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LOW CYCLE RESPONSE AND FATIGUE LIFE OF ALUMINIUM ALLOY 7020 IN THE WHOLE AREA OF LIFETIME

NÍZKOCYKLOVÁ ODEZVA A ÚNAVOVÁ ŽIVOTNOST SLITINY HLINÍKU 7020 V CELÉ OBLASTI ŽIVOTNOSTI

Abstract

In this article, cyclic hardening-softening behaviours of high strength aluminium alloy 7020 in T6 condition are studied. By comparison of cyclic deformation curve and unidirectional curve was found, that there is no significant change in cyclic response on tested material and that material can be accepted as cyclic stable. Experiments in high cycle area no discontinuity between low-cycle and high-cycle area was detected. Presented properties were not influenced by the different loading frequency (5 a 145 Hz) on different testing machines for low and high fatigue area.

Abstrakt

Tato práce se zabývá studiem cyklického zpevnění-změkčení vysokopevné slitiny hliníku 7020 ve stavu T6. Z porovnáním cyklické deformační křivky s jednosměrnou křivkou bylo zjištěno, že u studovaného materiálu nedochází k výrazným změnám cyklické odezvy a můžeme jej považovat za cyklicky stabilní. Mezi nízkocyklovou a vysokocyklovou oblastí nebyla nalezena nespojitost. Uvedené chování neovlivnila ani rozdílná frekvence zatěžování (5 a 145 Hz) při provádění únavových zkoušek na různých zařízeních.

1 INTRODUCTION

Alloys of AL-Zn-Mg type in the condition after hardening belongs to the structural aluminium alloys with higher strength. Thanks to its good weldability, they are intended for stressed structural components and parts mainly in transport industry. The good weldability is stated by the low content of Cu and good corrosion resistivity in the T6 condition. The typical representative of the group aluminium alloy is the alloy EN AW-7020 (AlZn4.5Mg1) [1-4].

The aim of the work determination of cycle response of the alloy that is subject of study in low cycle area based on analyses of cycling hardening – softening curve. The secondary objective is determination of fatigue life curve on smooth testing specimens of 7020 alloy at symmetric loading tensile – pressure at room temperature in the direction of forming of rod-shaped semi-product (L direction). The final objective is to determination of Wöhler curve for the whole area of lifetime (0.5 to 10^8 cycles) and alignment experimental measured data useful regression function and determination of fatigue limit s_C.

2 EXPERIMENTAL MATERIAL

Tested samples for static and fatigue tests were made from 7020 aluminium alloy and supplied as rod-shaped with diameter D=20 mm from the company Alcan Děčín Extrusion s.r.o. The material

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was heat treated to the T6 condition (artificial ageing). Chemical composition determined through optical emission spectrometer is stated in table 1. Cylindrical testing samples were used for determination of basic mechanical properties at static loading in tensile mode. Cylindrical testing samples with screw heads (d_0 = 7 mm a L_0 = 12.5 mm) were used for determination of the low cycle parameters and for high cycle area experiments. Tests were done at room temperature.

Tab. 1 Chemical composition of studied aluminium alloy

Element	Zn	Mg	Cu	Si	Mn	Cr	Fe	Ti	Al
[wt.%]	4.2	1.36	0.02	0.12	0.30	0.16	0.28	0.04	Base

3 EXPERIMENTAL PROCEDURE

Samples for static tensile tests were tested at computer controlled tension testing machine TiraTest 2300. The initial diameter of the cylindrical part was d_0 = 10 mm. The extension was measured at extensometer at initial measured length L_0 = 50 mm. The conditions of testes fulfilled ČSN EN ISO 6892-1.The results of tensile tests and hardness measurement are stated in Tab 2.

The samples for determination of low cycle parameters were loaded in computer managed electro hydraulic testing system INSTRON 8801 in the loading force mode at sinusoidal wave required value with asymmetry $P = 1$ ($R = -1$, i.e. symmetric cycle). The constant frequency of loading cycle $f = 5$ Hz was maintained during testing. Deformation was measured with sensitive axial extensometer with measured length 12,5 mm. An extreme values of deformation and hysteresis loop were recorded in digital form during the loading. The amplitude of the total deformation ε_{at} was determined by the analyses of hysteresis look as the half value peak to peak from the total deformation. Number of cycles to failure N_f was determined based on 3% change in efficient module E_{eff} against the values determined in half lifetime on the stated loading level. Experiments in high cycle area were made on high frequency pulsator Amsler HFP 1478 with asymmetry of loading cycle $P = 1$. The loading frequency as a function of sample stiffness was $f = 145 \pm 4$ Hz.

