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THE DYNAMIC PROPERTIES OF ZIRCONIUM-CONTAINING MAGNESIUM ALLOY MA14-T1

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Abstract. Experimental study of strength and deformation properties of the magnesium alloy MA14-T1, depending on the type of stress-strain state, the type of cutting the samples with respect to the rolling direction, strain rate and temperature. The static and dynamic stress-strain curves were obtained at different loading conditions and temperatures. It were determined the strength properties as well as their dependence on the strain rate and temperature. It is marked the substantial change in the course of the deformation diagram of samples with a longitudinal direction of cutting after the deformation ~6 %.

1. Introduction

Magnesium is the lightest known metals used as the basis for the development of structural materials. In the second half of XX-th century the era of wide industrial development of alloys based on magnesium has been associated primarily with the strategic direction of their application as structural materials in aircraft for civilian and military purposes.

Operational properties of deformable magnesium alloys are determined primarily by their structure and phase composition that have been shaped by casting condition, deformation and heat treatment.

The basis of most deformable magnesium alloys, currently used in the industry, is the system Mg-Zn-Zr. It is known the role of zirconium as the active modifier of magnesium alloys [1]. The maximum possible content of zirconium in the high-strength deformable alloys based on magnesium is restricted to 0.9 % (wt.). In practice it does not exceed 0.5-0.7 % (wt.).

Plasticity limits (δ and ψ) for MA14 alloy (foreign analogue ZK60A – in USA and MAG-E-161 – in Great Britain) are depending on temperature and have a pronounced maximum at 300-400 °C depending on the method of obtaining and processing of the alloy and as well as on the direction of sample cutting [2].

The purpose of the work is the study of features of the mechanical behavior of the alloy MA14-T1 under static and dynamic loading conditions at compression and tension at different temperatures.

2. Specimens for testing

To investigate the effect of strain rate, test temperature and cutting direction of the samples a set of specimens was made for static and dynamic tests. Samples for static compressive testing were manufactured in the form of cylinders of 15 mm diameter and 30 mm long cutted by two directions (longitudinal and transverse). For static tensile test, specimens with threaded heads with a working length of 60 mm and a diameter of 6 mm were produced with a longitudinal direction of the notch.

For tests at high strain rates the samples of two cutting directions were formed as tablets of 8 mm diameter and 4 mm in length (test under compression) in the form of solid cylindrical samples with a diameter of the working part of 5 mm and a length of 10 mm with threaded heads (tensile test).

3. Methods for testing

To determine the mechanical properties of magnesium alloy MA14-T1 at compression and tension over a wide range of strain rates a set of tests were conducted under static and dynamic loading.

Static tests were performed on the upgraded universal machine 1958-U10-1 with a maximum force of 10 tons. Tests of specimens were carried out in tension, compression and under alternating loading at room and elevated (+300 °C) temperatures.

To carry out dynamic tests in compression and tension the experimental complex is used (Fig. 1), which implements the Kolsky method with interchangeable sets of split Hopkinson bar (SHB) [3-5] and includes two pneumatic loading devices: gas gun caliber 10 mm (compressive tests) and 20 mm (tensile test) with the control system as well as the measuring and recording equipment. Tensile tests were carried out under the Nicholas scheme [6].

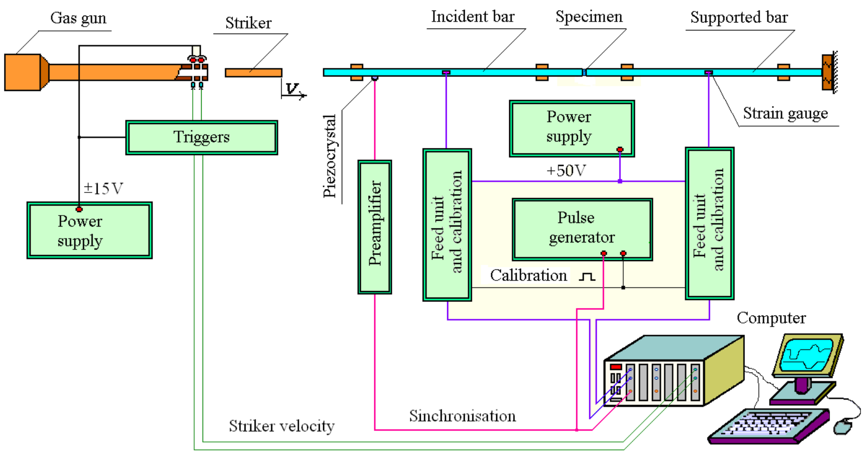


Fig. 1. The experimental setup for testing in compression.

As a result of a series of static and dynamic tests of samples of alloy MA14-T1 with different directions cutting out at +20 °C and +300 °C were obtained the true stress-strain curves σ~ε under tension and compression.

