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Influence of Tool Rotational Speed on the Mechanical and Microstructure Properties of Friction Stir Welded Al-B_4C MMCs ☆

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Abstract

Friction Stir Welding (FSW) is a solid state joining technique developed to join high strength aluminum alloys and different ceramic reinforced Metal Matrix Composite (MMCs). FSW produces sound welds in MMCs without any detrimental reaction between reinforcement and matrix. In this work, AA6061-10 wt. % B_4C Metal Matrix composites (MMCs) are joined using Friction Stir Welding (FSW) process. Different tool rotational speeds are developed to weld the MMCs and the effect of tool rotational speed on mechanical and metallurgical properties of the weldments has been investigated. The different tool rotational speeds, i.e. 800 rpm, 900 rpm, 1000 rpm, 1100 rpm and 1200 rpm are used to obtain defect free welds. It has been observed that, the joint welded with 1000 rpm of tool rotational speed exhibited better mechanical properties compared to the other tool rotational speeds. Weld nugget has finer grains compared to other weld zones and B_4C particulates are homogeneously present in Al matrix both in weld and parent metal.

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Keywords: Rotational speed, B_4C, Metal Matrix Composite, Tensile Strength

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1. Introduction

Friction Stir Welding (FSW) was introduced in 1991 by The Welding Institute (TWI) in Cambridge, England, as a solid- state metal joining process [1, 2]. In the FSW, process parts to be joined must be firmly clamped to backing plate in order to avoid them from moving during the welding process. A rotating pin tool is forced down into a hole along the weld line to the shoulder of the tool comes into contact with the parts to be joined. The rotating tool travels along the joint line direction with a constant welding (traverse) speed. The fig.1 explains the working principle of FSW process.

During the welding process, the material along the joint undergoes excessive plastic deformation due to frictional elevated temperature, resulting in fine and equiaxed recrystallized grains, which in turns increase the mechanical properties of the welded joint [3, 4]. The friction stir weld joint consists of four distinct zones as shown in fig. 2. They are: (a) nugget zone (NZ) or friction stir processed (FSP) zone, (b) thermomechanically affected zone (TMAZ), (c) heat-affected zone (HAZ) and (d) unaffected base metal. At the NZ, the plastic deformation will produce a recrystallized, equiaxed, and fine-grain microstructure. TMAZ exposes to lower plastic deformation (less than the NZ). Consequently, this zone consists of relatively large grains. The HAZ is not subjected to any plastic deformation only; it is exposed to thermal effects, which results in some modification and coarsening the grains. During the FSW process, because of the rotation of the profiled pin of the welding tool nearly concentric rings are developed in the NZ, which is called the onion ring structure [5]. The process can be used in many applications, such as the joining of similar metals, dissimilar metals [6], high-strength aerospace aluminum alloys, and composite materials that have limitations to be welded by conventional fusion welding process [7]. More details on the advantages and limitations of the FSW process can be found in [8].

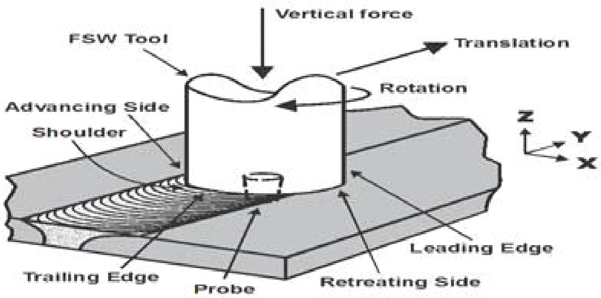

Fig. 1. Schematic representation of FSW principle.

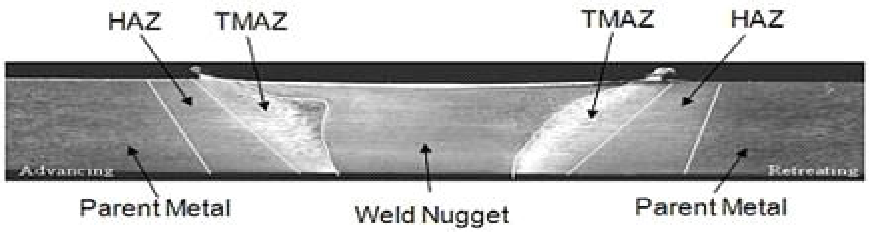

Fig. 2. Different regions of FSW joint.