4 RESULTS AND DISCUSIONS

The microstructure of aluminium alloy 7020 on the forging direction (a) and upright on (b) it is in Fig. 1a,b. The structure consists from elongated polyedrical grains from solid solution α and higher quantity of inclusions (Mn, Si, Fe base) which are directed through forming.

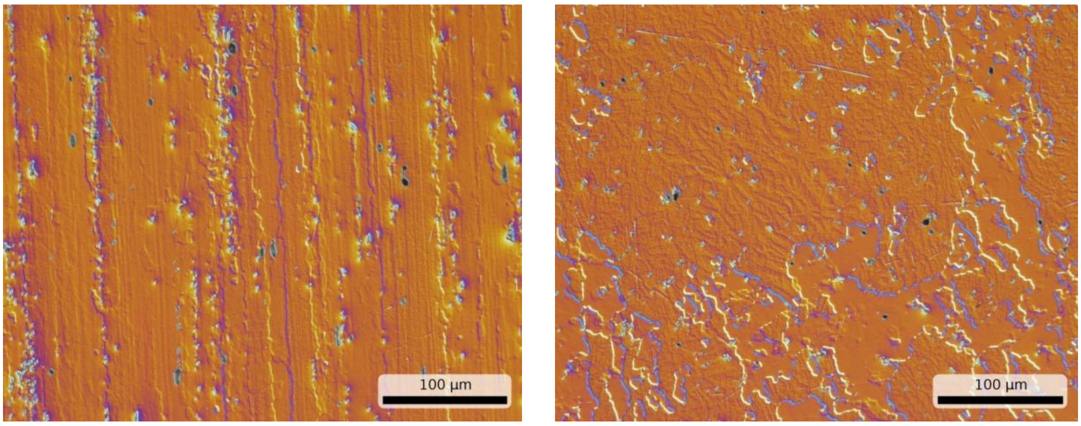

Fig. 1 Microstructure of studied aluminium alloy

The medium values of basic stress and deformation characteristics and hardness measurement determined from 3 testing samples are stated in Tab. 2.

Tab. 2 Basic mechanical characteristic

E [GPa]	R_m [MPa]	$R_{P0.2}$ [MPa]	A [%]	Z [%]	HBW 5/125
72.07	407	522	10.1	12.0	121

The comparison of cyclic and unidirectional deformation curve with denotation of the yield strength. direction is outlined in relation with amplitude of stress – total deformation in Fig. 2. Points creating cyclic deformation curve are interlarded by the modified Ramberg-Osgood function (1) [5]. Its parameters determined by the regression analyses (at condition of method of least squares), i.e. modulus of elasticity *E*, parameter of stress σ_0 and exponent *n* are stated in Tab. 3.

$$e(s) = \frac{s}{E} + \left(\frac{s}{s_0}\right)^n \tag{1}$$

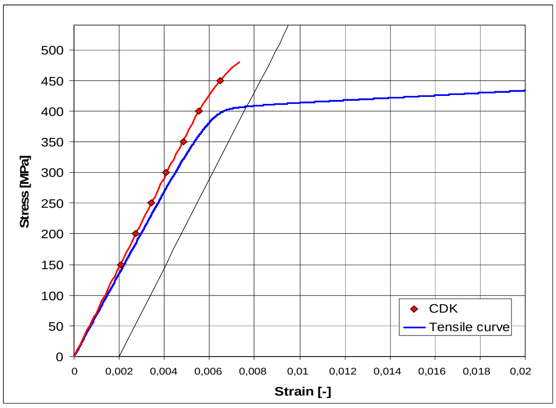

Fig. 2 Comparison of cyclic and unidirectional deformation curve

Curves of cyclic hardening – softening obtained from hysteresis loop analyses are illustrated in Fig. 3. There is slight decrease of total deformation amplitude and fast decrease ε_{ap} at the beginning of loading on the higher levels of loading cycle. The deformation response is stable on the lower levels of the loading cycle. The tested material can be considered as stable in total, the value of Manson's ratio $R_m/R_{p0,2} = 1.28$ [6].

