Saudi Journal of Engineering and Technology (SJEAT)
Scholars Middle East Publishers
Dubai, United Arab Emirates
Website: http://scholarsmepub.com/

ISSN 2415-6272 (Print)
ISSN 2415-6264 (Online)

Microstructure and Tensile Properties of Friction Stir Processed Al-Si Alloy

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Original Research Article

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Article History
Received: 07.09.2018
Accepted: 15.09.2018
Published: 30.09.2018

DOI:
10.21276/sjeat.2018.3.9.5

Abstract: In this study, a solid state processing tool for microstructure modification and material properties enhancement; friction stir processing (FSP) was applied on the surface of as-cast Al-Si-Cu-Ni aluminium alloy. Samples were subjected to FSP using fixed tool rotation speed 1400 rpm and traverse speed 42 mm/min, with tool angle tilted 3˚.The influence of the FSP on the microstructure and tensile properties of the cast Al-Si-Cu-Ni alloy samples were studied. Microstructural evolution of the samples was investigated using optical microscope (OM) and scanning electron microscope (SEM), tensile test carried out at 1 mm/min cross-head speed. The results showed that FSP improved the tensile strength of the samples by decreasing particles size and porosity. FSP improved the alloy strength by about 54%.
Keywords: Aluminium silicon, FSP, refinement, microstructure, tensile strength.

INTRODUCTION

Friction stir processing (FSP) is a solid state processing technique, used for modifying the microstructure of metallic materials [1]. It has shown remarkable microstructure refinement and mechanical properties enhancement. During the FSP process, a rotating non-consumable tool mainly consisting of a designed pin and shoulder is inserted into a clamped metal plate and the tool is moved in a controlled direction. The metal is subjected to thermal exposure, plastic deformation and material mixing, resulting in a modified microstructure [2].

Tool rotation speed and travel speed impact significant effect on the heat input and mechanical characteristics. Many researchers studied the influence of FSP parameters on the microstructure of cast aluminium silicon alloys. For example, Mahamoud and Mohamed [2] investigated the influence of FSP tool rotational speed, and traverse speed on the microstructure and mechanical properties of cast A413 alloy. FSP improved the microstructure and mechanical properties by eliminating defects in the microstructure of the A413 cast alloy. The size of Si particles increases by increasing tool rotation speed and/or decreasing tool traverse speed. Ma *et al.*, [1] used FSP to modify the as-cast A356 aluminium alloy microstructure. They revealed that FSP parameters influenced the microstructure in the processed region of the as-cast A356 aluminium alloy. Higher tool rotational speed produces more uniform microstructure in the processed region. Karthikeyan *et al.*, [3] on the FSP of cast Al A319 found that FSP enhanced the microstructure of the alloy by refining Si particles and intermetallic particles. And have major influence in determining the mechanical properties. Abdulmalik and ahmad [4] applied FSP on cast hypereutectic LM28 Al alloy aimed to improve tensile properties by decreasing casting defects such as coarse eutectic Si, large Si primary particles and porosity. It was found that FSP resulted in remarkable breaking up of the coarse eutectic and primary silicon particles into smaller particles, and eliminate porosity in the alloy. They achieved significant enhancement in tensile strength and related it with the microstructural refinement.

Al-Si-Cu-Ni cast Al-Si alloys are widely used in the automotive industry for aluminium piston parts, due to their low thermal expansion coefficient, high wear resistance, and high strength at elevated temperature [5]. However, the alloys are associated with various defects such as coarse eutectic Si, segregation of large primary Si particles, and porosity which resulted in the deterioration of mechanical properties [6]. Past studies have shown that FSP is a promising tool suitable for use in modifying microstructure in the cast aluminium alloys [7]. It produced a uniform distribution of Si particles in the aluminium matrix, and eliminates porosity [4, 6].

In this study, FSP was applied to modify the microstructure of Al-Si-Cu-Ni cast alloy. Effect of FSP on the microstructure and tensile properties of friction stir processed (FS-processed) Al-Si-Cu-Ni alloy was investigated.

MATERIALS AND METHODS

In this study, the base metal used was as cast hypereutectic Al-Si alloy having nominal composition in wt. %: 18Si, 0.9Cu, 1.15Ni, 0.2Mn, 0.16Mg, 0.06Zn, 0.19Fe, and 79.34Al. The cast metal was cut into plates having dimensions of 150 mm × 30 mm × 7 mm. The surface of the plates were subjected to one pass friction stir processing using a non-consumable H13 tool steel tool, that has a cylindrical pin, the tool shoulder diameter was 17 mm; the length and diameter of the pin are 3.5 and 6 mm, respectively. Vertical milling machine was employed for the FSP experiment at a tool rotation speed 1400 rpm and transverse speed 42 mm/min, tool tilt angle was set to 3˚.

