LOW-CYCLE FATIGUE CHARACTERISTICS OF ALUMINIUM ALLOY 2017A, MAGNESIUM ALLOY AZ31 AND TITANIUM ALLOY TI-6AL-4V

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Abstract

The paper presents the research on low-cycle fatigue of selected wrought light metal alloys, applied inter alia in the aviation technology. The material for the research consisted of hot-worked rods made of AZ31 magnesium alloy, dual-phase Ti-6Al-4V titanium alloy and 2017A (T451) aluminium alloy. Low-cycle fatigue tests were performed using an MTS-810 machine in an oscillatory cycle (R = -1) for two ranges of total strain $\Delta\varepsilon_t$ = 1.0 and 1.2 %. Characteristics of cyclic deformation of the tested materials σ_a = f(N), as well as characteristics of their low-cycle durability were prepared using obtained data. It was found that the titanium alloy had the highest fatigue durability expressed by the number of cycles until failure of the sample. Durability of the investigated magnesium alloy was ca. 3 times lower. The aluminium alloy exhibited the lowest fatigue life. In respect to the applied strain range it was 10 or 13 times lower than for the titanium alloy.

Keywords: Titanium alloy Ti-6Al-4V, aluminium alloy 2017A, magnesium alloy AZ31, low-cycle fatigue

1. INTRODUCTION

Currently, there is a growing interest in light metal (Al, Mg and Ti) alloys for use in the automotive and aviation industry. This is mainly due to the efforts to reduce vehicle weight and increase fuel efficiency.

Renewed interest in magnesium alloys results from the development of new coatings which can protect from corrosion, new alloys, new and improved technologies for casting blanks and forming that significantly improve the properties of the products [1-3]. The development of wrought magnesium alloys and their forming technologies so far was very limited. Wrought magnesium alloys were used sporadically, due to technological difficulties during forming and high manufacturing cost [4-6]. Mechanical properties of wrought magnesium alloys are higher than that of casting alloys [7]. Wrought alloys are also becoming more promising because of the development and improvement of new and existing forming technologies. The most preferred combination of properties is found in the alloys from Mg-Al-Zn-Mn group, containing up to 8 % Al, with the addition of Mn (2 %), Zn (up to 1.5 %) [8, 9].

Aviation industry, where the material requirements include high durability and fatigue resistance and low weight, is more and more dominated by the aluminium alloys. It is estimated that over 60% of the airliner construction is made of aluminium alloys [10].

The material used in this study consisted of hot formed bars of AZ31 magnesium alloy, dual-phase Ti-6Al-4V titanium alloy characterised by very high strength and machinability [11] and the 2017A aluminium alloy which has a very good susceptibility to stamping and folding. 2017A alloy is only moderately resistant to corrosion, but because of high mechanical properties is still used for components in automotive industry, machine parts and aircraft parts [10].

The usefulness of wrought light metals based alloys for machine parts manufacturing is determined by their low density and a number of advantageous mechanical properties. In case of application in automotive and aviation industries this alloys should have, among other things, advantageous fatigue characteristics.

The paper presents the results of low-cycle fatigue testing, carried out with two total strain ranges $\Delta\varepsilon_t$ = 1.0 and 1.2 %. Based on the obtained results, the cyclic deformation $\sigma_a = f(N)$ and low-cycle fatigue characteristics were prepared for tested materials.

2. MATERIALS AND PROCEDURES

The experiments were performed using hot worked rods made of AZ31 magnesium alloy, two phased titan alloy Ti-6Al-4V and 2017A aluminium alloy. Tensile and low-cycle fatigue tests were performed on MTS machine under room temperature using cylindrical samples prepared as shown on **Fig. 1**. The results of tensile tests (**Fig. 2**) were the basis for determining the low-cycle fatigue test parameters.

