



## Effect of FSP Multipass on Microstructure and Impact Strength of AL6063

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**Abstract:** Need for low weight and high performance structural materials have revolutionized the technology and had led to the emergence of new processes and methodologies. Frictions stir processing (FSP), based on principle of friction stir welding, is an emerging solid state metal working process. This technique causes intense plastic deformation and high strain rates in the processed material resulting in precise control of the microstructure through material mixing and densification. FSP process has been successfully used for achieving significant grain refinement and enhancement of surface properties. Current study focused on the study of behavior of aluminium cast alloy (Al-6063) processed by friction stir processing technique. Samples of FSPed aluminium were examined and their microstructures, strength were studied with various methods and compared with base metal Al-6063. Impact test is employed to know the Impact Strength of samples against the Impact of Hammer.

**Keywords:** FSP, Multipass, Microstructure, Izod Impact Test,

### I. Introduction

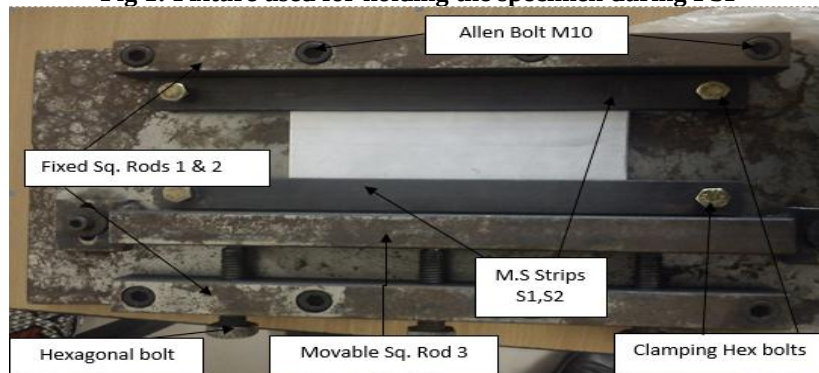
Aluminum alloys are very promising for structural applications in aerospace, military and transportation industries due to their light weight, high strength-to-weight ratio and excellent resistance to corrosion. However, the low hardness and low strength of aluminium alloys limit their use, especially for tribological applications. Therefore to enhance these properties several properties enhancement techniques can be used, from them one is Friction Stir Processing [16]. Friction stir processing (FSP), developed based on the basic principles of friction stir welding (FSW), a solid-state joining process originally developed for aluminium alloys, is an emerging metal working technique that can provide localized modification and control of microstructures in near-surface layers of processed metallic components. The FSP causes intense plastic deformation, material mixing, and thermal exposure, resulting in significant microstructural refinement, densification, and homogeneity of the processed zone [25]. Friction stir processing (FSP) is a unique technique for refining and modifying the microstructure of materials. In many aspects, the basic principles of FSP are the same as those of FSW. Besides, FSP has been successfully used for fabricating the surface composites, for refining the surface microstructures of various materials as well as for synthesizing the composite and intermetallic compounds. FSP is a solid state processing based on friction stir welding (FSW). FSW is innovation of The Welding Institute (TWI) of UK in 1991. FSP is defined as a severe plastic deformation technique used in order to improve surface properties. Fine microstructure and absence of casting defects are the main advantages of FSP. During FSP, rotational tool (non-consumable) with a specially designed pin and shoulder is plunged into the plate and traversed in desired direction [6]. Cavalier et al conducted FSP on Aluminium alloy 7075 and concluded that Maximum hardness occurred at a distance of 3.5 mm from the center rather than at the centre of FSPed zone [24]. Zahmatkesh et al studied the effect of FSP on AL2024 alloy and concluded that FSP was found to be beneficial in improving the wear resistance. The maximum hardness was achieved in NZ (110 HV) [4]. Surekha et al 2009 studied the Effect of multipass FSP process on AA2219 and he concluded that only the rotation speed was found to influence the corrosion behaviour, while the traverse speed had negligible influence [23]. Elangovan et al conducted FSP on AL6061 to study the Influence of tool pin profile and axial force and he concluded that Joints fabricated by straight cylindrical pin profiled tool exhibited inferior tensile properties compared to their counterparts [22]. Devaraju et al showed the effect of rotational speed and reinforcement particles such as silicon carbide (SiC), alumina (Al<sub>2</sub>O<sub>3</sub>) on wear and mechanical properties of aluminium alloy based surface hybrid composites fabricated via friction stir processing and Microhardness was increased, wear and tensile properties decreased as compared to the base metal [2]. Deepak et al prepared the 5083 Al-SiC surface composite by FSP and found that the micro hardness is increased from 44HV to 84 HV. The wear resistance of FSPed sample is inferior to that observed for 5083Al in spite of its higher hardness [16]. The literature survey reveals that FSP can be successfully employed to enhance the surface properties (viz. micro-hardness, wear resistance etc.) of metals and their alloys. However, the work pertaining to enhancement of surface properties of

