EXPERIMENTAL EVALUATION OF INFLUENCE OF WELDING PARAMETERS ON THE FATIGUE BEHAVIOUR OF FRICTION STIR WELD OF ALUMINIUM ALLOYS

Jihan P. Patel[1], Prof. Ravi C. Patel[2], Prof. Ajay Gupta[3]
[1]P.G. Student, M.E (Production) Ahmedabad Institute, Ahmedabad, Gujarat
[2]Prof. at Ahmedabad Institute of Technology, Gota, Ahmedabad, Gujarat
[3]Prof. at L.J. Institute of Technology, Ahmedabad, Gujarat

Abstract: Friction stir welding is a solid state joining process. Mechanical characterization, similar and dissimilar combinations, microstructural characterization and influence of tool pin profiles for FSW processes are some of the important areas of research. It is important to understand the fatigue characteristics of FSW welds due to potentially wide range of engineering applications of FSW technique. This has led to increasing research interest on evaluating the fatigue behaviour of FSW welds. The aim of the present work is to investigate influence of welding parameters on the fatigue behaviour of friction stir welds of aluminium alloys: AA6082-T6. Here butt joint will be prepared by friction stir welding. Here tool design, tool rotation speed and transverse speed are selected as input parameter. Tool will be prepared using H13 steel material with hexagonal and tri-flute threaded profile of probe.

I. INTRODUCTION

Friction stir welding is a solid state joining process which involves non-consumable rotating tool for joining similar or dissimilar metals. [[2]] Friction stir welding was invented and experimentally proven at The Welding Institute (TWI) U.K. in December 1991 by Wayne Thomas et al.[1] In friction stir welding two or more parts are joined in the solid state much as in other methods of friction welding that have been in existence since 1950. Friction stir welding (FSW) is a fairly recent technology that utilize a non-consumable tool to generate frictional heat and plastic deformation at the welding location, thereby affecting the formation of joint while the material is in the solid state. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint. The tool serves two primary functions: (a) heating of workpiece, and (b) movement of material to produce the joint. In recent times, focus has been on developing fast, efficient processes that are environment friendly. The spot light has been turned on friction stir welding as a joining technology capable of providing welds that do not have defects normally associated with fusion welding processes. FSW being a solid state, low energy input, repeatable mechanical process capable of producing very high strength welds in a wide range of materials, offers a potentially lower cost, environment friendly solution to these challenges.

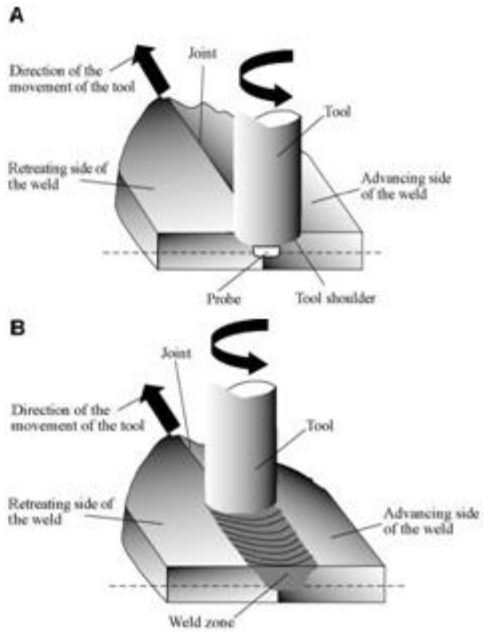

Figure 1Schematic diagram of the FSW process

FSW can be used to produce butt, corner, lap, T, spot and fillet joints, as well as for hollow objects, such as tanks and tubes/pipes, stock with different thickness, tapered sections and parts with 3-dimensional contours.

II. LITERATURE REVIEW

M. Ericsson et al. (2002) presents a study on “Influence of welding speed on the fatigue of friction stir welds, and compared it with MIG and TIG.”[[7]] The objective of this study investigation was to determine whether the fatigue strength of friction stir welds is influenced by the welding speed, and also to compare the fatigue results with results of conventional arc-welding like MIG and TIG. On the basis of this study it was concluded that the fatigue strength of FS welded aluminium alloy 6082 is higher than that of MIG and TIG welds of the same material. Also mechanical and fatigue properties of the FS welds are relatively independent of welding speed in range of low to high commercial welding speed in this alloy. An extra low speed gave improved properties. M.N. James et al. (2003) presents a study on “Weld tool travel speed effects on fatigue life of friction stir welds in 5083 aluminium.”[[8]] This paper reports the results of a study into the influence of weld tool travel speed (in the range 80–200 mm/min) on the occurrence of ‘onion-skin’ forging-type defects (similar to the root defects known as 'kissing bonds') in single pass friction stir (SP FS) welds, and on the effect of these defects on fatigue crack initiation and overall life. Results indicate that such defects are generally not associated with fatigue crack initiation, but may act to reduce fatigue life by providing easy linking paths between two fatigue cracks. It is likely that their influence on fracture toughness of SP FS welds would be higher, as they occur more readily when growth rates and levels of plastic deformation are higher.

