METHOD OF LOW-CYCLE FATIGUE TEST RESULTS PROCESSING

S. MROZIŃSKI, A. LIPSKI

University of Technology and Life Sciences, Bydgoszcz, Poland

There is considered the method of proceeding during elaboration of low-cycle fatigue test results of metals. Presented method enables to determine the material data in various periods of fatigue life. The results obtained with the use of proposed method allow taking into account during fatigue life calculations as the visible changes of cyclic properties of material. The above is of special importance in the case of material characterized by the absence of stabilization period.

Keywords: *low-cycle fatigue, mechanical properties.*

In the method of fatigue life calculations, which is based on local strain and stress, analysis [1] the material data determined in fatigue tests in the low-cycle fatigue area are used. The test realization and elaboration of the results correspond to ASTM E 606-04: Standard Practice for Strain-Controlled Fatigue Testing. According to the directions in this document the low-cycle properties of metals are determined on the base of constant – amplitude test on several (five minimum) levels of controlled stress or strain [2]. On each strain or stress level at least three fatigue tests are performed. During each fatigue test for the selected loading cycles momentary values of loading force and strain of the specimen are recorded. Recorded stress and strain values enable to carry out the analysis of the basic hysteresis loop parameters and to define relations between them.

One of the two characteristics evaluated on the base of the performed fatigue tests is the diagram of cyclic strain describing the relation between plastic strain amplitude ε_{ap} and stress amplitude σ_a. It is assumed that there is the exponential relation between these parameters from the stabilization period. In the bilogarithmic coordinate system this relation is described with the Morrow equation [3]

$$\lg \sigma_a = \lg K' + n' \lg \varepsilon_{ap} , \qquad (1)$$

where K' is exponent of the diagram, n' is directional coefficient of the diagram (coefficient of hardening). The n' and K' parameters of equation (1) are the basic material data used during fatigue life calculations. There are no doubts about the presented method of results elaboration in the case of cyclically stable materials. They are obvious, however, in the case of materials characterized by the changes of cyclic properties they do not reveal the period of stabilization.

In the papers on low-cycle fatigue tests of metals [4] it can be found that the period of stabilization of metals and their alloys is very short or even it is absent [5]. For such materials the necessary hysteresis loop parameters (σ_a and ε_{ap}) are obtained from the period which corresponds to the half-life $n/N = 0.5$, where N is fatigue life on the given loading level until failure, $n = 0.5N$.

The method of the determination of hysteresis loop parameters, in the case when there is no stabilization period, is presented in Fig. 1. Schematically the example of the changes of diagrams of one of the parameters (σ_a), which can be found in equation (1) is shown for five values of total strain ε_{ac}.

Corresponding author: S. MROZIŃSKI, e-mail: Stanislaw.Mrozinski @utp.edu.pl

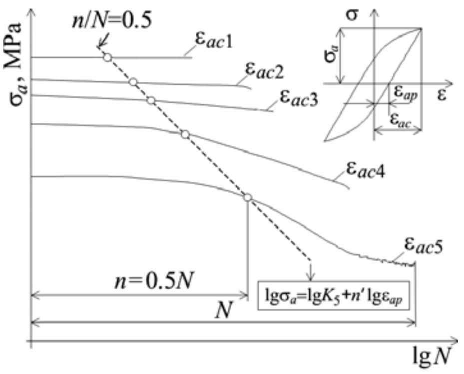


Fig. 1. Method of tests results processing with the use of the classical method (material without a stabilization period).

It results from the course of σ_a changes that the material undergoes visible weakening. Points marked with a circle on individual stress diagrams indicate the fatigue half-life ($0.5n/N$) at each level of total strain ε_{ac}. The values of n' and K' parameters obtained as the result of coordinates approximation of these points with the equation (1) describe only the momentary cyclic properties of the material from the life period $n/N = 0.5$. During fatigue life calculations they are informally approximated for the whole range of fatigue life. Such an approach in determination of material data can be one of the reasons of the calculations and test results diversification for many metals and their alloys [5].

The basic aim of this paper is the analysis of the influence of the material damage degree on the momentary parameters of equation (1). The additional aim is the evaluation of the possibility of analytical description of material data in various periods of fatigue life.

Test procedure. Tests were carried out with the use of specimens made of AW2024 aluminium alloy (σ_u = 514 MPa, σ_y = 322 MPa). The specimens for the tests were prepared according to standard [1]. Shape and dimensions (in mm) of the specimen are presented in Fig. 2.

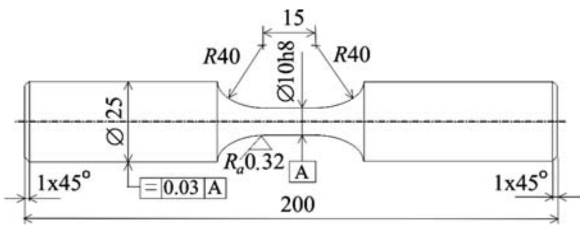


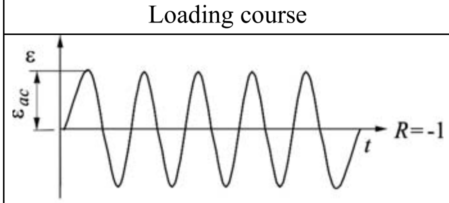
Fig. 2. Test specimen.

