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Microstructure and Thermomechanical Properties of Magnesium Alloys Castings

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Abstract

Magnesium alloys thanks to their high specific strength have an extensive potential of the use in a number of industrial applications. The most important of them is the automobile industry in particular. Here it is possible to use this group of materials for great numbers of parts from elements in the car interior (steering wheels, seats, etc.), through exterior parts (wheels particularly of sporting models), up to driving (engine blocks) and gearbox mechanisms themselves. But the use of these alloys in the engine structure has its limitations as these parts are highly thermally stressed. But the commonly used magnesium alloys show rather fast decrease of strength properties with growing temperature of stressing them. This work is aimed at studying this properties both of alloys commonly used (of the Mg-Al-Zn, Mn type), and of that ones used in industrial manufacture in a limited extent (Mg-Al-Sr). These thermomechanical properties are further on complemented with the microstructure analysis with the aim of checking the metallurgical interventions (an effect of inoculation). From the studied materials the test castings were made from which the test bars for the tensile test were subsequently prepared. This test took place within the temperature range of 20°C – 300°C. Achieved results are summarized in the concluding part of the contribution.

Keywords: Mechanical Properties, Metallography, Magnesium Alloys, Thermomechanical Properties

1. Introduction

Magnesium alloys all the time belong to very prospective materials in particular for automobile and aircraft industry where the most important demand is low weight or sufficiently high specific strength, i.e. the strength characteristics to low specific weight ratio. In spite of the above mentioned reasons the more extensive use in these industrial branches is limited with their low resistance to corrosion and worse mechanical properties under higher temperatures. Standard alloys under higher temperatures are less stable and therefore they aren't suitable for such applications where they are stressed with such temperatures. In addition to it the more difficult casting technology must be taken into account as magnesium and its alloys belong to highly reactive metals. But these difficulties can be already partly eliminated by the choice of a suitable preparation in the liquid metal, moulding mixture or the protective atmosphere in the melting device.

The use of light metal alloys (aluminium and magnesium) in the car structure can considerably help in lowering the car weight without deteriorating its safety. A study of the Aachen University of Technology shows that the use of aluminium in a lower mid-class car is price comparable e.g. with the use of hybrid technologies and the fuel savings are almost concordant too. Lighter aluminium cars have far better road qualities than heavy hybrids from steel materials. This will enable to lower also the costs and demands to drive units. With the use of high-strength steel only 11 percent of weight can be saved with preserving the present structure strength. Aluminium is able to achieve 40 percent of savings. Similar results can be expected when using magnesium alloys too.

2. Division of magnesium alloys according their use

Magnesium alloys are most often marked according to the American system ASTM. Every alloying element corresponds here to a relevant letter (e.g. A – aluminium, M – manganese, Z – zinc, S – silicon, Z – zinc, J – strontium, RE – rare earth metals, etc.) and further on its average percentage content. A condition of an economically available material is met by magnesium alloys of the Mg-Al system. Mg-Al, Mg-Al-Zn, Mg-Al-Mn alloys belong to the most frequently used materials. Then the AZ91 (9 weight % Al, 1 weight % Zn) alloy is perhaps the most frequently used one from this group. A rather fast decrease of strength with growing temperature of stressing them is a disadvantage of these alloys. The alloys of the Mg-Al-Sr and Mg-Al-RE types could solve the low resistance to high temperatures because under these conditions they achieve a better microstructural stability and also fairly good strength properties. These parameters are decisive for using these materials for thermally considerably stressed parts, e.g. engine blocks. In addition to it an another important demand is the corrosion resistance (internal and external ones) because a majority of drive units is 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 with sufficient strength up to temperatures of 250°C are of the Mg-Y-RE, Mg-Sc, and Mg-Gd types without the aluminium addition. These materials meet all the above mentioned conditions for industrial use but a problematic question is their economical availability. A condition of high resistance to creep is met by magnesium alloys with thorium (up to temperatures of 370°C) that is, however, slightly radioactive and the technology of preparing and using them is controlled with special processes. Then among the lightest structural materials at all belong the alloys of the Mg-Li type that are, however, also characterized by difficult way of their manufacture and treatment.

Development in the field of magnesium alloys (Fig. 1.) is aimed at obtaining the materials with high strength under normal and elevated temperatures, good ductility, and acceptable price in particular. These characteristics are decisive ones for meeting a condition of their more extensive use.

