Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 13 (2018) 424–429

Structural Integrity Procedia

www.elsevier.com/locate/procedia

ECF22 - Loading and Environmental effects on Structural Integrity

Microhardness and Macrostructures of Friction Stir Welded T-joints

Andrijana Đurđević[a], Aleksandar Sedmak[b], Aleksandar Živković[c], Đorđe Đurđević[a], Milan Marković[a], Miodrag Milčić[d]

[a]*Tehnikum Taurunum - Collage of Applied Engineering Studies, 11080 Belgrade, Serbia*
[b]*Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*
[c] *Goša FOM Company, 11420 Smederevska Palanka, Serbia*
[d]*Faculty of Mechanical Engineering, 18000 Niš, Serbia*

Abstract

The results of research regarding the friction stir welding process of T-joints are presented in this paper. Experimental welding of two and three aluminium plates were performed in order to obtain T-joints. Microhardness measuring and macrostructural examinations of welded T-joints of aluminium alloy are processed. All phases of the welding process are monitored by visual control.

Peer-review under responsibility of the ECF22 organizers.

Keywords: Friction stir welding, aluminium alloy 5754-H111, T-joints, microhardness, macrostructures

1. INTRODUCTION

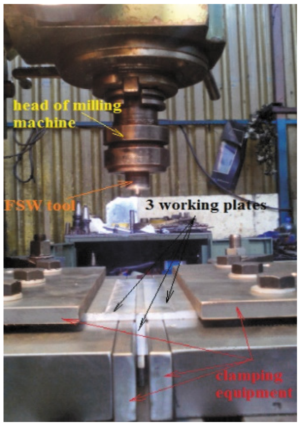
T-joints of aluminum alloys are used in many industries: automotive, aerospace, shipbuilding, etc. Aluminum has good corrosion resistance. The main role of T-joints is to increase the rigidity of structures. But aluminum alloys are hardly welded by conventional welding processes. The poor solidification microstructure and porosity in the fusion zone which leads to the loss in mechanical properties as compared to the base material make these alloys generally classified as nonweldable alloys. Friction stir welding (FSW) was found to be a very successful approach to weld aluminium alloys in a solid-state joining process. [1-3]

The friction stir welding of the T-joint is done in the following way: two or three working plates are rigidly clamped on the machine table. Welding machines can be specialized, figure 1.a and it is very expensive. Also, welding can be done on milling machine, figure 2.b. The welding tool consists of three main parts: shoulder, top of shoulder and probe. The probe is the part of welding tool that passes entirely through the working plates to and the tool shoulder is

2452-3216 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the ECF22 organizers.
10.1016/j.prostr.2018.12.071

the surface of the tool that contacts the working plates surfaces during welding. The tool capitalizes two primary functions, heating of work piece and movement of material to produce the joint. Heat generated by friction between the tool and the work piece causes softening of the material being welded due to the localized heating. Also, severe plastic deformation occurs in the area around the rotating tool. As the tool is translated along the welding direction the flow of the plasticised metal occurs and the material transported from the front of the tool to the trailing edge where it is forged into a joint. As a result of this process a solid state weld joint is produced [6].

a)



b)

Figure 1. a) ESAB SuperStir, working space 6x16m [4], b) Milling machine

The welding parameters that affect the quality of welded joints and control of FSW process are: the speed of rotation of the tool, welding speed, vertical force to work materials, tool tilt-angle, tool-plunge depth and tool geometry [5]. Experimental welding of aluminium plates was performed, and welded T-joints were experimentally examined to demonstrate the effect of the welding process parameters on the macrostructure and microhardness values.

2. EXPERIMENTAL WELDING

Experimental welding was performed on milling machine, which set up is shown in figure 1.b. T-joint was produced by welding two or three plates. The following technological process parameters were varied in order to obtain T-joints without defects: transverse (welding) speed, the speed of rotation of the tool, tool-plunge depth in the working material and tool tilt-angle.

