ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 15
Special Issue
4/2015

95 – 98

20/4

Experimental and Numerical Analysis of Uniaxial and Multiaxial Fatigue in the Lock of Scraper Conveyor Cast from ADI

J. Piekło[a], **M. Maj**[a]*
[a]AGH University of Science and Technology, Faculty of Foundry Engineering
Department of Foundry Process Engineering,
ul. Reymonta 23, 30-059 Cracow, Poland
* Contact for correspondence: e-mail: mmaj@agh.edu.pl

Obtained 20.11.2015; accepted for printing 29.12.2015

Abstract

The article presents and compares the results of experiments and numerical calculations of fatigue life of the cast lock of scraper conveyor used in the mining industry. The scope of research included determination of the fatigue life characteristics of ADI based on LCF and MLCF tests and fatigue life studies carried out directly on the casting of the lock. The state of stress in casting caused by the effect of forces applied in the test equipment was determined by the finite element method. The obtained results were used in calculation of the fatigue life of the lock applying selected hypotheses of the multiaxial fatigue. The results of calculations were compared with the results of experiments, evaluating at the same time also the validity of the adopted hypotheses.

Keywords: fatigue testing, multiaxial fatigue hypothesis, FEM calculations, mining equipment, ADI

1. Introduction

Locks operate as parts of conveyors for the underground mining transportation. In most cases they are forged from the low-alloy structural steel of 25HGNM grade (Fig. 1).

During operation, these elements are subject to a process of fatigue induced by forces changing in the links of chains clamping and pulling the individual locks. The state of stress and strain in the numerical model of the lock corresponding to the mode of loading and the type of connection made has been discussed in earlier works [1, 2, 3]. The model of the lock examined in this study corresponds to the boundary conditions which occur in the test equipment during cyclic loading of the casting done on an MTS 810 testing machine.

2. Fatigue criteria

The prevalence of complex states of stress in all kinds of cyclically loaded structures creates interest in the study of time-varying spatial states of stress and encourages formulation of multiaxial fatigue criteria. The most commonly applied type of classification is the division into criteria based on deformation, stress and energy. There are different ways of systematizing these criteria, to mention as an example the division proposed in [4] into the experimental and global criteria with subdivision into the criteria based on the invariants of the state of stress, on energy and on integrals, and also based on the concept of the, so-called, critical plane.

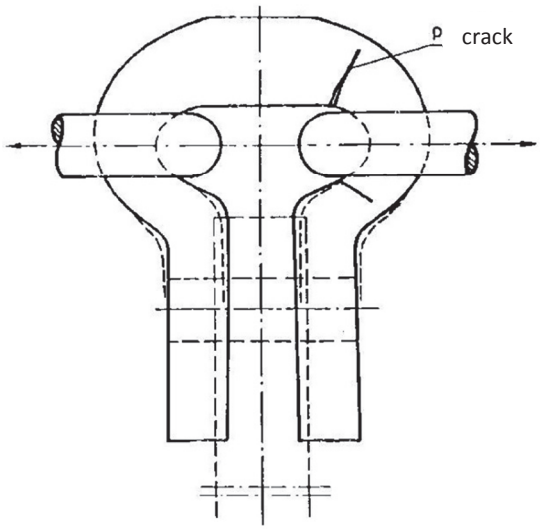

Fig. 1. The shape of the lock and the test mode of loading with the deformation (dashed line) and direction of crack propagation during destructive testing [1, 2].

The latter ones are increasingly being used in the range of both low and high number of cycles for which they were originally set [5]. The determination of the triaxial fatigue criterion is subject to the below mentioned points:

1. The triaxial criterion should be equally well applicable in a uniaxial state of stress.
2. The direction of crack propagation predicted by the criterion should be consistent with the experimental data.
3. The triaxial fatigue criterion should be expressed by a mathematical formula similar to the uniaxial criterion to enable the determination in a classical uniaxial fatigue test of all the necessary coefficients present in the equation.

The following briefly discusses the use of the multiaxial criterion of principal strain in fatigue life prediction along with the uniaxial Manson-Coffin-Morrow criteria and the Smith-Watson-Topper criterion:

Coffin-Morrow (C-M) criterion

The basic Coffin-Morrow equation defining the fatigue life criterion in a uniaxial state of stress has the following form:

$$\frac{\Delta\varepsilon_{sp}}{2}+\frac{\Delta\varepsilon_{pl}}{2}=\frac{\sigma_f^{'}}{E}\left(2N_f\right)^b+\varepsilon_f^{'}\left(2N_f\right)^c \tag{1}$$

where:

ε_{pl} – plastic strain,
ε_{sp} – elastic strain,
$2N_f$ – number of cycles,
$\varepsilon_f^{'}$ - fatigue ductility coefficient,
$\sigma_f^{'}$ - fatigue strength coefficient,
b – fatigue strength exponent,
c – fatigue ductility exponent.