After FSP, microstructures of the FS-processed zones were investigated. The friction stir processed (FS-processed) samples were cut in the transverse direction, ground using different grades of sand paper, polished with 0.5 alumina paste, and etched using 0.5 hydrofluoric acid to reveal the microstructures. Microstructure examination was accomplished using both optical microscope and scanning electron microscope. Image analysis technique was used for determining the sizes of the Si particles, and porosity.

For determining the tensile properties, tensile specimens were prepared from the samples (FS-processed regions) along the FSP direction as per ASTM: E8/E8M-11, with the gauge length and gauge width of 25mm and 4mm, respectively (Figure-1). The tensile test was carried out using a computer controlled Gotech universal testing machine at 1mm/min cross head speed. Tensile test is completed on both the as cast alloy and the FS-processed samples. At every condition, two specimens were tested and their average value was computed. Fracture surfaces of the tensile specimens were examined using SEM.

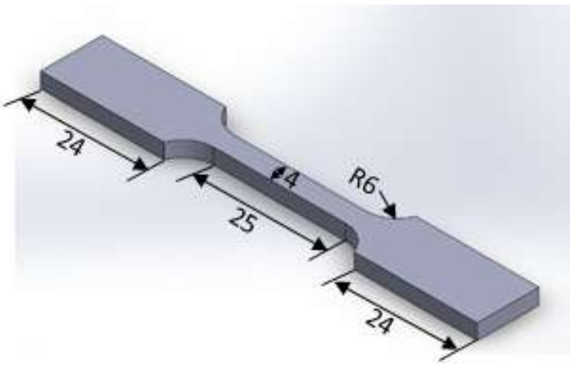

Fig-1: Tensile specimen

RESULTS AND DISCUSSION

Figure-2a shows the micrographs for the cast hypereutectic Al-Si-Cu-Ni alloy. The base alloy appeared to consist of platelet-like eutectic having irregular shape Si particles, and large primary Si morphology in the microstructure. The mean area of the eutectic and primary Si of the alloy was measured by image analysis. The mean particle area of the base alloy was measured to be 155.1 μm², and aspect ratio 2.86 respectively. Porosity of up to ~114 ECD was measured in the alloy. Influence of FSP on microstructure evolution of the base metal is shown in Figure-2b.

The measured Si particles area size, aspect ratio, and porosity of the as cast metal and after FSP (FS-processed) sample are plotted in Figure-3. FSP considerably resulted in breaking of coarse eutectic and primary Si, created an improved distribution of near circular Si particles in the stir zone, which is connected to heat exposure and sufficient plastic deformation during FSP [8]. The mean area particle size, and aspect ratio of the FS-processed samples are measured as 64.88 μm² and 1.86 respectively, which are much lower than that of the as cast base alloy. Porosity drastically reduced from 94 ECD to 7.5 ECD. This finding is consistent with the findings in [4], and Guru *et al.*, [9].

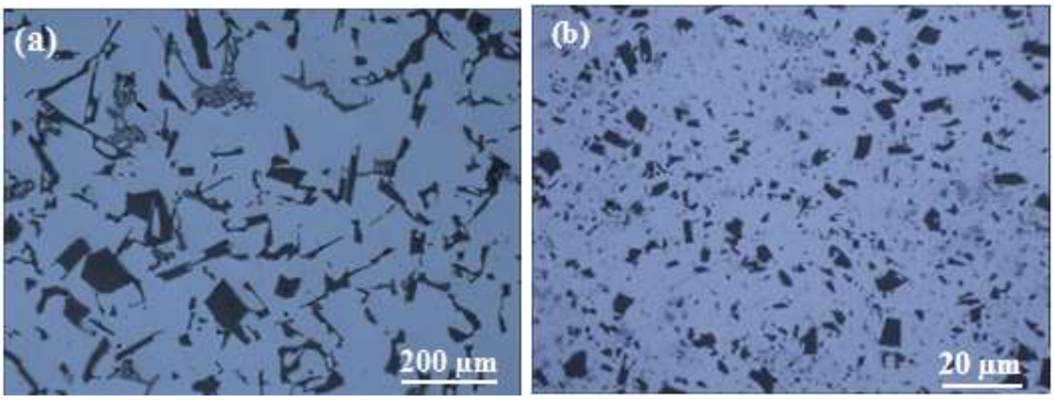

Fig-2: Micrograph: (a) as cast base metal before FSP, and (b) after FSP at 1400rpm-42mm/min

Figure-4 shows the scanning electron microscope (SEM) microstructures of the base metal and as FS-processed Al-Si-Cu-Ni alloy sample. The SEM microstructures of both the sample are similar with the optical micrographs. As in the optical micrograph Figure-2, the microstructure of cast Al-Si-Cu-Ni alloy sample contains non-uniform distribution of coarse eutectic Si and primary Si particles and in addition to this; coarse intermetallic particles are also observed. But in the FS-processed sample, improved distributions of fine Si particles were observed. The coarser intermetallic particles which were distinctly observed in the cast base sample were fragmented into smaller particle size in FS-processed sample.

