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

SUMMARY

The presented paper brings the results of Mg-alloy AZ 91D fatigue crack propagation and life measured under high frequency cyclic loading (frequency f = 20 kHz, temperature t = 20±10°C, alternating, symmetric tension-pressure, loading cycle asymmetry R = ±1) in the field of high number of cyclic from N = 6·10⁵ cycles to N = 1·10⁹ cycles.

Keywords: *fatigue crack propagation, experimental investigations*

WYTRZYMAŁOŚĆ ZMĘCZENIOWA STOPU MAGNEZU AZ 91D W WARUNKACH WYSOKOCZĘSTOTLIWOŚCIOWEJ ZMIANY OBCIĄŻENIA

W artykule przedstawiono rezultaty badań eksperymentalnych dotyczących wytrzymałości zmęczeniowej (rozwoju pęknięcia zmęczeniowego) na próbkach wykonanych ze stopu magnezu AZ 91D. Eksperyment przeprowadzono w warunkach wysokoczęstotliwościowej zmiany obciążenia (f = 20 kHz) w temperaturze t = 20±10°C dla symetrycznego (alternatywnie) rozciągania – ściskania (współczynnik symetrii cyklu R = ± 1) w zakresie bardzo wysokiej liczby zmian cykli obciążenia (od N = 6·10⁵ do N = 1·10⁹ cykli).

Słowa kluczowe: *pęknięcie zmęczeniowe, badania eksperymentalne*

1. INTRODUCTION

Nowadays, magnesium alloys are very interesting material for practice. Low specific weight and ability to damp vibrations preordains them for applications in automobile, airplane and rocket industry, in telecommunication and instrument technology [1]. Research of magnesium alloys is now aimed at obtaining their complete properties with respect to corrosion, creeping, fatigue and internal damping [2, 3, 4, 5, 6]. The most frequently used magnesium alloy is the alloy AZ 91. Aluminium content in this alloy is 9% and Zinc content up to 1%. The presented paper brings results of fatigue life of Mg-alloys AZ 91D ($\sigma_a = f(N)$, fractografic analysis) obtained under high-frequency cyclic loading in the region of high number of cycles from $N = 6 \cdot 10^5$ to $N = 1 \cdot 10^9$ cycles.

2. EXPERIMENTAL PART

The fatigue resistance in the region of high number of cycles of the magnesium alloy AZ 91D with chemical composition (Tab. 1), mechanical properties (Tab. 2) and microstructure (Fig. 1) after thermal processing T4 (melting annealing – temperature 413°C, holding stage 18 hours and cooling to water) has been carried out on the testing equipment KAUP-ŽU Žilina, under high-frequency cyclic loading of the type tension – pressure with sinusoidal course (f = 20 kHz, T = 20 ±10°C, R = ±1), while using methods and procedures in accordance with papers [7, 8].

Samples, on which metalographic analysis has been carried out, have been taken from cast plates with dimensions 200×100×21 mm (length × width × thickness), precisely from the plate edge to the plate centre. Microctructure of magnesium alloy AZ 91D samples after thermal processing (Fig. 1) is created by uniform polyedric 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. 1a) when compared to the samples taken from the plate edge (grain size 5) (Fig. 1b). 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.

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

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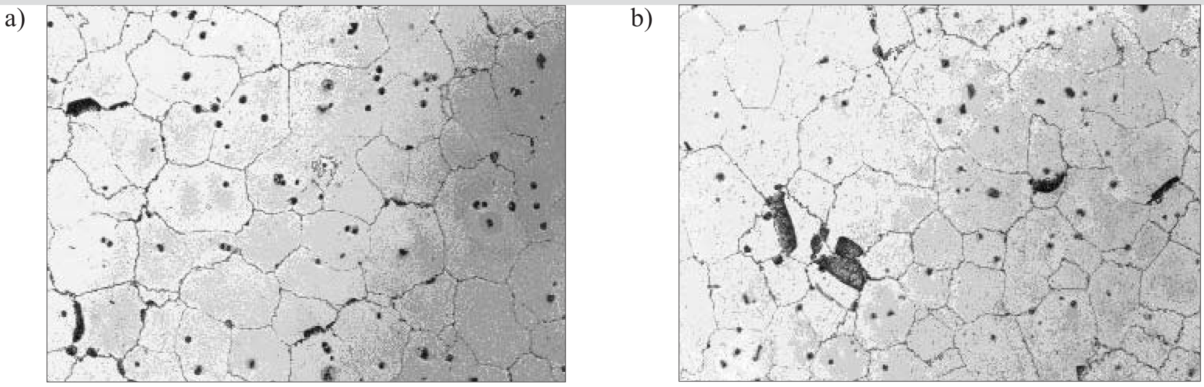

Fig. 1. Microstructure of Mg-alloy AZ 91D, magnified 100×, etched by 5% molybdenum acid: a) plate centre; b) plate edge

3. RESULTS AND DISCUSSION

On the tested magnesium alloy AZ 91D, the dependence $\sigma_a = f(N)$ in the region from $N = 6 \cdot 10^5$ to $N = 1 \cdot 10^9$ of cycles to fracture has been studied. Experimentally measured values of the fatigue resistance (Fig. 2) 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 centre (A) and the plate edge (B). Different size of grains (Fig. 1a, 1b) caused by different speed of hardening and cooling at the plate centres and at the plate edges in the course of casting, plays here a considerable role.

