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LOW AND HIGH FREQUENCY FATIGUE TESTS OF NODULAR CAST IRONS

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The paper deals with the comparison of fatigue properties of nodular cast iron at low and high frequency cyclic loading. The specimens from three melts of nodular cast iron with different microstructure and mechanical properties were used for experiments. Fatigue tests were carried out at low and high frequency sinusoidal cyclic push-pull loading (stress ratio $R = -1$) at ambient temperature ($T = 20 \pm 5$ °C). Low frequency fatigue tests were carried out using the fatigue experimental machine Zwick/Roell Amsler 150HFP 5100 at frequency $f \approx 120$ Hz; high frequency fatigue tests were carried out using the ultrasonic fatigue testing device KAUP-ZU at frequency $f \approx 20$ kHz.

Key words: nodular cast iron, fatigue test, microstructure, mechanical properties

INTRODUCTION

Fatigue has been a predominating fracture mode of load-bearing machine members. Therefore, through the years its prevention has become a fundamental design criterion. Although fatigue has been studied extensively over many years and excellent reference books are now available, further study is needed because the knowledge base is partly obsolete and new materials and treatments are continuously being developed.

Fatigue testing is usually performed to estimate the relationship between the amplitude of stress and the number of cycles to failure for a particular material or component. Fatigue testing is also conducted to compare the fatigue properties of two or more materials or components. In either case the reliability of any decision based on the results of a fatigue testing program is directly related to the manner in which the experiments are designed and analysed [1].

Fatigue tests are usually carried out using *low frequency cyclic loading* with frequencies in the range from $f \approx 10$ to 200 Hz. A norm prescribes the number of cycles $N_f = 10^7$ or 10^8 for determination of the fatigue characteristics. If it is necessary to determine the fatigue characteristics at higher number of cycles, it is very time demanding and expensive. Recently, the material research has been focused on the issue of verification of fatigue properties in the gigacycle regimes of loading. There have been developed new testing apparatus, methods and techniques with the aim to achieve the experimental data at the number of cycles $N_f = 10^9$ and more. One of the possible approaches is the application of experimental methods of *high frequency cyclic loading* for determination of the fatigue properties in materials [2].

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Time and economic efficiency of determining the fatigue characteristics by high frequency cyclic loading is evident from the Table 1. The time demands of low frequency cyclic loading (LFCL) with frequency $f \approx$ 120 Hz are compared with high frequency cyclic loading (HFCL) with frequency $f \approx 20$ kHz.

Table 1 **Time needed to determine the fatigue strength σ_c at LFCL and HFCL**

Loading, frequency	Number of cycles		
	$N_f = 10^7$	$N_f = 10^8$	$N_f = 10^9$
LFCL, $f = 120$ Hz	23,1 hours	9,6 days	96,5 days
HFCL, ***f* = 20 kHz**	8,3 min	83,3 min	13,9 hours

This paper deals with comparison of the fatigue properties of nodular cast iron at low and high frequency fatigue testing.

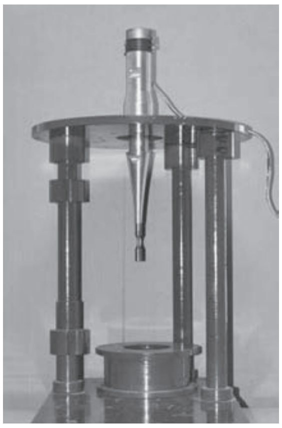
EXPERIMENTAL METHODS

Microstructure of the specimens was evaluated according to STN EN ISO 945 and by automatic image analysis (using NIS Elements software) [3-4].

The fatigue tests were performed according to STN 42 0362 at high and low frequency sinusoidal cyclic push-pull loading (stress ratio $R = -1$) at ambient temperature ($T = 20 \pm 5$ °C). Low frequency fatigue tests were carried out using the fatigue experimental machine Zwick/Roell Amsler 150HFP 5100 at frequency f » 120 Hz (Figure 1a). High frequency fatigue tests were carried out using the ultrasonic fatigue testing equipment KAUP-ZU at frequency f » 20 kHz (Figure 1b) [5-8].

The specimens from three melts of nodular cast iron were used for the experiments. The melts differed in charge composition. The basic charge of individual melts was formed by different ratio of pig iron and steel

a) LFCL



b) HFCL

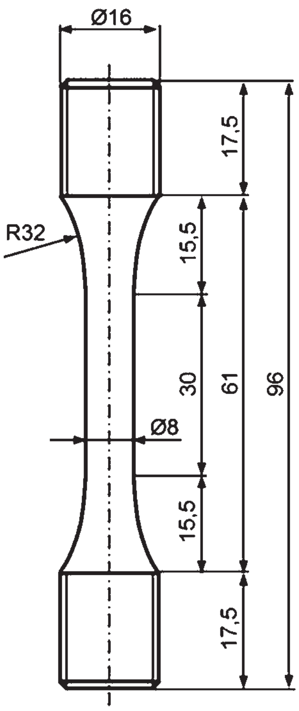
Figure 1 Fatigue experimental apparatus for LFCL and HFCL

scrap and by different additive for the regulation of chemical composition (metallurgical silicon carbide or ferrosilicon) [9-12]. Therefore, microstructure and mechanical properties of the melts are different.

