IJE TRANSACTIONS A: Basics Vol. 30, No. 4, (April 2017) 597-603

International Journal of Engineering

Journal Homepage: www.ije.ir

Effect of Friction Stir Welding on the Tensile Properties of AA6063 under Different Conditions

R. Singh[a] , S. A. Rizvi*[b], S. P. Tewari[c]

[a] *Shri Ramswaroop Memorial University, Barabanki, INDIA*
[b] *Department of Mechanical Engineering IIT(BHU), Varanasi, INDIA & Faculty Member in U. P, Jamia Millia Islamia, New Delhi*
[c] *Department of Mechanical Engineering IIT(BHU), Varanasi, INDIA*

PAPER INFO

Paper history:
Received 19 June2016
Received in revised form 26 December 2017
Accepted 09 February 2017

Keywords:
Aluminium Alloys
Friction Stir Welding
Taguchi Technique
Mechanical Properties

ABSTRACT

The basic aim of present study is to examine the effect of main friction stir welding (FSW) parameters on the quality of AA 6063 plate welds. Welding of AA6063 was carried out by a vertical milling machine, using different tools with a stationary shoulder and during the welding no external heating system was used. Different welding parameters studied were the tool rotational speed which varied from 2700 to 5400 (rpm), the traverse speed of table which varied from 12 to 17 (mm/min), and the tool shoulder diameter ranging from 17 to 22 mm. In the present research three levels, three factorial designs were used for optimization by taguchi approach. The results indicated that tensile strength of welded joint was increasing with rotational speed and decreasing with increasing transverse feed because frictional heat was directly proportional to rotational speed of tool.

***doi**: 10.5829/idosi.ije.2017.30.04a.19*

1. INTRODUCTION

Friction stir welding (FSW) is solid state newer joining process of different aluminum alloy series for example 1XXX, 2XXX, 4XXX, 5XXX, 6XXX, 7XXX, and many other materials like stainless steel, mild steel, magnesium alloy, copper, etc. [1]. It is a latest technique developed by The Welding Institute (TWI) UK, for joining of metal sheets in solid state [2, 3]. In this welding process a rotating tool moves with transverse feed rate along the weld center line. So rotational speed, transverse feed rate, plunge force and tool geometry affect the mechanical and microstructure properties of welded plates [4]. The AA6061 classes have been broadly employed in pipelines, marine frames, aircrafts and storage tanks [5].

The related literature reviews revealed that several researches have attempted to calculate the optimal process parameters in FSW. Shen et al. [6] investigated the effects of welding parameters such as tool traveling speeds and depth of penetration up to lower steel sheet on the tensile strength, interfacial bonding, and failure mechanism and finally they concluded that weld strength increases considerably by increasing the dispersion depth into the lower steel substrate at all travel speeds. Zhang et al. [7] and Su et al. [8] performed FSW at a high temperature which was above then the β-transus and finally they concluded that the mechanical properties of the welded joints increased by decreasing in the heat input. Cox et al. [9] performed Friction Stir Spot Welding on 6061-T6 thin plates in a lap joint using different pin lengths tools and they found that the tensile strength increased when the pin penetrated to the lower plate. Bahemmat et al. [10] obtained mechanical, micro and macro structural characteristic of AA 6061-T6 & AA 7075-T6 by friction stir welding and they concluded that fracture occurs in the TMAZ-HAZ crossing point of AA6061 due to its lesser hardness and strength in the weld.

Sundaram and Murugan [11] conducted experiment to determine tensile behavior of AA 2024-T6 & 5083-H321 and concluded that increase of tool rotational speed or welding speed led to increase in tensile strength, reached an utmost value and then decreased. Elangovan et al. [12] studied the effect of tool rotational speed and tool pin profile on mechanical properties of

*Corresponding Author's Email: saritbhu@gmail.com (S. A. Rizvi)

AA6061 aluminium alloy. Five different tool pin profiles including threaded cylindrical, straight cylindrical, square, tapered cylindrical and triangular, were used to produce the joints at five different tool rotational speeds (800–1600 rpm). Tensile properties, microstructure and microhardness of the welded joints were evaluated and finally they concluded that the joints produced by the use of square pin profiled tool with a tool rotational speed of 1200 rpm exhibited superior mechanical properties compared to other joints.

