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PRODUCTION DEVELOPMENT OF AA 5754-H111 LAP JOINT BY FRICTION STIR WELDING

RAZVOJ IZRADE PREKLOPNOG SPOJA AA 5754-H111 POSTUPKOM ZAVARIVANJA TRENJEM SA MEŠANJEM

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Keywords
- friction stir welding
- lap joint
- aluminium alloy
- microhardness
- visual inspection

Abstract

The paper presents the results of research into the possibility of aluminium alloy lap joint production. The friction stir welding process is used to weld two aluminium alloy 5754-H111 plates into a lap joint. Friction stir welding ensures material joining without melting and use of additional material. By correctly selecting technological parameters of the welding process, the lap joint is successfully produced. Visual inspection of the face and root side of the weld metal is presented in the paper. Microhardness $HV_{0.15}$ *was measured at the face of lap joint as well as through the cross section. Hardness is measured to include all structural zones of the joint: base metal, heat affected zone, thermo-mechanically affected zone, and nugget. As expected, the microhardness of the weld metal has reached the microhardness value of the base metal.*

Ključne reči
- zavarivanje trenjem sa mešanjem
- preklopni spoj
- legura aluminijuma
- mikrotvrdoća
- vizualna kontrola

Izvod

U radu su prikazani rezultati istraživanja mogućnosti izrade preklopnog spoja od legure aluminijuma. Proces zavarivanja trenjem sa mešanjem je korišćen za zavarivanje dve ploče od legure aluminijuma 5754-H111 u preklopni spoj. Zavarivanje trenjem sa mešanjem obezbeđuje spajanje materijala bez topljenja i upotrebe dodatnog materijala. Pravilnim odabirom tehnoloških parametara procesa zavarivanja, uspešno je proizveden preklopni spoj. U radu je prikazana vizuelna kontrola lica i korene strane metala šava. Izmerena je mikrotvrdoća $HV_{0.15}$ *na licu spoja, kao i kroz poprečni presek spoja. Tvrdoća je merena tako da se obuhvate sve strukturne zone spoja: osnovni materijal, zona uticaja toplote, zona termomehaničkog uticaja i grumen. Kao što je i očekivano, mikrotvrdoća metala šava dostigla je vrednost mikrotvrdoće osnovnog materijala.*

INTRODUCTION

Aluminium alloys are widely used in the aircraft industry, rail vehicles, automotive industry, military industry, shipbuilding and production of process equipment. These materials have lower ductility compared to steel and are often difficult to weld or are even non-weldable. In recent years, the friction stir welding (FSW) process has been proposed and applied in order to obtain good mechanical and technological characteristics of joints, including analysis of heat input effects, /1-5/.

Friction stir welding is a solid-state welding technology that provides the joining of materials without melting and without the use of additional materials. Joining of material is performed by a combined action of heat and mechanical work. Tool and base material remain in solid-state, while in the welding zone the base material is slightly softened, i.e., plastic-state. This is the result of heat generated by friction between the tool and base material. Temperatures that occur during the process do not exceed the melting point of the base material and reach about 80 % of the melting point. The welding temperature for aluminium alloys is about 500 °C, /6-10/.

A lap joint produced by FSW process obtained by joining two or more working plates is discussed in /11/. Lap joints are widely used in the assembly of parts and products of aeronautic industries. Lightweight alloys and in particular aluminium ones are often called non-weldable materials since conventional welding processes, such as GTAW or even advanced ones, such as laser welding, produce joints characterised by tensile properties at the level of 60 % or even 50 % of the parent material. It should be observed that such decrease in joint strength is fundamentally due to metallurgical aspects, namely the increase of the average grain size observed in the melted material is up to 10 times with respect to the parent material. Figure 1 shows a simplified example of the welding tool position and working plates for the production of a lap joint by FSW process, /13/.

A lap joint was successfully produced by choosing the optimal technological parameters of the welding process. Visual inspection of the face and root of the weld metal was performed after welding. Microhardness $HV_{0.15}$ testing was measured on the face of the lap joint as well as through the cross-section of the joint which is normal to the welding direction. The microhardness was measured to include all structural zones of the joint: the base metal, the heat-affected zone (HAZ), the thermo-mechanically affected zone and the nugget.

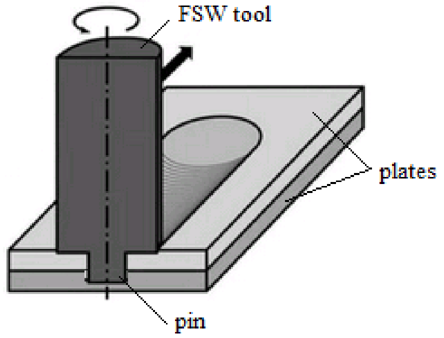

Figure 1. Simplified representation of the FSW lap joint, /12/.

