GIGACYCLE FATIGUE AT HIGH-FREQUENCY LOADING

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Summary

In this work there are information about an experimental high-frequency testing apparatus and specimens enable to determine the fatigue properties in the ultra-high-cycles region (gigacycle fatigue) and the rates of long fatigue cracks growth in near-threshold areas. The selected characteristic examples about fatigue resistance of various structural materials are presented. The results are utilizable in the field of material engineering and threshold states of material.

Keywords: gigacycle fatigue, high-frequency loading, structural materials.

1. INTRODUCTION

At the actual operation, the components and construction are mainly loaded by repeating loading that could lead to the ultimate state, fatigue fracture in the final consequence. If it is assumed that the structural material will be repeatedly cyclically loaded in the operation, then it will be necessary to determine very complex fatigue characteristics for the given operation conditions [1]. To determine the fatigue characteristics there is usually realized the determination using normal frequencies, in the range from f ≈ 10 Hz to f ≈ 200 Hz, that is very time demanding and expensive. This statement emphasizes the fact, that fatigue fractures occur even after billion cycles and more [2, 3] and the stated, conventional criteria [4] do not fulfill the requirements for the safety and evaluation of components and constructions lifetime. Bathias, G. [5], Sakai, T. et all [6], Masuda, C. et al. [7], Naito, T. et al. [8], Bathias, G. and Bonis, J. [9], Asami, K. and Hironaga, M. [10], Bokůvka, O. and Nový, F. et al. [11-14] stated f. e. the decreasing of the fatigue characteristics, dependence stress amplitude (σ_a) vs. number of cycles (N) beyond conventional limit of cycles ($10^6 < N < 10^7$ cycles) in structural materials. Recently, the material research has been oriented on the questions of the verification of fatigue properties in the gigacycle regimes of loading ($10^7 < N < 10^{11}$ cycles); there have been developed the new testing apparatus, methods and techniques with the aim to achieve the experimental data in the ultra-high-cycles region, there are monitored the rates of the long fatigue cracks growth in near-threshold areas to $da/dN = 10^{-12} \div 10^{-13}$ m.cycle^{-1} [1, 3, 5, 15-18]. One of the possible directions is the application of experimental methods of high-frequency cyclic loading (f ≈ 20 kHz) to determination of the fatigue properties in structural materials. These experimental methods are progressive without question, with a wide future application, they are very time and economically effective [15-19].

2. TESTING APPARATUS AND SPECIMENS

The unique experimental testing apparatus of acoustic fatigue KAUP-ZU, KAUP-LM-ZU (at the working centres of the paper authors) enable to determine these fatigue characteristics – dynamic modulus of elasticity E_D, fatigue lifetime $\sigma_a = f(N)$ in the region from $N = 10^4$ to $N = 10^{11}$ cycles of loading, rate of long fatigue crack growing in dependence on stress intensity factor amplitude ((da/dN = f (K_a)), threshold values K_{ath} at $da/dN = 10^{-12} \div 10^{-13}$ m.cycle^{-1}. The applied high-frequency cyclic loading (frequency ≈ 20 kHz) has usually sinus character, fully reversed push-pull loading with the stress ratio R = -1 and the temperatures usually T = 20 ± 10 °C [15-18]. The testing apparatus KAUP-ZU is in Fig. 1.

The tested specimens with the shape and the general parameters are in Fig. 2 and Fig. 3. These specimens were proved successfully to investigating the fatigue lifetime $\sigma_a = f(N)$ on the testing apparatus KAUP-ZU and the testing apparatus KAUP-LM-ZU to investigate the long fatigue cracks growth rate in the dependence of the factor stress intensity amplitude ((da/dN = f (K_a)) incl. the threshold value K_{ath} [15-18]. To fulfill the resonance conditions the specimen with their parameters including cross-sections, by the given testing structural material and its acoustic properties, must suit to certain conditions [20]. For the entry experiment planning it is important to consider the initial parameters, diameter D = 12 mm, length L ≈ 80 mm in the case of specimen (Fig. 2) and diameter D = 16 mm, length L ≈ 80 mm in the case of specimen (Fig. 3).