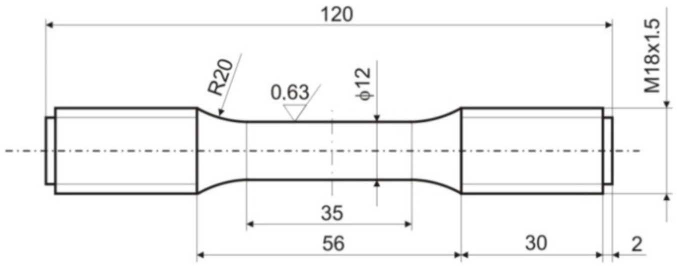

Fig. 1 Dimensions of test sample

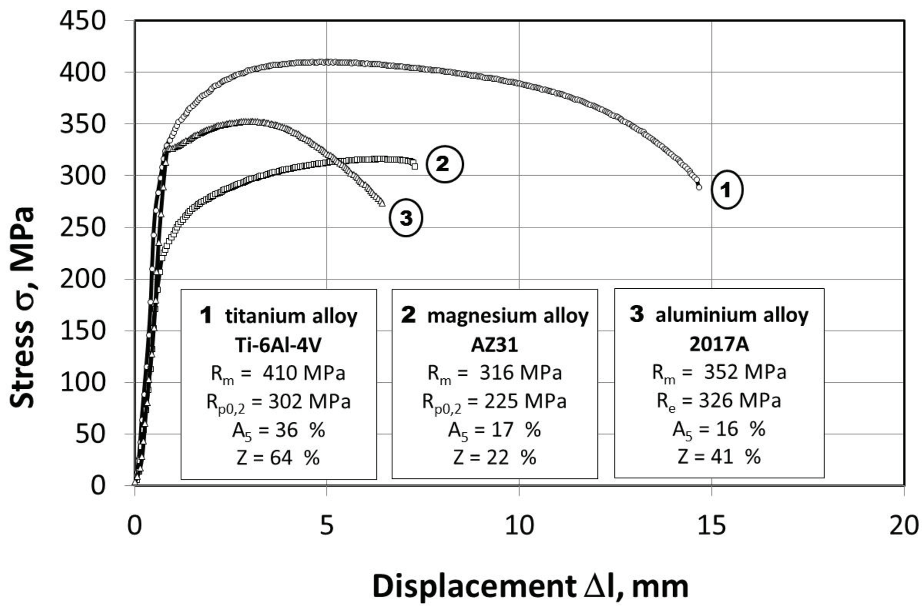

Fig. 2 Comparison of static tensile test charts and mechanical properties of light metals based alloys

Fatigue tests were performed in tension-compression cycle at a rate of asymmetry R = -1. The machine was controlled by strain. Two ranges of total strain $\Delta\varepsilon_t$ = 1.0 and 1.2 % were used. Hysteresis loops (**Fig. 3**) for tested materials were registered during stabilized state of fatigue process (so called saturated state). Cyclic strain $\sigma = f(N)$ charts (**Fig. 5**) and durability characteristics N_f (number of cycles to rupture, **Fig. 5d**) were prepared using obtained results. In order to clarify the reasons for the lack of symmetry in the cyclic strain charts and irregularities in hysteresis loops for AZ31 magnesium alloy additional static tensile and compression test were performed with the accurate measurement of elongation (**Fig. 4**). **Fig. 6** shows the fractographic analysis of low-cycle fatigue fractures.