Vijayan et al. [13] optimized process parameters in FSW of Aluminum Alloy 5083 with MR based on orthogonal array with grey relational analysis. Taguchi experimental design of L_9 orthogonal array was used for optimizing the FSW process parameters on tensile strength of welded joints and input power required for the (FSW) process. The process parameters considered for optimization were the speed of the rotational tool in rpm, transverse speed in mm/min, and the axial force in kN. The objective of that research work was to find out the optimum levels of the process parameters which yielded in maximum tensile strength and consumed minimum power. Based on the grey relational grade, optimum levels of parameters were identified, and ANOVA tool was used to determine the significant contribution of parameters and finally they concluded that the optimal levels of the rotational speed, transverse speed, and axial force were 650 rpm, 115 mm/min, and 9 kN, respectively.

Rambabu et al. [14] developed a composite design with four factors and five levels to minimize the experimental conditions. To determine the critical pitting potential in mille volt dynamic polarization testing was carried out, which is a criteria for measuring corrosion resistance and the statical data was used in model. Response surface method (RSM) was used to develop the model. The generated mathematical model was optimized using the simulated annealing algorithm optimizing technique to maximize the corrosion resistance of AA2219 welded joints. And finally they reported that the geometry of the pin had a momentous effect on the joint structure and the corrosion properties. The best quality weld was acquired using hexagon tool profile. Rodriguez et al. [15] studied the microstructure and mechanical properties of friction stir welded dissimilar butt joints of AA 6061 to AA7050 and they told that microstructure analysis of the welded stir zone revealed the presence of bands of mixed and unmixed material that demonstrated the degree of material bonding, as the tool rotational speed was varied. Material intermixing and joint strength were found to increase with the increasing tool rotational speed.

Langari et al. [16] measured the axial force, mechanical properties, microhardness and weld morphology during the FSW of A7075-T651 and finally they concluded that with increasing the welding speed and at the same rotational rate, the axial force and microhardness increased but the weld appearance quality decreased while with increasing the tool rotational speed in the same welding speed, there was not any certain relationship among the axial force, hardness and weld morphology.

2. MATERIAL AND EXPERIMENTAL METHOD

AA 6063 is an aluminum alloy with magnesium and silicon as the alloying elements. In general AA6063 has good mechanical properties, is heat treatable and weldable. It is similar to the British aluminum alloy HE9. AA6063 is mostly used in extruded shapes for architecture, particularly window frames, sign frames, door frames, roofs, and partition. AA6063 having very smooth surfaces fits for anodizing. The material used for FSW is commercial 6063 Aluminum alloy plate with nominal thickness of 5 mm and the samples dimensions are 50x5 mm cross section. The nominal compositions of the material are shown in Table 1.

Extensive work on the influence of pin geometry on mechanical properties of 6063 aluminium alloy friction stir welds has been carried out. Tool has very important role in friction stir welding. Three different tools of different geometries as shown in Figure 1 were used.

All tools had cylindrical tip and cylindrical tool shoulder diameter. These tools were manufactured for 5 to 6 mm thick aluminium plate, because tip length was limited. The lower most part of tool inserted into spindle of vertical milling machine. The tool material was die steel; it had sufficient strength to stir the aluminium alloys (Table 3).

No heat treatment was performed on the tool. For instance, the height and shape of the pin, together with the shoulder diameter, exercised substantial influence on both the material-flow and heat generated only by friction as well as fast plastic deformation.

