN AW 5754 H24	138	141	6

Table 2 The local chemical analysis of joined materials [mass. %]

Material	C	Mn	Si	P	Ni	Al	Cu
H220PD	0.012	0.435	0.119	0.057	0.013	0.041	0.040
EN AW 5754	-	0.5	0.4	-	-	Balance	0.1
Material	Cr	Ti	V	Zn	Mg	Co	Fe
H220PD	0.046	0.033	0.012	-	-	0.047	Balance
EN AW 5754	0.3	0.4	-	0.2	2.6-3.6	-	0.4

Tension test, microhardnesses test and metallographic analysis were performed to evaluate the clinched joint`s properties.
The following combination of materials were chosen for clinching (P-punch side of specimen, D-die side of specimen):

- $H220PD^P$ + AW 5754 $H11^D$, AW 5754 $H11^P$ + H220PD ^{D}, double joints $H220PD^P$ + AW 5754 $H11^D$ and AW 5754 $H11^P$ + H220PD ^{D}
- $H220PD^P$ + AW 5754 $H22^D$, AW 5754 $H22^P$ + H220PD ^{D}, double joints $H220PD^P$ + AW 5754 $H22^D$ and AW 5754 $H22^P$ + H220PD ^{D}
- $H220PD^P$ + AW 5754 $H24^D$, AW 5754 $H24^P$ + H220PD ^{D}, double joints $H220PD^P$ + AW 5754 $H24^D$ and AW 5754 $H24^P$ + H220PD ^{D}

The dimension of the specimens were given by STN 05 1122 standard. Our previous research [19] showed that clinched joints can reach about 40-50% of the load bearing capacity of the joints made by resistance spot welding. Therefore, for each combination of observed materials we decided to test both single (**Fig. 2**) and double clinched joints (**Fig. 3**). Since we examined the possibility of joining steel H220PD and aluminium alloy AlMg3, we also observed the influence of position of the joined sheets relative to the punch and die on the load bearing capacity of the clinched joints. Ten specimens were prepared for every combination of sheets. The surfaces of the specimens was not cleaned before mechanical clinching, because it is cold joining process and it was not necessary.

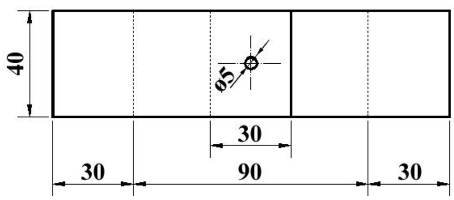


Fig. 2 Specimen dimensions with one clinched joint for the tension test

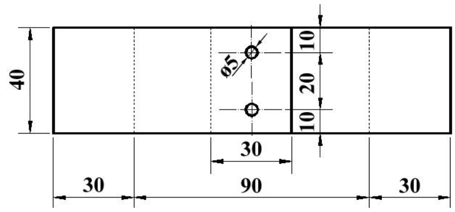


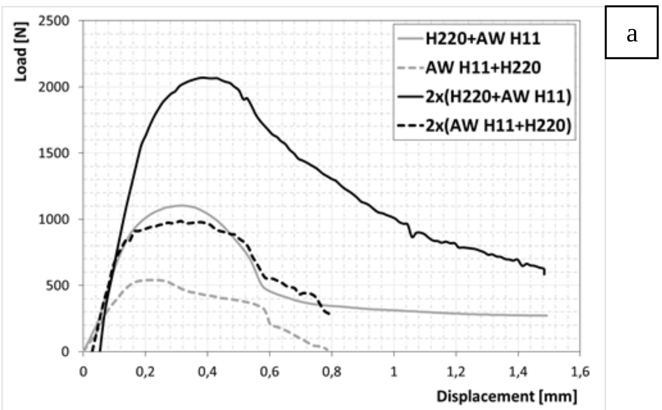
Fig. 3 Specimen dimensions with two clinched joints for the tension test

The load bearing capacities of the clinched joints were obtained from static tensile test according to above mentioned standard STN 05 1122 – Tension test of spot welded joints. The tension test was used for measuring the maximum force Fmax until failure of the joints occurred. The 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.

Further tests for the quality evaluation of clinched joints included: the metallographic analysis and microhardnesses analysis. The microhardness analysis according to STN EN ISO 6507-1:2006 standard is frequently used for determination of hardness of small items and identification of individual phases in the metal structure. The principle of measurement is identical to Vickers hardness test, but with considerably smaller load. In this experiment, the applied load was 980 mN in the range of 10-15 s.

3 Results and discussion

The tension tests were performed to characterize the static behaviour of the clinched joints of observed materials. The maximum values of load bearing capacity obtained from tension test are shown in the load-displacement curves in **Fig. 4**. The curve forms indicate the behaviour of the clinched joints under load. The lowest values of load bearing capacity were measured on the specimens, where aluminium alloy was positioned on the punch side of the tool.