Equation (1) does not allow for the effect of mean stress σ_m, which can be introduced using the, so-called, Morrow correction:

$$\frac{\Delta\varepsilon_{sp}}{2}+\frac{\Delta\varepsilon_{pl}}{2}=\frac{\sigma_f^{'}-\sigma_m}{E}\left(2N_f\right)^b+\varepsilon_f^{'}\left(2N_f\right)^c \tag{2}$$

This criterion is based on the observations that mean stress plays an important role when the principal component is derived from elastic strain.

Smith-Watson-Topper (S-W-T) criterion

The SWT criterion does not have the above mentioned limitations related to the range of strain and as such assumes the following form:

$$\frac{\Delta\varepsilon_{sp}}{2}\sigma_{\max}+\frac{\Delta\varepsilon_{pl}}{2}\sigma_{\max}=\frac{\left(\sigma_f^{'}\right)^2}{E}\left(2N_f\right)^{2b}+\sigma_f^{'}\varepsilon_f^{'}\left(2N_f\right)^{b+c} \tag{3}$$

where:

σ_{max} – the maximum stress for hysteresis

The criterion of principal strain

This criterion assumes that fatigue cracks develop perpendicularly to the plane on which the amplitude of principal strain $\Delta\varepsilon_1$ is the largest. In the case of a uniaxial state of stress, the maximum vector size of the principal strain assumes the same direction as the maximum axial strain. The replacement of axial strain in a Coffin-Morrow uniaxial fatigue criterion with the amplitude of principal strain changes this criterion into a triaxial form.

$$\frac{\Delta\varepsilon_{1sp}}{2}+\frac{\Delta\varepsilon_{1pl}}{2}=\frac{\sigma_f^{'}}{E}\left(2N_f\right)^b+\varepsilon_f^{'}\left(2N_f\right)^c \tag{4}$$

The criterion of principal strain can be successfully used in studies of the brittle materials, including cast iron and high-strength iron alloys. It does not apply to alloys characterized by high ductility, because it dangerously overestimates the fatigue life compared with experimental results.

3. Experimental and numerical calculations

The aim of the conducted experimental studies and numerical calculations was to compare the obtained results and choose the right criterion. Experiments consisted in fatigue testing carried out in the range of low cycles on samples of ADI at a loading cycle asymmetry coefficient R = -1 and in shape testing, during which the cast lock was subjected to fatigue loading. Because of the necessity to shorten the test time, the arms of the lock were not fastened with screws as is the case during operation of the connection. Table 1 shows the results of fatigue testing, and other values which are included in the numerical model of the lock.

During positive tensile cycles stretching the lock with the applied force of 75kN, the fatigue shape testing has demonstrated that the average life of the lock was 168 cycles. For the numerical model, the same scheme of loading and mounting was designed as for the test model. As a result of numerical calculations made in an Abaqus program, the value of effort was determined for the entire casting of the lock (Fig. 2).

Table 1.
Parameters used in numerical calculations

R_m	$R_{0,2}$	ν	K'	n'	b	c	ε_f'	σ_f'	R_z
[MPa]	[MPa]		[MPa]				[mm/mm]	[MPa]	[μm]
978	787	0,275	1620	0,125	-0,088	-0,139	0,5255	1440	50

where:
R_m – tensile strength,
$R_{0,2}$ – yield strength,
ν - Poisson number,
K' – cyclic strength coefficient,
n – cyclic strain hardening exponent,
R_Z - casting surface roughness.

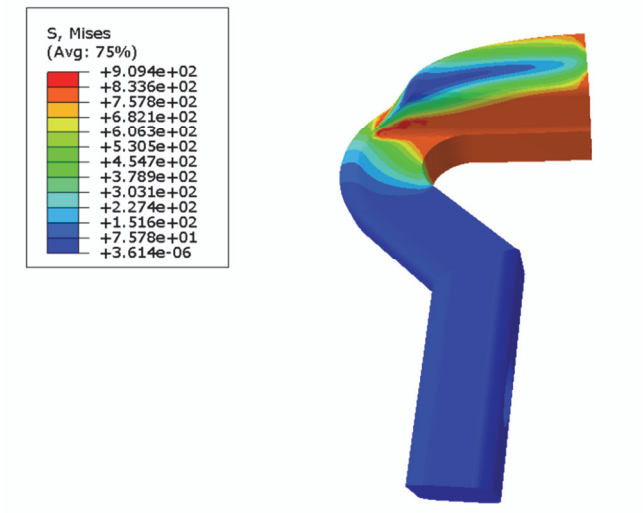

Fig. 2 Effort in the casting of the lock under the influence of a tensile force of 75kN applied in the test equipment.

