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INVESTIGATION OF THE THERMOMECHANICAL PROPERTIES AND MICROSTRUCTURE OF SPECIAL MAGNESIUM ALLOYS

PREISKAVA TERMOMEHANSKIH LASTNOSTI IN MIKROSTRUKTURE POSEBNIH MAGNEZIJEVIH ZLITIN

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Thanks to their high specific strength together with a low density, magnesium-based alloys have an extensive potential for the use of their castings in automotive industry. The castings based on these materials show relatively good mechanical properties that decrease significantly with an increasing temperature of their thermal exposure. The aim of this work is to study the properties of two alloys commonly used (Mg-Al-Zn, Mn type). From the studied materials the test castings were made and these were formed into the test bars used for a tensile test. This test was carried out within the temperature range of 20–300 °C. Further on, the tests of the thermomechanical properties were complemented with a microstructure analysis with the aim of checking metallurgical interventions (the effect of inoculation).

Keywords: castings, magnesium alloys, thermomechanical properties, microstructure

Zaradi velike specifične trdnosti in majhne gostote imajo magnezijeve zlitine velik potencial za uporabo v obliki ulitkov v avtomobilski industriji. Ulitki iz teh materialov kažejo relativno dobre mehanske lastnosti, ki pa se močno zmanjšajo, če so izpostavljeni povišanim temperaturam. Namen tega dela je študij teh lastnosti pri dveh pogosto uporabljanih vrstah zlitine (Mg-Al-Zn, Mn). Iz preiskovanih materialov so bili izdelani preizkusni ulitki, iz katerih so bile pripravljene palice za natezne preizkuse. Ti so se izvajali v temperaturnem območju 20–300 °C. Ugotovitve termomehanskih lastnosti so bile dopolnjene z analizo mikrostrukture, namenjene za preverjanje metalurških ukrepov (učinek inokulacije).

Ključne besede: ulitki, magnezijeve zlitine, termomehanske lastnosti, mikrostruktura

1 INTRODUCTION

Magnesium alloys have always been very prospective materials, in particular for automobile and aircraft industries where the most important requirement is for a low weight or sufficiently high specific strength, i.e., the strength-characteristics-to-low-specific-weight ratio. In spite of the above mentioned reasons, a more extensive use of these alloys in the above industrial branches is limited by their low resistance to corrosion and a decrease in their mechanical properties under higher temperatures. Standard alloys are not stable under high temperatures and therefore not suitable for the applications, in which they would be stressed by such temperatures. In addition, a more advanced casting technology must be taken into account as magnesium and its alloys are highly reactive metals. But these difficulties can already be partly eliminated by choosing a suitable preparation in a liquid metal, moulding mixture or a protective atmosphere in a melting device.

The use of magnesium alloys in a car structure can considerably help in reducing the car weight without deteriorating its safety.[1]

2 DIVISION OF MAGNESIUM ALLOYS ACCORDING THEIR USES

The basis for the foundry magnesium alloys are binary alloys enhanced with additional alloying elements in order to improve technological properties, mechanical properties or to increase the corrosion resistance. There are the basic systems – Mg-Al, Mg-Zn and Mg-Mn. The most widespread magnesium alloys for manufacturing castings are the Mg-Al-(Zn, Mn)-type alloys. The advantages of these materials are as follows:

- They are well castable and have a low thaw point, which improves some other foundry characteristics;
- A proper alloying-element selection can eliminate the occurrence of casting defects – microshrinks and thermal cracks.

The AZ91 alloy is perhaps the most frequently used from this group.[2] A rather fast decrease in the strength when stressing them with a growing temperature is a disadvantage of these alloys. The alloys of the Mg-Al-Sr and Mg-Al-RE types could compensate for the low resistance to high temperatures with better microstructural stabilities and also fairly good strength properties[3] under these conditions. These parameters are decisive when using these materials for the parts that are exposed to a considerable thermal stress, e.g., engine blocks. In

Table 1: Chemical compositions of the used magnesium alloys in mass fractions, *w*/%
Tabela 1: Kemijska sestava uporabljenih magnezijevih zlitin v masnih deležih, *w*/%

Alloy	Element								
	Zn	Al	Si	Cu	Mn	Fe	Ni	Ca	Be	residue
AZ91D	0.56	8.80	0.06	0.004	0.20	0.004	0.001	0.000	0.000 7	<0.01
AZ91Be	0.62	8.22	0.03	0.001	0.15	0.006	0.000	0.000	0.009 0	<0.01
AMZ40	0.14	3.76	0.02	0.001	0.34	0.003	0.000	0.000	0.001 1	<0.01
AM60	0.07	5.78	0.03	0.001	0.33	0.003	0.001	0.000	0.000 9	<0.01

addition, another important requirement is the corrosion resistance (internal and external) because the majority of drive units are cooled with a liquid and the used materials have to be able to resist the corrosive effects of the cooling medium for a long time. The alloys retaining a sufficient strength under the temperatures of up to 250 °C are of the Mg-Y-RE, Mg-Sc and Mg-Gd types without an aluminium addition. These materials meet all the above mentioned requirements for industrial use, but a problematic issue is their economical availability. The requirement for a high resistance to creep is met by the magnesium alloys with thorium (up to the temperatures of 370 °C). Then, the Mg-Li type alloys belong to the lightest structural materials; however, it is difficult to manufacture and treat them.

