ARCH. MECH. TECH. MATER. VOL. 39, (2019) 41-45

DE GRUYTER OPEN

ARCHIVES OF MECHANICAL TECHNOLOGY AND MATERIALS
WWW.AMTM.PUT.POZNAN.PL

Effect of FSW welding parameters on the tensile strength of aluminum alloys

Mohamed Serier [a], Mohamed Berrahou[b], Affaf Tabti [a]*, Seif-E Bendaoudi[b]

[a]Institute of Sciences and Technology, University center of Relizane, Relizane 48000, Algeria
[b] Institute of Sciences and Technology, University center of Relizane, Relizane 48000, Algeria
[b] Institute of Sciences and Technology, University center of Relizane, Relizane 48000, Algeria
[a] Institute of Sciences and Technology, University center of Relizane, Relizane 48000, Algeria*
[*] Corresponding author, Tel.: +213781713614, e-mail address: moha_serier@yahoo.fr

ARTICLE INFO

Received 05 January 2019
Received in revised form 17 October 2019
Accepted 21 October 2019

KEY WORDS

Tensile strength
Friction stir welding
aluminum alloy
ANOVA

ABSTRACT

The friction stir welding process is an innovative technique for joining metals using plasticity, without presenting the fusion. It was first applied to aluminum alloys, for example copper, steel alloys, polymers and others. In this work the effects of the rotational speed, the speed of travel and the axial force of the tool were grouped in a mathematical model to quantify their influences on the weld seam. In this context and with of the experimental tests, the desired objective through this study is to describe the tensile strength of the cord resulting from this welding operation, for the qualification of this type of parts with an optimum adapted to a given application.

1. INTRODUCTION

Friction stir welding is based on an invention of which first patent was filed in 1991 by The Welding Institute (TWI) [1], it is a solid-state welding process that offers an attractive alternative to fusion welding. Recent studies show that the friction stir welding (FSW), a solid-state joining technique successfully applied in cases of similar and dissimilar low-temperature materials, will be a potential candidate for the dissimilar joining of Al alloys and steels [9]. More recent works on FSSW include Klobčar et al. [10] on sheet aluminum joining and on development of FSW robot system for automobile industry [11]. The entire process appears relatively simple in that a rotating tool is plunged between the surfaces of two abutting plates and it is then traversed along the length of the plates. The advancing and retreating sides of the weld are defined by the direction of tool rotation with respect to the tool translation. It is composed of a pin and a shoulder, it is brought to the level of the joint plane and it is rotated. On the advancing side, the tool rotation and translation are in the same relative direction while tool rotation and weld direction oppose each other at the retreating side. The friction of the tool pin inserted between the parts to be welded causes a heating which results in a "softening" of the material. The material flow during FSW is very complex, but can be explained as a simple extrusion process. Tool rotation causes material transfer around the tool, stirring the two plates together. As the tool is translated, it essentially extrudes the stirred material through a "die" created by the tool and the UN softened plate material. This welding process reveals several advantages that make this technique a very important challenge. Among these advantages we quote: Absence of porosity and gaseous protection, a welding of mechanical properties very close to those of the base metal. To study the influence of weld parameters on weld bead quality, let us recall the study result of Palanivel et al [7] which dealt with the influence of the welding parameters (the speed of rotation, the speed of welding and the plunging face of the tool) on the mechanical characteristics of the weld bead, based on tensile tests. The interest of this study is to optimize the conditions of welding FSW by the implementation of an experimental modeling based on the method of the plans of experiments (complete plan) to predict the quality of the welded bead at the tensile resistivity.