Figure 1. Tool round type with shoulder diameters of 17 mm, 20 mm and 22 mm

TABLE 1. Composition of 6063 aluminium alloys

Component	Fe	Al	Mg	Si	Cr	Mn	Ti	Zn	Others
Wt. %	0.30	97.5	0.67	0.45	0.1	0.1	0.08	0.05	1.2

2. 1. Tensile Test The most common type of test used to measure the mechanical properties of material is the tension test. The tension test is widely used to provide basic design information on strength of material and is an acceptance test for the specification of materials. The standard sample for tensile test is shown in Figure 2. C. The major parameters which explain the stress strain(σ-ε) curve obtained during the tension test are tensile strength (UTS), yield strength, elastic modulus, present elongation and toughness. The tensile test was conducted on fifteen samples at three rotational speeds by three different tools as shown in Figure 3. A. The main factor was to find the effect of shoulder diameter of tools (Table 2). To analysis it, design of experiment of three levels and three factor designs was selected. The UTM and FSW set are shown in Figure 2. A and B, respectively.

Tensile specimens were fabricated as per the American Society for Testing of Materials (ASTM E8M-04) standards to evaluate the tensile properties of the joints. For tensile specimen welded part shown in Figure 3. B, they were cut in horizontal manner and then milled for shape.

TABLE 2. FSW process parameters

S.No	Level		
Parameters	1	2	3
Rotational speed (rpm)	2700	3500	5400
Feed (mm/min)	12	15	17
Tool shoulder diameter (mm)	17	20	22

TABLE 3. Specification of tool material

Name	FSW tool
Material	Die steel
Shoulder diameter	17 mm, 20 mm, 22 mm
Shank	Round
Tip	ROUND 3.5 mm diameter
Tip length	4.5 mm
Colour	Black
Total length	100 mm

Figure 2. A. Tensile testing machine

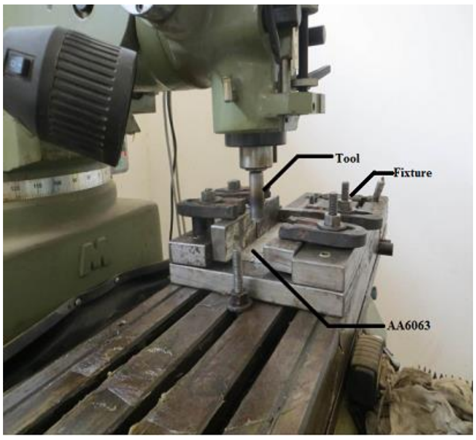

Figure 2. B. Working setup

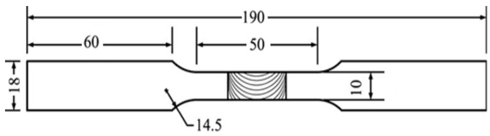

Figure 2. C. Configuration and size of tensile specimen

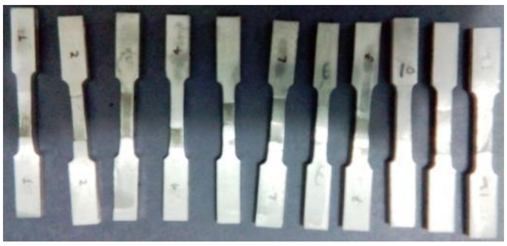

Figure 3. A. Tensile samples

3. RESULTS AND DISCUSSION

3. 1. Tensile Test From the above tensile test result, ultimate tensile strength is increasing with rotational speed and decreasing with transverse feed (Figure 4, Figure 5, Figure 6). At constant transverse feed, 20 mm shoulder diameter tool gives better strength than other tools (Figure 7).

The strength depends upon the heat generated during FSW welding and heat is mainly produced by rotational speed, feed and plunge force. If feed rate is very slow it means heat is generating due to friction but is not transferring away to the weld line very fast.

The transverse feed is inversely proportional to the strength of welded part. The main important factor of FSW for better strength is mixing of material in plastic state.

