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Properties in Tension of Semi Continuous Cast and Extruded Zn-22Al-2Cu alloy

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ABSTRACT

Circular bars of the Zn-22Al-2Cu alloy were prepared by utilizing the semi continuous vertical casting technique. Solid as cast showed high values in the mechanical strength (497 MPa) and hardness (71 R_B). The micro structure of the bars consisted of equiaxed dendrites with eutectoidal composition surrounded by eutectic. At higher magnifications it can be observed that dendrites are two-phase eutectoid cells with lamellar structure. X-ray diffraction studies revealed that phases α'_S, η'_S and ε are present in such circular bars with ε phase as second phase particle. Later, the bars were preheated at 523 K then extruded, observing that, with preheating, the hardness value diminish down to 33 RB. By analyzing a piece of bar, it was observed that with preheating the ε phase disappears and there is a coarsening of lamellas at interior of cells and interdendritic space. Finally, the results of the tension tests showed that elastic modulus and tensile strength values, decrease substantially after extrusion, while the ductility value is increased.

Key words: Zn-22Al-2Cu (weight %) alloy; Semi continuous cast; Extrusion; Dynamic recrystallization; Ductility; Elastic modulus, yield and tensile strength.

INTRODUCTION

In recent years, a number of modifications of Zn-Al based alloys, between 20 and 30 weight % Al, they have been developed and studied with improvements in the properties. For example, the addition of copper in more than 2 weight % result in high-strength material[1]. It is worth to mention, that the obtaining process and later treatments of the solids of these alloys also play an important role as for the properties that will be had.

The solids of the Zn-22Al-2Cu (weight %) alloy are usually conformed by two solid solutions, a zinc-rich solid solution named η-phase and an aluminium-rich solid solution named α-phase. Unit cell of η-phase is hexagonal while the unit cell of α-phase is face-centred cubic. Other phases as ε ($CuZn_4$) and τ'(Al_4Cu_3Zn) can be present as consequence of heat treatments. This alloy has been obtained in the laboratory by different processes of condensation and studied in each case.

In general, continuous casting technique produces metallic materials of fine granular structure with good mechanical properties; however, thermodynamic state of the solids so obtained is not stable. In the case of the Zn-22Al-2Cu alloy, this means that the solute content can be modified through atomic diffusion and therefore the cell parameters will change. As known, the atomic diffusion is a thermal activated process but, there is evidence that atomic diffusion can be activated by mechanical means also in this alloy[2]. Therefore, it would be expected that the extrusion process modify the atomic structure, in addition to the grain shape in pieces of this type of solid.

Development of these high strength alloys as ZA-27 (ASTM B669)[3] and Zinalco (T. M.)[4] extended the capabilities of traditional zinc alloys to others than die casting. Alloy Zn-22Al-2Cu, known generically as Zinalco, can be extruded in the same way as aluminium is extruded[5]. Several advantages have been found, among others, the alloy requires lower extrusion pressure and temperatures. The main objective of the present study is the comparison of the Zn-22Al-2Cu alloy mechanical behaviour obtained by semi continuous vertical cast and extruded.

MATERIALS AND METHODS

The alloy studied in this work was based upon the Zn-Al eutectoid composition modified with 2 weight % Cu. The actual composition was Zn-22wt%Al-2wt%Cu. High Grade zinc (99.99 %) and 99.9 % Al ingot were used to prepare the alloy studied.

Conventional semi continuous vertical casting technique was used to cast the alloy into 190 mm diameter extrusion billets. Afterwards, the billets were preheated at 523 K then extruded into roads of 13.5 mm diameter using a die with 6 apertures. Extrusion was carried out in a 15 MN hydraulic press at a constant ram speed and lubricants were not used.

Rockwell B (R_B) hardness measurements were performed in axial and transverse direction of the rods, in the as cast and as extruded conditions. No significant variations in the hardness were found among these directions.

Tensile test were conducted at room temperature on an Instron 1125 machine on round specimens 20 mm in diameter, 60 mm gage length. Strain rates in the range of 0.0001 to 0.1 sec^{-1} was employed. Elongation value was determined using a displacement transducer (Instron's strain gage extensometer). Elastic modulus determinations were made by direct measurement of the slope of the stress-strain resultant curve.

Scanning electron microscopy (SEM) technique was used to examine the alloy microstructure.

