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M. MAJ*, K. PIETRZAK**, J. PIEKŁO*

MODIFIED LOW CYCLE METHOD AS A NEW CRITERION FOR A LIFE FATIGUE ASSESSMENT IN FOUNDRY INDUSTRY

ZMODYFIKOWANA NISKOCYKLOWA PRÓBA ZMĘCZENIOWA, JAKO NOWE KRYTERIUM TRWAŁOŚCI ZMĘCZENIOWEJ W PRZEMYŚLE ODLEWNICZYM

The study describes the investigations of fatigue life carried out on selected grades of the G20Mn5 cast steel by two methods, i.e. the standard low-cycle fatigue test (LCF test) and modified low-cycle fatigue test (MLCF). The aim of these investigations was to verify the reliability of tests conducted by the novel method of MLCF [1, 2, 3].

Table 1 shows the results of mechanical tests carried out in accordance with the MLCF methodology on the G20Mn5 cast steel, while Figures 1a-b and 2 show the selected $\sigma = f(\varepsilon)$ curves. Similar studies were carried out for the Mn-Ni cast steel [4].

Low-cycle fatigue tests (LCF) were carried out on an MTS 810 testing machine with control of force exerted on specimens whose dimensions were specified in [2].

Keywords: fatigue life, cast steel, variable loads

W prezentowanej pracy przeprowadzono dla wybranego staliwa G20Mn5 badania trwałości zmęczeniowej dwiema metodami, zarówno zgodnie z procedurą LCF (klasyczna, niskocyklowa próba zmęczeniowa), jak i MLCF (zmodyfikowana niskocyklowa próba zmęczeniowa). Badania te miały służyć weryfikacji wiarygodności badań zgodnie z nowatorską metodą MLCF [1, 2, 3].

W tablicy 1 przedstawiono wyniki badań wytrzymałościowych wykonanych zgodnie z metodyką MLCF staliwa w gatunku G20Mn5, a na rysunkach 1a-b i 2, wybrane wykresy $\sigma = f(\varepsilon)$. Podobne badania przeprowadzono dla staliwa Mn-Ni [4].

Badania zmęczeniowe w zakresie małej liczby cykli LCF, to zrealizowano na maszynie wytrzymałościowej MTS 810, przy sterowaniu siłą na próbkach o wymiarach przedstawionych w pracy [2].

1. Introduction

One of the major problems regarding properties of materials is to know how these materials will behave under variable and fast-changing loads, in other words – to know their fatigue life [1]. For this reason, the methods that serve an assessment of this property are subject to continuous improvements. In this publication, two methods were used. Both were discussed in other studies, where they were treated as a tool to explore the material characteristics based on the resistance to the effect of variable loads. These methods are the standard low-cycle fatigue test (LCF) and its modified version called MLCF [2, 3, 4].

2. Test material

In this study, fatigue tests were carried out on the specimens of G20Mn5 cast steel. Table 1 gives chemical composition of the examined cast steel, while specimen geometry and dimensions are illustrated in Figure 1 and Table 2, respectively.

TABLE 1

Chemical composition of the G20Mn5 cast steel

Content of individual elements [wt.%]									
C	**Mn**	**Al**	**Ni**	**Mo**	**Cu**	**Cr**	**Si**	**P**	**S**
0.17÷ 0.2	1.0÷ 1.2	0.02÷ 0.04	max 0.1	max 0.1	max 0.1	max 0.1	max 0.6	max 0.15	max 0.15

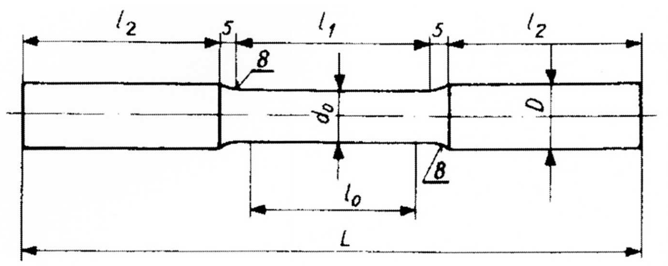


Fig. 1. Specimen geometry used in tests

* AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, FACULTY OF FOUNDRY ENGINEERING, REYMONTA ST. 23, 30-059 KRAKOW, POLAND

** MOTOR TRANSPORT INSTITUTE, JAGIELLOŃSKA 80, 03-301 WARSAW, POLAND

TABLE 2

Specimen dimensions used in tests

d_0 [mm]	D [mm]	l_0 [mm]	l_1 [mm]	l_2 [mm]	L [mm]	D [mm]	H [mm]
8	10	40	45	30	125	12	16

