INFLUENCE OF TEMPERATURE ON FORMABILITY OF MAGNESIUM ALLOY AZ31B

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Abstract

According to European Parliament and Council (ES) No. 443/2009 the emissions of CO_2 in personal cars exhaust gases should decrease on 95 g/km till 2020. Nowadays these emissions commonly vary about 158 g/km. Such regulation thus creates stress on car producers to reduce carbon dioxide emissions at newly developed cars. Great potential of saving CO_2 emissions offer alternate drive vehicles in combination with using new material with low specific weight based on Al and Mg. Principal difference between forming of magnesium alloys and steel can be found in selection of forming temperature. Because there is insufficient number of slip systems, magnesium alloys are badly formed at cold forming and there are used forming technologies at higher temperature to achieve required shapes. In this paper is by means of static tensile test evaluated influence of temperature on mechanical properties of magnesium alloy AZ31B. These tests were carried out within the temperature range from 20 °C to 250 °C. For such tests were used stress-temperature analyzer Gleeble 3500.

Keywords: Magnesium alloy AZ31B, tensile test, Gleeble 3500

1. INTRODUCTION

Processing of magnesium alloys by means of sheet forming means technological and economical problems. From these reasons are magnesium alloys in technical praxis still used only in limited range. Magnesium and its alloys crystallize in hexagonal close packed lattice (HCP - hexagonal close packed) and their specific weight is 1.738 g/cm^3 at temperature 20 °C [1]. Thus specific weight of magnesium alloys is in comparison to steels 4.5x lower and in comparison to aluminum then 1.5x lower. Tensile modulus of elasticity (Young´s modulus) of magnesium alloys is E = 42 GPa [1]. Thus for magnesium alloys is valid that their tensile modulus of elasticity is markedly lower than for steels (E = 210 GPa) and such reality is necessary to take into account at proportioning parts and proportionally increase thickness. For its specific physical and mechanical properties there is presumption of still higher utilization of magnesium alloys in technical praxis. One of the basic type for plastic deformation of metals is slip of dislocations. In this case deformation occurs by mutual movement of individual crystal layers which are placed above each other. Such movement is concerned into series of planes while blocks among them retain undeformed. Slip direction is always similar with the direction which contains the highest number of atoms. Thus slip mostly occurs in planes with the highest number of atoms. From given group of planes and directions is acting such slip system (plane and direction) where slip stress has the highest values. At materials with hexagonal close packed (HCP) slip occurs in direction <1120> because this direction has the highest density of atoms [2]. However active slip plane depends on value of axis ratio. For ideal ration c/a = 1.633 is basal plane also slip plane. For lower axis ratio then ideal value does not basal plane the highest density of atoms and that is why there is possible to observe another slip planes. This is mainly important e.g. for Zr (c/a = 1.593) or Ti (c/a = 1.587). For magnesium is valid ratio c/a = 1.623 (thus almost equals to ideal value) and at room temperature there is observed slip only at basal plane. Nevertheless at temperatures over 250 °C there is slip also in planes {1011}. So other planes can become active at higher temperatures. It is obvious that slip plane in every lattice is mainly influenced by temperature and chemical composition. Scheme of slip mechanism is shown in **Fig. 1**. Graphical illustration of change in slip plane number at higher temperature is shown in **Fig. 2**.

a) Undeformed lattice b) Slip mechanism of deformation

Fig. 1 Plastic deformation of lattice

Fig. 2 Additional slip planes at higher temperatures [2]

Another from possible types of material deformation is twinning. Among three basic types of crystal lattices for metals and their alloys (FCC - face centered cubic, BCC - body centered cubic and HCP - hexagonal close packed) has twinning in HCP lattice the easiest course. Twinning in metals and their alloys with HCP lattices is possible to observe on the quite high number of different planes. One common type for twinning in HCP lattice is by plane {1012}. One of three possible setting of these planes is shown in **Fig. 3a**. It is obvious that twinning will occur at plane {1011} and direction <1011>, where is the highest final shear stress. For better explanation are in the **Fig. 3b** shown angle conditions between non-deformed plane, basal plane and plane of A prism side [3].

