International Journal For Technological Research In Engineering
Volume 4, Issue 8, April-2017 *ISSN (Online): 2347 - 4718*

FATIGUE BEHAVIOUR OF ALUMINIUM ALLOY(6082 T6) PLATES JOINED BY FRICTION STIR WELDING

Tejal D. Vadher[1], Asst. Prof. G S.Parmar[2]
[1]M.E Advance Manufacturing System,[2]Asst Prof Department of Mechanical Engineering
ACT, Ghandhinagar, Gujrat

ABSTRACT: Friction stir welding is a solid state joining process enabling to develop new design concepts for light weight metallic materials, where previously conventional manufacturing processes as riveting or classical welding were used. Aluminium and its alloys generally has low weldability by traditional fusion welding process. The development of the friction stir welding (FSW) has provided an alternative improved way of producing aluminium joints, in a faster and reliable manner. Many materials like aluminium alloys 2000, 6000 and 7000 series have been joined using this technique. 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 and AA7050. 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

Key Words: Friction Stir Welding ; Fatigue; Heat treatable aluminium alloys; Tool Geometry; Rotational Speed; Micro hardness

I. 1.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 has used worldwide due to its advantages over traditional joining processes.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.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.

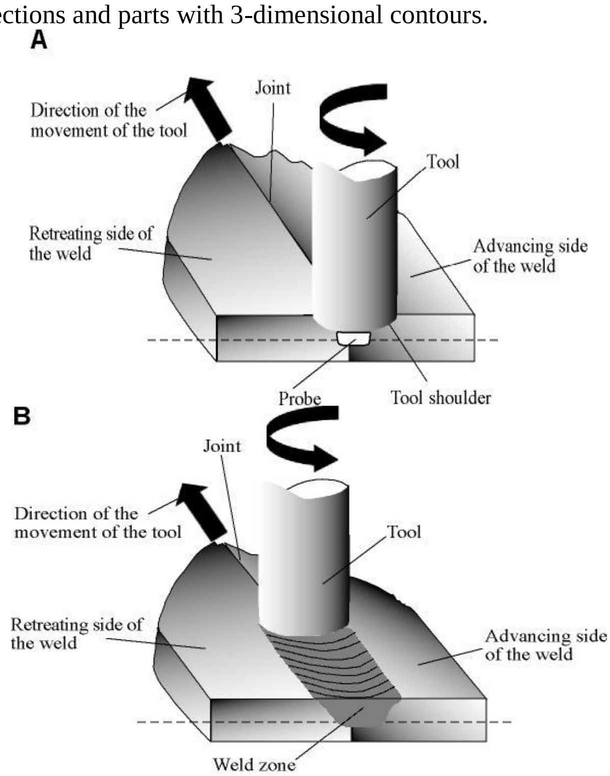

Figure 1 Schematic diagram of the FSW proces

- A constantly rotated non consumable cylindrical-shouldered tool with a profiled probe is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material.[**Error! Reference source not found.**]
- The probe is slightly shorter than the weld depth required, with the tool shoulder riding a top the work surface.
- Frictional heat is generated between the wear-resistant welding components and the work pieces.

- This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting.
- As the pin is moved forward, a special profile on its leading face forces plasticised material to the rear where clamping force assists in a forged consolidation of the weld.
- The advancing (AS) is the side where the velocity vectors of tool rotation and traverse direction are similar.
- The side where the velocity vectors of tool rotation and traverse direction are opposite is referred as retreating side (RS).

II. AREAS OF FSW RESEARCH

The welding of aluminium and its alloys has always represented a great challenge for researchers and technologist. Development of the FSW process since 1991 has encompassed various experimental investigation. Many researchers have been work done in the field of tool pin profile, which is very important during the welding process. For carrying out research work in any area, the first and an important phase is to review the available literature for the selected topic and the research problem can be formulated with clear objectives.

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.”[[10]] 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 weld sin 5083 aluminium.”[[11]]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 aregenerally 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.