TABLE 3

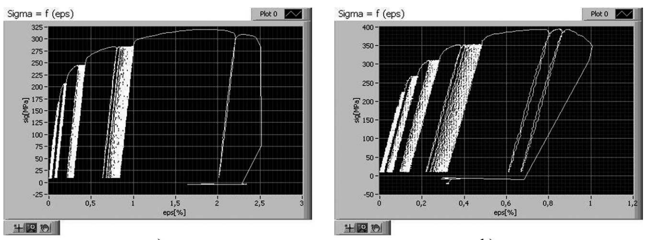
The results of fatigue tests carried out by the MLCF method on specimens of the G20Mn5 cast steel

No.	**R_m [MPa]**	**$R_{0,02}$ [MPa]**	**$R_{0,2}$ [MPa]**	**R_a [MPa]**	**Z_{go} [MPa]**	**b**	**c**	**n'**	**K [MPa]**	**$\varepsilon_{\cdot max}\cdot 10^6$**
5.1	196,6	92,8	152,7	165,3	60,5	-0,13408	-0,30431	0,24415	250,5	843
5.2	320,4	143,0	217,1	283,9	83,4	-0,11693	-0,50599	0,15491	294,1	540
5.3	394,6	218,8	311,6	352,2	122,47	-0,11168	-0,52826	0,16148	424,8	445
5.4	380,2	210,5	299,6	348,4	121,65	-0,11263	-0,51436	0,15438	435,7	485
5.5	192,8	88,5	150,4	161,1	54,5	-0,10971	-0,30561	0,25413	241,1	755
5.6	193,1	85,6	143,2	164,1	58,3	-0,12431	-0,39328	0,23214	238,5	665

3. Mechanical testing of G20Mn5 cast steel

As mentioned in the introduction, fatigue tests were carried out on the G20Mn5 cast steel applying two methods, i.e. the standard low-cycle fatigue test (LCF) [6] and its modified version MLCF. The former, force-controlled, test was run on an MTS 810 testing machine, equipped with a modern TestStar IIs control system. The MLCF test was carried out on an INSTRON machine with machine control software written in LabView environment, using controllers provided by Instron. The studies, comparative in nature, were done in order to verify the accuracy of the results obtained in tests conducted by the novel method of MLCF [2, 3, 4].

Table 3 shows the results of MLCF tests carried out on the G20Mn5 cast steel, while Figures 2a-b and 3 show the selected $\sigma = f(\varepsilon)$ curves. Similar studies were also performed on the Mn-Ni cast steel [5].



a) b)

Fig. 2. The $\sigma = f(\varepsilon)$ curve for G20Mn5 cast steel; a) specimen 5.2, b) specimen 5.3

The test results were recorded and interpreted in a "Fatigue v. 4.0" programme developed by MTS specifically for this type of research. Tests were carried out at ambient temperature on specimens subjected to positive pulsating sinusoidal loading cycles (R = 0). In each test, the number of cycles to the specimen failure was recorded, and also parameters such as plastic strain, elastic strain and total strain for the number of cycles followed by stabilisation of the hysteresis loop, determined automatically by an algorithm operating in the "Fatigue v. 4.0" programme.

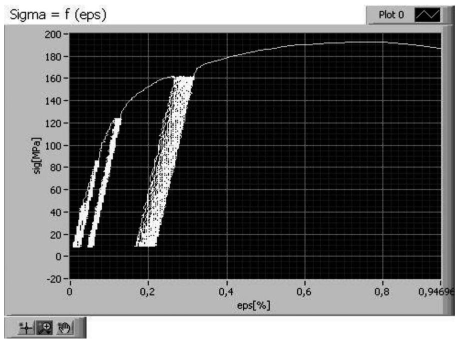


Fig. 3. The $\sigma = f(\varepsilon)$ curve for G20Mn5 cast steel; specimen 5.5

The averaged results of the tests carried out are compared in Table 4 and illustrated graphically in the form of a fatigue life curve (Fig. 4).

TABLE 4

The results of fatigue tests carried out by the standard LCF method on specimens of the G20Mn5 cast steel

eps(max)= 1,744 e-04			
b=-0,1			
c=-0,36			
cycle	eps_pl	eps_spr	eps_pl+eps_spr
201	0,000634	0,005268	0,005902
1177	0,000558	0,005030	0,005588
2936	0,000423	0,004829	0,005252
5324	0,000258	0,004171	0,004429
25554	0,000115	0,003273	0,003388

The test results obtained on a series of specimens were processed by the method of least squares, calculating the exponents b and c in equation (1), which determines the total strain amplitude, expressed as a sum of amplitudes of the elastic and plastic strain.