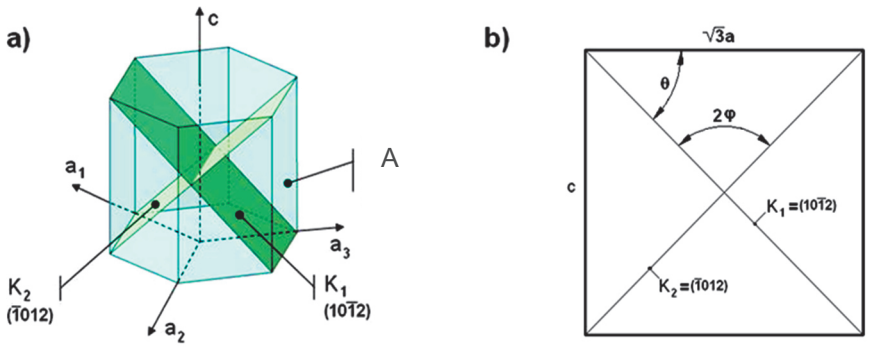

Fig. 3 Possibilities for setting planes K_1 and K_2 in HCP lattice [3]

a) basal plane, prism side plane and two undeformed planes b) plane scheme acc. to direction a_2

2. EXPERIMENTAL PART

For testing forming temperature influence on the mechanical properties of magnesium alloy AZ31B (composition and content of additive agents for tested magnesium alloy AZ31B is shown in **Table 1** was used device Gleeble 3500 which enables to carry out simulation of temperature, strain and stress cycles. Material tests were carried out within the temperature range from 0 °C up to 1300 °C. Device Gleeble 3500 is mainly suitable to gain material input data for numerical simulations of technological processes as are forming, welding, casting, thermal treatments technologies. Chemical composition of material from which are produced testing samples was measured by means of spectral analysis. The basic element is magnesium and there are also other additives (see **Table 1**). Among them aluminium, zinc and manganese revealed the highest content.

Table 1 Contents of additive agents (wt.%)

Al	Zn	Mn	Si	Cu	Ni	Fe	Ca
2.75	1.32	0.56	<0.003	0.002	<0.001	<0.005	<0.01

Mechanical properties tests were carried out at temperatures 20, 100, 150, 200 and 250 °C. Required material temperature is achieved by electric current passage at vacuum chamber which is part of device Gleeble 3500. Reaching of desired temperature and heating rate is controlled by thermocouple that is placed in the middle of the tested sample. Thermocouple of K type is welded directly on the tested material surface in the required place by capacitor-discharge welding machine. In the **Fig. 4** is shown the device Gleeble 3500 and AZ31B alloy tested sample with welded thermocouple to control desire temperature.

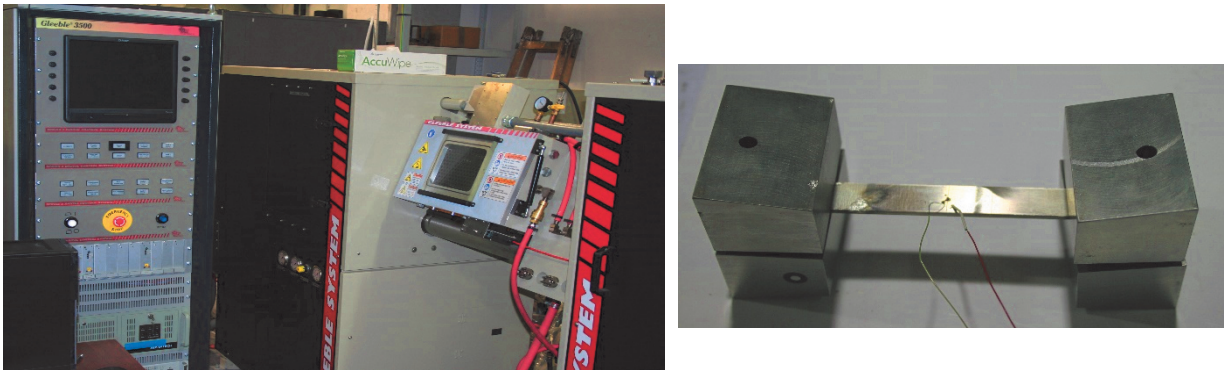

Fig. 4 Device Gleeble 3500 and tested sample of AZ31B alloy with the thermocouple

