FRICTION STIR PROCESSING OF Al-SiC COMPOSITE FOR SUPER PLASTIC FORMING

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ABSTRACT: Friction stir processing (FSP) is one of the new and thermo mechanical processing techniques that alters the micro structural and mechanical properties of the material in single pass to achieve maximum performance withlow production cost in less time using a simple and inexpensive tool. Friction stir processing can reduce the grain size conferring excellent super plastic behavior in aluminium alloys. The important aspects of the friction stir processing tool is material selection, Tool Geometry, Load bearing ability, mechanisms of tool degradation and process economics. Preliminary studies of different FS processed alloys report the processed zone to contain fine grained, homogeneous and equiaxed microstructure. In the present work, sheets of aluminum alloys were friction stir processed under various combinations of rotational and translational speeds. The processing forces were measured during the process and the resulting microstructure was analyzed. The grain refinement was observed to vary directly with rotational speed and inversely with the translational speed.

keywords: Friction Stir Processing (FSP), Heat Affected Zone (HAZ), Stir Zone (SZ)

INTRODUCTION

Friction stir welding (FSW) uses a rotating tool traversed along the seam of two abutted work pieces to join them together. FSP has the same fundamental concept, but is not a joining process. The tool is plunged and moved in a predetermined pattern to process a volume of material. The toolrotation rate and traverse speed can be modified to change the heat input to the work piece. FSP will promote super plasticity in a material by refining the grain size, homogenizing the particle distribution and increasing the fraction of high angle boundaries. This fabrication method has been credited for reducing waste, weight and cost. An important criterion for enhancement of super plasticity is grain refinement. Finer grain size increases the optimum strain rate (forfaster forming) and strain rate sensitivity (for increased ductility) and reduces the temperature at which optimum super plastic forming is achieved (reduced energy requirement). Grain refinement can be achieved by either thermo-mechanical processing or advanced severe plastic deformation processes, which include torsional strain severe plastic deformation, equal channel angular extrusion and friction stir processing. Friction Stir Processing (FSP) is less complex and less expensive when compared to thermo-mechanical processing and it is not limited to a small processing area as are equal channel angular extrusion and torsional strain severe plastic deformation.

SUPERPLASTIC FORMING

Super plasticity is a state in which a crystalline material will deform well beyond its normal yield point in tension. As a standard, super plastic behavior occurs at elongations over 200% of the original length. Super plasticity is dependent on the strain rate, as shown in Equation

$$\sigma = k\, \acute{\varepsilon}^{m}$$

σ - Effective flow stress $\acute{\varepsilon}$ - Strain rate $<10^{-3}$ sec^{-1} k – Material Constant
m - Strain rate sensitivity index (0.3-0.9)

Super plastic forming is becoming increasingly important due to high demand for lightweight but strong materials. AA6063 is a material of particular super plastic forming interest because of its corrosion resistance, weldability and high strength to weight ratio. The material investigated in this study is a stir cast AA6063 in the as-cast condition. The primary goal of this study is to assess the effects of FSP on the material. This will be accomplished by studying the microstructure before and after FSP and testing the mechanical properties of the material, specifically the super plastic behavior.
Super plastic materials have several advantages. With elongations over 200%, and sometimes as large as 1000%, all super plastic materials exhibit excellent deformability. The high ductility allows super plastic materials to be molded into intricate shapes. Continuous cast metals that are not super plastic cannot be used to form small, thin or intricate shapes by plastic deformation because of their low ductility. Another advantage of super-plastic materials is that they do not have to be heat treated to achieve high ductility. Cast, or continuously cast materials must be heat treated, quenched, and then aged at temperature before being formed into a work-piece. This process is time-consuming and the apparatuses required for this process are expensive. The heat treatment process creates distortions in the CC materials. These distortions must be fixed before final processing can occur, once again slowing down the procedure. Superplastic materials, because they do not need to be heat treated, do not have these residual stresses. The high ductility and ease of processing make super plastic materials an ideal material for many applications.
The microstructure of a material is related to its super plastic behavior. The driving force behind this behavior is a small average grain size. Typical grain sizes are around 20-25 □m in conventional aluminum alloys, but it is understood that a smaller grain size is necessary for super plasticity. The small grain size enables the deformation of the material by grain boundary sliding, allowing the material to stretch super plastically. Another characteristic of super plastic materials is a large amount of high angle grain boundaries. High angle grain boundaries make it

easier for grain boundary sliding to occur, leading to super plasticity. Finally, a homogeneous dispersion of fine-grained particles within the material promotes plastic deformation. Understanding the microstructure of the material leads to an understanding of how to process a material to obtain these characteristics and thus a super plastic material.

TOOL DESING & PROCESS PARAMETERS

Friction stir processing tool design was created using Auto CAD. The tool design may affect the performance of the friction stir processing. Shoulder diameter of the tool is 20 mm. Pin shape is Straight Circular pin. The diameter of the pin is 5mm. pin thickness is 3mm and the tool was prepared based on the literature survey. The FSP used a straight pin tool with a pin diameter of 5 mm, pin length of 3 mm and a shoulder diameter of 20 mm. The process was run at various speeds from 1500 rpm, 1800rpm and 2000rpm, and the feed rate is 60 mm min-1. The dimensions of the work piece material are 100x100 mm and 5 mm thickness. Friction stir process was done in a 5 mm thickness plate.

