SELECTION OF THE BEST METHOD FOR ASSESSMENT OF THE FATIGUE LIFE OF ALUMINIUM ALLOYS BASED ON THE ROOT OF THE SCATTER MEAN-SQUARE VALUE

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Abstract: The paper presents comparison of three methods of fatigue life assessment related to aluminium alloys. One of these methods is a new way of statistical interpretation of the fatigue test results by means of the root of the mean-square value of the error expressing a half of scatter of the calculated fatigue life. The results of fatigue tests of specimens, and different geometries of welded joints made of aluminium alloys were considered. The calculated fatigue lives were obtained with use of critical plane orientations determined according to the variance of normal and shear stresses, and the covariance of normal and shear stresses.

Key words: Aluminium Alloys, Critical Plane, Fatigue Life

1. INTRODUCTION

Estimation of the fatigue life of elements of machines and structures is a complex process and it can be performed according to many known mathematical models, depending on the material applied and geometry of the element. However, it is difficult to find in literature standards informing how to compare different models in order to select the best one. Some proposals can be found in papers by Berger et al. (2002), Bracessi et al. (2005), Eibel et al. (2003), Karolczuk, Macha (2004). However, they cannot be applied in all the cases. There is no one model precisely comparing different models of fatigue life estimation ad allowing to distinguish the best one.

This paper presents three methods of estimation of the fatigue life of elements made of aluminium alloys, compared by means of a new way of statistical interpretation of fatigue test results.

2. ANALYSIS OF FATIGUE TEST RESULTS

Analyzing fatigue life scatters, we usually use logarithms of ratios of experimental and calculated lives determined according to the following expression:

$$E = log\ \frac{N_{\exp}}{N_{cal}} = \log N_{\exp} - \log N_{cal}, \tag{1}$$

(see the paper by Li et al. (2009)).

The mean value of the considered magnitude can be defined as:

$$\overline{E} = \frac{1}{n}\sum_{i=1}^{n} E_i\ , \tag{2}$$

where *n* is a number of measurements.

Variance is determined from the following formula:

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(E_i - \overline{E}\right)^2\ , \tag{3}$$

and standard deviation is defined from:

$$s = \sqrt{s^2}\ . \tag{4}$$

Finally, the mean scatter is determined from the formula:

$$\overline{T}_N = 10^{\overline{E}}\ , \tag{5}$$

in the scatter band of the scatter coefficient T_N given by the formula:

$$T_N = 10^{t_{n-1}\alpha/2\cdot s}\ . \tag{6}$$

Thus, we obtain parameters (2) and (6), in case of which explicit interpretation is not possible. Karolczuk and Macha (2004) proposed their following connection:

$$E_s = \sqrt{\overline{E}^2 + s^2}\ . \tag{7}$$

There are no theoretical foundations for application of the proposed models. However, another method can be proposed, namely we can determine a root from the mean-square error value as:

$$E_{RMS} = \sqrt{\frac{\sum_{i=1}^{n}\log^2\frac{N_{\exp i}}{N_{cali}}}{n}}\ , \tag{8}$$

so finally the obtained scatter value is:

$$T_{RMS} = 10^{E_{RMS}}\ . \tag{9}$$

3. EXPERIMENTS

The results of own tests and tests from literature were analyzed. The considered results concerned some selected aluminium alloys and welded joints of those alloys under combined bending with torsion.

Specimens made of the aluminium alloy 2017A, known as PA6 were subjected to pure bending, pure torsion, cyclic and random proportional and non-proportional combinations of bending with torsion (Walat, 2010).

The proposed method was also verified with use of the results of cyclic tests obtained by Kueppers and Sonsino (2001, 2003) for aluminium welded joints of tube-tube and tube-flange types, made of aluminium-magnesium-silicon for plastic working, AlSiMgMn T6, which present numerical notation is EN AW-6082 T6. Experiments were realized for pure bending, pure torsion and combined proportional and non-proportional bending with torsion.

Results of fatigue tests of duralumin D-30 realized by Nishihara and Kawamoto (1941) were also analyzed. Specimens made of D-30 were subjected to the same loadings as those tested by Kueppers and Sonsino.

The calculated fatigue lives were obtained with use of orientations of critical planes determined according to variance of normal stresses μ_σ, shear stresses μ_τ and covariance of normal and shear stresses $\mu_{\sigma\tau}$.

