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jmr&t Journal of Materials Research and Technology

www.jmrt.com.br

Review Article

Microstructural evaluation of an asymmetrically rolled and recrystallized 3105 aluminum alloy

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ARTICLE INFO

Article history:
Received 27 April 2014
Accepted 17 February 2016
Available online 3 April 2016

Keywords:
Aluminum alloy
Asymmetric rolling
Superplasticity
Solubilization heat treatment

ABSTRACT

This study evaluates the influence of the structural changes promoted by a solution heat treatment (ST) on recrystallization and grain growth during annealing of the 3105 Al alloy subject to asymmetric rolling. Optical Microscopy, Scanning Electron Microscopy (SEM)/X-Ray Energy Dispersive Spectroscopy (EDS), X-Ray Diffraction (XRD), dilatometric analysis and Vickers hardness tests were used to evaluate the microstructural and mechanical properties. The influence of solution heat treatment on grain growth kinetics could not be evaluated because of incomplete recrystallization due to the chosen annealing parameters.

1. Introduction

According to the present scenario, searching for greater energy efficiency and weight reduction of metallic structures in aeronautical and automotive industries is a valuable strategy. This weight reduction has been achieved, for example, through the elimination of joining processes, such as welding and riveting. The conformation of parts with complex geometries is an excellent choice to avoid joining, and superplasticity, obtained through materials with ultrafine grains [1,2], has gained interest over the last few years as a mean of achieving deformation of complex shapes. A techniques called Severe Plastic Deformation (SPD) was created and is considered a viable alternative to obtain materials with ultrafine grain size [3–5].

To achieve the superplasticity property in metals, it is not only necessary to obtain ultrafine grain size, but also equiaxed recrystallized grains with high angle disorientation and precipitates or second phase particles [1,6]. This last characteristic is very important for superplasticity, because the materials processed by SPD techniques, in order to exhibit

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http://dx.doi.org/10.1016/j.jmrt.2016.02.001

superplastic behavior, experience high temperatures in various steps of the process, during which, without the presence of these second phase particles, grain growth would occur, and superplasticity would be spoiled.

Thus, alloys having coarse precipitates, such as most alloys produced at industrial scale, that do not require a rigorous control of these particles, are not suited for the superplasticity applications, because according to Gottstein [7], a particle size less than 50 nm is needed to avoid the grain growth.

In order to provide a convenient microstructure, including precipitate size, to enable superplastic behavior on some metals where the solute concentration is slightly above the solubility limit of the solvent, e.g. aluminum and aluminum alloys, a heat treatment is an effective option, providing size reduction of coarse precipitates and complete dissolution of some others.

In the broadest sense, this heat treatment consists of heating an alloy at a sufficiently high temperature for a time long enough to achieve a nearly homogeneous solid solution in which almost all solutes are dissolved, so that a single-phase structure is attained [8,9].

This study evaluated the influence of a solution heat treatment (ST), on retardation of the recrystallization and/or retention of grain growth when a 3105 aluminum alloy is subject to asymmetric rolling and recrystallization for different soaking times. This alloy is commonly used in simple applications where size control of the second phase particles is not necessary, but has the potential to improve the mechanical properties of the alloy.

2. Material and methods

2.1. Material

The material used for this study was a 3105 aluminum alloy, a 7 mm thickness hot-rolled sheet, donated by Votorantim Metals (originally from Aluminum/SP, Brazil). Table 1 shows the sheet chemical composition.

Sample nomenclature is as follows:

(i) The leading four digits represent the alloy analyzed = 3105;
(ii) The following two letters indicate the initial condition of the alloy: AR = As Received and ST = subject to a Solution heat Treatment;
(iii) The last two symbols indicate the final condition of the sample processing: AS = ASymmetrically rolled or 15, 30, 45 or 60 = asymmetrically rolled and subject to an annealing heat treatment for recrystallization with soaking times of 15, 30, 45 and 60 min, respectively.

2.2. Methods

Half of the samples were subject to ST in an electric resistance furnace at a soaking temperature of approximately 500 °C for 60 min, and where quenched in water at room temperature under agitation.

For ASymmetric rolling (AS), was used a pilot-mill with the rolling cylinders revolving at the same speed (1.676 rad/s), in the same direction and with the same coefficient of friction and a ratio between cylinder radii ~ 1.18. The rolling directions of the AR sheet and the AS process are the same. These tests were conducted at room temperature, after 90 passes with a thickness reduction of about 4.7% per pass.

After the AS, small samples with dimensions of approximately 2 × 20 × 10 mm were cut and subjected to Annealing Heat Treatment for Recrystallization (AHTR) at a soaking temperature of 350 °C with 4 distinct soaking times (15, 30, 45 and 60 min) and then cooled in air.

For the microstructure characterization, the samples were cut and metallographically prepared according to the following procedures:

- for Vickers hardness measurements and Scanning Electron Microscopy (SEM)/X-Ray Energy Dispersive Spectroscopy (EDS), the samples were hot encapsulated with phenolic resin, sanded with 220–4000 mesh SiC paper and mechanically polished with diamond pastes (6 μm, 3 μm and 1 μm).
- for Vickers hardness measurements in the AS samples subject to AHTR with different soaking times, the samples were cold encapsulated with acrylic resin instead, before being subject to the same grinding and polishing procedure.
- for X-Ray Diffraction (XRD) and optical microscopy, the samples (not encapsulated) were subject to the same sanding step (sandpaper with grain size 220–4000 mesh) followed by electrolytic polishing (solution: 59% CH_4O, 35% $C_2H_4(OH)_2$ and 6% $HClO_4$ (in volume); electric potential difference between 14 and 24 V during 10–24 s at room temperature).

The microstructure observation by Optical Microscope – OM (Image Pro Plus software) was performed over points associated with ¼ and ½ in thickness cross section associated to the rolling direction (RD).

The SEM analysis was performed with the secondary electron detector: 12 keV, spot size of 500 and a working distance of 11 mm.

The Vickers hardness test (Manufacturer Spectrum Instrumental Scientific LTD) was performed with a load of 100 g (0.1 kgf) and a dwelling time of 18 s. For samples on AR and ST conditions, 10 measurements were performed, at ½ and ¼ of the thickness, and at ¼, ½ and ¾ of the thickness for the samples processed by AS.

Table 1 – Aluminum 3105 alloy – chemical composition (weight percent).

	Chemical composition (%)									
	Si	Fe	Cu	Mn	Mg	Ti	Cr	Zn	Other	Al
3105 alloy	0.220	0.540	0.094	0.580	0.580	0.020	0.011	0.036	0.025	Remainder