Effect of minor Sc and Zr addition on the mechanical properties of Friction Stir Processed 2024 Aluminium alloy

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The effect of Friction Stir Processing (FSP) on the mechanical properties of a Sc, Zr modified 2024 aluminium alloy was investigated in the present paper. The room temperature tensile properties of the material were obtained in longitudinal direction respect to the processing one and compared with those of the unstirred material and unmodified alloy. Tensile tests were also performed at higher temperatures and different strain rates in the nugget zone. The superplastic properties of the recrystallized material were evaluated and the differences with the parent material as a function of the strong grain refinement due to the Friction Stir Process were put in evidence. The high temperature behavior of the material was studied, in longitudinal direction, by means of tensile tests in the temperature and strain rate ranges of 450–525°C and 10^-1–10^-3 s^-1 respectively.

Introduction

The presence of minor Sc and Zr produces, in Al Alloys, a strong increase in strength, ductility and Fatigue life [1]. This is due to the formation of very fine disperse Al(Sc, Zr)3 particles acting as grain boundary pinners and than as grain structure stabilizers up to very high temperatures [2]. This aspect permits to increase the possible use temperatures of commercial AI-alloys. The strengthening mechanism is due to the coherent thermodynamically stable particles with ordered L12 structure [3]. It has been demonstrated that a minor Sc and Zr addition in Al alloys is sufficient to raise the recrystallization temperature by 150°C [4].

It is clear that it is possible to achieve superplasticity at high strain rates, in conventional materials, by making a strong reduction in grain size; this can be obtained by using a process such as equa-channel-angular pressing or Friction Stir Processing in which the samples are subjected to a severe plastic deformation leading to a strong grain refinement.

The FSP process is a solid state process and therefore solidification structure is absent and the problem related to the presence of brittle inter-dendritic and eutectic phases is eliminated [5–7].

The Frictioned zone consists of a weld nugget, thermomechanically affected zone and a heat affected zone. The process results in the obtaining of a very fine and equiaxed grain structure in the weld nugget obtained through a continuous dynamical recrystallization process causing a higher mechanical strength and ductility.

The strong grain refinement produced by the process lead the microstructure to the fine dimensions proper of the possibility to exhibit superplastic properties [8–10].

In FSP the work piece does not reach the melting point and the mechanical properties of the material are much higher compared to the traditional techniques [11–13].

The aim of the present work is the study of the effect of minor Sc and Zr addition on the mechanical properties of 2024 aluminium alloy subjected to Friction Stir Processing.

Experimental procedure

The material used in the present study was a commercial 2024 aluminium alloy with the addition of 0.26 Sc and 0.13 Zr (wt%), this Sc and Zr quantity was chosen because of the strong grain refinement effect observed in previous studies [14]. The used sheets with 5 mm...
thickness, were Friction Stir Processed by employing a steel flat tool with rotating speed of 1000 RPM and a traveling speed of 5.2 mm/s, the tool was rotated in the clockwise direction while the specimens, fixed at the backing plate, were moved. The nib was 4.5 mm in diameter and 4.8 mm long, and a 20 mm diameter shoulder was machined perpendicular to the axis of the tool; the tilt angle of the tool was 3°.

Tensile tests were performed in order to evaluate the mechanical properties of the material at room temperature and at higher temperatures (450–525°C) and different strain rates (10^{-1}–10^{-3} s^{-1}) by employing specimens obtained by EDM from the nugget zone cut parallel to the processing direction; before tests, the surfaces of the specimens were mechanically polished in order to eliminate all the possible surface defects effects. The tensile tests were carried out using a LLOYD Instruments LR5K testing machine equipped with a resistance furnace.

The strain rate sensitivity coefficient (m) of the material was calculated employing the following equation:

$$m = \frac{\partial \log \sigma}{\partial \log \epsilon_{e, T}}$$

The m value was calculated by interpolating the data obtained by tensile tests at an equivalent strain of one. The cubic interpolation was applied between \sigma and \epsilon logarithmic values.

Surfaces were prepared by standard metallographic techniques and etched with Keller’s reagent and grain

Figure 1 Very fine and uniform microstructure observed in the nugget zone (a), revealing a mean grain size of 1 micron (b).