Materials Science
ISSN: 0974-7486

Material Science: An Indian Journal

Research Article | Vol 19 Iss 6

Microstructure and Corrosion behavior of hybrid composite produced by friction stir processing

Rokkala Srinivasu*

Department of Metallurgical Engineering, Andhra University College of Engineering Visakhapatnam, India

***Corresponding author:** Rokkala Srinivasu, Department of Metallurgical Engineering, Andhra University College of Engineering Visakhapatnam, India, Tel: 7675868401; E-Mail: drsrinivasu2015@gmail.com

Received date: September 02, 2021; **Accepted date:** September 16, 2021; **Published date:** September 23, 2021

Abstract

Cast aluminum-silicon alloys have found in the manufacture of various automotive engine components, aerospace, defense application such as cylinder blocks, pistons and piston insert rings, torpedoes and manufacture of Missile bodies where adhesive wear (or dry sliding wear) and corrosion is a predominant process. Cast Al-alloys possesses poor corrosion resistance when compared to wrought Al-alloys and is attributed to high concentration of intermetallics in the dendritic structure. Recently, much attention has been paid to Friction Stir Processing (FSP) as a solid-state surface modification technique. In the present work an attempt has been made to modify the surface of the Aluminum Silicon alloy using Friction Stir Processing (FSP). Boron carbide powders (B_4C) and Molibdinum Disulphide (MoS_2) as solid lubricant with various particle sizes are used in the friction stir processing of the A356 Aluminum Silicon alloy. Carbide powder particles and solid lubricant were compressed into the lined up holes on the surface of the alloy. Coating was formed using two different FSP tools. Metallography, micro compositional analysis, and pitting corrosion tests dynamic polarization studies were used for characterizing the surface composite coating. Friction stir processed surface hybrid composite was having better pitting resistance when compared to as cast A356 alloy, Enhancement in pitting corrosion resistance was obtained with a decrease in carbide particle size.

Keywords: ***Friction stir processing; Aluminium silicon alloy; Boran Carbide Powders; Surface composites***

Introduction

A356 Aluminum Silicon alloy is widely used to cast high-strength components in the aerospace and automobile industries because they offer a combination of high strength with good casting characteristics. However, Cast Aluminium alloy mechanical Properties like ductility, toughness, wear resistance and fatigue resistance limited due to porosity, coarse acicular Si particles and coarse primary aluminum dendritic microstructure. One of the defects found in the casting process that can adversely affect both surface finish and mechanical performance is micro porosity. Cast Al-alloys possesses poor corrosion resistance when compared to wrought Al-alloys and is attributed to high concentration of intermetallic in the dendritic structure. In the past two decades, various surface modification and heat-treatment techniques have been developed to refine the microstructure of as cast Al-Si alloys. Generally, chemical modification and thermal treatment have been adopted to modify the coarse acicular silicon particles to fine and globular particles. Chemical modification methods involve adding very small amounts of sodium, strontium, or antimony, known as eutectic modifiers. Thermal modification involves heat treatment of cast alloys at high temperature, usually at the solid solution temperature around 540°C for long times. However, solution treatment at high temperature for long time increases material cost. None of the modification and heat-treatment techniques mentioned previously can eliminate the porosity effectively in A356 alloy and redistribute the silicon particles uniformly into the aluminum matrix. Therefore, a more effective modification technique is highly desirable for microstructural modification of as cast A356 alloy to enhance mechanical properties, in particular, ductility, fatigue and wear resistance [1].

Recently, much attention has been paid to Friction Stir Processing (FSP) as a solid-state surface modification technique. It is well known that the stir zone consists of fine and equiaxed grains produced due to the dynamic recrystallization. FSP has also been used to fabricate surface composites. Mishra fabricated the Al/SiCp surface composites by FSP, and shows that SiCp were well distributed in the Al matrix, and good bonding with the Al matrix was obtained

In view of the problem associated with high performance engineering applications of cast aluminium alloys a systematic approach in investigation has been planned in the present study to enhance the corrosion resistance of A356 Al alloy by reinforcing of carbide particles of different sizes and MoS_2 particles on its surface using friction stir processing technique.

