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DEFECTS ANALYSIS OF T-JOINT FRICTION STIR WELDED SAMPLES OF ALUMINIUM ALLOY 6101-T6

Dharmendra Kumar Prasad[1], Shabbir Ali[2], Sachindra Shankar[3], Ratnesh Kumar[4], Dr. Somnath Chattopadhyaya[5]

[1,2,3,4,5]*Department of Mechanical Engineering, Indian School of Mines, Dhanbad, India*

ABSTRACT

Friction stir welding (FSW) is a solid-state welding process in which the relative motion between the welding tool and the work pieces produces heat. This makes the material soft, and therefore it can be joined by plastic deformation and diffusion. This method relies on the direct conversion of mechanical energy to thermal energy forming the weld joint without any external source of heat. In the FSW process, a non-consumable rotating tool is forced down into the joint line under conditions where the frictional heating is sufficient to raise the temperature of the work pieces. It can plastically deform and locally plasticize.

The main aim is to study micro structural properties of FSW Butt T-joints of AA 6101-T6 and further detail analysis of defects occured.FSW T-joint setup is developed on vertical milling machine of HMT make. Friction stir welding of Al 6101-T6 alloy (material used for bus bar conductor, requiring minimum loss of electrical conductivity and good mechanical properties) was performed in butt T-joint configuration using varying welding speed and rotary speed. A good T -joint of AA 6101 is achieved with this setup. Welded samples have post processed and prepared for microstructure analysis. Field emission scanning electron microscope is used to take micro structural images. After analysis of these images it is found that a satisfactory T-joint is achieved. Further explained detail analysis of defects occurred in weld specimen.

Keyword-AA6101, Defects, Friction stir welding (FSW), FESEM, and T-joint.

I. INTRODUCTION

Friction stir welding (FSW) is a solid-state joining technique that has expanded rapidly since its development by Mr. Wayne Thomas in 1991 at TWI (The Welding Institute) and has found applications in a wide variety of industries, including aerospace, automotive, railway, and maritime. The FSW process exhibits a number of attractive advantages when compared to other welding processes, perhaps the most significant of which is the ability to weld alloys that are difficult or impossible to weld using fusion welding techniques. The FSW process takes place in the solid-phase, at temperatures below the melting point of the material, and as a result does not experience problems related to re-solidification such as the formation of second phases, porosity, embrittlement and cracking. In addition, the lower temperature of the process enables joining with lower distortion and lower residual stresses.FSW is also an energy efficient process that requires no filler material and, in most cases, does not require the use of a shielding gas. Furthermore, the process lacks the fumes, arc flash, spatter, and pollution associated with most fusion welding techniques. For these and many other reasons, FSW has become an attractive joining process for many manufacturers. [2]

Various light-weight materials like aluminum, magnesium etc. are alternative to high density material, out of which aluminum is the best suited candidate because of high strength-to-weight ratio The complete process can be divided into three stages. The sequence ofthe FSW process is schematically shown in Fig.1. The first stage is known as plunging, which is analogous to a drilling operation. Here, the pin of a specially designed nonconsumable rotating tool plunges on the abutting edges of the clamped workpiece. This produces heat because of friction at the shoulder face (at the interface of the tool and the work piece) of the tool, and plastic deformation of the work piece. Generated heat raises the temperature and softens the workpiece. Plunging is followed by the dwelling operation, which is the second stage. Here, the tool stirs at a constant rotational speed at the same plunging position to increase the temperature further up to a desired level, and this brings the material to a viscous state. In the third stage, the rotating tool travels along the welding line, and mixing of viscous material takes place under the influence of an axial force.

