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MICROSTRUCTURAL AND STRENGTH COMPARISON OF FRICTION STIR WELDING ALUMINIUM ALLOYS

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Abstract: Joining of metals and alloys is still a challenging process to maintain the mechanical and thermal properties in post welding. To avoid this problem, a new solid-state joining process has been introduced, which is called as Friction Stir Welding (FSW) energy efficient, echo friendly and versatile welding process. This joining process is carried out by the heat developed between the tool and the work piece material. In this paper aluminum alloy AA6061 plates has been considered to join using FSW. High Speed Steel H13 tool is considered to join the plates using FSW. Moreover, microstructural analysis of the FSW plates at weld region and for parent aluminum alloy is carried out to analyze the microstructural properties. A comparison has been done in terms of strength for the parent metal plates and the FSW welded plates to know the strength variation between them. A stress strain graph is plotted to know how the strength is varying between the parent plates and FSW welded plates.
Key words: friction stir welding, aluminum alloy, high speed steel, and solid state welding.

1. INTRODUCTION

Aluminium is wide range of metal used in many applications. A new age of aluminium welding is addressed by TWI (The institute of welding) Friction stir welding is solid state process which was proposed in 1991 by United Kingdom, [1].

The process FSW involves in rotating tool with plunging shape at high speed in between abutting faces of material to be welded, coalescence of material takes place because of the friction generated at the contact area of the tool. The tool using here contains two portions shoulder and tip, the tip introduced in between the abutting faces of the plates to be welded and shoulder is allowed to be slide on the top face of the plates. Thus the contact area under the shoulder generates additional frictional heat to the tool tip. The frictional heat generated in both the cases causes the material to be deformed plastically around the immersion of the tool [2].

Advantages over fusion welding strategy have drawn consideration of fluctuated analysts around the globe. Friction stir welding has different applications potential zones like space transport fuel tanks Al compound for vehicle ships planning of compound Al extrusion and automotive structural elements [3]. Ti alloys steel and metal matrix composites are reported on some experiments. This technology is to be used in a more effective way by optimizing different input parameters is needed [4]. Works on FSW showing better results because of metallurgical and environmental aspects are improved. When FSW is compared with laser assisted welding process, FSW showed 2.5% energy efficient. G. Rambabu [4] developed a mathematical model for FSW to optimize using the simulated hardening annealing to maximize the corrosion resistance of the FSWAA2219 Al alloy joint.

S. Raja Kumar [5] the craft Al composites by and large present low weld capacity by fusion welding technique. Development of the friction stir welding has given an option improved strategy for sufficiently producing Al joints, in an exceedingly speedier and dependable way. During this current work the effect of methodology and mechanical assembly boundaries on Tensile properties of AA7075-T6 joint made by friction stir welding was analyzed square butt joint was manufactured by different parameters and tool parameters. Quality properties of joint were assessed and correlative with the microstructure, little hardness of nugget. From this assessment it's conuled that the joint produced at instrument rotational speed of 1400 rpm, welding pace of 60mm/min pivotal intensity of 8KN maltreatment with 15mm shoulder broadness 5 mm pin width 45 HRC Tool hardness yielded more excellent property diverged from different joints. Dhancholia et al. [6] have created An exploratory examination and advancement of activity boundary on friction stir welding of AA 7039 Al combination utilizing response surface methodology (RSM) with 3 measurable factors (rotational speed, cross speed, hub power,) and the reactions (rigidity, Yield quality (YS) and % Elongation were set up. The sufficiency of the created exact relationship for the reaction factors UTS, YS and was tried utilizing the investigation of change (ANOVA) procedure. The exploratory Friction stir welding boundaries and their levels during this examination in the real structure. The fit synopsis uncovers that the fitted quadratic model is factually huge to investigations the reaction factors. It is discovered that the determined F proportions are bigger than the classified qualities at a 95% certainty level; subsequently, the models are viewed as satisfactory. Fuji et al [7] have study the impact of little instrument tool pin profiles to the smaller scale structures and mechanical properties of 6061 aluminum joints using friction stir welding (FSW) framework was investigated. Three diverse pin profiles: strung tightened tube shaped, triangular and square were used to make the joints. The outcomes show that the weld joints are prominently influenced by getting together with various instrument pin profiles. The triangular tool pin profile creates the best metallurgical and mechanical weld properties contrasted and other tool pin profiles. Likewise, micro hardness and strength are obtaining for friction stir welded joints with tool pin profile.