Materials and Methods

Cast A356 alloy (Al-7.0% Si) was used in as cast condition. The chemical composition is given in Table 1. Commercially available boron carbide powder of size 78 mm was used and its size was reduced using High Energy ball mill. Particle sizes of the B4C powder was characterized by using XRD which are 78 mm, 6 mm and 40 nm MoS_2 powder of size 30 mm as solid lubricant was used to study the effect of addition of solid lubricant and MoS_2 powder (99% pure and average particle size of 50 µm) was used in this study. Friction stir processing was carried out on A356 alloy of 40 mm thick slab using friction stir welding machine at Defence Metallurgical Research Laboratory, Hyderabad. The process parameters used for friction stir processing are listed. These process parameters were arrived at after extensive trials aiming at defect-free interface. The top surface of as cast A356 Aluminum alloy was specially designed by introducing holes. Holes with 2 mm in diameter and 2 mm in depth were drilled by numerically controlled drilling machine. The schematic diagram of friction stir processing. The FSP experimental a straight cylindrical friction stir tool without pin was used to process first so has to get the carbide particles get compacted into the holes; A high carbon steel tool with pin was used in the present study. A tool rotational speed of 650 rpm, a transitional speed of 50 mm/minute, and plunging speed 40 mm/minute were employed (**TABLE 1**) [2].

TABLE 1. **Friction stir processing parameters.**

Nomenclature	**150 mm thick plate**
Tool details	H13 tool steel threaded pin,
	Pin diameter:4.5 mm,
	Pin length: 6.7 mm,
	Shoulder diameter: 20 mm
Tool rotational speed	650 rpm
Transitional speed	50 mm/min
Plunging speed	30 mm/min
Tool tilt	2°

A software based basic electrochemical system of GILL AC unit. Potentiodynamic polarization tests to study the pitting corrosion behavior of the as cast A356 alloy and after the friction stir processed surface metal matrix composites. A Saturated Calomel Electrode (SCE) and carbon electrode were used as reference and auxiliary electrodes respectively. All experiments were conducted in aerated 3.5% NaCl solutions with PH adjusted to 10 by adding potassium hydroxide. The potential scan was carried out at 0.166 mVs^{-1} with the initial potential of -0.25 V (OC) SCE to the final pitting potential. The exposure area for these experiments was 1 cm^2.

Results and Discussion

The microstructure of the as cast A356 alloy consisted of primary α-Al dendrites and interdendritic irregular Al–Si eutectic regions. Coarse acicular silicon particles are distributed along the primary Al boundaries, which indicate the non-uniform distribution of silicon particles throughout the aluminium dendrite arm spacing in as cast condition of the alloy is about 20 m. The Eutectic liquid during the terminal stage of solidification in ingot casting solidifies and decomposes into large and small eutectic particles As can be seen. micrographs, friction stir processing results in significant breakup of acicular Si particles and aluminum dendrites, fine and equiaxed silicon particles were uniformly distributed in the aluminum matrix due to an intense breakup of the as cast microstructure and subsequent material mixing. Virtually there is no evidence of dendritic solidification microstructure in the stir zones and the grain size in the present friction stir processing stir region is found to be in the order of 4-5 m. These microstructural modifications significantly improve the mechanical properties of A356 alloy.

In the present investigation solid lubricant of molybdenum disulphide (MoS_2) and boron carbide powder of different sizes dispersed in stir zone aim to enhance properties of the friction stir processed A356 Al-alloy. Scanning electron micrographs of boron carbide powder of different size reinforced in to A356 Al-alloy matrix to form surface composite. It is clear from the micrographs that MoS_2 is dispersed along with boron carbide in the Al-matrix. It is believed that solid lubricant from a film which modifies the mechanical and corrosion properties

Electron probe micro analysis of as cast and friction stir processed A356 alloy with back scattered electron image and the corresponding elemental mapping of Si and Al is the processed zone. It is very clear that distribution of Si and Al elements is uniform in Friction stir processed alloy when compared to as cast A356 alloy. Significant microstructural refinement, homogeneity and densification by friction stir processing in as cast A356 alloy was obtained are mainly because of the fact that the material within the stir zone experienced intense plastic deformation and mixing. This would also lead to break-up of the coarse Si particles and dendrite structure which have resulted in a homogenous distribution of fine Si rich particles throughout the Al alloy.

Elemental mapping of friction stir processed surface of A356 alloy with B_4C. A homogeneous distribution of boron particles thought the matrix may be noted. EPMA line scan across the reinforced B_4C with MoS_2 in the matrix. Absence of Al, Si, Mg and presence of B, C and little Mo in the particle region conforms that the particles were B_4C only with no melting or dissolution at the interface. It indicates that carbide particles and molybdenum disulphide particles were well bonded with the α-solid solution matrix

Corrosion behavior of both friction stir processed A356 aluminium-silicon alloy and surface metal matrix composite are studied. In the later stage of investigation, effect of boron carbide particle size variation and also effect of solid lubricant MoS_2 on corrosion behavior studied. Results of pitting corrosion testing are presented in this section [3].

Potentiodynamic polarisation curves for as cast A356 alloy and friction stir processed. Potential at which current increase rapidly is taken as the pit potential (Epit) and more positive values of Epit is an indication of better pitting corrosion resistance. It can be witnessed that samples exhibited passivation behavior with well defied pitting potential Epit values.