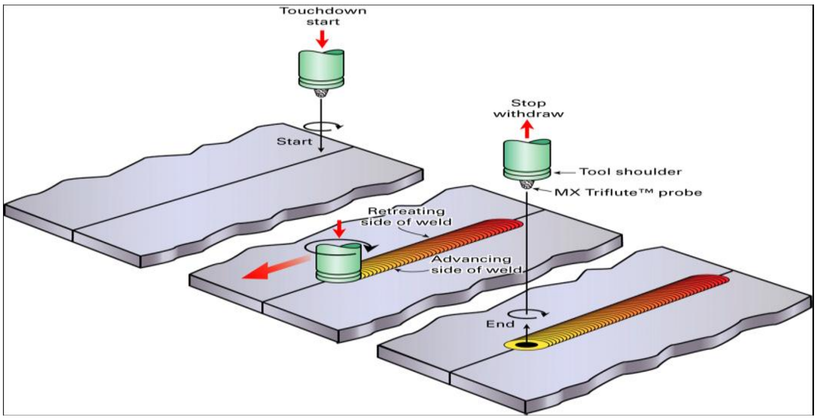

Fig.1- The sequences of a Friction Stir Welding event

Nonconsumable tool primarily performs two major functions; heat generation through friction, and plastic deformation and mixing of materials to perform welding. Apart from the above stated functions, tool also contains the viscous material beneath its shoulder face. FSW, being a solid-state joining process, eliminates complexities and defects (like porosity, blow holes etc.) related to the solubility of gases and solidification of molten material during welding. Temperature required in FSW is in the range of 0.6–0.8 times of Tm (Tm is the melting point of work piece, in °C). The temperature in this process never goes beyond the stated value, because frictional and mechanical (plastic deformation) works only get converted to the heat energy, which in turn raises the work piece temperature. With the increase in temperature, workpiece strength reduces as both are inversely proportional to each other. Since, working temperature in FSW is above the recrystallization temperature, new grains form in the weld zone. In addition to the high temperature rise, work material is also under the compressive loading. Therefore, new grains, formed in the weld zone, are smaller in size and almost identical in shape. This improves weld strength.

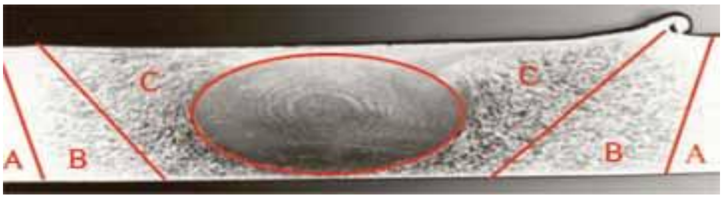

Fig. 2. Micro structural zone classification in a friction stir weld (A: parent material, unaffected by process; B: HAZ, thermally affected but with no visible plastic deformation; C: TMAZ, affected by heat and plastic deformation) .

Temperature and plastic strain have different effects on grain size and microstructure of the material. A transverse cross-section of FSWed sample can be classified into four different zones viz. nugget zone (NZ), thermomechanical affected zone (TMAZ), heat-affected zone (HAZ), and base material (BM). A material at the nugget zone is subjected to high strain and heat due to stirring actions of tool pin and shoulder. Grain size of the nugget zone is finer as compared to that of the base metal because of dynamic recrystallization. TMAZ is majorly subjected to heat, and a small deformation of material, which slightly changes the grain orientation; and HAZ is subjected to heat only. Since heat input in FSW is less as compared to fusion welding, softening of material in HAZ is negligible, and even in some cases HAZ does not exist .

Table 1. Process variables in FSW process

Process variables	Design variables	Material parameters
Tool rotational speed	Pin geometry and its dimension	Tool material
Welding speed	Shoulder geometry and its dimension	Work piece material
Tool tilt angle	Joint configuration	Back up material
Plunge depth		

Defects in FSW

A good understanding on the effect of combination of process parameters and physics of the process is required to get a defect-free weld. As discussed earlier, each process parameter is vital and optimum combinations of those parameters lead to formation of the sound weld. Thorough understanding on various defects and their mechanisms of formation can also help in eliminating them. Different types are defects are categorized based on the physics of their formation in Table 2.