The special tool used for welding plates of AA5754-H111 was of material H13 tool steel. Welding tool has tipical geometry, cylindrical shoulder and tapered probe with a cone angle of 20°. Probe was etched curvaceous right coil whose tilt is 5°, which promotes better mixing and secondary flow of softened material. Hight of probe was 5.,5 mm. Diameter of shoulder was 25 mm. Top of shoulder is concave, with a tank. Photo of tool with the basic elements is shown in figure 2. Figure 3 shows the construction of clamping tool. Material of clamping tool is stainless steel 1.430, and its mechanical properties are $R_{p0,2}$=280÷300 MPa and R_m =580÷600 MPa according to EN 10028-7/2008 [6]. Mechanical properties and chemical composition of AA5754-H111 are shown in tables 1. and 2. respectively.

Table 1.Chemical composition of aluminium working plates [7]

EN AW 5754-H111	Mg	Si	Mn	Cu	Fe	Zn	Ti	Cr
%	2,6-3.6	0-0,4	0-0,5	0-0,1	0-0,4	0-0,2	0-0,015	0-0,3

Table 2.Mechanical properties aluminium working plates [8]

EN AW 5754-H111	Yield stress $R_{p\,0,2}$ [MPa]	Tensile strength R_m [MPa]	Elongation A [%]	Brinell hardness HB
Value	80	190-240	18	52

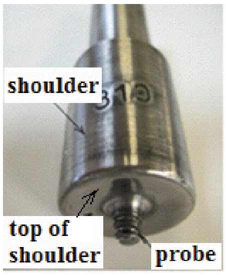


Figure 2. Photo of FSW tool

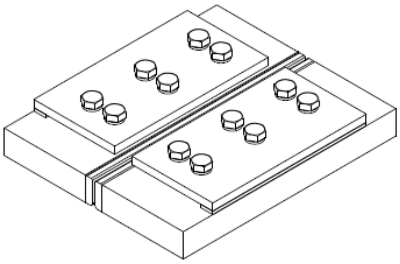


Figure 3. Construction of clamping tool used for FSW of T-joints

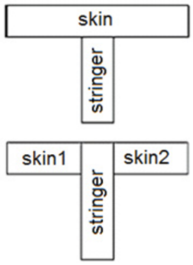


Figure 4. Position of working plates

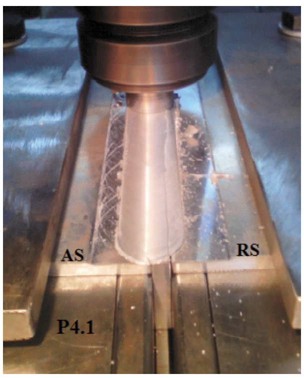
The dimensions of the working plates were 32x200x5 mm and 65x200x5 mm. The length of each weld metal is 170 mm. Three T-joints were welded and tested, and their labels are: P 3.1, P 4.1 and P 4.2. T-joints are welded using the same welding speed, rotation speed of tool and tool tilt angle. The following process parameters are varied: tool plunge depth and radius of backing plates. The number of working plates is two or three and their positions are shown in figure 4. The process parameters used for experimental welding of each T-joint are given in table 3.

Table 3. Values of process parameters for T-joints

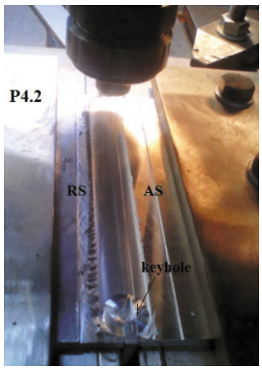
T-joint	Welding speed $v_{wel}\left[\frac{mm}{min}\right]$	Speed of rotation $v_{rot}\left[rpm\right]$	Tool tilt angle α [°]	Tool plunge depth $a\left[mm\right]$	Radius of backing plates $r\left[mm\right]$
P 3.1	950	27	1	5,8	2
P 4.1	950	27	1	5,8	4
P 4.2	950	27	1	5,6	4