aluminum/aluminum alloys through friction stir processing (FSP) is rather scant. The present study deals with FSP of 6063Al alloy. Aluminium alloy 6063 is a medium strength alloy commonly referred to as an architectural alloy. It is normally used in intricate extrusions. It has a good surface finish, high corrosion resistance, is readily suited to welding and can be easily anodised. Most commonly available as T6 temper, in the T4 condition it has good formability. But the tribological applications of this alloy is limited due to its poor hardness. Aluminium alloy 6063 is typically used in: Architectural application, Extrusions, Window frames, Door, Shop fittings, Irrigation tubing. The present study investigates the effect of multipass on the surface of 6063 Al through friction stir processing on its mechanical behavior viz. microstructure and impact strength.

## II. Experimental Procedure

In this study 6063-Al alloy in plate form (Length: 150 mm, Width: 100 mm, Thickness: 6 mm) has been selected for the purpose of carrying out multipass FSP. The chemical composition of the alloy, as estimated through spectroscopic technique, is Si (0.600%), Mg (.619%), Cu (0.082%), Fe (0.350%), Mn (.044%), Zn (0.061%), Cr (0.007%) and Ti (0.015%). Three pass FSP was carried out on the AL6063. The set up used for carrying out friction stir processing consists of a CNC vertical milling machine and a specially designed rotating FSP tool. The fixture for holding the base plate, while carrying out FSP, was designed and fabricated in house (Fig. 1). The fixture consists of a rectangular base plate of dimensions 400 mm x 200 mm x 20 mm. Three rods, having square X-section (25 mm x 25 mm) and length 300 mm were machined to achieve surface finish of the order of 5  $\mu$ m. Out of these square rods, two rods were drilled with counter sunk holes (4 Nos.) to adjust allen bolts of size M10. These two rods were fixed at the ends of rectangular base plate (Fig. 1). The square rod-2 consists of three-additional drilled holes with M12 internal threads to accommodate hexagonal bolts of size M12. The third square rod was placed between rods 1 and 2 and was movable with the help of hexagonal bolts tightened to square rod 2. The base plate, to be friction stir processed, was held tight between the square rods 2 and 3. The base plate was also tightened to the rectangular base plate with the help of two MS strips (S1 and S2) which were screwed to rectangular base plate with the help of hexagonal bolts (M8). The whole of the fixture (Fig. 1) was fitted to the bed of CNC milling machine with the help of sliding screw arrangements.

**Fig 1: Fixture used for holding the specimen during FSP**



A specially designed tool with shoulder and pin was used for the purpose of FSP. The tool was made of HSS with hardness ranging around 61-62 HRC, achieved through hardening and tempering treatment. The specifications of FSP tool used are given as below

**Table 1: Showing specification of tool**

|                           |                                    |
|---------------------------|------------------------------------|
| Pin and Shoulder Material | High Speed Steel (Heat Treated M2) |
| Shoulder Dimension        | Dia. =12mm, Length = 60mm          |
| Pin Dimension             | Dia =mm, Length = 3.5mm            |
| Tool Hardness             | 61-62 (Rockwell Hardness)          |

The symbol M2 refers to a special type of HSS in tungsten-molybdenum series having high wear resistance. The carbides in it are small sized and evenly distributed.

