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EFFECT OF FRICTION STIR WELDING ON THE TENSILE STRENGTH OF AL-4.5%CU/2.5% TIB_2 IN SITU METAL MATRIX COMPOSITEWITH VARYING TOOL GEOMETRIES AND PROCESS PARAMETERS

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ABSTRACT

Current investigation discusses the feasibility of friction stir welding to join Al-4.5%Cu/2.5% TiB2 in situ metal matrix composite. The FSW tool used was a bimetallic tool hardened by flame hardening method. The threaded probe was made of hardened titanium while die steel was used as the shank and shoulder part of the tool. Two tools with different shoulder geometries were used. Also, two different tool rotating speeds and two different welding (traverse) speeds were used to make the weld. In total, eight welds were made and their tensile strengths were checked and compared with that of the base composite.

Keywords: aluminium metal matrix composite, in situ metal matrix composite, friction stir welding, FSW

I.INTRODUCTION

Particulate ceramic reinforced Aluminium Matrix Composites (AMCs) are finding their applications in industries which require high specific strength, such as aerospace, automotive, marine etc. AMCs are favoured because of the enhanced properties they possess, such as low density, high strength, improved wear resistance, fatigue resistance, electrical and thermal conductivity, low thermal expansion coefficient and many more. Due to the sharing of load by reinforcement, increase in mechanical properties is observed in AMCs [1]. However, despite having so much to offer, applications of AMCs are very limited due to the problems faced during fabrication and joining of AMCs.

In situ AMCs are found to have good adhesion at matrix-reinforcement interface and hence, possess better mechanical properties with relatively better distribution of reinforcement particles in matrix phase [2-3]. To prepare in situ composites, stir casting technique is generally accepted as promising technique and used commercially.

To join AMCs, conventional fusion techniques cannot be applied. Fusion welding of aluminium and its alloys is itself very troublesome, and the addition of ceramic reinforcements further reduce their weldability. Fusion welded joints of AMCs are characterized by porosity, cracking, theta-phase precipitates (formed due to deleterious reactions between molten aluminium and reinforcement), reinforcement particle segregation and entrapment of gases in the weld [4-6]. These all lead to poor weld properties, making it unfit for use in service conditions. In order to avoid all these problems, solid state joining of AMCs is preferred. A relatively novel technique, Friction Stir Welding (FSW) has emerged as a promising technique for solid state joining of AMCs.

Friction Stir Welding (FSW) was developed by The Welding Institute (TWI) in Cambridge, UK in early 1990s [7]. FSW uses a non-consumable tool with a specially designed probe and shoulder mounted on a rotating spindle. In traditional FSW, the tool plunges into the abutting edges of the plates needed to be joined and as the tool traverses along the joint line, the material behind the tool consolidates due to the forging pressure from the tool shoulder, forming a weld region consistent with the width of the shoulder, as shown in fig.1. The material is softened by the frictional heating between the plates and the tool shoulder, as well as the heat generated by the probe rotating inside the material. The resultant weld is free from the defects found in conventional fusion welding of AMCs.

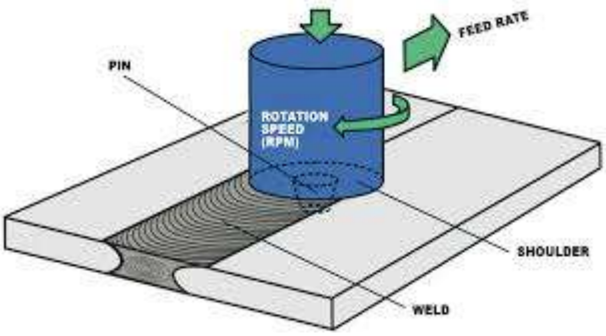

Figure 1: Friction stir butt welding

Some of the distinct advantages of FSW over fusion welding are lower distortion in the weld zone, enhanced repeatability and lower power requirements [8]. FSW can be stated as green technology because it is energy efficient, versatile, produces less material waste with high weld quality and has low impact on environment as it neither uses any shielding gases nor produces any fumes or spatter.