Raj Kumar [8] worked on FSW, dissimilar Al alloys AA5052 & AA6061 and observed mechanical characteristics. The coupons of top of metals were friction - stir welded make a use of cylindrical shaped pin device misuse at steady speed of 710 rpm and feed rates of 28 and 20 mm/min. Macrographs demonstrated right mix because of successful mixing of cylinder shaped tool pin whereas keeping the lower feed rate. Further, broad smaller scale basic assessment indicated variety of grain size in each zone and their impact on mechanical properties. Tensile test and hardness estimations were done as a piece of mechanical depiction. Partner mechanical and metallurgical properties it is determined that the model welded at lower feed rate performed better as far as malleability. A pure copper and aluminum materials joined by friction stir welding studied by Satish et al., [9]. Investigated the joining of the pure copper and aluminum by friction stir processing. They found that when welding was carried out within proper speed range with low friction pressure and reasonable upset pressure, the weld region exhibited the sign of burn along the weld length. Anticipated of recrystallization grain size in the weld zone hardness in the welded area is more than heat effected zone was founded. Due to poor ductility of order 0.6 to 1.5% brittle inter metallic are observed.

Su et al. [10] contemplated the subsequent microstructure of friction stir prepared commercially 7075 Al alloy. The grain structure of FS was reviewed by TEM. Su et al. seen that the microstructure of FS arranged domain didn't have a uniform grain size movement. The typical grain size gently diminishes from top to bottom. Also diffraction rings were seen which; as indicated by them affirm that there are huge miss-directions between the individual grains. Usually the dislocation density wasn’t uniform inside the mix zone even with comparative grain size; this perception educated that non-uniform plastic disfigurement was presented inside the re-solidified grains all through FSP. By running numerous covering passes related wanted sheet size will be prepared to an ultrafine grained microstructure. The investigations showed that multiple overlapping passes indicated can be used as an effective technique to fabricate along relatively uniform micro structure with large bulk ultrafine material. Behzad et al. [11] announced the characterization of AA5083 FSW examination on mechanical properties, micro structural and residual stress are carried. And identified, thermal inputs on the FSW dominate distortions caused mechanically on the weld properties. Their outcomes showed that increasing up and consequently decreasing the heat input limited weld zone, additionally that the re-crystallization in the weld zone had significantly lower hardness and yield stress than the parent AA5083.

It was seen that practically all the plastic stream happened inside the re-solidified weld zone and the synchrotron residual stress examination demonstrated that in longitudinal and transverse direction the surrounding area of weld bead is in tension. The pinnacle longitudinal stress expanded as the navigate speed increments. They proposed that this expansion is most likely because of more extreme thermal inclinations during welding and the diminished time for stress unwinding to happen. The ductile burdens give off an impression of being restricted to the soften weld zone bringing about a narrowing of the tensile district as the traverse speed expanded.

Sutton et al [12] considered the microstructure of contact friction stir welds in 2024-T3 aluminum. Light microscopic and scanning electron microscopes (SEM) were utilized to capture the microstructure. Likewise, vitality dispersive X-beam spectroscopy (EDX) was utilized to break down the substance arrangement of the material. Microstructure as a component of transverse area and as an element of through-thickness area is appeared. The outcomes demonstrated that more grain refinement happened inside the nugget, and that the grain size diminished as made a trip from the top to the bottom and this is no doubt because of higher heat contribution on the top causing extra grain growth.

The outcomes from metallurgical, hardness and quantitative EDX estimations demonstrated that friction stir welding can make an isolated joined micro structure comprising of exchanging hard molecule rich and hard molecule poor districts.

The hardness was higher on the propelling side than that of the retreating side. Kwon et al. reasoned that the outcomes exhibit that the frictions stir welding strategy is exceptionally compelling for making improved mechanical properties resulting from grain refinement. Itharaju et al. [13] investigated the micro structure at different sequence of rotational and transnational speeds and endeavored to relate the resulting grain sizes to the delivered powers in friction stir welding 5052 aluminum sheet. They saw that the resulting typical grain size of the FS procedure AA5052 sheet were some place in the scope of 1.5 and 3.5 μm depending upon the technique boundaries, diverged from 37.5 μm for the characteristic sheet, which suggest that phenomenal refinement has been cultivated. The translational speed is almost free from outside control the plunging force increases with rotational speed is high was concluded.

2. EXPERMENTAL SETUP

This experimental research focoused on development of an experimental setup with suitable modification and incorporation of attachment on vertical milling machine. The experimentation is carried out with different process parameters such as tool rpm; tool feed velocity and depth of tool plunge during the welding. The effect of these process parameters on microstructure, hardness and tensile strength has been evaluated for joining two similar AA6061 alumium alloy plates. Microstructure of the weld region and heat affected zone is examined by scannning electron microscope (SEM) study. Grain structure has been examined by scanning electron microscope. The effects of rotational speed, translational speed, and position within the processed area on hardness are presented in this chapter.