3 DESCRIPTION OF THE USED ALLOYS

The main alloying element of magnesium alloys is aluminium. For the experimental evaluation both commonly used alloys (AZ91, AZ91Be, AM60) and the AMZ40 alloy were chosen as they had not yet been industrially processed in the Czech Republic. All the compared materials were supplied by a Czech manufacturer and **Table 1** shows their chemical compositions taken from the supplier's certificates.

4 PREPARATION OF THE TEST SAMPLES

Castings were gravity cast in an iron mould (**Figure 1**) that was preheated before the casting to achieve a sufficient running property of the metal. The

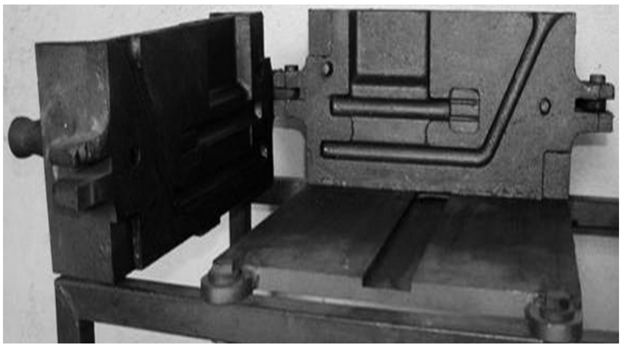

Figure 1: Metal mould for casting the test bars according to the ČSN 42 0334 standard
Slika 1: Kovinska kokila za ulivanje preizkusnih palic, skladna s standardom ČSN 42 0334

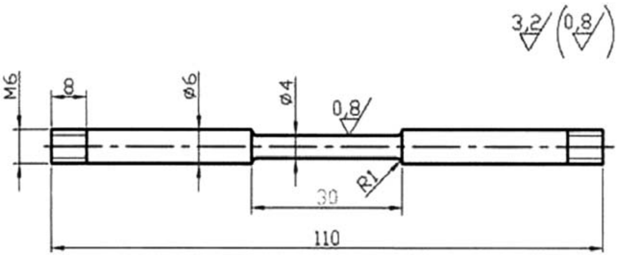

Figure 2: Scheme of a test bar destined for the general tensile test (dimensions are in millimeters)
Slika 2: Shematski prikaz preizkusne palice za natezni preskus (dimenzije so v milimetrih)

samples for the tensile test (**Figure 2**), the metallographic analysis and the measurements of the other mechanical properties were subsequently made from these castings. The material was melted in a steel crucible in an electric resistance furnace. To ensure the metal's protection during the melting, a covering preparation with a commercial product named EMGESAL was used to prevent excessive oxidation or burning on the melt surface.

During the measurement the temperatures of the metal mould and the cast alloy were observed for process checking and description.

To ensure the improved mechanical properties of the large-sized castings poured in the sand moulds, the melt was treated in foundries with a preparation based on hexachloroethane supplied under the commercial name of MIKROSAL MG T 200. After introducing the nuclei, the casting structure became finer and a fine-grained structure of the material with improved mechanical properties was formed. In our case this preparation was also used for the melt.

5 MICROSTRUCTURES OF THE CAST SAMPLES

The microstructures of the used alloys were evaluated in different parts of the casting from which the test bars were prepared. The differences between the structures of the observed materials could only be found in the central parts of the castings where the heat removal during the solidification and cooling was not so intensive. **Figures 3** and **4** show the microstructures of the AZ91 alloy cast in a preheated metal mould. In the AZ91 alloy without an inoculant addition (**Figure 3**) high shares of the $Mg_{17}Al_{12}$

