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RETESTED RUNOUT SPECIMENS IN FATIGUE RESEARCH

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Abstract: *The problem of samples that did not break is quite often seen in fatigue tests. This situation particularly frequently occurs in the staircase method. With this in mind a question occurs whether these samples may be loaded again. This paper includes tests on steel S355J2+C for finite fatigue life, as well as for infinite fatigue life. The samples that did not break in the staircase method were repeatedly tested at higher load. The results obtained were compared with the results obtained on samples that had not been previously loaded. An impact of the previous tests was identified. With the use of statistic calculations, it is possible for adjust for the obtained values of cycle numbers, so that they correspond to the values of samples not previously loaded. The results obtained may be accepted as satisfactory.*

Keywords: Fatigue tests, S-N curve, Steel, Statistical analysis, Runout.

1. Introduction

The occurrence of samples that did not break at the assumed level of stress is an issue that frequently comes up during the performance of fatigue limit tests with the purpose of determining S-N characteristics. It is related with the fact that the research, performed according to ISO-12107 (2003) standard, are performed at two areas. The first is a finite life range, where the relation between fatigue life and stress is described by linear regression according to the following formula:

$$\log(N) = m.\log(S) + c \tag{1}$$

where: N – number of cycles,
S – stress amplitude [MPa],
m – slope coefficient,
c – intercept term.

The other range is the infinite life area, where tests are performed until reaching the basic number of cycles, e.g. $5 \cdot 10^6$ cycles. This value is adopted depending on the material. Suggested values may be found in papers Sonsino (2007), Dyląg and Orłoś (1962). Infinite life fatigue strength is evaluated using the staircase method. The application of this method effects in that about 50 % of the samples do not break (see Tab. 1, Fig. 1a).

In the case when the number of samples for performing the examinations is limited, like in case of biological material, research on which may be found in paper Topoliński et al. (2012). Another example is collection of samples from a real object, as presented in paper Tomaszewski et al. (2017). Sampling method for such samples is presented in paper Zastempowski et al. (2015). In such case, each sample is important from the point of view of statistical calculations. The use of not broken samples that reached the basic number of cycles is recommended.

This paper presents a statistical method for adjusting the number of cycles obtained for samples not broken in previous tests, which the method is described in paper Gänser et al. (2015). This method assumes that neither strengthening nor weakening occurs in the material during the previous loading. In the case of occurrence of the above effects, research papers for the given material must be referred to. Examples of papers in this regard include AKITA et al. (2012), Sinclair (1952) or Kheder et al. (2011).

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2. Statistical model

This method assumes that the distribution of fatigue life logarithm is normal. Moreover, it is assumed that the not broken samples, for infinite life, have reached the following probability of failure for the given population:

$$P_j = \begin{cases} f_j / n_j & \text{for} \quad f_j > 0 \\ 1/2n_j & \text{for} \quad f_j = 0, \end{cases} \tag{2}$$

where: f_j – samples failure at stress S_j,
n_j – number of samples tested at stress S_j.

The following formula must be used for determining the adjusted number of cycles:

$$N_i = N_i^* \cdot 10^{-\frac{\sigma_N}{1-P_j} \cdot \frac{1}{\sqrt{2\pi}} \exp\left(-\left(\Phi^{-1}\left(P_j\right)\right)^2 / 2\right)}, \tag{3}$$

where: N_i – number of cycles to failure after correction,
N_i^* – number of cycles to failure of the runout at stress S_i,
Φ^{-1} – the inverse of the cumulative distribution function (the quantile),
σ_N – standard deviation of $N = \log(N)$.

Test results

S355J2+C material was used for the tests. Examinations for evaluating the S-N characteristics are presented in paper Strzelecki et al. (2016). The S-N curve for this steel is presented in Fig. 1.

Tab. 1 presents the cycle number values obtained for not broken and repeatedly tested samples. Additionally, the last column contains values calculated according to formula (3). Graphical representation of these results is presented in Fig. 2.

Tab. 1: Coefficients of regression for standard test results and with retested runouts.

