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Technical Paper

Enhancing strength, ductility and machinability of a Al–Si cast alloy by friction stir processing

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ABSTRACT

Cast Al–Si alloys are used for automotive applications. Friction stir processing (FSP) is being used in recent years to improve the performance of these alloys. Secondary machining operations are highly essential on friction stir processed materials to improve the surface finish. However, machinability of friction stir processed cast alloys has rarely been reported. The influence of friction stir processing on microstructure, mechanical properties and machinability of a cast Al–Si alloy was studied in the present work. The main objective is to correlate the metallurgical and mechanical characteristics to the machinability of the friction stir processed material. The age hardening response of as received cast alloy and friction stir processed alloy on machinability and mechanical behavior was also investigated. The strength, ductility and machinability of friction stir processed alloy before and after age hardening treatment were observed to be higher than that of as received cast alloy. The significant improvement in properties of friction stir processed alloy is due to elimination of porosity, formation of fine recrystallized grain structure, homogenization of silicon particles and dissolution of iron rich intermetallics.

1. Introduction

Aluminum–Silicon (Al–Si) cast alloys are widely used in automotive applications because of their low cost, low density, high temperature capability, and excellent castability. However, these alloys often suffer from low ductility, low tensile strength, low fatigue resistance, low wear resistance and poor machinability due to the presence of porosity, coarse acicular Si particles and coarse grains.

It is well established that the mechanical properties Al–Si alloys can be enhanced mainly by two methods. The first approach is the addition of alloying elements to refine the microstructure of these cast alloys, and the second approach is implementation of additional heat treatments to refine the morphology of Si particles. The first category of research is aimed at refining the morphology of Si particles by using eutectic modifiers such as sodium and strontium. Kashyap has mentioned in their review paper that, the addition of trace elements such as sodium and strontium in the Al–Si cast alloys significantly improves the tensile properties [1]. Atxang has observed effective improvement of fatigue life due to addition of strontium in Al–7Si–Mg cast alloy [2]. However, the application of this approach is not widespread due to difficulty in dissolution of the modifying elements and disappearance of the modifying action at high temperatures. Additional heat treatment approach has been adopted by many researchers to refine the morphology of Si particles. The mechanical properties of a A356 cast alloy after subjecting to post heat treatment are reported to be higher [3]. But, heat treatment at high temperature for long time increases the material cost. It is important to highlight that, both of the above mentioned processes can neither eliminate the porosity content nor effectively redistribute the Si particles uniformly into Al matrix. Therefore, an alternative technique is highly desirable for effective microstructural modifications of cast Al–Si alloys to improve strength, ductility, fatigue properties and machinability simultaneously.

The above discussed problem can be overcome by using a relatively new technique called friction stir processing (FSP). Friction stir processing has been identified as a novel approach to improve the surface properties of cast light weight materials like aluminum and magnesium alloys by effective microstructural modification [4–12]. Mishra and his coworker reported that, friction stir processing is an effective process for microstructural modification of various aluminum and magnesium alloys [13–15]. During friction stir processing, the material undergoes extensive plastic deformation at elevated temperature, which results significant microstructural modification.

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Table 1
Chemical composition of Al–Si cast LM25 alloy.

Element	Cu	Si	Mg	Mn	Fe	Ti	Ni	Zn	Pb	Sn
wt%	0.072	6.5	0.35	0.03	0.22	0.027	0.006	0.01	0.003	<0.001

Machining operations are generally essential for finishing of such Al–Si castings. FSP has been used as a tool for grain refinement and microstructural modification of thin sheets, casting modification of bulk materials and manufacturing of surface composites. The friction stir processed (FSPed) materials may not be implemented directly as end products in the automobile and aircraft industries without using secondary manufacturing processes. Further, conventional or non-conventional machining process is required to take the FSPed material in to final shape. But machining is associated with producing lot of heat which will alter the properties of FSPed materials. Therefore, it is required to study the effect of friction stir processing on machinability of cast Al–Si alloys. The effect of FSP on microstructure, tensile properties, fatigue behavior, superplasticity and corrosion behavior of different materials has been studied by many researchers [15–17]. The influence of friction stir processing on fatigue and superplasticity behavior of various Al alloys has been studied the transition in tension/compression deformation behavior in an ultrafine grained magnesium alloy processed by FSP [15,16]. The influence of FSP on corrosion behavior of a rare earth contained magnesium alloy has been studied [17]. However, the influence of FSP on machinability of any of the alloys has rarely been reported.

