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MLCF – AN OPTIMISED PROGRAM OF LOW-CYCLE FATIGUE TEST TO DETERMINE MECHANICAL PROPERTIES OF CAST MATERIALS

MLCF – ZOPTYMALIZOWANY PROGRAM NISKOCYKLOWEJ PRÓBY ZMĘCZENIOWEJ DO OKREŚLANIA WŁAŚCIWOŚCI MECHANICZNYCH TWORZYW ODLEWNICZYCH

The article describes the mechanical properties determined from an optimised program of modified low-cycle fatigue test (MLCF) using ductile iron as a test material. The results were compared with the results obtained from standard low-cycle fatigue test (LCF). The investigations are particularly interesting in all those cases when obtaining the required repeatability of properties of the investigated material poses some problems, even if samples are taken from the same melt, or the same variant of heat treatment is applied.

W artykule zaprezentowano właściwości mechaniczne określone w oparciu o zoptymalizowany program zmodyfikowanej niskocyklowej próby zmęczeniowej (MLCF) dla żeliwa sferoidalnego i porównano je z wynikami uzyskanymi zgodnie z procedurą klasycznej wersji niskocyklowej próby zmęczeniowej LCF. Badania te są szczególnie interesujące w tych wszystkich przypadkach, w których trudno jest uzyskać powtarzalność właściwości materiału badawczego, pochodzącego nawet z tego samego wytopu, czy wariantu obróbki cieplnej.

1. Introduction

Different applications of cast products and efforts to use them in a best way possible are one of the reasons why it is so important to provide some tools that would enable collecting a complete set of data regarding properties of the examined materials. One of the main problems commonly faced in the application of materials is to know their behaviour under the normally and rapidly changing loads, in other words, to know their fatigue strength [1].

The fatigue strength of materials is one of the basic criteria which enable forecasting the behaviour of a selected material when operating under load conditions. This property determines the level of admissible loads, i.e. of the safe loads that the material can endure without failure.

The standard fatigue test, which consists in plotting a Wöhler curve for the examined material, has been known since a long time. A definite drawback of this test is the relatively large number of the specimens that should be examined to obtain reliable results. This means that if the test stands and the testing equipment are not available in a number sufficient for several fatigue tests to be carried out at the same time, applying different medium loads and varying maximum stress amplitude, the whole experiment may take quite a long time (several weeks even).

The application of static tensile test with modified low-cycle fatigue test enables the test time to be reduced quite considerably. The test uses positive tensile cycles ranging from a near-zero value to the preset value. Between these values, the cyclic fatigue loading (load on – load off) is carried out. A test of this type eliminates the necessity of using in one single measurement several or several dozen specimens. It has been observed that the condition of permanent strain is well stabilised after the number of cycles definitely smaller than the number of cycles resulting in failure (accommodation). This makes loading of a specimen with the number of cycles leading to its failure unnecessary [1, 2, 3, 4, 5].

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2. The description of computer-aided MLCF test program

In its original form, the computerised program was first used by A. Karamara [4] and M. Maj [3]; later it has been adapted to the use with an MTS TestStar IIs machine, equipped with modern control system [5]. In this study, the most important elements of the system will be described. Quite naturally, they all require further improvements to raise the versatility of the whole application.

The program enables the modulus of elasticity to be determined in its general form, within the range of different stresses for stable mechanical hysteresis: (1)

$$E = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1}, \qquad (1)$$

where: σ_1; ε_1 – the stress and strain for the lower vertex of a mechanical hysteresis loop,
σ_2; ε_2 – the stress and strain for the upper vertex of the loop.

As a next step, the following parameters are determined: the apparent elastic limit – $R_{0,02}$; the apparent limits $R_{0,05}$ and $R_{0,1}$; the yield strength – $R_{0,2}$; the accommodation limit – R_a; the estimated value of the rotary bending fatigue strength – Z_{go}; the values of material constants determined from a low-cycle fatigue test: b, c, n', the true stress – K; the maximum total admissible strain – ε_{max}, and the tensile strength – R_m.

The fatigue strength Z_{go}, necessary for computation of the parameters used in MLCF test, is determined from the test curve plotted for different material families, starting with pure metals and ending in ferrous and non-ferrous metal alloys (Fig.1.)