In the FSW process, the microstructure evolution and the mechanical properties of the weld joints is influenced by the material flow in the weld zone. The most consequential parameter affects the material flow is the tool geometry [9]. Among other parameters affecting the material flow are the friction rotational speed and welding (transverse) speed. All these parameters have a remarkable influence on the grain size of the NZ microstructure, which, in turn, will affect the mechanical properties of the weld zone [10]. In general, it can be stated that FSW is a combination of extruding, forging, and stirring of the material [9]. Most of the earlier studies in the recent developed field of FSW have concentrated on the effect of welding (transverse) speed and rotational speed on the properties of welded joints [11]. Little work has been done to study the effect of the welding pin profile tool on properties of friction stir welded joints [12], especially with composite materials. Accordingly, the present work was concentrated on studying the effect of tool rotational speed on mechanical properties using aluminum matrix composites.

2. Experimental Work

The rolled plates of 7mm thickness, ($AA6061+B_4C$) aluminum metal matrix composite, have been cut into the required size (100x50 mm) by power hack saw cutting and milling. Square butt joint configuration, as shown in figure 3 has been prepared to fabricate FSW joints. The initial joint configuration is obtained by getting the plates in position using mechanical clamps. The direction of welding is normal to the rolling direction. The single pass welding procedure has been followed to fabricate the joints. Non-consumable tools made of super HSS (high speed steel) have been used to fabricate the joints.

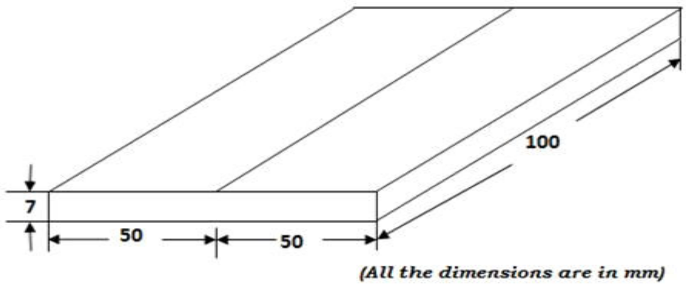

Fig. 3. Dimensions of square butt joint.

The chemical composition and mechanical properties of the base metal are presented in Table 1a. An indigenously designed and developed a machine (15 HP; 3000 rpm, 25kN) was used to fabricate the joint. Cylindrical taper threaded pin profile tool are used to fabricate the joints. Using this tool, 5 joints were fabricated in this investigation. Trial experiments were carried out to find out the working limits of welding parameters. The three different welding speeds (0.5 mm/s, 0.67 mm/s, and 0.83 mm/s) and three different tools, tilt angles (0^0, 1^0 and 2^0) were used to fabricate the joints. Then the joints were visually tested for exterior weld defects and it was found that the joints fabricated at the welding speed of 0.83 mm/s and tool tilt angle of 2^0 was free from any external defects. The welding parameters and tool dimensions are presented in table 2.

Table 1a. Chemical composition (wt. %) of Aluminum alloy (AA6061).

Elements	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
% by weights	0.64	0.294	0.261	0.095	0.88	0.033	0.089	0.032	Bal

Table 1b. Mechanical properties of base metal

Material	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
Base Metal	198	212	8.5

The welded joints were dividing using a power hacksaw and then machined to the required dimensions to prepare tensile specimens as shown in Fig. 5. American Society for Testing of Materials (ASTM) instructions were followed in preparing the test specifications. Tensile test was carried out in 100 kN, electro-mechanically controlled Universal Testing Machine. The specimens were loaded at the rate of 1.5 kN/mim as per ASTM instructions, so that tensile specimens undergoes deformation. The specimen conclusively fails after necking. 0.2% offset yield strength, ultimate tensile strength and percentage of elongation were evaluated.

Microstructral investigation was carried out using a light optical microscope (VERSAMET-3) induced with an image analyzing software (Clemex-Vision). The specimens for metallographic examination were sectioned to the required sizes from the joint constitute nugget zone and base metal regions and polished using different grades of emery papers. Final polishing was done using the diamond compound (1µm particle size) in the disc polishing machine. Specimens were etched with the Kellers reagent to reveal the microstructures.