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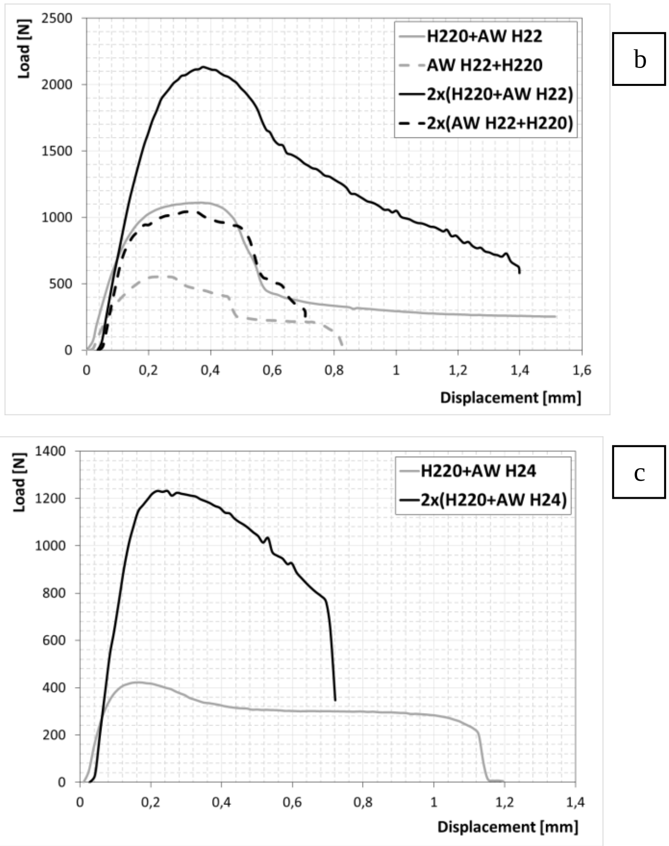

Fig. 4 Load-displacement curves of clinched joints of combination: a) H220PD and AW 5754 H11, b) H220PD and AW 5754 H22 and c) H220PD and AW 5754 H24

The load bearing capacity of the specimens with AW 5754 H24 positioned on punch side of the tool and steel H220 PD positioned on the die side were not measured, because the clinched joints were not successfully created. The mechanical joining failed during clinching process in both types of these specimens - single clinched joint and double clinched joint.

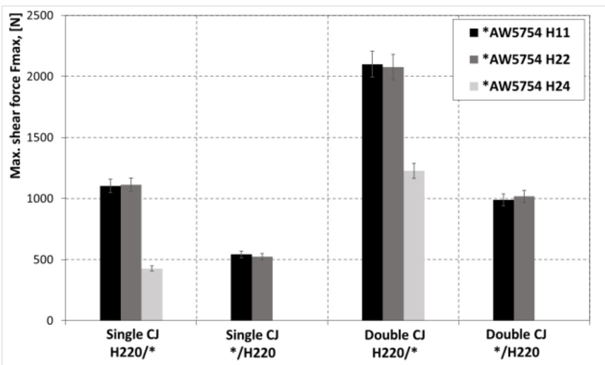

Fig. 5 Influence of position of H220PD steel sheet in the clinched joint (CJ) on the average value of maximum shear force for single and double clinched joints

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All observed specimens with steel H220PD oriented on the punch side of tool had higher values of load bearing capacity; in specimens with single clinched joint and double clinched joints as well. The average values of load bearing capacity of observed specimens are shown in **Fig. 5**.
In the specimens where steel sheet H220PD was positioned on the punch side, a loosening of the joint occurred after quite bigger displacements. The part of upper sheet in the joint was deformed and then the failure occurred in the interlocking area (**Fig. 6b, Fig. 7b and Fig. 8b**). In the specimens with aluminium alloy positioned on the punch side, the failure occurred directly in the interlocking area with a part of the upper sheet (AW5754) stayed locked in the clinched joint (**Fig. 6c, Fig. 7c**). As shown in **Fig. 8c**, there is no failure after tensile test in the interlocking area, because the clinching joint was not successfully created.