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma_f'}{E}(2N_f)^b + \varepsilon_f'(2N_f)^c \qquad (1)$$

The exponents assume the values of ***b*** **= - 0,1** ***c*** **= - 0,36**.

Finally, for the tested G20Mn5 cast steel, equation (1) assumes the following form:

$$\frac{1}{2}\Delta\varepsilon_c = \frac{1}{2}\Delta\varepsilon_{as} + \frac{1}{2}\Delta\varepsilon_{apl} = 0,01026\left(2N_f\right)^{-0,1} + 0,00718\left(2N_f\right)^{-0,36}$$

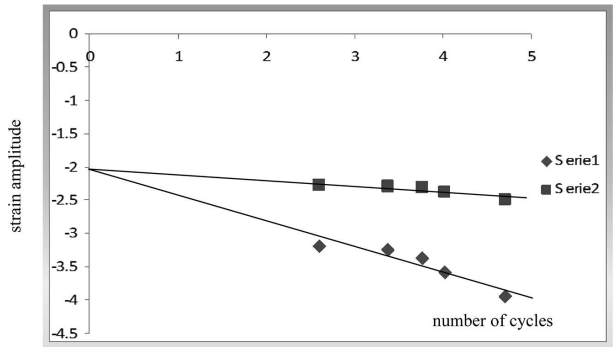


Fig. 4. Cast steel fatigue life plotted in logarithmic coordinates

The cyclic strain curve (Fig. 5) was plotted in logarithmic coordinates. The results were processed by the method of least squares and coefficients and exponents were determined in equation (2), used in stress control:

$$\sigma_a = K'(\varepsilon_p)^{n'} \qquad (2)$$

Ultimately, for the tested cast steel, equation (2) assumed the following form:

$$\lg\sigma_a = \lg 3585 + 0,21\lg\varepsilon_{aps} \qquad (3)$$

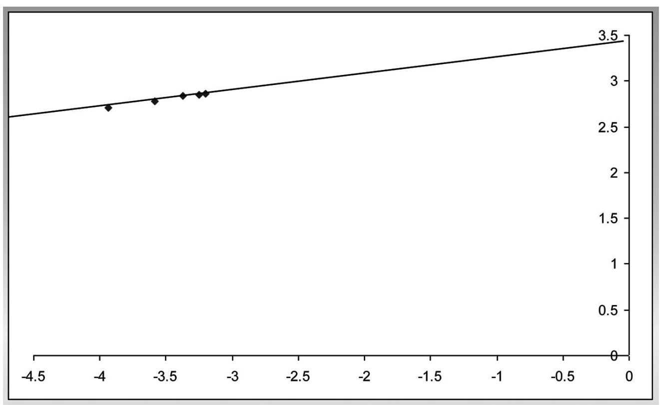


Fig. 5. The cyclic strain curve plotted in logarithmic coordinates

Considering the results of the tests carried out in the range of a small number of cycles in accordance with the standard low-cycle fatigue test (LCF), the examined cast steel shows very low plastic deformation, which is confirmed by the previously calculated value of exponent c, which is -0.36. Typically, the value of this exponent is comprised in the range of -0.5 to -0.7, and decreases with increasing ductility of the material (its absolute value is increasing). The exponent b, the value of which for the tested cast steel amounts to -0.1, depends on the tensile strength R_m of the material. It is typically comprised in the range of -0.05 to -0.15, and decreases with a decrease of the tensile strength (its absolute value is increasing). The analysis of both exponents after the test carried out in accordance with the MLCF procedure shows that the average value of exponent b is -0.1182, and of exponent c -0.4. So, as regards the parameter b, the results are consistent with the results obtained by the standard LCF method, but as regards the fatigue ductility exponent, its value slightly exceeds that determined by standard LCF. The maximum allowable permanent strain is $\varepsilon_{max} \cdot 10^6 = 622$, and as such also slightly exceeds the value obtained by LCF test.

4. Materialographic studies of g20mn5 cast steel by light microscopy and sem

To determine the effect of the G20Mn5 cast steel microstructure on the mechanical characteristics obtained under low-cycle variable loads, qualitative and quantitative materialographic studies were conducted using an Olympus PMG3 light microscope.

Quantitative examinations were performed on a computer image analyser coupled on-line with a light microscope. In quantitative studies, efforts were made to provide exactly the same conditions for all the measurements taken on the examined material.