4. The results of static tests*

Samples for static compressive tests were manufactured in the form of cylinders of 15 mm diameter and 30 mm long. At such sizes of samples, measuring deformation of the sample is possible only indirectly - by moving of grips of the testing machine. Since in the circuit of sample loading, a special extenders and adapters have used the strain measurement error, especially at the initial part of the loading is big enough.

The results of the static tests in compression of samples by two directions of cutting (with the index L - longitudinal H and T - transverse) at normal and elevated (up to +300 °C) temperatures are shown in Fig. 2. Here the true stress-strain curves in compression are shown

*The results of static tests are kindly provided by Ph.D. Kazakov D.A.

for specimens at longitudinal cutting at temperatures +20 °C and +300 °C. Samples of 1L, 2L and 5L at room temperature were loaded up to failure, and samples 3L, 4L and 6L were tested with a limited degree of deformation of the sample without breaking. At a temperature of +300 °C the samples are not destroyed, but lose their stability.

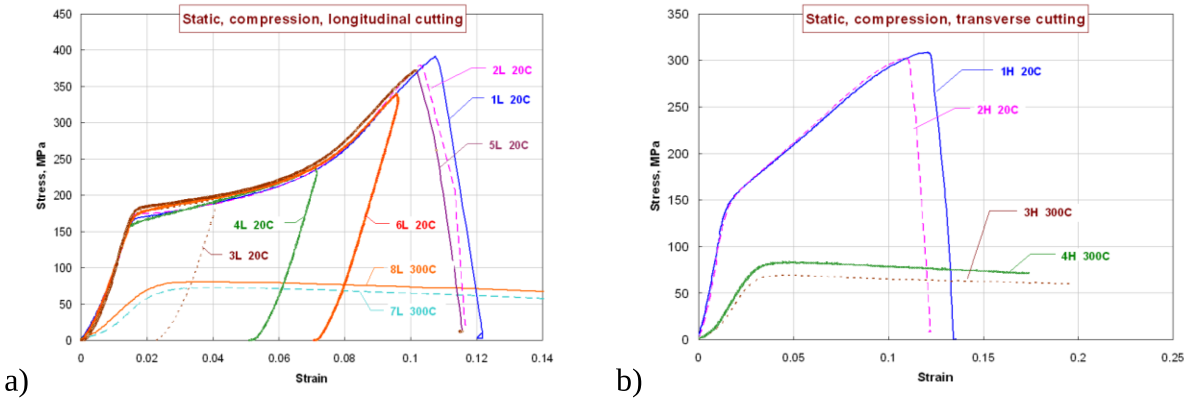


Fig. 2. Stress-strain curves in compression for samples with a longitudinal (a) and transverse (b) cutting at temperature +20 °C and +300 °C.

Note the unusual behavior of the alloy MA14. Figure 2a shows clearly that in the site of deformation hardening curves of samples with the longitudinal cutting direction at room temperature after the strain about 6 % the character of hardening branch is changing that seem to be related to the change of phase state or microstructure. After strain reaching 10-11 % the specimens have been brittle cracked.

Figure 2b shows the true stress-strain curves in compression for samples of transverse cutting. Visible to the very strong dependence of the mechanical behavior from the test temperature, and plot changes dramatically strengthening. At a temperature +20 °C the samples were fragile cracked when the deformation of 11-12 %, and at a temperature +300 °C the samples were not destroyed, but lost stability.

Destruction of the samples of both cutting directions at room temperature was a splitting into two parts by a plane inclined at an angle 45 ° to the axis of loading.

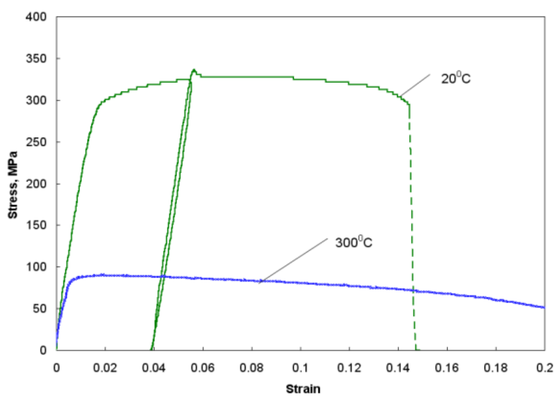


Fig. 3. True static tensile stress-strain curves at +20 °C and +300 °C.

In the initial part of the chart up to the yield strength the Young's modulus was determined which amounted to ~43 GPa, which is in good agreement with the reference data of the Young's modulus for alloy MA14-T1.

The effect of temperature on the mechanical properties of the alloy MA14-T1 at tension is shown in Fig. 3. Well you can see a strong influence of temperature on the yield strength and on the character of the hardening site.