Table 2. Classification of various FSW defects

Improper heating	**Excessive heating**	**Defects due to faulty design**
Kissing bond	Nugget collapse	Oxide entrapment
Tunnel defect	Ribbon flash	Lack of penetration
Lack of fill	Root flaw	Excessive indentation

Kissing bond: It is a type of defect that occurs in the solid-state joining processes.Joining between two sides occurs at a small portion. Insufficient softening of material leads to improper mixing or fusion of material. Static load bearing capacity of the kissing bonded materials is less. Higher heat input by increasing tool rotational speed or proper selection of pin geometry can be a remedy of this defect.

Tunnel defect: Formation of cavity due to insufficient material flow near the advancing side, or due to too high welding speed. It occurs due to lack of plungem force or proper welding speed.

Lack of fill: It is a surface void formed due to insufficient plunge force or plunge depth. Proper plunge force or tilt angle can eliminate this defect.

Nugget collapse: It occurs due to excessive softening of material due to high heat generation. It can be avoided by controlling the tool rotational speed or by reducing the shoulder diameter.

Ribbon flash: It occurs because shoulder is unable to contain the viscous material beneath it. Tilt angle and concave tool shoulder can eliminate this defect.

Root flaws: Excessive heat generation softens work piece to a high extent; and under compressive load, material tends to stick with the backing plate. This can be controlled by selection of proper process parameters and proper choice of pin height.

Surface galling: It is a series of void visible on advancing side of material due to excessive softening of work piece. This occurs due to excessive heat generation and can be controlled by proper selection of process parameters.

Oxide entrapment: Aluminum has a strong affinity toward oxygen, and thus forms a layer of a hard and brittle layer of aluminum oxide. This oxide layer, especially on the abutting edges, mixes with material during welding. Surface preparation before welding can be a remedy of this problem.

II. EXPERIMENTAL PROCEDURE

Friction stir welding set-up is developed on vertical milling machine of HMT 1U make at Indian School of Mines, Dhanbad, India. SS 410 is selected as tool material and aluminium alloy AA 6101-T6 having 6 mm thickness is selected as working material. AA 6101-T6 is used in making bus bar conductors.Figure 2 shows the augmented friction stir welding set-up on milling machine. Work piece i.e. aluminium plate is fixed on milling machine base with the help of fixtures. Tool is fixed on milling machine tool spindle head as shown in figure

.Table 3:- Different process parameter used for welded samples

Serial No.	Sample No.	Rotational speed(rpm)	Traverse speed (mm/min)
2	1	1	500
3	3	1000	25
4	4	1400	25
5	5	500	40
6	6	710	40
7	7	1000	40
8	8	1400	40

