PRODUCTION ENGINEERING ARCHIVES 17 (2017) 15-18

PRODUCTION ENGINEERING ARCHIVES

ISSN 2353-5156 (print)
ISSN2353-7779 (online)

Exist since 4th quarter 2013
Available online at www.qpij.pl/production-engineering-archives

Comparison of low and high frequency fatigue tests

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Article history
Received 31.10.2017
Accepted 30.12.2017
Available online 31.01.2018

Keywords
fatigue test
low frequency cyclic loading
high frequency cyclic loading
nodular cast iron

Abstract

The paper presents the results of low and high frequency fatigue tests carried out on nodular cast iron. The specimens of synthetic nodular cast irons from three different melts were studied in the high cycle fatigue region (from 10^5 to 10^8 cycles) using fatigue experimental equipments for low and high frequency cyclic loading. Low frequency fatigue tests were carried out at frequency f ≈ 120 Hz using the fatigue experimental machine Zwick/Roell Amsler 150HFP 5100; high frequency fatigue tests were carried out at frequency f ≈ 20 kHz using the ultrasonic fatigue testing device KAUP-ZU. Both fatigue tests were realised at sinusoidal cyclic push-pull loading (stress ratio R = –1) at ambient temperature (T = 20 ± 5 °C).

1. Introduction

The 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 warranted because the knowledge base is partly obsolete and new materials and treatment are being continuously 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 decisions based on the results of a fatigue testing program is directly related to the manner in which the experiments are designed and analysed (BOKŮVKA O. 2002).

Fatigue tests are usually preformed using *low frequency cyclic loading* with frequencies in the range from f ≈ 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 extremely time demanding and expensive. Recently, the material research has been oriented on the questions of the 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 directions is the application of experimental methods of *high frequency cyclic loading* for determination of the fatigue properties in materials (BOKŮVKA O. 2014, ULEWICZ R. 2017).

Time and economical effectiveness of determination of the fatigue characteristics by high frequency cyclic loading is evident from the Tab. 1. The time demands of low frequency cyclic loading (LFCL) with frequency f ≈ 120 Hz are compared with high frequency cyclic loading (HFCL) with frequency f ≈ 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

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

2. Experimental material and methods

The specimens from three melts of nodular cast iron were used for experiments. The melts have been different by charge composition (Tab. 2). The basic charge of individual melts was formed by different ratio of pig iron and steel scrap and by different additive for the regulation of chemical composition (metallurgical silicon carbide or ferrosilicon) (COPI K. W. 2003, ZHANG W. H. 2009). For modification and inoculation, modifier FeSiMg7 and inoculant FeSi75 were used in the same amount for all the melts.

Table 2. Charge composition of experimental melts

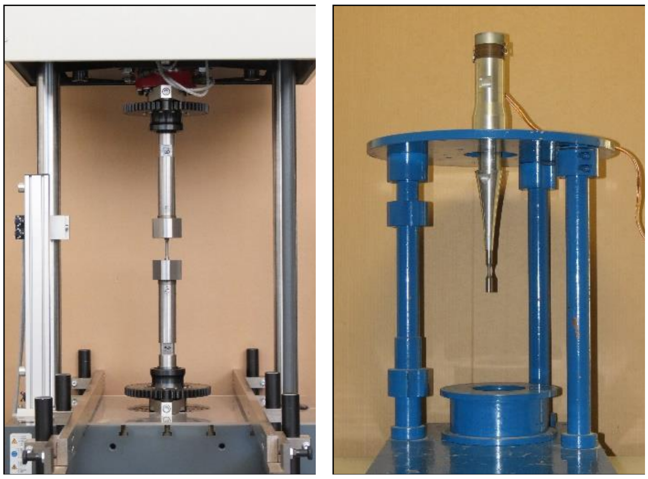
Melt number	pig iron (%)	steel scrap (%)	additives
1	40	60	carburizer + SiC90
2	0	100	carburizer + SiC90
3	40	60	carburizer + FeSi75

The metallographic analysis of specimens from experimental melts was made with the light metallographic microscope Neophot 32. The specimens for metallographic analysis were taken out from the cast bars and prepared by usual metallographic procedure (KONEČNÁ R. 2014). The microstructure of specimens was evaluated according to STN EN ISO 945 and by automatical image analysis using NIS Elements software (SKOČOVSKÝ P. 2007, VAŠKO A. 2016).

The static tensile test was carried out according to STN EN ISO 6892-1 by means of the testing equipment ZDM 30 with a loading range $F = 0$ to 50 kN. The impact bending test was carried out according to STN EN ISO 148-1 by means of the Charpy hammer PSW 300 with a nominal energy of 300 J. The Brinell hardness test was carried out according to STN EN ISO 6506-1 by means of the testing equipment CV-3000 LDB with a hardmetal ball of diameter $D = 10$ mm forced into specimens under the load $F = 29\,430$ N (3000 kp) (VAŠKO A. 2014, BORKOWSKI S. 2009).