P 3.1 T-joint was obtained by welding two working plates, dimensions 65x200x5 mm, with one tool movement, figure 5.a. First, the tool with constant rotation speed penetrates into the material of working plates and then moves in the direction of symmetry axis of the T-joint. P 4.1 obtained by welding three working plates dimensions 32x200x5 mm, with two movement of welding tool. First, rotating welding tool passes along the joint line on the advancing side of weld metal, and then the tool goes out from the joint leaving a keyhole. Then the welding tool again comes to the beginning of the joint, and moves along the joint line on the retreating side of weld metal. Figure 5.b shows the welding process when the tool moves along the line of joining the working plates on the advancing side of weld metal.

a)



b)



c)

Figure 5. Experimental welding T-joints

P 4.2 obtained with two movement of welding tool like P 4.1, but the first movement of the tool was on the retreating side, and the second was on the advancing side of weld metal. There were three working plates dimensions 32x200x5 mm, too. The figure 5.c shows the position of FSW tool when it has completed the first pass. Now, tool will penetrate again in the material of working plates and move along the joining line on the advancing side of weld metal. It can be seen the keyhole as a result of the tool's exit from the joint.

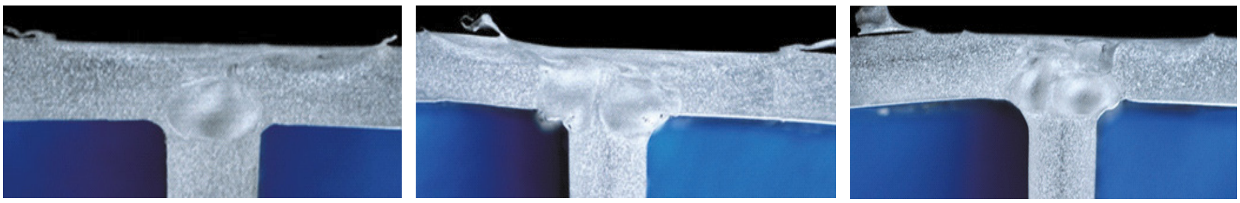
3. EXPERIMENTAL RESULTS AND DISCUSSION

Visual inspections and macrographic tests have been carried out for all welded joints. Specimens were prepared using standard metallographic methods for macroscopic examinations of the weld zones. Visual inspection of the face of the weld metal were done according the standard EN 970 [9]. The macrostructural analysis of the cross-section of the welded joint normal to the welding direction was carried out on T-joints. The macrostructural analysis was done according to standards SRPS EN ISO 17639: 2014[10], and SRPS EN ISO 25239-5 [11].

Interesting results can be obtained by visual inspection because of the possibility of verifying the presence of possible macroscopic external defects, such as surface irregularities, excessive flash [12], and lack of penetration or insufficient penetration of tools. Qualitative inspection of the welds was performed by visual examination to detect surface defects, followed by metallographic analysis to detect internal flaws (reported in the following section).

Typically, the surface appearance of FSW is a regular series of partially circular ripples, which pointed towards the start of the weld. figure 6.a. It was observed that these ripples were essentially cycloidal and were produced by the final sweep of the trailing circumferential edge of the shoulder during traverse. The rotation speed of the tool and traverse speed of the work piece determines the pitch between the ripples. A good selection of welding parameters should be made and the smooth face of weld metal should be obtained. For each T-joint, a smooth surface of weld metal is obtained, as can be seen in figure 6.

Each T-joint were characterized by an excessive presence of lateral flash, resulting from the outflow of plasticized material from underneath the shoulder.



a) P 3.1 b) P 4.1 c) P 4.2

Figure 6. Macroscopic views of section of T-joints

There is a bending of P 4.1 and P 4.2 joints due too large welding forces and temperatures, and inadequate clamping of working plates.

