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Influence of Friction Stir Welding Variables on Surface Appearance of Joints Produced in SSM Cast A356 Aluminum Alloy

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Abstract

As a solid-state welding process, friction stir welding (FSW) offers several advantages over conventional fusion welding processes. However, the FSW process has been introduced to the world in recent decades but it quickly caught the attention of manufacturing companies. Tool travel speed (ν) and tool rotation speed (ω) are the main parameters of FSW process that can affect the weld surface appearance. Aluminum alloys with a wide range of properties are widely used in various industries such as aircraft, automotive, and aerospace applications. The effects of FSW process parameters on the weld surface appearance in SSM cast A356 aluminum alloy were investigated in this study. For this aim, the tool travel speeds and tool rotation speeds were chosen as 45, 60, and 75 mm/min, and 400, 600, and 800 rpm, respectively, and FSW samples were produced using various combinations of process parameters. Having finished the welding process, a visual inspection was performed on the surface of all welding samples at room temperature.

1. Introduction

Welding is an important joining process because of high joint efficiency, simple set up, flexibility and low fabrication cost [1]. So far, various welding processes have been introduced to the world, each of which has many benefits and applications such as electric arc welding processes, resistance welding processes, friction welding, gas welding process, electron beam welding process, etc. Friction stir welding (FSW) is a new and a very effective solid-state joining technique invented in TWI in Cambridge, England in 1991 for joining aluminum alloys [2]. It is technically a simple process where a non-consumable rotating tool with a specially designed pin profile and shoulder is inserted into the abutting edges of metal sheets or plates to be joined and traversed along the line of joint [3,4]. Compared to conventional fusion welding methods, the advantages of the FSW process include better mechanical properties, low residual stress and distortion, and reduced occurrence of defects [2,3]. In the past two decades, numerous researches focused on this process since it is characterized by being energy efficient, versatile, and no localized melting and shielding gas are required [3,5]. There are many welding parameters which influence the surface appearance of a FSW joint such as tool travel speed and tool rotation speed. Due its corrosion resistance and light weight among other properties, aluminum and its alloys are part of the major engineering materials, and indispensable for various industries. As a result of its wide areas of applications, aluminum and its alloys keep on attracting different areas of research [6]. Non-destructive tests (NDT) are widely applied to inspect the base materials and joints in various industries. This type of tests has a special place in the welding industry. One of the advantages of nondestructive tests is the ability to perform on a specimen for many times. The common non-destructive tests applied in industry are classified in following: (a) Visual Test (VT): It is one of the most important techniques for evaluating base materials and welded joints. This technique is widely used as an initial inspection method in all industries. Although this technique is only able to evaluate the surface of the sample due to the limitations of the human eye, it has always been of interest to welding researchers. (b) Penetrant Liquids Test (PT): It is based on capillary action in liquids. This method can detect only surface discontinuities but its accuracy is somewhat more than VT. (c) Magnetic Particles Test (MT): It is based on magnetic flux leakage. This method can detect surface and subsurface discontinuities. Its accuracy is more than VT and PT. (d) Ultrasonic Test (UT): It uses ultrasound waves. This method can detect both surface and internal discontinuities. This method has accuracy more than previous methods. It also can be applied to measure the specimen thickness. (e) Radiography Test (RT): It uses X-ray and gamma-ray. These rays have very short wavelength and are able to arrive into specimen.

2. Methodology

In this study, the examinations were carried out on A356 aluminum alloy plates with 275 mm × 100 mm × 8 mm size. The chemical composition of the base material is given in Table 1. Before the welding process, the aluminum oxide layers were removed from the base material surface by grinding, and then the edges were cleaned. The square butt joint configurations were prepared to produce the FSW samples, and two clamps were used to prevent the workpieces from moving during welding operations.

