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FATIGUE RESISTANCE OF MAGNESIUM ALLOY AZ 91D AT HIGH-FREQUENCY CYCLIC LOADING.

KUFFOVÁ * , M.

ABSTRACT

The presented paper brings the result of Mg-alloy AZ91D metalographic and fractographic fracture surfaces analysis, fatigue crack propagation and fatigue life measured at high-frequency cyclic loading.
Microctructure of magnesium alloy AZ 91D specimens after thermal processing is created by uniform polyhedric grains of phase δ. At some places, within the grain boundaries there has been found the presence of small amount of discontinual precipitates consisting of fine lamellas of phase γ (electron compound $Al_{12}Mg_{17}$) in matrix of δ phase.
Experimentally measured values of the fatigue resistance of alloy AZ 91D has been caused, first of all, by the presence of cast defects (micropipes, structural heterogeneities). The occurence of these defects, their character, size, orientation, amount and location on the surface and in subsurface layers influenced in a negative way and to a various degree the strength the fatigue resistance of the studied alloy.
The fatigue behaviour and character of the fatigue fracture of the alloy AZ 91D are highly dependent on structural factors and on the level of technical perfection of their production, the character of the fracture surface morfology dependends on the size of stress amplitude σ_a to a considerable degree, due to strong structural heterogeneity and occurrence of large amount of cast defects (first of all, usually appearing microscopic cavities) it was not possible to show really the influence of the amplitude size of the applied strain on the initiation and micro-mechanism of fatigue failure development.

KEY WORDS

Magnesium alloy, High-frequency cyclic loading, Fatigue crack, Gigacycle mode of loading.

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* Dipl. Eng., Ph.D., Dpt. of Mechanical Engineering, Academy of the Armed Forces of Gen. M. R. Stefanik, Liptovsky Mikulas, Slovakia

1. INTRODUCTION

During real operation, the structures are strained by repeated load which results in fatigue fracture. Therefore, increasing attention is paid to the laws which govern the fatigue process. If the structure material is exposed to repeated cyclic loading, it is necessary to determine fatigue characteristics as completely as possible. It follows that concrete values have to be determined experimentally: coefficient of fatigue ductility ε'_f, exponents of lifetime curves c, b, coefficient of fatigue resistance σ'_f, fatigue limit σ_C, or timing fatigue limit σ_{CN}, basic threshold amplitude value of stress intensity coefficient K_{ath}, material characteristics A, m, fatigue fracture toughness K_{fc} [1]. Experimental defining the above fatigue characteristics is usually realized by means of general frequencies within the area from f ≈ 10 Hz to f ≈ 200 Hz, which, in term of time and cost, is very demanding. Authors [2-6] discovered decrease of fatigue characteristics, dependence $\sigma_a = f(N_f)$ beyond conventional boundary $N_C = 10^7$ cycles, first of all in high-strength and surface-strengthened steels. That is why material research is oriented to obtaining fatigue properties in gigacycle modes of loading; or propagation speeds of long fatigue cracks are monitored in near-threshold regions up to $da/dN = 10^{-12} \div 10^{-13}$ m/cycle [2], [7-9].
One of possible solutions is applying experimental methods of high-frequency cyclic loading (f ≈ 20 kHz) for the purpose of defining fatigue properties in structural materials. These experimental methods are efficient as far as time and cost concerns [9-12].
Nowadays, magnesium and its alloys are very interesting materials for practice. Its advantage is due to the lowest specific weight from among all metal used for structural purposes, declining availability and rising prices of raw materials, as well as subsiding supply of metals on a world scale. Mechanical properties of pure magnesium are not favourable. It has low strength and ductility due to its crystalline structure. However, by alloying we can obtain important structural materials. Suitable alloying partially eliminates occurrence of casting defects, considerably increases strength, toughness, resistance against corrosion and castability. [13].
Outstanding features of commercially used magnesium alloys are their low specific weight, good castability, machinability and weldability in protective atmosphere. Drawbacks which restrict their wider employment are caused by low modulus of elasticity, limited resistance against creeping at higher temperatures, high shrinkage during hardening and, first of all, low resistance against corrosion arising from their high chemical reactivity [13, 14].
Low specific weight and ability to absorb vibrations make them suitable for applications in automobile, aviation and rocket industries as well as in telecommunication and instrumentation. The most widely used Mg alloys in industry are those based on Mg-Al-Zn-(Si) and Mg-Al-Mn.
The submitted paper introduces results of Mg alloy AZ 91D fatigue lifetime ($_a$ = f (N), growth trajectory of fatigue crack and fractographic analysis) obtained under high-frequency cyclic loading within the region of high number of cycles from $N = 6.10^5$ cycles to $N = 1.10^9$ cycles.

