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Friction Stir Processing of Aluminum Alloys: A Literature Survey

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ABSTRACT

Many aluminum alloys with specific properties, like high strength, suffers from certain limitations in terms of cost and time of production, apart from the reduction in ductility. High strength accompanied by high ductility is possible with materials having fine and homogenous grain structures. Hence there arises a necessity to develop a processing technique that would produce a material with small grain size that satisfies the requirements of strength and ductility, friction stir processing is such a new promising technique, but still in research phase.
Keywords: Aluminum alloys, grain structure, processing technique, friction stir processing.

I. INTRODUCTION

Aluminum and its alloys have wide range of applications especially in the fabrication industries, aircraft manufacturing, automobile body building, shipbuilding and other structural applications, due to their high strength to weight ratio, higher ductility and good corrosive resistance.

Probably the most serious weakness of aluminium from an engineering viewpoint is its relatively low modulus of elasticity, about one-third that of steel. Under identical loadings, an aluminium component will deflect three times as much as a steel component of the same design. Since the modules of elasticity cannot be significantly altered by alloying or heat treatment, it is usually necessary to provide stiffness through design features such as ribs or corrugations. These can be incorporated with relative ease, however, because aluminium adapts quite readily to the full spectrum of fabrication processes.

Selection of material with specific properties is the key parameter in many industrial applications, especially in the aircraft and automotive industries. However, processing of such alloys with specific properties, like high strength, suffers from certain limitations in terms of cost and time of production, apart from the reduction in ductility. High strength accompanied by high ductility is possible with materials having fine and homogenous grain structures. Hence there arises a necessity to develop a processing technique that would produce a material with small grain size that satisfies the requirements of strength and ductility as well as the cost and time of production.

There are new processing techniques like Friction Stir Processing (FSP), Equal Channel Angular Extrusion (ECAE), being developed for this purpose in addition to the improvements in conventional processing techniques like the Rockwell process, powder metallurgy technique. Friction Stir processing (FSP) was developed as a generic tool for microstructural modification based on the basic principles of Friction Stir welding (FSW).

FSP expands the innovation of friction stir welding (FSW) developed by The Welding Institute (TWI) of United Kingdom in 1991 to develop local and surface properties at selected locations. FSP is a new and unique thermo-mechanical processing technique that alters the microstructural and mechanical properties of the material in a single pass to achieve maximum performance with low production cost in less time. FSP offers many advantages over the conventional and also the newer techniques of material processing which include being a single step process, use of simple and inexpensive tool, no expensive time consuming finishing process requirement, less processing time, use of existing and readily available machine tool technology, suitability to automation, adaptability to robot use, being energy efficient and environmental friendly.

In Friction stir process (Figure 1), a specially designed cylindrical tool is used which while rotating is plunged into the selected area of sheet. The tool has a small diameter pin with a concentric larger diameter shoulder. When the tool is plunged into the sheet, the rotating pin contacts the surface and friction between the sheet surface and the shoulder rapidly heats and softens a small column of metal, enabling the transverse movement of the tool through the material. The tool shoulder and length of the probe control the depth of penetration. During FSP, the area to be processed and the tool are moved relative to each other such that the tool traverses, with overlapping passes, until the entire selected area is processed to a desired (fine) grain size. The processed zone cools as the tool passes, forming a defect free, and dynamically recrystallized equiaxed fine-grained microstructure.

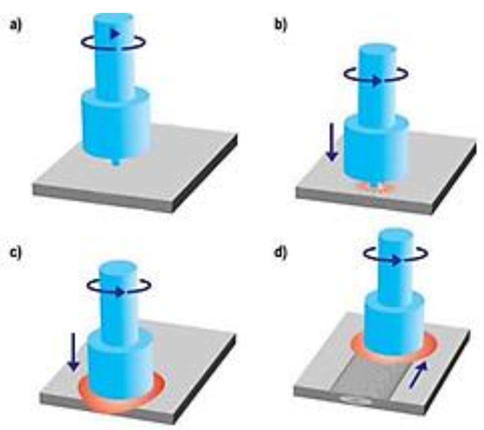

Figure 1. Schematic illustration of friction stir processing

II LITERATURE REVIEW

Mishra et.al (1999) investigated the FSP of a commercial 7075 Al alloy that resulted in significant enhancement of superplastic properties. The optimum superplastic strain rate was observed to be 10^{-2} s^{-1} at 490 °C in the FSP 7075 Al alloy, and the maximum elongation was observed to be about 1000%. Also, the average grain size was determined by mean linear intercept technique (grain size = 1.78 × mean linear intercept), and was approximately 3.3±0.4μm.

Kwon et.al (2003) studied the FS processed Al 1050 alloy. The hardness and tensile strength of the FS processed 1050 aluminium alloy were observed to increase significantly with decreased tool rotation speed. It was noted that, at 560 rpm, these characteristics seemed to increase as a result of grain refinement by up to 37% and 46% respectively compared to the starting material.

Itharaju et al. (2004) investigated the microstructure at different combinations of rotational and translational speeds and tried to relate the resulting grain sizes to the generated forces in friction stir processed 5052 aluminum sheet. They observed that the resulting average grain size of the FS processed AA5052 sheet were between 1.5 and 3.5 μm depending on the process parameters, compared to 37.5 μm for the unprocessed sheet, which mean that great refinement has been achieved. Itharaju et al also concluded that, in general, the plunging force increases with increasing rotational speed and it is almost independent of the translational speed.