Previous studies [4,9-11] on FSW of AMCs show that apart from the unaffected base composite, the macrostructure of friction stir welds consists of three differentiable zones: (i) heat affected zone (HAZ), (ii) thermomechanically affected zone (TMAZ), and (iii) weld zone or stir zone (SZ). The stir zone is characterized by severe plastic deformation followed by dynamic recrystallization, resulting in very fine reinforcement particles. The TMAZ, adjacent to SZ, suffers deformation but there is no recrystallization in this zone. Therefore, the particles in this zone are larger than in SZ. HAZ is affected only by heat. The distribution of particles in HAZ is similar to that in base composite. In case of cast composites, the strength and ductility increase after friction stir welding due to the modification of microstructure after solidification of the casting [12-14].

The process parameters of FSW largely affect the weld properties [15-20]. There are three process parameters for FSW: (i) tool rotational speed, (ii) welding speed, and (iii) axial force on the tool. Tool geometry also plays a major role in deciding the quality of the weld. Elangovan and Balasubramanian [18] investigated the influence of tool probe profiles and rotational speed on the friction stir processed zone in AA2219 aluminium alloy. Padmanaban et. al. [21] reported that tapered and straight cylindrical probe tools had high possibilities of tunnel defects, and threaded probe tools provided best results. Hidetoshi et. al. [22] also studied the effect of threaded probe FSW tools on the welding of 1050-H24 and 6061-T6 and emphasized the benefits of using threaded probe tools.

Based on the literature review presented here, it can be said that FSW has been reported as the most promising technique for joining AMCs, but very limited literature is available for FSW of in situ AMCs. However, no literature is available for FSW of AMCs reinforced by TiB_2. Hence there was a need to work in this direction. Present work focuses on the joining of the said composite using FSW method with varying tool geometries and process variables and studying their effects on tensile strength of the joint.

II.EXPERIMENTATION

The composite to be welded (Al-4.5%Cu/2.5% TiB_2) was fabricated using stir casting process. To cast the composite, mixed salt route method was used. Two salts, KBF_4 and K_2TiF_6 were added to molten mixture of aluminium and copper. This addition of salts resulted in exothermic reaction, which in turn produced the desired in situ metal matrix composite.

III.FSW TOOL AND PROCESS PARAMETERS

The plates sheared from the castings were rolled to the dimensions 100mm x 50mm x 5mm. these plates were fixed in square butt configuration to make welds. Non-consumable tools with two different shoulder geometries were used for welding. The probe of the tool was made from hardened titanium (due to abrasive nature of TiB_2 particles) while the shank part of the tool was made from die steel.

The probes of the tools were cylindrical having diameter of 6mm having anticlockwise threads of 1mm pitch. The schematics of the two tools is shown in figure 2, showing the first tool having full flat shoulder while second tool having 1mm flat surface and then 7°concave towards the centre.

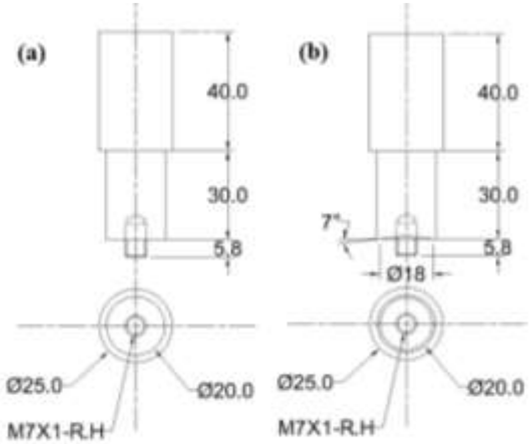

Figure 2: Schematics of the FSW tool used with (a) full flat shoulder, (b) 1mm flat and then 7° concave towards the centre

There are three process parameters in friction stir welding, namely, (i) speed of tool rotation (revolutions per minute), (ii) welding speed (mm/minute), and (iii) axial force on the tool (kN). For this experiment, an axial force of 6kN was kept constant throughout the experimentation work. Two tool rotational speeds were used: 665rpm and 930rpm. 15mm/minute and 30mm/minute were selected as the welding speeds for this experiment. Thus, a total of eight welds were made with two tool shoulder geometries, two welding speeds and two tool rotational speeds. All these values are listed in the table 1 below.