Methods of magnesium alloy casting can be divided to casting into expendable moulds (sand moulds and shells) and into metal moulds (gravity, low-pressure and pressure casting). In recent years, manufacture of castings into metal moulds using semisolid metalworking methods etc. has been expanded, where input material is in semisolid state. By these procedures, higher product quality with internal defect elimination can be obtained.

A specific foundry problem is high flammability of magnesium alloys in molten state. Molten metal has to be protected with an appropriate slag or atmosphere which is generated on the hot metal surface when sublimed sulphur is burning. At present, gaseous atmospheres are mostly mixtures of air, carbon oxide and sulphur hexafluoride [1-4].

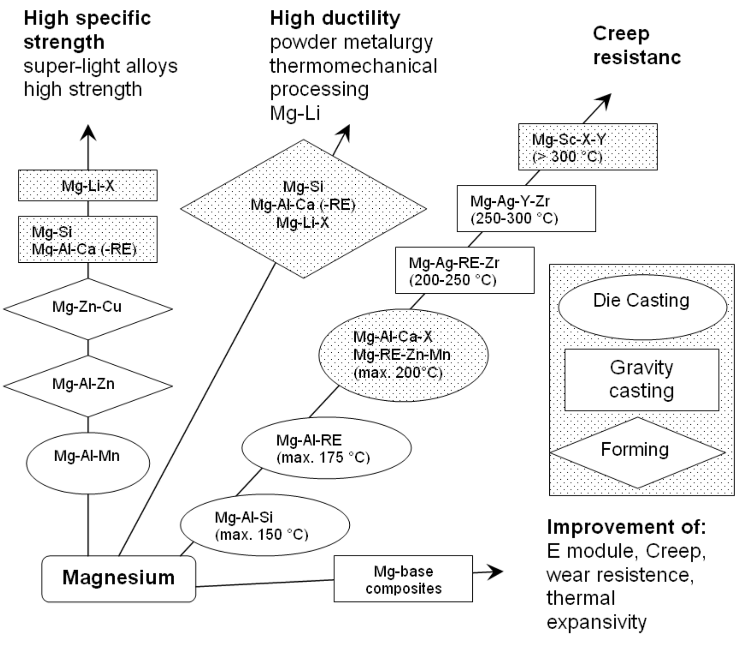

Fig. 1. Magnesium alloys development trends [1, 2]

Table 1.
Chemical composition of used magnesium alloys

alloy	element [%]									
	Zn	Al	Si	Cu	Mn	Fe	Ni	Ca	Be	residue
AZ 91D	0,56	8,80	0,06	0,004	0,20	0,004	0,001	0,000	0,0007	<0,01
AZ 91Be	0,62	8,22	0,03	0,001	0,15	0,006	0,000	0,000	0,0090	<0,01
AMZ 40	0,14	3,76	0,02	0,001	0,34	0,003	0,000	0,000	0,0011	<0,01
AJ 62	0,01	5,78	0,04	0,001	0,35	0,003	0,001	0,008	0,0006	<0,01

3. Description of used alloys

The main alloying element of magnesium alloys is aluminium. For experimental evaluation both commonly used alloys (AZ 91, AZ 91 Be), and the AMZ 40 and AJ 62 alloys too were chosen that weren't industrially processed in the Czech Republic yet. All the compared materials were supplied by a Czech manufacturer and Tab. 1. gives their chemical composition according to the supplier's certificate.

4. Preparation of test samples

Castings were gravity cast in a cast iron mould (Fig. 2.) that was preheated before casting for the reason of achieving a sufficient running property of metal. Samples for the tensile test (Fig. 3.), metallographic analysis, and measurements of other mechanical properties were subsequently made from these castings.

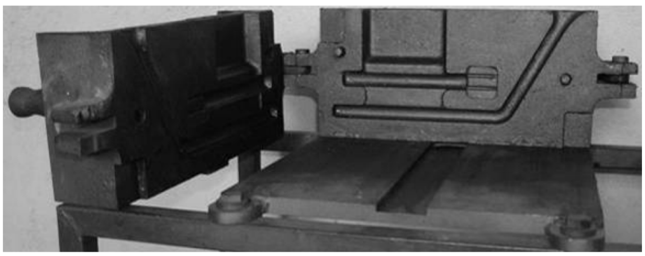

Fig. 2. Metal mould for casting the test bars according to the ČSN 42 0334 standard

The material was melted in a steel crucible in an electric resistance furnace. For ensuring the metal protection during melting a covering preparation of a commercial name EMGESAL was used that served against excessive oxidation or burning on the melt surface. During the pouring itself the ground sulphur was dusted in the metal stream for limiting the development of the alloy oxides on the flowing metal surface. During the own measurement the temperatures of the metal mould and the cast alloy were observed for process checking and description.