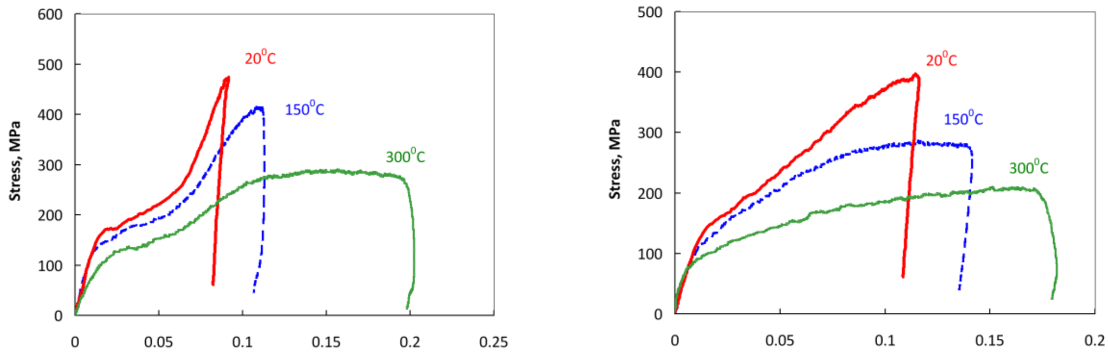
Analysis of fracture character showed that at room temperature it is a brittle fracture of the sample, whereas at a temperature of +300 °C a material plasticity is high, a neck is formed and rupture occurs in a very small area, i.e. specimen's contraction has a very large value.

5. The results of dynamic tests

Dynamic compressive tests were performed using steel pressure bars by diameter of 10 mm, the striker was accelerated by a gas gun of caliber 10 mm. Test temperature was ranged from room temperature up to +300 °C. Specimens were prepared with longitudinal and transverse cutting directions.

Figure 4 shows the effect of test temperature on the course of dynamic charts when tested at a strain rate ~2200 s^{-1} for specimens with the longitudinal (a) and transverse (b) directions of sample cutting.

As can be seen, the course of loading curve for specimen with a longitudinal cutting direction at a strain degree of ~6 % is radically changed (as at the static loading conditions) that may be due to process changes the phase state of the material similar to evolution during deformation of shape memory alloys [8].



a) b)

Dynamic compressive strain diagram at +20 °C, +150 °C, and +300 °C specimens with longitudinal (a) and transverse (b) directions of cutting samples.

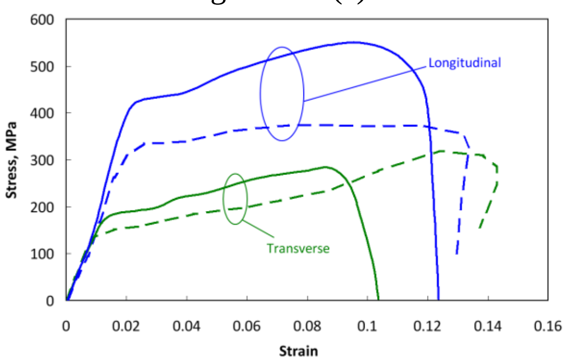


Fig. 5. Dynamic stress-strain curves in tension

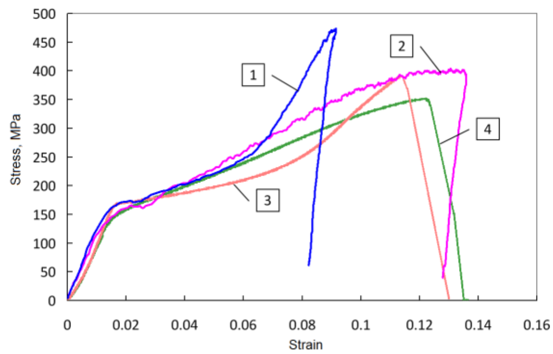


Fig. 6. Comparing the dynamic and static curves in compression

Figure 5 shows the stress-strain curves for the specimens of longitudinal and transverse cutting out at temperatures of +20 °C (solid line) and +150 °C (dashed lines). One can see well a strong influence on the direction of cutting the mechanical properties of the alloy MA14-T1. At elevated temperatures, in addition, the curve course is significantly changing on hardening portion.

Comparing the dynamic (1) and (2) as well as static (3) and (4) stress-strain curves during compression samples with longitudinal (1) and (3) as well as transverse (2) and (4) cutting out and static compressive deformation curves for specimens of both cutting directions tested at room temperature is shown in Fig. 6. A strong influence of cutting direction of samples is also observed.

6. Conclusions

As shown by the results of static and dynamic tests, the strain rate has a positive effect on the mechanical properties of the alloy MA14, moreover, the characteristics of the material depends on the direction of cutting, i.e. material has a significant anisotropy of properties. In samples with the longitudinal direction of cutting at a degree of deformation ~6 %, both at static load and at high strain rates anomalous hardening observed probably due to changes in the phase state or other processes similar to those observed during deformation of shape memory alloys.

Acknowledgements

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