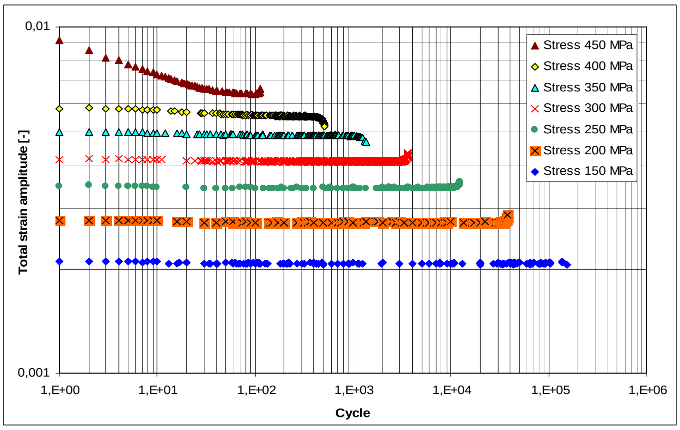

Fig. 3 Curves of cyclic hardening - softening

Wöhler-Basquin curve was obtained as experimental data dependence of stress amplitude σ_a on half-cycle to failure. The parameters fatigue strength coefficient σ_f' and fatigue strength exponent *b* were determined based on that curve. [6].

$$s_a = s'_f \cdot (2N_f)^b \tag{2}$$

The prevailing impact of elastic deformation part above the plastic deformation part was found based on hysteresis loop analyses also in the area of low number of cycles to failure. This effect is typical for aluminium alloy in over-ageing condition [7].

The amplitude of plastic deformation determined as half of hysteresis loop width in $N_{f/2}$, was about value $2{\cdot}10^{-4}$ also for highest loading level 450MPa. For relation between number of half-cycles to failure and both part of deformation applies the equation (3) [7].

Parameters of power relation $\varepsilon_{at} - 2N_f$ (Fig. 4b) are stated in Tab. 3.

$$e_{at} = \frac{s'_f}{E} \cdot (2N_f)^b + e'_f \cdot (2N_f)^c \tag{3}$$

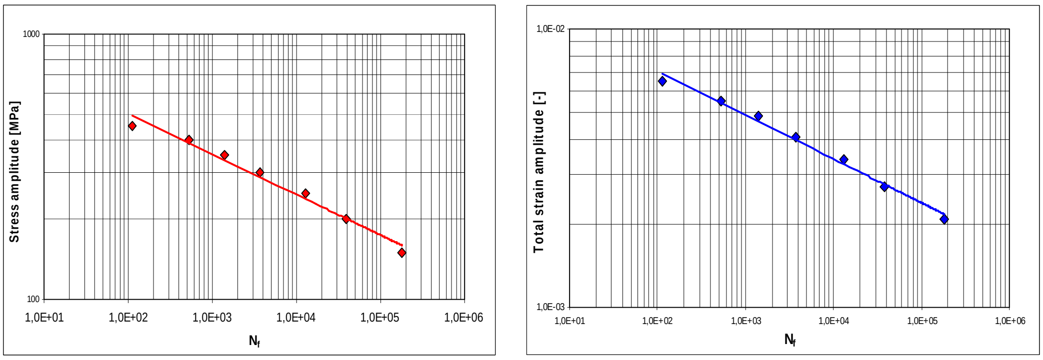

Fig. 4 (a) Wöhler-Basquin (a) and derived Manson-Coffin (b) curve

Tab. 3 Summary of acquired fatigue parameters

Wöhler-Basquin		Manson-Coffin		Cyclic Curve		
σ'_f	b	ε'_f	c	E	σ_0	n
MPa	-	-	-	MPa	MPa	-
440.35	- 0.1524	0.0163	-0.1576	72947.87	0.2339	13.757

Palmgren regression function was used for alignment experimental determined data about relation stress amplitude and number of cycles to failure on range 0,5 to 10^8 cycles. This function accurately designates values of regression parameters, it has affinity between parameters and geometric waveform for aluminium alloy.

