International journal of basic and applied research
www.pragatipublication.com
ISSN 2249-3352 (P) 2278-0505 (E)
Cosmos Impact Factor-5.86

Investigations into friction welding of marine-grade aluminium alloys

Dr. B. Ravi [1] Perumallapalli Gandhi [2], Dr G Raja Kumar [3]
Assistant Professor [1,2,3]
Department of Mechanical engineering,
[2] SV engineering college, Surya Peta (DIST). TS-508213
[1,3] Swarna Bharati Institute of Science and Technology, Khammam, TS-507002

ABSTRACT

Aluminium alloys are the most common materials joined by friction stir welding, a relatively new joining technique. Research into the effects of different weld conditions on friction stir welding of marine grade 5083 aluminium alloy was, therefore, the objective of this study. Researchers looked examined how changing the speed of the tool's traversal and rotation affected the microstructure and mechanical properties of the welded joint in many tests. The results of the welded junction were found to be significantly affected by the tool traverse speed. The TMAZ improved the mechanical properties of the welded connection by eliminating grain boundaries. Raising the welding speed resulted in the regrettable loss of mechanical characteristics, even if the rotation speed remained constant. It is possible to get an exceptionally high-quality marine grade 5083 aluminium alloy welded connection, according to the results, provided that the process parameters are chosen correctly.

1. INTRODUCTION

Friction stir welding, invented at Cambridge's Welding Institute, is a method for joining metals that doesn't include filler or fusion agents. It is necessary for critical applications such fastening structural components made of aluminium and its alloys. The process of joining materials involves the employment of a non-food, rotating instrument. In order to solidify the connecting zone, the instrument plasticises it while simultaneously stirring it. A portion of the material gets heated by plasticising as a result of friction between the material and the rotating tool. While adjustments may be made to accommodate pipes, hollow sections, and positional welding, the technique is most effective when used to long, flat components like as sheets and plates. A tool in motion causes physical deformation in addition to frictional heating. The maximum temperature that may be reached during welding is about 0.8 times the metal plates' melting point. The instrument is comprised of a spherical part that is terminated by a probe. The probe and the cylindrical portion connect at its shoulder. The probe is inserted into the work piece while the shoulder brushes against the top surface. When a rotating-translation tool's shoulder rubs against a work piece, it generates heat due to friction. A relatively recent technique for solid-state joining, friction stir welding (FSW) was patented in 1991 [1] by the Welding Institute (TWI). Stronger and more malleable welds are the consequence of FSW's use of lower welding temperatures compared to fusion welding [14]. When it comes to steel and aluminium sheets, FSW may stand in for riveting and resistance spot welding, respectively, in the aerospace and automotive industries [15]. The temperature of the workpiece was recorded in FSW by Tang et al. [3] and McClure et al. [2]. Colegrove et al. [4] used FSW to model the pin's effect on material and thermal fluxes. In their theoretical model, Russel and Shercliff postulated that the heat input is determined by the shear strength of the material [5]. In order to anticipate microstructural changes caused by the temperature cycle enforced in FSW, Shercliff. [6] and his colleagues developed basic process models on British soil.Using the aerospace alloys 2014 at their peak-aged state, they created a softening model for heat-treatable aluminium alloys of the 6000 family.

The solid-state nature of FSW means that it has the potential to create high-quality, defect-free welds in aluminium alloys. Stronger and more malleable welds are the outcome of FSW's utilisation of low welding temperatures compared to fusion welding [7]. It would be a suitable match to automate the FSW operation. Many more advantages of FSW are also mentioned [8]: A non-consumable tool is one of its features. • Filler wire is no longer necessary. • It's capable of welding curvy shapes. • Gas shielding is not necessary while welding aluminium. • Certification as a welder is not required. • There's no need to prepare the surface. The distortion is minimal, even in lengthy welds. • No harmful gases are released. • It is impermeable. • No molten metal is involved since it is a solid state process. The process parameters, such as the rotating speed, the translational weld speed, and the downward plunge force, must be fine-tuned in order to achieve a perfect weld.