The fatigue tests were realised according to STN 42 0362 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 at frequency $f \approx 120$ Hz using the fatigue experimental machine Zwick/Roell Amsler 150HFP 5100 (Fig. 1a). High frequency fatigue tests were carried out at frequency $f \approx 20$ kHz using the ultrasonic fatigue testing equipment KAUP-ZU (Fig. 1b).

For a given material the ralationship between the applied amplitude of cyclic stress and the number of cycles to failure is customarily identified from its S-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 (VĚCHET S. 2001).



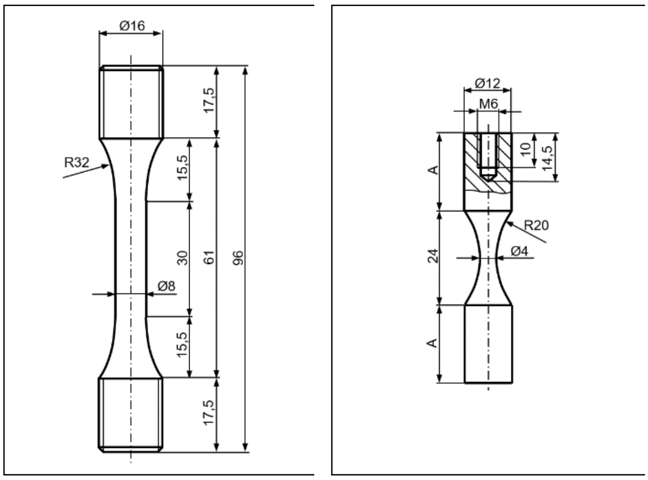
a) fatigue experimental machine Zwick/Roell Amsler 150HFP 5100

a) ultrasonic fatigue testing equipment KAUP-ZU

Fig. 1. Experimental device for low and high frequency fatigue test

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 Fig. 2 (TRŠKO L. 2014).

For both fatigue tests (low frequency cyclic loading and high frequency cyclic loading), ten specimens from each melt were used to obtain the relationship between the applied amplitude of cyclic stress and the number of cycles to failure (Wöhler curve) and to determine the fatigue strength.



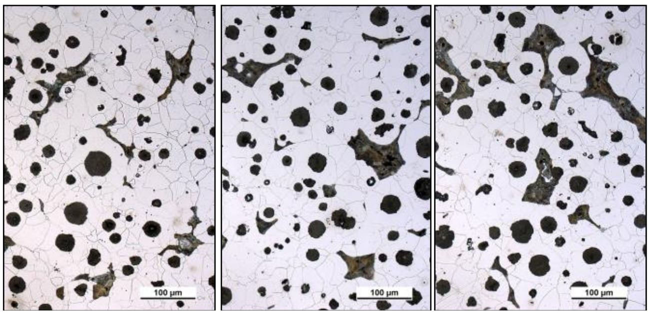
a) specimen for low frequency cyclic loading

b) specimen for high frequency cyclic loading

Fig. 2. Shape and parameters of the specimens used for experiments

3. Experimental results and discussion

Microstructure of the specimens from experimental melts is shown in the Fig. 3.



a) melt 1 b) melt 2 c) melt 3

Fig. 3. Microstructure of the specimens from cast bars, etched by 1% Nital

From a microstructural point of view, the specimens from all the melts are ferrite-pearlitic nodular cast irons with different content of ferrite and pearlite in the matrix, different size of graphite and count of graphitic nodules (Tab. 3). Different microstructure is caused by different charge composition.

Table 3. Microstructure of the specimens

Melt number	Microstructure (according to STN EN ISO 945)	Count of graphitic nodules (mm^{-2})	Content of ferrite (%)
1	80%VI6 + 20%V6	199.8	74.0
2	70%VI5/6 + 30%V6	179.8	78.0
3	70%VI5/6 + 30%V6	151.0	65.2

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 character of matrix (content of ferrite and pearlite) and also with the size and count of graphitic nodules (Tab. 4).

Table 4. Mechanical properties of the specimens

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 $\sigma_a = f(N)$ and determine fatigue strength σ_c.

The results of fatigue tests (Wöhler curves) obtained at low frequency cyclic loading (f ≈ 120 Hz) are shown in Fig. 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 Tab. 5. The fatigue strength in analysed specimens of nodular cast iron increases with an increasing tensile strength.

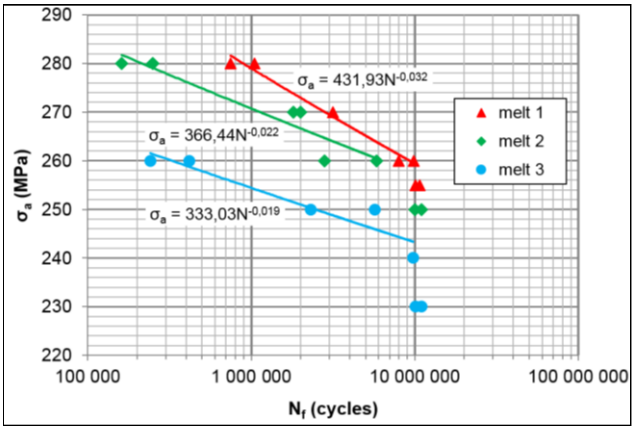


Fig. 4. Wöhler curves $\sigma_a = f(N)$ for low frequency cyclic loading

The results of fatigue tests obtained at high frequency cyclic loading (f ≈ 20 kHz) are shown in Fig. 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 Tab. 5. At higher values of tensile strength there was observed an increase of fatigue strength.