**Fig 2 Friction stir processing of AL6063**

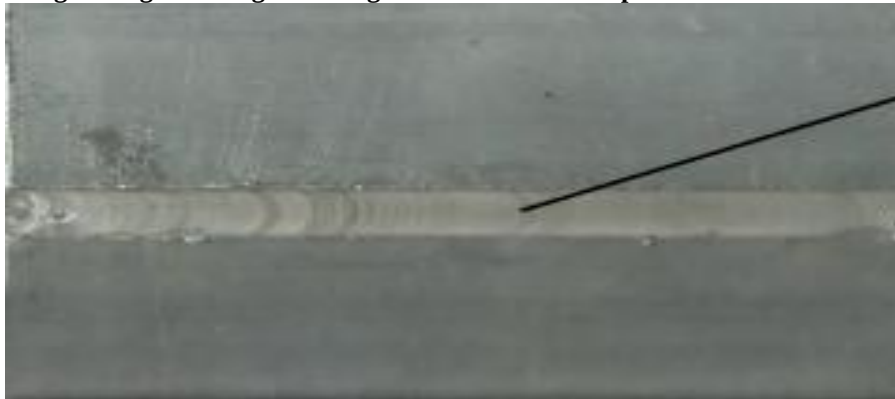


Friction stir processing (FSP) was carried out using a CNC vertical milling machine set up fitted with a specially designed cylindrical FSP tool which was rotated. The base metal (i.e. Al 6063) was fixed in a fixture that was held on the bed of milling machine. The FSP tool was rotated on the surface of base material to fabricate or machine the surface of Al6063. The machining parameters were kept constant i.e. the speed rate was kept at 1100rpm and the feed was kept at 15mm/min.

**Fig.3 showing the used parameters on CNC display**



**Fig.4 Image showing tunneling effect in friction stir processed 6063Al Plate**



#### **A. Microstructural Examination**

The microstructure of the samples were observed under inverted optical microscope (Metallurgical microscope with image analyzer, (Make-Qualitech) having PC interface and Measurement software. The specimen prepared for viewing their microstructure. Firstly the friction stir processed samples were cut into small sizes along the longitudinal as well as transverse sections. The cutting was performed with the help of hand hacksaw so as to avoid heating of the specimens, which might have cause microstructural changes. The cut pieces were mounted inside thermosetting plastic. The samples were placed inside a hollow pipe (dia.=50mm, length=20mm) with pressed surface downward. A freshly prepared mixture of selfcure polymer powder and selfcure monomer liquid was poured inside the hollow pipe from the top and the mixture was allowed to set for 5 min. The mounted process was carried out on metal base with greased surface so as to avoid adhesion of mounted samples with the metal base. The mounted samples were first ground on the flat belt grinder followed by manual grinding on successive grades of emery papers starting from 250 grits to 400, 800 coarse to fine grits of 1600 and 2000. The polishing was done until mirror finished and crack free surface was obtained. The final polishing was done on buffing machine by using diamond paste and continuously running water. In order reveal the microstructure of the polished specimens, the samples were etched with 5% Nital (0.5ml HF in 99.5ml H<sub>2</sub>O) for 5 to 10 sec followed by washing with wet cotton. The etched surface was dried with forced hot air to remove traces of moisture.

