EFFECT OF TOOL ROTATIONAL SPEED ON MICROSTRUCTURE AND MECHANICAL BEHAVIOR OF FRICTION STIR WELDED AA7075/WC METAL MATRIX COMPOSITES

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ABSTRACT

In order to prevent the problems of fusion welding of aluminum alloys, the friction stir welding (FSW) is one of the better ways of the joining method to enrich the mechanical properties. Tool Rotational Speed is one of the important process parameter in friction stir welding machine which effects the characterization of FS weld. In the present examination, Aluminum with 6 wt% WC composites is prepared and welding is done by using friction stir welding (FSW) process. In this present work we are using four different Rotational Speeds are used i.e. 500, 700, 900, and 1100(RPM) to weld metal matrix composite joints. It is concluded that those weld joints welded by with the Rotational Speed of 1100rpm. It shows good mechanical properties compared to the other Rotational Speeds. And also from metallurgical examination finer grain structure identified in Nugget zone compared to TMAZ and HAZ.

Keywords: AA7075 aluminum, Stir Casting, Friction Stir Welding, Tool Rotational Speed, Tensile Properties


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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 tightly clamped to backing plate in order to prevent them from moving during the welding process. A rotating pin tool is forced down into a hole along the weld line until 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 intense plastic deformation due to frictional elevated temperature, resulting in fine and equaled recrystallized grains, which in turn enhances 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 exposure to lower plastic deformation (less than the NZ). Therefore, this zone consists of relatively large grains. The HAZ is not subjected to any plastic deformations. Only; it is exposed to thermal effect, 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 rings structure. The process can be used in many applications, such as the joining of similar metals, dissimilar metals, high-strength aerospace aluminum alloys, and composite materials that have limitations to be welded by conventional fusion welding process more details of the advantages and limitations of the FSW process can be found.

![Figure 1 Schematic representation and Nomenclature of FSW principle](image1.png)

![Figure 2 Different regions of FSW joint.](image2.png)

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 significant parameter affects the materials 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 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 materials (9). Most of the previous studies in the recent developed field of FSW have focused 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 tool Rotational speeds on Microstructure and Mechanical properties of friction stir welded joints (12), especially on composite materials. Accordingly, the present work was concentrated on studying the effect of tool Rotational Speeds of the welding tools on Microstructure and mechanical properties, utilizing aluminum matrix composites.
2. EXPERIMENTAL PROCEDURE

In this present work Al-WC Metal matrix composite was prepared by liquid metallurgy Route (stir casting process) Route. In this AA7075 alloy was used as a matrix, Tungsten carbide (wc) with a size of 10µ was used as reinforcement and K$_2$TiF$_6$ (Potassium fluotitanate) flux was used for enhancing wettability of WC with Al melt during stir casting process. The chemical composition and the mechanical properties of AA7075 are given tables 1 and 2 respectively.

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>Cu</th>
<th>Mg</th>
<th>Si</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Cr</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA7075</td>
<td>1.16</td>
<td>1.92</td>
<td>0.119</td>
<td>0.132</td>
<td>0.003</td>
<td>4.57</td>
<td>0.005</td>
<td>Bal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Property</th>
<th>Al</th>
<th>WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm$^3$)</td>
<td>2.92</td>
<td>2.52</td>
</tr>
<tr>
<td>Melting Point (°C)</td>
<td>652</td>
<td>2872°c</td>
</tr>
<tr>
<td>Coefficient of thermal expansion (10$^{-6}$/°C)</td>
<td>23.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Hardness (VHN)</td>
<td>107</td>
<td>2900</td>
</tr>
<tr>
<td>Young’s Modulus (GPa)</td>
<td>72</td>
<td>600</td>
</tr>
</tbody>
</table>

2.1. Composite preparation

Liquid Metallurgy route were adopted to prepare the cast composites. A batch of 1250 grams of aluminum alloy was melted in clay graphite crucible. It was then melted in a resistance heated muffle furnace to the desired temperature of 8500°C. In the meantime WC particulates of size 10 µm were heated in another crucible to a temperature of 2500°C to remove moisture, and the die was preheated to a temperature of 6000°C. The mixtures of preheated WC particles with an equivalent amount of K2TiF6 flux were added at a constant feed rate into the vortex. The crucible was covered with a flux and degassing agents to improve the quality of aluminum composite casting. The mixture was stirred continuously by using mechanical stirrer for about 10-15 minutes at an impeller speed of 500 rpm. The melt temperature was maintained at 8000°C during addition of the particles. The molten metal was then poured into the preheated die to cast plates of 150mmx100mmx10mm size. The AMCs having different weight percentages (1.5, 3, 4.5 and 6) of WC were fabricated by same procedure. The manufactured MMCs are shown in Figure 3