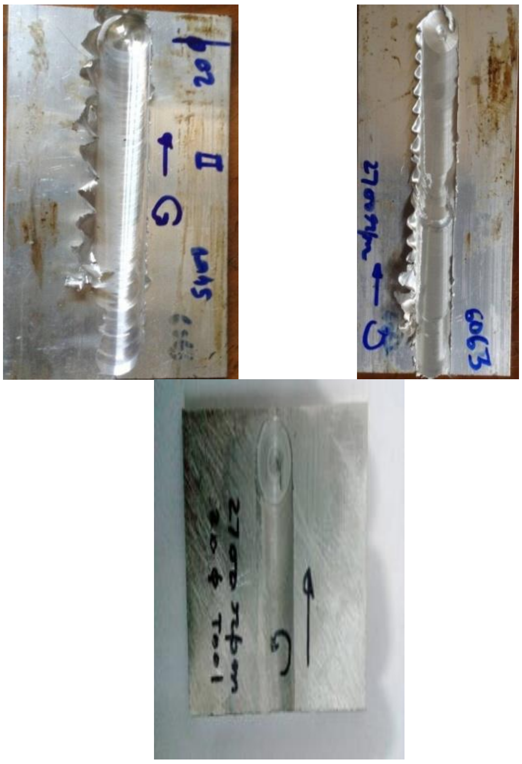

Figure 3. B. Welded samples

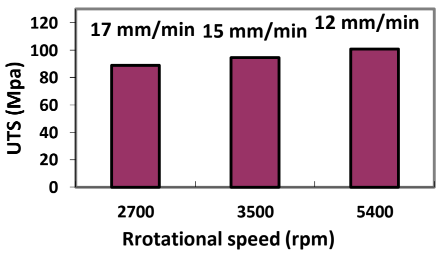

Figure 4. Variation of tensile strength with rotational speed by tool of 22 mm shoulder diameter

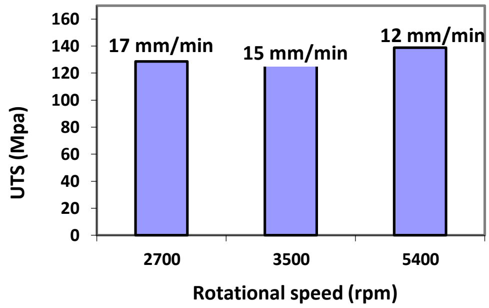

Figure 5. Variation of tensile strength with rotational speed by tool of 20 mm shoulder diameter

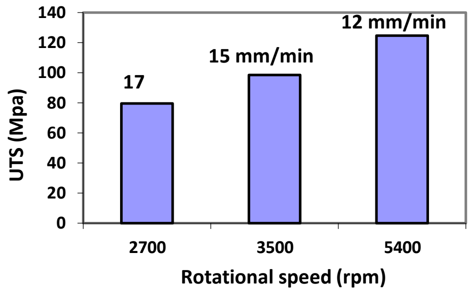

Figure 6. Variation of tensile strength with rotational speed by tool of 17 mm shoulder diameter

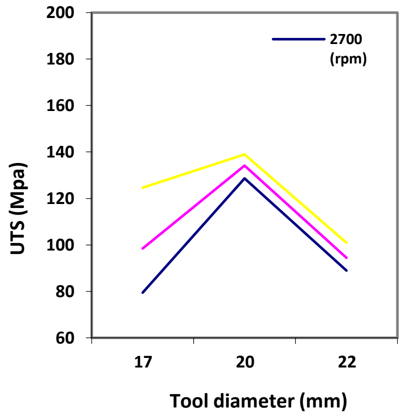

Figure 7. Variation of strength with shoulder diameter of tool

The mixing depends on the tool geometry (shoulder diameter, pin diameter, pin length and pin profile). The 17 mm diameter tool has less strength due to insufficient heat generated by shoulder diameter. This is the reason of low strength by this tool. And the same thing is happening with larger shoulder diameter tool where more heat is transferred to base material other than nugget zone (weld line). Response surface method is used to design experiments and determine the weld tensile strength and it is found that increasing clay content in the base material increases its tensile strength but decreases the weld tensile strength; such that in the specimens with 0, 3 and 6% clay content, the weld tensile strength equals to 94, 80 and 61 percent of the respective base materials [17].

