

RESEARCH AND ANALYSIS OF FRICTION STIR WELDING PARAMETERS ON ALUMINIUM ALLOYS (6082-T6)

Vukčević Milan, Plančak Miroslav, Janjić Mileta, Šibalić Nikola
University of Montenegro, Faculty of Mechanical Engineering Podgorica, Montenegro

ABSTRACT

Research field related to geometrical and mechanical parameters in friction stir welding process is current and insufficiently explored, it is particularly present considering the class of aluminum alloy series 6000 (AlMgSi). The research paper is related to the friction stir welding of aluminum alloy 6082-T6 (AlMgSiMn) with the thickness of 7.8 mm. The research paper includes forces measurement: the down force - F_z , which is known as the welding force, traversing force F_x - and side force - F_y , as well as mechanical testing - tensile testing of welded joints and tensile testing of welding zone using standard machines and standard test pieces. The paper includes the drawings of the designed supporting equipment which allows measurement of forces by the friction stir welding process, the analysis and discussion of the process are included, as well as results. The experiment was performed in the laboratory of the Mechanical Engineering Faculty in Podgorica.

Keywords: *Friction stir welding - FSW, welding force, pin, shoulder, tensile tests.*

1. INTRODUCTION

During the nineties of the last century a new method of joining similar and dissimilar materials in the solid state without melting of material, known as friction stir welding - FSW is developed. The process is patented by The Welding Institute - TWI in England in 1991, and invented by Wayne M. Thomas who has successfully joined plates of aluminum alloys [1]. It is primarily used to join plates of larger thickness. Tools that are used in the process of welding are cylindrical and consisted of two concentric parts, which are rotating at the great speed. A larger diameter part of the tool is called the shoulder, while the smaller diameter part is called the pin (Fig. 1.). Rotating tool slowly approaches the joint line and plunges into material (Al alloys - sheet metal with of thickness 7.8 mm), which creates heat. Due to that the temperature increases to the heat metal forming where mechanical mixing and joining of materials is performed, enabling the tool to move

in the longitudinal direction or along the joint lines (Fig. 2.). After passing of the tool along the joint lines the solid phase of weld (joint) remains, where the upper plane remains smooth and flat thanks to the tool shoulder, while the lower plane of the workpiece is formed from the basis on which the workpiece is standing and it is also smooth and flat [3, 5, 6].

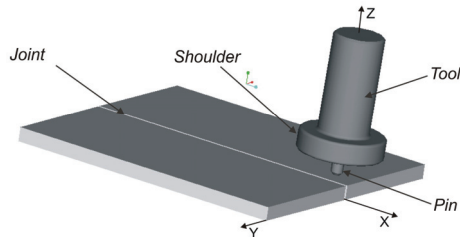


Fig. 1 - Presentation of tools and sheet

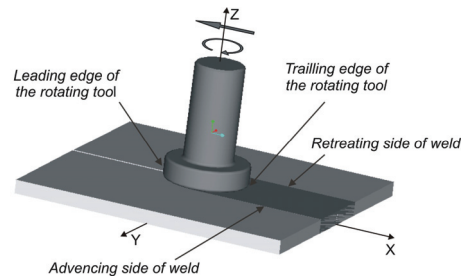


Fig. 2 - Presentation of friction stir welding process

2. MATERIALS AND EXPERIMENTAL PROCEDURE

For the friction stir welding process, a vertical milling machine of great power was used. The process is conducted in laboratory conditions, similar to the production. Material used in the experiment includes the sheet aluminum alloy 6082-T6, whose chemical composition is given in Table 1., and mechanical properties of basic material in Table 2. The size of workpiece is 2000 x 50 mm, and it was obtained by cutting boards of sheet with the thickness of 7.8 mm.

Table 1: Chemical composition of used alloys 6082-T6 (AlMgSi1Mn)

Chemical composition %										
% Al	% Fe	% Si	% Ti	% Cu	% Zn	% V	% Cr	% Mn	% Mg	% Na
98.29	0.21	0.83	0.01	0.002	0.060	0.006	0.001	0.15	0.43	0.001

Table 2: Mechanical properties of used alloy 6082-T6 (AlMgSi1Mn)

Proof Stress 0.2 % MPa	Tensile Strength MPa	Shear Strength MPa	Elongation A5 %	Hardness Vickers HV	Melting Point °C	Modulus of Elasticity GPa
310	340	210	11	100	555	70

Material used for making welding tools in the experimental research, for work in the hot conditions, is č.4751 steel and is thermally processed. The tool is designed in Pro/Engineer, a program for parametric modeling (Fig. 3.).