In the investigated G20Mn5 cast steel, a large degree of porosity was detected. Therefore, the measurements were taken at a low magnification of 25x. The measurements covered the cross-section of the gripped portion of the specimen and at a magnification so low it is not surprising that they were taken in four measurement fields only, the sum of which made a complete surface area of the cross-section examined. Quantitative analysis has included porosity only, based on the assumption that in the case under discussion, other microstructural differences will have little significance and will constitute a factor completely negligible in the context of the analysed mechanical properties. The results of the quantitative research are held by the authors of the study, and in this publication, the figures listed below show only selected images of the microstructures.

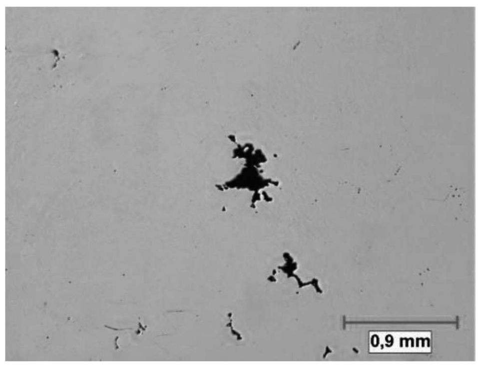


Fig. 6. Specimen 3 – Porosity in the G20Mn5 cast steel, 25x, ordinary light

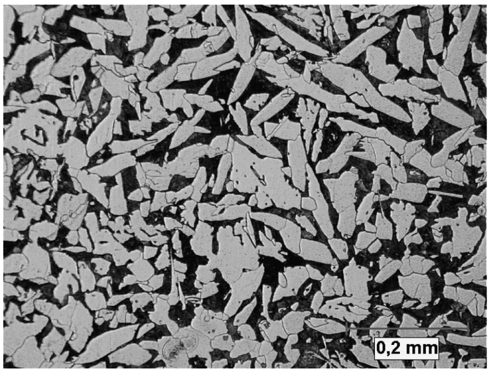


Fig. 7. Specimen 3 – Microstructure of the G20Mn5 cast steel, 100x, ordinary light

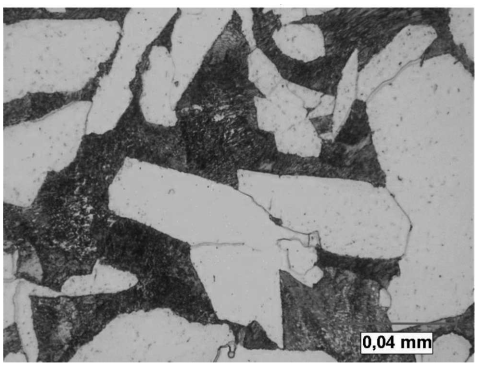


Fig. 8. Specimen 3 – Microstructure of the G20Mn5 cast steel, 500x, ordinary light

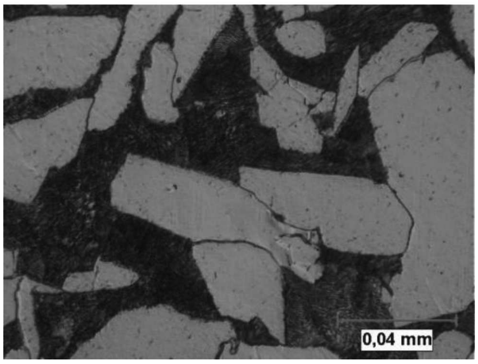


Fig. 9. Specimen 3 – Microstructure of the G20Mn5 cast steel, 500x, phase contrast

Fractures of the specimens fatigue tested by the MLCF method and examined by the SEM technique are virtually identical and consistent with the nature of the specimens (castings). Photographs of specimen fractures (SEM – Figs. 10-21) following in the text show typical dendritic structures (noticeable especially in photographs taken at a 100x magnification).

In the dendritic fields, places can be distinguished where the tested cast steel specimen failed, showing typical fatigue striations and cracks within the fractured area, marked as an example in some of the photographs. Attention deserves the fact that in the fracture of the specimen designated as number 2, the dendrites are less pronounced.