3. 2. Optimization of Process Parameters of FSW Welding Taguchi optimization technique is applied under the condition that maximum is best (strength). The three factors and three levels are selected for design. The factors are process parameters of FSW (rotational speed, feed, and shoulder diameter) [18]. The response is selected as ultimate tensile strength. The three level for rotational speeds are 2700, 3500, 5400 rpm, for transverse feed of 12, 15 and 17 mm/min and tool shoulder diameter of 17, 20 and 22 mm (Table 4). From the above design the optimum condition for FSW are 5400 rotational speed, 12 mm/min feed and 20 mm shoulder diameter tool (Figure 8). It means maximum rotational speed and minimum transverse feed are desirable for better tensile strength.

Yousif et al. [19] developed a model for the investigation and simulation of the relationship between the FSW parameters of aluminum (Al) plates and mechanical properties.

TABLE 4. Taguchi analysis

Sr. No.	Rotational speed (rpm)	Feed (mm/min)	UTS (MPa)	Tool shoulder diameter (mm)
1	2700	17	88.9	22
2	3500	15	94.43	22
3	5400	12	95.87	22
4	2700	17	128.67	20
5	3500	15	134.08	20
6	5400	12	138.91	20
7	2700	17	79.40	17
8	3500	15	98.39	17
9	5400	12	124.6	17

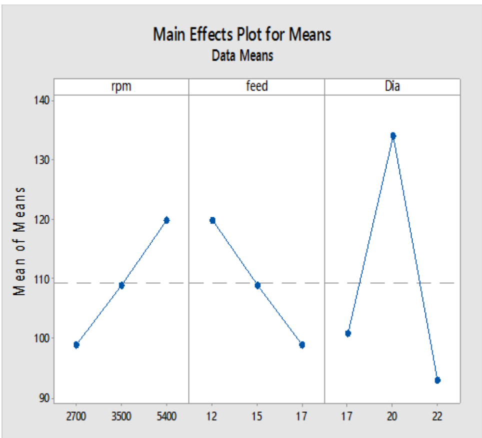

Figure 8. Taguchi analysis of process parameters

The input parameters of the model consisted of weld speed and tool rotation speed and finally they compared the measured and calculated data and found that calculated results were in good agreement with measured data. Nikoi et al. [20] examined the strength of Polypropylene Composite through Box-Behnken test and concluded that amplitude, welding time, amount of GF and air pressure were the most significant factors affecting the weld tensile-shear strength.

3. 3. Regression Analysis (Fit of Graph) From the regression of analysis a relationship between ultimate tensile strength with rotational speed, feed and tool shoulder diameter can be obtained approximately. (Figure 9, Figure 10. B). The above analysis shows the linear relationship between tool rotational speed, feed rate and ultimate tensile strength.

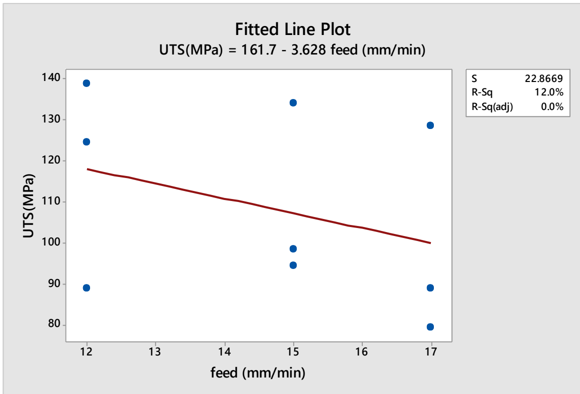

Figure 9. Variation of tensile strength with transverse feed (linear)

