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AN EXPERIMENTAL STUDY ON THE EFFECT OF WELDING PARAMETERS ON MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF AA 6082-T6 FRICTION STIR WELDED BUTT JOINTS

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ABSTRACT

The effect of processing parameters on mechanical and microstructural properties of aluminium alloy 6082-T6 Friction stir-welded (FSW) joints were investigated in the present study. Different welded specimens were produced by employing variable rotating speeds and welding speeds. Tensile strength of the produced joints was tested at room temperature and the correlation with process parameter was assessed. Microstructures of various zones of FSW welds are presented and analyzed by means of optical microscopy and microhardness measurements. Several studies have been conducted to investigate the properties and microstructural changes in Friction Stir Welds in the aluminium alloy 6082-T6 in function of varying process parameters. The experimental results indicated that the process parameters have a significant effect on weld macrostructure and mechanical properties of joints.

Keywords: welding, butt joints, aluminium alloy, FSW, properties, mechanical, structural.

1. INTRODUCTION

There is an increasing need for low distortion aluminium alloys in sheet and plate form in the fabrication industry, such as ship panels, bridge decks and other transportation applications such as train and airplane components. Therefore, sound welding methods are necessary to fabricate large Al alloy sheet and plate.

In many industrial applications steels are readily replaced by non-ferrous alloys, in most cases by aluminium alloys. Some of these materials combine mechanical strength comparable with structural steels and low weight, allowing for a significant reduction of weight. While production of components of aluminium alloys is not very complex, joining of these materials can sometimes cause serious problems [1]. Lack of structural transformations in solid state and excellent thermal and electrical conductivity cause problems in fusion and resistance welding of aluminium alloys [2]. That led to the development of Friction Stir Welding [3] a solid state joining technique in which the joined material is plasticized by heat generated by friction between the surface of the plates and the contact surface of a special tool, composed of two main parts: shoulder and pin [4]. Shoulder is responsible for the generation of heat and for containing the plasticized material in the weld zone, while pin mixes the material of the components to be welded, thus creating a joint (Figure-1). This allows for producing defect-free welds characterized by good mechanical properties.

Among aluminium alloys aluminium-magnesium-silicon (Al-Mg-Si) heat treatable wrought alloys, although of only medium strength, appears to have weldability advantage over high strength alminium alloys. For this reason Al-Mg-Si alloys are widely used for structural components in welded assemblies. However, Al-Mg-Si alloys (6000 series) are crack sensitive when they are fusion welded without filler metal [5].

The major advantages of friction stir welding (FSW) in aluminium alloys, when compared to conventional fusion welds, are primarily the elimination of cracking and evaporative loss of alloying elements. This is due to the solid-state joining and a weld zone with fine worked or recrystallized grain structure generated by stirring and forging during FSW [6]. During friction stir (FS) welding, temperatures remaining below the melting point result in a low shrinkage phenomenon and excellent mechanical properties, together with reduction of residual stress within the weld zone [7-18] mechanical properties of the FSW joint are quite good and fatigue properties are practically the same as the parent metal [6]. Generally tensile failure occurs well away from the nugget [6,7].

To date, the major application fields of FSW are marine industries(ship sections, hulls, structures), aerospace industry (fuselages, wings, fuel tanks), railway industry (high speed trains, carriages), automotive industry (chassis, wheel rims, space frames, truck bodies) motor cycle frames and other sections, such as electrical and refrigeration [6].

Due to the combined effect of tooling, FSW produces five different microstructure zones: The nugget in the centre of the weld where the pin has passed, A shoulder contact zone on the top surface, Thermo-mechanically affected zones (TMAZ) that are immediately on each side of the nugget, heat affected zones (HAZ) adjacent to the TMAZ that experiences a thermal cycle but not a mechanical shearing, and the unaffected parent material [8, 9, 11].