The method of maximum variance of normal stresses can be written as:

$$\mu_\sigma = \frac{1}{T_0}\int_0^{T_0} \sigma_\eta(t)\sigma_\eta(t)dt \ , \tag{10}$$

where T_0 observation time, $\sigma_\eta(t)$ is history of normal stress oriented at the angle of α in relation to stress $\sigma_{xx}(t)$ for combination of bending with torsion, where σn(t) is assumed as:

$$\sigma_n(t) = \cos^2\alpha\sigma_{xx}(t) + \sin 2\alpha\tau_{xy}(t). \tag{11}$$

The method of maximum variance of shear stress is expressed by the following formula:

$$\mu_\tau = \frac{1}{T_0}\int_0^{T_0} \tau_{\eta s}(t)\tau_{\eta s}(t)dt, \tag{12}$$

where $\tau_{\eta s}(t)$ is history of shear stress at the angle of α in relation to stress $\sigma_{xx}(t)$ for combination of bending with torsion can be written as:

$$\tau_{\eta s}(t) = -\frac{1}{2}\sin 2\alpha\sigma_{xx}(t) + \cos 2\alpha\tau_{xy}(t). \tag{13}$$

Another method including variations of both normal stresses and shear stresses is the method of covariance of normal and shear stresses written as:

$$\mu_{\sigma,\tau} = \frac{1}{T_0}\int_0^{T_0} \sigma_n(t)\tau_{\eta s}(t)dt. \tag{14}$$

Figs. 1÷6 present mean-square errors obtained with use of the proposed Eq. (9) for successive considered tests according to three analyzed models. The numerous tests of aluminium alloy 2017 A were realized in laboratories of Opole University of Technology, and the results were shown in three separate figures. Fig. 1 shows the test results for loadings under in-phase combination of bending with torsion, and in Fig. 2 presents the results of tests under the phase shift. Fig. 3 presents the scatters for combination of in-phase and out-of-phase loadings. From the figures it appears that the maximum scatters occur always in the case of application of the criterion on the critical plane defined by variance of normal stresses μ_σ (the mean-square scatter for all the tests equals 6.5), and the minimum scatters occur for the criterion defined by covariance of normal and shear stresses $\mu_{\sigma,\tau}$ (the mean-square scatter for all the tests is 1.5). In the case of the criterion defined by variance of shear stresses μ_τ the mean-square scatter for all the tests is 4.7. The mean-square scatters for variable-amplitude loadings are 2.103.

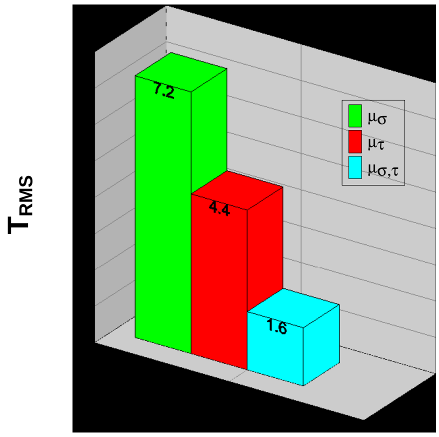

Fig. 1. Root of the mean-square error of scatters for specimens made of 2017A under in-phase loadings

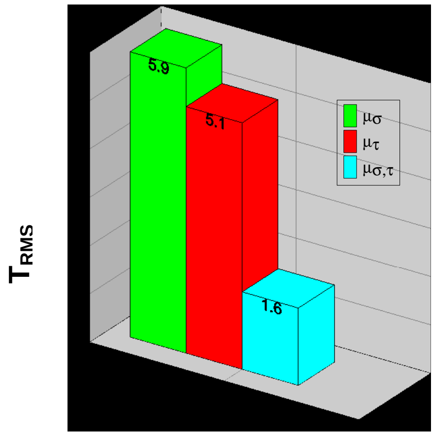

Fig. 2 Root of the mean-square error of scatters for specimens made of 2017A under out-of-phase loadings

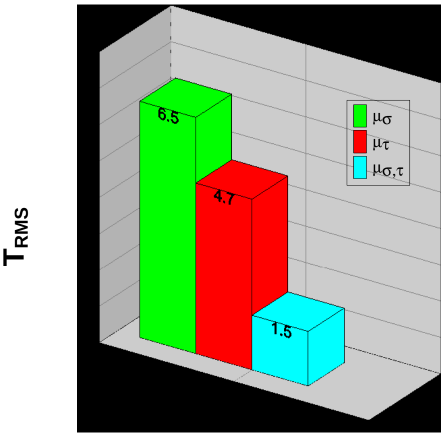

Fig. 3. Root of the mean-square error of scatters for specimens made of 2017A under in-phase and out-of-phase loadings

Fig. 4 presents the test results obtained for specimens made of the aluminium alloy D-30. The maximum scatters were obtained for the criterion on the critical plane defined by variance of normal stresses (the mean-square scatter for all the tests was 12.6). The minimum scatters were obtained for the criterion defined by covariance of normal and shear stresses (the mean-square scatter for all the tests was 1.2). Thus, the results are similar as those obtained for the aluminium alloy 2017A. When the criterion defined by variance of shear stresses was applied, the mean-square scatter was 4.4 for all the tests.