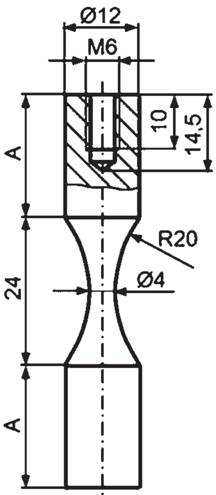
Specimens of circular cross-section were used for fatigue tests. Shape and parameters of the specimens for low and high frequency cyclic loading are shown in Figure 2.

For both fatigue tests (low frequency cyclic loading and high frequency cyclic loading), ten specimens from each melt were used to determine the fatigue characteristics.

For a given material the relationship between the applied amplitude of cyclic stress and the number of cycles to failure is customarily identified from its $\sigma_a - N$ diagram (Wöhler curve) in which the stress amplitude is plotted with the corresponding number of cycles to failure using a semi logarithmic scale. The number of cycles that the metal can endure before failure increases with a decreasing stress amplitude and for some engineering materials (including nodular cast iron) the Wöhler curve becomes horizontal at a certain limiting stress known as the fatigue limit (fatigue strength). Below the fatigue limit the material will not fail in an infinite number of cycles [13].



a) specimen for LFCL



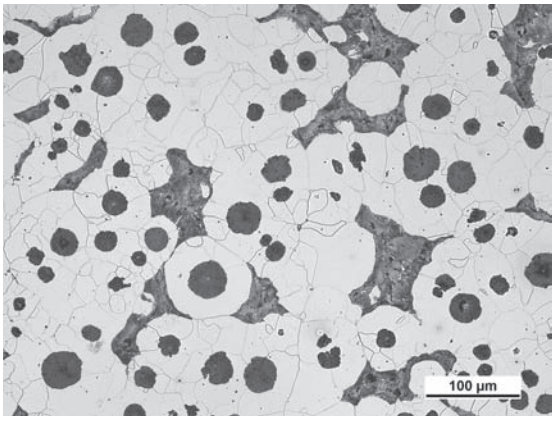
b) specimen for HFCL

Figure 2 Shape and parameters of the specimens used for experiments

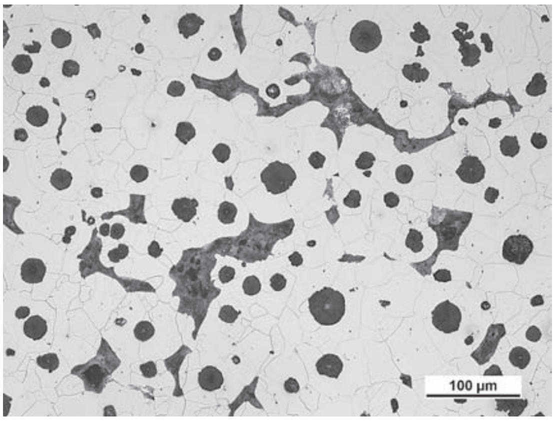
RESULTS AND DISCUSSION

Microstructure and mechanical properties of the melts are given in Tables 2 and 3.

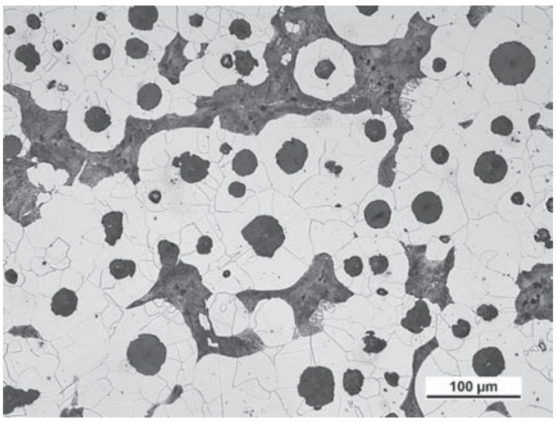
From a microstructural point of view, the specimens from all the melts are ferrite-pearlitic nodular cast irons (Figure 3) with different content of ferrite and pearlite



a) melt 1



b) melt 2



c) melt 3

Figure 3 Microstructure of the specimens in the matrix, different size of graphite and count of graphitic nodules (Table 2). Different microstructure is caused by different charge composition [14].

Table 2 **Microstructure of the melts**

Melt number	Microstructure (according to STN EN ISO 945)	Count of graphitic nodules/ mm^{-2}
1	80 %VI6 + 20 %V6 – Fe94	199,8
2	70 %VI5/<u>6</u> + 30 %V6 – Fe94	179,8
3	70 %VI5/<u>6</u> + 30 %V6 – Fe80	151,0

Mechanical properties (tensile strength R_m, elongation A, absorbed energy $K0$ and Brinell hardness HBW) are connected with the microstructure of the specimens, especially with the characteristics of the matrix (content of ferrite and pearlite) and also with the size and count of graphitic nodules (Table 3).