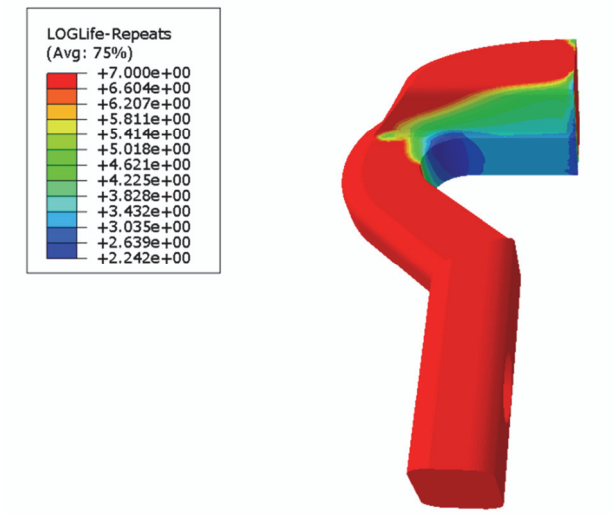

Fig. 3. The number of cycles to failure determined for the entire casting of the lock according to Morrow principal strain criterion of multiaxial fatigue. The results are expressed in decimal logarithms

Using "fe - safe" software and the results of strength calculations, based on the above mentioned fatigue criteria, the durability of the cast lock was predicted. The result obtained for a multiaxial fatigue criterion is shown in Figure 3.

In the area of contact with the chain link, the fatigue of the material assumes its highest value reducing the durability of the lock to 174 cycles (log 2 N = 2.242), while in the remaining part of the casting the durability is practically unlimited and reaches 10^{10} cycles (log 2 N = 7). In a way similar to Figure 3 are distributed the durability areas for the remaining criteria, remembering that the uniaxial C-M criterion provides a durability of 123 cycles, while the value of mean stress introduced to the S-W-T criterion reduces the predicted life even more, i.e. to 69 cycles. Comparing the obtained numerical results with the results of experiments it follows that the best result gives the multiaxial criterion of principal strain. Therefore, it is used to predict the fatigue life of the lock with the arms joined together by screws in the same way as under the operating conditions in the mine. The connecting of both arms has significantly reduced the level of stress and increased the lock durability in the crucial area up to $2.5*10^6$ cycles.

4. Conclusions

1. The fatigue of the lock assumes its highest value in the area of contact with the chain link.
2. Regardless of the applied criterion, the areas of durability in the lock are distributed in a similar way remembering, however, that the value of mean stress introduced to the S-W-T criterion gives the durability of 69 cycles, while according to the C-M criterion the durability amounts to 123 cycles.
3. Comparison of numerical calculations with experimental studies proves the validity of multiaxial criterion of principal strain.

References

[1] Piekło, J., Maj, M. (2014). Evaluation of Casting Fatigue Life Based on Numerical Model and Fatigue Tests. *Archives of Foundry Engineering, Vol. 14*, 4/2014, 95-100.

[2] Piekło, J., Maj, M. & Stachurski, W. (1995). Ocena naprężeń eksploatacyjnych w silnie obciążonym elemencie przenośnika zgrzebłowego na podstawie badań elastooptycznych i obliczeń numerycznych. *Prace instytutu Odlewnictwa*, vol. 1-2, pp. 19-30.

[3] Maj, M. (2012). *Trwałość zmęczeniowa wybranych stopów odlewniczych*. Katowice–Gliwice: Archives of Foundry Engineering. Monografia.

[4] Weber, B., Labesse-Jied, F., Robert, J.L., (2001). Comparison of multiaxial high cycle fatigue criteria and their application to fatigue design of structures. In *Proceedings of the sixth International Conference on Biaxial/Multiaxial Fatigue & Fracture, (Vol. 1)*, 195-202, Lisboa, Instituto Superior Tecnico.

[5] You, B.R., Lee, S.B., (1996). A critical review on multiaxial fatigue assessments of metals. *International Journal of Fatigue* 18(4), 235-244.

[6] Jing, L., Chun-Wang, L., Yan-Jiang Q. & Zhong-Ping, Z. (2004). Fatigue life prediction for some metallic materials under constant amplitude multiaxial loading. *International Journal of Fatigue* 68, pp.10-23.

[7] Gates, N. & Fatemi, A. (2004). Notched fatigue behavior and stress analysis under multiaxial states of stress. *International Journal of Fatigue* 67, pp. 2-14.

[8] Li, B., Reis, L. & Freitas, M. de (2006). Simulation of cyclic stress/strain evolutions for multiaxial fatigue life prediction. *International Journal of Fatigue* 28, pp.451-458.

[9] Piekło, J. (1994). A simulation of the phenomenon of crack propagation in an insert of die casting die – part I: Thermal stresses. *Prace Instytutu Odlewnictwa*, vol. 3, pp. 139-158.

[10] Piekło, J. (1995). A simulation of the phenomenon of crack propagation in an insert of die casting die – part II: Initiation and propagation of cracks. *Prace Instytutu Odlewnictwa*, vol. 1-2, pp. 1-18.