Change of mechanical properties of tested alloy AZ31B in dependence on temperature is shown in **Fig. 5** where are noted stress-strain curves for chosen forming temperatures. Arithmetic means from 5 tests for determination of basic mechanical properties are for every temperature summarized in **Table 2**. It is quite very important to state here that such results (and generally testing of magnesium alloys) is still quite at the beginning and every effort in this branch should be appreciated. E.g. it is quite difficult to carry out static tensile tests of these magnesium alloys due to “strange” temperature behaviour of magnesium alloys which can sometimes results as damage of testing device or even fire. And such safety factor is beside technological and economical factors another very important restriction for wider utilization of magnesium alloys.

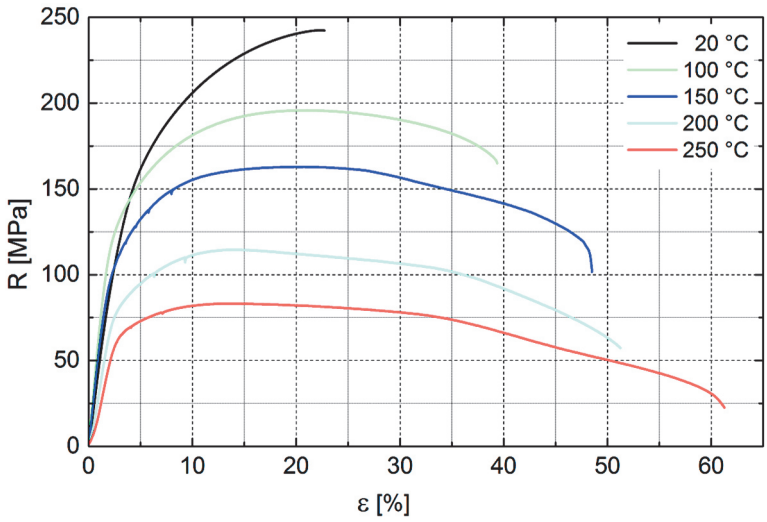

Fig. 5 Change of tested alloy AZ31B mechanical properties in dependence on temperature

Table 2 Forming temperature influence on the mechanical properties of alloy AZ31B

T [°C]	R_m [MPa]	R_e [MPa]	A_g [%]	A_{80} [%]
20	242	123	22.7	22.7
100	196	107	19.8	39.4
150	163	88	21.2	48.5
200	114	72	13.2	51.1
250	83	60	14.6	61.3

3. THE QUALITATIVE EVALUATION OF THE STRUCTURE USING THE DEBYE-SCHERRER METHOD

The backscattering arrangement of the Debye-Scherrer method was used. For this purpose, *ISO DEBYEFLEX 3003* device *(***Fig.6***)*, non-filtered radiation from X-ray tube with chromium anode, cylindrical primary slit with 1 mm in diameter and image plate detector was employed. This method is non-destructive and, therefore, suitable for a qualitative evaluation parameters of the real structure, i.e. for the crystallite size, the extent of plastic deformation and also detecting the presence of the texture. The advantage of the image plate detector lies in the simple processing of the image by using a scanner and the possibility of repeated use. The measurement was performed by the voltage of 30 kV in the X-ray tube and electric current 20 mA. The exposure time of the diffraction image on the crystallographic planes was 180 seconds. [4].

