

## THERMOPHYSICAL AND THERMOMECHANICAL PROPERTIES OF SELECTED ALLOYS BASED ON MAGNESIUM

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The paper is focused on very perspective magnesium alloys. It deals with observation of thermophysical and thermomechanical properties of two magnesium alloys (AMZ40 and AJ62). This article describes preparation of cast specimens and methods of assessment of their thermophysical properties. Influence of metallurgical processing (inoculant) upon the parameters observed was studied as well. Microstructures of the obtained materials are documented.

*Keywords:* magnesium alloys, thermophysical properties, tension test, microstructure

### INTRODUCTION

Utilization of light metal (aluminum and magnesium) alloys in a car structure can contribute to reduce the car weight noticeably without deterioration of safety [1]. Recent studies indicate using aluminum in a lower middle class car as price comparable for example with the use of hybride technologies and fuel savings are almost the same as well [2]. Broader use in these industrial fields, despite of all the reasons mentioned above, is restricted by their low corrosion resistance [3] and worse mechanical properties at elevated temperatures. Standard alloys are not stable enough at higher temperatures therefore they are not advisable for these applications where they are subjected to such temperatures. Further, more difficult casting technology should be considered, because magnesium and its alloys belong among very reactive metals. However, these difficulties can be partly eliminated by using an effective inoculant to liquid metal, sand mixture or protective atmosphere in the melting aggregate.

A condition of being cost-effective material is met by Mg-Al system magnesium alloys. Mg-Al, Mg-Al-Zn, Mg-Al-Mn alloys belong among the most widely used materials. AZ91 [4] is the most widely used alloy of this group. A disadvantage of these alloys is a relatively fast strength decrease with increasing stressing temperature. Mg-Al-Sr and Mg-Al-RE type alloys could solve low resistance against high temperatures because they reach better microstructural stability and also quite good tensile properties under these conditions. These parameters are decisive in using these materials for highly thermally stressed components, e.g. engine blocks. Apart from that, corrosion resistance (inner as

well as outer) is another significant requirement because most of drive units are liquid-cooled and used materials must be able to resist cooling medium corrosion effects on a long term basis. Alloys featuring satisfactory strength up to 250 °C temperature are of Mg-Y-RE, Mg-Sc and Mg-Gd type, without aluminum addition [5].

The aim of development in the magnesium alloy sphere is to obtain materials featuring high strength at normal as well as elevated temperatures, good ductility and acceptable price above all.

### PREPARATION OF THE TEST SPECIMENS

For the observation of thermophysical properties, magnesium alloys AMZ 40 and AJ 62 were chosen. Their chemical composition according to the supplier's attests (Table 1). These materials have not been used in the Czech Republic industrially.

Castings were gravity-cast into a cast iron mould which was preheated ( $450\text{ °C} \pm 30\text{ °C}$ ) before casting in order to reach sufficient metal fluidity. Figure 1 shows a casting model which was acquired using Rhinoceros 3D program. The casting was cast into the bottom gate and was topped-up by a massive casting in the upper part to achieve directional solidification and elimination of possible inner defects occurring during solidification. Specimens were made of these castings for the tensile test (Figure 2), metallographic analysis and measurement of other thermophysical properties of selected magnesium alloys.

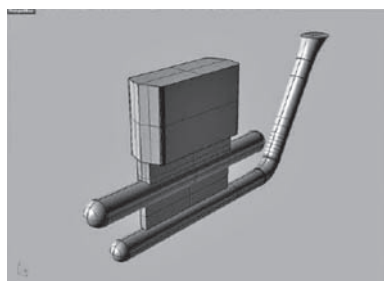
Magnesium alloys were molten in a steel crucible in an electric resistance furnace.

The molten metal protection was provided by a covering and refining preparation EMGESAL. To verify the inoculation effect with the aim to achieve better mechanical properties, the melt was treated with MIKRO-SAL MG T 200. The casting structure was refined due

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**Table 1** Chemical composition of used magnesium alloys / wt. %

alloy	Element									
	Zn	Al	Si	Cu	Mn	Fe	Ni	Ca	Be	residue
AMZ 40	0,14	3,76	0,02	0,001	0,34	0,003	0,000	0,000	0,001	<0,01
AJ 62	0,01	5,78	0,04	0,001	0,35	0,003	0,001	0,008	0,001	<0,01