Table 2. Welding parameters and tool dimensions

Process Parameters	Values
Rotational Speed (RPM)	800, 900, 1000, 1100, 1200
Welding Speed (mm/min)	50
Tool tilt angle (degree)	2
D/d ratio of tool	3
Pin Length (mm)	6.5
Tool shoulder diameter, D (mm)	21
Pin diameter, d (mm)	7

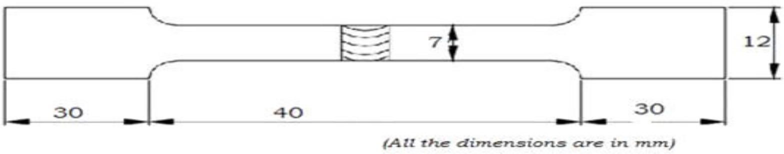

Fig. 4. Dimensions of tensile specimen.

3. Results

3.1. Tensile properties

Tensile properties of FSW joints such as yield strength, ultimate tensile strength, percentage elongation and joint efficiency were evaluated. Three specimens were tested at each condition and average of the results of three specimens is presented in the Fig.5. Since the observed variation in yield strength and tensile strength data was ±3% and the variation in elongation was ±2%, the average of the results of three specimens was calculated. From the fig.5, it can be inferred that the tool rotational speed is having influence on tensile properties of the FSW joints. Of the five joints, the joints fabricated at the rotational speed of 800 rpm and 900 rpm have shown lower tensile strength and joint efficiency compared to the joints fabricated at a rotational speed of 1000 rpm. Similarly, the joints fabricated at the rotational speed of 1100 rpm and 1200 rpm have also shown lower tensile strength compared to the joints fabricated at a rotational speed of 1000 rpm. As far as the effect of rotational speed is concerned, the joints fabricated at a rotational speed of 1000 rpm are showing superior tensile properties compared to other joints.

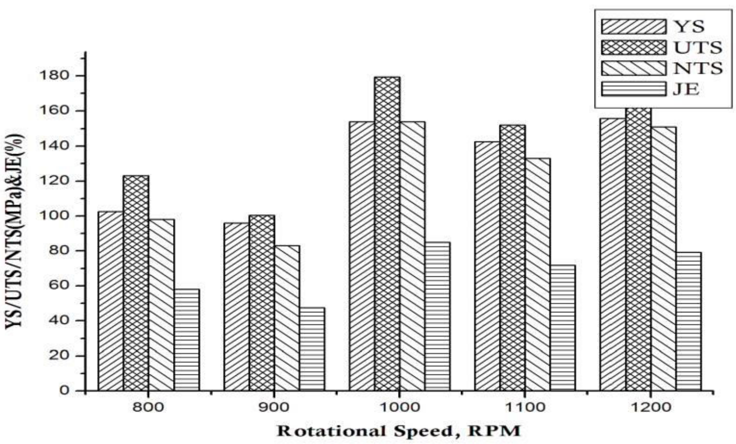

Fig. 5. Effect of rotational speed on tensile properties.

Table 3. Effect of tool rotational speed on tensile properties of the joints.

Rotational Speed (RPM)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Notch Tensile Strength (MPa)	Notch Strength Rartio	Eongation (%)	Reduction in C/S area (%)	Joint Efficiency (%)
800	103	123	98	0.79	5.42	7.13	58.16
900	96	101	83	0.83	4.13	1.43	47.52
1000	171	194	166	0.86	6.36	10.11	91.49
1100	143	151	133	0.87	5.16	3.2	71.87
1200	156	168	151	0.9	6.45	10.17	79.2

3.2. Microstructure

The optical photomicrograph of the AA6061-B_4C friction stir welded is shown in fig.6. The optical photomicrograph as FSW MMCs is revealed in fig.6. It is clear from those micrographs that the weld nugget has a fine equiaxed recrystallized structure, while the parent metal has a dendrite structure as it is produced using stir casting process. Fig. 6 shows microstructures of the nugget zone welded using a cylindrical taper thread tool pin profile and welding speed is 50 mm/min with a shoulder diameter of 21 mm. the microstructures are clearly indicates the homogeneous distribution of B_4C particulate in the weld zone.