2.2. Fabrication of Friction Stir weld joints

The rolled plates of 8mm thickness, (AA7075, AA7075-6%WC MMCs) aluminum metal matrix composite, were cut into the required size (cross-section of 100X50 mm2 ) by power hack saw cutting and milling. Square But joint configuration was used to prepare FSW joints

Figure 3 Stir Casting Set-up used for fabrication of Composite Plates (AA 7075/WC)
Effect of Tool Rotational Speed on Microstructure and Mechanical Behavior of Friction Stir Welded AA7075/WC Metal Matrix Composites

by using Mechanical clamps. The welding direction is normal to the rotating tool Direction. For the purpose of getting fabricated joints a single pass welding procedure and non-consumable tools which is made of H13 tool was used. An indigenously designed and developed machine (15 HP; 3000 rpm, 25kN) was used to fabricate the joints. The FSW machine is given in Figure 4. The tool nomenclature is shown in Figure 5. The details regarding the welding condition and process parameters are given in the following table 6 with four different Rotational Speeds i.e. 500,700,900 and 1100 tool to fabricate the joints.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>AA7075 6% WC (FSW Joint)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool Pin Profile</td>
<td>Square</td>
</tr>
<tr>
<td>Tool Welding Speed (mm/min)</td>
<td>50</td>
</tr>
<tr>
<td>Tool Shoulder Diameter (mm)</td>
<td>21</td>
</tr>
<tr>
<td>Tool Tilt Angle (°)</td>
<td>2</td>
</tr>
<tr>
<td>Tool Pin Length (mm)</td>
<td>7.5</td>
</tr>
<tr>
<td>Tool Material</td>
<td>H13</td>
</tr>
</tbody>
</table>

Figure 4 FSW Machine Figure 5 Nomenclature of FSW Tool

3. RESULTS AND DISCUSSION

3.1. Effect of tool Rotational Speed on tensile properties of the joints

In this three tensile samples were extracted from each joint. These samples were tested using universal testing machine (UTM) as per the ASTME 8-04 Guidelines. The average of three Reading is presented in Table 8. The Results Show that the tensile properties of the welded joints are significantly varied with regard to different Rotational Speeds. A Higher tensile strength of 197MPa was attained in the joint made by with Rotational Speed of 1100rpm. A lower Tensile Strength of 101MPa was attained in the joint made by with Rotational Speed of 500rpm. The percentage of Elongation of Welded joints was varied with different Rotational Speeds Fig 7(a) shows the Dimensions of the tensile test specimen before test and Fig 7(b) 7(c) Shows the Failure locations of the tensile tested samples.
3.2. Discussion on Effect of Tool Rotational Speed on Tensile Properties

In FSW Process, the welding parameters affect the amount of heat generation and mixing process. Therefore, there is a need for optimum welding parameters selected to produce the best joint strength. It is accepted that the Tensile Strength of the FSW joints of aluminum matrix composites increases by increasing the Rotational Speed until a specific limit (500-1000). The Maximum Tensile Strength of AA7075/WC Metal matrix friction stir welded joints obtained at 1100rpm due to sufficient heat input is produced. If the rotational speed is below 1100, this leads to the conclusion that there is insufficient heat input in friction stir welding joints.
3.3. Effect of tool Rotational Speed on Macrostructure

Fig 8 shows the macrostructures for Four Different Rotational Speeds. The Macrostructure examination of nugget zone can be used to reveal the quality of welded joints. Generally we have identified Four Different zones: Nugget Zone (NZ), Thermo Mechanically affected zone (TMAZ), HAZ and BM. The macrostructure of Rotational Speed of 500rpm shows Defect in the Left side of the advancing Side like Tunnel Defect. In the case of Rotational Speed of 700rpm shows Defect like hole in the top portion of weld in the advancing side. In case of Rotational Speed of 1100rpm shows Defect free in the form of elliptical.

<table>
<thead>
<tr>
<th>Rotation speed(RPM)</th>
<th>Macrostructure</th>
<th>Type of defect</th>
<th>Quality of weld metal</th>
<th>Probable causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td></td>
<td>Tunnel Defect</td>
<td>Poor</td>
<td>Turbulence of Metal Flow</td>
</tr>
<tr>
<td>700</td>
<td></td>
<td>Hole in the top portion of the weld in AS side</td>
<td>Poor</td>
<td>Insufficient heat generation and insufficient metal transportation</td>
</tr>
<tr>
<td>900</td>
<td></td>
<td>Tunnel in the bottom of the weld in the advancing side (RS)</td>
<td>Poor</td>
<td>Insufficient metal transformation</td>
</tr>
<tr>
<td>1100</td>
<td></td>
<td>Defect free</td>
<td>Good</td>
<td>Sufficient heat generated</td>
</tr>
</tbody>
</table>