RESULTS

Microstructure of the semi continuous cast material

Microstructure of the semi continuous cast alloy is composed of equiaxed dendrites 7 µm of mean width and a mean length of 30 µm, with a significant amount of interdendritic eutectic (Figure 1). At higher magnifications, the SEM technique showed that the dendrites are two-phase lamellar eutectoid cells (Figure 2). There is not micro segregation within the small dendrites arms, according to the microanalysis studies done in a transverse section of the dendrite arm in the as cast

Table 1: Mechanical properties at room temperature of Zn-22Al-2Cu (wt. %) alloy. Strain rate e' = 0.1 sec^{-1}

	Elastic modulus (MPa)	Yield strength (MPa)	UTS (MPa)	Strain to fracture (%)	Hardness (R_B)
Semi continuous casting	197000	395	497	20-28	71±3
Extruded	20000	400	410	30-35	55±2

material. Most of the Cu was detected in the interdendritic spaces and none in the dendrite arms. Therefore, it is deduced that Cu is rejected into the liquid by the η'_S primary phase at solidification. Porosity was found to be casting rate dependent, the lower the casting rates the longer the amount of porosity. Porosity was very low at the casting rate reached by the semi continuous vertical casting device (2.3 mm/sec).

Microstructure of the semi continuous cast and heat treated material

Before the extrusion, the ingots require a preheated and the starting material microstructure may be significantly modified during this stage. From X-ray diffraction studies, it was observed that the semi continuous cast sample is constituted by the phases η'_S, α'_S, η'_T, α'_T of the Al-Zn system (according to Presnyakov et al and modified by

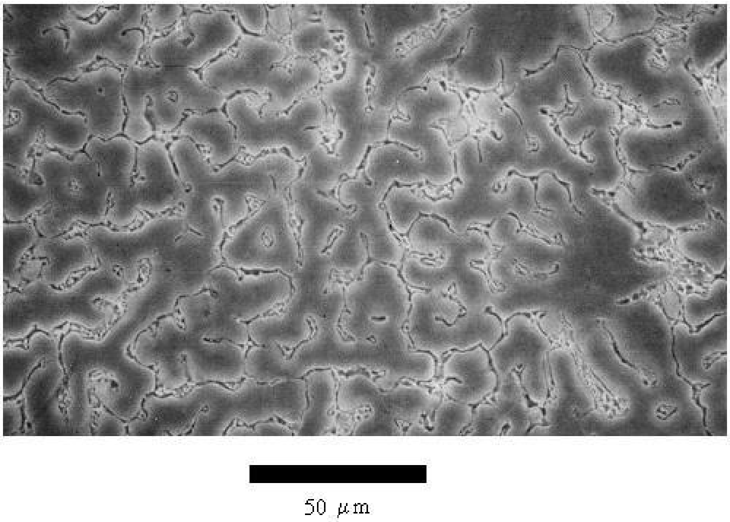

Fig. 1: Scanning electron photomicrograph of Zn-22Al-2Cu (wt %) alloy obtained by semi continuous casting. The image shows an equiaxed dendritic structure

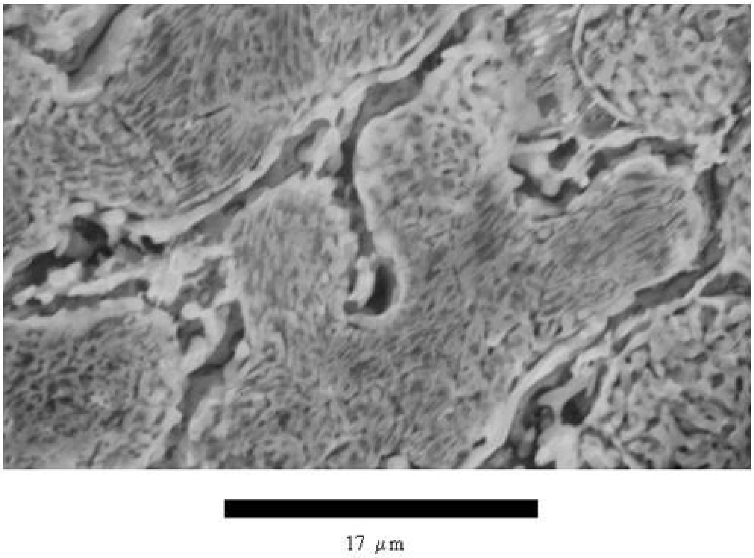

Fig. 2: Scanning electron photomicrograph of Zn-22Al-2Cu (wt %) alloy obtained by semi continuous casting and heat treated at 523 K during 3 hours. In detail, coarsening of lamellas inside the dendrites can be observed

Goldak and Parr)[6] and the ε phase of the Cu-Zn system[7], whereas, for the heat-treated ingot, the metallic material is constituted by the phases η_T, α'_T [8]. From literature, for this alloy so solidified, the phase transformation $\eta'_S + \varepsilon \rightarrow \eta'_T$ was observed during the preheating at 523 K as reported[8]. This transformation produces coarsening of the η'_T lamella as much inside the dendrite arms as in the interdendritic spaces (Figure 2).