FSW produces an asymmetric micro structure in which the advancing and retreating sides experience different strain levels and thermal cycles [8]. Material on the advancing side (rotation opposed to plate motion) experiences more shear than the retreating does [8]. The closer the material to the tool, the higher is the deformation and temperature gradients to which it is subjected. This implies as effective deformation rate higher in the advancing side than in the retreating, resulting in different stress, flow and temperature cycles. Moreover, almost all the metal form in front of the tools is transformed to the retreating side creating a much broader flow band than that of the advancing. In addition to the grain and substructure evolution during the severe thermo-mechanical conditions imposed by FSW, the various thermal cycles in the different weld zones induce different precipitate distributions with in each zone.

This paper presents the results of an experimental setup in which the aluminium alloy AA6082-T6 was FS Welded, using various combinations of process parameters (rotational and travel speed). Mechanical properties of the test welds were assessed by means of static tensile test. Macro and microstructure of the welds were examined by means of optical observations and Vickers hardness measurement.

2. EXPERIMENTAL DETAILS

2.1 FSW tool design

The crucial part in this work was to design an experimental setup which would fit in the available machine tool. Understanding the tool design plays a very important role in friction stir welding. The initial FSW tool designed was a simple cylindrical tool with 20mm shoulder diameter, diameter and height of the pin equal to the thickness of the sheets processed i.e., 5mm. The forces generated using this tool especially during the penetration of the tool in to the work piece, were very high and caused excessive machine vibration. Then the pin of the tool is tapered and threaded (Figure-3) in order to reduce the initial high forces during plunging operation.

2.2 Production of Joints

The sheets used in the present study were 5mm thick 6082-T6 aluminium alloy, and the chemical composition as well as mechanical properties are provided in table1. Given the Al-Mg-Si alloys are rather easily weldable even with conventional techniques; it was decided to verify weldability of AA 6082-T6 alloy by the most possible range of process parameters.

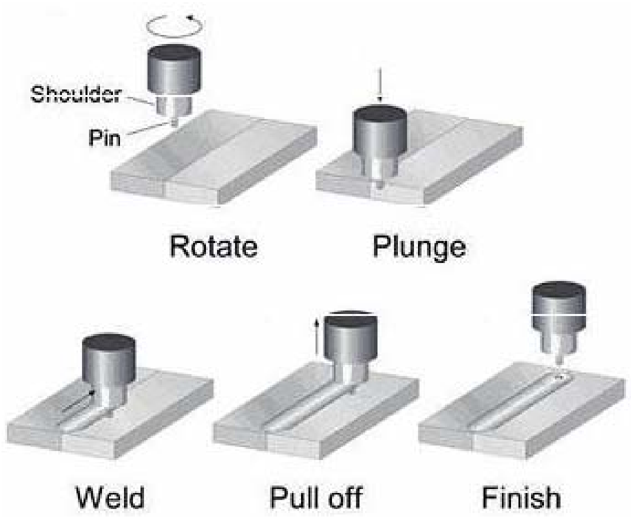

Figure-1. Schematic representation of FSW process.

Table-1. Chemical composition and mechanical properties of AA 6082-T6 aluminium alloy

Chemical composition (wt %).

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.81	0.20	0.05	0.66	0.66	0.001	0.03	0.009

Mechanical properties.

0.2% Yield strength (MPa)	**Ultimate tensile strength** (MPa)	**Elongation** (%)
250	290	10

The base metal samples 150 x 75 x 5mm were butt welded using 3-axis Makino computer numerical controlled milling machine with FANUC controller (Figure-2). Specially designed tool made of HSS (hardened) has frustum shaped probe with threads (Figure-3) used in this study. The FS welding tool dimensions are shown in Table-2 and welding parameters are listed in Table-3. For all joints a 20 second preheat time was applied in order to increase the plasticity of the material and decrease the bending loads on the pin.

Table-2. FSW tool dimensions used in experiments.

Shoulder diameter (mm)	**Pin diameter** (mm)	**Pin length** (mm)
20	5	4.9

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Figure-2. FSW using Makino 3-axis computer numerical controlled milling machine.