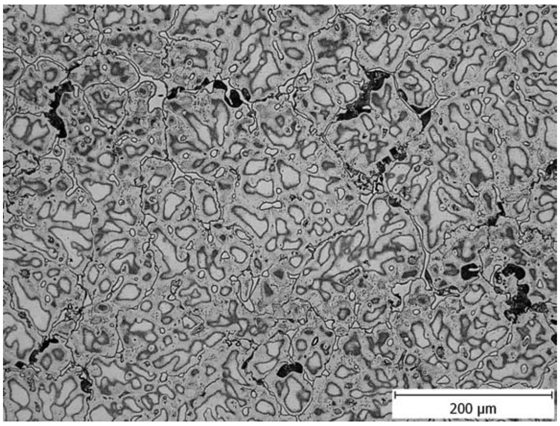

Figure 3: Non-inoculated material AZ91
Slika 3: Material AZ91 brez inokulacije

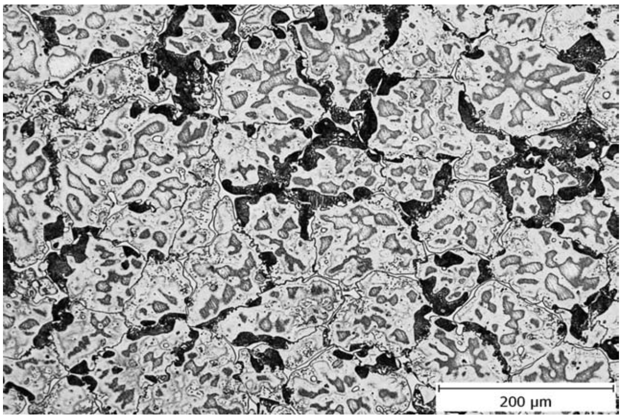

Figure 4: Inoculated material AZ91
Slika 4: Inokuliran material AZ91

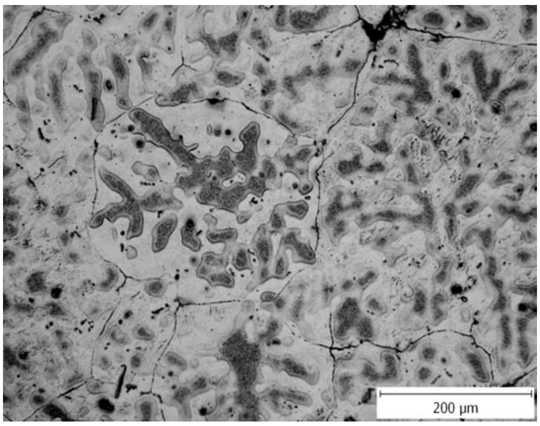

Figure 5: Non-inoculated material AM60
Slika 5: Material AM60 brez inokulacije

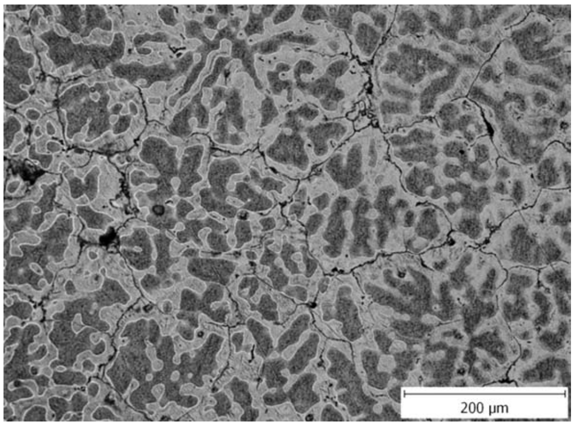

Figure 6: Inoculated material AM60
Slika 6: Inokuliran material AM60

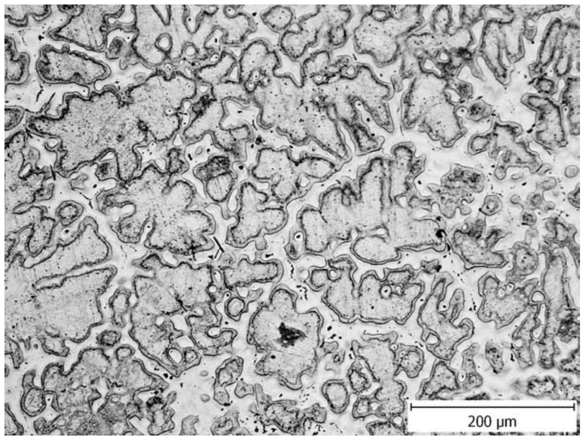

Figure 7: Non-inoculated material AMZ40
Slika 7: Material AMZ40 brez inokulacije

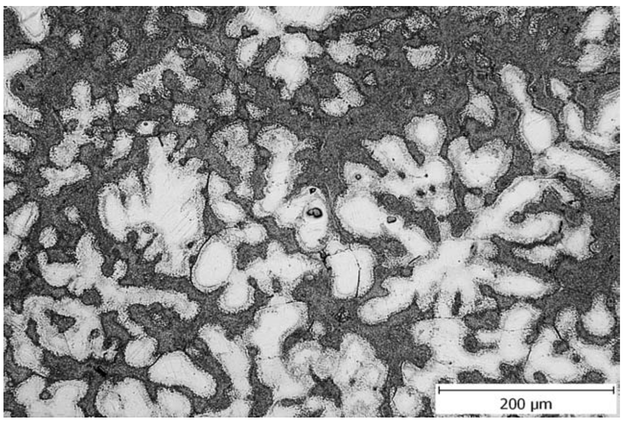

Figure 8: Inoculated material AMZ40
Slika 8: Inokuliran material AMZ40

tabular precipitate and α+β eutectic can be observed. In the alloy with an inoculant addition (**Figure 4**) the precipitate share was considerably higher. The situation was similar in the case of AZ91Be, an alloy with a beryllium addition.