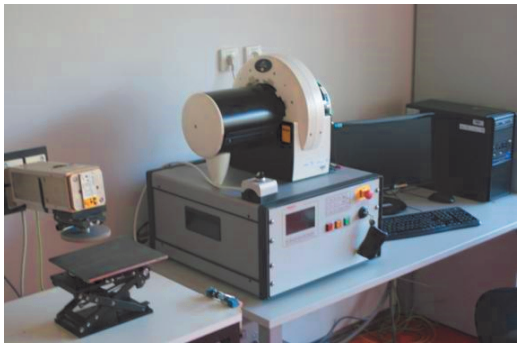

Fig. 6 The backscattering arrangement of the Debye-Scherrer method

By Debey-Scherrer method it is possible to observe the change of real structure on the testing samples which were tested on the device Gleeble 3500 at different temperatures and subsequently were measured on the diffraction device ISO DEBYEFLEX 3003. Backscatter diffraction patterns with Debye rings (**Fig. 7**) at unloaded tested sample (basic material) revealed non-influence real structure. At temperatures 20, 100 and 150 °C are from the diffraction rings evident changes of structure where diffraction ring was made wider and smoother which characterizes certain crystallites orientation and presence of texture. For sample loaded at temperature 200 °C there was reveled reduction and low disintegration of diffraction ring in comparison to the previous case. Such behavior means beginning of deformed structure change. From comparison of images for basic material and deformed material at 250 °C it is possible to see similar character of diffraction rings so-called real structure state. There was already recrystallization at such temperature but with regard to the low differences from rings of basic states, such recrystallization did not coursed completely.