For ensuring the improved mechanical properties of more large-sized castings poured in sand moulds the melt is treated in foundries with a preparation based on hexachloroethane supplied under the commercial name of MIKROSAL MG T 200. In consequence of introducing the nuclei the casting structure becomes to be finer and a fine-grain structure of improved mechanical properties is formed. This preparation was used in the melt in our case too.

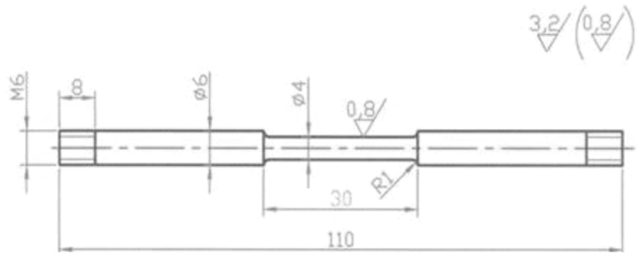

Fig. 3. Scheme of the test bar destined for the general tensile test, dimensions are in mm

5. Microstructure of cast samples

Microstructure of used alloys was evaluated on a casting part from which the test bars were prepared. Structures on its edge were observed, i.e. the parts where the heat transfer was the most intensive, and central parts where the material was less influenced by the metal mould. Figs. 4 – 7 show microstructures of the AZ 91 alloy cast in the metal mould preheated to temperature of 461°C (Figs. 4 and 5) and temperature of 420°C (Figs. 5. and 6.). Microstructure on Figs. 4 and 6 corresponds to structure in the central casting part. Figs. 5 and 7 show the casting microstructure in the point of its contact with the metal mould. It is evident from the figures that the inoculation effect (Figs. 6 and 7) cannot be identified unambiguously on metallographic samples. More conspicuous difference is only in the case of Fig. 5 where partial coarsening of structure can be observed. In the AZ 91 alloy a high share of the $Mg_{17}Al_{12}$ tabular precipitate and α+β eutectic can be observed. In the alloy with the inoculant addition the precipitate share was considerably higher.