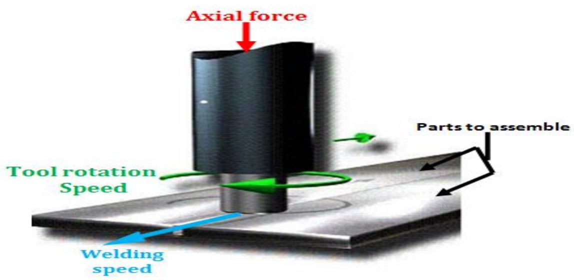
DOI: 10.2478/amtm-2019-0008

© 2019 Author(s). This is an open access article distributed under the Creative Commons Attribution-Non Commercial-No Derivs license (http://creativecommons.org/licenses/by-nc-nd/3.0/)

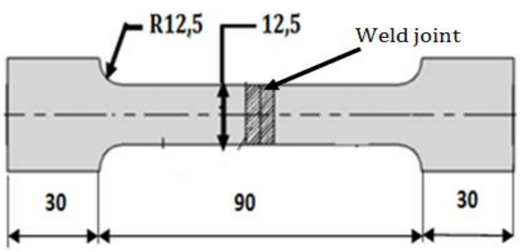
Bereitgestellt von Politechnika Poznanska - Poznan University of Technology | Heruntergeladen 14.01.20 09:24 UTC

2. EXPERIMENTAL

The material used is the aluminum alloy with copper (AW-2017A), used in the industry does not exceed a proportion of 12% copper. It is about an alloy of density is about 2.79 kg/dm3. The principle of welding by the technique of FSW consists of attaching the two plates on the table of the machine in order to avoid any movement of these last two. The faying surfaces were then mechanically polished using 300-grit emery paper to ensure gap-free contact between the faying edges, and the pieces were thoroughly cleaned using acetone. The machine used is a milling machine adapted for this purpose. The tools used during the operation of welding are made out of steel strongly allied X200Cr12, of the truncated pawn of form. The pawn is used primarily for malaxation of the matter. The shoulder serves à apporter of heat by friction and to contain the matter mixed around the pawn (Fig. 1).



a)



b)

Fig. 1. Experimental processes: a) parameters operation of Welding fsw; b) Tensile specimen for FSW.

During the welding process, the plunge depth of shoulder was controlled manually in order to modify the quality of weld formation. The material of the parts to be assembled is heated at the level of the weld zone by friction and plastic deformation to a temperature of the order of magnitude of that attained in hot forging. There is no fusion of matter compared with conventional fusion welding processes. In this study and on the basis of our work carried out previously three parameters were chosen because of their great influence on this process. The first is the rotational speed of the tool which is between 1000 and 1400 RPM, the second is the speed of advance of the tool, it is between 22 and 75 mm / min, the last is the axial force of tool penetration and it is between 2 and 4 KN as indicated in the table 1. The tensile tests were performed on standard flat specimens according to ASTM E8 M-04 (fig.1-b) for the purpose of measuring the tensile strength as shown in Table 1. The tests are carried out on a universal tensile strength machine with a capacity of 200KN maximum.

Table 1. Experimental values of tensile strength

N	Tool rotation Speed (rpm)	Welding speed (mm/min)	Axial force (KN)	Tensile strength (MPa)
01	1000	22	2	110
02	1400	22	2	106
03	1000	75	2	116
04	1400	75	2	108
05	1000	22	4	118
06	1400	22	4	111
07	1000	75	4	126
08	1400	75	4	110

3. MODELING OF THE PHENOMENON

3.1. Calculation of factor effects

A simple application is provided by the complete plan. The calculations can be performed by a simple matrix calculation as indicated in table 2 named matrices of experiments. Where X_1, X_2 and X_3 respectively represent the coded variables representative of the main factors and the interactions between these factors are represented by I_{12}, I_{13} and I_{23}.

Table 2. Main factors coded

N	overall average	Tool rot-speed X_1	Welding speed X_2	Axial force X_3
01	+1	-1	-1	-1
02	+1	+1	-1	-1
03	+1	-1	+1	-1
04	+1	+1	+1	-1
05	+1	-1	-1	+1
06	+1	+1	-1	+1
07	+1	-1	+1	+1
08	+1	+1	+1	+1

Table 3. Interactions coded

N	rot-speed/ weld- speed I_{12}	rot-speed/ axial force I_{13}	Weld-speed/ axial force I_{23}
01	+1	+1	+1
02	-1	-1	+1
03	-1	+1	-1
04	+1	-1	-1
05	+1	-1	-1
06	-1	+1	-1
07	-1	-1	+1
08	+1	+1	+1