Table 1: Chemical composition of the base material

Base Metal	Al	Si	Mg	Fe	Ti	Cu	Mn	Cr	Ni	Sr
% wt.	Balance	7.28	0.35	0.18	0.12	0.006	0.0065	0.005	0.005	0.039

The tool was tilted 4º from the plate normal direction, and the welding tool parameters including shoulder diameter, pin diameter, and pin length of 12, 4, and 5 mm, respectively were applied in this study. The tool travel speeds and tool rotation speeds were chosen as 45, 60, and 75 mm/min, and 400, 600, and 800 rpm, respectively, and totally nine FSW samples were produced using various combinations of process parameters. The welding operations were carried out at room temperature in a flat position. Having finished the welding process, a visual inspection was performed as much as possible to evaluate the surface appearance of the FSW samples and reveal the welding defects on the samples surface.

3. Results and Discussion

The effects of the FSW process parameters on the weld surface appearance in SSM cast A356 aluminum alloy were studied in this work, and the results are shown in Figs. 1-3. As seen in Figs. 1-3, a keyhole defect remains at the end of the weld line in all welding conditions used in this study. The keyhole at the end of a conventional FSW joint is one of the major concerns in certain applications [7]. This defect is unfavorable due to high stress concentration point and weaken the FSW joint mechanical properties [8].

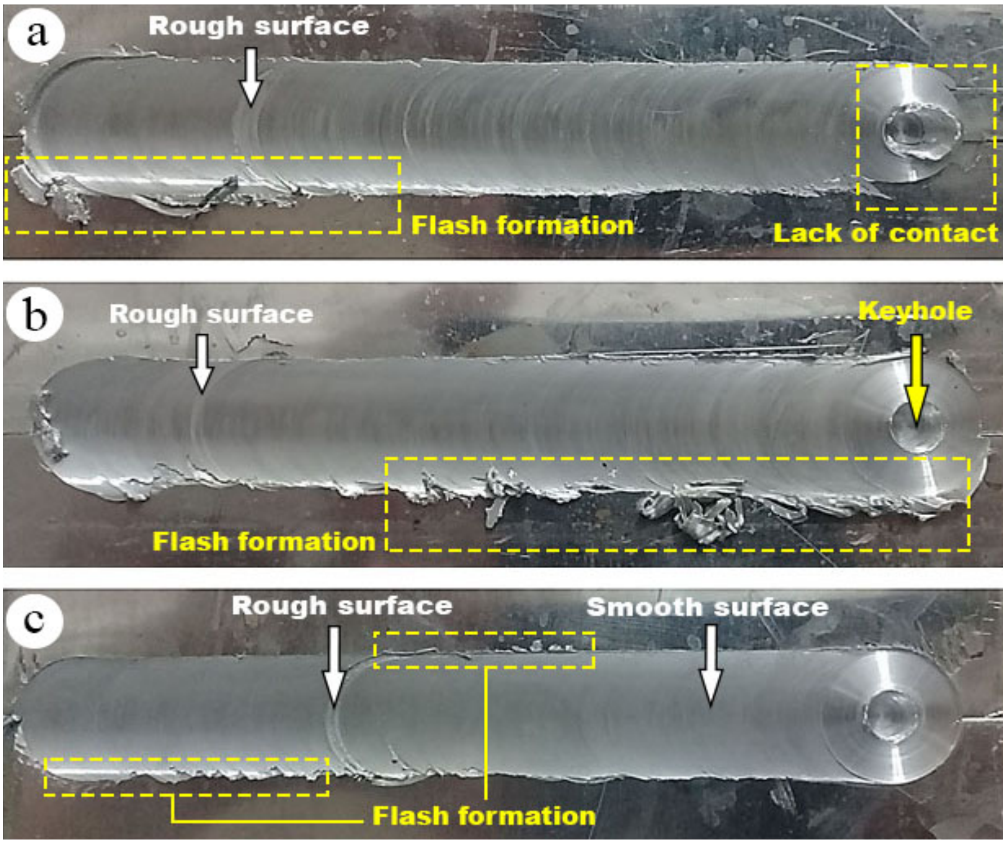

Figure 1. Surface appearance of the FSW samples at tool rotation speed of 400 rpm and tool travel speeds of (a) 45, (b) 60, and (c) 75 mm/min.