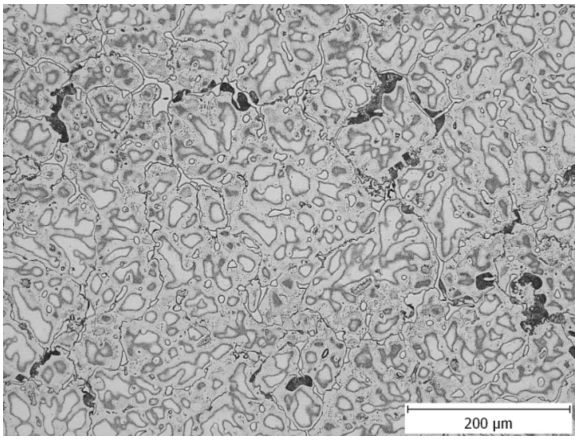

Fig. 4. Non-inoculated material AZ 91 the casting central part

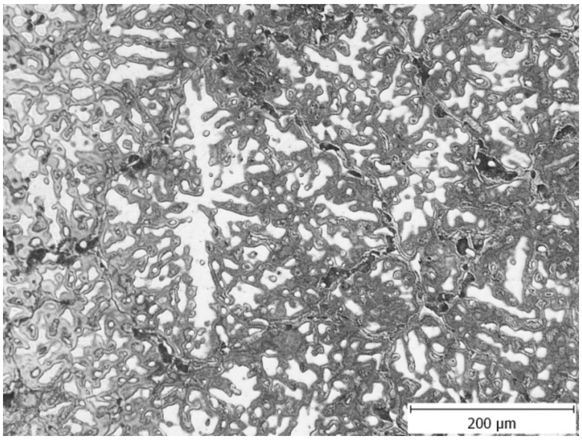

Fig. 5 Non-inoculated material AZ 91 the casting edge

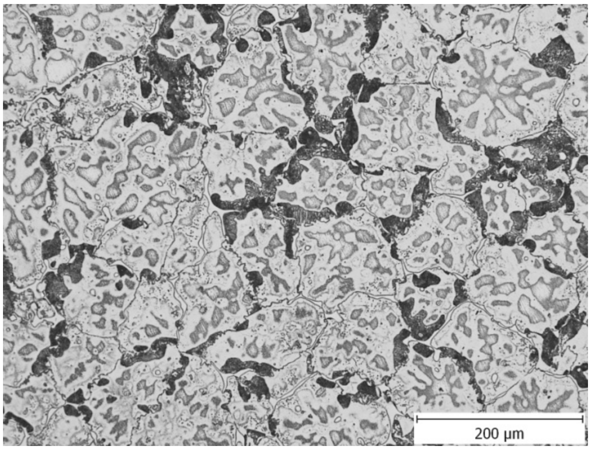

Fig. 6 Inoculated material AZ 91 the casting central part

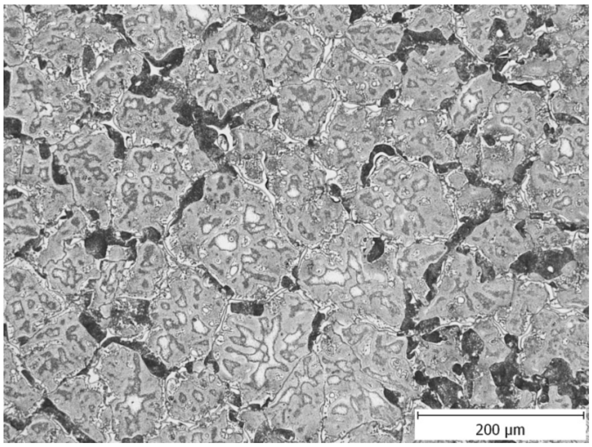

Fig. 7. Inoculated material AZ 91 the casting edge

6. Measurement of mechanical properties at elevated temperatures

The tensile test was carried out on the TSM 20 tension testing machine made by INOVA Praha company. The device enables to carry out the tensile test according to ČSN 42 0310 and a so-called general test which allows setting of test conditions in wide limits in six separate steps. The elevated temperature test is performed as a general one. When measuring mechanical properties, we carried out the above mentioned general test at room temperature and at elevated temperatures with beginning at 100ºC and a gradient by 50°C up to 200 – 300ºC temperatures. The final temperature for the observed alloys varied and it was selected according to possibilities by reason of a limited amount of specimens. When testing at elevated temperatures, holding time at the temperature for each specimen was applied for 5-minute period for temperature equalization on the surface and inside the specimen. During the test, the specimens were protected against oxidation in argon protective atmosphere to avoid oxidation of fracture areas. Analysis of mechanical properties was extended by a tensile test with work-of-fracture determination. Plasticity is defined as contraction in a place of breakage of specimens after the performed tensile test.

7. Achieved results

Influence of the test temperature on resulting values of tensile strength of materials was evaluated with the tensile test. The graph on Fig. 8. contains results for alloys metallurgically untreated and for alloys influenced with inoculating agent too. The tensile test was done especially for comparison of individual alloy types, for observation of inoculation effect and the influence of elevated temperature on mechanical properties (tensile strength).

Absolutely the highest tensile strength values under the room temperature are achieved in the AZ 91Be alloy, i.e. the alloy with higher beryllium content. The AZ 91 and AMZ 40 alloys show as a matter of fact the same tensile strength. The lowest values about

90 MPa under room temperature were achieved in the AJ62 alloy. Considerable decrease of tensile strength of the AZ 91, AZ 91Be, and AMZ 40 alloys is observed with growing test temperature. Under the temperature of 300°C the lowest strengths about 80 MPa were monitored. The inoculation effect was more considerable in the AZ 91 and AJ 62 alloys only. During the tests under the room temperature the growth by 8 % or 12 % respectively was observed. With growing test temperature (above 150°C) the tensile strength considerably decreases. The steepest drop was observed in the AZ 91Be alloy where the tensile strength under the temperature of 200°C ranges about 150 MPa only.