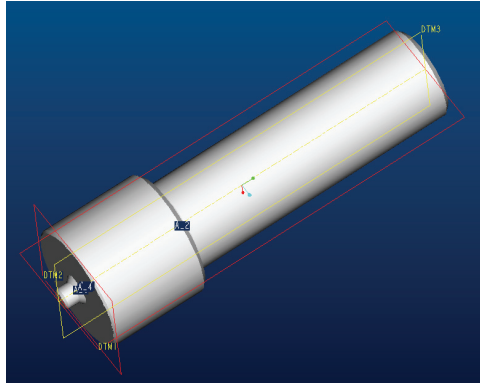


Fig. 3 - Model of the tool designed in Pro/Engineer

The diameter of the tool shoulder in a central point of the plan is $D=26.46$ mm, while the pin diameter $d=5.92$ mm. Tilt angle of the pin is $\alpha=3.87^{\circ}$. Schematic presentation of the tool with dimensions is given in Fig. 4, and the used tool in Fig. 5.

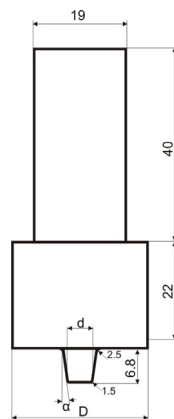


Fig. 4 - Tool: $D=25$ mm, $d=5$ mm i $\alpha=3^{\circ}$



Fig. 5 - Tool made of steel č.4751

Rotation speed of the tool at the central point of the plan is 630 rpm, while the welding speed 125 mm/min. Macrostructure of the alloy 6082-T6 is shown in Fig. 6.. Fig. 7. and Fig. 8. present the complete process of friction stir welding with basic tools and materials with supporting equipment. During the process of friction stir welding recording of forces was performed, as well as temperature and acoustic emission signals.

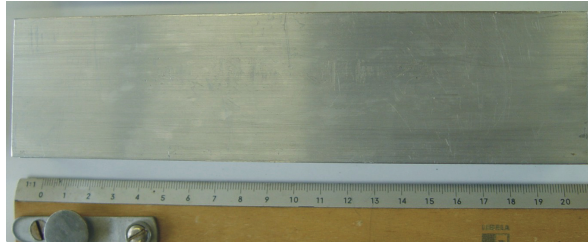


Fig. 6 - Macrostructure of alloy 6082-T6 (AlMgSi1Mn)



Fig. 7 - Machine is idle

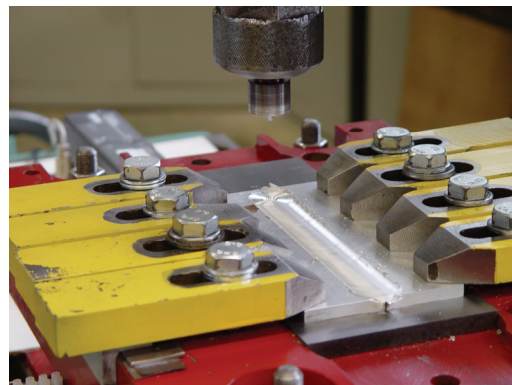


Fig. 8 - Machine performing FSW

For mechanical testing of welded joints, tensile tests are used. The testing is performed with the standard testing machines and test pieces. For the tensile tests, MEST EN 10002-1:2008 standard was used [7], and testing is performed at a ambient temperature. Testing machine is used when testing with modules of 200 KN, 500 KN and 1000 KN. Samples which are cropped from welded workpieces were taken from two normal directions. One sample is normal to the direction of welding y - direction (side direction), and the second is taken from the welding zone and coincides with the direction of welding x - direction (longitudinal direction). Fig. 9. provides a schematic view of test pieces, and Fig. 10. and Fig. 11. provides the samples of the test piece in the central point of the plan in y and x direction.