2. EXPERIMENTAL EQUIPMENT

Fatigue tests were carried out on KAUP-ZU experimental equipment (Fig. 1) which enables to detect experimentally the following fatigue characteristics of structural materials under high-frequency cyclic loading and working frequencies ≈ 20 kHz: dynamic module of elasticity E_D, complete Wőhler curves ($\sigma_a = f(N_f)$) including fatigue limit σ_C, propagation speed of long fatigue cracks depending on amplitude of stress intensity factor ($da/dN = f(K_a)$) within interval from $da/dN = 10^{-9}$ m/cycle to $da/dN = 10^{-12}$ m/cycle, basic threshold values of stress intensity factor amplitude K_{ath} (at $da/dN = 10^{-12}$ m/cycle). Applied high-frequency cyclic loading (hereinafter called HFCL) is of a sinusoidal character, alternating symmetrical push–pull with asymmetry coefficient R = -1 and usual temperatures T = 20 ± 10 °C [9-12].

3. EXPERIMENTAL MATERIAL

Experiments were carried out with AZ 91D magnesium alloy which is mainly used in automobile industry. Chemical composition and mechanical characteristics are shown in Table 1 and Table 2. Fatigue tests were realized on KAUP-ZU Zilina testing equipment, at high-frequency cyclic loading of the push-pull type (f ≈ 20 kHz, T = 20 ± 10°C, R = -1, cooling in NaOH solution).

Table 1 Chemical composition (mass %)of Mg – alloy AZ 91D

	Al	**Zn**	**Mn**	**Si**	**Cu**	**Fe**	**Be**	**Pb**
AZ 91D	7,98	0,63	0,22	0,045	0,007	0,013	0,0003	0,057

Table 2 Mechanical properties of Mg – alloy AZ 91D

	Rm [MPa]	**A_5 [%]**	**Z [%]**	**$HB_{2,5/62,5/30}$**
AZ 91D	223	8,0	0,5	64,2

Magnesium alloy was delivered after being cast into sand moulds in the form of half-finished products, i.e. plates with dimensions 21 x 100 x 200 mm. The alloy was thermally processed in T4 mode – dissolving annealing. Due to non-uniform hardening in the course of experimental material cooling, samples were taken from the plate edge as well as the plate middle.

Microstructure of magnesium alloy AZ 91D samples after thermal processing (Fig. 2) is created by uniform polyhedric grains of phase δ. The grain size (assessed according to STN 42 0462) is not the same in the whole cast body. Bigger grain has been observed in samples taken from the plate middle (grain size 4) (Fig.2a) when compared to the samples taken from the plate edge (grain size 5) (Fig.2b). At some places, within the grain boundaries there has been found the presence of small amount of discontinual precipitate consisting of fine lamellas of phase γ (electron compound $Al_{12}Mg_{17}$) in matrix of δ phase.

4. REULTS AND DISCUSSION

On the tested magnesium alloy AZ 91D, the dependence $\ _a$ = f (N) in the region from N ≈ 6.10^5 to N ≈ 1.10^9 of cycles to fracture has been studied. Experimentally measured values of the fatigue resistance (Fig. 3) show relatively high dispersion. This dispersion of the measured values has been caused, first of all, by the presence of cast defects (micropipes, structural heterogeneities). The occurence of these defects, their character, size, orientation, amount and location on the surface and in subsurface layers influenced in a negative way and to a various degree of strength the fatigue resistance of the studied alloy. Experimental results show an obvious difference in the values measured on test bars taken from the plate middle (A) and the plate edge (B). Different size of grains (Fig.2a, 2b) caused by different speed of hardening and cooling at the plate middles and at the plate edges in the course of casting, plays here a considerable role.