In this experiment 6061 grade Aluminum alloy of size 300x50x5mm 4 plates is chosen for conduction the experiment. Most widely used aluminum amalgam for welded joints are toughened (O) 6061, Heat-treated T6 6061 and heat-treated aged T651 6061 are the few examples. Al-6061 is a solidified precipitate alloy with major alloying material of Magnesium and silicon. Due to their weldability and mechanical properties are the major factors for using Al6061 in joining process. The chemical composition of AA6061 was founded using XRF spectrometer at Centurion University Odishs given below.

The measured value of AA6061 element weight percentage of (Si 0.593, Fe 0.532, Cu 0.303, Mn 0.092, Mg 0.921, Zn 0.064, Ni 0.0122, Cr 0.209, Ti 0.16, Al rem).

The most flexible of the warmth treatable aluminum alloys, while keeping the vast majority of the great characteristics of aluminum. This evaluation has an extraordinary scope of mechanical properties and corrosion resistance. It tends to be manufactured by the vast majority of the regularly utilized systems and it has great functionality in the toughened condition. It is welded by all techniques and can be furnace brazed. Thus, it is utilized in a wide assortment of items and applications where appearance and better consumption obstruction with great quality are required. The tube and angle shapes in this evaluation ordinarily have adjusted corners.

2.1. Selection of tool material

Materials, for example, tool steel are used for welded aluminum, magnesium amalgams, and aluminum matrix composite. Steel tools have additionally been utilized for the connecting of comparative and develop materials in both butt and lap designs. Welded Al–Mg combination with low carbon steel in lap joint setup utilizing device steel as device material without its extreme.

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Propelling side and the instrument is marginally counterbalanced from the butt interface towards the soft work piece. In this trial high speed steel of evaluation H-13 and M35 tools are utilized as appeared in Tables 1 and 2.

Table 1. Composition of H-13 Material

C	Si	Mn	P	S	Cr	Mo	V
0.42	1.20	1.50	<0.03	<0.04	5.40	1.40	1.10

Table 2. Composition of M-35 Material

C	Cr	Mo	V	W	Co
0.92	4.10	5.00	1.90	6.40	4.80

The fixture is designed to support FSW on a vertical milling machine. Fixture mainly comprises of base plate, side plates which are welded and a screw and nut system is provided in such a way that to confine the movement of work pieces while welding operations performed. For mounting the fixture on the vertical milling machine, base plate is provided with groves in all corners. The design details of the component of fixture to hold the work piece designed using 3D experincr as shown in Figure 1 and Figure 2 shows the fixture used in this work.

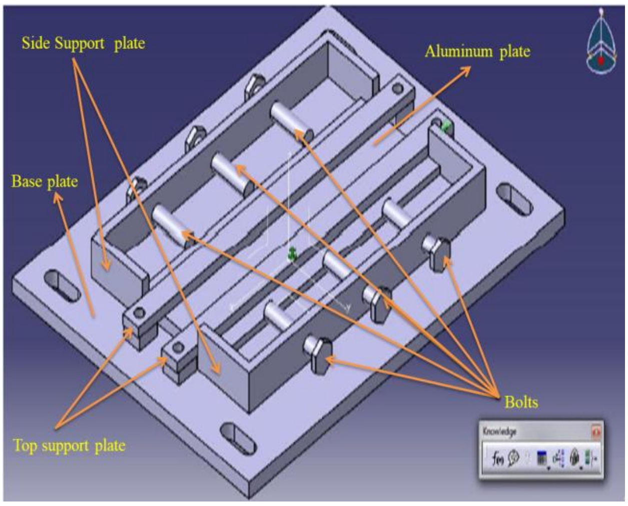

Fig.1. Fixture Design

Fig.2. Prepared Fixture

As the workpiece size is 300x50x5 mm in order to clamp the work piece the bed size of length and width given in Table 3.

Table 3. Represents the fixture specifications

Bed length	400mm
Bed Width	300mm
Maximum job that can be fit	300mm x 100mm

2.2 Friction stir welding pin design

The design of welding pin has to be in very appropriate so that maximum frictional heat should be generated in between the tool and the workpiece. The design elements that influence the friction stir welding are pin, and the shoulder. The frictional heat can also damage the pin. For providing good strength tapered pin is designed to withstand the operating conditions. The image of the welding pin along with the shoulder is showed in the Figure 3.

