American Journal of Materials Engineering and Technology, 2016, Vol. 4, No. 1, 11-15
Available online at http://pubs.sciepub.com/materials/4/1/3

DOI:10.12691/materials-4-1-3

Investigation of Weld Defects in Similar and Dissimilar Friction Stir Welded Joints of Aluminium Alloys of AA7075 and AA6061 by X-ray Radiography

Chetan Patil[1], Hemant Patil[2], Hiralal Patil[3,*]

[1]Mechanical Department, PSE, Saki-Palsana, Gujarat, India
[2]Mechanical Department, D. N. Patel C.O.E., Shahada, Maharashtra, India
[3]Mechanical Department, GDEC, Abrama, Gujarat, India
*Corresponding author: hspatil28@gmail.com

Abstract X-ray radiography techniques are used for evaluation of the quality of the friction stir welded aluminium butt joints. This paper reports X-ray radiography testing conducted on similar friction stir welds between $AA7075T_{651}$ aluminium alloy and dissimilar friction stir welds between aluminium alloys $AA7075T_{651}$ and $AA6061T_6$. The Friction stir welds of AA7075 & AA6061 aluminium alloy were produced at different tool rotational speeds and transverse speed. The tool rotational speed was varied from 800, 900, 1000 rpm while the transverse speed was varied from 30, 35, 40mm/min. The visual inspection and the x-ray radiographic testing techniques were employed to conduct the tests; these tests were conducted on the welds to ascertain the joint integrity before characterization to have an idea of the quality of the welds. In visual defects, the lateral flash was observed in most of the welds, but the x-ray radiography technique revealed the presence of lack of penetrations flaws in all weld samples and cracks, voids, wormhole defects in some of the welds. It was found that increasing the transverse speed increases the occurrence of weld defects.

Keywords: *FSW, rotation speed, transverse speed, radiography*

Cite This Article: Chetan Patil, Hemant Patil, and Hiralal Patil, “Investigation of Weld Defects in Similar and Dissimilar Friction Stir Welded Joints of Aluminium Alloys of AA7075 and AA6061 by X-ray Radiography.” *American Journal of Materials Engineering and Technology*, vol. 4, no. 1 (2016): 11-15. doi: 10.12691/materials-4-1-3.

1. Introduction

Friction Stir Welding (FSW), a solid state joining process was developed and patented by The Welding Institute (TWI) in 1991 [1]. This, which is currently being developed for difficult to- weld high strength aluminium alloys such as 2xxx and 7xxx series Over the last decade, frictions stir welding (FSW) has offered excellent welding quality to the joining of many alloys such as aluminum alloys [2,3] magnesium alloys [4] , Copper alloys [5], and steel alloys [6,7]. It is a new and promising welding process which welds the material below its melting temperature and it has shown superior features such as excellent joint performance, mechanical properties and low energy consumption. However many defects like porosity, kissing bong, solid inclusion and linear crack cavity or groove like defects, large mass of flash out are reported due to improper heat input during the process [8,9]. It reduces the quality of weld joints and impacts the manufacturing cost. Thus it is required to detect the defects in FSW by using non-destructive test method. Non-destructive testing (NDT) is based on techniques that rely on the application of physical principles to determine the characteristics of materials and to detect and assess flaws or harmful defects without change of the usefulness or serviceability of materials [10]. There is a broad range of NDT methods based on different physical principles like ultrasonic, eddy currents evaluation, X-radiography, magnetic particles inspection and dye penetrant application. M. Moles et al [11] used ultrasonic and eddy currents arrays for inspection of friction stir welds in aluminum. L .S. Rosado et al [12] used eddy current probe to detect the imperfections in the friction stir welding of metals. Lie et al [13] have reported on multiple non-destructive testing methods on the FSW of AA 2219-T6. Hu *et al* [14] also employed a high-precision magnetic sensor to detect the weld defects in aluminium Friction stir welds. In this paper, X- radiography methods are used to study the defects in FSW. Radiography can detect flaws or discontinuities in welds such as cold lap, porosity, incomplete penetration or lack of penetration (lop), incomplete fusion, and internal concavity or suck back, internal & external undercut offset or mismatch, inadequate & excess weld reinforcement and cracks. Radiography technique is based upon exposing the components to short wavelength radiations in the form of X-rays of wavelength less than $0.001x10^{-8}$cm to about $40x10^{-8}$cm from a suitable source. The portion of the weldments where defects are suspected is exposed to X-rays emitted from the X-ray tube. During exposure, X-rays penetrate the welded object and thus affect the x-ray film.