The fractographic analysis of fracture surfaces of test bars disturbed by fatigue has shown that the fatigue cracks, almost in all cases, have been initiated from the surface of the test bars. In most cases, an initiation place was a cast defect reaching to the surface of the test bar. The cast defects were mostly microscopic small, nevertheless their occurrence was very frequent and sometimes they created rather a wide network. Parts of fracture surfaces that showed signs of fatigue disturbance had a transcrystallic character for the most part. The disturbance character of test bars taken from the plate middle and plate edge has not disclosed any substantial differences from the fractografic point of view. The fracture surfaces generally have had a mixed character of disturbance. In addition to facets having character of transcrystallic fatigue disturbance, on the fracture surfaces there also appeared inter-crystallic facets. Clearly visible fatigue grooving could be observed at the studied fracture surfaces very seldom only.

The character of fracture surface morphology was to a considerable degree dependent on stress amplitude σ_a. Morphology of fatigue fracture areas of test bars disturbed at lower values of σ_a appeared to be less relief. At higher σ_a values the fatigue fracture areas were more relief. In general, the fatigue areas had a mixed character of disturbance and in addition to facets having character of trans-crystalline fatigue disturbance, inter-crystalline facets occurred at fracture areas too. Fatigue striae at fracture areas could be observed very seldom only. Disturbance character of tested rods taken from margin and middle of slabs did not show any substantial differences from the fractographic point of view.

The fatigue cracks, which were observed in AZ 91D magnesium alloy, propagated in a transcrystalline way. At higher values of stress intensity factor the trajectory of fatigue crack was less dissected and propagation of fatigue cracks was accompanied by intensive slip. With gradually decreasing value of stress intensity factor the trajectory of fatigue cracks became more dissected and the propagating crack started to copy their boundaries in some of the grains. At low values of voltage intensity factor this effect manifested relatively often and the trajectory of fatigue crack copied here and there grain boundaries at their close proximity. At very low values of voltage intensity factor within near-threshold region, there occurred branching of cracks as well as an extensive network of secondary cracks.

5. CONCLUSION

Experimental assessment of fatigue resistance of the studied AZ 91D magnesium alloy in the region of high number of loading cycles (N ≈ $6.10^5 \div 1.10^9$ cycles), carried out under high-frequency cyclic loading (f ≈ 20 kHz, T = 20 ± 10°C, R = -1) showed that:

- appearance of casting defects, their character, size, orientation, amount and localization at the surface and sub-surface layers with various intensity, influence fatigue resistance of the studied Mg alloy in a negative way,
- studying trajectory of fatigue cracks growth in the observed AZ 91D Mg alloy showed ruggedness of growth (branching, linking, secondary cracks, stages...) as a consequence of interaction of crack front with micro-structural factors (casting defects, grain boundaries, intermetallic particles and the like);
- fatigue behaviour and character of fatigue fracture of AZ 91D alloy are considerably dependent on structural factors and level of technical perfection of their production,
- the obtained knowledge showed principled possibility of efficient verifying fatigue characteristics within a wide range of number of loading cycles (from N = 1.10^5 to N= 1.10^9 cycles) under high-frequency cyclic loading (f ≈ 20 kHz).

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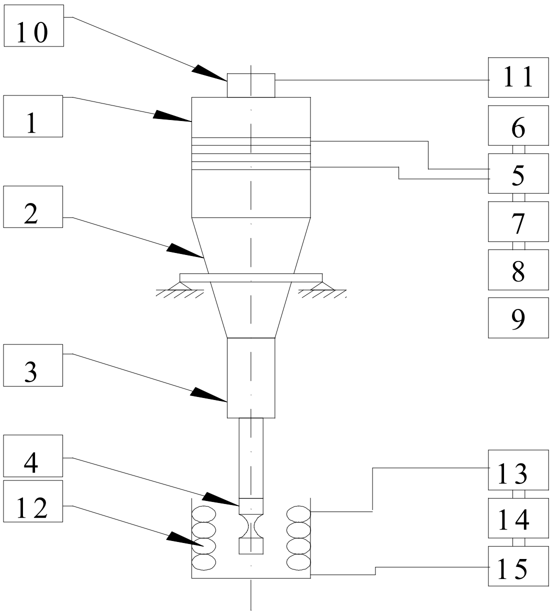
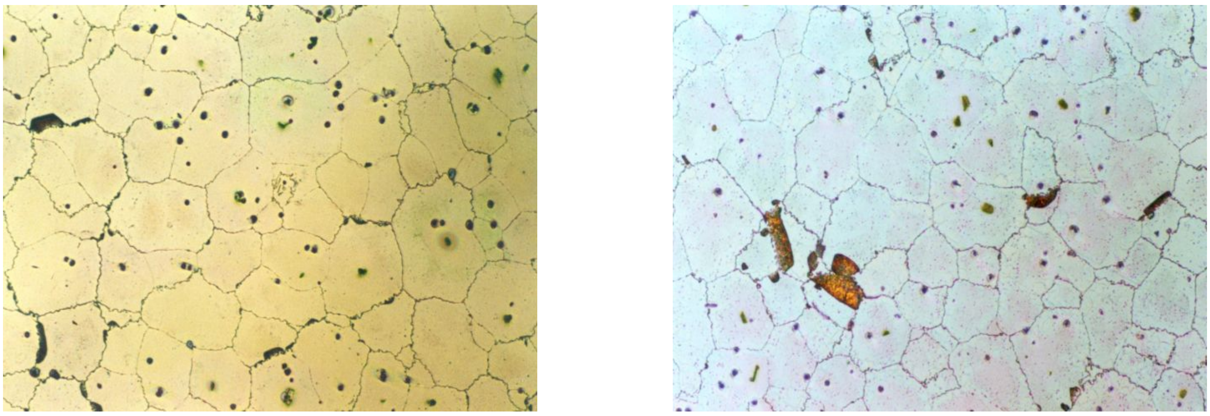