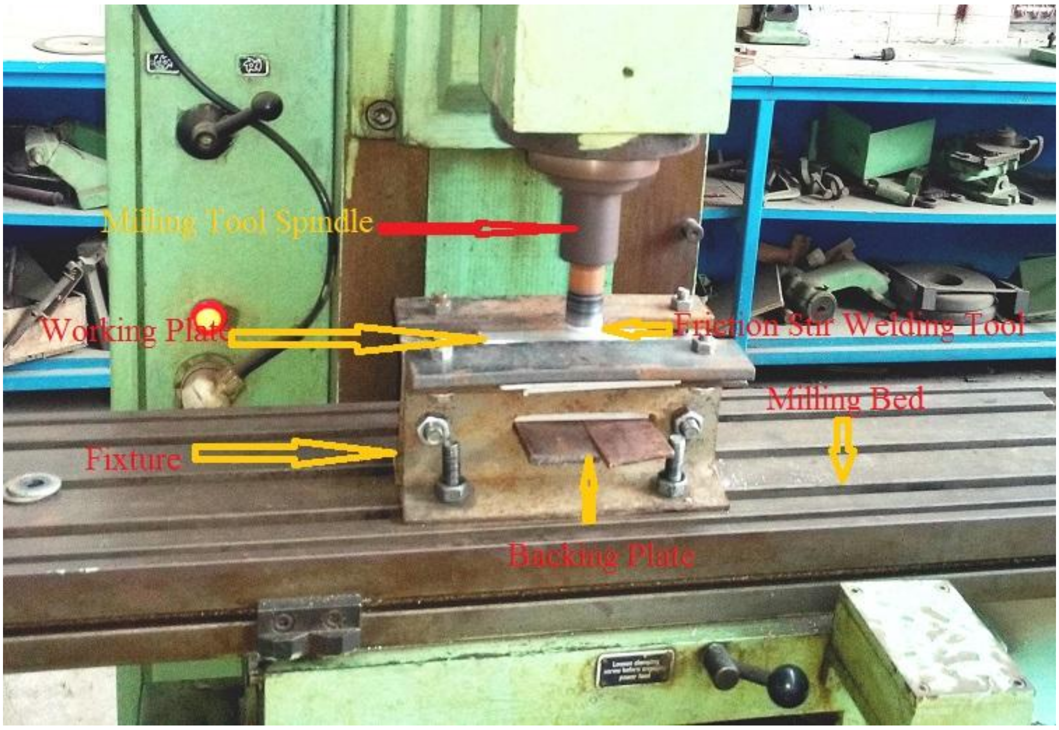

Fig. 3: Experimental setup used for the present study: Friction Stir Welding setup

Chemical composition of Aluminium Alloy 6101-T6

Chemical element	Si	Fe	Cu	Zn	Mg	Al
Weight %	0.50	0.50	0.05	0.10	0.65	Balance

Mechanical properties of working materials:

Al Alloy	UTS (Mpa)	YS (Mpa)	Elongation (%)	Hardness (VHN)
6101-T6	220	195	15	71

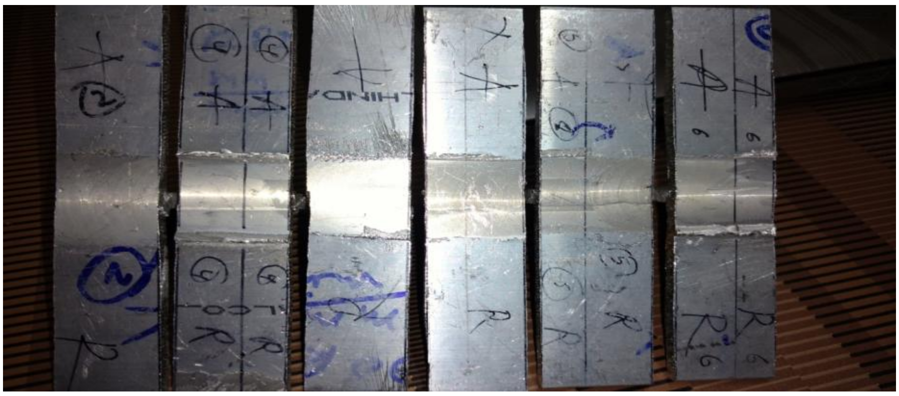

Fig.4- Welded Samples of Friction Stir Welding T-joints

Selection Of Tool Material:-

Grade 410 stainless steels are general-purpose martensitic stainless steels containing 12.5% chromium, which provide good corrosion resistance properties. However, the corrosion resistance of grade 410 steels can be further enhanced by a series of processes such as hardening, tempering and polishing. The fabricated friction stir welding tool has two main parts: shoulder and tapered pin as shown in Fig. The fabricated steel FSW tool has been heat treated.

Chemical composition of FSW tool material (410 SS):-

Constituents	Cr	Mn	Si	Ni	C	P	S
Wt %	12.5	1	1	0.75	0.15	0.04	0.03

FSW tool material mechanical properties:-

Properties	Values
Density	7800 kg/m^3
Modulus of Elasticity	**200 GPa**
Melting Range	1482-1532°C
Ultimate tensile strength	517 MPa
yield strength	310 MPa
Poisson's ratio	0.275-0.285

Tool Design and specification :-

Tool	Shoulder	Pin		
	Diameter (mm)	Base diameter (mm)	Top diameter (mm)	Length (mm)
1	25	5	3	5
2	30	6	4	5

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III. RESULT

Following types of defects like worm hole, kissing bond, vertical crack, horizontal crack, scalloping, ribbon flash, surface lack of fill, nugget collapse, surface galling and many more are found in FSW AA6101 T-6 joints during fesem image study.