Figure 8 Macrostrutures

3.4. Discussion on Effect of Tool Rotational Speed on macrostructures

All Four Different Rotational Speeds of macrostructures are identified with tool pin Profile of Square rotational and welding speed of 50mm/min. Under these welding conditions, the heat generation is almost the same for the four Different Rotational Speeds. It is well known that 2/3 of heat generation is caused by mechanical friction between tool shoulder and plate to be joined. Under this condition, the joint made by Rotational Speed of 500rpm shows Tunnel Defect due to insufficient heat generation occurred. Joint made by Rotational Speed of 700rpm shows Defect at top surface of the weld in the advancing side due to insufficient metal transformation. Joint made by Rotational Speed of 900rpm shows tunnel defect due to
turbulence metal flow. From this investigation Rotational Speed of 1100 shows Defect Free because proper heat generation between tool and workpiece.

3.5. Effect of tool Rotational Speed on Microstructure

The heat generated through the Rotation of FSW tool ideally Reaches approximatley the melting Temperature of the joine aluminium matrix composite. This leads to reinforcement, redistribution, refinement and recrystalzation in the nugget zone flow Patterns, grain size and its orientation in various regions with varying of Rotational Speeds were analyzed by at low magnification using optical microscopy and shown in Fig in this we have identified combinations of TMAZ and NZ. In the nugget zone homogenous distribution obtained. In this investigation different Rotational Speeds of NZ&TMAZ microstrutures identified in Fig 9.

![Figure 9](image)

Figure 9 Effect of the tool Rotational Speed on the TMAZ and Weld nugget microstructure

3.6. Discussion on Effect of Tool Rotational Speed on microstructure

The microsturture of the all four pin profiles In the combinations of TMAZ&NZ as a result of production process it shows that reinforcement materials are clustered and distributed heterogeneously in the matrix. because insufficient working of the plasticized material and the absence of pulsating action, the grain size is higher in the nugget zone produced by straight Taper cylindrical pin and taper thread cylindrical pin. The pin with threads induced more heat and excess vertical flow of the material in the Nugget Zone caused by wash and backwash of the threads and tends to increase the grain size and precipitate size in the case of square and triangular pin profiles shows equal grain distribution occurred in the combination of TMAZ&NZ.

3.7. Micro hardness

The hardness was measured across the weld at mid thickness region using Vicker’s micro hardness testing machines and the values are presented The harness of the base metal (unwelded parent metal) is 86 Hv. It is observed that, at a constant welding speed of 50 mm/min and tool shoulder diameter of 21 mm, as the tool rotational speed increased from 900 rpm to 1100 rpm, the hardness values was found to increase considerably. Further increase in tool rotational speed, will cause accumulation of WC particles leading to lower hardness. (Gopikrishna 2016).
3.8. Discussion on Effect of Tool Rotational Speed on micro Hardness

The hardness was measured across the weld at mid thickness region using Vicker’s micro hardness testing machines and the values are presented. The harness of the base metal (unwelded parent metal) is 86 Hv. It is observed that, at a constant welding speed of 50 mm/min and tool shoulder diameter of 21 mm and tool pin profile is square with this condition the tool rotational speed increased from 500 rpm to1100 rpm, the hardness values was found to increase considerably. Due to sufficient heat input is generated between tool and work piece.

3.9. Fractographs

Fig 11 shows the fractographs of smooth tensile test samples. The Rotational Speed of 500rpm shows fine dimples with few featureless flat surfaces are shown in The Rotational Speed of 700 shows the fine populated dimples oriented towards the loading direction The Rotational Speed of 1100rpm shows the fine populated dimples.

5. CONCLUSIONS

The effects of tool pin profile on microstructure and mechanical behavior of friction stir welded of AA7075/WC metal matrix joints were investigated and the following conclusions are derived.

1. The tool Rotational Speeds influences the hardness of the friction stir zone and subsequently, the tensile properties of friction stir welded AA7075-6%WC MMC joints
2. In this investigation four tool Rotational speeds were used i.e. 500,700,900 and 1100 of the four tool Rotational Speeds, the joint fabricated with the rotational Speed of 1100rpm exhibited superior tensile strength. Also the maximum hardness and joint efficiency were observed.
3. Formation of Finer and uniformly distributed precipitates circular onion rings and smaller grains are the reasons for superior performance of joints fabricated with the rotational Speed of 1100rpm compared to other tool Rotational speeds. 

4. This improvement is due to; the screw thread on the pin exerts an extra downward force that will be beneficial to accelerate the flow of the plastic material. Material transports from the advanced side to the retreated side, and goes around the pin, back to the advanced side 

REFERENCES