The figures of the AM60 alloy microstructure evidently show lower proportions of the $Mg_{17}Al_{12}$ precipitate and the eutectic phase in the non-inoculated material structure (**Figure 5**) as well as in the inoculated one compared to the AZ91 alloys, due to a lower aluminium content in the alloy. There are apparent material grain boundaries in the microstructure figures and the inoculant-addition effect is clearly evident here (**Figure 6**). In the case of the AMZ40 alloy the difference between the

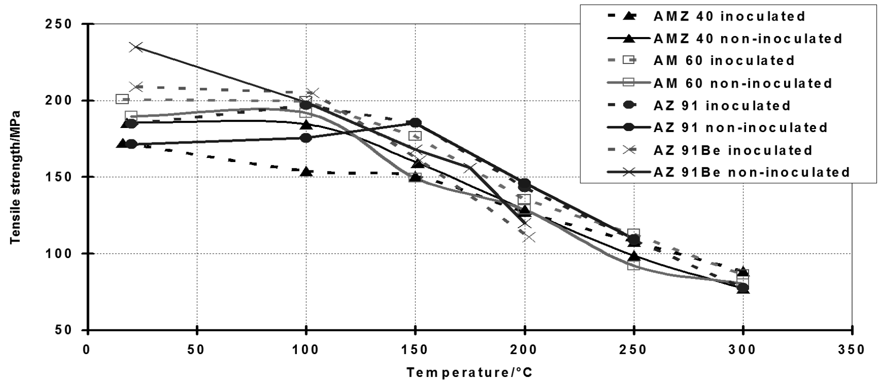

Figure 9: Thermal dependence of the tensile strength
Slika 9: Temperaturna odvisnost natezne trdnosti

non-inoculated material (**Figure 7**) and the inoculated one (**Figure 8**) is the least significant of all the studied alloys. This material structure with the minimum proportion of the $Mg_{17}Al_{12}$ precipitate is very close to the AM60 alloy due to their similar chemical compositions.

6 MEASUREMENT OF THE MECHANICAL PROPERTIES AT ELEVATED TEMPERATURES

The tensile test was carried out on a TSM 20 tension-testing machine. The elevated-temperature test was performed as a general one. When measuring mechanical properties, we carried out the above mentioned general test at room temperature and at elevated temperatures, beginning at 100 °C, at a gradient of 50 °C, up to 300 °C. The final temperature for the observed alloys varied and it was selected according to the possibilities, with respect to a limited amount of specimens. When testing at elevated temperatures, the holding time at the temperature for each specimen was 5 min for the temperature equalization on the surface and inside the specimen.

7 ACHIEVED RESULTS

The influence of the test temperature on the resulting values of the tensile strength of the materials was evaluated with the tensile test. The graph in **Figure 9** shows the results for the metallurgically untreated alloys and for the alloys influenced by the inoculating agent. The objectives of the tensile test were to compare the particular alloy types, observe the inoculation effect and the influence of the elevated temperature on mechanical properties (the tensile strength). The highest tensile strength values under room temperature were achieved for the AZ91Be alloy (above 200 MPa). As a matter of fact, the AZ91, AM60 and AMZ40 alloys showed the same tensile strengths. A considerable decrease in the tensile strengths of the AZ91, AZ91Be and AMZ40 alloys was observed with the growing test temperature. Below the temperature of 300 °C the lowest strengths of about 80 MPa were observed. The inoculation effect was more significant only for the AZ91 and AM60 alloys, where it was also reflected in the microstructures of these alloys. During the tests under room temperature a growth by 8 % or 10 %, respectively, was observed. With the growing test temperature (above 150 °C) the tensile strengths considerably decreased. The steepest drop was observed for the AZ91Be alloy where the tensile strength below the temperature of 200 °C was only about 120 MPa. In the case of the AMZ40 alloy there was no inoculation effect, which was also confirmed with the analysis of the given-alloy microstructure.

8 CONCLUSION

The presented work aimed at studying the thermomechanical properties of magnesium alloys. The highest tensile strength was achieved for the AZ91Be alloy at room temperature. The inoculation effect was more significant only at low temperatures and for the AZ91 and AM60 alloys, where a grain refinement was evident in the microstructures of the observed samples. In the other materials no structure refinement was observed, perhaps due to the extensive heat removal from the castings.

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