Shusheng Di et al. (2006) present a work on "comparative study on fatigue properties between AA2024-T4 friction stir welds and base materials."[[6]] Here the zigzag-curve defects across weld section on the fatigue properties of FSW joints were investigated.

From the study it is concluded that:

The zigzag-curve defect is the inherent feature of single sided FS joints, which is produced by the initial oxide layer on the butt surface of welded plates and deficient friction stir heat input energy. It will change into special root defect at the root site of FS welds. The term 'kissing bond' is unsuitable to express the partly bonded feature with relatively poor strength, in here the term 'weak-bond defect' is used to define the special root defect in FS welds.

The root site is always the most dangerous place for single side friction stir welded joints and the existed 'weak bonded' defect is the dominant actor to reduce the fatigue strength of the friction stir welded joints of 2024-T4 al alloy. The characteristic fatigue strength FATk (corresponding to a 95% survival probability) decreases from 96.19 MPa for base material to 73.71 MPa for FS welded joints with the reduction of 23.4%.

Although the fatigue strength of A2024-T4 friction stir welds was lower than that of the base material, the single side friction stir welds achieved higher fatigue property than that of the double-side traditional fusion welds. The present experiment limited at low R-ratio and constant amplitude loading, more tests are needed to assign a higher category to assess friction stir welds.

K. Kumar et al. (2007) presents a study on "The role of friction stir welding tool on material flow and weld formation."[[3]] In this investigation an attempt has been made to understand the mechanism of friction stir weld formation and the role of FSW tool on it. This has been done by understanding the material flow pattern in the weld produce in a special experiment, where the interaction of the friction stir welding tool with the base material is continuously increased.

In this experimental study with the help of a simple experimental procedure following conclusions are derived:

•There are two different types of material flows, namely shoulder- and pin-driven material flows. Pin transfers the material layer by layer, while the shoulder transfers the material by bulk.

•The effectiveness of the pin and the shoulder can be tested using this experimental procedure.

•Onion ring formation in the friction stir welds are due to the combined effect of geometric nature of pin-driven material flow, and vertical movement of the material due to shoulder interaction.

•For the given set of parameters the optimum axial load is found to be 8.1 kN

•Based on the experimental result the mechanism of friction stir weld formation is proposed as follows. In FSW material flow occurs in two different modes by pin and shoulder. The shoulder-driven material forges against advancing side base material and pin-driven material, and the boundaries between the layers in the pin-driven material are eliminated.

HosseinPapahn et al. (2015) presents study on "Effect of friction stir welding tool on temperature, applied forces and weld quality."[[4]]

In friction stir welding (FSW), a proper selection of the FSW tool is an important factor which, as an appropriate tool, cannot only improve the quality of the weld but also diminish the destructive effects including applied forces and high temperature induced during the welding process. This research is aimed to scrutinise the effect of the tool geometries on the axial and translational forces, temperature and mechanical properties for AA7075-T6 are investigated. The threaded tapered, non-threaded triangular and non-threaded cylindrical pins were employed.

On the basis of this study it is concluded that:

•As the tool shoulder diameter is increased, the axial and translational forces, temperature and the grain size increase.

•The optimum trade-off between the mechanical properties and destructive factors were recorded in the case of the tool with a shoulder diameter of 19 mm and a shoulder to pin diameter ratio of 3.17.

•The trend of axial and translational forces was reported as follows: non-threaded cylindrical pin > non-threaded triangular pin > threaded tapered pin; whereas a converse trend was detected for temperature, elongation, UTS and grain size.

•Threaded tapered pin is the most appropriate selection because the tool and the workpiece are less damaged due to the observed reduction in the extent of the force and the most proper characteristics of the fabricated welds compared with the other two pins.

V. Infante et al. (2015) presents a "study of fatigue behaviour of dissimilar aluminium joints produced by friction stir welding."[[5]] This study was conducted within the LighTRAIN project that aims to improve the life cycle costs of the underframe of a passenger railway car. The major objective of the research was to study the fatigue behaviour of dissimilar welded joints based on two different aluminium alloys: AA6082 and AA5754. The paper presents the experimental results obtained in two different structures: AA6082-T6 2mm and AA5754-H111 2mm thick joints, and AA6082-T6 2mm thick joints. Fatigue test were carried out on lap joints specimens with a constant amplitude loading with stress ration R=0.1.