Microstructure of the extruded material

Typical microstructure of the extruded

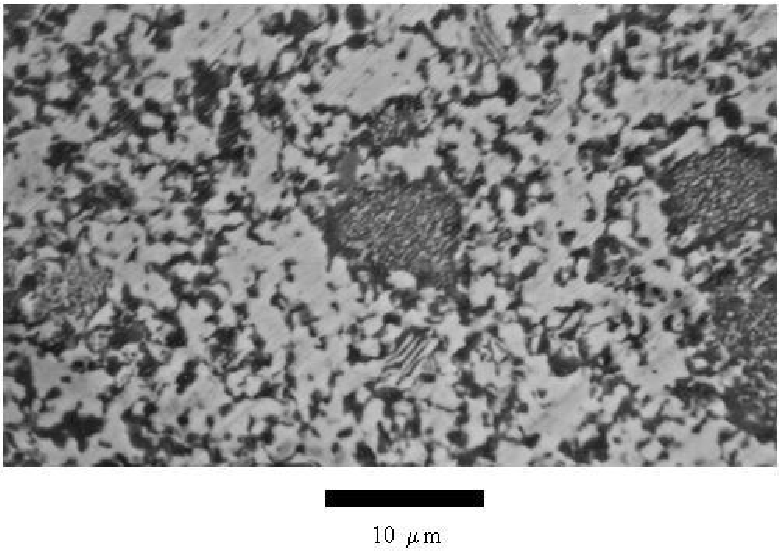

Fig. 3(a): Scanning electron photomicrograph of Zn-22Al-2Cu (wt %) alloy obtained by semi continuous casting, heat treated and extruded, showing the transverse structure composed of pearlite patches surrounded by non-equiaxed grains of α'_T (dark) and η'_T (clear) phases

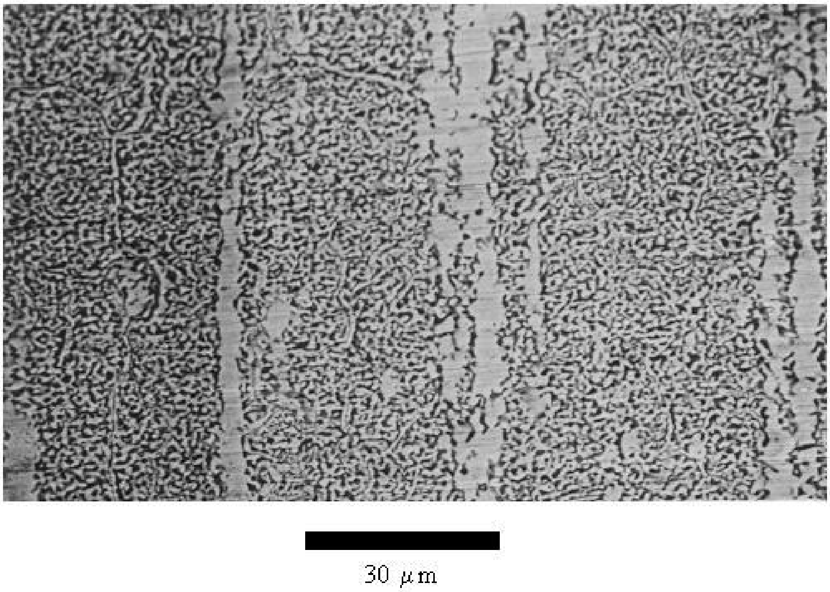

Fig. 3(b): Scanning electron photomicrograph of Zn-22Al-2Cu (wt %) alloy obtained by semi continuous casting, heat treated and extruded, showing the longitudinal structure composed of deformed large grains surrounded by non-equiaxed grains of α'_T (dark) and η'_T (clear) phases material in the transverse section is shown in Figure 3a, as can be observed in the microstructure image, it is composed of fine pearlite patches (~ 10 μm) surrounded by small non-equiaxed grains of α_T and η_T phases. The structure observed in the longitudinal section is mixed consisting of the same non-equiaxed grains (granular pearlite) and deformed large grains; these grains are elongated in the extrusion direction (Figure 3b).

Mechanical properties

Room temperature mechanical properties of as-cast material and extrusion products are summarized in Table 1. Hardness of the semi continuous cast material decrease from 71 to 33 R_B after 30 minutes of annealing at 523 K. Based on the reaction $\eta'_S + \varepsilon \rightarrow \eta_T$, it is possible to said that hardness fall is due to the ε phase decomposition, since the dislocation glide is favoured by the reduction of the inter-phases number[8]. Hardness value of 33 R_B doesn't changes in a notorious amount after 3 hours of preheating. Hardness dependence with the annealing time is shown in Figure 4.