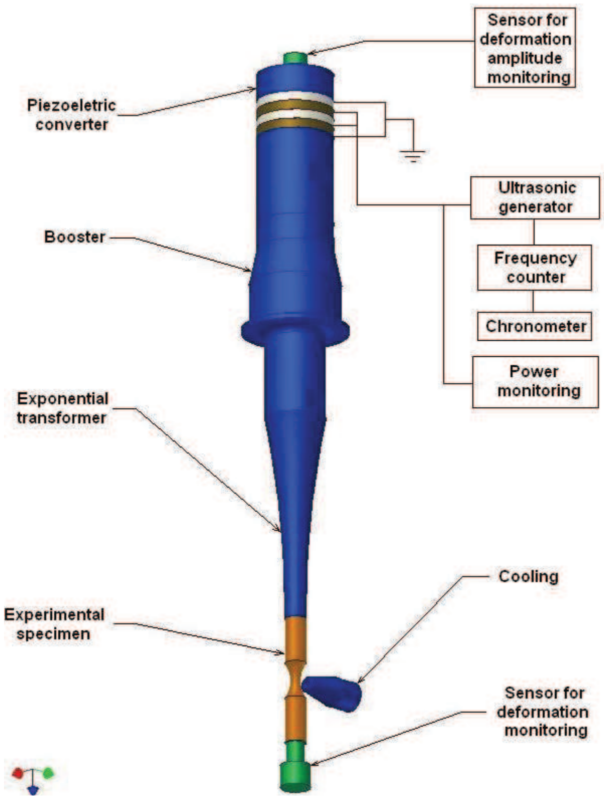

Fig. 1. The testing apparatus KAUP-ZU

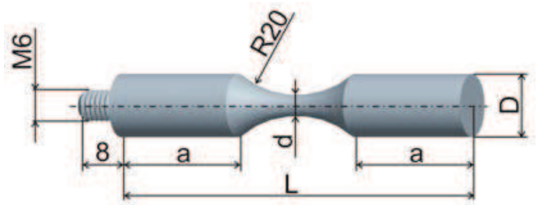

Fig. 2. The shape and general parameters of the specimens to determine $\sigma_a = f(N)$

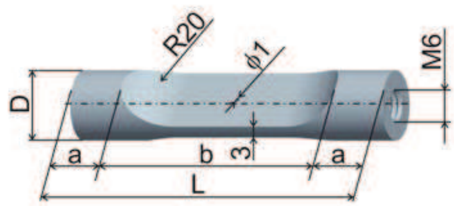

Fig. 3. The shape and general parameters of the specimens to determine $da/dN = f(K_a)$ and K_{ath}

3. APPLICATIONS

In the coarse of more than 30-years there were solved the tasks related with the methods and processes by high-frequency cyclic loading applications [15-18, 21-26] and in the last 10-years an interest is especially dedicated to gigacycle regimes of loading. The fatigue lifetime of various structural materials (steels incl. biomaterials, austempered ductile irons, Mg and Al alloys, brasses, …) respecting the external and internal influences was experimentally obtained [11-14, 27-30]. Selected characteristic examples from the ultra-high-cycles region and long fatigue crack growth rate are presented bellow (see Fig. 4 - Fig. 8).

