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Study of Selected Properties of Magnesium Alloy AZ91 after Heat Treatment and Forming*

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Due to its attractive properties, magnesium alloys has been successfully used in various structural applications. The results of tensile test, impact test and hardness test of magnesium alloy AZ91 after heat treatment and forming are presented.

1. INTRODUCTION

Magnesium alloys has been used for a wide variety of applications, namely from the reason of their low density and high strength–to–weight ratio. Low inertia, which results from its low density, is advantageous in rapidly moving parts, for example automobile wheels and other automobile parts. The similar situation is in the aeronautical market and air–frame application. Trends in magnesium alloys progress for the automotive market were analyzed recently by Magers [1].

Scope of utilisation of foundry magnesium alloys is continuously being extended, so if we want to operate as competitive producers, it is necessary to investigate very actively properties of individual alloys, optimise their chemical composition, study issues of their metallurgical preparation, verify experimentally their casting properties and conditions of successful casting of castings by individual methods, including thermal treatment. Recently, however, increases also utilisation of formed magnesium alloys [1-3].

2. EXPERIMENTAL PROCEDURES AND RESULTS

For the experimental study of selected mechanical properties the model magnesium alloy AZ91 was used. This model alloy was cast in the shape of plates and rods. Plate dimensions were 200x100x15 mm and the rod diameter was 12 mm.

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There were used two states of these alloys for next investigation:
-Initial casting alloy (casting into sand form) – signed A.
-Casting alloy with application of heat treatment in electrical vacuum furnace classic type 0816 Vak with argon atmosphere with next conditions of treating–signed B.

The following diagram shows the procedure used at individual types of heat treatment:
B1-TZ1 – pre-heating 375 °C/3 hours + 415 °C/18 hours (solid solution heat treatment –T4 after ASTM), air cooling
B2-TZ2 – pre-heating 375 °C/3 hours + 415 °C/18 hours, water cooling
B3-TZ3 - pre-heating 375 °C/3 hours + 415 °C/18 hours, cooling in the furnace – up to temperatures 200 °C. The samples were taken out of the furnace at the t = 23 °C
B4-TZ4 - pre-heating 375 °C/3 hours + 415 °C/18 hours, air cooling + 168 °C/8 hours (agening), air cooling
B5-TZ5 - pre-heating 375 °C/3 hours + 415 °C/18 hours, water cooling + 168 °C/8 hours, air cooling

