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Forging and Rolling of magnesium alloy AZ61

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Manufacturing and processing

ABSTRACT

Purpose: The paper summarises results of experiments aimed at development of structure of modified alloy AZ61 at hot deformation.
Design/methodology/approach: Deformation behaviour of alloy was verified at the temperature of 420°C by rolling at 380°C by forging, respectively.
Findings: Magnesium alloy AZ 61 have hexagonal structure and their forming is at room temperatures very difficult, that's why big plastic deformations are carried out in hot condition. After plastic deformations was obtained that original grain size decreased 15 times.
Research limitations/implications: This paper provide data about magnitude of deformation, strain rate and temperature of forming at different techniques of plastic deformation. It was aimed to determine the conditions for non problem rolling and forging respectively.
Practical implications: Initial structure was as cast and after heat treatment T4. Heat treatment appeared much better for forming as well as forging than rolling because of state of stress.
Originality/value: Role of βphase ($Mg_{17}Al_{12}$) in these alloys at plastic forming is very important, such that how it was obtained, best final properties of AZ 61 alloy supports very fine particles, distributed into Mg matrix. Next a relevant information is that multi stage forming process is much better in comparison with a big single reduction.
Keywords: Plastic forming rolling; Forging; Magnesium alloy

1. Introduction

Modified alloy AZ61 can be processed by rolling, forging, and extrusion. Mode of processing influences development of structure and hence the resulting mechanical properties. The alloy AZ61 crystallises in the system HTU (as all magnesium alloys with the exception of alloys with lithium), that's why its cold formability is low. It increases significantly at the temperature around 220 °C, when other slip planes apply [1-4]. Formability is significantly influenced also by dynamic re-crystallisation. In this type of alloy there are achieved higher plastic properties at temperatures of forming in the zone of homogenous solid solution. Heterogeneity of structure of alloy deteriorates formability in the same way as too coarse grain. Grain size and resulting mechanical properties depend to a great extent on conditions of deformation (T,ε, ε´).

2. Experimental methods

We have verified by rolling development of structure of modified alloy AZ61 in dependence on magnitude of individual reduction passes and on temperature of rolling 420 °C and in next step at forging on temperature 380°C. We have also monitored hardness obtained after rolling. Chemical composition of the alloy was the following table 1.

Table 1.
Chemical composition of AZ61

Alloy	Chemical composition, %					
	Al	Zn	Mn	Si	Cu	Fe
AZ61	5,92	0,49	0,15	0,037	0,003	0,007

Initial cast structure of samples was in two states: without heat treatment (WHT) and after heat treatment T4. Heat treatment T4 comprises: heating to the temperature of 375°C/3 h and consequent heating to the temperature of 415°C/18 h followed by air cooling.

Both groups of samples were progressively rolled at temperatures of 420 °C. The samples had shape of a prism with dimensions 150x15x10 mm. Rolling rate was approx. 60 mm/s. Strain rate varied within the interval from 1.2 – 15 s^{-1} and it was calculated from the relationship:

$$\dot{\varepsilon}_h = \frac{v_v}{l_d} \cdot \ln \frac{h_n}{h_{n-1}} \quad (1)$$

where v_v is circumferential speed of rolls, l_d is length of the zone of deformation, h_n is initial height of the sample before passing, h_{n-1} is height of the sample after passing,

Length of the zone of deformation (l_d) influences distribution of deformation as well as state of stress in the formed sample. Average values (l_d) varied around 8 mm and they were calculated from the relationship:

$$l_d = \sqrt{R \cdot \Delta h} \quad (2)$$

where R is radius of rolls, Δh is value of absolute reduction pass.

We have measured during rolling dimensions of samples before passing and after it. In dependence on development of state of side free surface we evaluated degree of formability.

After each pass part of the sample was cut away in order to enable investigation of structure. The remaining part was put again into the furnace with required temperature and after dwell of 15 min. another was carried out. We made altogether max. 7 passes[5]. Distribution of deformations in individual passes and total deformation are shown in the Fig. 1.

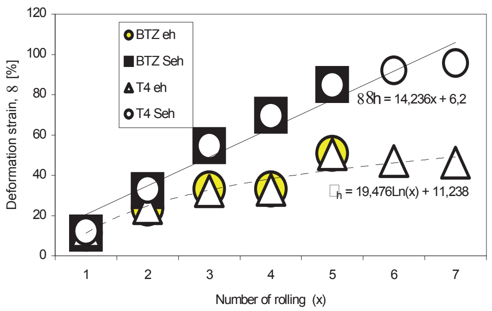

Fig. 1. Magnitude of deformation at rolling

In this section it is necessary to present in details assumptions and course of own researches to such an extent that a reader could repeat those works if he was going to confirm achieved results. In short papers those information should be given in as short a version as possible.