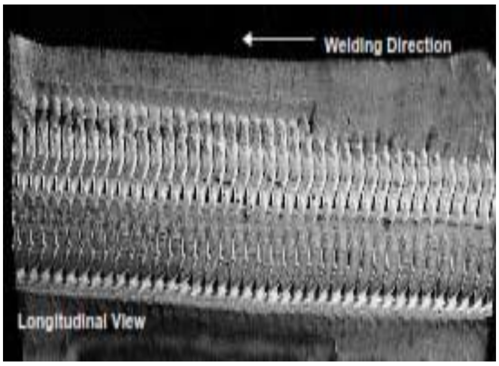


Fig. (a): Worm Hole (b). Scalloping

Worm hole [a] is the tunnel of inadequately consolidated andforged material running in the longitudinal direction which is formed due to excessive heat input due to high rotational speed, low transverse feed.

Defect in which the Series of small voids located in the advancing side interleaving the stir zone along the weld is known as Scalloping [b].

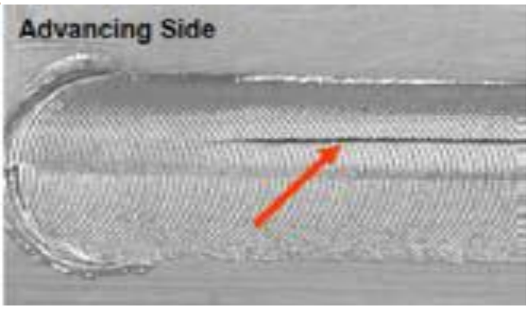


Fig. :(c). Ribbon Flash, (d). Surface Lack of Fill

Ribbon flash [c] is the excessive expulsion of the material on the top surface leaving a ribbon like effect along the weld line. Excessive forge load, plunge depth will lead to ribbon flash. On the other hand insufficient forge pressure, plunge depth will induce surface lack of fill [d] which is a continuous or intermittent top surface void in the weld line.

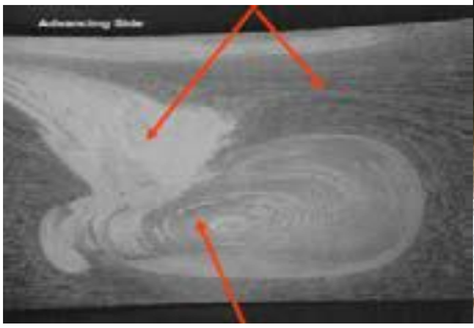


Fig. (e): Nugget Collapse [f] Surface Galling

Nugget collapse [e] is an improper formation of dynamically recrystallized zone, which is a unique defect in Friction Stir Welding. This defect will occur due to too high welding speed, excessive material flow to stir zone and excessive hot weld. Sticking of metal to tool pin leads to the surface galling[f].