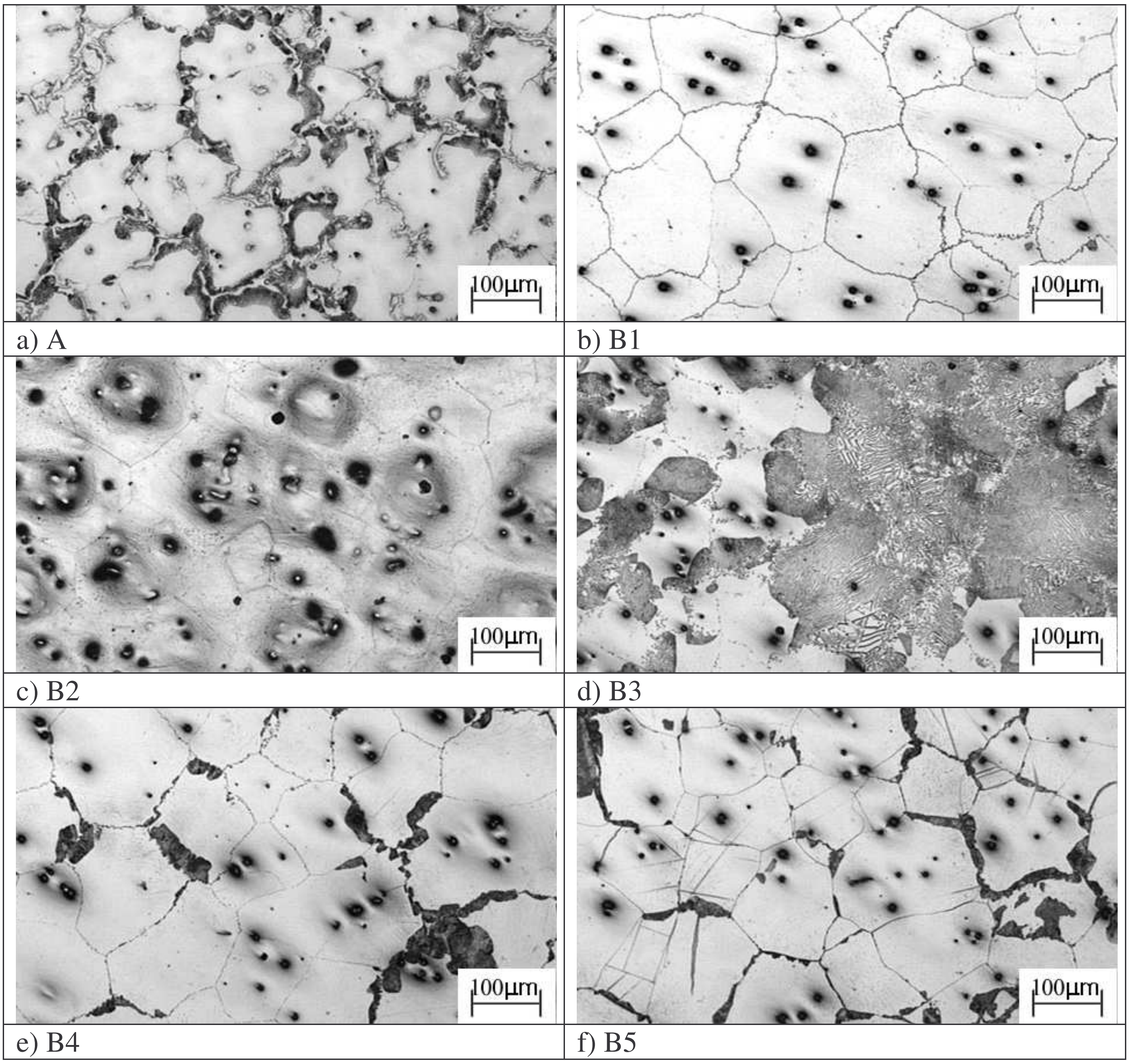
2.1 Structure and properties of alloy

The samples were etched in highly diluted Nital. The selected typical structure of this alloy in initial state (A) is shown in the Figure 1a , The basic structure of magnesium alloy AZ91 consists of solid solution matrix on the Mg base and massive γ- phase $Mg_{17}Al_{12}$, resp. $Mg_{17}(Al,Zn)_{12}$ with fine precipitates this phases near the grain boundary and was detailed described in papers [4,5]. We have chosen for future investigation five types of thermal treatment (marked as TZ1-TZ5, state B) in order to assess the impact of this thermal treatment on the alloy structure. The selected structures are given in the Figures 1b-f.

It is possible to observe similar differences in samples after heat treatment T4. At first the comparison makes it possible to observe further little magnification of the grain as compared with the initial state. It can also be seen that both massive and precipitated γ phase has been dissolved again. This is connected with the special shape of grain boundaries (meandering- Figures 1b-c.). It is also obvious from this analysis, suppose that applied heat treatment contributes to homogenisation of castings made of magnesium alloy. This homogenization is not so perfect, from the reason of observation new precipitates near grain boundary after agening Figures 1e-f. In Figures 1d we can see creation more fine precipitation phase γ namely near grain boundary. There is some difference in structure after agening Mg alloy with previous cooling in air and water (state B4 and B5, Figures 1e-f).In Figure 1f we can see the twinning in grain.

Tensile test:

The samples for tensile test were made from rod shape alloy. The results of tensile test, using INOVA TSM 50 tensile machine are given in Table 1.



a) A | b) B1 | c) B2 | d) B3 | e) B4 | f) B5

Figure 1. Structure of magnesium alloy AZ91 in initial state (A) and after heat treatment.

Table 1. Mechanical properties of the alloy AZ91

Sample	**Rp0,2 [MPa]**	**Rm [MPa]**	**A [%]**	**KCV [J]**	**Hardness HV**
A	118	180	4	2	50
B1	125	280	20	6	54
B2	125	282	22	6	53
B3	184	260	14	1,5	55
B4	129	267	14	5	54
B5	142	279	17	4	57

Impact test:

The samples for impact test- Charpy V-notch were made from plate shape alloy. The results of impact test- Charpy V-notch are given in Table 1.

Hardness:

Measurements of hardness were made on the polish surface of the plate A and B. The results of hardness are given in Table 1.

Measured mechanical properties correspond to structure investigations. The highest ultimate strength after heat treatment TZ2 was determined. Sample of heat treatment TZ3 showed lowest value of KCV from the reason highest content of precipitated γ phase.

2.2. Structure and properties of alloy after forming

Thanks to hexagonal structure magnesium and its alloys are characterised by limited cold formability. Forming techniques are therefore based mostly on hot forming. There were used cold forming and hot forming methods on two-high rolling mill with diameter of rolls 70 mm. The speed of rolling was 1,23.s^{-1}.