The model chosen a priori is the following:

$$Y = a0 + a1X1 + a2X2 + a3X3 + I12\ X1\ X2 + I13\ X1\ X3 + I23\ X2\ X3 \qquad (1)$$

So the system is written in the following form:

$$\{y\} = [X] * \{a\} \qquad (2)$$

The solution of the system which results the coefficients of the model is obtained by the least squares method. This solution is given by the following formula:

Bereitgestellt von Politechnika Poznanska - Poznan University of Technology | Heruntergeladen 14.01.20 09:24 UTC

$$\hat{a} = (X^t X)^{-1} X^t y \qquad (3)$$

Table 4. Coefficients of models

Factor	Value
The overall average	113,12
Tool rotation Speed	-4,37
Welding speed	1,87
Axial force	3,12
Interaction: rot-speed/welding speed	-1,62
Interaction: rot-speed/axial force	-1,37
Interaction: weld-speed/axial force	-0,12

3.2. Validation of the model

Before going to parametric analysis, it is necessary to test the model chosen by variance analysis in order to predict whether this model represents the phenomenon and introduces an acceptable bias.

3.2.1. Residual variation

The predicted responses are calculated from the equation of the model and the standard deviations are obtained (difference between the two models as shown in Fig. 2) (Table 5)

$$Y_{observed} = (Y_{predicted} = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + I_{12}X_1X_2 + I_{13}X_1X_3 + I_{23}X_2X_3) + e$$

$$e = \sum_{i=1}^{n} (y_i^{abs} - y_i^{pre})^2 \qquad (4)$$

e=6.24

Table 5. Predicted responses and standard deviations

N	$Y_{observed}$	$Y_{predicted}$	$e_i = \lvert Y_{obs} - Y_{pred} \rvert$
01	110	109.68	0.32
02	106	106.57	0.57
03	116	116.45	0.45
04	108	107.3	0.7
05	118	118.55	0.55
06	111	110.2	0.8
07	126	125.32	0.68
08	110	111.93	1.93

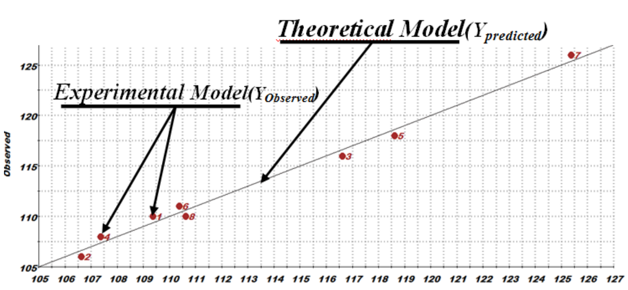


Fig.2. Schematization of both models (experimental and theoretical).

3.2.2. Variation due to the linear connection

$$SCEL = \sum_{i=1}^{n} (y_i^{pre} - y_{med})^2 \qquad (5)$$

SCEL = $(109,68-113,12)^2 + (106,57-113,12)^2 + (116,45-113,12)^2 + (107,3-113,12)^2 + (118,55-113,12)^2 + (110,68-113,12)^2 + (125,32-113,12)^2 + (111,39-113,12)^2$

SCEL = 287, 95

Table 6. ANOVA for tensile strength

Variation Source	ddl	Sum of squares	Mean squares	F_{abs}
Regression (model)	(k-1) 5	SCEL = 293,32	MCF = SCEL/(k-1) 58,66	MCF/ MCR 28,69
Residuals	(n-k) 2	SCER = 4,08	MCR = SCER/(n-k) 2,04	
Total	(n-1) 7			

The Fcrit test value, taken from the Fischer table with (k-1) and (n-k) degrees of freedom, is equal to 19.30 and the value calculated by our model (Fabs) is 28.69. The comparison of these two values shows that Fabs> Fcrit; therefore, this model is globally significant.