2. Materials and Methods Used

2.1. Materials and Welding Procedure

Aluminium alloys AA7075-T651 and AA6061-T6 sheet was cut on shear machine and brought to required dimensions 150 mm x 70 mm x 6.35 mm. The FSW joints were produced for similar alloys AA7075 and dissimilar alloys AA7075 and AA 6061. The FSW welding parameter used in this experiment were tool rotation speed of 800 rpm, 900 rpm and 1000 rpm, transverse speed of 30 mm/min, 35 mm/min and 40 mm/min. The tool tilt was maintained 0^0 during the experiment and plunge depth was of 6mm throughout the weld path. Tool tip plunge feed 10 mm/min throughout the weld path. The plates to be welded by FSW process are fixed by a clamping fixture on a Joyti CNC vertical machining center PX20 series as shown in Figure 1. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was used to fabricate the FSW joint.

Figure 1. Friction stirs welding on VMC machine with FSW joint

The FSW tool employed was square trapezoidal pin of H13 tool steel material with dimensions of 4mm top face and 6mm bottom face, 20mm flat shoulder diameter and 6mm pin height. The chemical composition of base material is as shown in Table 1.

Table 1. Chemical Composition of Base Aluminium Alloys

Chemical Composition %											
AA7075T651	**Elements**	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Zr
	Required	0.4	0.5	1.2-2	0.3	2.1-2.9	0.18-0.28	-	5.1-6.1	0.2	-
	Contents	0.05	0.18	1.4	0.04	2.5	0.19	-	5.9	0.08	-
AA6061T6	**Elements**										
	Required	0.4-0.8	0.7	0.15-0.40.	0.15	0.8-1.2	0.04-0.35	-	0.25	0.15	-
	Contents	0.62	0.45	0.2	0.13	1.05	0.09	-	0.03	0.07	-

2.2. Radiography Method

X-Ray radiographic inspection was carried out on the welded plates using radiographic unit of china makes model XXQ-3005 as per radiography standard methods ASME section-article-22. The radiography exposure parameters are given in Table 2.

Table 2. Radiography Exposure Parameters

Voltage	210 KV
Developing Time & Temperature	5min/20^0
Exposure Time	30sec
Film Density	2.7d
RT Technique	S.W.S.I
Film Type	D-4 AGFA
RT Sensitivity	2%

3. Results and Discussion

3.1. Visual Inspection of Friction Stirs Welds

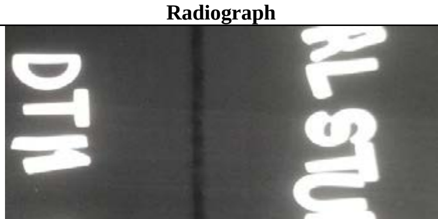
Perhaps the most straight forward and simplest inspection technique, visual inspection is an excellent means of inspecting for surface features including excess flash, galling, shoulder voids, and even weld misalignment. Visual inspection was performed on all welded samples in order to verify the presence of possible macroscopic external defects, such as surface irregularities, excessive flash, and surface-open tunnels. The lateral flash was observed in most of the welds, resulting from the outflow of the plasticized material from underneath of the shoulder. Figure 2 shows an example of joint with lateral flash.

Figure 2. Lateral flash in the joint FSW-A2

Table 3. Weld Photographs and Radiographs at rotational speed of 900rpm & different transverse speed

No.	Weld photo	Radiograph	Transverse speed	Observations
A			30mm/min	Lack of penetrations, Moderate mixing
B			35mm/min	Slight sign of lack of penetrations & wormhole defect , Good mixing
C			40mm/min	Lack of penetrations, wormhole defect, Sufficient mixing

Table 4. Weld Photographs and Radiographs at rotational speed of 800rpm & different transverse speed

No.	Weld photo	Radiograph	Transverse speed	Observations
D			30mm/min	Lack of penetrations Slight signs of incomplete fusion
E			35mm/min	Lack of penetrations, crack, voids
F			40mm/min	Lack of penetrations , wormhole defect, incomplete fusion, discontinuity at the joint interface

3.2. Radiographic Inspection of Friction Stirs Welds

The results of the radiographic tests conducted on all the similar FSW weld joints produced at rotation speed of 800, 900, 1000 rpm and transverse speed of 30, 35, 40mm/min are hereby presented in Table 3, Table 4, Table 5. The results of the radiographic tests conducted for dissimilar FSW weld joints produced at rotation speed of 650, 700rpm and transverse speed of 35, 40mm/min are hereby presented in Table 6, where base metal position has been changed on advancing side. These tables include the weld photograph, X-ray radiographs and the observations on each sample examined. From the X-ray radiographs presented in Table 3 at 900 rpm and 30, 35, 40 mm/min, it was observed that these welds are characterized with lack of penetration, slight sign of wormhole defect, but good mixing was also noticed. With reference to Table 4, Table 5 it was found that welds produced at a constant rotational speed of 800 & 1000 rpm respectively at varying transverse speed of 30, 35 and 40 mm/min has evidence of lack of penetrations , wormhole defect, incomplete fusion, cracks, discontinuity at the joint interface.