Cold forming:

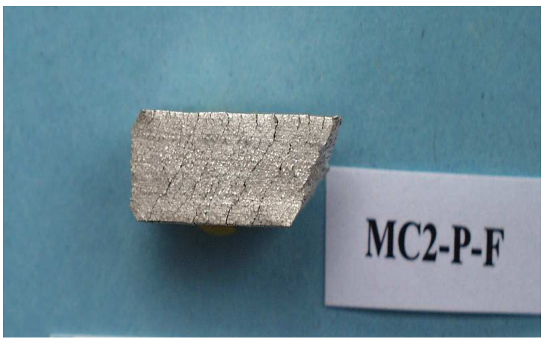
Cold forming was performed on prisms with dimensions 10x10x55 mm on sample A and B1. Results of study of cold forming on the given samples were the following:

- macro photographs of parts of samples after cold forming are shown in Figure 2. After failure of samples we analysed fracture surface after separation of individual parts of the sample.

-on the sample without thermal treatment there were applied 3 passes to failure, while on the sample with thermal treatment T4 there were applied 4 passes to failure. We choose a reduction of 0.6 mm for each pass.

Indication of first cracks was observed by one pass sooner before failure (at visual observation by a naked eye)

-direction of cracks across the sample was located approximately within the range of 45° in respect to the direction of rolling.

a) 

b) 

Figure 2. Macro photograph of magnesium alloy AZ91 a) State A, b) StateB1

Hot forming:

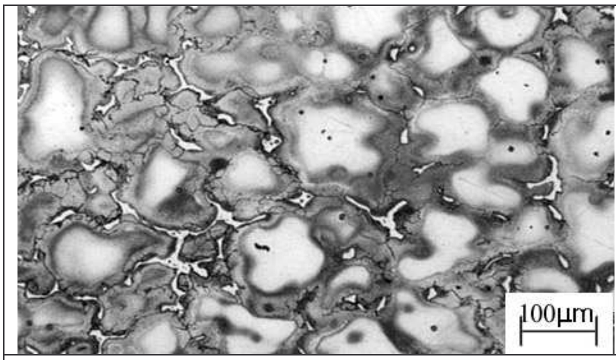
Hot forming was performed on prisms with dimensions 10x20x100 mm for sample of state A and B1 at forming temperature T_1=380°C and T_2=420°C. The speed of forming was the same as given above. Each pass represents thickness reduction approximately 1,5 mm. It means that deformation with increasing passes is increased. Heating of the samples was made between each pass. Results of study of hot forming on the given samples were the following:

- microphotographs of selected samples after hot forming are shown in Figure 3. The structures after hot forming (Figure 3b,d) is fine.

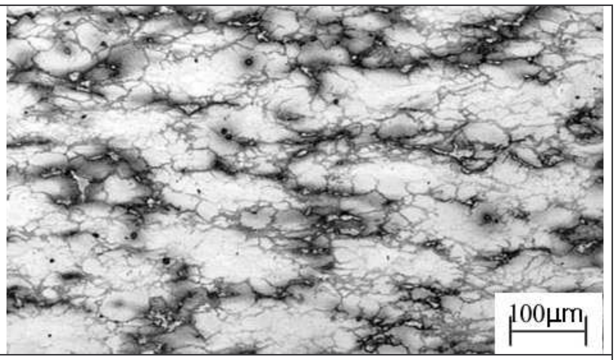
- on the sample without thermal treatment and with thermal treatment T4 there were applied 6 passes to failure. Indication of forming of first little cracks was observed by one pass sooner (at visual observation by a naked eye) on the sample without thermal treatment.

- observation of microstructure was completed measurements of hardness on the polish surface of the plate A and B perpendicular to rolling surface. The results of hardness are given in Figure 4. After next deformation the hardness were increased in agreement with process of hardening after strengthening and decreasing of grain.

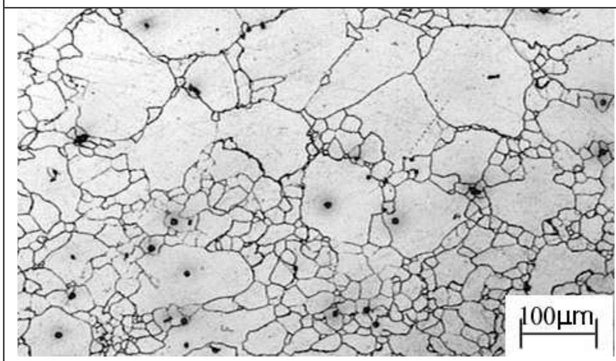
- for sample of state A more hardening at first passes were observed. For sample of state B1 more hardening at medium passes were observed.