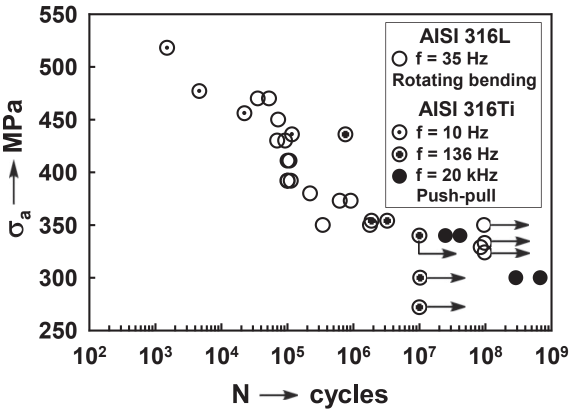

Fig. 4. Fatigue lifetime of AISI 316L and AISI 316Ti austenitic stainless steel

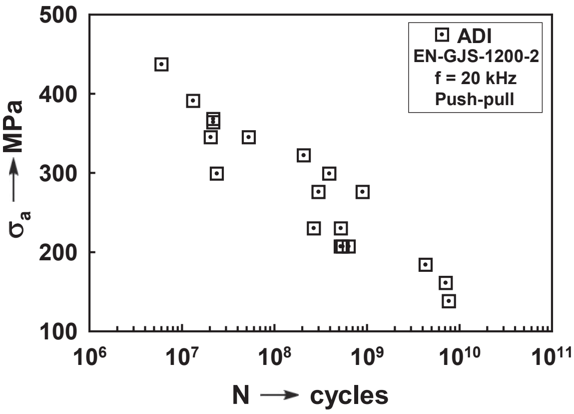

Fig. 5. Fatigue lifetime of EN-GJS-1200-2 ADI (Austempered Ductile Iron)

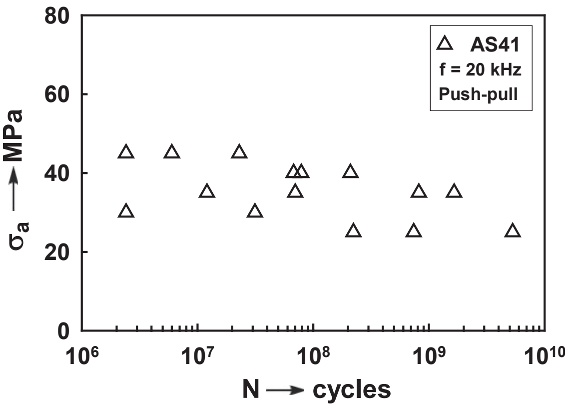

Fig. 6. Fatigue lifetime of AS 41 Mg-alloy

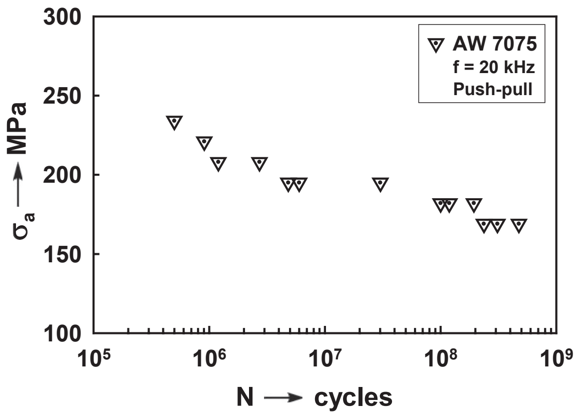

Fig. 7. Fatigue lifetime of AW 7075 Al-alloy

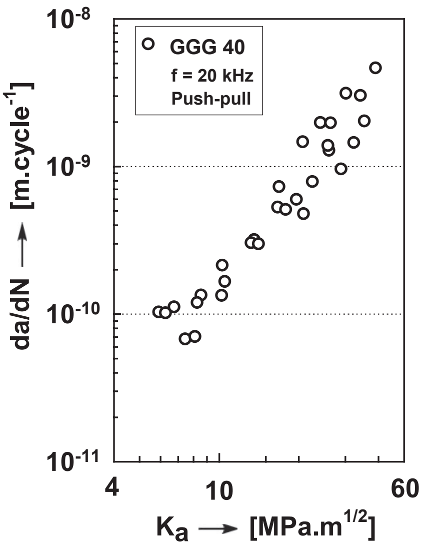

Fig. 8. Fatigue crack growth rate in nodular cast iron

4. CONCLUSION

The application of high-frequency cyclic loading (f ≈ 20 kHz) for the obtaining of fatigue characteristics in the ultra-high-cycles region and long fatigue crack growth in near-threshold areas is characteristic with the significant time, energy and work saving, the results are utilizable in the field of material engineering and threshold states of structural materials.

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