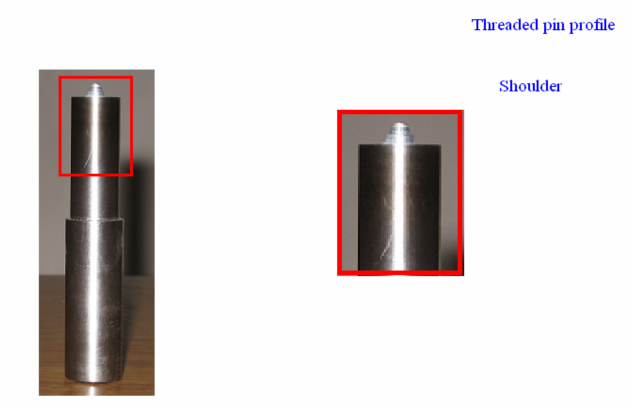

Figure-3. Friction-stir welding tool geometry.

Table-3. FSW welding parameters for AA 6082-T6 alloys.

Weld number	**Rotation** (rpm)	**Travel** (mm/min)
FSW-01	460	115
FSW-05	630	170
FSW-10	630	260
FSW-02	880	170
FSW-09	880	260
FSW-03	1230	115
FSW-07	1230	170
FSW-06	1230	260
FSW-04	1700	390
FSW-08	1700	585

3. RESULTS AND DISCUSSIONS

3.1 Friction stir weld visual inspection

The first step was the visual inspection of the FS weld. Several types of defects were revealed. In case of the joint FSW-07 a surface-open tunnel was found as a result of insufficient downward pressure [20]. Excessive lateral flash was also observed in most of the welds, resulting from the outflow of the plasticized material from underneath of the shoulder (Figure-4). For some of the welds no flaw or defect was detected on the weld. The visual observation of the weld is presented in Figure-5, it is clearly seen that a sound joint was obtained.

Figure-4. Lateral flash in the joint FSW-08.

Figure-5. Visual inspection of FSW joints, top and bottom surfaces.

Figure-6. Weld result visualization.

Since the sheet top face perpendicular to the weld line was cut, it is possible to identify the different hardness zones in each face, as shown in Figure-6. This type of result is well documented by several authors, e.g. [15,16]. In both figures the darker zone, in the centre of the image, indicates that the material was affected by the welding process. This increase in the area of the darker zone when it intercepts the weld line is expected to be characteristic of lower values of hardness when compared to those of the base material.

3.2 Optical metallography

Microstructures of various zones of FSW joints, in particular case of the joint FSW-06 are presented in Figure-7. Grains in base metal (BM) are elongated with average dimensions LxH equal µm. In weld nugget (WN) the grains are refined, equiaxed of average diameter 1-5 µm. This refinement is the result of dynamic recrystallization [21,22,23], i.e. a combined action of high rate strain and elevated temperatures. Such recrystallized structure is characterized by a very low level of residual stresses, excellent ductility and mechanical properties superior to those of HAZ [24]. The concentric rings visible in WN, called "onion rings" are a typical feature of FSW process and document the complex mechanics of the process: combination of rotational, longitudinal and vertical movement of the plasticized material [25]. The WN is a part of a bigger zone, the Thermo-mechanically Affected Zone (TMAZ), in which grains are deformed, elongated and rotated due to the strain to which they were subjected. Moving away in the direction of BM, the successive zone is HAZ. The microstructure here is similar to that of BM; the grains are slightly overgrown as a result of the exposure to welding heat.

