Experimental Analysis of the Defects in Friction Stir Welding Of Aluminum Alloy 5083

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Abstract— Friction stir welding (FSW) is a solid-state joining process. A non-consumable tool is used to join two facing workpieces without melting the workpiece material. There are various advantages of this process over fusion welding processes. The various type of defects associated are typical to this process and haven't been investigated in a systematic manner so far. The main effort is done on the various parameters that influence the process. The paper presents an overview of different types of defects at friction stir welding of aluminium alloy 5083. In order to explain the reasons for their occurrence.

Keywords: Friction Stir Welding, Aluminum, Welding Defects, Microstructure of Weld

I. INTRODUCTION

Friction-stir welding (FSW) has been considered as the most significant development in metal joining. Compared to conventional welding methods FSW consumes much less energy, produces no toxic fumes, doesn't need any shielding gas or filler metal and is therefore considered to be an environmentally friendly, energy efficient material joining process. Many failures in industries are attributed to poor welding. Most of steel welding to this date is done by fusion welding. Fusion welding of steel lead to several problems like residual stresses/distortions, microstructural changes in HAZ, defects like porosity, hot cracking, hydrogen embitterment etc[1-2] Most of these defects are present because of inherent melting of base metal involved in of fusion welding process. It is often very difficult to completely prevent these defects.

Although, defects don't appear when friction stir welding is done under proper conditions and using correct process parameters, there are few defects that are observed during improper welding. It is very important to identify these defects and to fully understand the reasons that lead to occurrences of these defects. The defects that occur in friction stir welding are very different than those that appear in other fusion welding processes. Therefore there is need that these defects should be given special attention. Researchers working on friction stir welding of aluminum and magnesium alloys have observed defects that often occur during improper welding [3,4]. Modeling of defect formation has also been carried out by different research scholars [5]. The fatigue properties of friction stir welds in aluminum alloys that contain root flaws have been determined and have reported that certain levels of root flaws are acceptable [6].

Although lot of work has been done on friction stir welding of Aluminum and its alloys, works on steels have been very limited. First attempts to friction stir weld ferrous metals were made only in 1997[8-10]. But most of these were first attempts to show their capabilities to somehow weld ferrous alloys. A feasibility study was done in 1998 by T.W.I.[11] Which indicated that promising results could be achieved if tool wear were taken care of and the process be made more versatile for other grades of steels. First scientific studies on friction studies were published not before 2003 when several researchers published results on friction stir welding of different grades of steel. Initial studies were done on hot rolled Aluminum Alloy 5083 of 6.3 mm thickness[12]. This was followed by comparative study done on friction stir welding of two grades (X-80 and L80 with carbon equivalents of 0.44 and 0.94 respectively) and on S12C and S35C steels[13]. Welding of stainless steels was also taken on [14-17]. Later works were carried out on FSW of high carbon steels[18], ultra fine grained steel[19, 20], boron steel [21]and recently on FSW of HSLA steel[22]. Joining of nonferrous alloys with steel have also been carried out and the initial results are quite encouraging [10]. 7075-T651 aluminium alloy was friction stir processed in order to improve superplastic behavior. Materials and Method[19]. Studies related to welding of dissimilar aluminium alloys.[20]

II. PRINCIPLE OF OPERATION

The friction stir welding is shown in Fig. 1. A non-consumable rotating tool with a shoulder and specially designed is inserted into the abutting edges of plates to be joined and traversed along the line of joints. The plates have to be clamped in a manner that prevents the buckling or bending of the joint. The tool have two main functions:

1) Heating of work piece
2) Movement of material (To produce the joint)

The heating is accomplished by friction between the tool and work piece and plastic deformation of work piece. The heating softens the material around the pin and the tool rotation and translation leads to movement of material from the front of the pin. As a result of this process a joint is produced in 'solid state'. The material movement around the pin can be little complex because of various geometrical features of the tool,

During plunging and forward movement of the stirring tool the brittle oxide layer of the surface gets ruptured and resulting surface is free from oxide layer and hence no problem of oxide inclusion is encountered. As the whole process occurs at the plastic stage, the temperature that is 0.6-0.8 times the melting point of aluminum results in a solid phase joint. During this process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine and equiaxed recrystalized grains. The fine microstructure in friction stir welds produces good mechanical properties. The process not only generates a Heat-Affected Zone (HAZ) but within the HAZ near the weld nugget a Thermo Mechanically Affected Zone (TMAZ) is also produced.

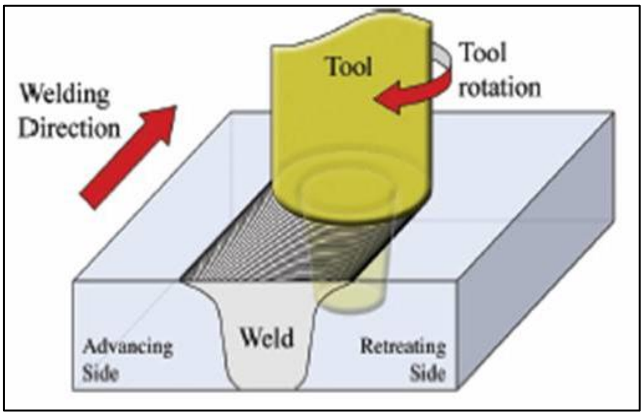

Fig. 1: Schematic of Friction stir welding process

III. Material and Method

AA 5083 is extensively used in marine industry, transportation and pressure vessels due to its very attractive strength to weight ratio and its excellent corrosion resistance. FSW of Aluminum Alloy 5083 was carried out on 6 mm Aluminum Alloy 5083 specimens 150 mm x 50 mm were butt welded in a single pass. A robust vertical milling machine (VF-3.5 of BFW make with spindle motor power of 11 kWatt).was used for performing the experiments. The composition given in the table 1.