Since the Welding Institute patented this method in 1991, there have been ongoing discussions on the metal flow channel and other parts of it [1]. Currently, in order to get a good weld, the processing parameters for an FSW are determined by trying out various values until the welded connection reaches a sufficient tensile strength. One disadvantage of this technique is that it extends the development time and adds extra costs to the production schedule by include FSW. There is a plethora of pin tools on the market, and each one boasts an enhanced welding experience [12]. Steel, ceramics, and composites are among the materials that may be used to create the pin tool.

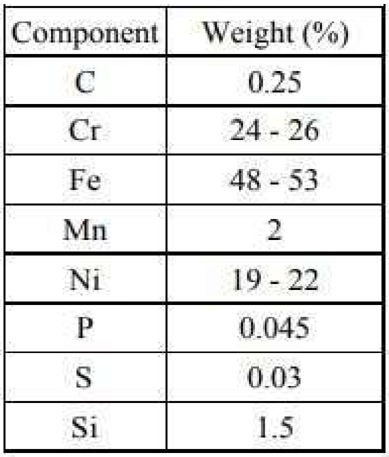
To endure high temperatures, all the tool material has to be much tougher than the workpiece material. A marker insertion approach was used to examine the shearing around the tool pin by Seidel et al. [13]. As part of the procedure, Al 2195 workpieces had holes cut into their faying surfaces, and thin sheets of Al 5454 were inserted into those slots. By utilising a serial sectioning approach to recreate the flow route, the distorted marker was displayed in three dimensions. From what we can tell, the flow route within an FSW is probably complex and multi-channeled [13]. Strong welded connections on 5083 marine grade steel are the primary focus here, along with investigating the effects of various process parameters on the mechanical properties and microstructural characteristics of the final welded junction.

Fig.1FSWtool

EXPERIMENTAL SETUP

A suitable experimental setup wasdeveloped to carry out FSW of 5083 aluminum alloy. FSW tool with a particular taper pin geometry was designed and developedusing310stainlesssteelasshown in Fig.1. A milling machine having a 7.5 hp motor was used to carry out the experiments on FSW. The tool was mounted in the vertical arbor of the milling machine by a suitablecollate.Thehorizontalbedwasused for fixing the test samples. The FSW experimental setup is shown in Fig.2.

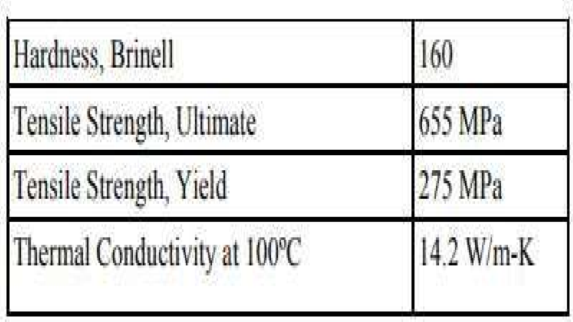
The material composition and the relevant physical properties of the material used for manufacturing the tool are shown in Tables1 and 2 respectively. A friction stir welded sample is shown in Fig.3



Component	Weight (%)
C	0.25
Cr	24 - 26
Fe	48 - 53
Mn	2
Ni	19 - 22
P	0.045
S	0.03
Si	1.5

Table1: FSW Tool Material Composition

Table2: FSW Tool Material Physical Properties



Hardness, Brinell	160
Tensile Strength, Ultimate	655 MPa
Tensile Strength, Yield	275 MPa
Thermal Conductivity at 100°C	14.2 W/m-K

Fig.2ExperimentalsetupofFSW process

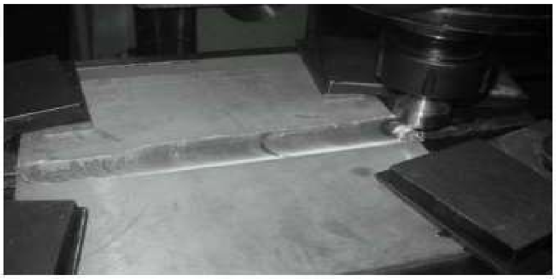


Fig.3Africtionstirweldedsample

2. MECHANICALPROPERTIES

The effect of the tool rotational speed and the tool traverse speed on the hardness, tensile strength and elongation of frictionstir welded samples were investigated.

