Materials Chemistry and Physics 173 (2016) 192–199

Contents lists available at ScienceDirect

Materials Chemistry and Physics

journal homepage: www.elsevier.com/locate/matchemphys

Surface modification of Al–Si alloy by excimer laser pulse processing

S. Mahanty*, Gouthama

Department of Materials Science and Engineering, Indian Institute of Technology, Kanpur 208016, India

HIGHLIGHTS

- Coarse Si and β phase intermetallic are melted and the constituent elements dispersed into the matrix during re-solidification.
- The solid solubility of the Si at the surface enhanced after the laser treatment.
- The Cellular structure with the size range ~30–50 nm observed in α-Al after 45 laser pulses.
- Si nano particles in size ~ 2–15 nm were observed in the intercellular region.
- Surface hardness increased after laser processing.

ARTICLE INFO

Article history:
Received 22 January 2015
Received in revised form
2 October 2015
Accepted 2 February 2016
Available online 12 February 2016

Keywords:
Nanostructures
Solidification
Electron microscopy
Precipitation
Surface properties

ABSTRACT

The laser irradiation on Al-Si alloy sample is carried out by excimer laser in ambient conditions for 30 or 45 pulses. Microstructural investigation of laser treated sample is done by OM, SEM and TEM and the surface hardness is evaluated by Vickers micro indentation. Laser treated, samples suggested the dissolution of coarse primary Si and β-AlFeSi particle in α-Al matrix. The SEM/EDS study shows the enhancement of retained Si in α-Al matrix. The interface analysis of laser treated sample suggested the effected modified depth is ~6 μm. TEM investigation shows the formation of nanocrystalline Si in size ~2–15 nm. The cellular structures of size range ~30–50 nm are observed after 45 pulses. The α-Al cells and Si precipitates sizes were considerably refined at higher number of pulses. The fine Si precipitates are found to be dispersed in the intercellular boundaries. An improvement in surface hardness from ~1.6 to 1.8 is observed 30 and 45 pulse treatment, respectively. The mechanism involves for improvement in surface properties are non-equilibrium solidification, metastable phase formation and microstructural refinement.

1. Introduction

Aluminum and aluminum alloys come in the category of light alloys. Al–Si alloy is superior in terms of high strength to weight ratio, high formability, good thermal and electrical properties [1,2]. These properties make it useful in different branch of engineering field like aerospace, sports and automotive industries [3]. The LM6 is one of the Al-Si alloy with Si present as a major alloying element. The solid solubility of Si in Al matrix is fairly low and about ~1.6 wt.% at eutectic temperature [4]. This lead to rejection and segregation of Si with high fraction in the interdendritic region during the slow cooling process [2,5]. The morphology of Si being coarser flakes or acicular/polygonal plates [2,6]. In addition to this, the Fe-rich intermetallic is also found in coarse plate morphology [6–9]. The presence of coarse β-AlSiFe (intermetallic particles) and primary Si degrades the materials properties by breaking the continuity in the α-Al matrix [10–14]. The performance and durability of Al-Si alloy mainly depends on various parameters like surface microstructure and surface chemistry [15–18].

To enhance the performance of Al–Si alloy, thermal and thermo-mechanical treatments have been attempt over the years. For many applications like corrosion, wear, fatigue etc., the surface properties are more crucial and appropriate surface treatment can effectively enhance the surface properties and expected to give good advantage. The pulse laser treatment is one of the alternative tool which can effectively enhance the surface properties leaving the bulk property unaffected. The pulse laser treatment induces rapid melting and cooling ~10^8–10^{10} K s^{-1} [19,20], resulting in, non-equilibrium solidification, metastable structure and new phases formation with a complete microstructural modification

* Corresponding author.
E-mail address: soumitro@iitk.ac.in (S. Mahanty).

http://dx.doi.org/10.1016/j.matchemphys.2016.02.001
0254-0584/

Table 1
Laser parameter used for surface treatment of Al–Si alloy.

Excimer pulse Laser parameter	
Wavelength (nm)	248
Pulse Width (ns)	~20
Fluence (J cm^{-2})	~4.75
Pulse repitition frequency (Hz)	3
Number of pulses	30 and 45
Process condition	Ambient

[19–22]. Aim of this paper is the evaluation of surface microstructural changes of Al–Si alloy after 30 and 45 pulses treatment. Also, an effort is made to establish the correlation between the laser processing parameter on the surface microstructure and surface hardness.

2. Materials and methods

The Al–Si alloy used for the laser treatment is a commercial LM6, obtained in as-cast ingot condition. The nominal composition of the alloy is (10–13%Si – 0.6%Fe – 0.5%Mn – 0.2%Ti– 0.1%Cu – 0.1%Mg – 0.1%Pb – 0.1%Ni – 0.1%Zn – 0.1%Sn and rest is Al) in wt. %. The sample sizes of ~6 mm × 6 mm × 3.5 mm were slice out by low speed diamond saw cutter (Buehlers – Labcut 1010) from the block. Later standard metallographic technique was adapted for sample preparation. Afterwards samples were cleaned by acetone and dried.