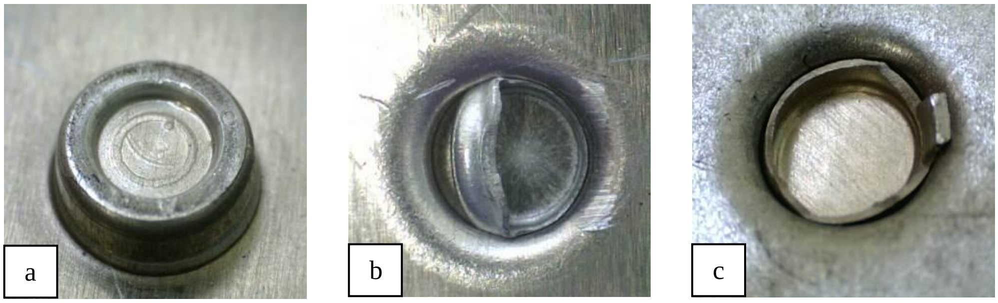

Fig. 6 Clinched joints of combination H220PD and AW5754 H11 after tension test a) die side of H220PD, b) failure in H220PD^{P} and c) failure in AW5754 H11^{P}

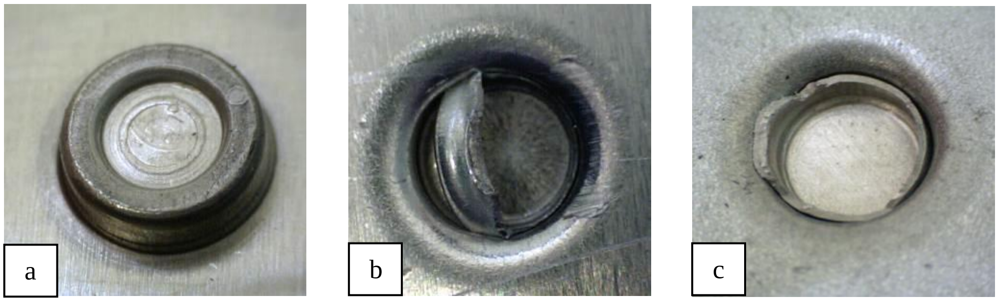

Fig. 7 Clinched joints of combination H220PD and AW5754 H22 after tension test a) die side of H220PD, b) failure in H220PD^{P} and c) failure in AW5754 H22^{P}

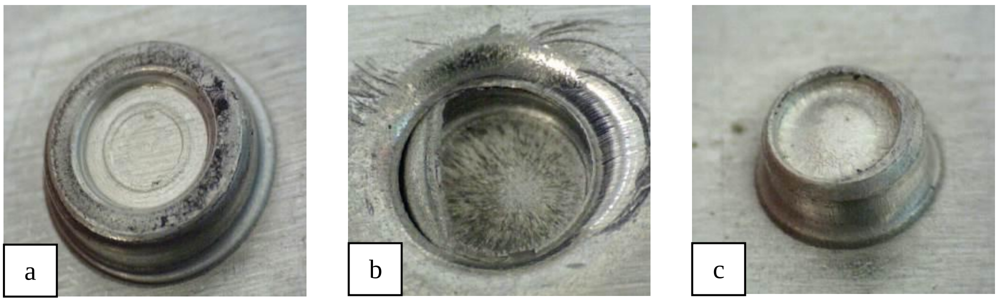

Fig. 8 Clinched joints of combination H220PD and AW5754 H24 after tension test a) die side of H220PD, b) failure in H220PD^{P} and c) pulled AW5754 H24^{P} from clinched joint

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Metallographical analysis confirmed the suitability of mechanical clinching as a method for joining material combinations of H220PD steel with the observed aluminium alloys. No cracks or failures occurred during the joining process, except above mentioned combination of AW 5754 H24 and H220PD. The differences among specimens were observed mainly in the interlocking area on the upper sheet of the joint (**Fig. 9**).