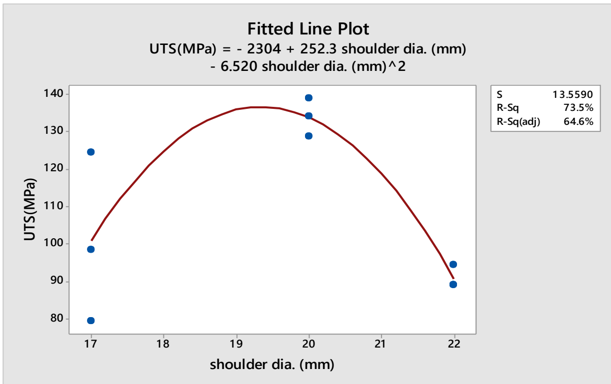

Figure 10. A. variation of UTS with shoulder diameter (quadratic)

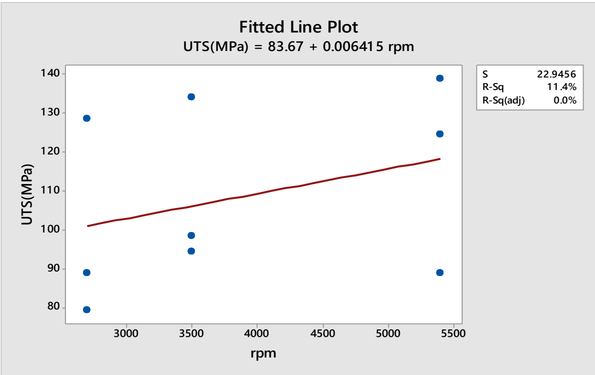

Figure 10. B. Variation of UTS with rotational speed (linear)

But there is a quadratic relationship between tool shoulder diameter and ultimate tensile strength (Figure 10. A). The surface plot of these parameters are shown in Figure 11. A, Figure 11. B and Figure 11. C. From the above Taguchi design analysis surface plot is obtained for ultimate tensile strength with rotational speed (2700, 3500, 5400 rpm), feed (12, 15, 17 mm/min) and shoulder diameter (17, 20, 22 mm).

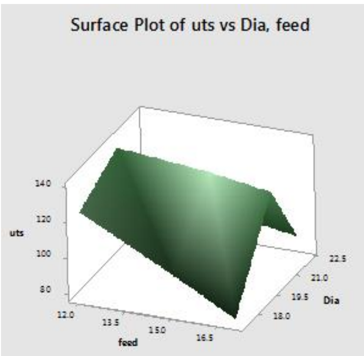

Figure 11. A. Variation of UTS with feed and shoulders diameter

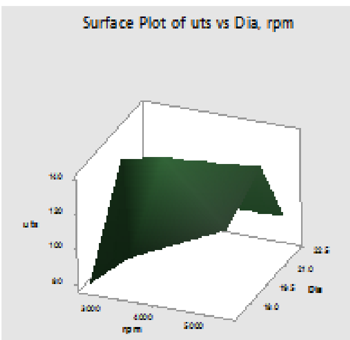

Figure 11. B. Variation of UTS with rotational speed and shoulders diameter

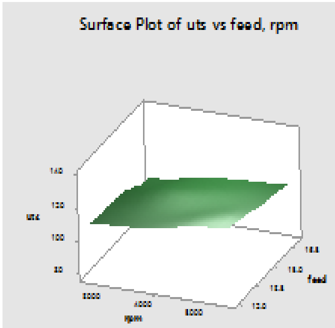

Figure 11. C. Variation of UTS with rotation and feed (Response Graph)

4. CONCLUSION

Tensile strength is increasing with rotational speed and decreasing with increasing transverse feed because frictional heat is directly proportional to rotational speed of tool. For low transverse feed heat will not transfer rapidly along the weld line so that low feed helps in better strength. Tensile strength is optimum with 20 mm shoulder diameter tool and 5400 rotational speed and 12 mm/min transverse feed for 5 mm thick plate of AA6063. For larger shoulder diameter, generated frictional heat will not concentrate near the weld line so 22 mm shoulder diameter tool does not provide maximum UTS as compared to 20 mm tool. The converted vertical milling machine capacity is very low (2.5 kW) so more rotational speed is required for welding of 5 mm thick plate of AA6063.