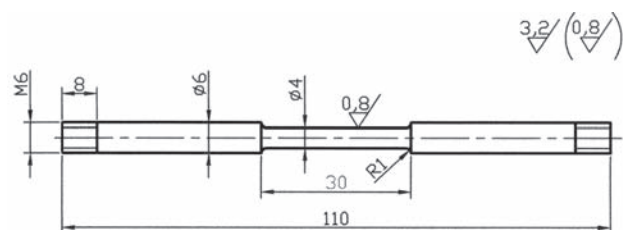
**Figure 1** Test bar cast into the metal mould for the tensile test according to created in Rhinoceros 3D

to nuclei introducing and fine-grained structure with better mechanical properties was originated [6]. In order to reduce ignition of the liquid metal and development of alloy oxides, sulphur powder was introduced into the metal flow. During the very casting of the particular testing specimens, the liquid metal temperature as well as the metal mould temperature was observed in order to ensure equal casting conditions preferably.

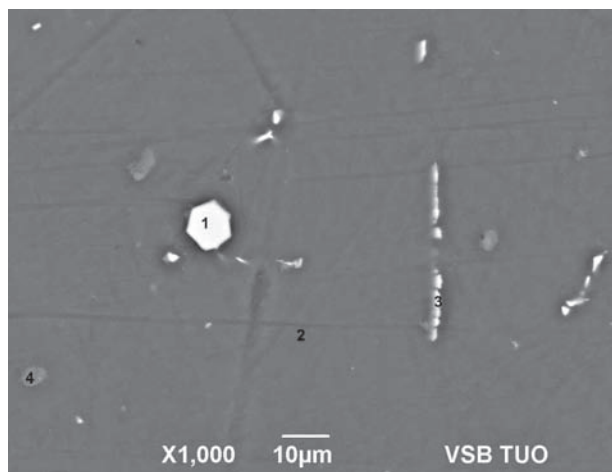
**MICROSTRUCTURE TESTS**

With regard to microstructure the prepared samples were examined on a scanning electron microscope (SEM) with X-ray energy-dispersion superficial and spot microanalysis (EDAX). In Figure 3, AMZ40 alloy structure without addition of an inoculant (mould temperature 420 °C, metal temperature 650 °C) is shown. Figure 4 shows the same material structure with addition of an inoculant (mould temperature 460 °C, metal temperature 680 °C). The structure of these materials is completely identical, with a basic matrix (No. 2) with prevailing proportion of Mg. The most distinctive structure components are particles marked with No. 1 in which Mn has the largest apportionment and they are of Mn-Al type. No. 3 represents the Mg-Al-Mn type material structure component and No. 4 shows Mg<sub>2</sub>Si precipitates, in some case complex phases of Mg-Si-Al.

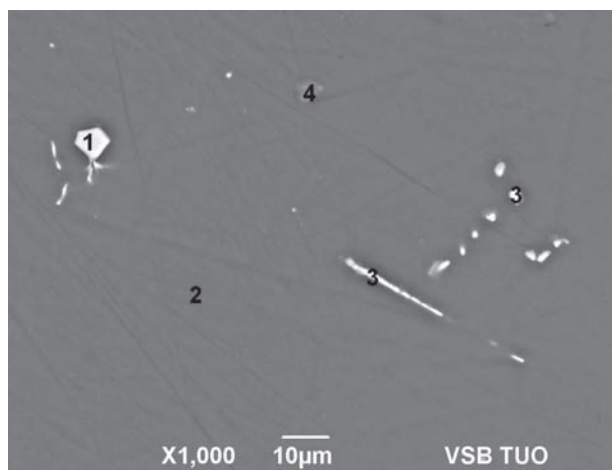
Figure 5 shows the microstructure of the non-inoculated alloy (mould temperature 430 °C, metal temperature 700 °C) and the microstructure of the alloy with



**Figure 2** Sheme of the test bar destined for the general tensile test, dimensions are / mm



**Figure 3** AMZ40 non-inoculated alloy



**Figure 4** AMZ40 inoculated alloy

addition of an inoculant is shown in Figure 6 (mould temperature 440 °C, metal temperature 650 °C). The structure is formed by a solid solution α (marked with No. 4), then along the grain boundaries there are visible precipitates of other alloy components and various intermetallic phases. Ratio of the Sr/Al content for this alloy is 0,51. With ratio higher than 0,3 the ternary Mg-Al-Sr (Al<sub>3</sub>Mg<sub>13</sub>Sr) complexes are formed in this alloy represented with particles designated 2, 3 (Figures 5 and 6).

Further on the phases rich with Mg and Al (number 5) are identified in the structure; the intermetallic phase of Mg<sub>17</sub>Al<sub>12</sub> can be a question here. In the case of the inoculated alloy the clearly visible particles (designated 1) were identified in the structure that contained, besides the important Al and Mg content, great amount of manganese, too.