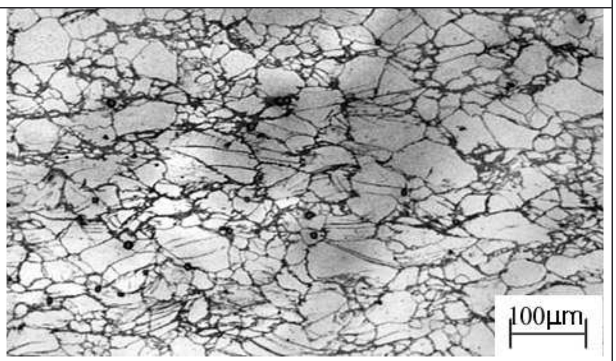
a) A- after 1st pass



b) A- after 4st pass



c) B1- after 1st pass



d) B1- after 4st pass

Figure 3. Structure of magnesium alloy AZ91 after hot rolling.

3. CONCLUSIONS

- Mechanical properties of model magnesium AZ91 cast alloy in initial and application next solution heat treatment (T4) state were tested.
- This measurement showed large scattering from the reason great inhomogenity of alloy AZ91

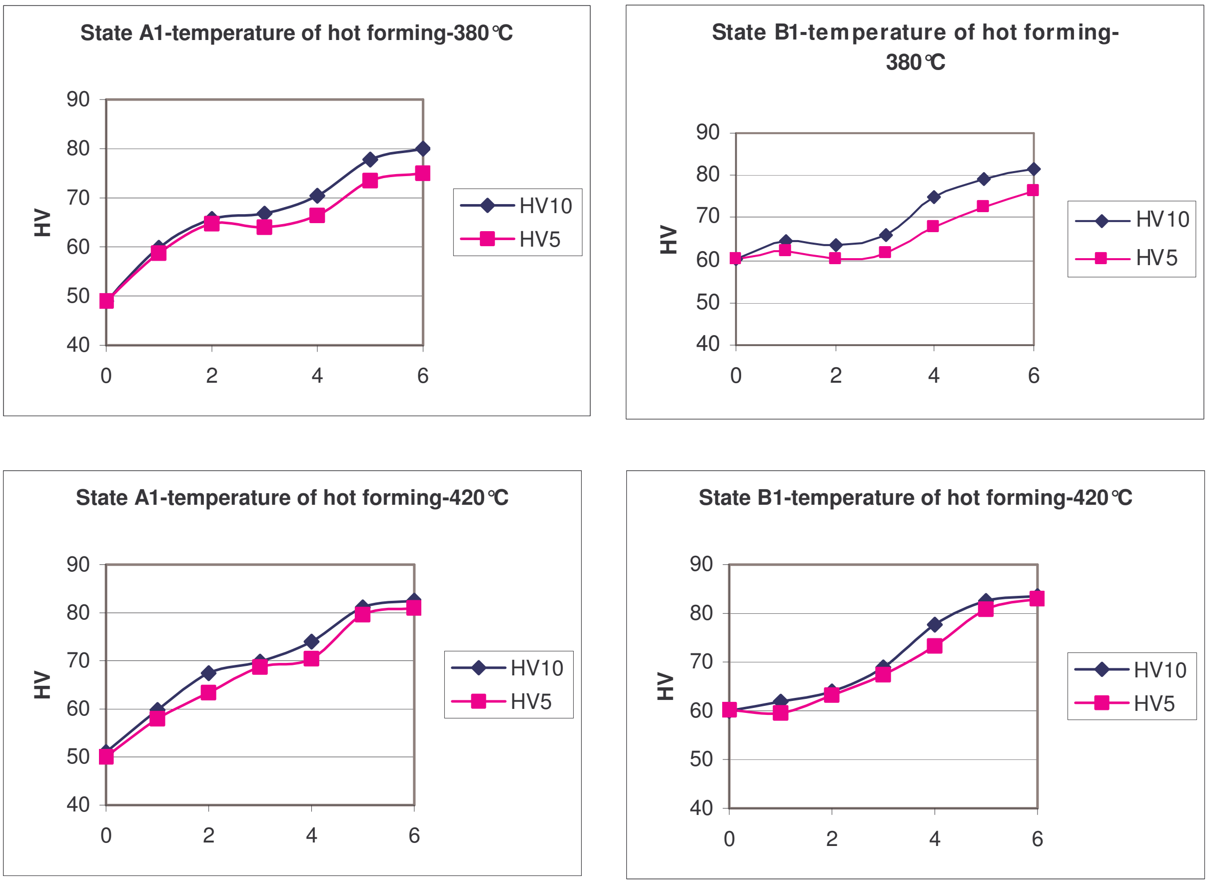


Figure 4. Hardness on the polish surface of the plate A and B perpendicular to rolling surface.

- It is also obvious from this analysis, suppose that applied heat treatment contributes to homogenisation of castings made of magnesium alloy.
- The results show the possibility of heat treatment for higher mechanical properties achievement.
- It is possible to form the casting alloys AZ91
- Much higher formability for application of hot forming method was observed.

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