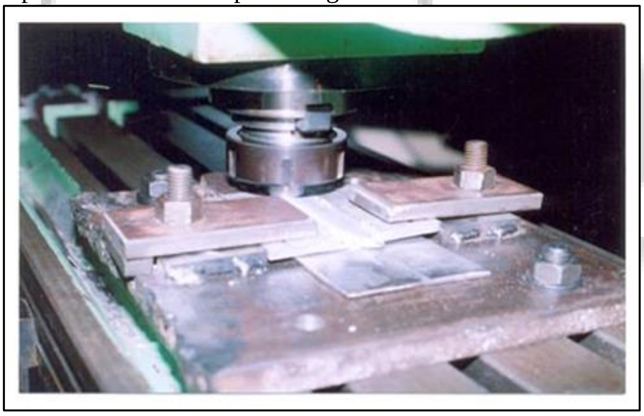

Fig. 2: Set up of the work piece for FSW

The tool material used was tool Steel. The dimensions of the tool were, shoulder diameter 16 mm-25mm, pin diameter 6 mm -10 mm, pin length 2.8 mm was used for the experimentation. The tool was held in a tool holder and the tool holder was held directly in the collet of the machine. No shielding gas was used. The tool composition given in the table 2.

	Chemical composition (wt. %)								
	Mg	Mn	Si	Fe	Cu	Ti	Cr	Zn	Al
Spec.	4.0-4.9	0.4-1.0	0.40 max	0.40 max	0.10 max	0.15 max	0.05-0.25	0.25 max	Rem.
Actual	4.95	0.78	0.17	0.24	0.05	0.02	0.08	-	93.71

Table 1: Chemical composition of experimental alloy

Elements	C	Mn	Si	Cr	Ni	Mo	V	Cu	P	S	Fe
Wt %	0.32-0.45	0.2-0.5	0.8-1.2	4.7-5.5	0.3	1.1-1.7	0.8-1.2	0.25	0.03	0.03	Rem.

Table 2: Chemical composition of tool material

Trial runs were carried out at different tool RPM and welding speed to see the effect of process parameters on weld defect formation.

Parameters	Units	Symbol	Limits	
			Low (-)	High (+)
Tool Shoulder Diameter (D)	mm	D	14	18
Tool probe Diameter (d)	mm	d	6	10
Tool Rotational speed (N)	RPM	N	500	700
Welding speed (v)	mm/min	v	80	120

Table 3: Welding parameters and their levels

IV. Defects in Friction Stir Welding

Many of the defects that occur in friction stir welding of steel are macroscopic and can be observed by naked eyes. The reasons for these defects are also quite obvious. But a few of the defects were observed only under the microscope. Also more investigations are required for ascertaining the causes for the occurrence of these defects.

The following are the defects that were observed during the trial runs of friction stir welding of Aluminum.

A. Crack at the centre

This defect was observed when welding 6 mm thick Aluminum plates at a higher tool RPM, high welding speed with high amount of constraining. The tool rpm being high led large amount of heat generation followed by quick removal of heat source (welding tool). The sudden heating and cooling of the plates led to crack being developed at the centre of the weld. This defect has been shown inFig. 3.

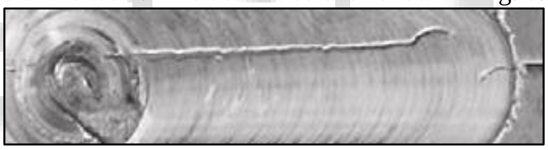

Fig. 3: Crack obtained at the centre of the weld

B. Excessive flash

The groove like defect discussed above could be removed is the plunge depth could be sufficiently increased. This excessive plunging compensated for the tool tilt and hence resulted in defect free welds. But this increased plunge lead to excess material throwing out in form of flash. This excessive flash not requires additional machining, but more importantly leads to thinning of work piece that the weld. This may not be acceptable as per design in most of the cases. This defect has been shown in Fig. 4.

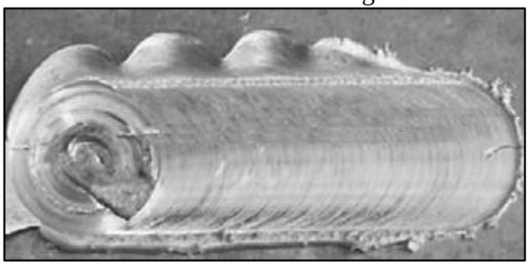

Fig. 4**:** Excessive flash in FSW weld

C. Groove like defect just below the surface of weld

With this larger diameter pin used, it became difficult for the material to flow and fill the space created by the moving pin particularly near the tip of the pin. This defect has been shown in Fig. 5.

Fig. 5: Defect observed just below the surface of weld in bead on plate weld

D. *Defect due to separation of the plates before joining*

Proper clamping of plates is very important in friction stir welding. If the plates separate out during welding, a gap will be created and this gap would not be filled by the material flowing back. One such case of defect was observed and has been shown in Fig. 6.

Fig. 6**:** Defect due to separation of the plates

V. Conclusions

Defects are normally not seen if friction stir welding has been properly carried out. But to carry out proper welding care needs to be taken. Any of the reasons mentioned above can lead to such defective welding. If any of the defects as mentioned above are observed, efforts should be made to look for the reasons mentioned above and suitable corrections should be made. Special care is needed to avoid Lazy 'S' formations as it may do undetected as this defect cannot be seen by unaided eyes.

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