3. Results and discussion

Structure of the alloy AZ61 before deformation in initial state as cast and after heat treatment T4 is shown in the Fig. 2.

Microstructure in this type state consists of majority phase (solid solution of aluminium in magnesium) and of 2 types of other minority phases.

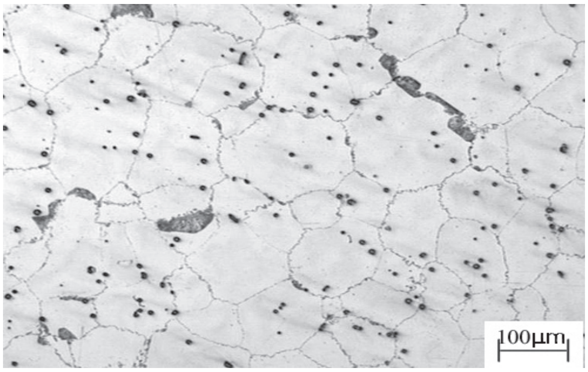

Fig. 2. AZ61 alloy after T4

The first type is formed by comparatively massive particles of the phase $Mg_{17}Al_{12}$, or $Mg_{17}(Al,Zn)_{12}$. The second type shows fine needle-shaped or granular particles of the same phase, occurring in the very proximity of grain boundaries of majority phase. Described type of microstructure is not quite in conformity with binary equilibrium diagram Al – Mg. Structure of the alloy is normally related to thermodynamic and kinetic aspects of solidification and cooling [6,7].

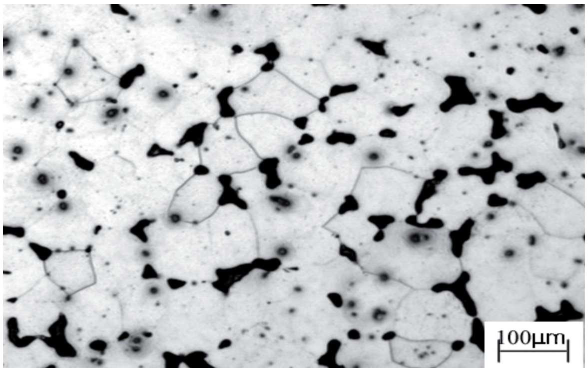

Fig. 3. AZ61 after T4 after rolling (cooling by air)

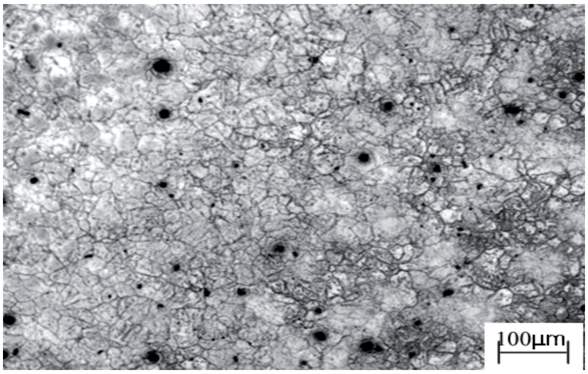

Fig. 4. AZ61after T4 after rolling (cooling by water)

After application of heat treatment T4 precipitate and compact phase largely dissolve [8,11]. During air cooling there does not occur repeated precipitation from solid solution in greater extent and resulting structure is formed by over-saturated solid solution on the basis of magnesium, as well as by non-dissolved small residues from the massive phase $Mg_{17}(Al, Zn)_{12}$, (Fig. 3). Fig. 4 shows structure after using water, like cooling medium.

Figures 5,7 and 6,8 show structures in longitudinal direction after forging AZ 61+T4 alloy again with two different cooling mediums.