2.1 VICKERSMICROHARDNESS

A specified load and dwell time were used to determine the hardness by inserting an indenter into the substance to be tested. The "hardness number" was determined by measuring the impression left behind after the indenter was removed. The material's elasto-plastic properties largely dictate the modifications brought about by the indenter's entrance. A four-sided pyramid with a square base, the Vickers indenter has an apex angle of α = 136o (± 15'), as seen in Figure 9. Dividing the load (indentation force) by the imprint's surface yielded the hardness value (HV). A metallographic finish is necessary for the tested surface; the surface finish level is directly proportional to the load size. On the cross sections that were perpendicular to the welding direction, hardness measurements were taken. This study used an indentation force of 25 gf and changed the two diagonal indentation widths from 30µm to 45µm. Fig.10 shows the Vickers Microhardness tester in its assembled state.

Fig.9Vickersindenter

Fig.10VickersMicrohardnesstester

The hardness in the different zones of weldedsamples obtained from this study are shown in Figs.11 to 13. Figs.11 and 12 indicate that the hardness gradually decreases from parent metal towards center of weld line. At the same time keeping the tool rotational speed same the hardness in the HAZ increased with increasing traverse speed as shown in Fig.13

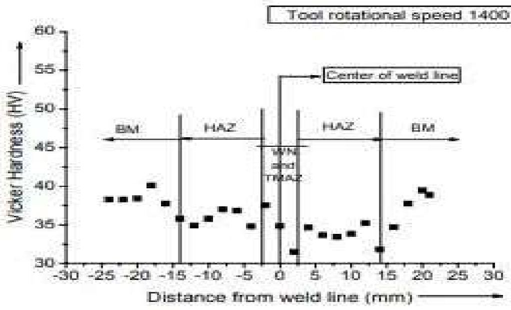


Fig.11Variationsofthehardnessatvarious regionsofweldedplateforatraversespeed of 160 mm/min

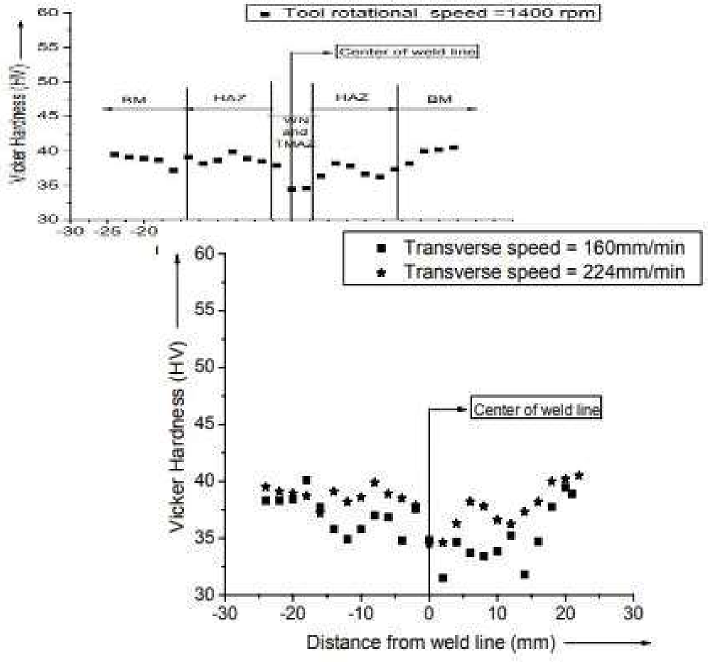


Fig.12Variationsofthehardnessatvarious regionsofweldedplateforatraversespeed of 224 mm/min

Fig.13 Comparison of hardness at various regions of welded plate for variation in traversespeedandkeepingrotationalspeed constant at 1400 rpm

2.2 TENSILESTRENGTH

The tensile test specimens were sectioned in the longitudinal direction i.e. (along weld line) and transverse direction i.e. perpendicular to the welding direction from friction stir welded 5083 aluminum alloytest samples. All tensile tests wereperformed at a constant crosshead displacement rate of 10 mm/min using a Tinius Olsen tensile testing machine.