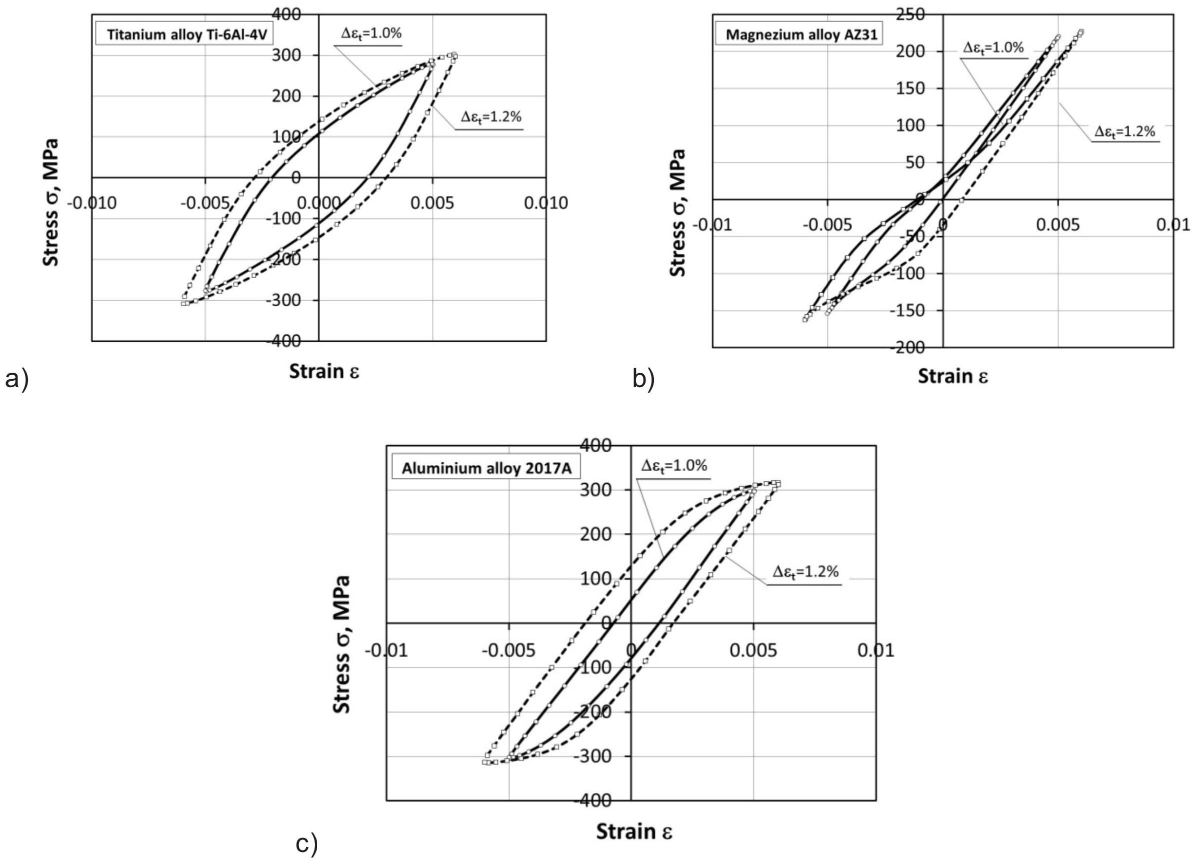

Fig. 3 Characteristic hysteresis loops:
a), titanium alloy Ti-6Al-4V b) magnesium alloy AZ31, c) aluminium alloy 2017A

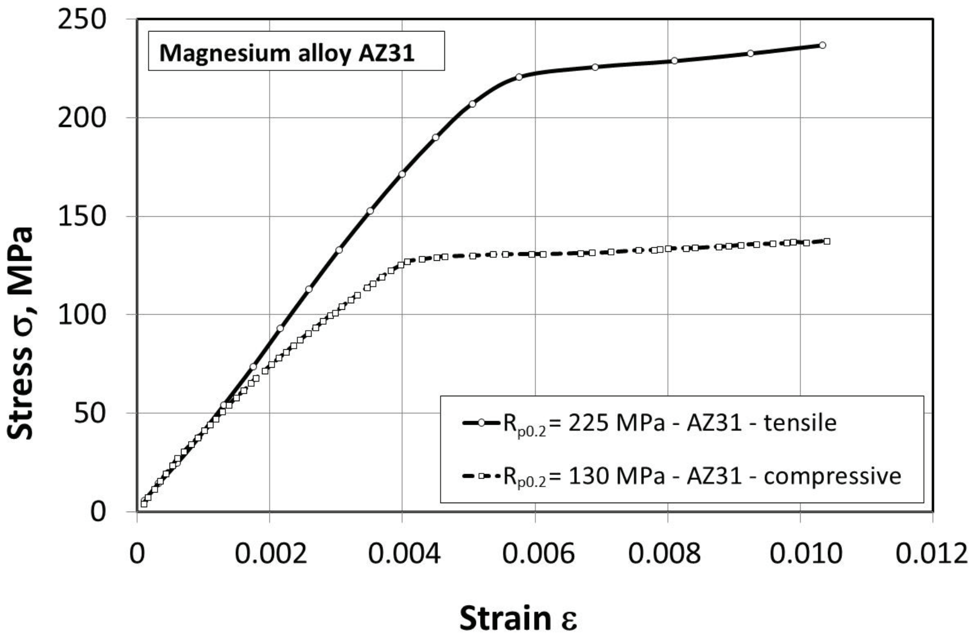

Fig. 4 Static tensile and compression charts with precise strain measurement for AZ31 magnesium alloy