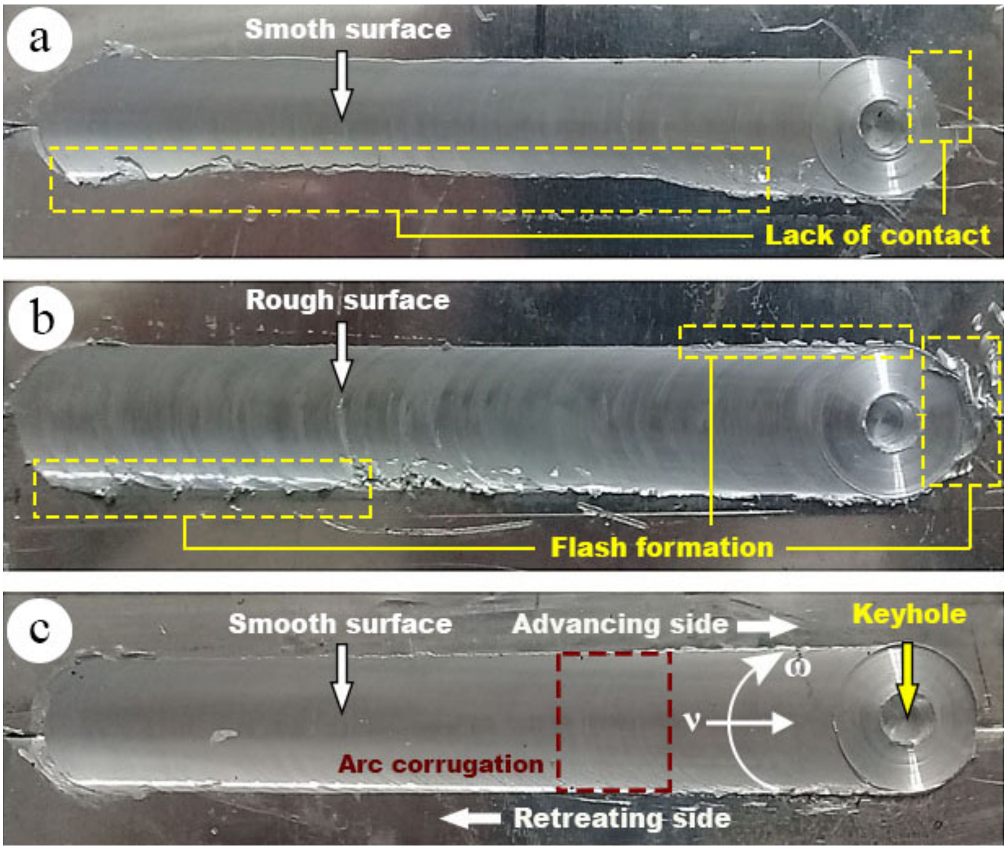

Figure 2. Surface appearance of the FSW samples at tool rotation speed of 600 rpm and tool travel speeds of (a) 45, (b) 60, and (c) 75 mm/min.

