www.ijiarec.com

ISSN:2348-2079

Volume-7 Issue-2

International Journal of Intellectual Advancements and Research in Engineering Computations

Influence of tool pin profile on the mechanical properties of friction stir welded aluminium alloy

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ABSTRACT

Friction stir welding is an emerging solid-state joining process which is used to join metals and alloys having low weld ability. The process has provided an improved way of satisfactorily joining aluminium alloys, especially the precipitation hardens able aluminium alloys like AA 7XXX series. The fusion welding of AA 7XXX series alloy is generally not preferred due to its highly sensitive to weld solidification cracking. Friction Stir Welding parameters such as tool pin profile, rotational speed, welding speed, and axial force control the mechanical properties of the FS welded joints significantly. These works focused on the consequence of tool pin profile on the weldment tensile strength of the joints were calculated.

In this work, different tool pin profiles are fabricated to weld the aluminium alloy and the effects of tool pin profile on mechanical properties of the aluminium weldments are studied. The stirred zones of aluminium alloys joined with Straight Square (SS), Straight Pentagon (SP), Tapered Square (TS), Tapered Pentagon (TP) and Threaded Cylinder (TC). The effect of tool pin profiles on mechanical properties are investigated and it is found that joints welded with straight square pin profile have improved the mechanical properties of the weldments compared to the other tool pin profiles.

INTRODUCTION

Welding is most important and widely used process in fabrication industries. There are number of welding techniques used for fabrication according to the applications, environment and material to be welded. Welding techniques are divided into different categories; friction stir welding is one of the categories of solid state welding process. Friction stir welding (FSW) was invented at The Welding Institute (TWI) of The United Kingdom in 1991 as a solid state (fusion less) joining technique [1]. Friction stir welding is considered to be the most significant development in metal joining in decades and, in addition, is a “green” technology due to its energy efficiency, environmental friendliness, and versatility. As compared to conventional welding methods, FSW consumes considerably less energy, no consumables such as a cover gas or flux, and produces no harmful emissions during welding, thereby making the process environmentally friendly [2]. Further, because FSW does not involve the use of filler metal and since there is no melting, any aluminium alloy can be joined without concern for compatibility of composition or solidification cracking issues associated with fusion welding. Also, dissimilar aluminium alloys and composites can be joined with equal ease [2]. The FSW basically uses a non-consumable rotating tool with a specially designed pin; and for the welding, shoulder is inserted into abutting edges of

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sheets or plates to be joined and subsequently traversed along the joint line.

EXPERIMENTAL PROCEDURE

Design and manufacturing of FSW tools

Eighteen various FSW tools are designed by varying the tool pin profile, ratio of Shoulder dia./Pin dia. (D/d) and configuration of shoulder – work piece interference surface [3,4]. The configurations of the designed FSW tools are:

- Tool pin profiles of square, hexagon and octagon with 16L draft and without draft.
- Tools having D/d ratios of 2.8, 3, and3.2.
- Shoulder – work piece interference surface – 3 concentric circular equally spaced slots of 2 mm depth on all tools.

Out of various tool materials like tool steel, high speed steel, high carbon high chromium steel (HCHCr),carbide, and carbon boron nitride, HCHCr steel is chosen as tool material because of its high strength, high hot hardness, easy to process, easily avail-able and low cost.

The FSW tools are manufactured using CNC Turning center and wire cut EDM (WEDM) machine. The tools are oil hardened to obtain a hardness of 60–62 HRC. The manufactured tools are shown in Figure.1

Fig. 1

FSW Parameters for DOE

Taguchi technique for design of experiment (DOE) has been implemented for finding number of experiments to be performed for selected variables for welding such as tool pin geometry, welding speed, and tool rotation speed. These design models have been prepared by choosing three levels. Taguchi design was used for experimentation by applying L9 orthogonal array, taking three levels for each factor.

Table-1 shows the tool, rotational speed and welding speed along with experiment number showing the order of experiment to be performed.

Table.1

Sample	Control factor	Unit	Level 1	Level 2	Level 3
A	FSW Tool		TSCP	TCP	SCP
B	Rotational speed	rpm	710	1000	1400
C	Welding speed	mm/min	28	40	56

Al–TiB2 MMC test plates of size 50 mm 50 mm 6 mm are prepared using WEDM from Al–TiB2 MMC cast blocks with 10 wt. % of TiB2 reinforcement that is obtained from in situ stir casting process and joined by FSW using hexagonal tool. Initially a mathematical model was derived based on response surface methodology to correlate FSW process parameters like tool rotational speed, axial force and welding speed with the weld quality. Using the developed mathematical model, FSW process was optimized to have better tensile strength [5]. The optimized FSW process parameters are given below:

- Tool rotational speed = 2000 rpm.
- Welding speed = 300 mm/min
- Axial force = 19.6 kN.

Six tools which yielded defect free weldments out of the eighteen different tools that were manufactured are selected based on trial welds using optimized FSW process parameters. The FSW tools of 16 mm shoulder diameter (D/dratio=2.8)havingbothstraightandtaperedconfig urationwithvariouspinprofilessuchassquare, hexagon and octagon are employed for final joining of the AM Cplates.