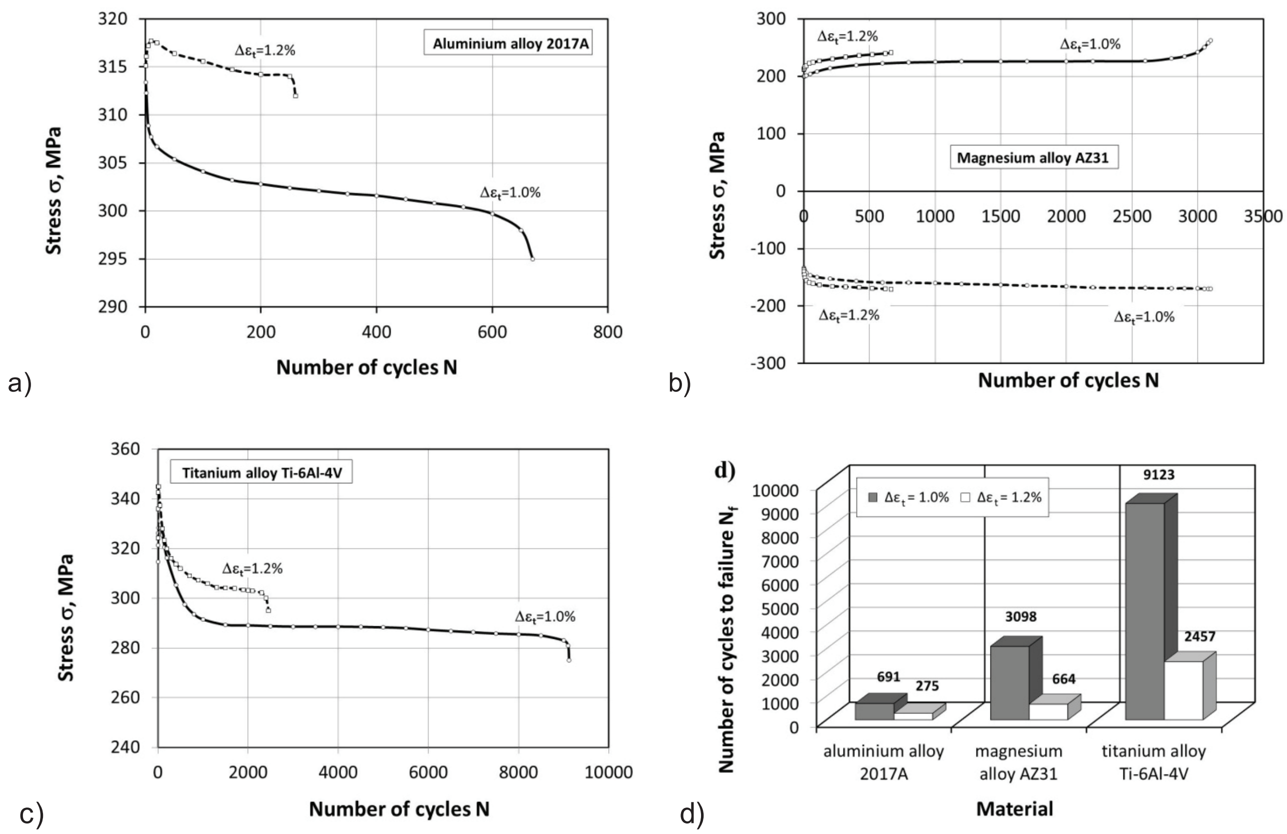

Fig. 5 Characteristics of cyclic deformation and durability:
a) aluminium alloy 2017A, b) magnesium alloy AZ31,
c) titan alloy Ti-6Al-4V, d) comparison of low-cycle durability

Fig. 6 Morphology of fatigue fractures: aluminium alloy 2017A (left), magnesium alloy AZ31, titanium alloy Ti-6Al-4V (right)

3. CONCLUSION

Analysis of basic mechanical properties (**Fig. 2**) shows that titanium alloy Ti-6Al-4V has the highest strength and plasticity (R_m = 410 MPa, $R_{p0.2}$ = 302 MPa, A_5 = 36 %). In contrast, magnesium alloy AZ31 has lowest mechanical properties (R_m = 316 MPa, $R_{p0.2}$ = 225 MPa, A_5 = 17 %). Magnesium alloy has also different values of $R_{p0.2}$ in tensile conditions ($R_{p0.2}$ = 225 MPa) and in compression conditions ($R_{p0.2}$ = 130 MPa).