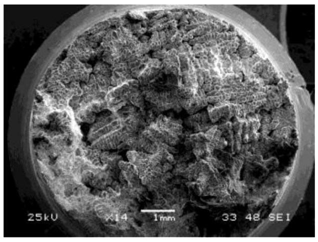


Fig. 10. G20Mn5 Specimen 5-1, x14, SEM

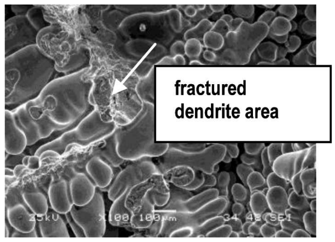


Fig. 11. G20Mn5 Specimen 5-1, x100, SEM

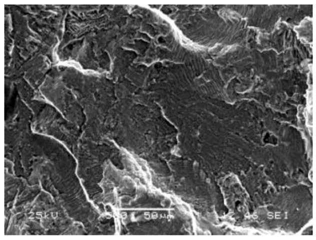


Fig. 12. G20Mn5 Specimen 5-1, x500, SEM

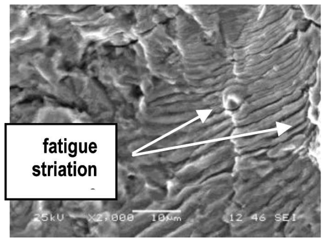


Fig. 13. G20Mn5 Specimen 5-1, x2000, SEM

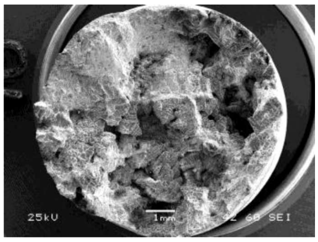


Fig. 14. G20Mn5 Specimen 5-2, x12, SEM

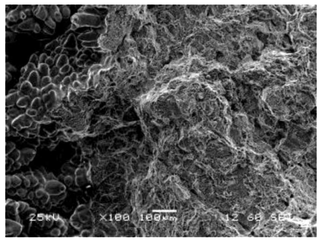


Fig. 15. G20Mn5 Specimen 5-2, x100, SEM

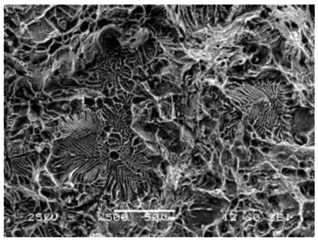


Fig. 16. G20Mn5 Specimen 5-2, x500, SEM

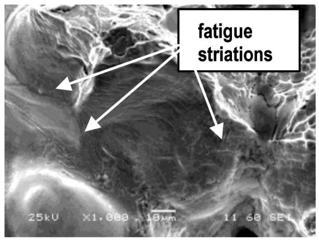


Fig. 17. G20Mn5 Specimen5-2, x1000, SEM

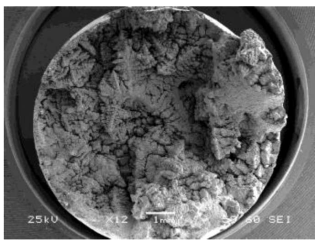


Fig. 18. G20Mn5 Specimen 5-3, x12, SEM

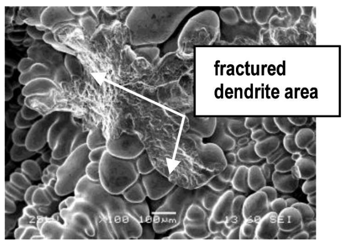


Fig. 19. G20Mn5 Specimen 5-3, x100, SEM

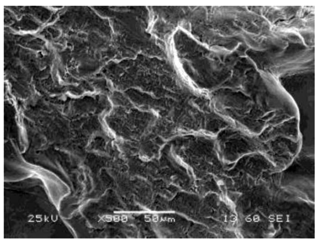


Fig. 20. G20Mn5 Specimen 5-3, x500, SEM

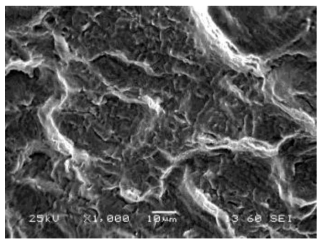


Fig. 21. G20Mn5 Specimen 5-3, x1000, SEM

5. Conclusions

Based on the obtained results it is reasonable to draw the following main conclusions:

- regardless of the method applied in evaluation of the low-cycle fatigue strength (standard LCF or author's own MLCF technique), a satisfactory consistency was obtained between the examined mechanical parameters of the G20Mn5 cast steel, thus proving the positive verification of the results of studies and full reliability of the method itself,
- in the case under discussion (the G20Mn5 cast steel), the MLCF method usefulness was confirmed in evaluation of the material defect so important for its correct performance as the observed porosity, the characteristics of which when developed based on Wöhler diagrams would be burdened with a large error,
- the presented results confirm full applicability of the novel MLCF method in studies of the microstructurally inhomogeneous materials.
- proposed method may be used in practical solutions concerning a new materials, constructional elements and ready products introduced to the foundry industry.

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