EXPERIMENTAL WELDING

The work plates to be welded are made of aluminium alloy 5754-H111. The chemical composition is shown in Table 1. This aluminium alloy has medium strength, good corrosion resistance, represents a typical alloy of Al-Mg series of alloys. The basic mechanical properties are as follows: $R_{p0.2}$ = 80 MPa, R_m = 190-240 MPa, HB 52, A = 18 %.

Table 3. Chemical composition of AA 5754-H111 /6/.

%	Mg	Mn	Si	Cu	Fe	Zn	Ti	Cr
min.	2.6	0	0	0	0	0	0	0
max.	3.6	0.5	0.4	0.1	0.4	0.2	0.015	0.3

Welding was done on a tool milling machine. The geometry and material selection of welding tools, clamping tool, and backing plate were made on the basis of theoretical knowledge and acquired practical experience /11/. The special tool used for welding is made of tool steel. The pin of the tool is of conical shape and has an engraved round coil that encourages better mixing and secondary flow of the softened material. The clamping tool is made of stainless steel. The experimental setup, i.e., the clamped working plates on the worktable of the milling machine and the position of the welding tool are given in Fig. 2.

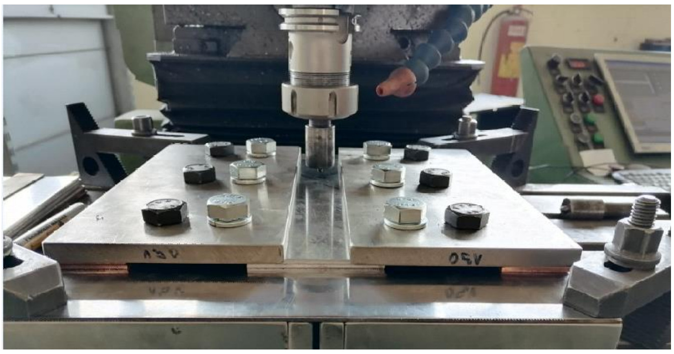
Figure 2. The experimental setup.

The lap joint is produced by welding two plates in one pass of the tool. The dimensions of the working plates are 80×200×3 mm. The length of the produced weld metal is 170 mm. The technological process parameters for lap joint are given in Table 2, while the process included:

– selection of welding tool, special clamping tool, and welding machine,
– placing the tool in the machine main spindle and setting the tool tilt angle, placing the clamping tool on the worktable of the machine, positioning and clamping the backing and working plates in the clamping tool,
– setting the rotation speed of the tool and presetting the tool on the machine (length correction of the tool),
– with the given speed of penetration of the tool, raising the worktable to contact with the tool (Fig. 1),
– penetration of tool into working plates until the moment of contact of the upper surface of the working plate with the face of the tool with the specified penetration speed and depth of immersion of the tool (duration 90 s),
– keeping the rotating tool in that position for 10 s,
– setting the welding speed (translational motion of the machine's worktable, duration 11 min., Fig. 3),
– interruption of translational motion,
– vertical movement of the machine table (tool extraction from the welded joint, Fig. 4),
– stopping the rotational motion of the tool and removing the welded lap joint from the clamping tool.

Table 2. Process parameters for lap joint.

v_{rot}	v_w	Tool tilt-angle α	Tool-plunge depth
950 min^{-1}	15 mm/min	0 °	5.6 mm

Figure 3 shows the tool movement, i.e., the worktable of the machine. Speed of translational motion is called the welding speed, v_w = 15 mm/min. The tool rotates at a constant speed during this motion with v_{rot} = 950 min^{-1}. The vertical movement of the machine table (tool extraction from the welded joint) is shown in Fig. 4.


Figure 3. Welding process.


Figure 4. Tool extraction from the welded joint.

VISUAL EXAMINATION AND DISCUSSION

Non-destructive testing of the lap joint was done by visual inspection according to SRPS EN-970 standard, /14/. A visual inspection of the face and root side of the weld metal was performed. Figure 5 shows the smooth surface of the weld metal face, and the presence of material flash, as well as the hole due to tool exiting from the working plates material. The flash is a phenomenon that with a proper choice of tools can be minimised but not eliminated.

Visual inspection of the root side of the weld metal clearly identifies the welding zone under the tool face, Fig. 6. Also, the surface of the material under the tool pin is expressed. Considering that the height of the pin is 5.5 mm, we chose that the penetration of the tool into the plate material should be 5.6 mm. The total height of the worktops is 6 mm and we originally thought that this phenomenon would not occur. For future welding, we can use a slightly larger thickness of work plates, with the same technological parameters.