5. ACKNOWLEDGEMENT

The authors would like to thanks to Mr. Hashmat Ali Khan, Mr. Sahabuddin and Arshad Ali Khan from University Polytechnic, Jamia Millia Islamia, New Delhi for their help in development of FSW set up by conventional milling machine.

6. REFERENCES

1. Chen, H.-B., Yan, K., Lin, T., Chen, S.-B., Jiang, C.-Y. and Zhao, Y., "The investigation of typical welding defects for 5456 aluminum alloy friction stir welds", ***Materials Science and Engineering: A***, Vol. 433, No. 1, (2006), 64-69.
2. Schmidt, H. and Hattel, J., "A local model for the thermomechanical conditions in friction stir welding", ***Modelling and Simulation in Materials Science and Engineering***, Vol. 13, No. 1, (2004), 77-93.
3. Feulvarch, E., Gooroochurn, Y., Boitout, F., Bergheau, J., David, S., DebRoy, T., Lippold, J., Smartt, H. and Vitek, J., "3D modelling of thermofluid flow in friction stir welding", ***Trends in Welding Research, Proceedings***, (2006), 261-266.
4. Aval, H. J., Serajzadeh, S. and Kokabi, A., "Theoretical and experimental investigation into friction stir welding of AA

5086", ***The International Journal of Advanced Manufacturing Technology***, Vol. 52, No. 5, (2011), 531-544.

5. Elangovan, K. and Balasubramanian, V., "Influences of tool pin profile and tool shoulder diameter on the formation of friction stir processing zone in aa6061 aluminium alloy", ***Materials & Design***, Vol. 29, No. 2, (2008), 362-373.
6. Shen, Z., Chen, Y., Haghshenas, M. and Gerlich, A., "Role of welding parameters on interfacial bonding in dissimilar steel/aluminum friction stir welds", ***Engineering Science and Technology, an International Journal***, Vol. 18, No. 2, (2015), 270-277.
7. Zhang, Y., Sato, Y. S., Kokawa, H., Park, S. H. C. and Hirano, S., "Microstructural characteristics and mechanical properties of Ti–6Al–4V friction stir welds", ***Materials Science and Engineering: A***, Vol. 485, No. 1, (2008), 448-455.
8. Su, J., Wang, J., Mishra, R. S., Xu, R. and Baumann, J. A., "Microstructure and mechanical properties of a friction stir processed Ti–6Al–4V alloy", ***Materials Science and Engineering: A***, Vol. 573, (2013), 67-74.
9. Cox, C. D., Gibson, B. T., Strauss, A. M. and Cook, G. E., "Effect of pin length and rotation rate on the tensile strength of a friction stir spot-welded al alloy: A contribution to automated production", ***Materials and Manufacturing Processes***, Vol. 27, No. 4, (2012), 472-478.
10. Bahemmat, P., Haghpanahi, M., Besharati, M., Ahsanizadeh, S. and Rezaei, H., "Study on mechanical, micro-, and macrostructural characteristics of dissimilar friction stir welding of AA6061-T6 and AA7075-T6", ***Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture***, Vol. 224, No. 12, (2010), 1854-1864.
11. Sundaram, N. S. and Murugan, N., "Tensile behavior of dissimilar friction stir welded joints of aluminium alloys", ***Materials & Design***, Vol. 31, No. 9, (2010), 4184-4193.
12. Elangovan, K., Balasubramanian, V. and Valliappan, M., "Effect of tool pin profile and tool rotational speed on mechanical properties of friction stir welded aa6061 aluminium alloy", ***Materials and Manufacturing Processes***, Vol. 23, No. 3, (2008), 251-260.
13. Vijayan, S., Raju, R. and Rao, S. K., "Multiobjective optimization of friction stir welding process parameters on aluminum alloy AA 5083 using taguchi-based grey relation analysis", ***Materials and Manufacturing Processes***, Vol. 25, No. 11, (2010), 1206-1212.
14. Rambabu, G., Naik, D. B., Rao, C. V., Rao, K. S. and Reddy, G. M., "Optimization of friction stir welding parameters for improved corrosion resistance of AA2219 aluminum alloy joints", ***Defence Technology***, Vol. 11, No. 4, (2015), 330-337.
15. Rodriguez, R., Jordon, J., Allison, P., Rushing, T. and Garcia, L., "Microstructure and mechanical properties of dissimilar friction stir welding of 6061-to-7050 aluminum alloys", ***Materials & Design***, Vol. 83, (2015), 60-65.
16. Langaria, J., Kolahana, F. and Aliakbarib, K., "Effect of tool speed on axial force, mechanical properties and weld morphology of friction stir welded joints of A7075-T651", ***International Journal of Engineering***, Vol. 29, (2016).
17. Rezaei, G. and Arab, N. B. M., "Investigation on tensile strength of friction stir welded joints in pp/epdm/clay nanocomposites", ***International Journal of Engineering-Transactions C: Aspects***, Vol. 28, No. 9, (2015), 1382-1391.
18. Mohamadreza, N., Abbas S, M. and Spiro, Y., "Taguchi optimization of process parameters in friction stir welding of 6061 aluminum alloy: A review and case study", ***Engineering***, Vol. 2011, (2011).
19. Yousif, Y., Daws, K. and Kazem, B., "Prediction of friction stir welding characteristic using neural network", ***Jordan Journal of Mechanical and Industrial Engineering***, Vol. 2, No. 3, (2008).
20. Nikoi, R., Sheikhi, M. and Arab, N. B. M., "Experimental analysis of effects of ultrasonic welding on weld strength of polypropylene composite samples", ***International Journal of Engineering-Transactions C: Aspects***, Vol. 28, No. 3, (2014), 447-453.