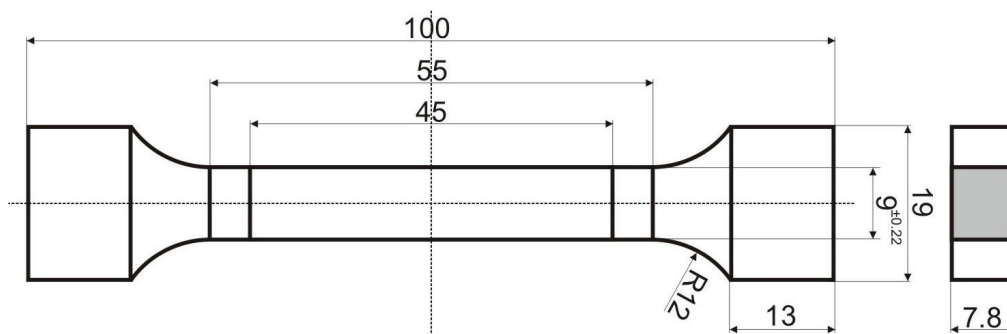


Fig. 9 - Test piece for tensile testing is made by the standard MEST EN 10002-1:2008

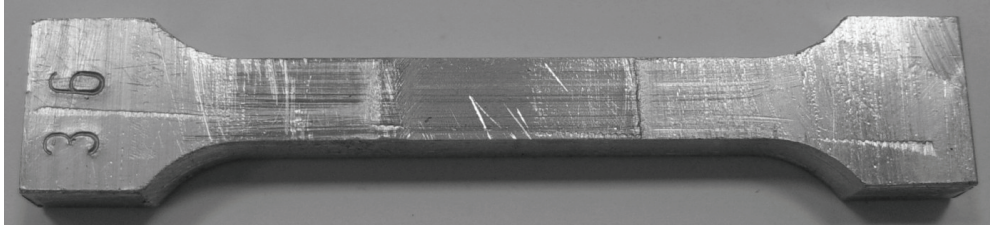


Fig. 10 - Sample (test piece), y - direction normal to the direction of welding

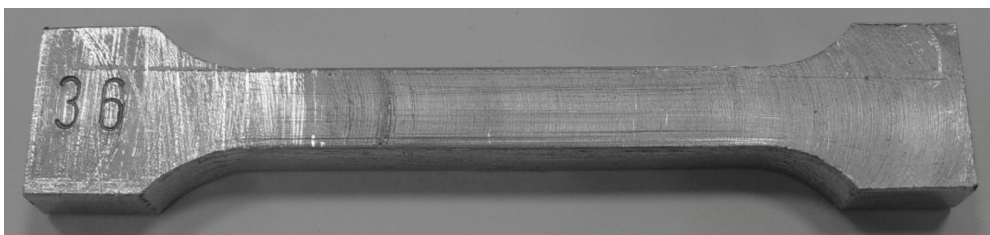


Fig. 11 - Sample (test piece), x - direction, which coincides with the direction of welding

3. RESULTS AND DISCUSSION

During the process of friction stir welding - FSW, measurement of forces by a precise analog digital measuring equipment connected to the information measuring system was performed. Sensors used in strain gauge (HBN 6/120LY11) affixed to the special carriers that are adapted to the conditions of the experiment and directions of the measured forces. Fig. 12. shows the force diagram of a function of time in the central point of the plan. During the welding process, welding force F_z has the highest value when the rotating tool plunges in the material (workpiece). At that point, workpiece is heated due to the effects of friction, pin tool and workpiece. Then the welding force F_z begins to decline until the moment of contact of the shoulder and workpiece surface, when the force reaches its greatest value, because the large surface shoulder begins to plunge in the workpiece. Workpiece becomes more heated due to the friction resulting from the shoulder and pin simultaneously. Then the welding force F_z begins to decline until the moment when the milling machine switches to transverse movement or selected welding speed 125 mm/min, where force F_z retains its constant value, until the moment when the tool exits the workpiece. Value of the traversing force F_x largely depend on the speed of welding, and specific effect has the geometric size of the tool, while the least value has the side force F_y .