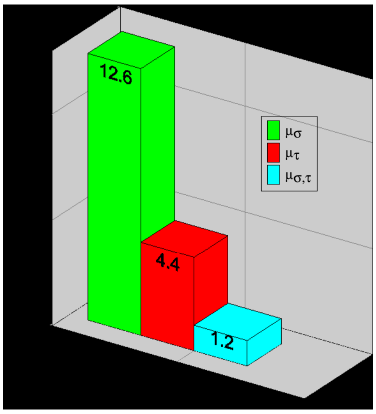

Fig. 4. Root of the mean-square error of scatters for specimens made of D-30

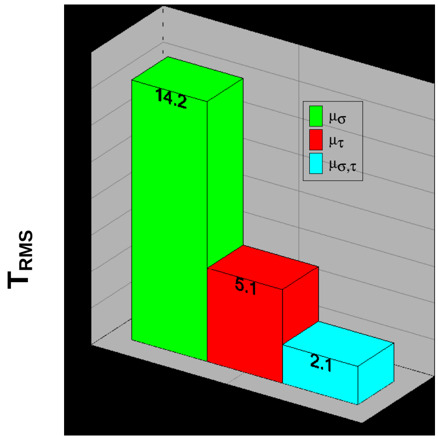

Fig. 5. Root of the mean-square error of scatters for specimens made as tube-flange welded joints of AlSi1MgMn-T6

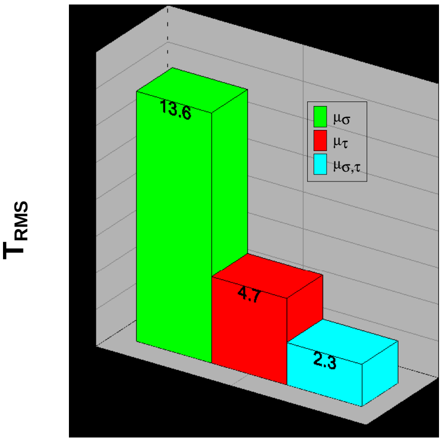

Fig. 6. Root of the mean-square error of scatters for specimens made of tube-tube welded joints of AlSi1MgMn-T6

Fig. 5 shows the test results for specimens made as tube-flange welded joints of AlSi1MgMn-T6. Fig. 6 presents the test results for tube-tube specimens made of the same material. From the figures it appears that each time the greatest scatters are obtained in the case of application of the criterion on the critical plane defined by variance of normal stresses (the mean-square scatter is 14.2 and 13.6). The minimum scatters are obtained for criterion of covariance of normal and shear stresses (the mean-square scatters are 2.1 and 2.3), like in the case of fatigue tests for aluminium alloys 2017A and D30. When the criterion defined by variance of shear stresses is applied, the mean-square scatter is 5.1 and 4.7 for all the tests.

4. CONCLUSIONS

The method of statistical interpretation of the fatigue test results by means of the root of mean-square error is an universal method for comparison of fatigue lives obtained by different methods (fatigue criteria). It allows to select the best method, giving the best conformity between the calculated and experimental results.

REFERENCES

1. **Berger C**., **Eulitz K.G., Heuler P**., **Kotte K.L., Naundorf H., Schuetz W., Sonsino C.M., Wimmer A., Zenner H**. (2002), Betriebsfestigkeit in Germany – an overview, *Int. J. Fatigue*, Vol. 24, 603-625
2. **Braccesi C., Cianetti F., Lori G., Pioli D**.(2005), Fatigue behaviour analysis of mechanical components subject to random bimodal stress process: frequency domain approach, *Int. J. Fatigue*, Vol. 27, 335-345
3. **Eibel M., Sonsino C.M., Kaufmann H., Zhang G**.(2003), Fatigue assessment of laser welded thin sheet aluminium, *International Journal Fatigue*, Vol.25, 719-731
4. **Karolczuk A., Macha E**.(2004), *Płaszczyzny krytyczne w modelach wieloosiowego zmęczenia materiałów. Wieloosiowe zmęczenie losowe elementów Maszyn i konstrukcji*-część IV. Studia i Monografie, Politechnika Opolska, Opole
5. **Kueppers M., Sonsino C.M**.(2003), Critical plane approach for the assessment of the fatigue behaviour of welded aluminium under multiaxial loading, *Fatigue Fract. Engng. Mater. Struct*., Vol. 26, 507-513
6. **Kueppers M.,Sonsino C. M**.(2001), *Festigkeitsverhalten von Aluminiumschweiss verbindungen unter mehrachsigen Spannungszuständen*, AiF-No. 10731N, LBF-Report No 280542, Fraunhofer-Insitut für Betriebfestigkeit (LBF), Darmstadt
7. **Li J., Zhang Z., Sun Q., Qiao Y**.(2009), A new multiaxial fatigue damage model for various metallic materials under the combination of tension and torsion loadings, *International Journal of Fatigue*, No. 31, 776-781
8. **Nishihara T., Kawamoto M.**(1941), *The Strength of Metals under Combined Alternating Bending and Torsion with Phase Difference, Memoirs of the College of Ingineering*, Kyoto Imperial University, Vol. 10, No.6, 117-122
9. **Walat K**.(2010), *Wpływ kowariancji naprężeń w płaszczyźnie krytycznej na trwałość zmęczeniową elementów maszyn*, Rozprawa doktorska, Politechnika Opolska, Opole
10. **Walat K., Łagoda T**.(2010a), Trwałość zmęczeniowa aluminiowych złączy spawanych według kryteriów opartych na położeniu płaszczyzny krytycznej wyznaczanych trzema metodami, *Transport przemysłowy i maszynowy* 2(8)/2010, 68-72