Further, radiograph was free from mottling effect, which is very common in fusion welding of aluminium plates.

Table 5. Weld Photographs and Radiographs at rotational speed of 1000rpm & different transverse speed

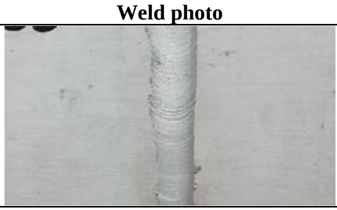
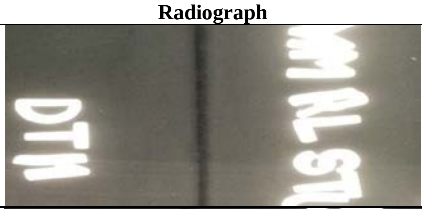
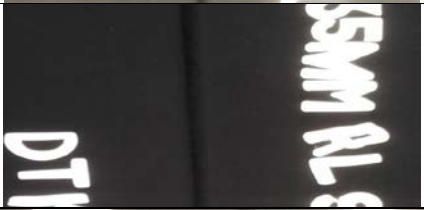
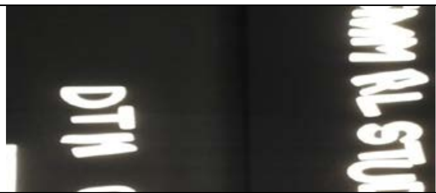
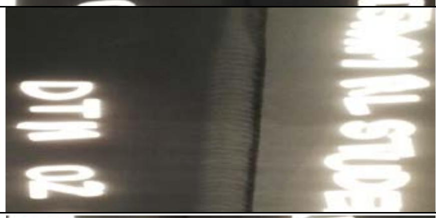
No.	Weld photo	Radiograph	Transverse speed	Observations
G			30mm/min	Lack of penetrations, Slight signs of incomplete fusion
H			35mm/min	Lack of penetrations, crack,, incomplete fusion
I			40mm/min	Lack of penetrations, hole left

Table 6. Weld Photographs and Radiographs at rotational speed of 650-700rpm & different transverse speed

No.	Weld photo	Radiograph	Weld Parameter	Observations
A1			700RPM, 40mm/min (AA6061 on Advancing side)	Lack of penetrations
A2			700RPM, 40mm/min (AA7075 on Advancing side)	Lack of penetrations, crack, incomplete fusion
A3			650RPM, 35mm/min (AA6061 on Advancing side)	Lack of penetrations,
A4			650RPM, 35mm/min (AA7075 on Advancing side)	Lack of penetrations, crack, wormhole defect

The defects found are mainly lack of penetrations, wormhole or voids. It can be seen from the results table that increasing the transverse speed increases the occurrence of defects. D has no apparent cracks of voids but revealed incomplete fusion while E shows lack of penetrations, crack, and voids. F shows lack of penetrations, wormhole defect, incomplete fusion, discontinuity at the joint interface. With regard to tool rotational speed, it is evident that the extent of mixing is directly related to the medium rotational speed of 900 rpm, thus a more consolidated weld is achieved. Figure 3 shows a graphical summary of the trends observed from the assessment of the radiographs. In dissimilar FSW joints it was observed that base metal 6061 positioned on advancing side have fewer defects in comparison with base metal AA7075 positioned on advancing side and that gives good mixing of materials.

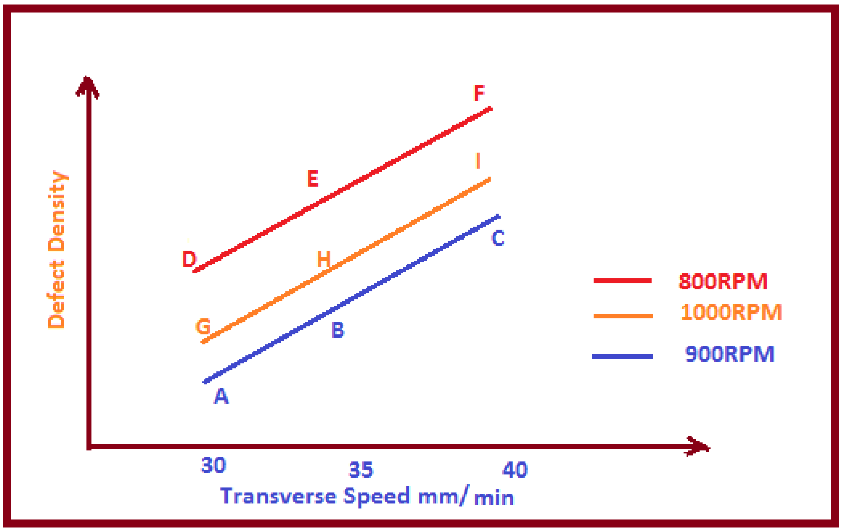


Figure 3. Defect density Vs. Transverse Speed (mm/min)