Generally, there is a decrease in endurance limit stress (at 107 cycles) in both as-welded and polished specimens, as travel speed increases from 80 to 200 mm/min. The decrease has a maximum value of about 11% for polished and 19% for as-welded specimens. More in-depth metalography would be required to ascertain likely reasons for this. Onion-skin forging-type defects (kissing bonds) occur with a similar frequency at all welding speeds, and hence do not appear to reflect the influence of a fluid dynamics vortex shedding mechanism. Occasional voids are present in the welded specimens and these act as crack initiation sites if no larger defect is present at the surface. Overall life is then lowered relative to specimens where no voids are present. Onion-skin defects are never associated with fatigue crack initiation, but they can affect overall fatigue life, however, through providing easy linking paths between two initiated cracks.

Shusheng Di et al. (2006) present a work on “comparative study on fatigue properties between AA2024-T4 friction stir welds and base materials.”[[9]] Here the zigzag-curve defects across weld section on the fatigue properties of FSW joints were investigated 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 singlesidefriction stir welds achieved higher fatigue property thanthat of the double-side traditional fusion welds. The presentexperiment limited at low R-ratio and constant amplitude loading, more tests are needed to assign a higher categoryto 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 testedusing this experimental procedure.Onion ring formation in the friction stir welds are due to thecombined effect of geometric nature of pin-driven materialflow, and vertical movement of the material due to should erinteraction. For the given set of parameters the optimum axial load isfound to be 8.1 kN Based on the experimental result the mechanism of frictionstir weld formation is proposed as follows. In FSW materialflow occurs in two different modes by pin and shoulder. Theshoulder-driven material forges against advancing side basematerial and pin-driven material, and the boundaries betweenthe layers in the pin-driven material are eliminated.

D. Muruganandam et al. (2010) worked on the "mechanical and micro structure behaviour of 2024-7075 aluminium alloy plates joined by friction stir welding."[[6]]The aim of the present work is to investigate on the mechanical and micro structural properties of dissimilar 2024 and 7075 aluminium plates joined by FSW. The two plates, aligned with perpendicular longitudinal direction, have been successfully welded; successively, the welded plates have been tested under tension at room temperature in order to analyse the mechanical response with respect to the parent materials. The fatigue endurance (S-N) curves of the welded joints have been achieved, since the fatigue behaviour of light welded plates is the best performance indicator for a large art of industrial application; a resonant electro-mechanical testing machine load and a constant load ratio R= σmin/σmax=0.1 have been used at a load frequency of about 75Hz. The resulted microstructure due to the FSW process hasbeen studied by employing optical and scanning electronmicroscopy either on 'as welded' specimens and on testedspecimen after rupture occurred.On the basis of this study it was conclude that the dissimilar AA2024 and AA7075 aluminium alloys in the form of 5mm thick plates can be joined by FSW. The presence of the FSW line reduces the fatigue behaviour but the comparison to the parent materials is acceptable and allows considering the FSW as an alternative joining technology for the aluminium plate alloys. The specimens fracture surfaces after testing have been deeply analysed by using a FEGSEM microscope, revealing the defects topology and location after the friction stirring process and microscopic mechanism occurred during high stress deformations and final failure.

R. Palanivel et al. (2012) presents a study on "Mechanical and microstructural behaviourof friction stir welded dissimilar aluminiumalloy."[[7]]This paper presents the mechanical and metallurgical propertiesof dissimilar joints of aluminium alloy AA6351-T6 and AAS083- H111 alloy produced by friction stir welding is analysed. Here high carbon high chromium steel (HCHCr) is used as tool material. And FSW tools were manufactured using CNCTurningcentre and wire cut electrical discharge machine. Three different welding speeds (50mm/min, 63mm/min, and 75mm/min)have been used to weld the joints. The dissimilar AA6351 and AA5083-H111 aluminium alloy can be welded by FSW without any defect.FSP zone has finer grains and TMAZ has elongated grains. The asymmetric pattern of material flow was observedat the bottom of the FSP zone. Tensile strength of the joints was affected by the welding speed.The joints produced using welding speed of 63mm/min showed better tensile properties.