Macrographic examinations (figure 7) clearly displayed the structure of all joints. All analyses revealed a good mixing of working plates material. There were no defects in weld metal in any joint. It is clear that the shape of the T-joint P 3.1 is better then P 4.1 and P 4.2. The two-pass welded joints shapes are not appropriate due to the excessive heat input.

One of the aims of the paper is to show the influence of technological parameters of welding on the position and size of the nugget zone of welds. The nugget zone has the highest values of the hardness of the welded joints. As can be seen in figure 6, the two-pass welded joints have larger nugget zone than single-pass welded joint.

The weld zones: heat affected zone-HAZ and thermo mechanically affected zone-TMAZ are wider toward the upper surface, because it is in contact with the tool shoulder, and therefore experiences more frictional heating and plastic flow, while the bottom surface is in contact with the clamping plates which extracts heat from the bottom area of the joint and contributes to smaller weld zones width. Figure 8. shows structural zones of FSW T-joint and points of microhardness measurement.

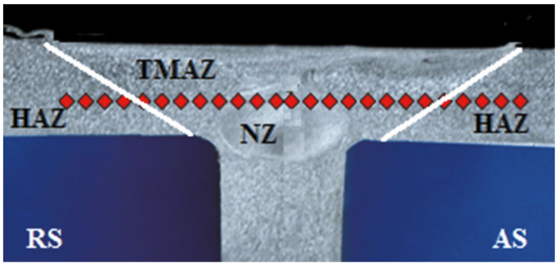


Figure 7. Macroscopic view of section of P 3.1

Effect of welding parametres and ways of productions T-joints on the hardness distributions of joints is shown in figure 8. The measurements were performed across the NZ, TMAZ and HAZ on the transverse cross-section of the welded joints. Figure 8 shows that at all welding conditions the hardness profile reached maximum levels at the nugget zone and had approximately the same values as that of the base metal, which proves the occurrence of re-precipitation of the hardening phase. This increase in the hardness at the SZ was also reported in FSW of other precipitation hardened alloys [13]. Slight decrease in hardness was observed in the TMAZ due to the coarsening of the hardening phases in that region. The lowest hardness was recorded in HAZ. The figure 8 also show that hardness profile depends on the ways of production T-joints (by welding two or three working plates).

The difference in the shape of the microhardness distribution diagram for a joint formed at single pass (P3.1) from the joints formed of two tool passes (P 4.1 and P 4.2) is clearly shown. Diagram P 3.1 has a one zone of maximum hardness values and this zone is smaller than for P 4.1 and P 4.2. Joint P4.2 have two areas of maximum hardness because there are two nuggets. If we observ P 4.2 and P 4.2 joints in the HAZ and TMAZ, the values of the microhardness are lower for P 4.2 joint, but in NZ values are higher then for P 4.2. It means that the tool plunge depth and on what side is the first pass of welding tool affect on microhardness values.