Tests were carried out at five values of strain ε_{ac}. Total strain amplitude (ε_{ac} = const) was the controled parameter during fatigue tests. Detailed chart of the tests is presented in Table.

During fatigue tests for the selected loading cycles the momentary values of loading and strain were recorded. As the criterion of the fatigue tests termination on each value of strain ε_{ac} there was accepted about 5% decreasing of the loading force in the half-cycle of tension in relation to its value from period of saturation.

New method of tests results processing and its verification. The loading and strain values recorded for the selected cycles of loading were processed in order do determine the changes of the basic hysteresis loop parameters, namely ε_{ap} and σ_a. Momentary stress in the specimen σ was determined by dividing the momentary value of the loading by the cross-section area of the specimen. With the use of maximum (σ_{max}) and minimum (σ_{min}) stress values the value of stress amplitude σ_a was evaluated. Similar way of proceeding was accepted in the case of plastic strain amplitude ε_{ap} determination. In Fig. 3 the example of the diagrams of two

Table. Parameters of loading courses

Loading course	Parameters
	ε_{ac1} = 0.5% ε_{ac2} = 0.65% ε_{ac3} = 0.8% ε_{ac4} = 1.0% ε_{ac5} = 1.5% f = 0.2 Hz

hysteresis loop parameters (ε_{ap} and σ_a) in the function of loading cycles number is shown.

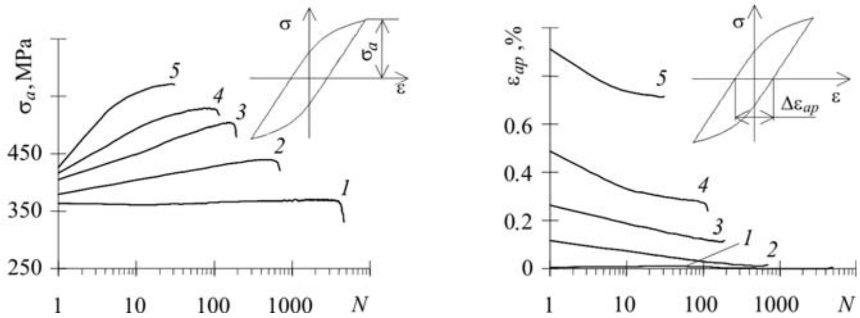


Fig. 3. Courses of changes of hysteresis loop parameters σ_a (*a*) and ε_{ap} (*b*): *1* – ε_{ac} = 0.5%; *2* – 0.65; *3* – 0.8; *4* – 1.0; *5* – 1.5%.

As it was expected the visible period of cyclic properties stabilization was not observed. With the increase of the loading cycle number *n* the characteristic parameters of hysteresis loop change. The stress amplitude σ_a increases (Fig. 3*a*) and at the same time the plastic strain amplitude ε_{ap} decreases (Fig. 3*b*). The changes of these loop parameters prove the cyclic hardening of aluminium alloy. Hardening increases with the increase of the strain level ε_{ac}.

In order to evaluate the influence of fatigue damage degree on the equation (1) parameters, a new method of the results processing was applied. The essence of this method is that during approximation of hysteresis loop parameters (ε_{ap} and σ_a) with straight lines described with equation (1) their values from various periods of relative life *n*/*N* are used. This is shown schematically in Fig. 4.

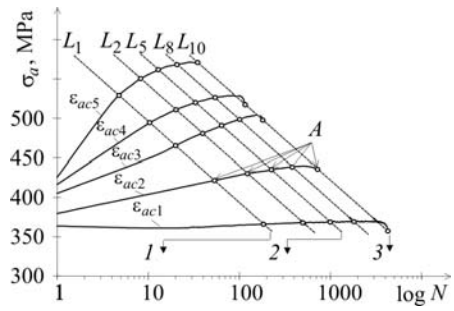


Fig. 4. The way of tests results elaboration: $L_1 = 0.1n/N$; $L_2 = 0.2n/N$; … , $L_{10} = 1.0n/N$; *1* – $\lg\sigma_a = \lg K_1 + n'_1 \lg\varepsilon_{ap}$; *2* – $\lg\sigma_a = \lg K_5 + n'_5 \lg\varepsilon_{ap}$; *3* – $\lg\sigma_a = \lg K_{10} + n'_{10} \lg\varepsilon_{ap}$; *A* – ε_{ap} and σ_a on level ε_{ac2} in various periods of *n*/*N*.

In Fig. 4 there the method of tests results processing after separation of 10 periods of relative life *n*/*N* for each level of loading are presented. These periods are obtained with the use of the parallel lines L_1–L_{10}, which indicate the periods of life in which the values of the loop parameters ε_{ap} and σ_a are determined.

Coefficients n' and exponents K' of equation (1) obtained in various periods of life are analysed in the function of the relative life *n*/*N*. Examples of the obtained diagrams are presented in Fig. 5. The values of the mentioned parameters obtained with the use of the classical and proposed method are marked with circles.