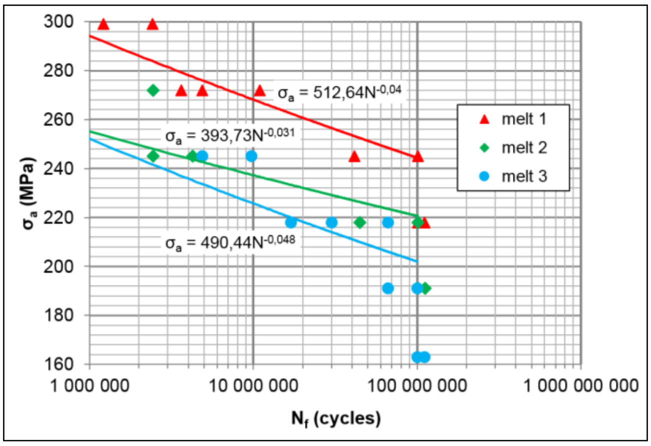


Fig. 5. Wöhler curves $\sigma_a = f(N)$ for high frequency cyclic loading

Table 5. Comparison of tensile strength R_m and fatigue strength σ_c for low and high frequency cyclic loading

Melt number	R_m (MPa)	LFCL (f ≈ 120 Hz)	HFCL (f ≈ 20 kHz)
		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.

4. 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 $f \approx 20$ kHz is not so time demanding as low frequency fatigue testing with frequencies $f \approx 10$ to 200 Hz.

The application of high frequency cyclic loading is characteristic with the 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 treshold states of materials.

Acknowledgements

The research has been supported by the Scientific Grant Agency of Ministry of Education, Science, Research and Sport of Slovak Republic, grant project VEGA No. 1/0533/15 and by the Culture and Educational Grant Agency of Ministry of Education, Science, Research and Sport of Slovak Republic, grant project KEGA No. 049ŽU-4/2017.

Reference

Borkowski S., Ulewicz R. 2009. *Laboratorium z materiałoznastwa dla inżynierów.* CWA Regina Poloniae, Częstochowa.

Bokůvka O., Nicoletto G., Kunz L., Palček P., Chalupová M. 2002. *Low & high frequency fatigue testing*. EDIS, Žilina.

Bokůvka O., Nicoletto G., Guagliano M., Kunz L., Palček P., Nový F., Chalupová M. 2014. *Fatigue of materials at low and high frequency loading*. EDIS, Žilina.

Copi K. W., Lerner Y. S., Laukhin N. S. 2003. *SiC vs. 75% FeSi: Comparing pre-inoculation effects*. Modern Casting 93, 29-31.

Konečná R., Fintová S. 2014. *Metódy štúdia štruktúry*. EDIS, Žilina.

Skočovský P., Vaško A. 2007. *Kvantitatívne hodnotenie štruktúry liatin*. EDIS, Žilina.

Trško L., Bokůvka O., Nový F., Guagliano M. 2014. *Effect of severe shot peening on ultra-high-cycle fatigue of a low-alloy steel*. Materials and design 57, 103-113.

Ulewicz R., Tomski P. 2017. *The effect of high-frequencies loading on the fatigue cracking of nodular cast iron*. Metalurgija 56, 33-36.

Vaško A., Skočovský P. 2014. *Vlastnosti a použitie kovových materiálov*. EDIS, Žilina.

Vaško A., Vaško M. 2016. *Correlation between shape factor and mechanical properties of graphitic cast irons*, Production Engineering Archives 11, 11-14.

Věchet S., Kohout J., Bokůvka O. 2001. *Únavové vlastnosti tvárné litiny*. EDIS, Žilina.

Zhang W. H., Ding J., Nie F. R. 2009. *SiC inoculation pretreatment of cast iron*. Foundry (Zhuzao) 58, 279-281.

低频和高频疲劳测试的比较

關鍵詞
疲劳测试
低频循环加载
高频率循环加载
球墨铸铁

摘要

本文介绍了对球墨铸铁进行低频和高频疲劳测试的结果。 采用疲劳实验装置对高周疲劳区（10^5～10^8次循环）进行了 3 种不同熔体的合成球墨铸铁试样的低频和高频循环加载试验。 使用疲劳试验机 Zwick / Roell Amsler 150HFP 5100 在频率 $f \approx 120$Hz 下进行低频疲劳试验；使用超声波疲劳试验装置 KAUP-ZU，以频率 $f \approx 20$ kHz 进行高频疲劳试验。 在环境温度（T = 20 ± 5 ° C）下的正弦循环推拉负载（应力比 R = -1）下都进行了疲劳试验。