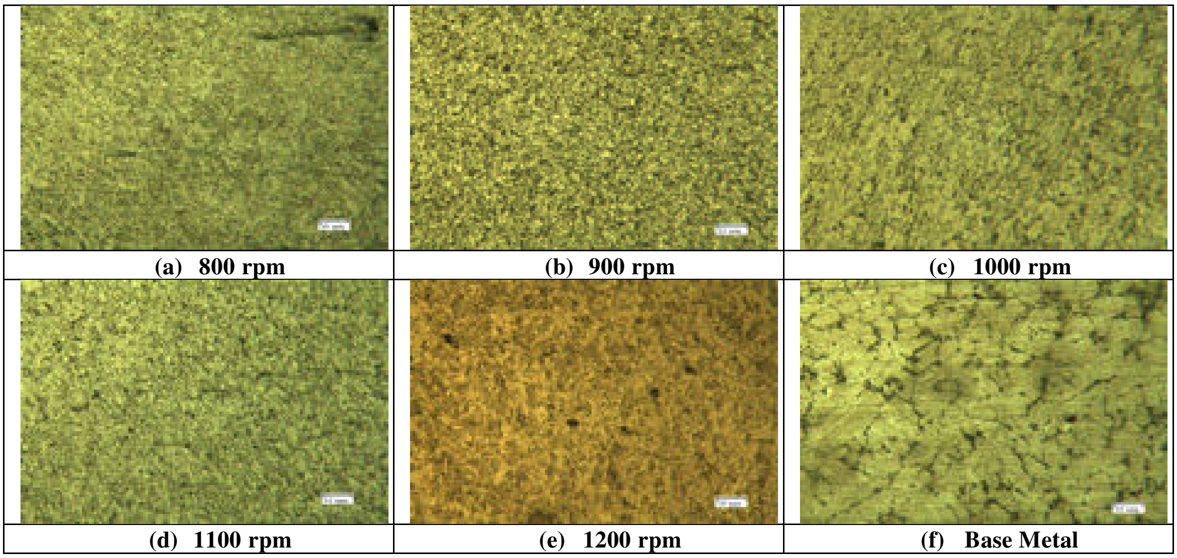

Fig.6. Effect of rotational speed on FSP (Nugget) zone microstructure. (a) 800RPPM, (c) 900RPM, (b) 1000RPM, (d) 1100RPM, (e) 1200RPM (f) Base metal

As it can be seen from the Fig.6, the fine grain microstructures were noticed for all the rotational speeds in the nugget zone due to the frictional heating and extensive plastic deformation occurs during welding. Microstructures of nugget zones with different speeds were found to be fine shown in figure. FSW led to grain refinement of the aluminum alloy matrix.

4. Discussion

Rotational speed presents to be the most paramount process variable since it additionally inclines to influence the translation velocity. Very high rotational speeds (>10000 RPM) could raise strain rate, and thereby influence the FSW process [13]. Higher rotational speed resulted in a higher temperature and more gradual cooling rate in the FSP zone after welding. A higher tool rotational speed causes the exorbitant release of stirred materials to the upper surface, which resultantly left voids in the friction stir welding zone. Lower heat input condition due to lower rotational speed resulted in lack of stirring. For a given RPM as the welding speed increases strength of the joint also increases. This is more or less true in case of all the RPM value tested. It can be safely recommended that welds can be made using moderate RPM, as this would result in low heat input and low damage in HAZ .The area of the friction stir welding zone decreases with and decrementing the tool rotation speed and affect the temperature distribution in the friction stir welding zone [14].

As the rotation speed increases, the stirred region widens, and the location of the maximum strain finally moves to the advancing side from the original retreating side of the joint. This implies that the fracture location of the joint is also affected by the rotation speed [15]. The tensile properties of the joints made with different welding conditions resulted in lowest tensile strength and ductility at lower spindle speed for a given traverse speed. As the spindle speed increased, both the strength and elongation improved, reaching a maximum before falling again at high rotational speeds. It is clear that, in FSW, as the rotational speeds increase, the heat input also increases. However, the calculated maximum temperatures are nearly the same in all the rotational speeds. This phenomenon can be explained by the following two reasons; first, the coefficient of friction decreases when a local melt occurs, and subsequently decreases with a local heat input; secondly, the latent heat absorbs some heat input. As the rotational speed is decreased, and the temperature within the nugget becomes lower and the volume fraction of the coarse second phase must be optimized to get a friction stir welding region with fine particles uniformly distributed throughout the matrix [16].

