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Constitutive Modelling of AZ31B-O Magnesium Alloy for Cryogenic Machining

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Abstract

The success of a FE model for metal cutting process is strongly dependent on the accurate characterization of the workpiece material, under similar conditions as those found in metal cutting. In this paper, dynamic shear tests using a Gleeble machine have been performed on 4 mm thickness disks of AZ31B-O magnesium alloy, using a special designed tool. In order to include the effects of the cryogenic cooling in the material behavior, the specimens have been submitted to temperatures ranging from -25ºC to 400ºC. A Johnson-Cook constitutive model has then been identified in order to describe the flow stress in machining.

Keywords: Magnesium alloy; constitutive modelling; cryogenic; machining

1. Introduction

Cutting process improvement can not be performed without a precise understanding of the chip and machined surface formation. Numerical simulation is a common way to understand and optimize these operations. The success of the model is dependent on the boundary and on the thermomechanical properties of the materials. But the problem is relatively complex since the material behavior is sensitive to the temperature and to the high shear rate observed in chip formation. The knowledge of the mechanical behavior of the alloy under thermomechanical conditions similar to those encountered in cutting process is therefore essential in order to develop a correct numerical simulation.
Mechanical behavior of AZ31B-O alloy under dynamic conditions have already been studied but these works are generally restricted to compressive or tensile loading [1] [2] [3] [4] [5]. They show that two different phenomena can occur during the deformation of the alloy: (i) dislocation glide and twinning and (ii) dynamic recrystallization. Depending on temperature and strain rate, one of these phenomena can be predominant compared to the other leading to some differences in the mechanical response of the material. Therefore, the aim of this work consists in characterizing the shear deformation behavior of 4mm thick AZ31B-O sheet material over a wide range of strain rates from $10s^{-1}$ to 5.10^4s^{-1} and at different temperatures from -25°C to 400°C in order to be representative of thermomechanical conditions encountered during cryogenic machining. Microstructure analysis is also performed to identify the possible deformation mechanisms due to strain rate and temperature. A standard Johnson-Cook model is finally suggested.

2. Experimental Setup

A shear test apparatus has been specially designed and developed at the author's laboratory. A schematic view of this apparatus is shown in Fig 1a. It consists of a flat cylindrical punch exhibiting a translatory movement, a blank holder, a die and a specimen. Punch and die diameters are respectively about 9.98mm and 10.02mm. Small disc specimen of 30mm diameter and 4mm thickness has been affixed between the blank holder and the die. Test has then been performed by forcing the flat cylindrical punch through the specimen with an

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adjustable displacement rate. A shear zone is thus generated into the specimen at the punch/die junction as illustrated in Fig 1b.

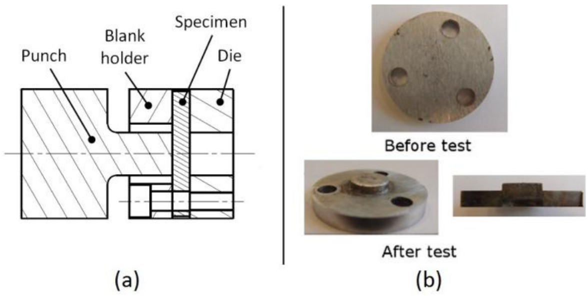

Fig. 1: (a) schematic view of the shear test apparatus; (b) specimen shape before and after deformation

This shear test apparatus has been affixed to a Gleeble 3500 machine in order to pilot punch displacement and specimen temperature. Punch displacement is thus linked to the crosshead displacement of the Gleeble machine. The specimen is heated by Joule effect at 5K/s until the desired temperature. The temperature has been measured by a K-type thermocouple welded in the central part of the specimen and has been monitored in real time to get close to the desired thermal cycle.

Shear tests at various temperatures between -25°C and 400°C with displacement rates ranging from 0.2 to 1000mm/s have been performed. It can be noticed that one negative temperature (it means -25°C) has been studied. For this temperature, the shear test apparatus (specimen included) has been frozen prior its fixing into the Gleeble machine.

Microstructures before and after deformation have been studied for each tested configuration by using optical microscopy in order to underline any microstructural evolutions. After being cut by half (Fig 1b), shear test specimens have been prepared by first a cold mounting. Then, they have been mechanically polished up to 40000 grit SiC paper. Final polishing has been performed on a felt with alcohol lubricant, using 3 microns, 1 microns and finally 0.02 microns silica suspension. Specimens have been then etched with an acetic and picric acid solution.

3. Experimental Results And Discussion

3.1. Initial microstructure

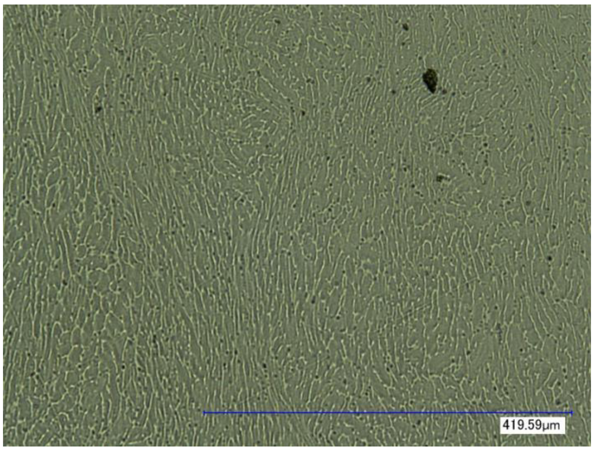

Fig. 2: dendritic structure of the sample (observed without etching)

The specimen alloy is composed of a dendritic structure with α Mg solid solution formed during the first steps of the cast solidification (chemical composition of the alloy is presented in table 1). Between the dendritic arms, an eutectic compound is formed due to the segregation of Al and Zn (Fig 2). It can be noted that this dendritic microstructure is quite original compared to the equiaxed structure generally studied in the literature [1] [5] [6] [7].

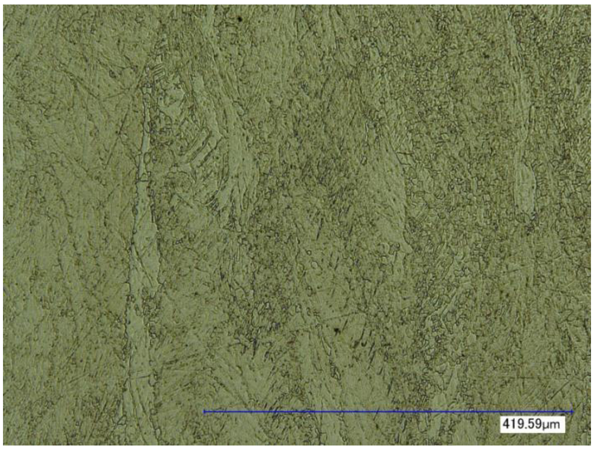

Fig. 3: grain boundaries (observed after etching)

Observations of new grain boundaries surimposed to the solidification dendritic structure are observed on Fig 3 and 4. These partially recrystallized zones are probably due to the rolling process of the magnesium sheet after the casting.