Figure 6. The face of weld metal.

Figure 7. The root side of the lap joint.

MICROHARDNESS MEASUREMENTS

The Vickers method was used to measure microhardness. Measurements were performed on the ‘PMT 3’ microhardness testing machine. Samples’ surfaces were ground and polished before measurement. All tested samples were prepared in the same way. The measurement procedure is performed by pressing a diamond pyramid into the surface of the sample. An indentation force of 1.4709975 N (150 gr.) was used. Standards defining Vickers hardness and the microhardness measurement are EN ISO 6507-1:2018 or ASTM E384, /15/.

Microhardness measurement was done at two places. It was measured to include all structural zones of the joint: the base metal (BM), the heat-affected zone (HAZ), thermo-mechanically affected zone (TMAZ), and the nugget. First, the microhardness was measured on the surface normal to the face and root, and in the cross-section of the weld metal. Microhardness was measured close to the weld metal surface, at a distance of 1.5 mm from the weld metal surface. Then the microhardness was measured on the surface of the lap joint where the weld metal face is. Figure 8 shows measurement locations in the lap joint cross-section. Comparative values of microhardness measured in the cross-section (blue) and on the face side of the weld metal (red) are shown in Fig. 9.

Figure 8. Measurement locations on the surface normal to the face and root side of weld metal.

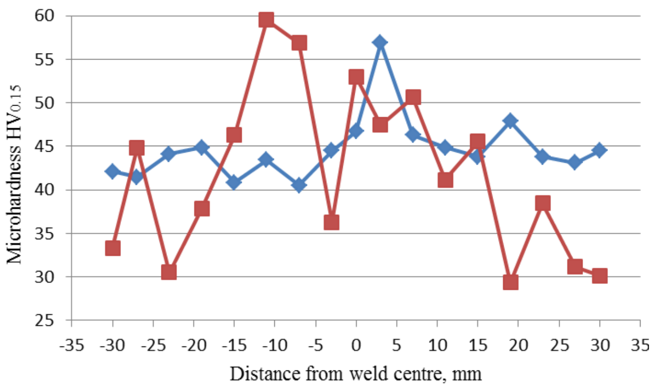

Figure 9. Microhardness distribution at weld face and root side.

Measuring the microhardness in the nugget zone makes sense only in the first case (blue line), indicating the highest hardness value in nugget zone and minimum values in HAZ, as expected, because increasing temperature leads to the increase of grain size in the structure. This hardness change in the nugget is due to recrystallization and fragmentation of structures.

In the second case, when the hardness is measured on the face of the weld metal (red line), high hardness values can be seen just in the zone below the tool shoulder of diameter 25 mm (in the range from -12.5 to 12.5 mm), and that is actually the weld metal zone. There, the working plates material is well mixed and under the influence of the tool shoulder.

The appearance of the impression after Vickers microhardness test is shown in Fig. 10.

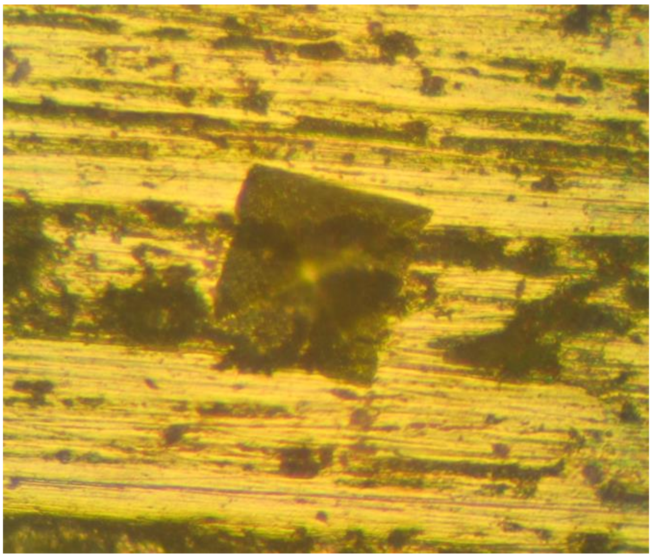

Figure 10. Impression on the sample after measuring the microhardness by Vickers method.

CONCLUSION

The selection of welding parameters established the successful production a lap joint by friction stir welding. The tool milling machine was simply adapted for this welding process. Visual examination did not detect the presence of defects, but further macroscopic examination is necessary. Presence of material flash formation can be removed by fine post-processing.

The highest microhardness value is present in the nugget zone. This change in hardness is expected due to recrystallization and fragmentation of structural grain. The minimum hardness values are found in HAZ, as expected, because increase in temperature leads to an increase in the grain size of the structure.

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