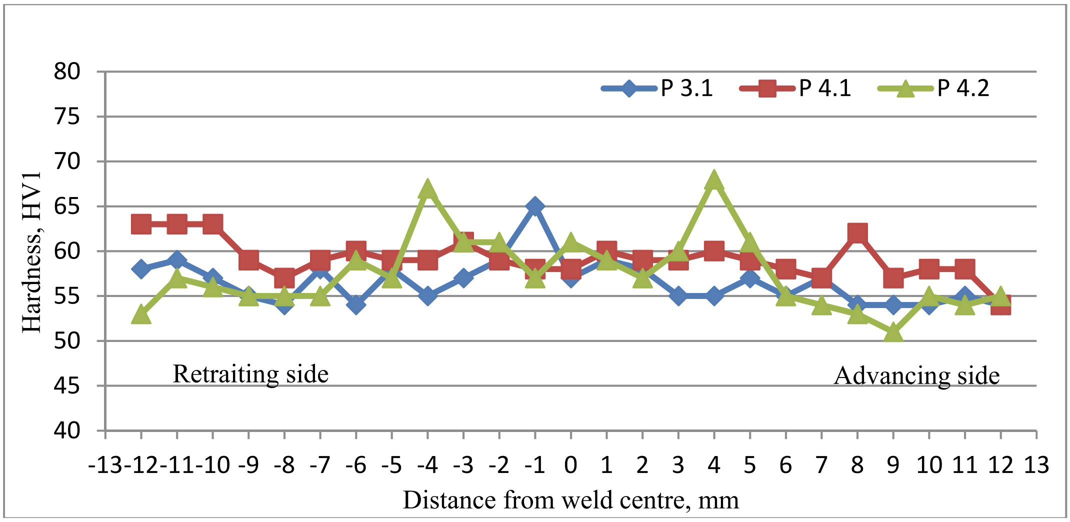


Figure 8. Microhardness distribution of AA5754-H111 T-joints welded on three different ways

4. CONCLUSIONS

In this work, macrostructures and microhardness of AA5754-H111 working plates joined by friction stir welding was studied by means of destructive and non-destructive tests. The main results can be summarized as follows:

- Working plates of AA5754-H111 have been joined successfully using FSW with selected process parametres. Three T-joints were production on three different ways.

- The macrographs and the visual inspections revealed a good mixing of working plates material and a good penetration of the tool in the joints.
- FSW process is followed by high temperatures, and consequently the bending of a joint formed by two tool passes can occur.
- Good matching of microhardness values has been achieved, the maximum difference is just 10HV1.
- If we compare T-joints produced by welding three working plates, in HAZ there are higher values of microhardness of P 4.1 than P 4.2. In the joint P 4.1 the tool plunge depth was higher 0.2 mm and the first pass of welding tool was on the advancing side of weld metal. But, the higher values of microhardness were in joint P 4.2 for 7HV1.

ACKNOWLEDGEMENT

This research is partially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through Grant ON 174004.

REFERENCES

[1] R. S. Mishra, Z. Y. Ma, *Friction stir welding and processing*, Materials Science and Engineering, vol. 50, no. 1-2, pp. 1–78, 2005
[2] W. Thomas, D. Nicholas, D. Staines, P. J. Tubby, M. F. Gittos, FSW Process Variants and Mechanical Properties, TWI Ltd (III-1293-04), 2004
[3] A. Pietras, B.Rams, FSW Welding of AluminiumCasting Alloys, AFE- Archives of Foundry Engineering, issue 2/2016, vol. 16,pp.119-124, 2016
[4] http://www.esab.de/de/de/support/upload/fsw-technical-handbook.pdf
[5] S. Celik, R. Cakir, Effect of Friction StirWelding Parameters on the Mechanical and Microstructure Properties of the Al-Cu Butt Joint, Metals, vol.6, issue 6, doi:10.3390/met6060133, 2016
[6] https://www.outokumpu.com/SiteCollectionDocuments/Austenitic-Standard-Cr-Ni-Grades-Data-sheet.pdf
[7] asm.matweb.com
[8] https://www.alcoa.com/mill_products/europe/en/nautical_products.asp
[9] SRPS EN-970, Non-destructive examination of fusion welds - Visual examination, ISS, Belgrade, 2003
[10] SRPS EN ISO 17639:2014, Destructive tests on welds in metallic materials - Macroscopic and microscopic examination of welds, ISS, Belgrade, 2014
[11] SRPS EN ISO 25239-5, Friction stir welding - Aluminium - Part 5: Quality and inspection requirements, ISS, Belgrade, 2012
[12] A. Živković, A. Đurđević, A. Sedmak, S. Tadić, I. Jovanović, Đ. Đurđević, K. Zammit, Friction Stir Welding of Aluminium Alloys - T joints, Structural Integrity and Life, vol. 15, no. 3, pp.181-186, 2015
[13] M. F. E.Ghada, M. Z. Hossam,, S. M. Tamer, A. K. Tarek , Microstructure examination and microhardness of friction stir welded joint of (AA7020-O) after PWHT, HBRC Journal, vol. 14, pp. 22-28, 2018