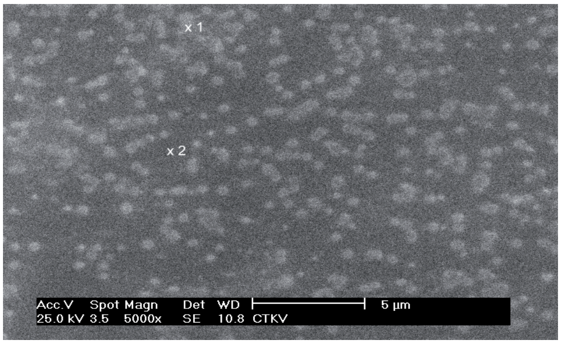

Fig. 5. SEM image of AZ61+T4, forged and cooled by air

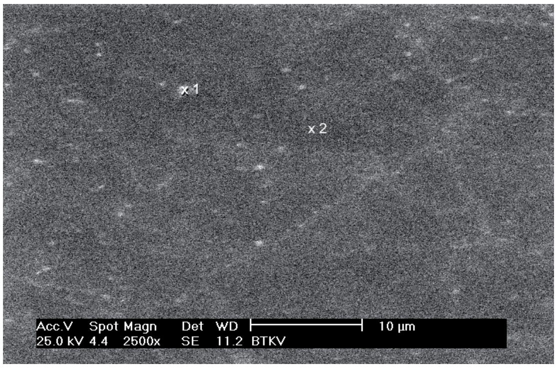

Fig. 6. SEM image of AZ61+T4, forged and cooled by water

It is evident from the Figures 5 and 6, that plastic deformation and precipitation at forming by forging run differently for the state after heat treatment T4 as well as for air and water cooled AZ 61alloy, respectively [9,10].

During forming of samples in state after heat treatment we have observed at lower amounts of deformation spheroidisation of fine phases in the area of grains and their progressive dissolving. In these areas, which form limited bright zones, re-crystallisation started at higher amounts of deformation (from 25 % of deformation,) – see Fig. 4. Re-crystallisation as well as precipitation was accomplished already at the 1st pass. Re-crystallisation begins in the areas of grains at the places, where we formerly observed the phase $Mg_{17}Al_{12}$, or $Mg_{17}(Al, Zn)_{12}$. During forming of samples after T4 the structural changes were effected by somewhat different mechanism. Re-crystallisation started sooner than in samples without heat treatment – already after 10 % of deformation. Volume of re-crystallised grains achieved at 30 % of deformation (3rd pass) almost 80 % [12,13], but thanks to forging technology it was achieved more than 95 %. We have observed at the same time intensive precipitation of fine phases both in the zone of grains and in the zone of slip bands in grains. The highest amounts of deformation were connected with formation of elongated grains and occurrence of slip bands. These phenomena [14,15] were less distinct in samples without heat treatment. We have determined higher formability in samples after heat treatment T4.

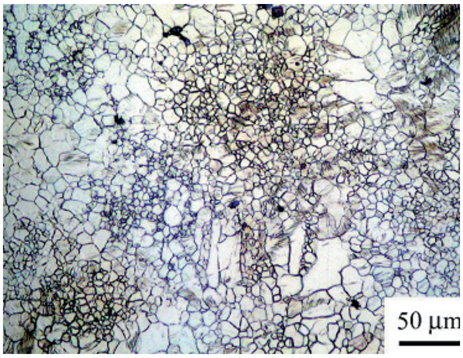

Fig. 7. AZ61+T4, forged and cooled by air

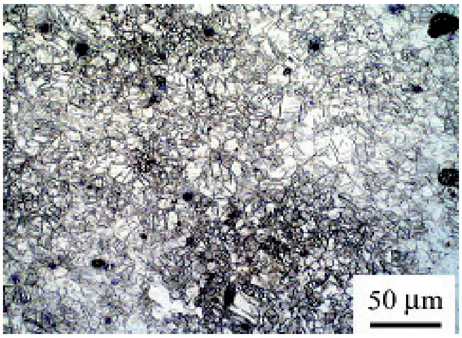

Fig. 8. AZ61+T4, forged and cooled by water

4. Conclusions

We have verified experimentally development of structure at forming of the modified alloy AZ91 at temperatures of 380°C and 420°C. Mechanism of deformation and range of re-crystallisation depends on type of initial microstructure and on its homogeneity. In samples without heat treatment there occurs in the area of grain boundaries dissolving of minority phases and partial re-crystallisation, particularly at higher deformations. Deformation of re-crystallised grains is limited, but even at the highest amounts of deformation we usually have not observed formation of slip bands or creation of fibrous structure. Scope of re-crystallisation is significantly smaller than in samples after heat treatment T4.

Re-crystallisation in samples after heat treatment T4 occurs in greater extent than in samples without heat treatment, practically after the first pass. At higher deformations there are formed slip bands, in which there occurs intensive precipitation of fine phases. There occurs also creation of fibrous microstructure. Water cooling medium was better for obtaining a finer structure than air which produced their growth as well as grain size but likewise longer time for feasible re-crystalization.

At higher deformations micro-cracks are formed, particularly on side surfaces. In samples after heat treatment T4 they have been observed only after the 5^{th} pass while after forging not have been observed anywhere, even if deformation was the same like before.

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