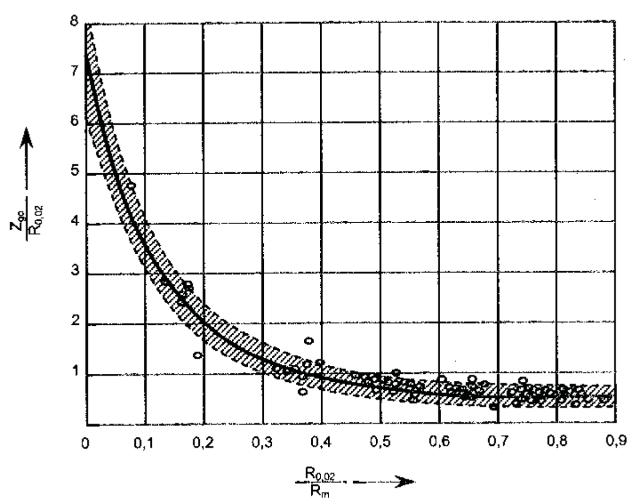

Fig. 1. The Curve for fatigue strength determination [2]

The most important quantity determined in the MLCF test is the maximum admissible total strain for the number of cycles corresponding to a fatigue limit of the examined material.

$$\varepsilon_c = \varepsilon_e + \varepsilon_p = \frac{\sigma_f}{E}(2N_f)^b + \varepsilon_f(2N_f)^c, \qquad (2)$$

where: ε_c – the maximum total admissible strain,
ε_e – the elastic (reversible) strain,
ε_p – the permanent (true) strain after $2N_f$ load cycles,
ε_f – the permanent (true) strain induced by the stress σ_f,
σ_f – the stress approaching the tensile strength (in materials with distinct plastic properties this is the stress preceding the formation of a “neck”),
b – the fatigue strength coefficient (Basquin coefficient),
c – the fatigue deformability exponent.

All of the above mentioned parameters are examined on one specimen, and this is obviously the most important advantage of the new method, especially if we consider the fact that the static mechanical properties and those which are responsible for the low-cycle fatigue strength give very exact picture of the examined material, irrespective of how heterogeneous its structure may be. In standard LCF test, to obtain information on the maximum total admissible strain, it is necessary to repeat the test on at least dozen specimens, and actually this is not the only problem posed by this method. It may also happen that the configuration of the examined object or material will make preparation of the required number of the specimens impossible, and so, also in this aspect the new method can offer some benefits.

3. Mechanical tests

Tests were carried out on ductile iron specimens.

The shape and dimensions of the specimens used in the present study are shown on figure 2 and in table 1.

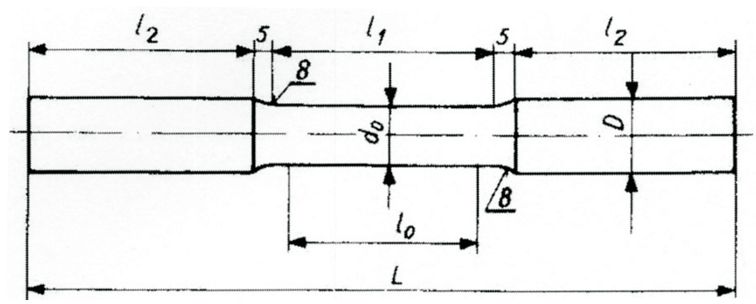

Fig. 2. The dimensions of the specimens used in the present study

TABLE 1

The dimensions of the mechanical test specimens used in the present study

d_0 [mm]	D [mm]	l_0 [mm]	l_1 [mm]	d_2 [mm]	L [mm]	D [mm]	H [mm]
8	**10**	**40**	**45**	**30**	**125**	**12**	**16**

Table 2 gives the results of the MLCF test carried out on the examined cast iron grade.

TABLE 2

The results of the MLCF test carried out on ductile iron

Sample No.	E_0	E_{10}	E_{80}	E_{180}	$R_{0,02}$	$R_{0,05}$	$R_{0,1}$	$R_{0,2}$
	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]
1	124 109	127 596	152 040	159 606	293,0	352,0	392,0	–
2	136 354	138 295	151 884	154 640	307,0	377,0	–	–
3	116 837	121 521	154 312	155 770	278,0	347,0	402,0	–
4	126 340	122 280	140 320	139 450	283,2	330,3	369,0	383,0
5	136 250	140 110	137 234	141 212	276,0	295,1	389,0	–

TABLE 2. cntd.