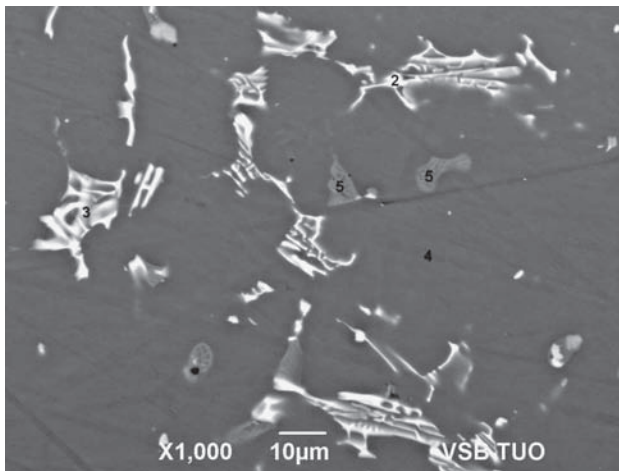


Figure 5 AJ62 non-inoculated alloy

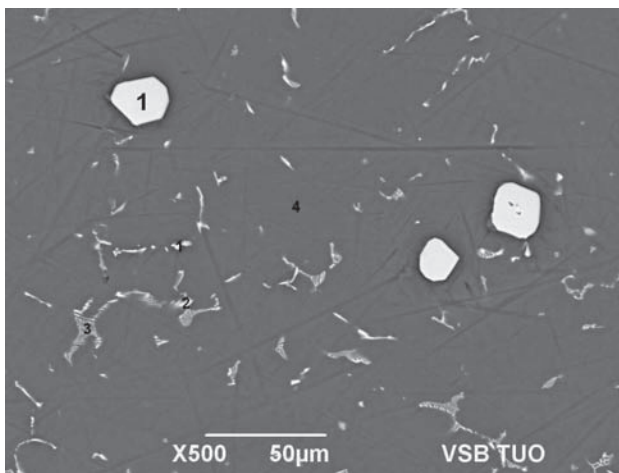


Figure 6 AJ62 inoculated alloy

### TESTS AT ELEVATED TEMPERATURES

The tensile test was carried out on TSM 20 device made by INOVA Praha according to ČSN 42 0310. The elevated temperature test is performed as a general one. When measuring mechanical properties, the above mentioned general test at room temperature and at elevated temperatures (100 – 300 °C with a gradient 50°C) were carried out. The final temperature for the observed alloys varied and it was selected according to possibilities by reason of a limited amount of specimens. During the test, the specimens were protected against oxidation in argon protective atmosphere to avoid oxidation of fracture areas. In Figure 7, the diagram of the resulting tensile strengths of the tested alloys is shown; they were observed at room temperature and then at elevated temperatures (100, 150, 200, 250 and 300 °C).

The results imply that AMZ40 alloy reaches substantially higher strength at room temperatures (up to 185 MPa in the case of the inoculated material) compared to AJ62 alloy (95 MPa in the case of the non-inoculated material). This trend can be noted up to the test temperature 250 °C. Equalization occurs at 300 °C temperature.

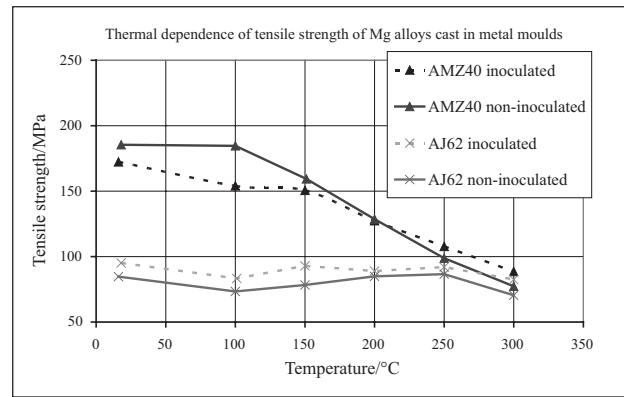


Figure 7 Tensile strength of the selected alloys in dependence on the test temperature

For AMZ40 alloy, the positive effect of the inoculant addition was not noted. For AJ62 alloy a contrary phenomenon can be noted, this effect is evident here within the whole test temperature interval. Higher temperature stability is also evident for this alloy, strength characteristics vary only minimally in the whole test temperature interval.