Relatively more positive Epit value of friction stir processed A356 alloy indicates better pitting corrosion resistance compared to that of as cast A356 alloy. The increase in corrosion resistance is attributed to the redistribution of second phase particles during friction stir processing. As can be seen from optical micrographs friction stir processing results fine and equiaxed Si particles were uniformly distributed in the aluminum matrix due to an intense breakup of the as-cast dendritic microstructure and subsequent material mixing. This increase in the amount of dissolved phases in the matrix raises the corrosion potential of aluminium matrix and thereby decreasing the potential difference between the matrix and the second phase particles and hence decreases the driving force for corrosion. Furthermore the pitting corrosion resistance of A356 alloy in friction stir processed condition was high which may be attributed to very fine discontinuous network of silicon rich intermetallics (Mg_2Si) and equilibrium precipitates. It is clear from the potentiodynamic polarization curve that pitting corrosion resistance of the alloy in friction stir processed condition was better than that of as cast condition and was attributed uniform distribution of silicon rich eutectics in a-matrix. Observed pit density in optical micrograph after pitting corrosion is clear indication of better pitting corrosion resistance of friction stir processed A356 alloy.

Higher pitting corrosion resistance was achieved in friction stir processed surface hybrid composite. During friction stir processing MoS_2 particles forms a lubricating layer, which also inhibits the formation of galvanic cell. The pitting potential value obtained for surface composite of B_4C (40 nm) with molybdenum disulphide is more positive [4].

Overall comparison of potentiodynamic polarization curves is presented. It reveals clearly that significant improvement in pitting corrosion resistance was achieved with friction stir process of as cast A356 alloy with boron carbide of 40 nm size along with solid lubricant MoS_2 addition. Optical micrograph also confirms that pit density is very low for hybrid surface composite when compared to that of as cast A356 alloy. Results of the potentio-dynamic polarization tests on as cast A356 alloy and friction stir processed are given in the TABLE 2. It can be concluded that by using friction stir processing for surface modification of as cast. A356 aluminum alloy with finer size of boron carbide and solid lubricant MoS_2, significant improvement in pitting corrosion resistance can be achieved [5].

TABLE 2. **Pitting potentials of as cast and friction stir processed A356 alloy.**

Condition	Epit(mV),
As cast A356 alloy	-791.56
Friction stir processed A356 alloy	-776.91
Friction stir processed B_4C (40 nm)	-620.08
Friction stir processed B_4C (40 nm) +MoS_2	-564.36

Conclusion

Friction stir surfacing of as cast A356 Aluminum alloy is able to refine the microstructure and form hard surface composite by reinforcing boron carbide particles in the aluminum matrix. It resulted in fine and uniform microstructure consisting of carbide particles uniformly distributed in aluminum matrix.Homogeneous distribution of boron particles throughout aluminum matrix of friction stir processed surface of A356 alloy was noticed from electron probe microanalysis elemental mapping. Absence of Al, Si, Mg and presence B and C of Friction stir processed B4C composite in the particle region conformed that the particles were B4C only with no melting or dissolution at the interface. It indicates that carbide particles are well bonded with the α-Solid Solution matrix.Pitting corrosion resistance of friction stir processed A356 alloy with boron carbide powder and solid lubricant of molybdenum disulphide was found to be better than in as cast condition. This was attributed to the formation of insulation paths in galvanic cells between eutectics, intermetallics and the matrix of aluminium. Pitting corrosion resistance of Friction stir processed A356 alloy with B4C of size 40nm with MoS2 was found to be better when compared to base metal.Significant improvement corrosion resistance was achieved with the addition of 40 nm size boron carbide and solid lubricant of molybdenum disulphide powder during friction stir surfacing.

References

1. Zhang DL, Zheng L. The quench sensitivity of cast Al-7 wt pct Si-0.4 wt pct Mg alloy. Metall Mater Trans A. 1996;27:3983-3991.
2. Din T, Campbell J. High strength aerospace aluminium casting alloys: A comparative study. Mater Sci Technol. 1996;12: 644-650.
3. Yu YB, Song PY, Kim SS, et al. Possibility of improving tensile strength of semi-solid processed A356 alloy by a post heat treatment at an extremely high temperature. Scripta Mater. 1999;41:767-771.
4. Kumai S, Hu J, Higo Y, et al. Effects of dendrite cell size and particle distribution on the near-threshold fatigue crack growth behaviour of cast Al-SiCp composites. Acta Mater. 1996;44:2249-2257.
5. Zhang B, Poirier DR, Chen W. Metall. Microstructural effects on high-cycle fatigue-crack initiation in A356.2 casting alloy. Mater Trans A. 1999;30:2659-2666.