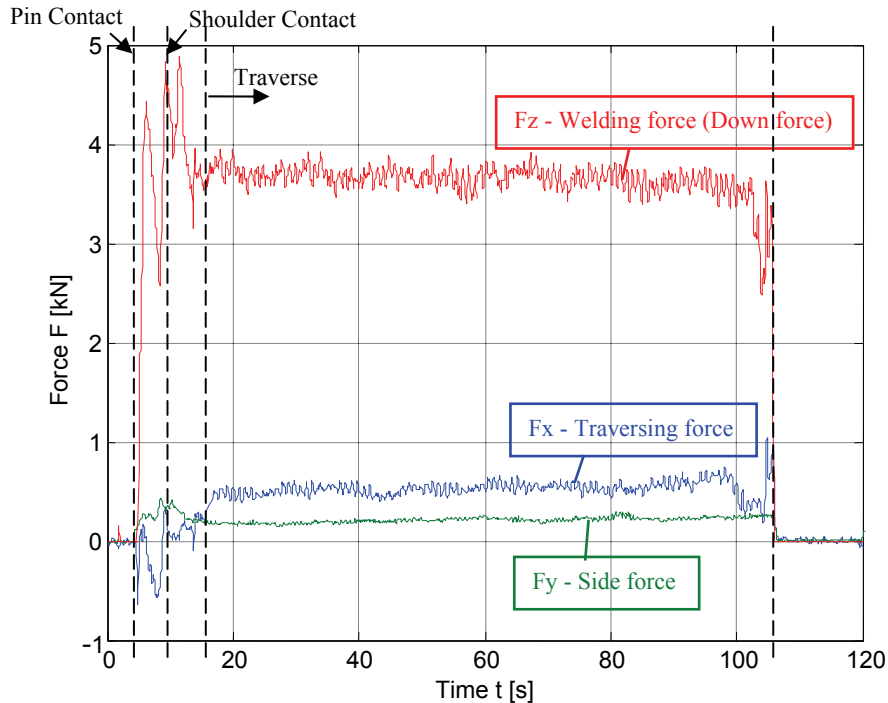


Fig. 12 - Diagram of the F_z , F_x and F_y force in the friction stir welding process

When tensile testing of samples of the welded workpiece, a small forming velocity is used. Samples that were created for tensile tests of the dimensions 100 mm x 19 mm x 7.8 mm are not processed by upper and lower surface of workpieces. On the upper surface of the workpiece of test piece from the y - direction to the place where the tool has passed a small dimple could be spotted, while in welding place of retreating side a small ridges occurs. While the underside of the test piece remains flat and smooth, at the point of connection of workpieces the tear could be recognized. On the sample from the x - direction the prints of the tools are shown at the upperside, whose size depends on the rotation speed of the tool. If the rotation speed is larger then the prints are smaller, and if the speed of turning tools is less, then the print of the tool can be clearly seen as a parallel ridges in form of a circle. Fig. 13, presents a stretched test piece cut from y - direction, while Fig. 14. presents a stretched test piece, cut from x - direction.



Fig. 13 - A stretched test piece, cut from the y - direction

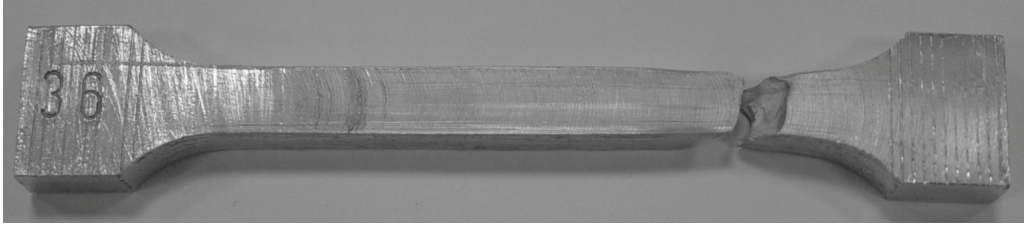


Fig. 14 - A stretched test piece cut from the x - direction.

When using adopted welding parameters (Rotation speed: 1000, 800, 630 rpm and welding speed: 200, 125 and 80 mm/min), different values of tensile strength R_m are obtained. Fig. 15. shows the diagram of stretch in the central point of plan, test pieces from y and x - directions, with values of tensile strength R_m .