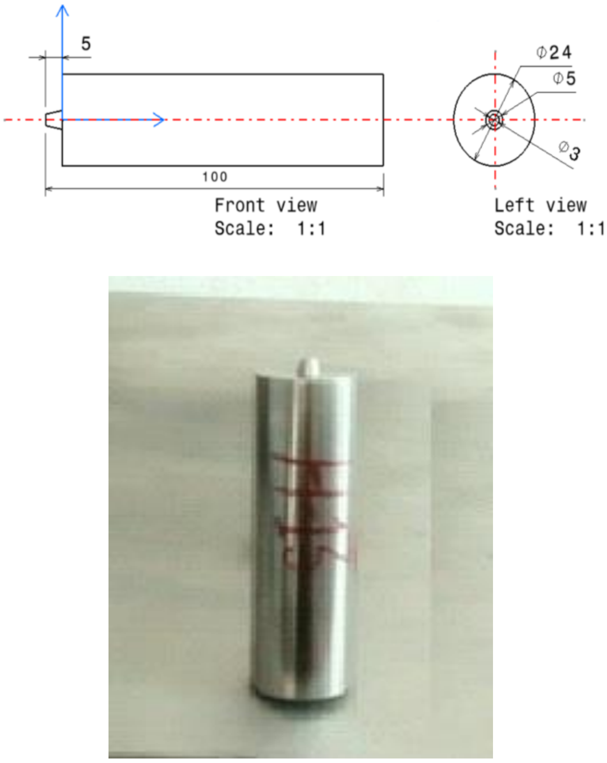

Fig.3. H13 tool

2.3 Equipment set up

A vertical milling machine of BFW make with 5.5 kW rated motor capacity is suitable modified with attachments and engaged for the experimentation which is available in Centurion University Odisha. The available range of spindle speed is 1000-2000 rpm. A tapered profile tool tip is used to carryout the operstions at speeds of 1000 and 2000rpm, feed rate of 63, 80 and 100mm/min

3. RESULTS AND DISCUSSIONS

AA6061- T6 aluminium alloy is welded by using friction stir welding with a taper pin profile H13 grade HSS tool. The welding is processed in all pre discussed conditions. The below Figure 4 shows the welded joint in varying different parameters.

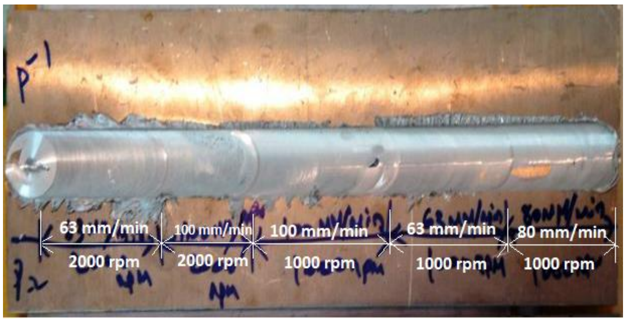

Fig.4. Weld Bead of FSW on AA6061-T6

The weld bead of the joint show less defect in macro level. Be that as it may, the cross section of the specimen was inspected and seen as conveying some imperfection because of the tool progressing or withdrawing. The weld bead obtained when tool rotating at 2000rpm and table feed of 63mm/min seems to be defect less. Though rest specimens were imperfection inclined might be because of inappropriate parameter mix during FSP.

Fig.5. Welded and original specimens

The role of process parameters is evaluated by conducting tensile test. The specimen for tensile test is as per ASTM B557 and the shape is machined by wire EDM machine. With a five combinations of processing parameters. Sample No. 1 of aluminum AA6061 alloy specimen taken by cutting from the bulk plate. Remaining speciemens is joined by FSW with 2000 rpm spindle spped and 63 mm/min,100mm/min traverse speed of the tool. The mechanical property of the samples such as ultimate tensile strength and yield strength is evaluated by Univeral testing machine equipment. The specimens joined by friction stir welding as shown in Figure 5. Original non-welded aluminum specimen exhibited ultimate tensile strength of 160MPa and yield strength of 133MPa in tension. Friction stirs welded speciemen exhibited ultimate tensile strength of 133.4MPa and yield strength of 111.4MPa in tension. The friction stir welded speciemen exhibited 83% value of ultimate tensile strength of the original sample. Similarly, the yield strength was achieved upto 84% of the original sample. This indicates the retention of ductility nature of the speciemen after friction stir processing.the stress vs strain in tension tests shown in Figure 6 which gives the correlation of tensile strength between original and welded specimen.