Table 3 **Mechanical properties of the melts**

Melt number	R_m / MPa	A/ %	$K0$/ J	HBW 10/3000
1	539,0	4,0	30,6	192,3
2	515,7	3,7	17,2	182,3
3	462,6	2,7	24,0	181,3

For the fatigue tests, ten specimens from each melt were used to obtain Wöhler fatigue curves σ_a = f(N) and determine fatigue strength σ_c.

The results (Wöhler curves) obtained at low frequency cyclic loading ($f \approx$ 120 Hz) are shown in Figure 4. The number of cycles to failure increases with a decreasing stress amplitude.

The values of fatigue strength σ_c determined for $N = 10^7$ cycles in comparison with tensile strength R_m are given in Table 4. The fatigue strength in analysed specimens of nodular cast iron increases with an increasing tensile strength.

The results obtained at high frequency cyclic loading ($f \approx$ 20 kHz) are shown in Figure 5. The number of cycles to failure also increases with a decreasing stress amplitude.

The values of fatigue strength σ_c determined for $N = 10^8$ cycles in comparison with tensile strength R_m are given in Table 4. At higher values of tensile strength there was observed an increase in fatigue strength.

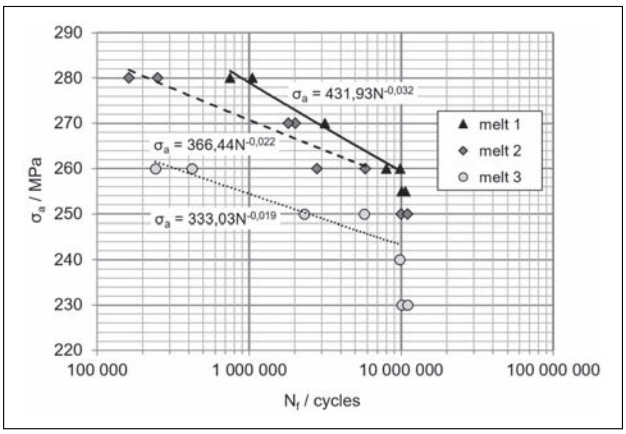


Figure 4 Wöhler curves σ_a = f(N) for low frequency cyclic loading

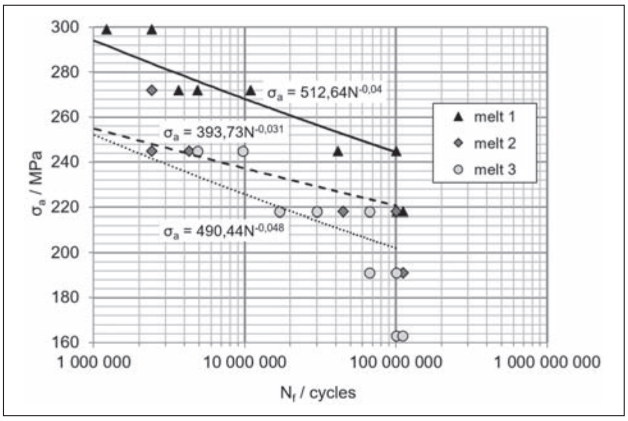


Figure 5 Wöhler curves σ_a = f(N) for high frequency cyclic loading

Table 4 **Comparison of tensile strength R_m and fatigue strength σ_c**

Loading, frequency		LFCL, f = 120 Hz	HFCL, f = 20 kHz
Melt number	R_m / MPa	σ_c / MPa for $N = 10^7$ cycles	σ_c / MPa for $N = 10^8$ cycles
1	539,0	255	218
2	515,7	250	191
3	462,6	230	163

The results obtained at high frequency cyclic loading are in a good agreement with the results obtained at low frequency cyclic loading. In both cases, the fatigue strength σ_c increases with an increasing tensile strength R_m.

CONCLUSIONS

The norm prescribes the number of cycles $N_f = 10^7$ (for steels and cast irons) to determine the fatigue characteristics. Nowadays, some experimental institutions deal with fatigue testing in the gigacycle regimes of loading (i.e. at the number of cycles $N_f = 10^9$ and more). The main problem of higher number of cycles is time demand of testing. Therefore, new testing apparatus, methods and techniques have been developed whereby the experimental methods for determination of the fatigue properties at high frequency cyclic loading have a predominant position. High frequency fatigue testing with frequency f » 20 kHz is not so time demanding as low frequency fatigue testing with frequencies f » 10 to 200 Hz.

The application of high frequency cyclic loading is characterised by significant time, energy and work saving. Moreover, the results obtained at high frequency cyclic loading are in a good agreement with the results obtained at low frequency cyclic loading. They are utilizable in the field of materials engineering and threshold states of materials.

Acknowledgements

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Note: The responsible translator for the English language is Mgr. Janka Súkeníková, Sarja, Žilina, Slovakia