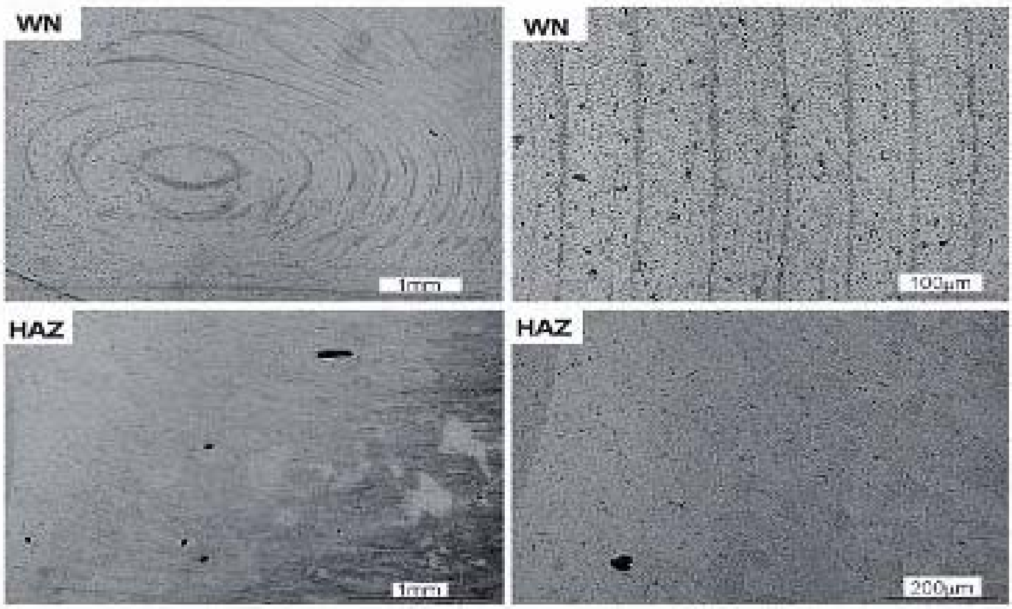

Figure-7. Microstructures in various zones of the weld FSW.

An interesting artifact was found in the sample FSW-03 (Figure-8). At the intersection of WN, TMAZ and flow arm (a band of material running from WN towards the joint edge on advancing side) the three distinct zones are starting to separate, giving origin to a tunnel defect. These defects are attributable to the combination of parameters: insufficient or excessive rotational speed combined with too low downward force. In such case the welded parts cannot be correctly stirred and mixed together and a tunnel (also called "worm hole") is created, running along the entire weld [27].

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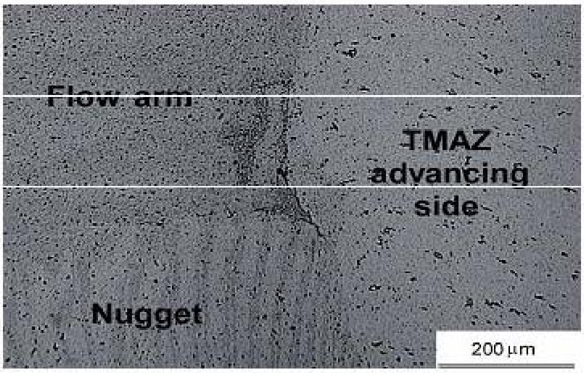


Figure- 8. Initial stage of tunnel defect in the weld FSW-03.

3.3 Hardness tests

The hardness profiles are extremely useful, as they can assist in the interpretation of the weld microstructure and mechanical properties. The results of hardness Vickers (Hv) with 200g are presented in Figure-9.