HosseinPapahn et al. (2015) presents study on "Effect of friction stir welding tool on temperature, applied forces and weld quality."[[3]]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. As the tool shoulder diameter is increased, the axial and translational forces, temperature and the grain size increases The optimum trade-off between the mechanical properties sand 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-thrededtriangular pin > threaded tapered pin; whereas a conversetrend was detected for temperature, elongation, UTS and grain size.Threaded tapered pin is the most appropriate selection because the tool and the work piece are less damaged due to the observed reduction in the extent of the force and the most proper characteristics of the fabricated weld scompared 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.

R.I. Rodriguez et al. (2015) present a work on "microstructure and mechanical properties of dissimilar friction stir welding of 6061 and 7050 aluminium alloys."[[8]] In this work, the microstructure and mechanical properties of friction stir welded dissimilar butt joints of 6061 and 7050 aluminium alloys were evaluated. Microstructure analysis of the cross-section of the joints revealed distinct laminar bands and various degree of intermixing that were correlated with the tool rotation speed.

FSWjoints were produced under a range of tool rotational speeds, while other parameters were held constant. Microstructure analysis of the stir zone revealed the presence of bands of mixed and unmixed material that demonstrated the degree of material intermixing, asthe tool rotational speed was varied. Material intermixing and joint strength were found to increase with the increasing tool rotational speed. Scanning electron microscopy analysis revealed that a majority of the welds tested under monotonic tensile loading failed through the heat-affected zone corresponding to the 6061 Al alloy side of the weld. However, for the low tool rotational speed, failure occurred in the stir zone due to poor material intermixing. Further research will focus on the optimization of the joint strength and its fatigue properties

III. EXPREMENTAL SETUP

Vertical Machining Center 762 x 508 x 508 mm, 40 taper, 30 hp (22.4 kW) vector drive, 8100 rpm, inline direct-drive, 20-station carousel tool changer, 25.4 m/min rapids, power-failure detection module, 1 GB program memory, 15" colour LCD monitor, USB port, memory lock keyswitch, rigid tapping and 208 litreflood coolant system

Table 1 : Parametric levels Selection

Process Parameters	Unit	Level 1	Level 2	Level 3
Tool design	-	Hexagonal probe	Tri-flute with threaded	-
Tool rotation speed	Rpm	800	1600	2400
Tool transverse speed	mm/min	40	60	80

Figure 2 Manufactured FSW Tool

IV. EXPRIMENTAL DESIGN &RESULTS

After Experimental Setup & Process on defined Combination of parameters on Aluminium Response Measured with help of ultimate Tensile tests as in table 2

Table 2 Experimental Results for Aluminium Plates

Sr. No.	Tool design	Rotation speed	Transverse speed	UTS
1	Hexagonal	800	40	121.165
2	Hexagonal	800	60	84.900
3	Hexagonal	800	80	102.995
4	Hexagonal	1600	40	136.559
5	Hexagonal	1600	60	133.589
6	Hexagonal	1600	80	126.719
7	Hexagonal	2400	40	123.450
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	171.590
16	Triflute	2400	40	162.584
17	Triflute	2400	60	142.157
18	Triflute	2400	80	193.907

V. RESULTS &DISCUSSION

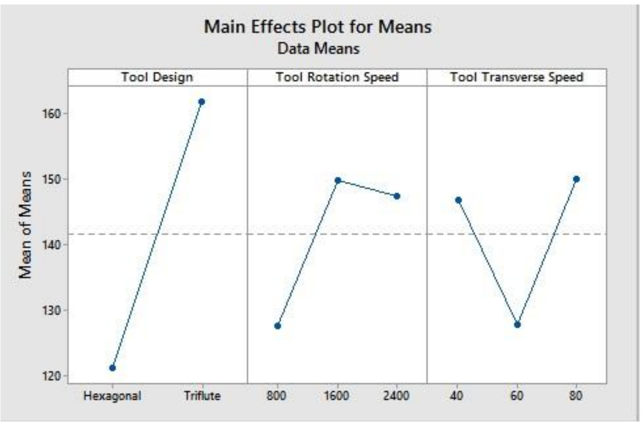

Figure 3 Main Effects Plots for tensile Strength

Fatigue Test Results

Table 3 Experimental Result of Fatigue Test

	Load percentage	max Load (kN)	Area Mmm m^2	Stress (MPa)	min load	Amplitu de	Set Point	No. of cycles complete till failure
TENSILE STRENGTH	100%=1	16.809						
R = 0.1	0.8	13.4472	94.37	142.4	1.3447	6.05124	7.3959	8785
Frequency= 10 HZ	0.7	11.7663	94.52	124.4	1.1766	5.29483	6.4714	9158
	0.63	10.5896	95.25	111.1	1.0589	4.76535	5.8243	11143
	0.5	8.4045	94.37	89.0	0.8404	3.78202	4.622	50000