3.2.3. Refining the model by Rejection of factors

This operation is important because it makes possible to reduce the dimension of the problem by rejecting non-significant factors, by using a Student's table [8] by the combination of degrees of freedom (ν = n - p (n: the number of experiments performed, p: the number of effects including the constant) and α and the risk of the first species (usually 5% or 1%), the test rule is as follows:

- If the │effect of a parameter│ >t_{crit} (α, ν) * s_i so the effect is significant.
- If the │effect of a parameter│ <t_{crit} (α, ν) *s_i so the effect is **not** significant.

The test is done using s_i to keep the same variance throughout the model.

$$S_i = \frac{s}{n} \qquad (6)$$

s : The variance
n : Number of experiments

$$s = \frac{1}{n-p} \sum e_i^2 \qquad (7)$$

So

s= 4,08

s_i= 0,51

And through the student table, the critical value is t_{crit}(α, ν) =4,30

So

t_{crit}(α, ν)*$S_i{}^2$ =1,12

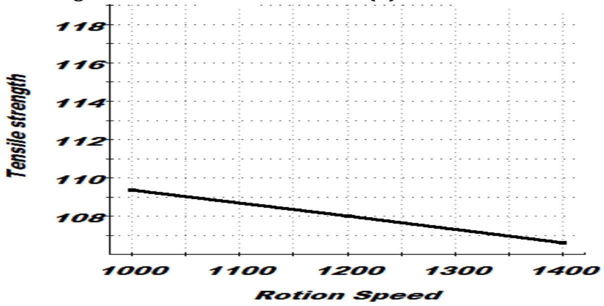
Bereitgestellt von Politechnika Poznanska - Poznan University of Technology | Heruntergeladen 14.01.20 09:24 UTC

By comparing this value with the effects values mentioned in Table 4, it can be seen that only the interaction I23 (weld-speed/axial force) has a non-significant effect.

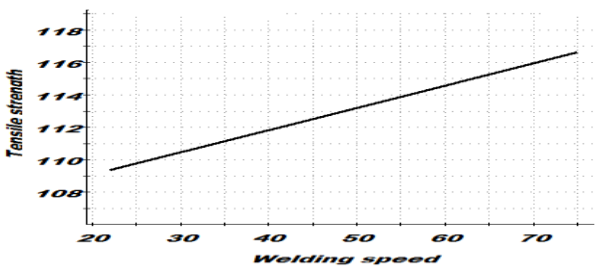
4. DISCUSSION

4.1. Analysis of a single factor effect

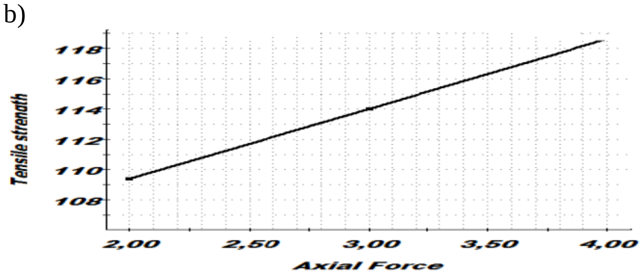
This analysis consists in maintaining a variable factor and fixing the other two in the model (1).



a)



b)



c)

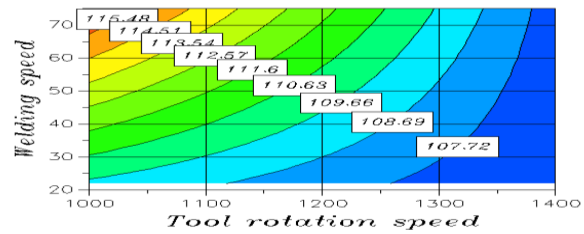
Fig.3. Effect of the factors separately

The importance of the effects caused by the main factors on the objective function can be estimated from FIG. 3. The analysis of the results shows that the good tensile strength is when the rotational speed of the tool is at its low level (Fig. 3 a) while the other two factors (the welding speed and the axial force) provoke a good tensile strength if they have found at its high level. Let us conclude that the axial force is more suggestible than the speed of advancement, as shown by the slopes of Figs. 3b and 3c.