This function has format [8, 9]

$$s(N) = a(N+B)^b + s_\infty \tag{2}$$

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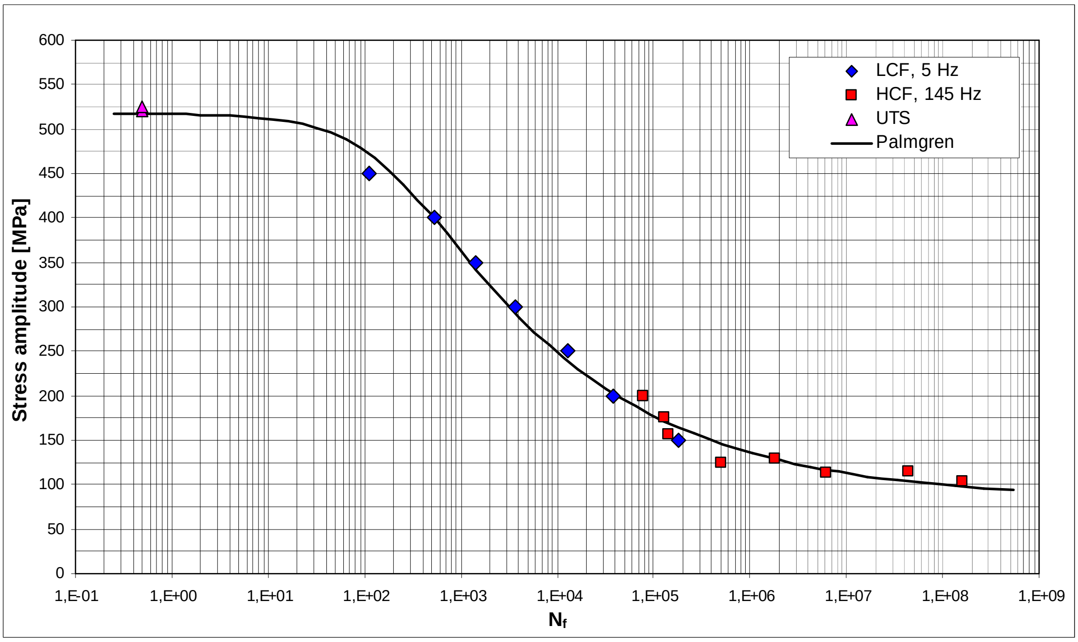

Fig. 5 Full area of fatigue lifetime and regression function for alloy 7020

Although both types of tests were performed on different testing machines and in different way of loading force realization (hydraulic vs. resonance machines) there is no discontinuity between low-cycle and high-cycle area of fatigue curve - as presented in Fig. 5. Change in frequency of loading cycle from 5 to 145 ± 4 Hz does not influence the result described. Fig. 5 also presents very good alignment experimental measured data with Palmgren function. Values of this regression parameters, i.e. parameters a, B, s_∞ and exponent b are together with other important results (sum of squared deviations S and fatigue limit s_C for 10^8 cycles) presented in Tab. 4.

Tab. 4 Parameters of Palmgren regression function

Parameter	a [MPa]	b	s_∞ [MPa]	B	S [MPa^2]	s_C [MPa]
	1600,536	-0,2454	82,26	203,227	2083,54	99,7

5 CONCLUSIONS

Tested alloy, which is commercially available, has very good strength and plastic properties. It means that there is optimal precipitation hardening (condition T6).

The microstructure consists from elongated polyedric grains and high quantity of inclusions which are directed through forming.

Based on development of cyclic hardening – softening curves can be concluded that there is decrease of total deformation amplitude on the higher level of loading cycle and that the deformation response is stable on lower levels.

Based on comparison of cyclic deformation curve and unidirectional curve was found, that there is no significant change in cyclic response on tested material and that material can be accepted as cyclic stable.

Through the regression functions material parameters of the Wöhler-Basquin curve σ'_f = 1122.1 MPa a b = -0.1524 were determined.

The full area of fatigue lifetime can be smooth by the Palmgren regression curve describing fatigue properties mainly in the high-cycle area of tested aluminium alloy.

No discontinuity between low-cycle and high-cycle area was found at tested material, although the fatigue tests were performed on different machines. Presented properties were not influenced by the different loading frequency (5 a 145 Hz).

Fatigue life for smooth testing specimens determined from calculation based on regression function for 10^7 cycles is $s_{C'}$ = 112.9 MPa and for 10^8 cycles is s_C = 99.7 MPa.

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