### THERMOPHYSICAL PROPERTIES

Thermal analysis (DIL) was employed for determination of thermophysical properties of selected magnesium alloys. The material thermal expansivity (linear changes) is characterized typically by the length expansion coefficient:

$$\alpha_T = \frac{l_T - l_{T_0}}{l_{T_0}(T - T_0)} = \frac{1}{l_0} \left( \frac{dl}{dT} \right) \quad (1)$$

where:  $\alpha_T$  – length expansion coefficient

$l_0$  – specimen length at a reference (e.g. laboratory) temperature

$dl_{T_0}$  – specimen length change

$dT$  – temperature difference

Changes of properties of magnesium alloy specimens were observed with the aid of DIL 402C/7 dilatometer made by Netzsch GmbH at the temperature interval  $20 \pm 5$  °C up to 350 °C with constant heating and cooling rate in the protective argon atmosphere. The dilatometric analysis was carried out for the specimens of thermally untreated materials (marked lab. T.) and specimens that were annealed to 350 °C temperature in order to simulate behavior of castings in operational conditions. Figures 8 and 9 imply an evident effect of the inoculants upon the resulting expansivity of magnesium alloys.

The maximum dilatation rate was found out for the non-inoculated alloys of thermally untreated materials (AJ62: 0.98 %; AMZ40: 0.93 %). By thermal stress simulating real conditions a lower dilatation rate was found out for the tested specimens, both for the inoculated alloys and for the non-inoculated ones.

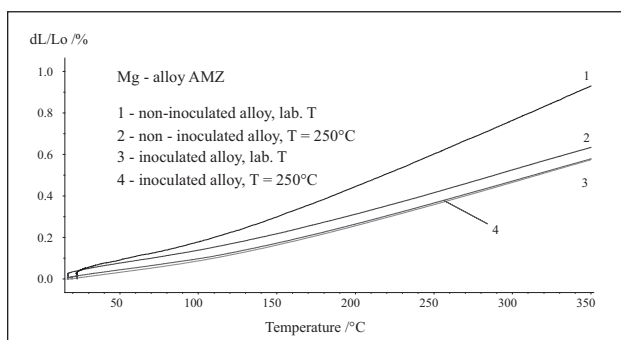


Figure 8 Dilatometric characteristics of AJ62 alloy specimens

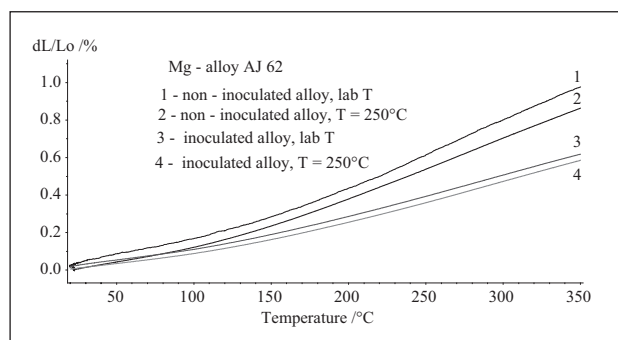


Figure 9 Dilatometric characteristics of AMZ alloy specimens

## CONCLUSION

For selected Mg alloys an inoculation effect upon structure, thermomechanical properties and selected dilatation characteristics was assessed. One can assume that better tensile strength for the given material can be reached by additional heat treatment. In term of thermophysical properties (linear expansivity) the noticeable effect of the inoculant was confirmed for the both observed alloys. This phenomenon is essential especially for the use of these alloys for thermally stressed castings, e.g. combustion engine cylinder heads.

## Acknowledgement

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## REFERENCES

- [1] D. Vojtěch: *Metalurgija*, 49 (2010)3, 181-185.
- [2] M. Holtzer; R. Daňko; S. Žymankowska-Kumon: *Metalurgy*, 51 (2012)3, 337-340.
- [3] J. Przondziono, W. Walke, A. Szula, E. Hadasik, J. Szala, J. Wieczorek: *Metalurgija*, 50 (2011)4, 239-243.
- [4] S. Roskosz, J. Adamiec, M. Błotnicki: *Archives of Foundry Engineering*, 7 (2007), 143-146.
- [51] K. N. Braszczyńska-Malik, A. Žydek, A. Polis: *Archives of Foundry Engineering*, 8 (2008), 19-22.
- [6] M. Pohludka, J. Malcharczikova, M. Kurša: *METAL 2011: (International conference on metallurgy and materials)*, 20 (2011), 947-950.

**Note:** The responsible translator for English language is Zdeňka Kunčická, Ostrava, Czech Republic