The processing parameters for laser treatment used in this study is summarize in the Table 1. Prepared sample surfaces were exposed to 30 and 45 number of pulses. TEM samples were prepared by the Precision Ion Polishing System (PIPS) (Gatan- 691). The sample preparation (thinning) was done from single side (untreated side) at 3 rpm stage rotation, ~3–5 kV acceleration voltage and at ~3–5° inclination angle.

KrF Excimer pulse laser model (Coherent GmbH Micro LAS COMPex Pro 205) was used for surface treatment. Optical Microscope Leica (LM 6000) was used for studying the microstructure of the samples. SEM (ZEISS EVO50) operating at accelerating voltage 20 kV with EDS was used for microstructural and compositional analysis. The transmission electron microscopy (TEM) observation was carried out by FEI Tecnai G^2 20 UTwin microscope, operating at 200 kV. Vickers hardness (Bareiss V-test) system was used for the hardness measurement at a load of 10 g.

3. Results

3.1. Optical microscopy

Fig. 1 compares the optical microstructure of untreated and laser treated Al–Si alloy. Untreated (prior to laser treatment) sample indicate the presence of dendrites with α-Al secondary dendrite arm spacing ~ 40–55 μm. In addition, coarse Si and β-AlFeSi (Fe-rich intermetallic particles) are also present in the matrix, mostly found at the inter-dendritic regions as indicated (white and black arrows, respectively) in Fig. 1 (a). The observation indicates that the coarse Si particles are found in size (length) ~ 5–20 μm, with acicular as well as polygonal plate morphology. Moreover, the morphology of Fe-rich intermetallic (β-AlFeSi) is acicular/irregular plate [6] of length ˂ 120 μm.

In contrast, laser treated sample (Fig. 1(c–d)) shows the absence of coarse Si and β-AlFeSi intermetallic. This suggested the dissolution of coarse Si and β-AlFeSi after 30 and 45 pulses treatment. The dissolved Si and β-AlFeSi were dispersed in α-Al matrix and leads to the formation of supersaturated solid solution.

In addition, the laser treatment leaves certain typical surface solidification morphology. Certain 'star-like' features are found emerging from central featureless spots. The details in these

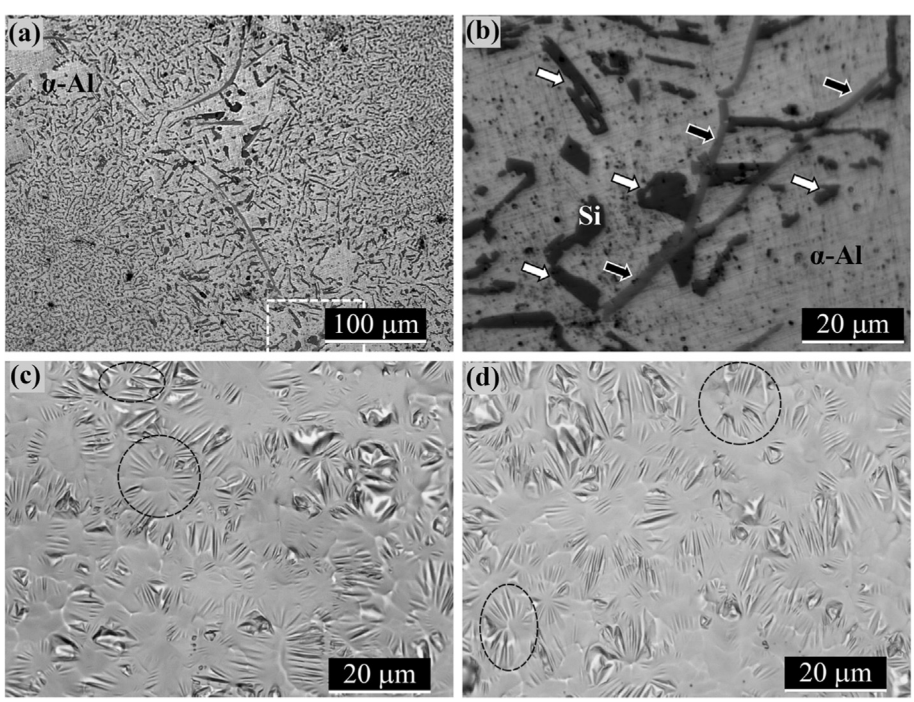

Fig. 1. Optical micrograph of Al–Si alloy: (a) and (b) microstructure before laser treatment showing cast structure at low and high magnification, respectively. Modified surface microstructure after laser treatment in ambient atmosphere: (c) 30 pulse and (d) after 45 pulses. The star-like features are seen all over the surface represented by dotted circle.