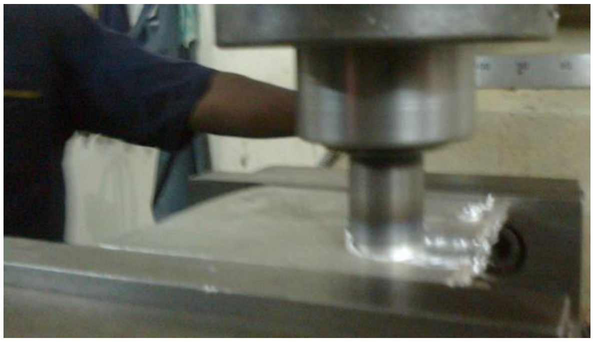
FRICTION STIR PROCESSING

FSP is a solid state joining process that uses a rotating tool to traverse along the seam of two abutted work pieces. FSP is similar in concept, but is not used as a joining process. In FSP, a tool is rotated and plunged into the surface of the work piece. The tool contains a shoulder and a smaller, projecting pin. After the pin has been plunged to the desired depth, the entire tool is traversed along the surface of the work piece in a pre-determined pattern.

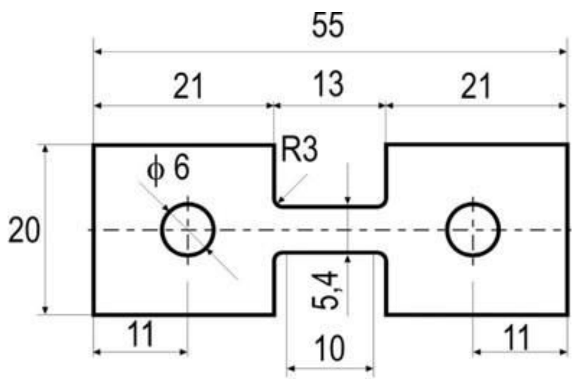
The rotation of the tool and the contact with the surface of the work piece creates a large amount of friction. Heat is generated within the work piece, both due to the surface friction and the adiabatic heating from the plastic deformation occurring in the work piece. Due to the heat input, the softened material flows around the pin tool from the advancing side to the retreating side. As the tool

continues along its traverse path, the material cools and re-solidifies with a refined grain structure.

It is theoretically stated that a lower heat input during FSP will result in the smaller grain size. Two parameters can be varied in FSP to control the amount of heat input. By slowing the rotation rate of the pin tool, the heat input will be minimized. This assertion is corroborated by the fact that the slower the pin tool rotation, the lower the maximum temperature reached in the processed zone. Another way to reduce the grain size is to increase the traverse rate. Although other factors, such as strain, cooling rate and tool design play a role in the grain size produced, the general trend of decreasing the tool rotation speed and increasing the traverse rate can be applied to minimizing the grain size. Al/SiC composite plate was friction stir processed under various combinations of rotational and translational speeds. The rotational speed is selected from 1500rpm, 1800rpm and 2000rpm. The table feed rate is 60mm/min.



The microstructure of the processed region was examined by optical microscopy. The microstructure of the plate before processing and after processing was viewed. The sample specimen for the hot tensile test was created.



MICROSTRUCTURE ANALYSIS

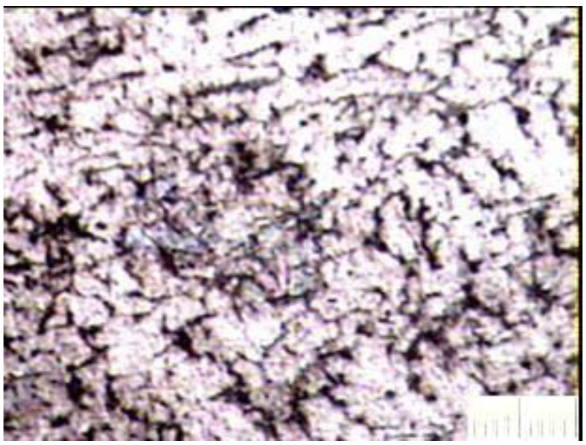
The microstructure of the processed region was examined by optical microscopy. The microstructure of the plate before processing and after processing was viewed. Wire EDM was used to cut a 17 mm x 5 mm x 1.5 mm sample for inspection in the optical microscope. The cut of the sample section was made perpendicular to the transverse axis in order to encompass the processed region and the surrounding base metal. A thermosetting resin was molded around the aluminum sample, exposing only the sample surface. The sample was polished with the Buehler Ecomet 14 Variable Speed Grinder-Polisher in order to eliminate surface defects. Table lists the order of abrasives used to achieve a mirrored finish, free of scratches, on the surface of the specimen.