Input Variables	Units	Value 1	Value 2
Tool Geometry	-	Full Flat	1mm flat and then 7° concave
Tool Rotational Speed	Revolutions per minute	665	930
Welding Speed	mm/minute	15	30

Table 1: Values of the various input variables used

In order to check the tensile strengths of the welds, tensile specimens in accordance with ASTM E8M-04 standard were cut from the welded plates. Figure 3 shows the dimensions of the tensile specimens. The specimens were taken along the weld joints so as to obtain the tensile strength of the weld, and not the joint. Tensile testing was done on computerized data acquisition system (INSTRON) with the tensile force being applied at a constant rate of 1kN/second at room temperature.

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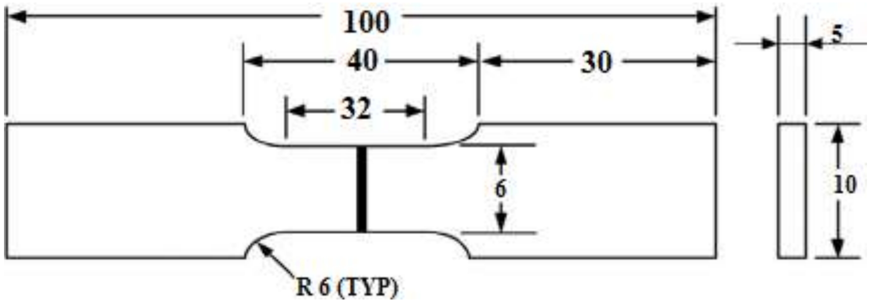

Figure 3: Tensile specimen in accordance with ASTM E8M-04 standard (dimensions in mm)

IV.RESULTS AND DISCUSSION

From visual inspection, the weld was found to be smooth and free from any surface defects. The weld surface is shown in figure 4. Figure 5 shows an optical macrograph of the weld zone. The stir zone can be seen to e distinct from the base composite in the macrograph. The TMAZ is adjacent to the stir zone on either side followed by HAZ and then, base composite itself. It was also found that the width of the stir zone decreased from top to bottom of the weld cross section.

Figure 4: Surface of the weld

Figure 5: Optical macrograph of the weld cross section showing stir zone, TMAZ, HAZ and base composite

Measured values of tensile strength (MPa) and percentage elongation are illustrated in table 2. It was found that the strength of the weld as well as its percentage elongation increased on increasing the welding speed and tool rotational speed. Also, it was observed that these values were higher for second tool type (1mm flat surface and then 7° concave towards the centre) than for the first tool type (full flat shoulder). This change of strength from first tool type to second tool can be attributed to the larger surface area in contact in case of second tool. Higher surface area in contact generated more frictional heat, which made the matrix of the composite soft. Softening of the composite resulted in better mixing of materials from the two plates making the joint strong.

Increasing rotational speed of the tool also contributed to the increased heat generation, resulting in better mixing of the composite materials. However, increasing the welding speed causes faster cooling rates to be observed which, in this experiment, inhibited the grain growth of the matrix. Fine grains in matrix also helped in increasing the tensile strength as well as the percentage elongation.

Welding Speed (mm/minute)	Tool Rotational Speed (rev./min)	Tool Type	Tensile Strength (MPa)	Elongation (%)
15	665	1	180.45	6.23
15	665	2	183.49	8.21
15	930	1	184.15	8.66
15	930	2	186.76	9.10
30	665	1	182.14	8.34
30	665	2	185.69	9.02
30	930	1	189.05	9.79
30	930	2	193.40	10.26

Table 2: Measured values of tensile strength and percentage elongation of the welds

Tensile strength for the base composite was also measured so that it could be compared with that of the welds. Tensile strength for the base composite came out to be 177.52Mpa. This clearly proved the common notion that FSW increases the strength of the weld in particulate reinforced composite by breaking the particulate reinforcement into finer particles. The maximum tensile strength was observed when welding was done using second type of tool with welding speed as 30mm/minute and tool rotational speed as 930rev/min.

V.CONCLUSION

From the current investigation it can be concluded that the strength and elasticity of the said particulate reinforced composite (Al-4.5%Cu/2.5% TiB_2) increases when welded using Friction Stir Welding. Higher contact area between the plates and the tool shoulder leads to higher values of tensile strengths. Also, welding speed as well as rotational speed play vital role in deciding the mechanical properties of the weld obtained. Higher values of welding and rotational speeds result in stronger welds.

However, more work is needed to determine the effects of these parameters on other properties of the welds, such as hardness, wear resistance, fatigue etc. Also, mathematical models can also be developed to estimate the influence of process variables on the weld properties before conducting the experiments.

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