4. MICROSTRUCTURAL INVESTIGATION

The micro-structural investigation is carried on the welded specimen's in-order to study the surface at the welding, and the surface at heat affected zone. The microstructure examination was carried out by grinding using emery paper of silican carbide various grites of (320, 500, 800 and 1000). Polishing of specimen is carried out using dimond paste of grain size (0.5µm).

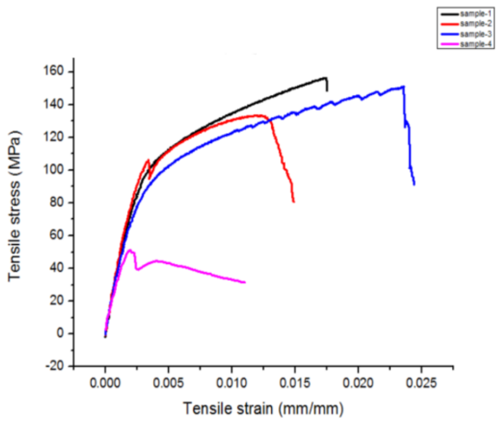

Fig.6. Stress strain curve

To obtain mirror polishing surface the etching process is done to the polishing surface by using (kellers regent (composition 90 ml H_2O, 2.6ml HNO_3, 1.6ml HCI, 1.0 ml HF) and the wash with water and alcohol and dried in oven. The study is carried on SEM (Scanning Electron Microscope). The images show the grin structure with the clear grain boundaries for the weld nugget zone obtained at 1400rpm and 80mm/min parameters at the tool. This confirms the moderate grain formation with more surface area and less voids. The black colour area indicate voids with lesser rpm of the plunged tool Figure 7 and Figure 8 shows the specimen welding at 1400rpm and 80mm/min parameters of the tool indicating two distinguished regions. Right hand side indicate the thermo mechanical zone (TMAZ) and left hand side indicate the heat affected zone (HAZ). the two regions indicate the effect of torque and heat generation during FSP process which leads to creation of more voids in TMAZ compare to HAZ. The grain boundaries are more prominent in TMAZ with identifiable voids.

At 20 micrometers the welded region is studied and it reveals that the joint is formed without any voids on the surface of the weld. The heat affected zone on the joint is also observed very less area in comparing with the same conditions but with different tool. Figures 7 and 8 shows the topographic images of the welded and the heated zone of the specimens. It is observed that the joint is formed with good grain structure and minimal heat affected zone.

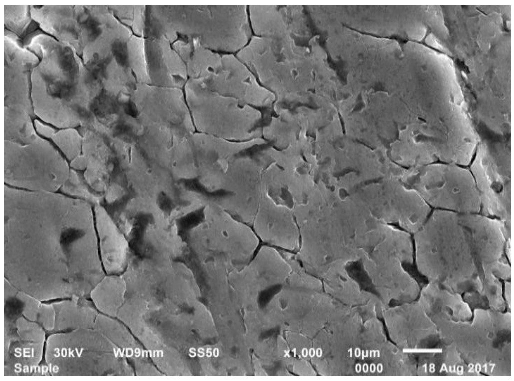

Fig.7. Microstructure of weld bead

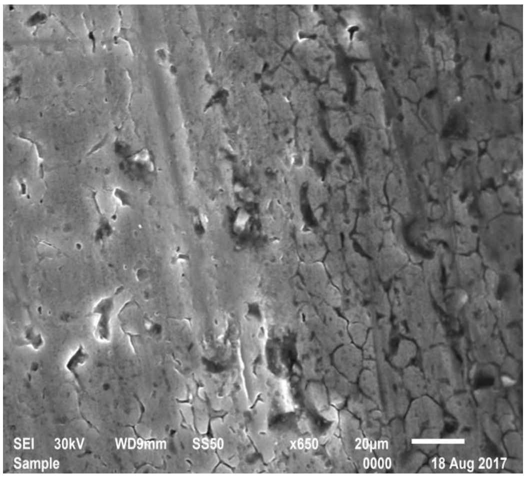

Fig.8. Weld zone and HAZ

5. CONCLUSIONS

The butt joint of similar Al 6061 alloy plates is successfully carried out according to various process parameters. The welding joint quality in the welding process is affected by process parameters. Up to 83% of the tensile strength both UTS and yield is achieved in this process. It infers that the material has sufficient ductility even after the welding, which is most desirable in real life application in aerospace sector. More the brittleness of the welded joint dimishes the chances of deformation and shock absorption capability under highly stressed and vibrating conditions leading to a catastrophic failure of the component. The welded joint was shown minimal defect on the surface with cross section without any unfilled regions. The microstructural investigation also revealed minimal heat affected zones is recorded and no voids are formed on the surface of the weldment.

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