Effect of Friction Stir Welding on the Tensile Properties of AA6063 under Different Conditions

R. Singh[a], S. A. Rizvi[b], S. P. Tewari[c]

[a] *Shri Ramswaroop Memorial University, Barabanki, INDIA*
[b] *Department of Mechanical Engineering IIT(BHU), Varanasi, INDIA & Faculty member in U. P, Jamia Millia Islamia, New Delhi*
[c] *Department of Mechanical Engineering IIT(BHU), Varanasi, INDIA*

P A P E R I N F O

Paper history:
Received 19June 2016
Received in revised form 26 December 2017
Accepted 09 February 2017

Keywords:
Aluminium Alloys
Friction Stir Welding
Taguchi Technique
Mechanical Properties

چکیده

هدف اصلی پژوهش حاضر بررسی اثر پارامترهای اصلی جوشکاری اصطحکاکی اغتشاشی (FSW) بر کیفیت جوش صفحه AA 6063 بود. جوشکاری AA6063 توسط یک ماشین فرز عمودی با استفاده از ابزار های مختلف با یک شانه ثابت انجام شد و در طول جوشکاری از هیچ سیستم گرمایش خارجی استفاده نشد. پارامترهای جوشکاری مختلف مورد مطالعه سرعت دورانی ابزار که از ۲۷۰۰ تا ۵۴۰۰ (دور در دقیقه) بود، سرعت گذشتن از جدول که از ۱۲ تا ۱۷ (میلی متر/ دقیقه) بود، و قطر ابزار شانه که از ۱۷ تا ۲۲ میلی متر بود. در پژوهش حاضر سه سطح، سه طراحی فاکتوریل برای بهینه سازی به روش تاگوچی استفاده شد. نتایج نشان داد که استحکام کششی اتصال جوش با سرعت چرخش افزایش یافت و با افزایش خوراک عرضی کاهش پیدا کرد زیرا که حرارت اصطکاکی به طور مستقیم با سرعت چرخش ابزار متناسب بود.

***doi**: 10.5829/idosi.ije.2017.30.04a.19*