**Fig 5 Mounted Specimens**



### B. Impact Test

Izod impact testing is an ASTM standard method of determining the impact resistance of materials. An arm held at a specific height (constant potential energy) is released. The arm hits the sample and breaks it. From the energy absorbed by the sample, its impact energy is determined. A notched sample is generally used to determine impact energy and notch sensitivity. The test is similar to the Charpy impact test but uses a different arrangement of the specimen under test. The Izod impact test differs from the Charpy impact test in that the sample is held in a cantilevered beam configuration as opposed to a three-point bending configuration. All the three samples were tested using izod test. The samples were cut into 75 x 10x 6. And the strength of samples were measured in joules. The sample prone to impact test was not broken from notch due to the ductility of aluminium that is high. But the pictures are shown below which depicts the effect of impact on the aluminium samples. The sample 1 which was single passed FSP sample have got broken or tear off from the notch with respect to sample 2 and 3( 2pass and 3 pass) which only showed bend in the sample rather than breaking or tearing off. Because AL 6063 finds its applications just in light work Architectural application, Extrusions, Window frames, Door, Shop fittings, Irrigation tubing so high strength is not important.

**Fig 5 Image showing breaking of sample from notch after impact test**



### III. Results and Discussion

In order to investigate the effect of Multipass FSP on 6063Al plate through FSP, the specimens were characterized for microstructure and Izod impact test, as described in previous section. The results obtained for friction stir processed samples are compared with those obtained for unprocessed 6063 Al.

#### A. Optical Microscopy

**Fig 6 Microstructure of base AL6063 [24] and after different passes on aluminium 6063 checked under 100x magnification.**

**Fig (a) shows microstructure of BM**

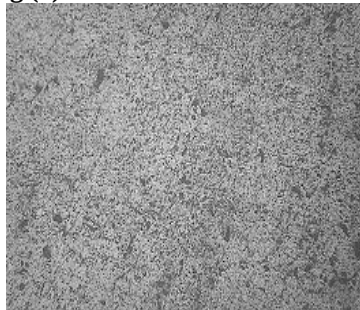


**Fig (b) shows microstructure of MS 1**



**Fig (b) shows microstructure of MS 2**



**Fig (b) shows microstructure of MS 3**



Samples for metallographic examination were cut from the surface of base alloy and FSPed sample. These samples were wet grounded using various grades of emery paper and polished to attain mirror finish by using buffing machine and alumina paste. The etching of the samples was done with the reagent 0.5 ml HF (40%) diluted with 99.5 ml distilled H<sub>2</sub>O before viewing the microstructure under optical microscope. Optical micrographs of Al-6063 base alloy and FSPed samples were viewed at magnification 100 x and are depicted in Fig 6. From these micrographs it is observed that the grain size of FSPed sample is relatively finer than the base alloy. The coarse grains size observed in base alloy leads to high ductility and low hardness than the FSPed

sample. But after the processing of aluminium by FSP, refinement of grain takes place due to high temperature produced by friction between the surfaces of the FSP tool and sample. The fine grain size observed in FSPed sample is responsible for its high hardness than the base alloy. The grain refinement in the matrix may be due to the occurrence of dynamic recrystallization phenomenon as a result of disruptive mechanical action of the tool pin provided in the FSP tool. The base metal had a coarse grain structure, after performing single pass FSP very fine uniformly discontinuity alloy silicides in a matrix of aluminium, some surface defects were observed in the base metal. In second pass very fine distributed alloy silicides in a matrix of aluminium was observed. And in third pass very fine uniformly distributed alloy silicides in a matrix of aluminium, no cavity/ crack/discontinuity observed between processed zone and base metal. The formation of these fine grains during FSP can be attributed to dynamic recrystallization and a low heat input during FSP results in an exceptionally fine grain structure along with dissolution of the precipitates.

#### B. Izod impact test

The impact test simulates the service conditions often encountered in transportation, agricultural and construction equipment which are frequently subjected to impact and shock loads during sudden blows and stoppages. The stress induced during impact loading are many more times the stress induced during gradual loading. The izod impact test was conducted on all the FSPed sample, using impact testing machine. Which showed decrease in impact strength as compared to the base metal AL6063. It was observed the samples were not totally broken from the notch due to the high ductility of aluminium alloy sample. The result obtained after testing the base plate was, the base metal have impact strength of 13 Joule, that subsequent decreased in first pass to 10 Joule, in the second pass the strength increased than 1st pass sample to 11 joule, and in third pass sample it little bit increased to 12 joule. The obtained result showed the impact strength was not improved very much as compared to base metal. The result comparison shown below in the graph.