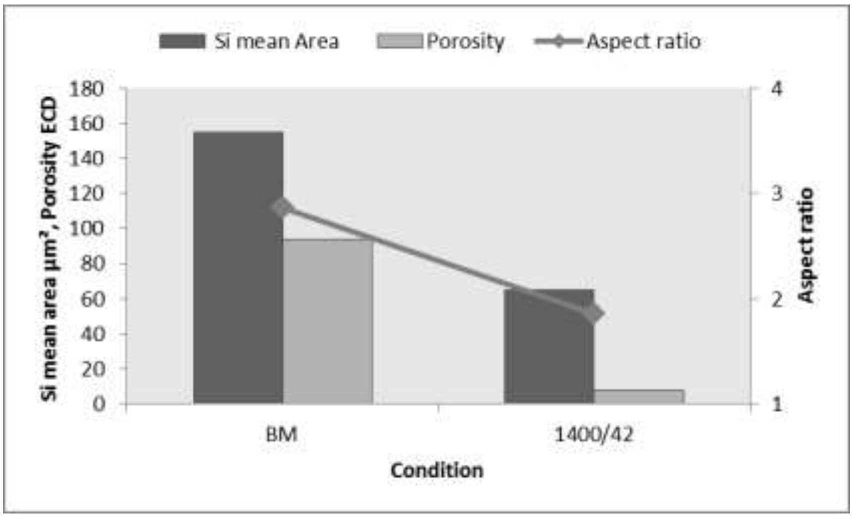

Fig-3: Mean Si particle area, porosity, and aspect ratio

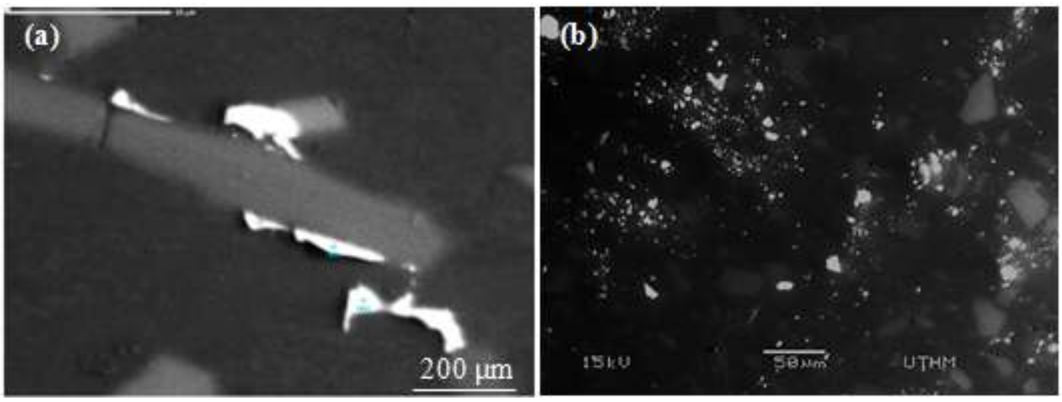

Fig-4: SEM micrograph of Al-Si-Cu-Ni samples: (a) before FSP, and (b) after FSP at 1400rpm-42mm/min.

Figure-5 shows the variation of tensile properties before and after FSP. It can be seen that, the strength and ductility of the alloy increased simultaneously by the effect of FSP. It is possible to see that before FSP the mean ultimate tensile strength (UTS) of the cast base alloy sample: 118 MPa, mean elongation (%El): 1.7 %, and mean quality index (Q): 156 MPa, were lower compared to that of the FS-processed sample. These lower properties of the base metal sample is mainly due to the presence of porosities and large brittle Si particles, in the alloy after casting and acted as crack nucleation sites [4].

After FSP the sample showed significant improvements in tensile properties. The UTS was increased to about 182 MPa, %EL 10.0%, and Q about 332 MPa, mainly due to the refinement of the microstructure and the reduction of porosity. Other researchers have shown that the tensile properties and fatigue of cast Al-Si alloys increased with refined microstructure, and decreasing casting defect such as porosity size [9-11]. In addition, an improved distribution of intermetallic particles is believed to have some effect on both tensile, and ductility, as reported by [4, 5, 9].