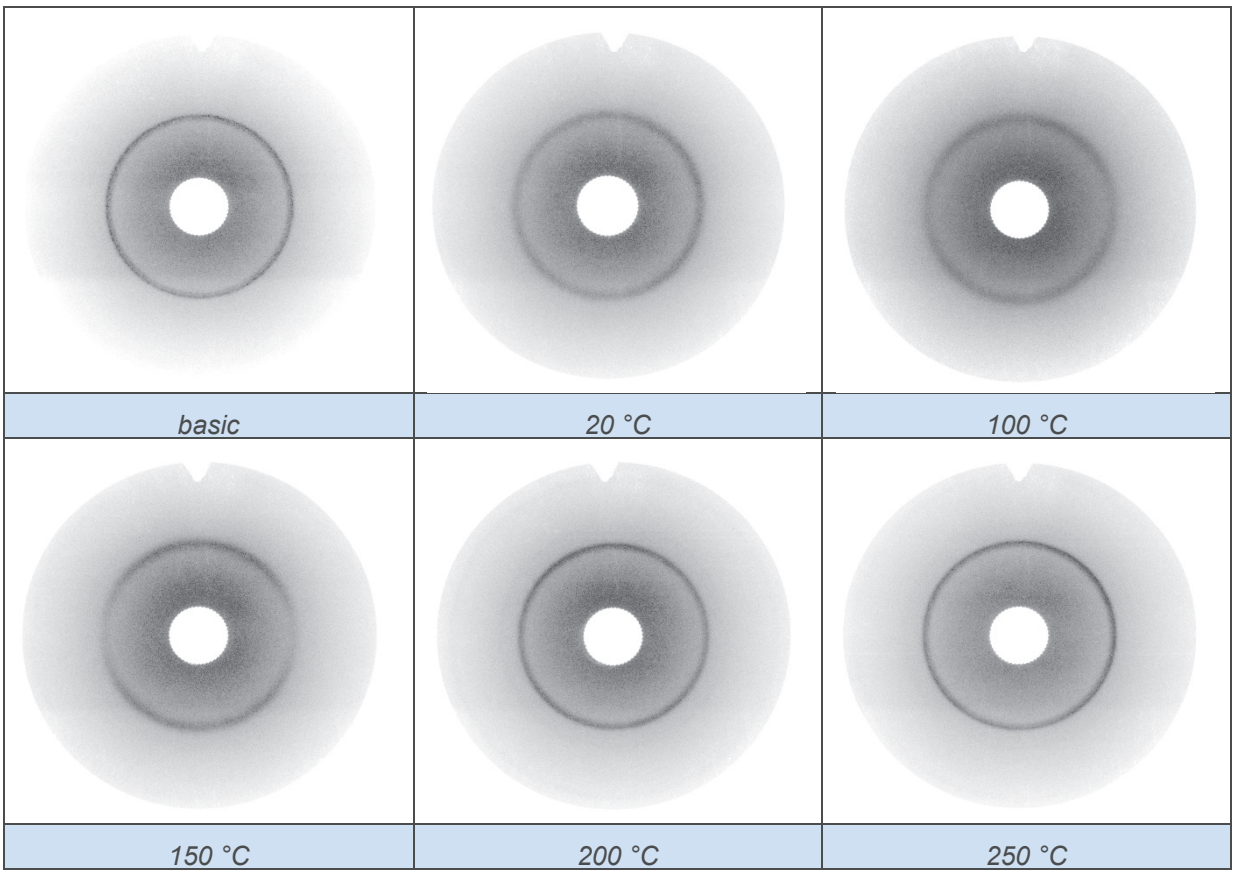

Fig. 7 The back-reflection X-ray diffraction patterns in various temperatures

4. CHARACTERISTICS OF FRACTURE BY MEANS OF THE ELECTRON MICROSCOPE

The scanning electron microscope Carl Zeiss ULTRA Plus enables the investigation of specimens with a resolution down to the nanometer scale. Here an electron beam is generated by an electron cathode and the electromagnetic lenses of the column and finally swept across the surface of a sample. The path of the beam describes a raster which is correlated to a raster of gray level pixels on a screen.

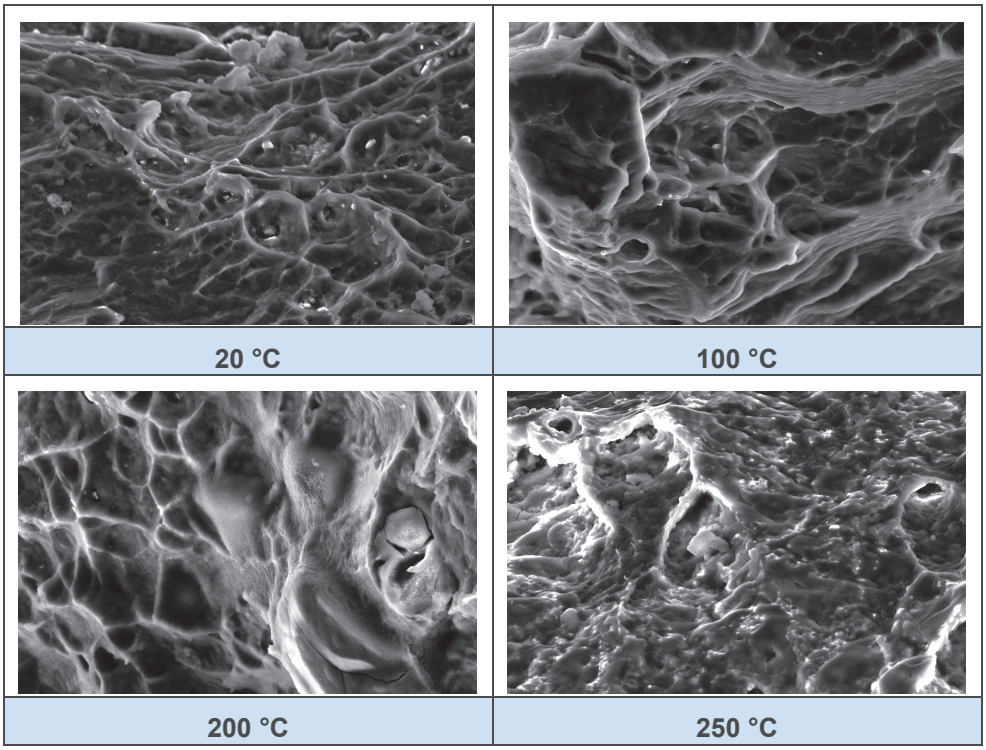

Fig. 8 Pictures from the electron microscope Carl Zeiss ULTRA Plus, magnification 5000x

CONCLUSION

For evaluation temperature influence on the formability of magnesium alloy AZ31B there were carried out static tensile tests at different temperatures and subsequently these samples were investigated by means of diffraction and electron microscope. From these tests there were proved strong influence of temperature on the tested alloy formability and deformation texture creation. At temperature 250 °C was ductility three times higher than at 20 °C, however such value is strongly influenced by localization of deformation. From the images of diffraction also results that at 250 °C is already deformation texture creation negligible and in the area of material fracture are evident markedly lower cavities. From these results is evident that for practical processing of tested material it is possible to recommend processing temperature already within the range 100 ÷ 150 °C when material revealed sufficient ductility without localization of deformation risk.

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