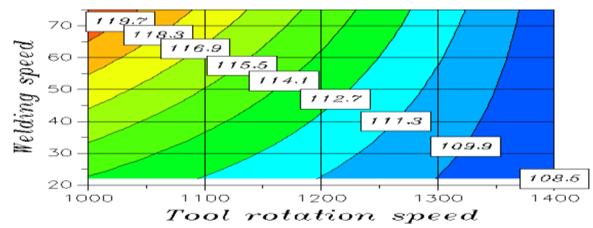
4.2. Analysis of simultaneous effect of two factors

4.2.1. Interaction tool rotation speed-welding speed

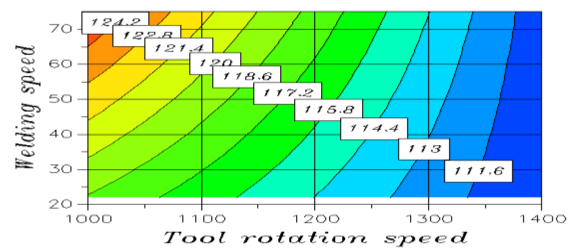
To analyze the impact of interactions on the response, the isos-curves are analyzed. The interaction between the Welding speed and the axial force was eliminated after the significance test.



Axial Force =2KN



Axial Force=3KN



Axial Force =4KN

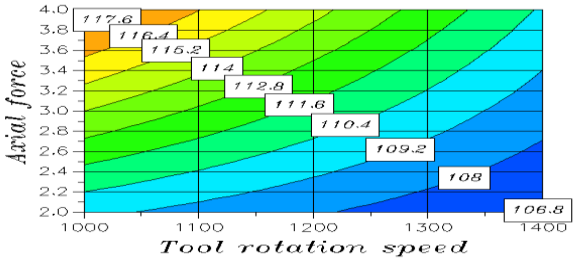
Fig.4. Interaction Tool rotation speed welding speed.

Fig. 4 represents the effect of the two factors (tool speed rotation) and (Welding speed) acting simultaneously while passing from their minimum value to their maximum value, with the third as a constant (three values are chosen: 2KN, 3KN and 4KN) on tensile strength. If we do a horizontal analysis, we notice that the enlargement of the rotational speed for the three cases of the fixed factor causes a drop in the tensile strength regardless of the value taken by the feed rate. In the same figure and by a vertical analysis it is found that the tensile strength takes its maximum value in the three chosen cases when the speed welding takes its high value, with a low speed of rotation. So overall to have a good tensile strength the rotation speed at 1000tr / min, the feed speed at 75mm / min and an axial force at 4 KN must be maintained.

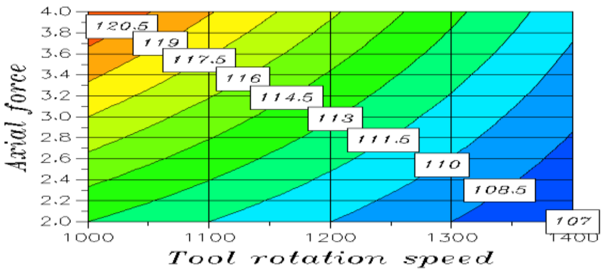
4.2.2. Interaction tool rotation speed -axial force

Fig. 5 shows the variation of the tensile strength as a function of the speed of rotation and the axial force when the speed of advance is fixed at a chosen value (22 mm / min, 48 mm / min and 75 mm / min). Note that the iso-curves are similar to those of the previous interaction. That is to say for the three values chosen for the speed of advance the good tensile strength is localized at a low speed of rotation 1000 rpm and a large axial force 4 KN whatever the value given to the speed of advance.