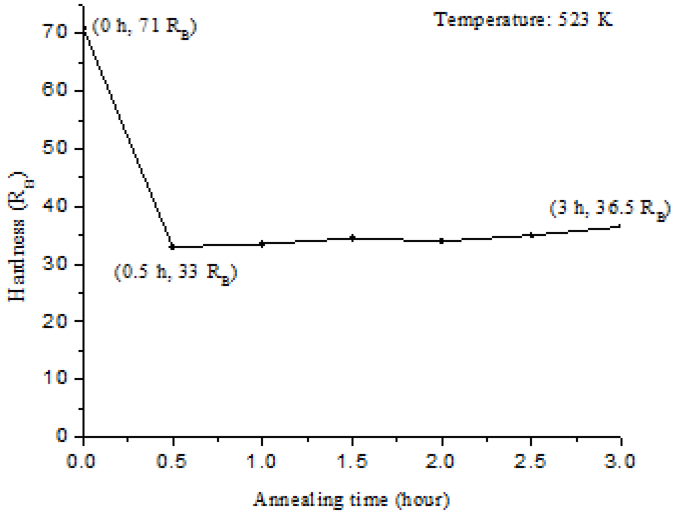

Fig. 4: R_B hardness values as a function of annealing time at 523 K

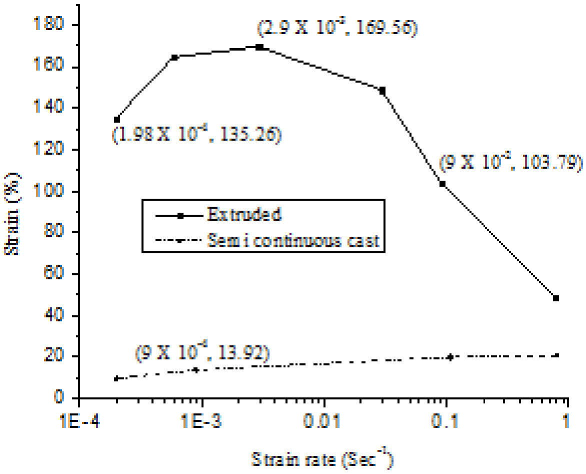

Fig. 5: Strain (%) as a function of strain rate (sec⁻¹) for extruded and semi continuous cast alloy at room temperature. Notice the high strain rate sensitivity shown by the extruded alloy

It was observed from tension tests that strain rate had an effect on flow stress for the as extruded material and very low effect in the semi continuous cast material. Figure 5 summarizes the effect of strain rate at room temperature on the extruded material over a range which includes super plastic behaviour with a maximum deformation close to 170 %, and extends to typical working strain rates. The main feature observed in the mechanical properties of the extruded solid is the low level of work hardening presented during the tension test and the sensible change in the Young's modulus. The high sensitivity to the strain rate observed in the extruded alloy (Figure 5) indicates a high influence of super plastic mechanism in the deformation of the extruded alloy instead of a dislocation's assisted deformation. This effect explains the absence of work hardening during deformation.

DISCUSSION

The small amounts of Cu added to this alloy are not enough to produce new stable phases; it is diluted in the Zn-rich solid solution, mainly. The increase of the strength of α and η phases could be explained by the insertion of copper in both solutions and is the reason of the observed increment in the strength of the Zn-22Al-2Cu alloy. Through the rapid solidification of this alloy, the solid solutions α_S and η_S with copper fully diluted are obtained; however, as consequence of the liquid-solid rapid pass, structural defects are introduced which lead to a metastable thermodynamic state. It is necessary to remark that, during the cooling that follows the solidification, it takes place the nucleation of the metastable å phase ($CuZn_4$)[9]. Such thermodynamic state of the solid produces a metallic material that is sensitive to subsequent mechanical and thermal treatments.

The extrusion process produces a softening of the alloy and a reduction in the elastic modulus. Dynamic recrystallization is the usual softening mechanism in the hot working of low stacking-fault energy materials; this fact should apply also to the present alloy. The above results indicate that dynamic recrystallization was not fully developed under the present extrusion conditions. Nucleation occurs during deformation and rapid growth takes place after deformation producing the very fine grains. The extrusion strain was apparently insufficient to induce complete recrystallization in the alloy with slightly hipereutectoidal composition as observed in Figure 5. The change in the deformation mechanism from dislocation assisted mechanism in the as cast structure to grain sliding (super plastic) is another reason for the observed reduction of strength and increment in ductility of this alloy.

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