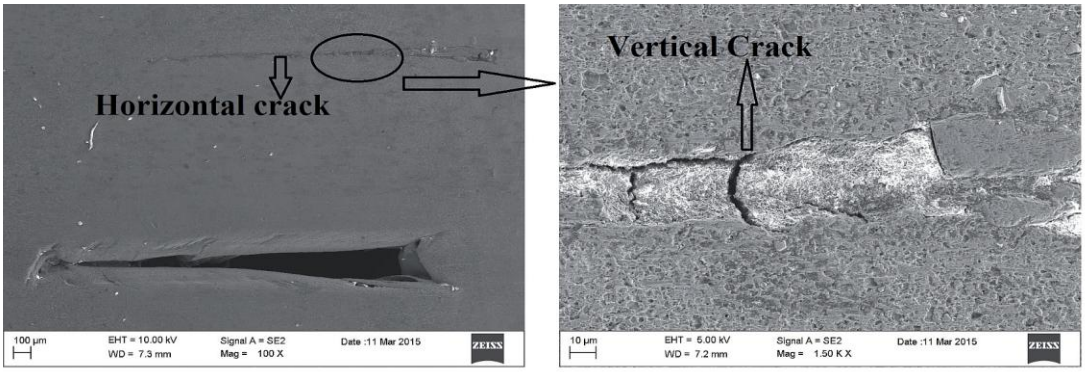
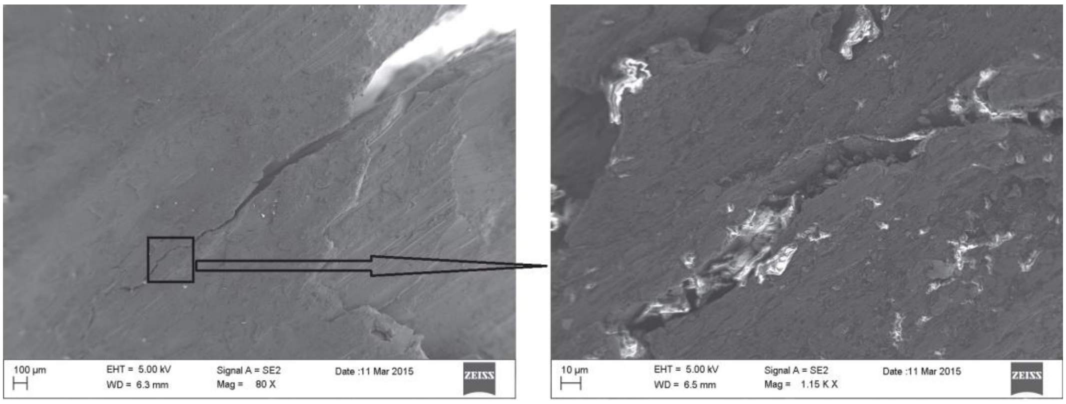
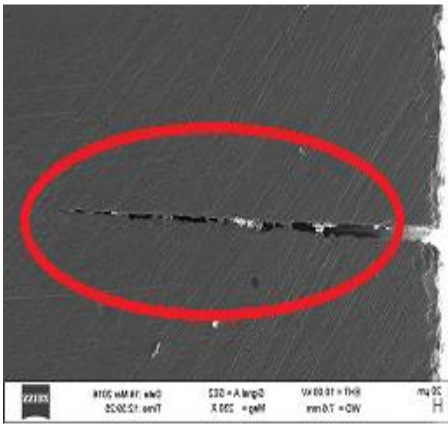
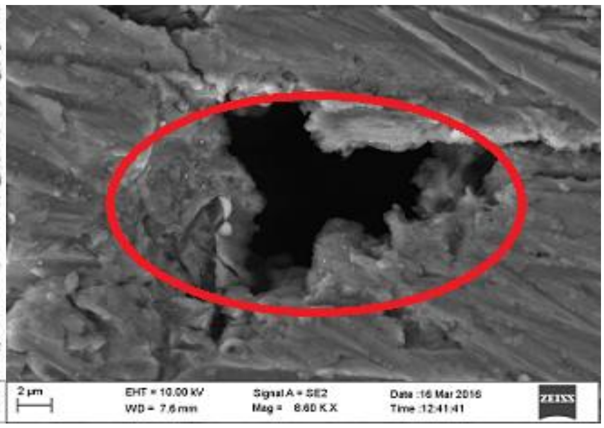


Fig.(g).- Horizontal and Vertical crack



Fig(h).-Fesem image of weld crack





Fig(i)-Fesem image of kissing bond defect (j)Fesem image of Tunnel defect

IV. CONCLUSION

1). At high tool rotational speed (i.e. 1400 rpm), defect free welds are obtained. Since, at higher rotational speed more heat is generated compared to lower rotational speed (i.e. 500 rpm , 710 rpm,and 1000rpm). So material can easily stir and good weld will be obtained at high temperature.

2) Tunnel defect was found at the intersection of weld nugget and thermo-mechanically affected zone due to high rotational speed and travel speed.

3). Selection of improper welding process parameters leads to insufficient heat input, excessive heat input, abnormal stirring, and insufficient pressure underneath the shoulder which leads to one or more of the defects as discussed above in the friction stir welding.

4) .Friction stir welding joints are prone to different types of defects which we can eliminate by choosing the proper tool design and process parameters.

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