Figure-6 presented the fracture surfaces of the as cast base metal and the as FS-processed tensile samples examined using SEM to determine their resulted failure pattern. Figure-6a shows the fracture surface of the as cast metal tensile sample. It can be seen that the surface was dominated by cleavage planes which indicate a brittle failure pattern; results in lower ductility [9]. After FSP, the FS-processed samples shows fracture surface with dimple rupture pattern Figure-6b. Formation of dimple pattern generally gives the indication of improved material ductility [2].

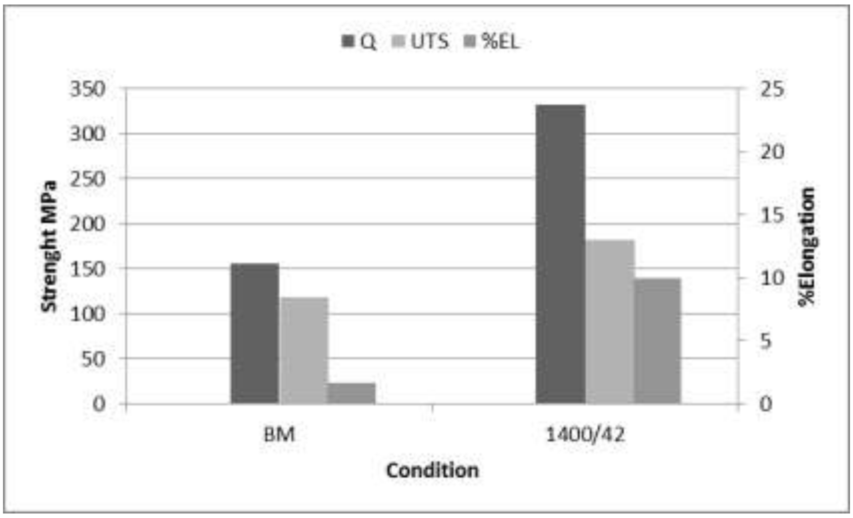

Fig-5: Tensile properties of the samples before and after FSP at 1400rpm-42mm/min speeds

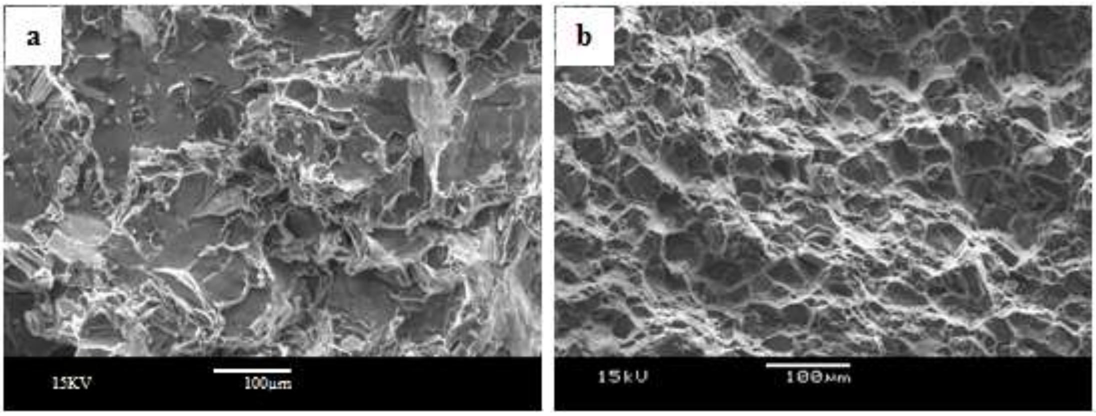

Fig-6: Fracture surface: (a) as cast base alloy, and (b) the as FS-processed sample at 1400rpm-42mm/min

CONCLUSION

- The influence of FSP on microstructure and tensile properties of Al-Si-Cu-Ni alloy was investigated. The microstructure constituents such as Si particles, intermetallic particles, and porosity had effect on tensile properties of base alloy.
- FSP refines the microstructure by reducing the porosity, refined the coarse eutectic and primary Si structures, as well as the intermetallic particles.
- The as-cast Al-Si-Cu-Ni alloy sample exhibited Si mean size and aspect ratio around 155.1 µm² and 2.86 respectively. After FSP the mean area particle size and aspect ratio have

been reduced to 64.88 μm² and aspect ratio 1.86 for the processed sample. Ductility of the as cast alloy was increased from 1.7 to 10.0%, FSP increased the quality index of the initial cast alloy by about 2 times, and an increase in the tensile property by 54%. FSP was beneficial in terms of enhancing microstructure and tensile strength.

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