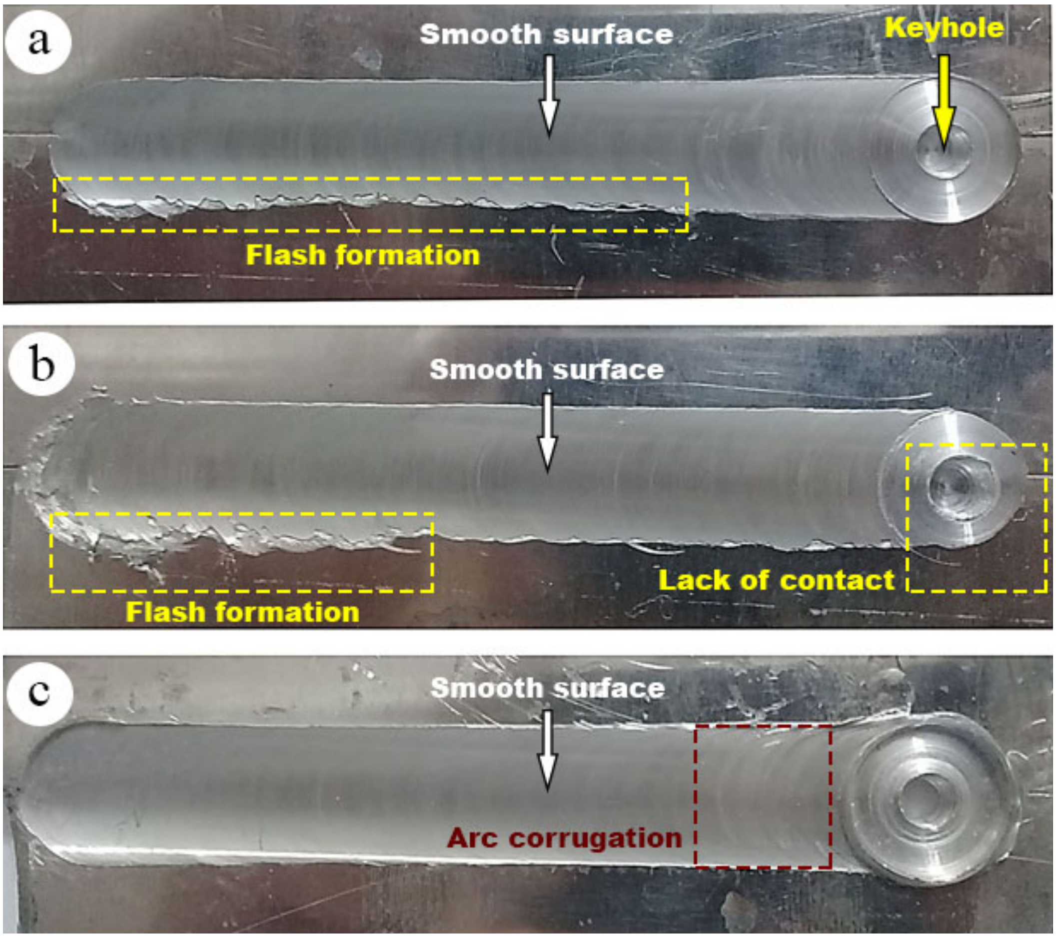

Figure 3. Surface appearance of the FSW samples at tool rotation speed of 800 rpm and tool travel speeds of (a) 45, (b) 60, and (c) 75 mm/min.

A keyhole is the weakest part of the FS welded zone. Therefore, the keyhole of the FSW must be repaired or eliminated in order to obtain defect-free zone at retracting phase [9]. Fig. 1 shows the surface appearance of the FSW samples at a tool rotation speed of 400 rpm and tool travel speeds of 45, 60, and 75 mm/min. As shown in Fig. 1, the rough surface regions with lateral flashes outside of the weld line appear in the FSW samples produced at all tool travel speeds in this study. From observations, the flashes formed at tool travel speeds of 45 and 60 mm/min are obvious while at a tool travel speed of 75 mm/min are small. In addition, a lack of contact (LOC) defect between the tool shoulder and the surface of the workpiece is formed at the end of the weld line at a tool travel speed of 45 mm/min. Flash is resulting from the outflow of the plasticized material from underneath of the shoulder [10].

Therefore, the lateral flash as a common defect in the FSW process appears often on the top surface and around the weld line. The defects like lateral flash reduce the quality of welding joints and impact the manufacturing cost [11,12]. In addition, flash defect severely affects the mechanical properties of a welding joint due to the reduction of the effective thickness of the workpiece in the joint area. Fig. 2 shows the surface appearance of the FSW samples produced at a tool rotation speed of 600 rpm and tool travel speeds of 45, 60, and 75 mm/min. The observations illustrate that the surface of the FSW sample produced at a tool rotation speed of 600 rpm and tool travel speed of 75 mm/min (Fig. 2-c) is smooth and sound which except keyhole, there is no noticeable defect on the surface. However, such a smooth surface is also formed in the FSW sample produced at a tool travel speed of 45 mm/min but the lack of contact defect between the tool shoulder and the surface of the workpiece is observed at the end and in a large part of the weld line. The rough surface regions with small and obvious flashes are appeared in the FSW sample produced at a tool travel speed of 60 mm/min. Fig. 3 shows the surface appearance of the FSW samples at a tool rotation speed of 800 rpm and tool travel speeds of 45, 60, and 75 mm/min. As shown in Fig. 3, a smooth surface is obtained in the FSW samples produced at all tool travel speeds. However, the tool travel speeds of 45 and 60 mm/min lead to the formation of the small flashes and obvious flashes, respectively, outside of the weld line (Figs. 3-a and b), and in addition, a lack of contact defect between the tool shoulder and the surface of the workpiece is observed at the end of the weld line at a tool travel speed of 60 mm/min. The surface views of the FSW samples illustrate that the surface of the FSW sample produced at a tool rotation speed of 800 rpm and tool travel speed of 75 mm/min (Fig. 3-c) is smooth and sound which except keyhole, there is no noticeable defect on the surface. Influence of friction stir welding variables on hardness, UTS, and yield strength of joints produced in SSM Cast A356 aluminum alloy (nine joints shown in the present article) was studied in detail in our previous literature [13]. Also, there are many published studies [14-23] on the quality, mechanical properties, and microstructure of the weld or welding joints produced by friction stir welding in various alloys.