**Fig 7 shows comparison between impact strength**



#### IV. Conclusions

From the above study it is concluded that the FSP multipass had effected AL6063, The triple pass FSP sample showed very fine uniformly distributed alloy silicide in a matrix of aluminium without any crack with respect to that of single pass, double pass, base metal which also coarse microstructure, and second pass have fine distributed silicides but not uniform. Single pass microstructure showed some surface defects with distribution of silicide shows discontinuity. So the mechanical properties are directly related with the fine microstructure. The impact strength does not showed any improvement, the impact resistance of the FSPed sample had been decreased as compared to the base metal, Because AL 6063 finds its applications just in light work Architectural application, Extrusions, Window frames, Door, Shop fittings, Irrigation tubing so high strength is not important.

#### References

- [1]. A.Yazdipoura, A. Shafiei Mc, K. Dehghanib; "Modeling the microstructural evolution and effect of cooling rate on the nanograins formed during the friction stir processing of Al5083". Materials Science and Engineering A 527 (2009) 192–197
- [2]. A.Devaraju , A. Kumar, A. Kumaraswamy , B. Kotiveerachari "Influence of reinforcements (SiC and Al2O3) and rotational speed on wear and mechanical properties of aluminium alloy 6061-T6 based surface hybrid composites produced via friction stir processing" Materials and Design 51 (2013) 331–341
- [3]. Adem Kurt, Ilyas Uygur, Eren Cete "Surface modification of aluminium by friction stir processing" Journal of Materials Processing Technology 211 (2011) 313–317
- [4]. B.Zahmatkesh, M.H. Enayati, F. Karimzadeh. "Tribological and microstructural evaluation of friction stir processed Al2024 alloy". Materials and Design 31 (2010) 4891–4896
- [5]. B. Zahmatkesh, M.H. Enayati; "A novel approach for development of surface nanocomposite by friction stir processing" Materials Science and Engineering (2010)
- [6]. B.M. Darras, M.K. Khraisheh, F.K. Abu-Farha, M.A. Omar; "Friction stir processing of commercial AZ31 magnesium alloy". Journal of Materials Processing Technology 191 (2007) 77–81
- [7]. C.F. Chen, P.W. Kao, L.W. Chang, and N.J. Ho "Effect of Processing Parameters on Microstructure and Mechanical Properties of an Al-Al<sub>11</sub>Ce<sub>3</sub>-Al<sub>2</sub>O<sub>3</sub> In-Situ Composite Produced by Friction Stir Processing" DOI: 10.1007/s11661-009-0115-8 The Minerals, Metals & Materials Society and ASM International 2009