In the low-cycle fatigue tests, aluminium alloy 2017 and titanium alloy Ti-6Al-4V were characterized by cyclic weakening, whereas magnesium alloy AZ31 exhibited cyclic stability in both tensile and in compression half-cycles. Significant differences in the surface of the hysteresis loop (**Fig. 3**) were registered in fatigue tests during stabilized state of low-cycle fatigue process. However, there was no relationship between the loop area, corresponding to the energy of destruction cumulated in the material during each cycle (highest for titanium alloy and lowest for magnesium alloy) and between the low-cycle durability N_f (**Fig. 5b**). Durability of titanium alloy was in fact several times higher than the durability of magnesium and aluminium alloys, which showed lowest durability (**Fig. 5**). Analysis of behaviour of magnesium alloy AZ31 shows, that the deformation of the hysteresis loop (**Fig. 3b**) and the lack of symmetry between static tension and compression half-cycles in the cyclic deformation charts (**Fig. 4b**) were the result of different values of $R_{p0.2}$.

Fractographic analysis showed differences in morphology of fractures resulting from low-cycle fatigue. The differences was mainly related to the occurrence of radial slips, which have been observed only in alloys AZ31 and Ti-6Al-4V (**Fig. 6b** and **Fig. 6c**).

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REFERENCES

[1] KUC D., HADASIK E., NIEWIELSKI G., PŁACHTA A. Structure and plasticity of the AZ31 magnesium alloy after hot deformation, Journal of Achievements in Materials and Manufacturing Engineering, Vol.27, 2008, pp: 27-31

[2] DOBRZAŃSKI L.A., TANSKI T., CIZEK L., MADEJSKI J. The influence of the heat treatment on the microstructure and properties of Mg-Al-Zn based alloys, Archives of Materials Science and Engineering, Vol. 36/1, 2009, pp. 48-54

[3] JIANG B., WANG J. DING P., YANG CH. Rolling of AZ31 Magnesium Alloy Thin Strip Materials Science Forum, Vols. 546-549, 2007, pp. 365-368

[4] KAINER K.U. Magnesium Alloys and Technologies. Wiley-VCH Verlag GmbH & Co. KGaA: Weinheim, 2003

[5] BEER A.G., BARNETT M.G. Microstructure evolution in hot worked and annealed magnesium alloy AZ3. Material Science and Engineering A, Vol. 485, 2008, pp. 318-324

[6] RUSZ, S., CIZEK, L., KEDRON, J., TYLSAR, S., SALAJKA M., DUTKIEWICZ J., KLOS M., HADASIK E. Structure of AZ31 Magnesium Alloy After ECAP Processing. In Journal of Trends in the Development of Machinery and Associated Technology.Vol. 16, No. 1, 2012, pp. 51-54

[7] RUSZ S., CIZEK L., KEDRON J., TYLSAR S., SALAJKA M., HADASIK E., DONIČ T. Structure and Mechanical Properties Selected Magnesium - Zirconium Alloys. In Journal of Trends in the Development of Machinery and Associated Technology.Vol. 16, No. 1, 2012, pp. 55-58

[8] MORDIKE B.L., EBERT T. Magnesium Properties - applications - potential, Materials Science and Engineering A302, 2001, pp. 37-45

[9] BOHLEN J., LETZIG D. KAINER K. U. New Perspectives for Wrought Magnesium Alloys, Materials Science Forum, Vols. 546-549, 2007, pp. 1-10

[10] OCZOŚ K., KAWALEC A. Kształtowanie metali lekkich. WN PWN: Warszawa 2012

[11] GARBACZ H., OSSOWSKI M., WIECIŃSKI P., WIERZCHOŃ T., KURZYDŁOWSKI K. Mikrostruktura i właściwości warstw międzymetalicznych na stopie Ti-6Al-4V. Problemy Eksploatacji, nr 1, 2007