

Mechanical and Micro-structural Study of Friction Stir Welding of Al-alloy

Biswajit Parida^{*}, Sukhomay Pal^{**}, Pankaj Biswas^{***}, M M Mohapatra^{****}, Sujoy Tikader^{*****}

^{*,**,**} Mechanical Engineering, IIT Guwahati, India-781039.

^{****} Mechanical and Industrial Engineering, IIT Roorkee, India-781039.

^{*****} Haldia Institute of Technology, West Bengal, India-721604.

Email: b.parida@iit.erner.in

Abstract: The present study is on the development of friction stir welding (FSW) of commercial grade Al-alloy to study the mechanical and micro-structural properties. The proposed research will include experiments related to the effect of FSW optimum process parameter on weldability of Al alloy. The present paper has been subdivided in to two different sections: 1. Study of Mechanical properties and 2. Study of micro-structural properties. Section1 describes the tensile strength of welded sample and distribution of micro-hardness in different zones of FSW weld specimen and section2 contains the microstructure characterization of different zones of friction stir welds.

Key words: FSW, weldability, mechanical properties, tensile strength, micro-hardness, microstructure.

1 Introduction:

The history of joining metals goes back several millennia, with the earliest examples of welding from the Bronze Age and the Iron Age. From that time the process of welding gone through several modifications, world wars caused a major surge in the use of welding processes, with the various military powers attempting to determine which of the several new welding processes would be best. Many sophisticated welding methods for different alloys of variety applications are available now.

Wang D. & Liu S. [1] studied the Friction stir welding of aluminum: In this, the Aluminum plates were friction stir welded at various rotation speeds (850 – 1860 rpm) and travel rates of 30 to 160 mm/min with welding forces ranging from 2.5 to 10 MPa using different dimension welding heads. From the experiments it has found that dimensions of the welding head are critical to produce sound weld. 10% higher micro-hardness is obtained than the parent metal. Scialpi A., et al. [2] studied the influence of shoulder geometry on microstructure and mechanical properties of friction stir welded 6082 aluminum

alloy: In this work, the tool analysis has been carried out on AA 6082 T6 1.5 mm thick sheets and the welding process was carried out rotating the tool at 1810 rpm and at a feed rate of 460 mm/min. Three types of shoulder geometries have been taken into consideration. From the experiments it was concluded that TFC tool (tool with fillet and cavity) crown is the best in terms of crown quality. Fujii H., et al. [3] studied the effect of tool shape of friction stir welded aluminum alloys. Boz M. & Kurt A. [4] studied the influence of Stirrer Geometry on Bonding and Mechanical Properties in friction stir welding process: In this, the effect of stirrer geometry on the weldability and mechanical properties of welded aluminum plates using FSW process was investigated. Cabibbo M., et al. [5] studied the microstructure and mechanical property studies of AA6056 friction stir welded plates: In this work, the author has investigated the microstructure and mechanical properties of a friction stir welded 6056-T6 aluminum alloy plate by using polarized optical and transmission electron microscopy techniques. Sarsilmaz F. & Caydas U. [6] studied the statistical Analysis on Mechanical Properties of Friction Stir Welded AA1050/AA5083 couples: In this, the effect of friction stir welding parameters on the mechanical properties of Aluminum alloys as investigated. Sakthivel T., et al. [7] studied the effect of Welding Speed on Mechanical Properties of Friction-stir Welded Aluminum: In this present investigation aluminum welds were made at various welding speed using the friction stir welding technique by using a hardened steel FSW tool. Adamowski J. & Szkodo M. [8] studied the friction-stir-welds (FSW) of Aluminum alloy AW6082-T6: In this paper the properties and micro-structural changes in friction stir welds in the aluminum alloy 6082-T6 in function of varying process parameters have been investigated. Softening of the material in the weld nugget and heat affected zone was observed i.e. the hardness of both the heat affected zone and the weld nugget is lower than that of the base metal. Rodrigues D. M., et al. [9] studied the influence of Friction Stir Welding Parameters on the Micro-structural and Mechanical properties of AA 6016-T4 Thin Welds: In this present work friction stir welds produced in 1 mm thick plates of AA6016-T4