Fatigue test performed on similar and dissimilar joints show low fatigue strength when compared with the base materials

AA5754 and AA6082, which associated with the typical "hook" defect inherent to this welding process.
The fatigue performance of AA6082 and AA5754 FSW welded joints suggest a shallower S-N curve than tor the similar AA6082 FSW welded joints with an improvement in fatigue performance for lower applied stress ranges.
Dissimilar joints presents a hook defect with 40° angle (with horizontal reference) and the similar material joints a higher inclination angle of 50°, suggesting that the influence of the defect angle can be negligible concerning the fatigue behaviour of both configuration.

III. EXPERIMENTAL SETUP

The material used in this study was 6mm thick AA6082. This material is widely used in rail car structural panels, etc. butt joint is produced on two plates having dimension 150*100*6mmof AA6082-T6 by friction stir welding. Two different FSW tool is produced to weld AA6082 and it is composed by three main components: body, shoulder and probe. Hass VF 2YT vertical milling center is used to produce FSW welding joints. Table 1 shows FSW parameters used to perform all the welds. The welding process was carried out under vertical downward force control. Among the FSW parameters it was decided to vary only three parameters: Tool Probe design, tool travel speed and tool rotational Speed.

Figure 2 hexagonal and Triflute tool pin profile

Input Parameter	Level 1	Level 2	Level 3
Tool probe design	Hexagonal	Triflute	-
Tool rotation speed(rpm)	800	1600	2400
Transverse speed(mm/min)	40	60	80

Table 1 process parameters and their levels

IV. EXPERIMENTAL DESIGN & RESULTS

To achieve our objective here different 18 specimen are welded with different parameter combination. Different combination of FSW weld parameter is shown in Table 2

Sr. No.	Tool Probe design	Rotation speed	Transverse speed	UTS (MPa)
1	Hexagonal	800	40	121.165
2	Hexagonal	800	60	84.900
3	Hexagonal	800	80	102.995
4	Hexagonal	1600	40	152.059
5	Hexagonal	1600	60	148.109
6	Hexagonal	1600	80	126.719
7	Hexagonal	2400	40	88.635
8	Hexagonal	2400	60	104.934
9	Hexagonal	2400	80	157.285
10	Triflute	800	40	176.463
11	Triflute	800	60	132.436
12	Triflute	800	80	147.835
13	Triflute	1600	40	161.252
14	Triflute	1600	60	169.231
15	Triflute	1600	80	156.998
16	Triflute	2400	40	162.584
17	Triflute	2400	60	142.157
18	Triflute	2400	80	193.907

Table 2 Design of experiment

Figure 3welded specimen

Tensile test are carried out on all 18 FS weld specimen.

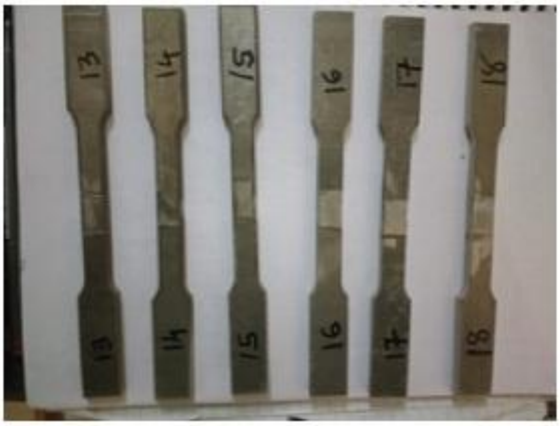

Figure 4 specimen for tensile test as per ASTM E8M

Taking into account tensile testing and defect in FS weld sample no. 10 (Triflute pin profile, tool rotation speed = 800 rpm, tool transverse speed = 40 mm/min) was selected for fatigue testing. From sample no. 10 four pieces are prepared for fatigue testing as per ASTM E0466.

Figure 5 specimen for fatigue test as per ASTM E0466

V. RESULTS & DISCUSSION

In order to assess the dynamic behaviour of the FSW specimens fatigue tests were carried out under sinusoidal axial tensile constant amplitude loading in a ±250 kN capacity servo-hydraulic Instron 8850 fatigue test machine. Stress ratio was set to R = 0.1. Frequency of cyclic load is set to 10 Hz. Butt joints were produced with 6 mm thick plates, the stopping criterion considered was the complete failure of the specimens or 50,000 cycles.