5. Conclusions

In this investigation an attempt has been made to study the effect of tool rotational speed on the mechanical and microstructure properties of friction stir welded Al-B_4C MMCs. From this investigation, the following important conclusions are derived:

(i) Of the five rotational speeds used in this investigation the joint fabricated at rotational speed of 1000 rpm executed superior tensile properties.
(ii) This study recommends moderate tool speed (RPM) to get defect free single pass welds.
(iii) Microstructural studies revealed fine recrystallised equiaxed grains in the weld nugget due to frictional heating and extensive plastic deformation.

Reference

[1] Kalle, S.W. Friction Stir Welding at TWI; The Welding Institute (TWI): Cambridge, England, 2006.
[2] Thomas, W.M; Dolby, R.E. Friction stir welding developments. Proceedings of the sixth International Trends in Welding Research, Material Park, ASM International, USA, 2003, pp. 203-211
[3] Jata, V.; Semiatin, s.L. Continuous dynamic recrystalization during friction stir welding of high strength aluminum alloys. Scripta Materialia 2000, 43 (8), 743-749.
[4]G.R. Mettam, L.B. Adams, in: B.S. Jones, R.Z. Smith (Eds.), Introduction to the Electronic Age, E-Publishing Inc., New York, 1999, pp. 281–304.
[5]. Krishnan, K.N. On the formation of onion rings in friction stir welds. Materials Science and Engineering 2002, A327, 246-251.

[6] Kwon, Y.J.; Shigematsu, I.; Saito, N. Dissimilar friction stir welding between magnesium and aluminum alloys. Materials Letters 2008, 62, 3827-3829.
[7] Storjohann, D.; Barabash, O.M.; Babu, S.S.; David, S.A.; Sklad, P.S.; Bloom, E.E. Fusion and friction stir welding of aluminum-metal-matrix composites. Metallurgical and Materials Transactions A 2005, 36, 3237-3247.
[8] Nandan, R.; Debroy, T.; Bhadeshia, H.K. Recent advances in friction –stir welding process, weldments structure and properties. Progress in Materials Science 2008, 53, 980-1023.
[9] Zhang, Z.; Zhang, H.W. Numerical studies on the effect of tranverse speed in friction stir welding. Materials and Design 2009, 30, 900-907.
[10] Zho, Y.H.; Lin, S.B.; Qu, F.X.; Wu, L. Influence of pin geometry on material flow in friction stir welding process. Materials and technology 2006, 22, 45-50.
[11] Jones, M.J.; Heurtier, P.; Desrayaud, C.; Motheillet, F,; Allehaux, D.; Driver, J.H. Correlation between microstructure and microhardness in a friction stir welded aluminum alloy. Scripta Materialia 2005, 52, 693-697.
[12] Kumar, K.; Kailas Satish, V.; Srivatsan, T.S. the role of pin design in influencing the mechanism for the formation of friction stir welds in aluminum alloy 7020. Materials and Manufacturing Processes 2011, 26, 915-921.
[13] Valerio Flores, O. Microstructural issues in a friction stir welded aluminum alloy. Scripta Materialia 1998, 38 (5), 703-708.
[14] Lee, W.B.; Yeon, Y.M.; Jung, S.B. Mechanical properties related to micro structural variation of 6061 Al alloy joints by friction stir welding. Material Transaction 2004, 45 (5), 1700-1705.
[15] Liu, H.J.; Fuji, H. Mechanical properties of friction stir welded joints of 1050-H 24 aluminum alloy. Science and Technology of Welding and Joining 2003, 8 (6), 450-454.
[16] Moataz, M.; Salem, A.H.G. Friction stir welding parameters; a tool for controlling abnormal grain growth during subsequent heat treatment. Material Science and Engineering 2005, A 391, 51-59.