aluminum alloy, with two different tools, were analyzed and compared concerning the micro-structure and mechanical properties. *Kim Y.G., et al.* [10] studied the effect of Welding Parameters on Microstructure in the Stir Zone of FSW Joints of Aluminum die Casting Alloy in this study the effect of the welding speed and the rotation speed on the microstructure in the stir zone has been investigated by measuring the Si particle distribution in the Aluminum die casting alloys which are made by the rapid injection of molten metal into metal molds under high pressure. *Sato Y. S. & Kokawa H.* [11] studied the distribution of Tensile Property and Microstructure in Friction stir Weld of 6063 Aluminum: The objective of the present study is to clarify dominant micro-structural factors governing the global tensile properties of the welded joint by estimation of the distribution of the local tensile properties in the joint including extensive regions from the stir zone to the unaffected base material region. In this study an extruded 6063-T5 Al, 4 mm thickness plates were friction stir welded keeping the travel speed and the tool shoulder diameter were 10 mm/s and 15 mm respectively. *Yeni C., et. al.* [12] studied the effect of Post Weld-aging on the Mechanical and Microstructural Properties of Friction-stir Welded Aluminum alloy 7075. It has been seen that left helical screw yields higher mechanical properties when tested at the same shoulder diameter.

The quality of welding joint highly depends on the process parameter. In the present investigation an attempt has been made to investigate the effect of optimum process parameters on mechanical properties and microstructural characteristics of the welded joint made from commercial aluminum alloy.

2 FSW tool geometry

From the survey of literature it was found FSW welding has been carried out by using complicated tool geometries, which are extremely difficult to manufacture. But it was observed that the complicated tool pin profiles tend to wear out after few numbers of runs leading to a conical form. This has been occurred specially while working with comparatively higher tensile strength materials, e.g. AA 7075-T651. Hence in the present work it was decided to study the performance of FSW tools having simple regular geometrical forms, like straight tapered cylindrical. On prolonged usage, even if these tools wear down, they will attain tapered cylindrical or cylindrical shape. Therefore a systematic study of this regular simple geometric shapes was taken up to

study the mechanical and micro-structural properties of FSW welded sample.

In this present study SS310 have been used to fabricate the FSW tools. The material composition and the thermo-mechanical properties of SS 310 are shown in Tables 1 and 2, respectively. The chosen tool geometries and the fabricated tool for FSW of 6mm thick aluminum alloy are shown in Fig.1 and Fig. 2 respectively.

Table 1: Composition of SS310 by percentage

Fe	C	Cr	Mn	Ni	P	S	Si
48–53	0.25	24–26	2	19–22	0.045	0.03	1.5

Table 2: Physical properties of SS310

Hardness, Brinell	160
Tensile strength, ultimate (MPa)	655
Tensile strength, yield (MPa)	275
Thermal conductivity at 100 deg C (W/m ² K)	14.2

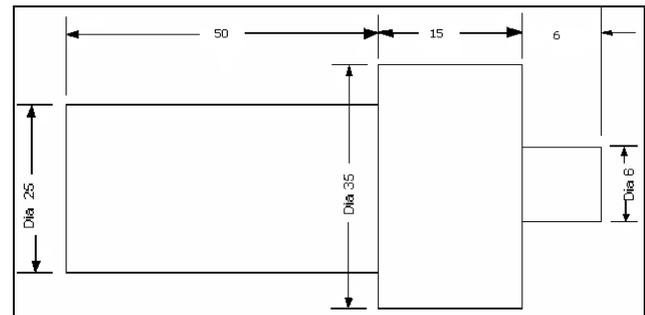


Fig.1 FSW tool geometry



Fig. 2 Fabricated FSW tools

3 Experimental details

To carry out the FSW experiment a vertical milling machine with 7.5hp motor capacity was used. The tool was mounted in the vertical arbor using a suitable collate. The plates to be joined were clamped to the horizontal bed with zero root gap. The clamping of the test pieces was done such that the movement of the plates was totally restricted under both plunging and translational forces of the FSW tool. The tool rpm and translational speed of the bed were set prior to each run of welding. After plunging the rotating tool at the plate butt and visually ensuring full contact of the tool shoulder with the plate surface, the bed movement was done. A typical experimental FSW setup is shown in Fig. 3.