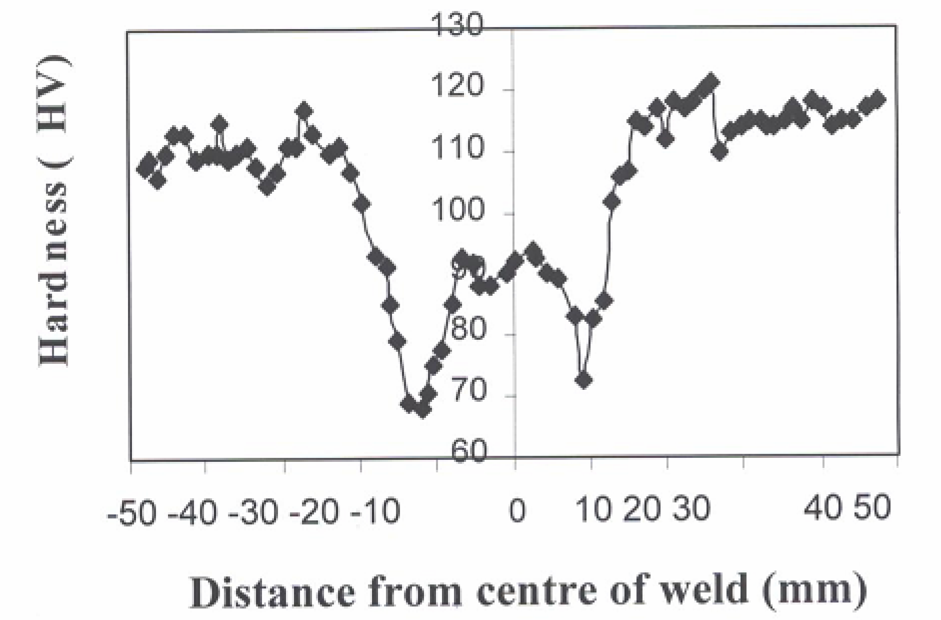


Figure-9. Hardness profile of the welds FSW 02-10.

Micro hardness tests were prepared in order to characterize the hardness profile in the vicinity of the weld affected area in the FSW specimens. The micro hardness tests were preferred in the top and side surface at half of the specimen thickness.

The as-welded hardness of the stir zone is considerably lower than that of the parent metal. The advancing side showed a slightly wider softened region than the retreating side. Hardness profile in particle-hardened materials is mainly governed by the distribution of the precipitates [28].

The hardness of both the heat affected zone (HAZ) and the weld nugget (WN) is lower than that of base metal (BM), respectively by 15-20% and 7-10%. The difference between HAZ and WN is attributable to the grain refinement in WN, caused by intensive stirring. The softest points of the joints correspond to the failure locations in tensile tests.

AA 6082-T6

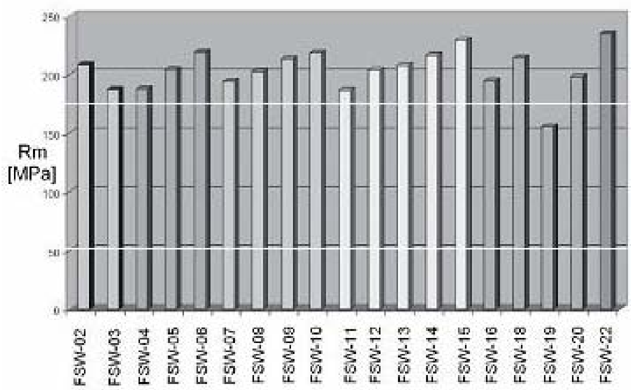


Figure-10. Results of tensile tests.

3.4 Tensile tests

In all cases the samples failed in HAZ of the advancing side, similarly as reported in [28]. The results are presented in Figure-10. It can be noticed that at constant rotational speed mechanical resistance of joints increases with increasing of the travel speed (Figure-10). This can be attributed to the decreased heat input and relative limited softening of the HAZ.The tensile friction stir welded specimens before and after the tensile tests are presented in the Figures 11, 12. In these specimens the rupture occurred in the HAZ. Also, a decrease in resistant area in the other side of the weld line was noticed.

Figure-11. Tensile specimen before test.

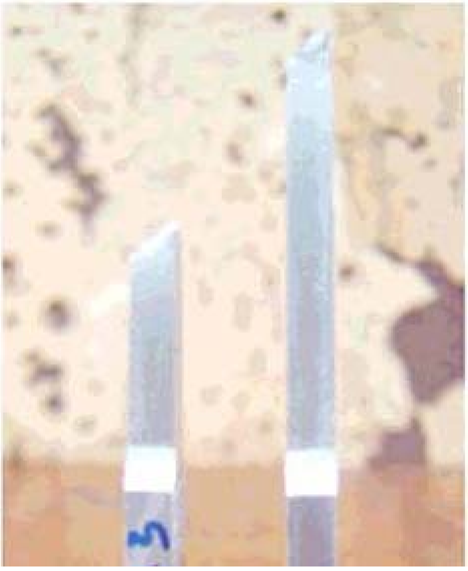
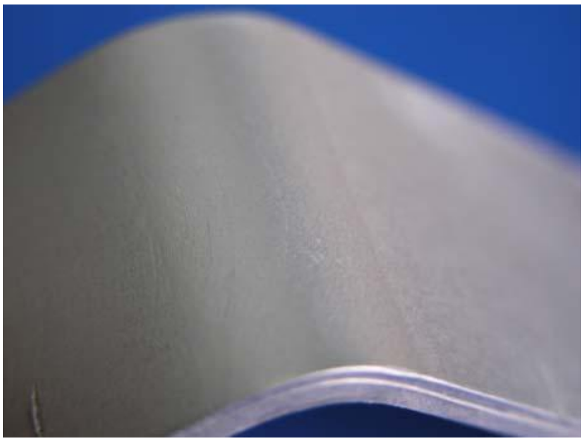