Sr. No.	Load percen tage	max Load(kN)	Stress(MPa)	No. of cycles complete till failure
1	80%	13.44	142.4	8785
2	70%	11.76	124.4	9158
3	63%	10.58	111.1	11143
4	50%	8.40	89.05	50000

Table 3 Fatigue data

As mentioned above, S–N curves were plotted for theAA6082-T6 butt joints. Data for AA6082-T6 base material and similar butt-joints are compered.

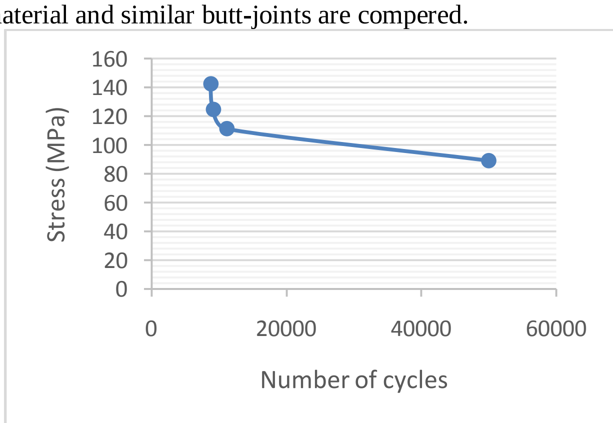

Figure 6 S–N curves at R = 0.1 for AA6082-T6 FS weld joints.

VI. CONCLUSION

It was concluded that - The tensile properties of the joints are lower than those of the base material. The welding parameters have significant effects on the tensile properties. Tool probe design is highly effective on tensile strength of FS weld. Tensile strength of FS weld using Triflute tool pin profile is higher than tensile strength of FS weld using Hexagonal tool pin profile.

So for hexagonal tool we can say that as rotational and transverse speed high the result obtained is good. For Triflute tool same condition is observed as rotational and transverse speed high the result obtained is good. By this we can conclude that as tool profile is complicated the strength of plate is increased. Fatigue strength of weld plate is lower than base plate. FSW welds are susceptible to fatigue crack initiation. Surface quality of the FSW welds exerted a significant effect on the fatigue strength of the welds. The effect of FSW parameters on the fatigue strength is complicated and no consistent trend is obtained so far.

ACKNOWLEDGMENT

First of all I am humbly expressing thanks to my respected guides Prof. R.C. Patel and Prof. Ajay Gupta for their valuable time and constant help given to me. I would also like to thank to Prof. Bankesh D. Patel, Head of Mechanical Engineering department who has always been ready to offer help at any time, in spite of having his busy schedule. Finally, I am thankful to our all the faculty members of mechanical Engineering Department and all my friends who have directly or indirectly helped me during this dissertation work.

REFERENCES

[1] Thomas W.M., Friction Stir Butt Welding. International Patent Application No PCTrGB92 Patent Application No.9125978.8, 1991
[2] R.S. Mishra, Z.Y. Ma. Friction stir welding and processing. Material science and Engineering R 50 (2005) 1-78, 0927-796X/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
[3] K. Kumar, Satish V. Kailas, “The role of friction stir welding tool on material flow and weld formation.” Material science and engineering A 485 (2008) 367-374, 0921-5093/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
[4] HosseinPapahn, PouyaBahemmat, Mohammad Haghpanahi, Iman Pour Aminaie, “Effect of friction stir welding tool on temperature, applied forces and weld quality” IET Sci. Meas. Technol., 2015, Vol. 9, Iss. 4, pp. 475–484 doi: 10.1049/iet-smt.2014.0150
[5] V. Infante, D.F.O. Braga, F. Duarte, P.M.G. Moreira, M. de Freitas, P.M.S.T. de Castro, “Study of the fatigue behaviour of dissimilar aluminium joints produced by friction stir welding” International Journal of Fatigue 0142-1123/© 2015 Elsevier Ltd. All rights reserved.
[6] Shusheng Di, Xinqi Yang, Guohong Luan, Bo Jian “Comparative study on fatigue properties between AA2024-T4 friction stir welds and base materials” Materials Science and Engineering A 435–436 (2006) 389–395, 0921-5093/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
[7] M. Ericsson, R. Sandstrom “Influence of welding speed on the fatigue of friction stir welds, and comparison with MIG and TIG” International

Journal of Fatigue 25 (2003) 1379–1387, 0142-1123/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.

[8] M.N. James, D.G. Hattingh, G.R. Bradley “Weld tool travel speed effects on fatigue life of friction stir welds in 5083 aluminium.” International Journal of Fatigue 25 (2003) 1389–1398, 0142-1123/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.