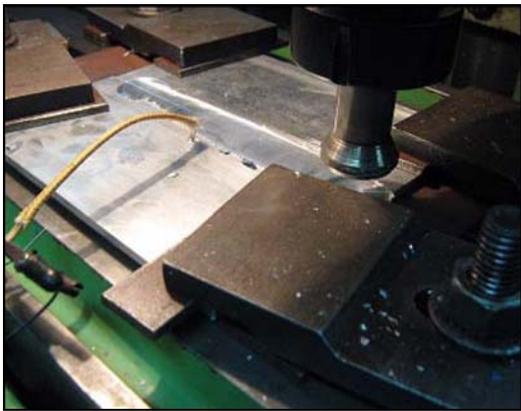


Fig. 3 FSW experimental setup

4 Results and discussion

Extensive FSW experiments were carried out to optimum the process parameter which give the good quality of welded joint by using the above designed tool geometry. From the experimental observation the optimum process parameters were decided which is shown in Table 3. The sample of FSW weld sample obtained by using above parameter is shown in Fig. 4.

Table 3: Experimental optimum FSW Process parameters for of 6mm thick aluminum alloy test samples

Sl. No.	Tool rotational speed (rpm)	Tool transverse speed (mm/min)	Tool plunging force (N)
1	1400	112	6300

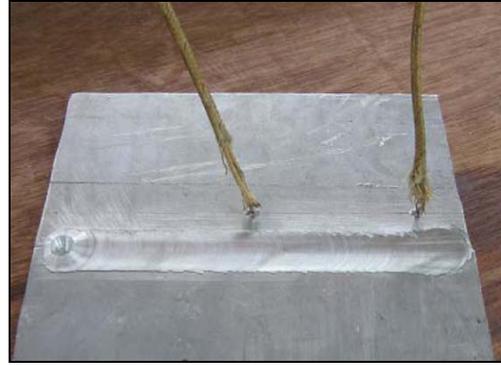


Fig. 4 FSW weld sample

The results of tensile testing, micro-hardness and microstructure have been described in three sub-sections below.

4.1 Tensile testing

The FSW welds cut according to the ASTM specifications for tensile testing are shown in fig 5. The tensile testing of the welds was done using a UTM machine and the load verses displacement graph has been obtained as shown in fig 6 and fig 7.



Fig. 5 Tensile Specimen

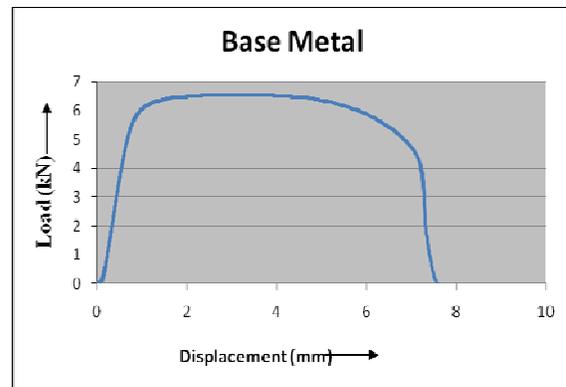


Fig. 6 Tensile test result for Base Metal

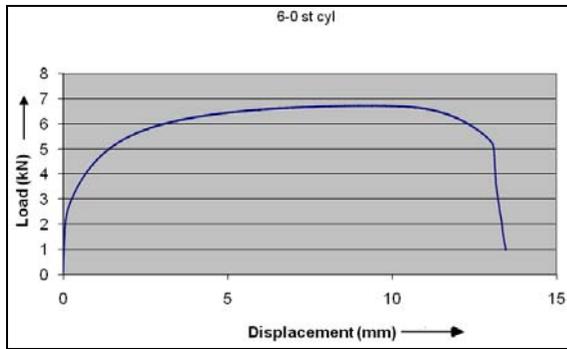


Fig. 7 Tensile test result for Welded Plate

The tensile testing results show that compared to base metal the tensile property of the weld improved considerably. And also the displacement before failure for welded plate is 13mm as compared to 7.5mm in case of base material which indicates the increase in ductility.