Sharma et al (2004) have reported the fatigue behavior of friction stir processed A356 alloy. They have reported a reduction in silicon particle size and reduced porosity volume fraction in FSP A356 alloy. An increase in the fatigue strength threshold stress by >80% over the parent material after friction stir processing was reported. They have also mentioned that FSP can be used as a tool to locally modify the microstructures in regions experiencing high fatigue loading and thus significantly improving the overall performance of aluminum castings.

Santella et al (2005) investigated the effect of FSP on mechanical properties of the A319 and A356 alloys. They reported that the ultimate tensile strengths, ductilities and fatigue lives of both alloys were increased by FSP.

Ma et al (2006a) investigated the effects of FSP on the microstructural evolution of cast A356 Al alloy. In this investigation single pass FSP was performed on 6.35mm thick plates. Four Different tool rotational speeds and four different traverse feeds were used to process the Al alloy. FSP resulted in a significant break up of fibrous Si particles and aluminium dendrites and redistribution of fine and equiaxed Si particles in the aluminium matrix. Fine grains of the order of 3 to 4 microns were generated due to FSP.

Elangovan and Balasubramanian (2007) studied the influences of pin profile and rotational speed of the tool on the formation of friction stir processing zone in AA2219 aluminium alloy. They have observed that the process parameters affect the process zone and defects like piping defects, tunnel defects, pinholes etc. could occur in the FSP/FSW material due to insufficient heat input or inadequate/improper plastic flow which would impair the effectiveness of the processed material. Further they have observed that higher tool rotational speeds resulted in a higher temperature and slower cooling rate in the FSP zone after welding. A higher rotational speed causes excessive release of stirred materials to the upper surface, which resultantly left voids in the FSP zone. Lower heat input condition due to lower rotational speeds resulted in lack of stirring. The area of the FSP zone decreases with the tool rotational speed and affects the temperature distribution in the FSP zone.

Elangovan and Balasubramanian(2008a) studied the influences of tool pin profile and tool shoulder diameter on the formation of friction stir processing zone in AA6061 aluminum alloy. They reported that, of the five tool pin profiles used (straight cylindrical, tapered cylindrical, threaded cylindrical, square and triangle) to fabricate the FSW joints, square pin profiled tool produced defect free FSP zone , irrespective of the shoulder diameter of the tools. They also reported that, a tool with 18mm shoulder diameter produced defect free FSP region, irrespective of tool pin profiles used. The FSW joint fabricated using square pin profiled tool with shoulder diameter of 18mm showed superior tensile properties.

Karthikeyan et al (2009) investigated the effects of Friction stir processing on Cast 2285 alloy and concluded that due to FSP the mechanical properties and microstructure are improved. 30% improvement in yield and tensile strengths were recorded and ductility increased around 4 times. He concluded that this improvement in mechanical properties was due to reduced porosity and grain size.

Tsai and Kao (2012) reported that the improvement of mechanical properties of a cast Al-Si base alloy can be achieved by friction stir processing. They reported that the tensile properties of cast AC8A alloy could be improved after FSP, particularly the tensile elongation, which increased from $< 1\%$ to 15.4%. The tensile strength of FSP AC8A alloy was improved due to the result of a combination of dissolution, coarsening and re precipitation of strengthening precipitates, which was achieved by the FSP parameters.

Magdy and Ehab (2012) have studied the influence of multi-pass friction stir processing on the microstructural and mechanical properties of aluminum alloy 6082. They reported that the effect of increasing the number of passes led to an increase in the SZ-grain size, more dissolution and reprecipitation with simultaneous intense fragmentation of second phase particles all of which are attributed to accumulated thermal cycles. The number of passes is more influential on the DRX of grain size of the SZ than the traverse speed does.

Darras et al (2015) studied the effect of various friction stir processing parameters on the thermal histories and properties of commercial AZ31B-H24 magnesium alloy sheet. They refinement and homogenization of microstructure is more an observation in a single pass. Fine grain size can be obtained in a single pass friction stir processing through severe plastic deformation and control of heat input during processing.

Fadhel A. et.al (2015) performed friction stir process (FSP) to enhance surface properties of AA2024-T3 alloy. The effect of friction stir shoulder rotation in addition to its pressing effect on surface topography and mechanical properties was studied. Samples were FS processed with a flat pinless cylindrical shoulder of 10mm diameter with a constant rotational and travel speeds 945 rpm and 85mm/min respectively. The maximum hardness increment is about 40-45% and the maximum value obtained at the surface is 190Hv compared to 130Hv before processing. A little bit increase was recorded in yield and tensile strengths by an amount of 15% and 9% respectively after FSP.

III CONCLUSION

As the concept of FSP is relatively new, there are many areas, which need thorough investigation to optimize and make it commercially viable. On the basis of the literature reviewed it has been observed that still there is limited research studies on optimizing the process parameters of friction stir processing. In order to optimize any process it is very essential to understand the effect of process parameters on the properties of the processed material. In order to obtain the desired finer grain size, certain process parameters, like rotational and translation speeds, tool geometry etc., are to be controlled.

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