- [8]. C. I. Chang Y. N. Wang H. R. Pei, C. J. Lee, X. H. Du, J. C. Huang “*Microstructure and Mechanical Properties of Nano-ZrO<sub>2</sub> and Nano-SiO<sub>2</sub> Particulate Reinforced AZ31-Mg Based Composites Fabricated by Friction Stir Processing*” Key Engineering Materials Vol. 351 (2007) pp. 114-119
- [9]. C.I. Chang,a X.H. Dua,b and J.C. Huang; “*Producing nanograined microstructure in Mg–Al–Zn alloy by two-step friction stir processing*” Scripta Materialia 59 (2008) 356–359
- [10]. C.J. Hsu, P.W. Kao , N.J. Ho “*Ultrafine-grained Al–Al<sub>2</sub>Cu composite produced in situ by friction stir processing*” Scripta Materialia 53 (2005) 341–345
- [11]. C.J. Hsu, C.Y. Chang, P.W. Kao, N.J. Ho, C.P. Chang; “*Al–Al<sub>3</sub>–Ti nanocomposites produced in situ by friction stir processing*”. Acta Materialia 54 (2006) 5241–5249
- [12]. C.J. Hsu, P.W. Kao, N.J. Ho; “*Intermetallic-reinforced aluminium matrix composites produced in situ by friction stir processing*”. Materials Letters 61 (2007) 1315–1318
- [13]. Charit I, Mishra R.S “*High strain rate super plasticity in a commercial 2024 Al alloy via friction stir processing*”. Mater Eng A pp 290–6 (2010)
- [14]. Chen Ti-ju, Zhu Zhan-ming, LI Yuan-dong, Ma Ying, Hao Yuan “*Friction stir processing of thixoformed AZ91D magnesium alloy and fabrication of Al-rich surface*” Trans.Non-ferrous Met. Soc. China 20(2010) 34-42
- [15]. Devaraju Aruri , Adepu Kumar& B Kotiveerachary “*Effect of III-Pass on Microstructure, Micro Hardness and Static Immersion Corrosion Resistance of AA6061-T6/SiCp Surface Composite Fabricated by Friction Stir Processing*” International Journal of Applied Research In Mechanical Engineering (IJARME), ISSN: 2231 –5950, Volume-1, Issue-2, 2011
- [16]. Dharmpal Deepak, Ripandeep Singh Sidhu, V.K Gupta; “*Preparation of 5083 Al-SiC surface composite by friction stir processing and its mechanical characterization* ” International Journal of Mechanical Engineering ISSN : 2277-7059 Volume 3 Issue 1 (January 2013)
- [17]. Don-Hyun CHOI, Yong-Hwan KIM, Byung-Wook AHN, Yong-I KIM, Seung-Boo JUNG; “*Microstructure and mechanical property of A356 based composite by friction stir processing*” Trans. Nonferrous Met. Soc. China 23(2013) 335–340
- [18]. Douglas C. Hofmann, Kenneth S. Vecchio; “*Thermal history analysis of friction stir processed and submerged friction stir processed aluminium*”. Materials Science and Engineering A 465 (2007) 165–175
- [19]. DU XingHao & WU BaoLin; “*Using two-pass friction stir processing to produce nanocrystalline microstructure in AZ61 magnesium alloy*”. Sci China Ser E-Tech Sci | Jun. 2009 | vol. 52 | no. 6 | 1751-1755
- [20]. Essam R.I. Mahmouda, Makoto Takahashi, Toshiya Shibayanagi, Kenji Ikeuchi “*Wear characteristics of surface-hybrid-MMCs layer fabricated on aluminium plate by friction stir processing*” Wear 268 (2010) 1111–1121
- [21]. F.C. Liu, B.L. Xiao, K. Wang, Z.Y. Ma “*Investigation of superplasticity in friction stir processed 2219Al alloy*” Materials Science and Engineering A 527 (2010) 4191– 4196
- [22]. K. Elangovan & V. Balasubramanian & M. Valliappan; “*Influences of tool pin profile and axial force on the formation of friction stir processing zone in AA6061 aluminium alloy*”. Int J Adv Manuf Technol (2008) 38:285–295
- [23]. K. Surekha, B.S. Murty, K. Prasad Rao; “*Microstructural characterization and corrosion behavior of multipass friction stir processed AA2219 aluminium alloy*”. Solid State Sciences 11 (2009) 907–917
- [24]. M.Puviyarasan, C.Praveen; “*Fabrication and Analysis of Bulk SiCp ReinforcedAluminum Metal Matrix Composites using FrictionStir Process*” World Academy of Science, Engineering and Technology 58 2011
- [25]. P. Cavaliere, A. Squillace; “*High temperature deformation of friction stir processed 7075 aluminium alloy*”. Materials Characterization 55 (2005) 136– 142
- [26]. Z.Y. Ma. *Friction Stir Processing Technology: A Review*. The Minerals, Metals & Materials Society and ASM International 2008