Conclusion

The effects of the FSW process parameters on the surface conditions of joints produced in SSM Cast A356 aluminum alloy were studied in this work. According to the results, keyhole defect remained at the end of the weld line in all welding conditions. The surface appearance of the FSW sample was more desirable with fewer defects at a higher tool rotation speed. A sound and high-quality surface was achieved for the FSW sample in these conditions. Such a trend also was observed at higher tool travel speeds. It seems that the conditions of (600 rpm # 75 mm/min) and (800 rpm # 75 mm/min) are the optimum states in this study for producing a FSW sample with the best surface appearance and with minimal defects whereas the lowest tool rotation speed and tool travel speed (400 rpm # 45 mm/min) caused the most unfavorable surface conditions with many defects for the FSW sample.

References

1. E. Armentani, R. Esposito and R. Sepe, The effect of thermal properties and weld efficiency on residual stresses in welding, *Journal of Achievements in Materials and Manufacturing Engineering*, 20 (2007) 319-322.
2. W.M. Thomas, E.D. Nicholas, J.C. Needham, M.G. Murch, P. Templesmith and C.J. Dawes (1991) International Patent Application No. PCT/GB92/02203 and GB Patent Application No. 9125978.8.
3. R.S. Mishra and Z.Y. Ma, Friction stir welding and processing, *Materials Science and Engineering R*: *Reports*, 50 (2005) 1-78. https://doi.org/10.1016/j.mser.2005.07.001
4. W.M. Thomas, K.I. Johnson and C.S. Wiesner, Friction stir welding - Recent developments in tool and process technologies, *Advanced Engineering Materials*, 5 (2003) 485-490. https://doi.org/10.1002/adem.200300355
5. M.M.E. Rayes, M.S. Soliman, A.T. Abbas, D.Y. Pimenov, I.N. Erdakov and M.M. Abdel-mawla, Effect of feed rate in FSW on the mechanical and microstructural properties of AA5754 joints, *Advances in Materials Science and Engineering*, (2019) Article ID 4156176. https://doi.org/10.1155/2019/4156176
6. O.I. Oluwole and O.J. Ajibade, Effect of welding current and voltage on the mechanical properties