4.2 Micro-hardness

The welded samples were tested for micro-hardness and measurements were taken on the cross sections perpendicular to the welding direction. A load of 100gf was kept for hardness measurement. The instrument used for the experiments is shown in the figure fig 8. The microhardness of the weld zone and the heat affected zones were measured for the sample. The obtained microhardness trend is shown in fig 9.

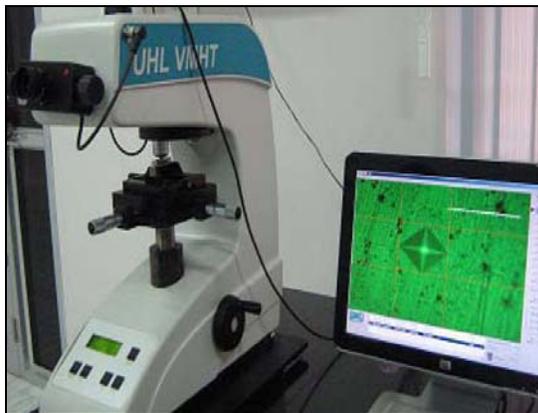


Fig. 8 Microhardness testing

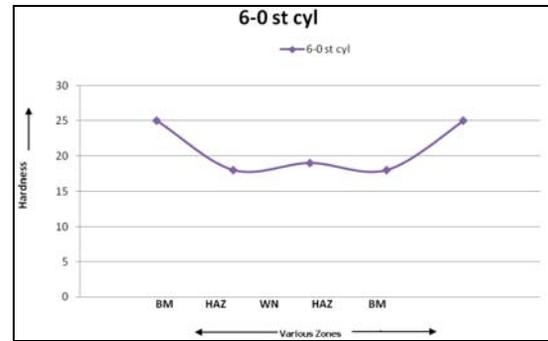


Fig. 9 Microhardness of FSW weld sample

It can be observed from the graph that the hardness values of the weld zone or the nugget is lower than the base materials. This indicates the improved ductility of the weld. And there is not much difference in the hardness values of weld zone and heat affected zone (HAZ).

4.3 Micro-structure

Metallographic tests on the transverse cross sections of different welded samples were carried out to study the microstructures of different zones of the welded samples. The samples were thoroughly polished and then etched with Keller's reagent. An optical image analyzer (Leica) was used for this purpose as shown in fig 10. The micro-structure has been revealed and the grain size of the different zones of the welded sample was measured.



Fig. 10 Electron optical microscope

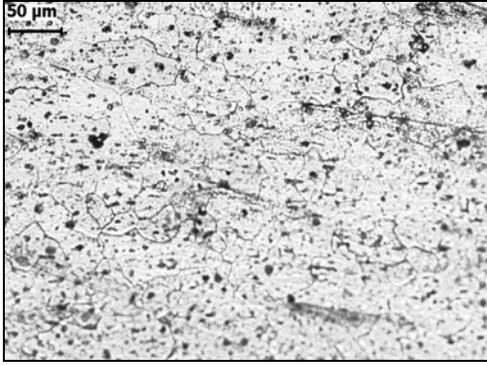


Fig. 11 Microstructure of HAZ

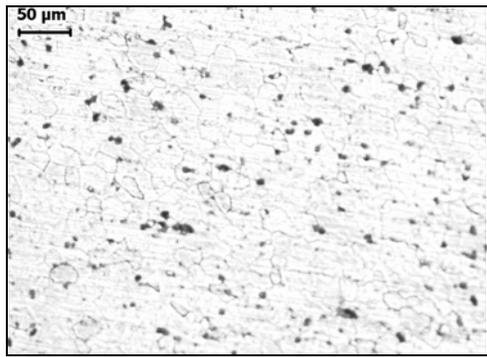


Fig. 12 Microstructure of WZ

From the microstructural evolution it has been found that grain refinement occurs in FSW process. The grain size of different zones has been listed below.