Fig. 1
Simplified diagram of KAUP-ZU experimental installation, HFCL, (1)- piezoelectric transducer, (2)- conical concentrator, (3)- stepped concentrator, (4)- test sample, (5)- ultrasound generator, (6)- automatic frequency balancer, (7)- frequency meter, (8)- printer, (9)- digital timer, (10)- deviation amplitude reader, (11)- millivoltmeter, (12)- cooling nozzles, (13)- thermostat, (14)- water pump, (15)- collecting vessel



a) b)

Fig. 2
Microstructure of Mg – alloy AZ 91D, magnified 100x, etched by 5 % molybdenium acid, a) plate centre, b) plate edge

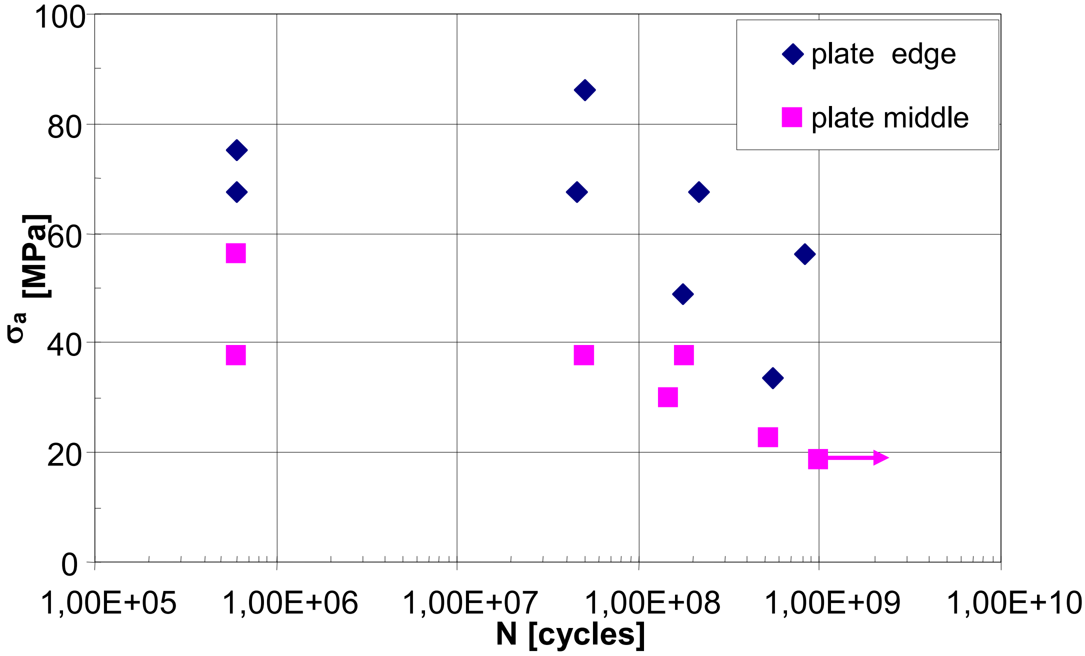


Fig. 3
Dependence of σ_a = f (N) for Mg-alloy AZ91 D