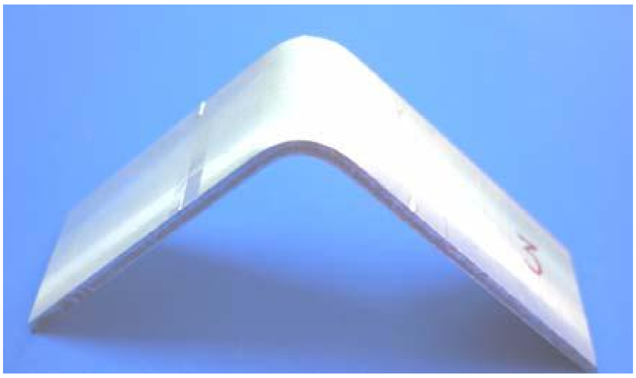
Figure-12. Tensile specimen after test.

3.5 Bend tests

Root and face bend tests were used as an important tool to understand about the ductility and toughness of friction stir welds. As-friction stir weld samples passed 90^0 bend test (Figure-13).



Face bend



Root bend

Figure-13. Face and root side bend test specimens.

CONCLUSIONS

1. FSW was successfully carried out on a computer numerical control milling machine and the quality of welded joints was found to be satisfactory.
2. Friction stir welding of alloy AA6082-T6 resulted in a dynamically recrystalized zone, TMAZ and HAZ. A softened region has clearly occurred in the friction stir welded joints of AA6082-T6 alloy.
3. Mechanical properties of FS welded aluminium alloy 6082-T6 are influenced by process parameters.
4. Tensile strength of FS welds is directly proportional to the travel / welding speed.
5. The tensile strength of the joint is lower than that of the parent metal.
6. Hardness drop was observed in the weld region. The softening was mostly evident in the heat affected zone on the advancing side of the welds. This zone corresponds to the failure location in tensile tests.
7. Tunnel defect was found at the intersection of weld nugget and thermo-mechanically affected zone due to high rotational speed and travel speed. By optimizing rotational speed (1230 rpm) and travel speed (115-170 mm/min) this defect was avoided.
8. Tool breakage was avoided with the design of tapered and threaded pin.
9. The FS welded aluminium alloy 6082-T6 samples did not fail in bend test.

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REFERENCES

[1] A.K. Jha, S.V.S.N. Murty, V. Diwakar, K. Sree Kumar. 2003. Metallurgical analysis of cracking in

weldment of Propellant tank. Engineering Failure Analysis. 10(3): 265-273.

[2] G. Huang, S. Kouc. 2000. Partially melted zone in aluminum welds-liquation- mechanism and directional Solidification. Welding Research Supplement. pp. 113-120.

[3] W.M. Thomas, E.D. Nicholas, J.C. Needham, M.G. Murch, P. Templesmith, C.J. Dawes. 1993. Intl. Patent Application No. PCT/GB92/02203.

[4] T. Dickerson, Q. Shi, H.R. Shercliff. 2003. Heat flow into friction stir welding tools. 4th Intl. Symposium on Friction Stir Welding, Park City, Utah, USA.

[5] Cam G., Dos Santos J.F. and Kocak M. 1997. Laser and electron beam weldability of Al- alloys: Literature review. GKSS report 97/E/25, IIW Document IX-1896-1898. GKSS Research Centre, Geesthacht.