Sample No.	R_a	Z_{go}	Rm	b	c	ε_{max} 10^6
	[MPa]	[MPa]	[MPa]	–	–	
1	293,0	177,0	481,2	-0,085	-0,200	1666
2	293,0	186,0	502,1	-0,090	-0,120	2050
3	233,0	177,0	501,7	-0,086	-0,140	1710
4	256,3	185,2	499,2	-0,088	-0,170	1430
5	240,2	179,0	470,8	-0,083	-0,150	1470

Table 3 gives the results of standard LCF test, while Figure 3 shows graphic representation of these results.

TABLE 3

The results of standard LCF test

cycle	*pl*	*sp*	*pl + sp*
1	0,365	0,3204	0,6854
860	0,013	0,34	0,353
1018	0,012	0,3006	0,3126
1140	0,01	0,2848	0,2948
3960	0,008	0,282	0,29
6549	0,006	0,2811	0,2871
7659	0,0055	0,2737	0,2792
9152	0,005	0,2675	0,2725
ε_{max} = 1,42 *e*-03 b = -0,061 c = -0,36			

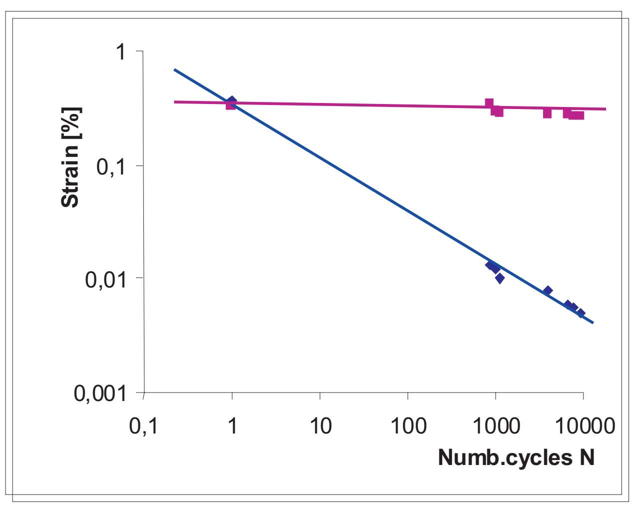

Fig. 3. The LCF material life curve for ductile iron

The results of the LCF test were processed by the method of the least squares. In the case of MLCF test, the arithmetic means of the examined parameters were analysed (specimens 1–5 from table 2). The following values were obtained: $\boldsymbol{b = -0{,}086, c = -0{,}160}$, $\boldsymbol{\varepsilon_{max}\ 10^6 = 1660}$. Table 3 gives the computed values of $\boldsymbol{b = -0{,}061, c = -0{,}36}$, $\boldsymbol{\varepsilon_{max} \cdot 10^6 = 1420}$; using these values the LCF life curves were plotted. They are shown in figure 3. Comparing the results obtained from the two testing methods, a good consistency between the calculated values can be observed.

Some attention deserves also the fact that in the standard LCF method, assigned as a matter of fact for the determination of maximum total true strain, to ensure the repeatability of results, it is necessary to provide a required number of the specimens. This condition can be satisfied only when the tested material is of a homogeneous structure, like e.g. the toughened steel characterised by a uniform dispersion of its structural phase constituents.

The problem becomes even more complicated when the fatigue test is carried out on a cast material, as in this case one should expect a very non-homogeneous structure, which may seriously affect the level and scatter of the obtained results of the mechanical properties testing. Therefore, basing on the obtained results, it seems fully justified to confirm once again the purposefulness of having the standard LCF test replaced with a new and original MLCF method, as the latter one requires only one specimen for the determination of several mechanical parameters, reducing in this way to minimum the possible side effects of the structural inhomogeneities. Moreover, if such inhomogeneities do happen to exist, it is possible to identify the causes of differences in the obtained mechanical characteristics of a product or material.

4. Summary

Tests conducted in accordance with the modified low-cycle fatigue program (MLCF) enable obtaining the reliable results. This refers to both the static properties and a fatigue behaviour of the tested materials – the fact that can never be overestimated when materials of a heterogeneous structure are to be examined, and when we remember that in the standard LCF test it is necessary to have at leat 15 specimens (3 specimens falling to one measuring point) to measure the parameters of a low-cycle test. In the original MLCF program, the same parameters of a low-cycle test can be obtained on one specimen only, besides properties like the fatigue limit or other apparent limits.

In this study, using ductile iron as an example, it has been proved that, irrespective of the method applied for evaluation of the low-cycle fatigue behaviour (standard LCF test vs the new original MLCF test), a satisfactory consistency between the measured mechanical parameters was obtained. Nevertheless, full validation of this method requires that the same investigations are carried out also on steel.

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