Grinding and Polishing Procedure	
Step	Abrasive Used
1	320 Grit SiC Paper
2	600 Grit SiC Paper
3	1200 Grit SiC Paper

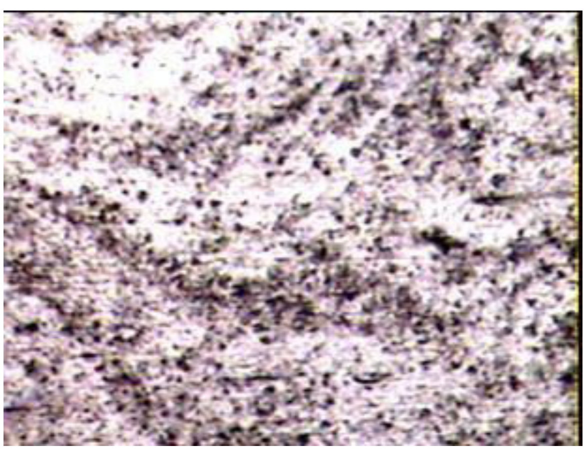
4	2400 Grit SiC Paper
5	3 µm Metadi Diamond Suspension
6	1 µm Metadi Diamond Suspension
7	0.5 µm Metadi Diamond Suspension

RESULTS

Following figure shows a montage at low magnification of a cross-section of the as-processed sample in a plane perpendicular to the tool traverse direction.



Before processing

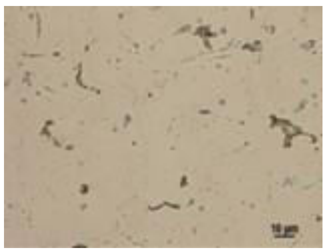


After processing

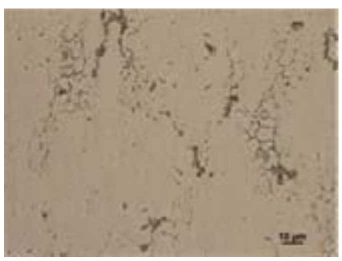
The stir zone is distinct from the base metal and shows a refined grain structure. In addition, a flow pattern is visible within the stir zone. These "onion rings" are the result of the tool traversing and rotating at the same time. The stir zone is intact and does not contain a tunneling defect found in previous work. Following figure compares two stir zones: a defect free stir zone created in this study and a stir zone with a tunnel defect.

The tunnel defect was formed in a plate processed by a smooth pin at a tool rotation rate of 1500 rpm and traversing rate of 65 mm min-1. A combination of the threaded pin design and processing parameters has contributed to the elimination of this defect. Higher magnification pictures were taken at various points across the surface of the FS processed sample.

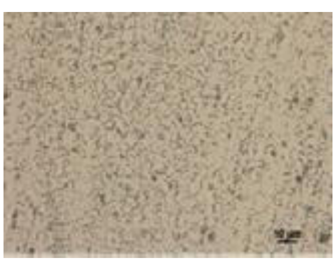
Following figure provides the optical micrographs from the seven numbered locations. Sites 4 and 5 are not in line with the other sites in order to show the variation in grain structure with depth.



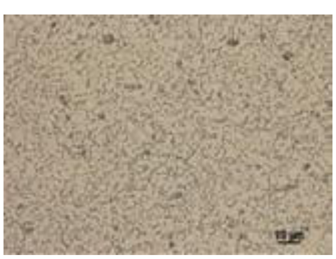
Site 1



Site 2

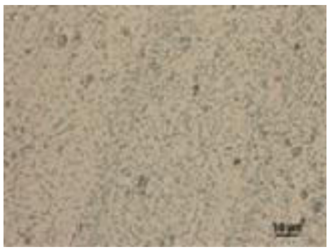


Site 3

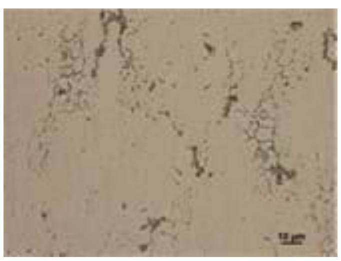


Site 4

Site 5



Site 6



Site 7

Sites 1 and 2 are in the base metal. Sites 3, 4, 5, and 6are within the stir zone, with site 5 being towards the bottom of the stir zone. Site 7 is in the HAZ on the far side of the stir zone. The base metal can be identified by a larger grain structure and non-uniform dispersion of constituent particles. The higher magnification micrographs taken within the stir zone reveal a refined grain structure. In addition, the particle distribution has become more homogeneous throughout. Site 5 is towards the bottom of the stir zone and close to the interface, and can be identified as such because the plastic deformation flow pattern produces a striping pattern. Site 7 can be identified asin the HAZ, and has a similar grain structure as the base metal. Overall, the low magnification optical micrographs show a distinct stir zone created by FSP. The high magnification micrographs reveal a refined grain structure as well as a homogeneous dispersion of particles within the stir zone.

FUTURE WORK

Uniaxial tensile test will be conducted before friction stir processing and after friction stir processing. The strain rate sensitivity index will be found out.

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