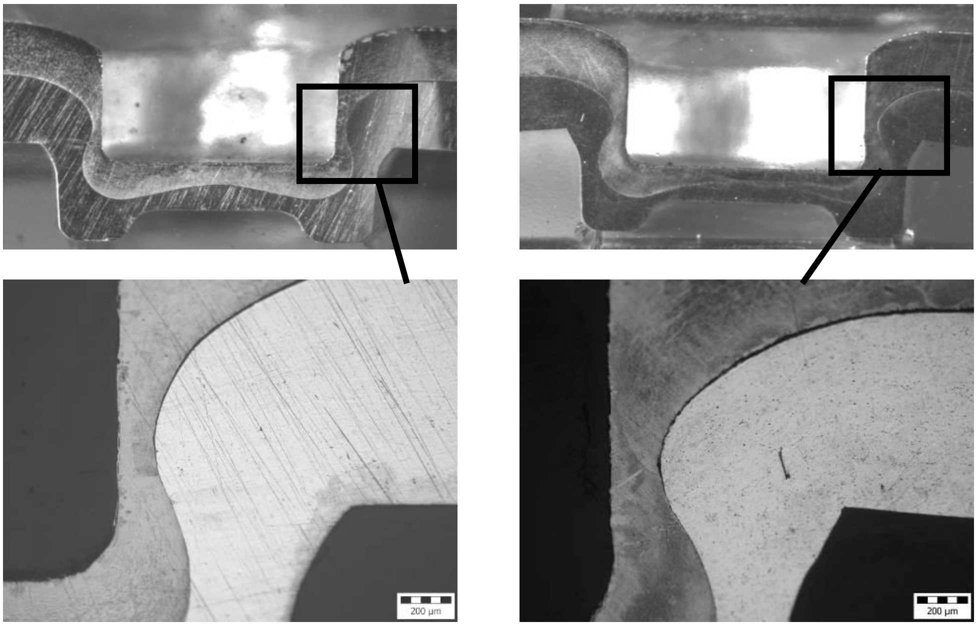

Fig. 9 Interlocking areas of the clinched joints: a) H220PD^{P}+AW5754 H11^{D}; b) H220PD^{P}+AW5754 H22^{D} (P-punch side of specimen, D-die side of specimen)

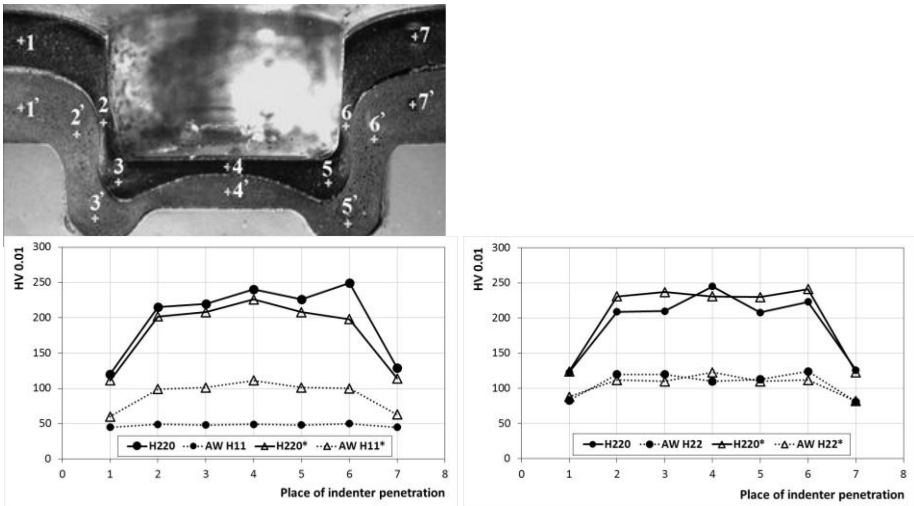

Fig. 10 Microhardness values of the clinched joints: a) marked area of indenter penetration in the test, b) H220PD steel and AW 5754 H11, c) H220PD steel and AW 5754 H22 (*specimens with H220PD oriented on the die side of tool)

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Microhardness measurements of the specimens with material combination of H220PD and AW 5754 H11 and H220PD and AW 5754 H22 are presented in **Fig. 10**. The measurements show the changes in the areas of clinched joints. The higher values of microhardness were measured on the hot-dip galvanized steel sheet H220PD in the interlocking area (points 2 and 6) as well as at the bottom of the clinched joint (point 4). The microhardness values are in accordance with the maximum deformation and the largest hardening of joined materials in these areas of clinched joint.

Conclusions

The emerging requirements of higher structural performance with lower weight, energy consumption but higher passenger safety in automotive industry are stimulating the rapid development of lighweight structures. Increasing amount of aluminium alloys utilized in car body production lead not only to the question, how to create a part from aluminium alloy, but also how to join such parts, especially when combination of steel and aluminium alloy is required. The method of mechanical clinching is suitable for joining the tested combination. The main benefits of this method include low operating costs, no need of rivets, high joining speed, higher corrosion resistance of galvanized steel sheets in comparison to welding, no thermal effects on the clinch area, and no need for pre-treatment of surface. The present investigation was aimed at analysing the possibility of joining the combination of hot-dip galvanized steel and aluminium alloy AlMg3. Based on the performed experiments, the following results can be stated:

- The load bearing capacities of the samples were sufficient and the metallographical analysis confirmed no occurrence of cracks or failures in the area of joints during joining processes, with the exception of samples of aluminium alloy AW 5754 H24 positioned towards the punch. In this case, the joint was not formed.
- The position of the joined sheets relative to the punch and the die of the joining tool plays an important role in the resulting load bearing capacity in the observed combination of H220PD steel sheet and aluminium alloy.
- When the materials were combined so that the steel H220PD faced the punch, the measured load bearing capacity was almost double compared to the samples in which the aluminium alloy faced the punch.
- The highest values of microhardness were measured in the areas with the most significant thinning of the joined materials as well as in the areas with the most significant hardening of joined materials in both types of joining.

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