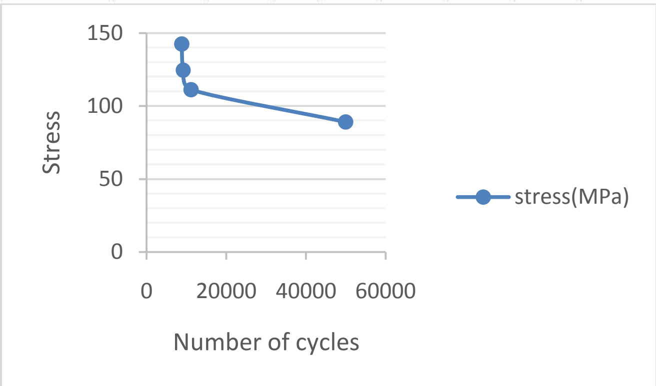

Figure 4 S-N Curves for AL 6082-T6

From the S-N curve we can see that for 63%, 70% and 80% Stress of its ultimate tensile strength the fatigue life of FS weld specimen is very low. As for 50% Stress of its ultimate tensile strength the fatigue life of same weld specimen is high (50,000 cycle). Here we have limit the cycle by 50,000. At this point after fatigue test no crack initiation is observed. So we can say that at 50% Stress of its ultimate tensile strength the fatigue life of FS weld specimen is higher.

So on we can say that at low lower load fatigue life of FS weld specimen is higher.

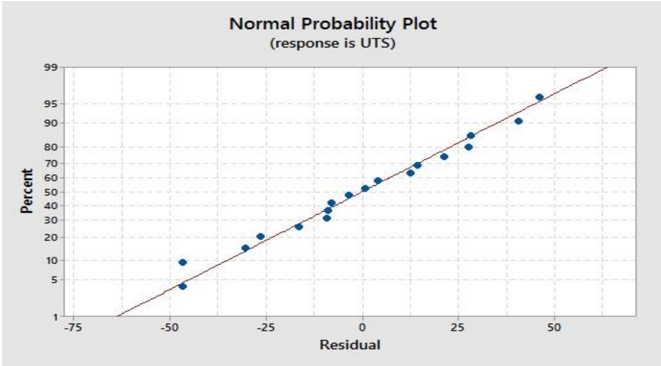

Figure 5 Normal Probability plots for Tensile Strength

VI. CONCLUSION

It was concluded that -

- The tensile and fatigue properties of the joints are lower than those of the base material. The welding parameters have significant effects on the tensile and fatigue 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.

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] D. Muruganandam, S. Ravikumar, Dr. SushilLal Das "Mechanical and Micro Structural Behaviour of 2024–7075 Aluminium Alloy Plates joined by Friction Stir Welding" 978-1-4244-9082-0/10/$26.00 ©2010 IEEE

[7] R. Palanivel, P. Koshy Mathews, "Mechanical and microstructural behaviour of friction stir welded dissimilar aluminium alloy." IEEE-International Conference on Advances In Engineering, Science And Management (ICAESM -2012), ISBN: 978-Sl-909042-2-3 ©20l2 IEEE

[8] R.I. Rodriguez, J.B. Jordon, P.G. Allison, T. Rushing, L. Garcia "Microstructure and mechanical properties of dissimilar friction stir welding of 6061-to-7050 aluminium alloys." Materials & Design 83 (2015) 60–65, 0264-1275/© 2015 Elsevier Ltd. All rights reserved.

[9] 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.

[10] 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.

[11] 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.

[12] Designation: E8/E8M – 09 American Association State Highway and Transportation Officials Standard, AASHTO No.: T68 An American National Standard "Standard Test Methods for Tension Testing of Metallic Materials."