On the base of obtained diagrams it can be found that values of n' and K' parameters undergo changes and depend on the period of relative life *n*/*N*. Analysis of the results elaborated with the use of the classical method demonstrates that values of n' and K' parameters determined in the half-life ($n/N = 0.5$) are not the mean values for the whole area of life. Comparative analysis of the obtained results shows the scale of simplification which is calculated by accepting the values of n' and K' parameters from one period of fatigue life $n/N = 0.5$ as the results of elaboration. Equation (1) parameters obtained during the tests can be presented in the form of the discrete diagram or continuous function. In Fig. 5 the example of the elaborated results approximation in 10 periods of life with the use of the continuous function by connecting the middles of each period of life with a fine line is shown.

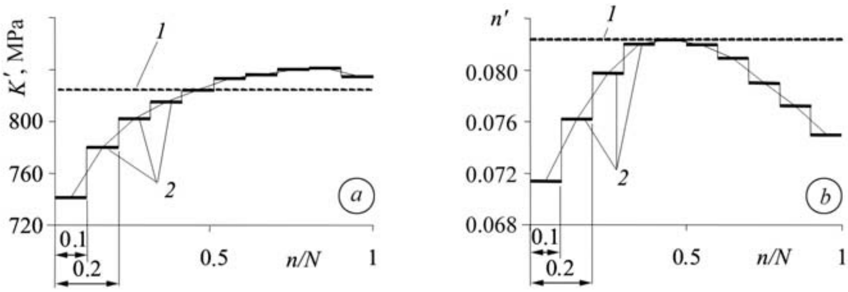


Fig. 5. Results of low-cycle tests elaboration with the use of the classical and new method: *a* – values of *K′* exponent (*1* – *K′* = const – classical method; *2* – *K′* = *f*(*n*/*N*) – new method); *b* – values of *n′* coefficient (*1* – *n′* = const – classical method; *2* – *n′* = *f*(*n*/*N*) – new method).

Примечание [A1]: Corrected units on the axis

CONCLUSIONS

The values of *n′* and *K′* parameters of AW2024 aluminium alloy obtained as a result of the fatigue tests results processing with the use of the classical method (method presented in standard [4]) describe only the momentary cyclic properties. As a result of the observed alloy hardening with the increase of loading cycles number the hysteresis loop parameters change (Fig. 3). The values of *n′* and *K′* parameters are not constant and depend on the period of life for which they were determined. A new test method of the results elaboration allows us to determine the values of *n′* and *K′* parameters in various periods of fatigue life. It can be important using *n′* and *K′* in fatigue life calculations of construction elements made of cyclically unstable metals (aluminium alloys, copper, titanium etc). Material data obtained with the use of the new method of results processing enable a designer to estimate the range of possible changes of cyclic properties. In the case of the crucial construction elements it allows us to carry out the verifying calculations for the extreme values of these parameters. The condition of obtaining a reliable description of changes of *n′* and *K′* parameters in the function of relative life *n*/*N* with the use of new method is division of the whole area of life into suitable number of partitions. When the number is high enough then it is possible to approximate obtained results with a continuous function. Results obtained in that form become very handy in use and can be applied during fatigue life calculations when observed changes of cyclic properties of the material are taken into account. Such an approach to fatigue life calculations was presented among others in paper [5].

РЕЗЮМЕ. Подано новий метод аналізу результатів малоциклових випробувань металів на втому, який дає змогу визначити характеристики матеріалів на різних стадіях втоми. Отримані дані можуть бути використані для розрахунків втомної довговічності елементів конструкцій.

РЕЗЮМЕ. Представлен новый метод анализа результатов малоцикловых испытаний металлов на усталость, который позволяет определить характеристики материалов на разных стадиях усталости. Полученные данные могут быть использованы для расчета усталостной долговечности элементов конструкций.

Aknowledgement. This paper was realized in the framework of the grant no. 1215/B/T02/2011/40 funded by Ministry of Science and Higher Education in 2011-2013.

1. *Fatigue* Testing and Analysis (Theory and Practice) / Y.-L. Lee, J. Pan, R. B. Hathaway, M. E. Barkey. – Elsevier, 2005. – P. 103–236.
2. *ASTM E 606-04* Standard Practice for Strain-Controlled Fatigue Testing. ASTM Int.
3. *Morrow J. D. W.* Internal Friction, Damping and Cyclic Plasticity: Cyclic Plastic Strain Energy and Fatigue of Metals, ASMT STP-378. – Philadelphia, 1965. – P. 45–84.
4. *Kocańda S. and Kocańda A.* Low-cycle fatigue strength of metals. – Warszawa: PWN, 1989. – 439 p. (in Polish).
5. *Mroziński S.* Stabilization of cyclic properties in metals and its influence on fatigue life // Dissertations № 128. – Bydgoszcz: Wydawnictwo UTP, 2008. – P. 1–148. (in Polish)

Примечание [A2]: Sorter name of the publisher

Received 05.04.2011