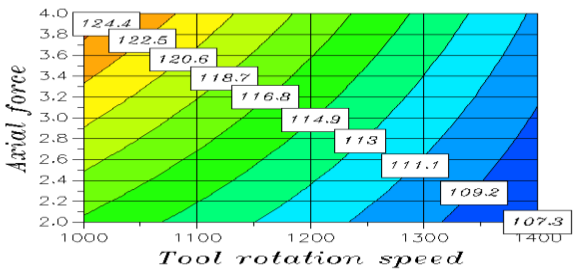
Bereitgestellt von Politechnika Poznanska - Poznan University of Technology | Heruntergeladen 14.01.20 09:24 UTC



Welding speed=22 mm/min



Welding speed=48 mm/min



Welding speed=75 mm/min

Fig. 5. Interaction tool rotation speed -axial force

5. CONCLUSIONS

The following conclusions were drawn from the above study.

1. The standard deviation (e) shows that the chosen experimental domain represents the phenomenon.
2. The effect of the combination of the welding speed and the axial force (I_{23} interaction) makes no change to the tensile strength of the weld joint.
3. Among the two different tool rotation speeds, the lower gives more tensile strength when compared to the greater whatever the levels of the other parameters.
4. The theoretical model developed through the experimental results shows that the rotation of the tools is the most important action in this process because it ensures friction and mixing.
5. The tensile strength is influenced by the working conditions according to this classification, tool rotation speed, effort axial and welding speed.
6. In the six interaction cases and regardless of the values taken by the welding speed and the axial force, the poor tensile strength is associated with the large tool speed rotation.

REFERENCES

[1] **José, F., Lindolfo, F., Ricardo, I.**, Thermomechanical Modelling of FSW Process Using a Cylindrical Tool in an Aluminum Alloy Alclad AA 2024-T3.*journal of Materials Research,*. (2018).

[2] **Merzoug, M., Boulenouar, A., Bouchouicha , B., Serier, M., Mazari, M**.. Effects of welding parameters on fsw: experimental and numerical study. *Journal of Arch. Metall. Mater*. (2018),.247-256.

[3] **Joaquín, M, P., Hernán, G, S**., Efecto de la velocidad de rotación y la indentación en soldadura de punto por fricción agitación de aleaciones de aluminio disimilares.*journal of Revista de Metalurgia*. (2017).2-13,

[4] **Rao, H, M., Yuan, W., Badarinarayan, H**.,. Effect of process parameters on mechanical properties of friction stir spot welded magnesium to aluminum alloys. *Journal of Materials and Design*. (2015) 235-245.

[5] **Oliveira, Miranda, A, C., Gerlich, A., Walbridge, S.**, Aluminum friction stir welds: *Review of fatigue parameter data and probabilistic fracture mechanics analysis. Engineering Fracture Mechanics*, (2015). 243–260

[6] **Qiu-zheng, Z., Wen, B, G., Wei, L**. (2014). Microstructure and mechanical properties of dissimilar Al–Cu joints by friction stir welding. *Trans. Nonferrous Met. Soc. China.* (2014)1779–1786.

[7] **Palanivel, R., Mathews, Koshy, P., , Murugan, N**., (2010). Influences of tool pin profile on the mechanical and metallurgical proprieties of friction Stir welding dissimilar aluminum alloy, *International Journal of En-gineering Science and Technology*, (2010). 2109-2115.

[8] **Fisher, R,***The design of experiments*. Oliver and Boyd 1935.

[9] **Tanaka, T., Morishige, T., and Hirata,T..** Comprehensive analysis of joint strength for dissimilar friction stir welds of mild steel to aluminum alloys. *Scripta Materialia (2009),* 756–759.

[10] **Klobčar, D ,Tušek, J , Skumavc, A. Smolej, A,**Parametric study of friction stir spot welding of aluminium alloy 5754, *METABK* (2014),21-24.

[11] **Sakano, R , Murakami, K .Yamashita,K, Hyoe, T, Fujimoto, M. Inuzuka, Y. Nagao,Y. Kashiki, H**, Development of Spot FSW Robot System for Automobile Body Members, *Proc. of the 3rd. Int. S of FSW, Kobe, Japa*n (2001).

Bereitgestellt von Politechnika Poznanska - Poznan University of Technology | Heruntergeladen 14.01.20 09:24 UTC