Sl. No.	Zones	Average grain size
1	HAZ	47.93
2	WZ	30.41

5 Conclusion

In this work 6mm thick commercial grade aluminum plates have been welded by using a 6mm diameter straight cylindrical probe / pin FSW tool. From the above designed FSW tool geometry and the above process parameters a very good quality weld has been achieved by which the following conclusions can be made:

- The tensile strength of the weld is better than the parent material.
- The hardness values of the weld zone and HAZ are lower than the base material which indicates the improved ductility of the weld.
- From the micro-structural study it has been observed that the weld zone is stirred and

having more grain refinement as compared to the HAZ zone.

The weld strength and quality of the weld obtained during the experiment indicated the success of the process.

Acknowledgements

The authors would like to thank Dr. N. R. Mandal (IIT,Kharagpur) for many helpful discussions and their interest in this work.

References

1. **Wang Deqing, Liu Shuhua**, “Study of Friction stir welding of aluminum”, Journal of Materials Science Volume 39 (2004) 1689 – 1693
2. **Scialpi, L.A.C. De Filippis, P. Cavaliere**, “Influence of shoulder geometry on microstructure and mechanical properties of friction stir welded 6082 aluminum alloy”, Journals for Materials and Design, Volume 28 (2007) 1124-1129 DOI:10.1016/j.matdes.2006.01.031.
3. **Hidetoshi Fujii, Ling Cui, Masakatsu Maeda, Kiyoshi Nogi**, “Effect of tool shape on mechanical properties and microstructure of friction stir welded aluminum alloys ”, Journal of Material Science and Engineering, Volume A 419 (2006),Pages 25-31.
4. **Mustafa Boz, Adem Kurt**, “The Influence of Stirrer Geometry on Bonding and Mechanical Properties in friction stir welding process”, Journal of Materials and Design, Volume 25 (2004), Pages 343-347.
5. **M. Cabibbo, H.J. McQueenb, E. Evangelista, S. Spigarelli, M. Di Paola, A. Falchero**, “Microstructure and mechanical property studies of AA6056 friction stir welded plate”, Journal of Materials Science and Engineering, Volume A 460-461 (2007), Pages 86-94.
6. **Furkan Sarsilmaz – Ulas caydas**, “Statistical Analysis on Mechanical Properties of Friction Stir Welded AA1050/AA5083 couples”, International Journal of Advanced Manufacturing Technology (2008), DOI 0.1007/s00170-008-1716-x.

7. **T Sakthivel, G S Senegar, J Mukhopadhyay**, “Effect of Welding Speed on Micro-structure and Mechanical Properties of Friction-stir Welded Aluminum”, International Journal of Advanced Manufacturing Technology (2008), DOI 10.1007/s00170-008-1727-7.
8. **J. Adamowski, M Szkodo**, “ Friction-stir-welds (FSW) of Aluminum alloy AW6082-T6 ”, Journal of Achievements in materials and Manufacturing Engineering, Volume 20, Issue 1-2, January-February 2007.
9. **D M Rodrigues, A Loureiro, C Leitao, R M Leal, B M Chaparro, P Vilaca**, “Influence of Friction Stir Welding Parameters on the Micro-structural and Mechanical properties of AA 6016-T4 Thin Welds”, Journals for Materials and Design (2008), DOI 10.1016/j.matdes.2008.09.016.
10. **Y.G. Kim a, H. Fujii, T. Tsumura, T. Komazaki, K. Nakata**, “Effect of Welding Parameters on Microstructure in the Stir Zone of FSW Joints of Aluminum die Casting Alloy ”, Journals for Materials Letters Volume 60 (2006) 3830–3837 DOI:10.1016/j.matlet.2006.03.123.
11. **Yutaka S Sato and Hiroyuki Kokawa**, “Distribution of Tensile Property and Micro-structure in Friction stir Weld of 6063 Aluminum”, Metallurgical and Materials Transactions, Volume 32A, December 2001-3023.
12. **C Yeni, S Sayer, O Ertugrul, M Pakdil**, “Effect of Post Weld-aging on the Mechanical and Micro-structural Properties of Friction-stir Welded Aluminum alloy 7075”, Achieves of Material Science and Engineering, Volume 34, Issue 2, December 2008, Pages 105-109.