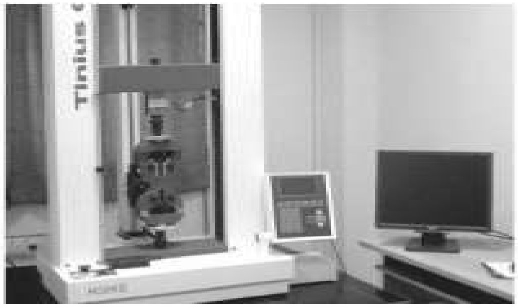


Fig.14Tensiletesting setup

Tensile tests were carried out on several FSW 5083 aluminum alloy test samples to study the effect of traverse speed keeping rotational speed of the FSW tool constant. The tensile test results are shown in Figs.15 and 16. The stress strain characteristics of the tensile test specimens along weld line with varying traverse speed are shown in Fig.15. Here one can observe a very distinct and conspicuous effect on the tensile strength and maximum elongation with variation of traverse speed. With increasing weld speed i.e. increasing tool traverse speed, a sharp drop in tensile strength aswell as drop in maximum elongation took place.

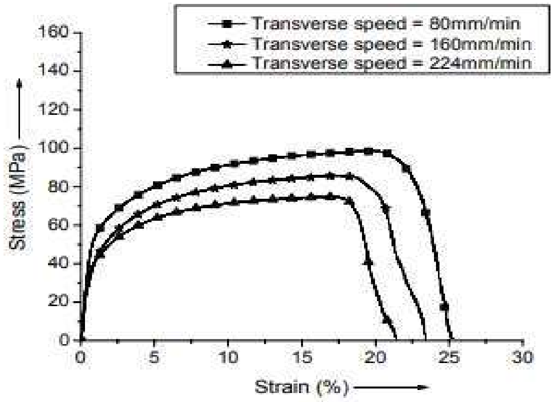


Fig.15Stressstraincharacteristicsoftest specimens along weld line with varying traverse speed keeping rotational speed constant at 1000 rpm

Fig.16 shows the stress strain characteristics of tensile test specimens of base metal, perpendicular to weld line and along weld line with same welding parameters (i.e. rotational speed = 1000rpm and transverse speed =80mm/min). From the Fig.16, one can observe that there is a distinct increasein the ductility of the welded metal compared to that of the original base metal.

3. CONCLUSIONS

Based on the findings mentioned before, the following conclusions have been reached. 1. The impact of weld parameters on microstructural characteristics and mechanical qualities of welded joints was investigated in an experimental study of flux-switching (FSW) of marine grade 5083 aluminium alloy. 2. The HAZ and TMAZ showed clear signs of grain refining as a result of FSW. In parent metal, HAZ, and TMAZ, the average grain sizes were determined to be 5.5 μm, 4.7 μm, and 3 μm, respectively. 3. The grain structure became coarser when the traverse speed was increased. At TMAZ, the average diameters for a traverse speed of 112 mm/min were 3 μm, while at a speed of 160 mm/min they were 3.94 μm. Friction stir welded test samples showed elongation and a precipitous decrease in tensile strength as a result of this. 4. The material's hardness in the HAZ and TMAZ decreased gradually, coinciding with grain refinement. The FSW of 5083 aluminium alloy likewise showed an increase in hardness as the traverse speed increased. 5. Granularity was more finely ground in the TMAZ, which lends credence to the increased ductility seen there. 6. With the right process parameters chosen, the research suggests that a marine grade 5083 aluminium alloy welded junction may be achieved.

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