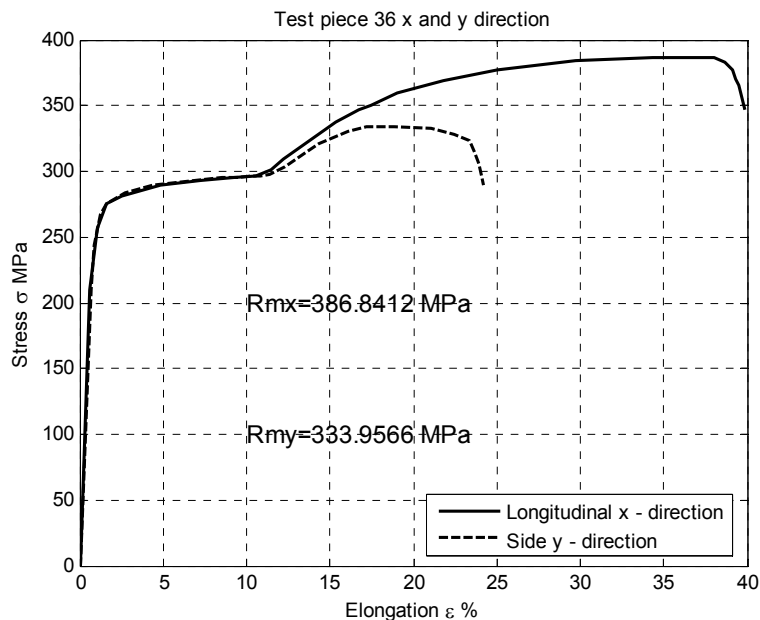


Fig. 15 - Diagram: Stress - Percentage Elongation

The diagram shows that the tensile strength is larger for the test pieces which are taken from the welding zone than the tensile strength from the test pieces which are taken from the side y - directions, so that the relative ratio of $R_{m_x}/R_{m_y}=1.15$, while a relative ratio of the percentage elongation of the test piece from the x - direction and the test piece from the y - direction $\epsilon_x/\epsilon_y=1.66$.

4. CONCLUSION

The experimental research successfully completed the joining of aluminum alloy 6082-T6 using friction stir welding procedure (FSW).

Experimental research has established that the dimensions of tools (shoulder diameter, pin diameter and tilt angle of the pin) have large effect on the quality of weld as well as regimes of welding (welding speed and rotation speed).

Regarding the research of FSW and determination of functioning of the input and output sizes of the process, experimental tools and supporting equipment were made. The paper presents a measurement of force which is defined by the components in x, y and z direction and mechanical tests were performed - determination of the tensile strength of welded joints and the tensile strength of welding zone.

Based on the experimental results of FSW welding joints of aluminum alloy 6082-T6, it can be concluded that this procedure with the use of optimal parameters of welding, welded joints with good characteristics can be obtained.

For further researches, good experimental conditions are made, and information base, which promise significant results in research that follows.

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ISTRAŽIVANJE I ANALIZA PARAMETARA ZAVARIVANJA TRENJEM KOD LEGURE ALUMINIJUMA (6082-T6)

Vukčević Milan, Plančak Miroslav, Janjić Mileta, Šibalić Nikola

REZIME

U današnje vrijeme zavarivanje trenjem, je proces koji se koristi skoro u svim oblastima - granama industrije. Najširu primjenu ima u brodogradnji, željezničkoj, avio, svemirskoj i drugim industrijama, a posebno se koristi za zavarivanje rezervoara za gorivo aviona, raketa itd. U radu su date pojedinosti o procesu zavarivanja trenjem. Korišćeni materijal je legura aluminijuma 6082-T6. Ova legura ima zateznu čvrstoću 340 MPa i pogodna je za izradu raznih držača, rešetkastih konstrukcija koje su izložene relativno velikim opterećenjima, udarima vjetra itd., a ujedno se uspješno spajaju korišćenjem procesa zavarivanja trenjem. U radu su prezentirana mjerenja sile zavarivanja - F_z (vertikalne sile), kao i ostale dvije komponente koje imaju manji uticaj na sam proces: uzdužne sile F_x i bočne sile F_y , urađena je analiza procesa kao i mehanička ispitivanja. Vrijednosti komponenata sila kod procesa zavarivanja trenjem prvenstveno zavise od debljine lima koji se zavaruje, brzine zavarivanja, broja obrtaja alata, dok određani uticaj imaju geometrijske veličine alata, kao i vrijednost dubine prodiranja alata u materijal. U radu je prikazan eksperiment zavarivanja lima od legure Al 6082-T6 debljine 7.8 mm, gdje su navedeni parametri varirani prema usvojenom eksperimentalnom planu. Pomoćni pribor je dizajniran tako da su napravljeni specijalni nosači, na kojima su nalijepljeni davači (mjerne trake), pomoću kojih su dobijene vrijednosti komponenata sila u tri normalna pravca F_x , F_y i F_z . Dijagrami sila su obrađeni u programskom paketu GLOBAL-LAB. Iz dobijenih zavarenih priprema isječeni su uzorci za mehanička ispitivanja (epruvete za određivanje zatezne čvrstoće). Eksperiment je realizovan u laboratoriji Mašinskog fakulteta u Podgorici.