The present work is focused to study the influence of friction stir processing on strength, ductility and machinability of a cast Al–Si alloy. An extensive microstructural quantitative work has been carried out to understand the mechanical behavior and machinability performance of the as cast and FSPed alloys before and after ageing treatment. The mode of failure surfaces was characterized through scanning electron microscope (SEM). Machinability studies of the FSPed sample before and after ageing treatment were characterized by measuring surface roughness and cutting force during machining. The aim of the present work was to correlate the microstructural information during friction stir processing with the resulting strength, ductility and machinability of Al–Si cast alloy.

2. Experimental procedure

The experimental work has been carried out to investigate the influence of friction stir processing on microstructure, machinability and mechanical properties of an Al–Si cast alloy. The nominal chemical composition of this alloy is shown in Table 1. The Al–Si cast ingots were procured from Sargam Metal Private Ltd, Chennai. These cast ingots were then pre-processed and machined into the dimensions of 8 mm × 60 mm × 310 mm.

These plates were friction stir processed (FSPed) at different rotation speeds (800 rpm to 1400 rpm), traverse speeds (60 mm/min to 150 mm/min) and plunge forces (4 kN to 9 kN). Among the various pilot experiments, the optimum rotation speed, traverse speed and plunge force was identified as 800 rpm, 120 mm/min and 9 kN, respectively. The shape of the pin used for friction stir processing is cylindrical. The pin diameter, pin length and shoulder diameter of the FSP tool is 5.5 ± 0.2 mm, 4.5 ± 0.2 mm and 15 ± 0.3 mm, respectively. The schematic drawing of friction stirs processing is shown in Fig. 1.

Scanning electron microscopy (SEM) and optical microscope was used to study the microstructural details of as received cast alloy and FSPed alloy. The cross section of the FSPed region was used for microstructural analysis. The as received cast alloy and FSPed samples were then polished using silicon carbide (SiC) emery papers from 320 to 2000 grades followed by 0.5 μm diamond polishing. Prior to microstructural analysis, the sample surfaces were etched by submerging into a bath of modified poulton's reagent (20 ml poulton's reagent, 12 ml HCl, 6 ml HNO_3, 1 ml HF, 1 ml H_2O), 10 ml HNO_3, 16 ml solution of 3 g chromic acid per 10 ml of water). The mean grain size was than estimated using the mean linear intercept method. The quantification of grain size, Si particle distribution and intermetallic particles was obtained by using image analysis software 'MICROCAM 4.0'. The Si particles and intermetallic phases of both cast and FSPed alloys were further analyzed using energy dispersive X-ray spectroscopy (EDX) in a SEM instrument.

The influence of FSP on mechanical behavior was studied by conducting microhardness and tensile testing on the cast and FSPed alloys. The age hardening behavior of as received and FSPed materials were studied by subjecting both of the materials at 170 °C for prolonged period of time followed by quenching and then microhardness testing. The samples for microhardness testing were prepared by grinding and polishing to create a flat and parallel surface. The test load and dwell time during microhardness testing was taken as 200 gf and 5 s, respectively. The samples for microhardness testing were taken from the transverse section of the processed area at the middle of the plate thickness. To determine tensile properties, mini-tensile specimens were prepared from the nugget region

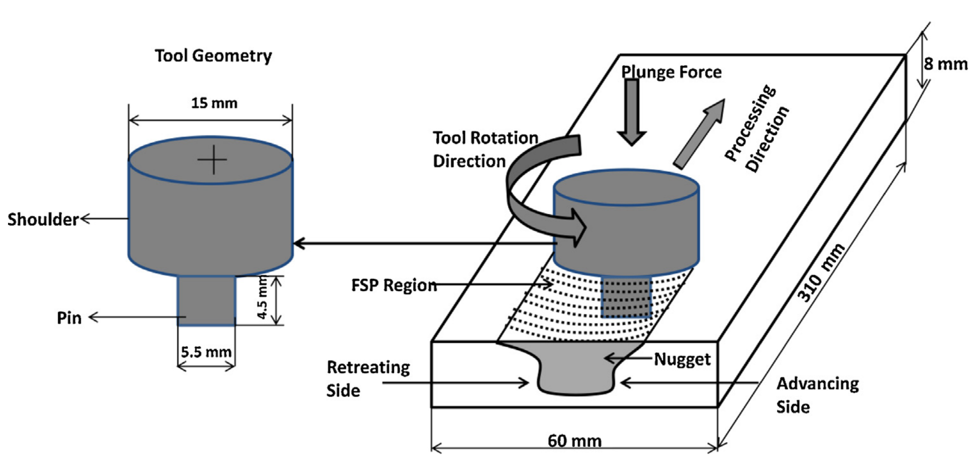

Fig. 1. Schematic diagram of friction stir processing.