of wrought (6063) aluminum alloy, *Materials Research*, 13 (2010) 125-128. https://doi.org/10.1590/S1516-14392010000200002
7. L. Deng, S. Li, L. Ke, J. Liu and J. Kang, Microstructure and fracture behavior of refill friction stir spot welded joints of AA2024 using a novel refill technique, *Metals*, 9 (2019) 1-12. https://doi.org/10.3390/met9030286
8. Li Peilin, Xu Zhongfeng, Yu Chun, Lu Hao, Yao Junshan and Chen Guoyu, Mechanical properties and microstructure analysis of refilling friction stir welding on 2219 aluminum alloy, *Acta Metallurgica Sinica*, 25 (2012) 225-234. 10.11890/1006-7191-123-225
9. K.P. Mehta and R. Patel, On FSW keyhole removal to improve volume defect using pin less tool, *Key Engineering Materials*, 821 (2019) 215-221. https://doi.org/10.4028/www.scientific.net/KEM.821.215
10. J. Adamowski and M. Szkodo, Friction stir welds (FSW) of aluminum alloy AW6082-T6, *Journal of Achievements in Materials and Manufacturing Engineering*, 20 (2007) 403-406.
11. C. Patil, He. Patil and Hi. Patil, Investigation of weld defects in similar and dissimilar friction stir welded joints of aluminum alloys of AA7075 and AA6061 by x-ray radiography, *American Journal of Materials Engineering and Technology*, 4 (2016) 11-15. 10.12691/materials-4-1-3
12. B. Raj, T. Jayakumar and M. Thavasimuthu, Practical non-destructive testing, Woodhead Publishing (2002) pp.184.
13. A. Honarbakhsh-Raouf, H.R. Ghazvinloo and N. Shadfar, Influence of friction stir welding variables on hardness, UTS and yield strength of joints produced in SSM Cast A356 aluminum alloy, *Australian Journal of Basic and Applied Sciences*, 4 (2010) 3010-3015.
14. A. Abbas and H.H. Abdulkadhum, Effect of shoulder-workpiece interference depth on the quality of friction stir welding of AA7075-T6 aluminum alloy, *Association of Arab Universities Journal of Engineering Sciences* 26(1) (2019) 150-159. http://dx.doi.org/10.33261/jaaru.2019.26.1.020
15. M.M.Z. Ahmed, M.I.A. Habba, M.M.El-Sayed Seleman, K. Hajlaoui, S. Ataya, F.H. Latief and A. E.EL-Nikhaily, Bobbin tool friction stir welding of aluminum thick lap joints: Effect of process parameters on temperature distribution and joints' properties, *Materials,* 14(16) (2021) 4585. https://doi.org/10.3390/ma14164585
16. D. mezrah, L. Kosec, T. Pepelnjak and J. Tušek, Microstructure and mechanical properties of friction stir welded AlMg4.5Mn alloy, *Engineering Review*, 32(2) (2012) 104-110.
17. N. Merah, M. Abdul Azeem, H.M. Abubaker, F. Al-Badour, J. Albinmousa and A.A. Sorour, Friction stir processing influence on microstructure, mechanical, and corrosion behavior of steels: A Review, Materials, 14(17) (2021) 5023. https://doi.org/10.3390/ma14175023
18. D.M. Rodrigues, A. Loureiro, C. Leitao, R.M. Leal, B.M. Chaparro and P. Vilaça, Influence of friction stir welding parameters on the microstructural and mechanical properties of AA 6016-T4 thin welds, *Materials & Design*, 30 (2009) 1913-1921. https://doi.org/10.1016/j.matdes.2008.09.016
19. H.I. Dawood, Kahtan S. Mohammed, Azmi Rahmat and M.B. Uday, Effect of small tool pin profiles on microstructures and mechanical properties of 6061 aluminum alloy by friction stir welding, *Transactions of Nonferrous Metals Society of China*, 25 (2015) 2856-2865. https://doi.org/10.1016/S1003-6326(15)63911-5
20. I. Radisavljevic, A. Zivkovic, N. Radovic and V. Grabulov, Influence of FSW parameters on formation quality and mechanical properties of Al 2024-T351 butt welded joints, *Transactions of Nonferrous Metals Society of China*, 23 (2013) 3525-3539. https://doi.org/10.1016/S1003-6326(13)62897-6

21. Umasankar Das, Ratnakar Das and Vijay Toppo, Analysis of some mechanical properties of friction stir welded joints of AA6101 and AA6351 aluminum alloys under T6 condition, *Materials Today: Proceedings*, 44, Part 1 (2021) 2700-2704. https://doi.org/10.1016/j.matpr.2020.12.685
22. M. Azizieh, A. Sadeghi Alavijeh, M. Abbasi, Z. Balak and H.S. Kim, Mechanical properties and microstructural evaluation of AA1100 to AZ31 dissimilar friction stir welds, *Materials Chemistry and Physics*, 170 (2016) 251-260. https://doi.org/10.1016/j.matchemphys.2015.12.046
23. A.-M. El-Batahgy, B. Terad and A. Omar, Effect of friction stir welding parameters on properties of AA6061 aluminum alloy butt welded joints, *Proceedings of the 1st International Joint Symposium on Joining and Welding*, Woodhead Publishing, 2013, pp. 33-40. https://doi.org/10.1533/978-1-78242-164-1.33

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