4. Conclusion

NDT techniques viz: visual inspection and radiography tests were successfully conducted on the welds of similar FSW joints of AA7075T651 aluminum alloys and dissimilar FSW joints of $AA7075T_{651}$ -$AA6061\text{-}T_6$ aluminum alloys at various weld parameter combinations. It can be concluded that the x-ray radiographic testing technique successfully detected the defects present in the welds and can be said to be appropriate in this regard. In all similar and dissimilar FSW joints lack of penetration defect was observed common in the radiograph, which could be eliminated simply by increasing the length of the pin profile. But in other weld samples, defects like crack, void, insufficient fusion and wormhole defect in addition to lack of penetration has been observed. An optimum rotational speed for producing defect-free welds of aluminium $AA7075T_{651}$ was found to be 900 rpm. It is also observed that increasing the transverse speed increases the occurrence of defects. In dissimilar FSW joints it has been observed that base metal 6061 positioned on advancing side gives good mixing of materials. An optimum rotational speed for producing defect-free welds of AA6061-AA7075 was found to be 650 rpm. It is observed that the occurrence of defects in dissimilar FSW joints is fewer with respect to similar FSW joints.

References

[1] W.M. Thomas, et al., Friction stir butt welding, International Patent Application PCT/GB92, Patent Application GB9125978.8, 6, December 1991.

[2] M. A. Sutton, B. Yang, A. P. Reynolds and J. Yan: Banded Microstructure in 2024T351 and 2524T351 of aluminium friction stir welds part-II Mechanical Characterization Material Science Engineering A 364 (2004) 66-74.

[3] C. G. Rhodes, M. W. Mahoney, W. H. Bingel, R. A. Spurling and C. C.Bampton: Effects of friction stir welding on microstructure of 7075 aluminium Scripta Materialia 36 (1997) 69-75.

[4] W. Xunhonga and W. Kuaishe: Microstructure and properties of friction stir butt-welded AZ31 magnesium alloy, Material Science Engineering A 431 (2006) 114-117.

[5] H.S. Park, T. Kimura, T. Murakami, Y. Nagano, K. Nakata,. M. Ushio, Microstructures and mechanical properties of friction stir welds of 60% Cu–40% Zn copper alloy,. Materials Science Engineering A 371 (2004) 160-169.

[6] H. Fujii, L. Cui, N. Tsuji, M. Maeda, K. Nakata and K. Nogi: Friction stir welding of carbon steels, Materials Science Engineering A 429 (2006) 50-57.

[7] Y. S. Sato, T. W. Nelson, C. J. Sterling, R. J. Steel and C.-O. Pettersson: Microstructure and mechanical properties of friction stir welded SAF 2507 super duplex stainless steel Materials Science Engineering A 397 (2005) 376-384.

[8] Y.G. Kim, H. Fujii, T. Tsumura, T. Komazaki, K. Nakata, "Three defect types in Friction stir welding of aluminum die casting alloy", Materials Science and Engineering A 415 (2006) 250-254.

[9] X. Cao, M. Jahazi, "Effect of welding speed on the quality of friction stir welded butt Joints of a magnesium alloy", Materials and Design 30 (2009) 2033-2042.

[10] B. Raj, T. Jayakumar, M. Thavasimuthu, "Practical Non-destructive Testing", Woodhead Publishing (2002).

[11] M. Moles, A. Lamarre, O. Dupuis, "Complete inspection of friction stir welds in Aluminum using ultrasonic and Eddy currents arrays", 16th WCNDT 2004 – World Conference on NDT, Montreal Canada, (2004), Paper No 84

[12] L. S. Rosado, T. G. Santos, M. Piedade, P. M. Ramos and P. Vilaca. "Advanced technique for non-destructive testing of friction stir weldingOf metals" Journal of Measurement. 43, (2010), 1021-1030.

[13] B. Li, Y. Shen and W. Hu. "The study of defects in aluminium 2219-T6 Thick butt friction stir welds with the application of multiple nondestructive Testing methods" Materials and Design, 32,(2011) 2073-2084.

[14] Hu, B, Yu R and Zou, H. "Magnetic non-destructive testing methods for thin plate aluminium alloys". NDT&E International, 47, (2012) pp. 66-69.