Figure.2

Evaluation of tensile strength of the friction stirs welded specimen. Tensile test specimens are prepared as per ASTM E8 standard and transverse tensile properties such as tensile strength, percentage of elongation and joint efficiency of the FS welded joints are evaluated using computerized UTM. For each welded plate, three specimens are prepared and tested. The fracture has occurred mostly in the TMAZ zone on the retreating side of the weldment. The Fig. 3 shows the tensile specimen before and after fracture for 3 set of welds the average values of the results obtained from those specimens are tabulated and presented in table 2 Mechanical properties of the friction stir welded Al-Ti MMC

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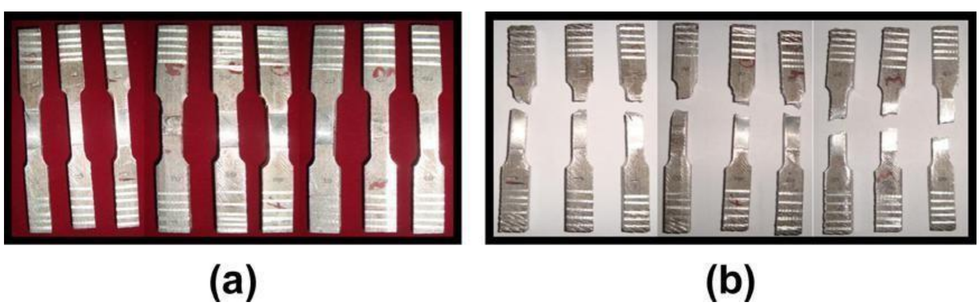

Figure.3

Table.2

properties	**Metric**	**Imperial**
Tensile strength	641 Mpa	93 ksi
Yield Strength	590 Mpa	85.7 ksi
Elongation	8%	8%

RESULTS AND DISCUSSION

From Fig. 4 it is clear that a defect free weld is obtained when tapered hexagonal pin and straight square pin tools are used for joining AMCs. Various zones viz., nugget, thermo mechanically affected zone (TMAZ), heat affected zone (HAZ), in the weldment, caused during the welding are also visible. The grains are coarse in the parent metal and are finer in stirred zone. The zones of nugget, TMAZ and HAZ of welded AMCs joined with tapered pin pro-files are narrower than that joined with straight pin profiles.

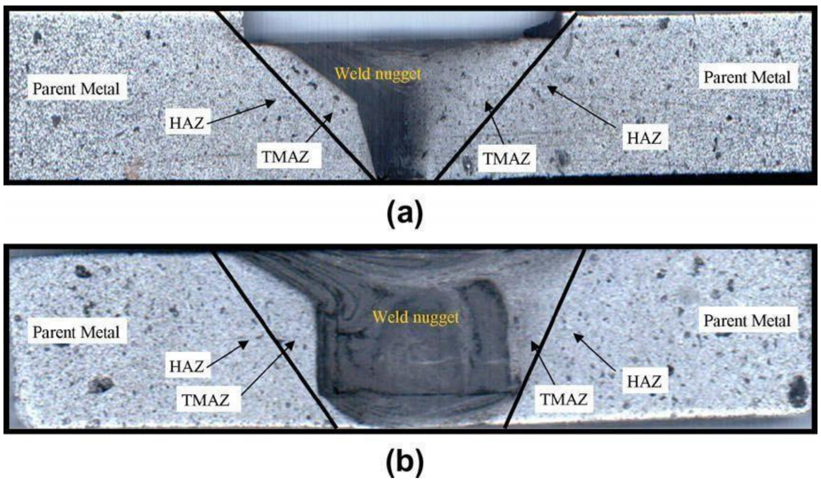

Figure.4

The weld nugget as a fineequiaxedre crystallized structure, while the parent metal has a dendrite structure as it is produced using stir casting process.

The effect of tool pin pro file on the mechanical properties of the FSW joint scan be in ferred from Table1.The joint welded by square pin profiled tool exhibits high tensile strength when com-pared to other joints. The joint fabricated by tapered square pin profiled tool has the least tensile strength. The tensile strength of joints, welded using hexagon, tapered hexagon, octagon and tapered octagon pin profiled tools do not change significantly. It is due to the difference in dynamic orbit created by the eccentricity of the rotating tool of the FSW process [6]. The relationship be-tween the static volume and dynamic volume decides the path for the flow of plasticized material from the leading edge to the trailing edge of the rotating tool. This ratio is equal to 1.56 for square, 1.21 for pentagon and 1.11 for tapered pentagon pin profiles. In addition, those pin profiles produce a pulsating stirring action in the flowing material due to flat faces. The square pin profile produces 133 pulses/s and pentagonal pin profile produces 200 pulses/s, when the tool rotates sat speed of 2000rpm. There is not much pulsating action in the case of octagonal pin profiled tool because it almost resembles a straight cylindrical pin profiled tool at this high rpm. In the tapered pin profiled tools, the same principle affects the material flow. Since the tapered square pin tool sweeps less material when compared to that of straight square pin tool, this joint exhibit less tensile properties. The microstructure also show bigger grains which account to the poor tensile strength in the joints made out of taper pin profiled tools. Table 2 also shows the effect of tool pin profiles on the % elongation of the welded AMCs.

It is evident from the table that the effect of tool pin pro file on the % elongation is in significant except for the octagon pin tool. The reason is the presence of TiB2 particles in the parent metal which considerably reduces the % elongation of the material [7]. The effect of tool profile on the joint efficiency is also similar to that of tensile strength. The joint efficiency is high when the AMC is welded using square pin tool and low when it is welded with tapered square pin tool.

CONCLUSIONS

The following conclusions can be derived from the above work:

1. Weld nugget has finer grains when compared to the cast parent metal.
2. Since the parent metal was cast by in situ stir casting process, it shows larger grains with dendrites.
3. The stirred zones are narrower for joints welded with tapered pin profiles than that of straight pin profiles.
4. The microstructure of the FS welded specimen is affected by the tool pin profile.
5. The weld made of taper pin profiled tools shows coarse grains when compared to the joints made of straight pin profiled tools.
6. The tensile strength of the friction stir welded specimen is also affected by the tool pin profile.
7. The square tool exhibited better tensile strength when com-pared to other tools.

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