8. Conclusion

The presented work was aimed at studying the thermomechanical properties of magnesium alloys based on aluminium, zinc, manganese, and strontium. The highest strengths under the room temperature were achieved in alloys with the beryllium addition (AZ 91Be) that, however, with growing temperature showed the steepest drop. In the tensile test with thermal stress of 150°C considerable drop of strength of studied alloys was observed. Considerably different course was observed in the AJ 62 alloy. In this material the measured values were the lowest ones but with growing stressing temperature they showed in effect the same values. This fact can be caused by unsuitable choice of the casting process (gravity casting). The studied material should achieve substantially higher mechanical properties with other casting process (e.g. die casting). Great differences between the used materials can be seen from measured values. The inoculation effect was more considerable under lower temperatures only, and namely in the AZ 91 and AJ 62 alloys. In other materials the structure refinement wasn't observed perhaps thanks to extensive heat removal from the casting. The research in this field will continue particularly in case of newly developed magnesium alloys of the Mg-RE type.

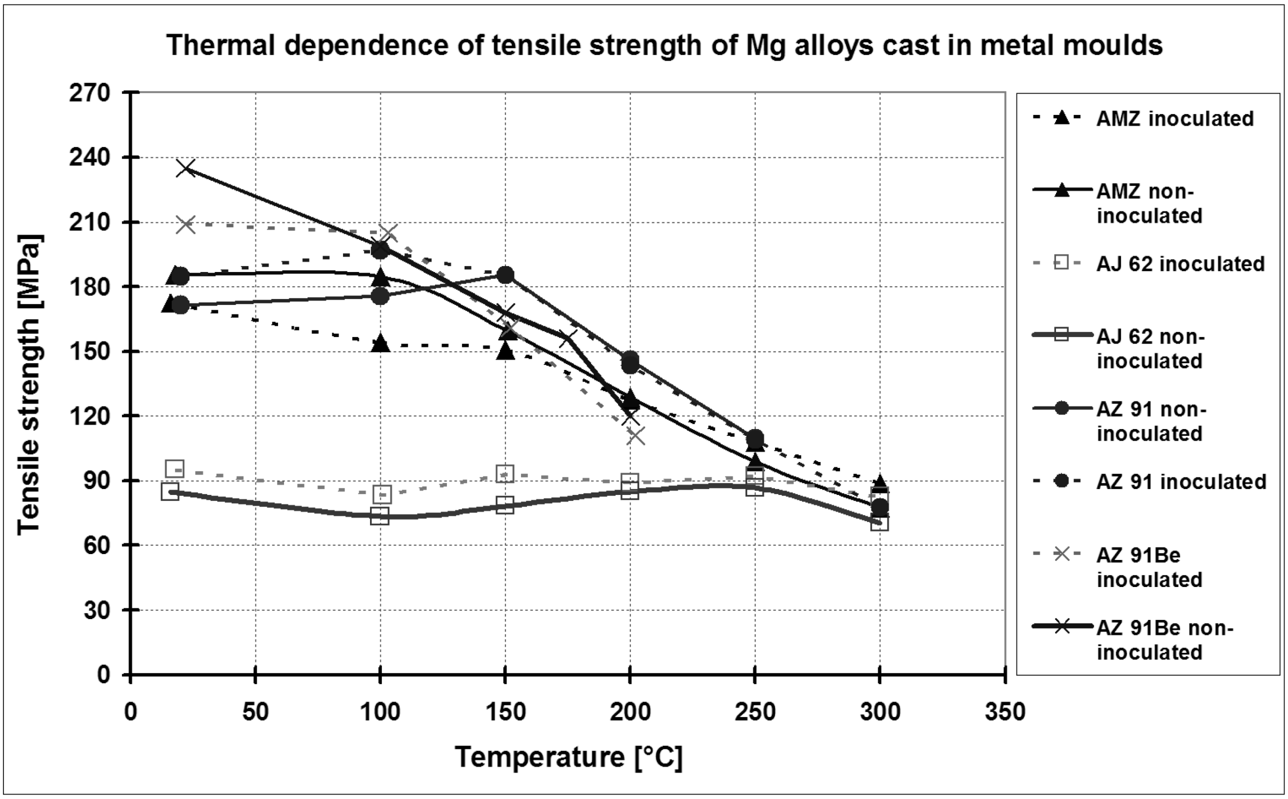

Fig. 8. Thermal dependence of tensile strength

Acknowledgements

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