[6] C.J. Dawes. 1990. Friction Stir welding, in training in aluminium. Application Technologies-TALAT. European Aluminum Association. In: CD-ROM Lectures 4410.

[7] O.T. Midling, E.J. Morley, A. Sandvik. Friction Stir Welding. European Patent Application 959 078 88.

[8] G. Liu, L.E. Murr, C.-S. Niou, J.C. McLure and F.R. Vega. 1999. Scripta Materialia. 37: 355.

[9] K.V. Jata and S.L. Semiatin. 2000. Scripta Materialia. 43: 743.

[10] T.J. Linenert, R.J. Grylls, J.E. Gould and H.L. Fraser. 1998. Deformation Microstructures in friction stir welds on 6061-T651, In: Proc. of the TMS Fall Meeting, The Minerals, Metals and Materials Soc., Warrendale, PA, USA.

[11] H. G. Salem, A.P. Reynolds, J.S. Lyons. 2002. Scripta Materialia. 46: 337.

[12] Y.S. Sato., H. Kokawa, K. Ikeda, M. Enomoto, S. Jogan and T. Hashimoto. 2001. Metallurgical and Material Transactions. 32A, 109.

[13] S. Benavides Y.Li, L.E. Murr, D. Brown and J.C. McClure. 1999. Scripta Materialia. 41: 809.

[14] Y. Li, L.E. Murr, D. Brown and J.C. McClure. 1999. Material Science and Engineering, A271.

[15] R.A. Prado, L.E. Murr, D.J. Shindo and K.F. Soto. 2001. Scripta Materialia, 45: 75.

[16] P.S. Pao, S.J. Gill., C.R. Feng and K.K. Sankaran. 2001. Scripta Materialia. p. 45.

[17] K.N. Krishnan. 2002. Material Science and Engineering, A327, p. 246.

[18] Ying Li, L.E. Murr and J.C. McClure. 1999. Scripta Materialia. 40: 1041.

[19] M. Ericsson and R. Sandstorm. 2003. Influence of welding speed on the fatigue of friction stir welds and comparison With MIG and TIG. International Journal of Fatigue. 25(12): 1379-1387.

[20] Y.G. Kim, H. Fujii, T. Tsumura, T. Komazaki, K. Nakata. 2006. Three defect types in friction stir welding of Aluminum dies casting alloy. Materials Science and Engineering. A415, 250-254.

[21] J-Q. Sua, T.W. Nelson, C.J. Sterling. 2005. Microstructure evolution during FSW/FSP of high strength aluminum Alloys. Materials Science and Engineering. A405, 277-286.

[22] A. Barcellona, G. Buffa, L. Fratini, D. Palmeri. 2006. On microstructural phenomena occurring in friction stir welding of aluminium alloys. Journal of Materials Processing Technology. 177: 340-343.

[23] J. Ouyang, E. Yarrapareddy, R.Kovacevic. 2006. Microstructural evolution in the friction stir welded 6061 Aluminum alloy (T6-temper condition) to copper. Journal of Materials Processing Technology. 172: 110-122.

[24] H.G. Salem. 2003. Friction stirs weld evolution of dynamically recrystallized AA2095 weldments. Scripta Materialia. 49: 1103-1110.

[25] K.N. Krishnan. 2002. On the formation of onion rings in friction stir welds. Materials Science and Engineering. A327, 246-251.

[26] G. Raghu Babu, K.G.K. Murti, G. Ranga Janardhana. 2006. An Approach to the Design of a Tapered Tool for Friction Stir Welding of Aluminium using CAD. Proceedings of National Conference on Emerging Technologies in Mechanical Enginnering for Sustainable Development. 1(A), pp. 1-4.

[27] P. Cavaliere, G. Campanile, F. Panella, A. Squillace. 2006. Effect of welding parameters on mechanical and microstructural properties of AA6056 joints produced by Friction Stir Welding. Journal of Materials Processing Technology. 180: 63-270.