When the number of loading cycles to fracture of individual test bars disturbed by fatigue is taken into consideration, the idea appears immediately, namely, to divide the experimental results, presented in Figure 2, into two areas (area I and II). In the case of such division we can think, to a certain probability, of different micro-mechanisms of fatigue disturbance initiation (surface and sub-surface initiation of fatigue cracks).

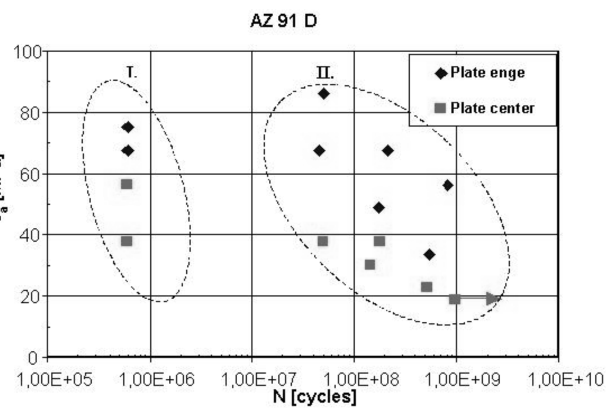

Fig. 2. Dependence of $\sigma_a = f(N)$ for Mg-alloy AZ 91D

The fractografic 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 (Fig. 3). 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 (Fig. 4) had a transcrystallic character for the most part.

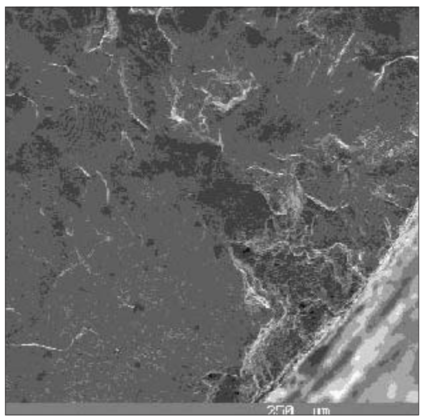

Fig. 3. Initiation of fatigue crack from surface cast defect, Mg-alloy AZ 91D

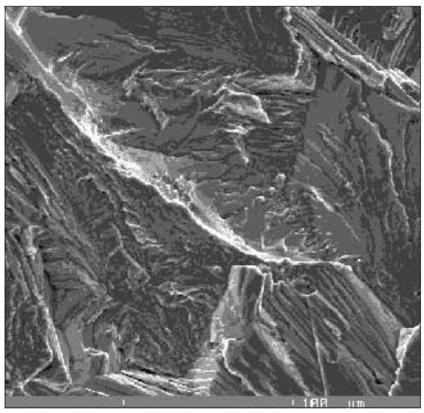

Fig. 4. Transcrystallic fatigue failure, Mg-alloy AZ 91D

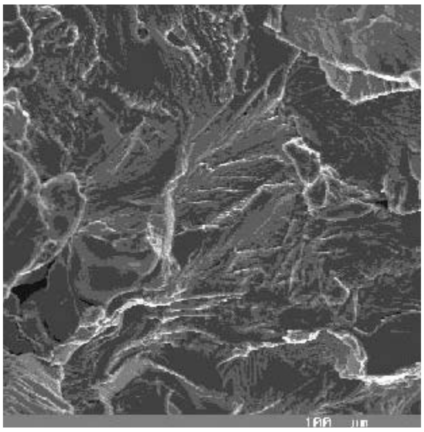

Fig. 5. Characteristic appearance of fracture surfaces of fatigue disturbed test bars, Mg-alloy AZ 91D

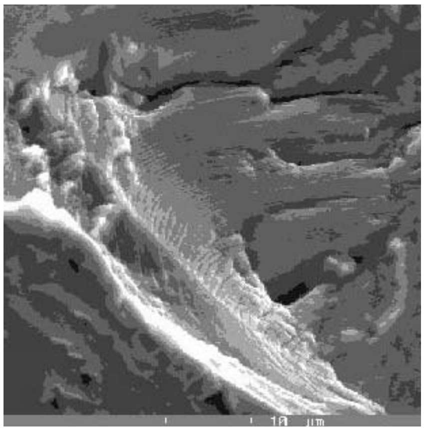

Fig. 6. Detail of fatigue grooving, Mg-alloy AZ 91D

The disturbance character of test bars taken from the plate centre 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 (Fig. 5). Clearly visible fatigue grooving could be observed at the studied fracture surfaces very seldom only (Fig. 6).

4. CONCLUSION

Experimental assessment of the fatigue resistance of the studied magnesium alloy AZ 91D in the region of high number of loading cycles ($N = 6\cdot10^5 \div 1\cdot10^9$ cycles), carried out under high-frequency cyclic loading ($f = 20$ kHz, $T = 20 \pm 10^{o}$C, $R = \pm 1$) has shown that:

- the fatigue behaviour and character of the fatigue fracture of the alloy AZ 91D are highly dependent on structural factors and the level of technical perfection of their production;
- the character of the fracture surface morfology depended on the size of amplitude of strain 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 factually the influence of the amplitude size of the applied strain on the initiation and micro-mechanism of fatigue failure development.

The most substantial enhancing of the fatigue properties of the produced magnesium alloy AZ 91D can be obtained by means of improving the level of technological perfection of its production (above all by reducing the amount and size of micro-cavities and making the grain size more uniform).

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