Stress level *j*	S_j	N_j	P_j	S_i	N_i^*	N_i
1	350	5 000 000	0.125	415	191 486	222 912
	350	5 000 000	0.125	460	60 628	70 578
	350	5 000 000	0.125	415	239 337	278 616
	350	5 000 000	0.125	460	57 711	67 182
2	357	5 000 000	0.4	415	97 648	150 823
	357	5 000 000	0.4	460	57 973	89 542
3	363	5 000 000	0.5	415	145 527	321 141
	363	5 000 000	0.5	460	74 845	165 163

Calculations were performed for the results obtained from Tab. 1 for the purpose of evaluating the S-N characteristics. Coefficients from formula (1) for 5 data cases were determined. In the first case only the results obtained without repeatedly tested samples were taken into account. In the subsequent case, the results for the repeatedly tested samples were added to the set, without any cycle number adjustment. In the third case, the characteristics for the repeatedly tested samples was determined, again without any cycle number adjustment. The fourth characteristics refers to the set from the standard tests, and to fatigue life from the repeatedly tested samples, with cycle number adjustment. The last case refers to a set only for repeatedly tested samples, with cycle number correction. The calculation results are presented in Tab. 2. Fig. 2 presents the obtained characteristics.

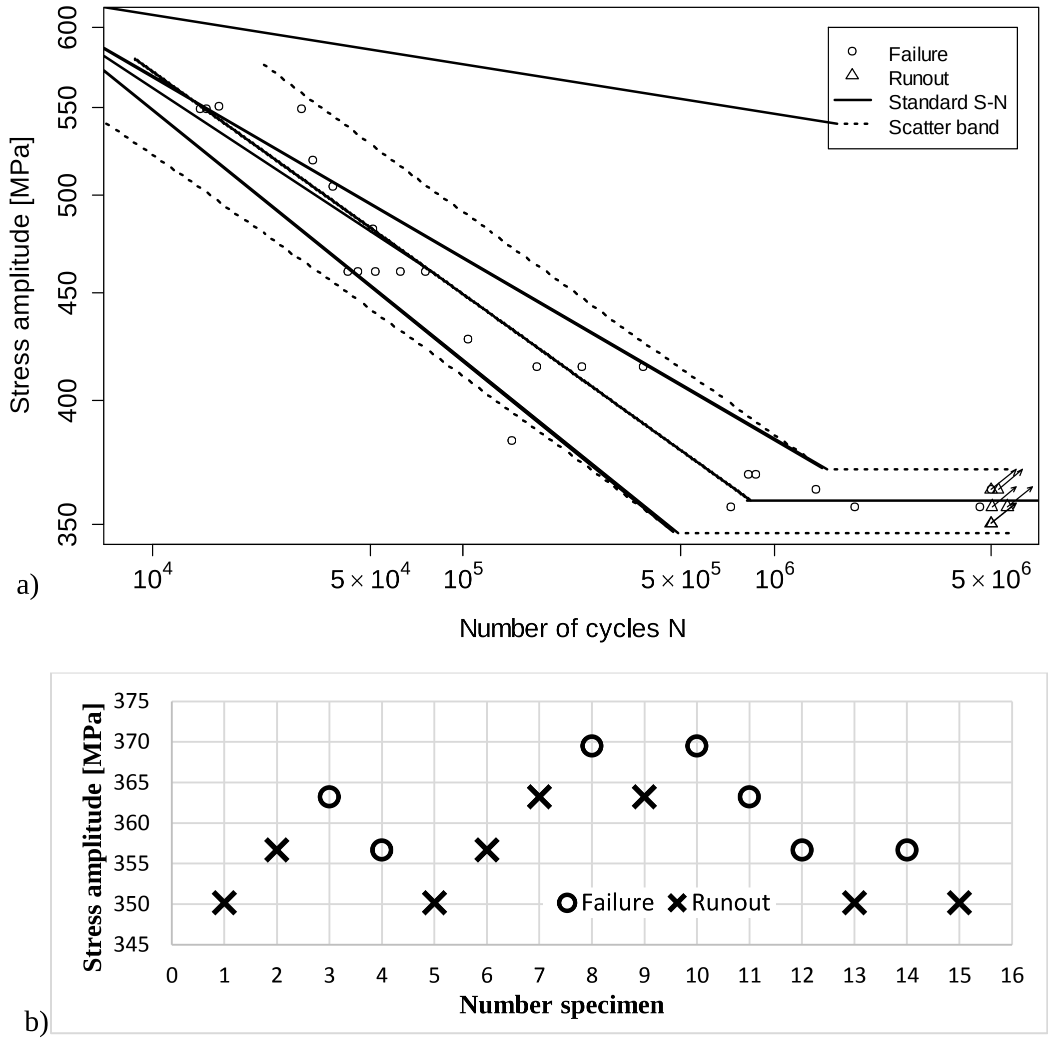

Fig. 1: S-N curves for S355J2+C a) and staircase method b).

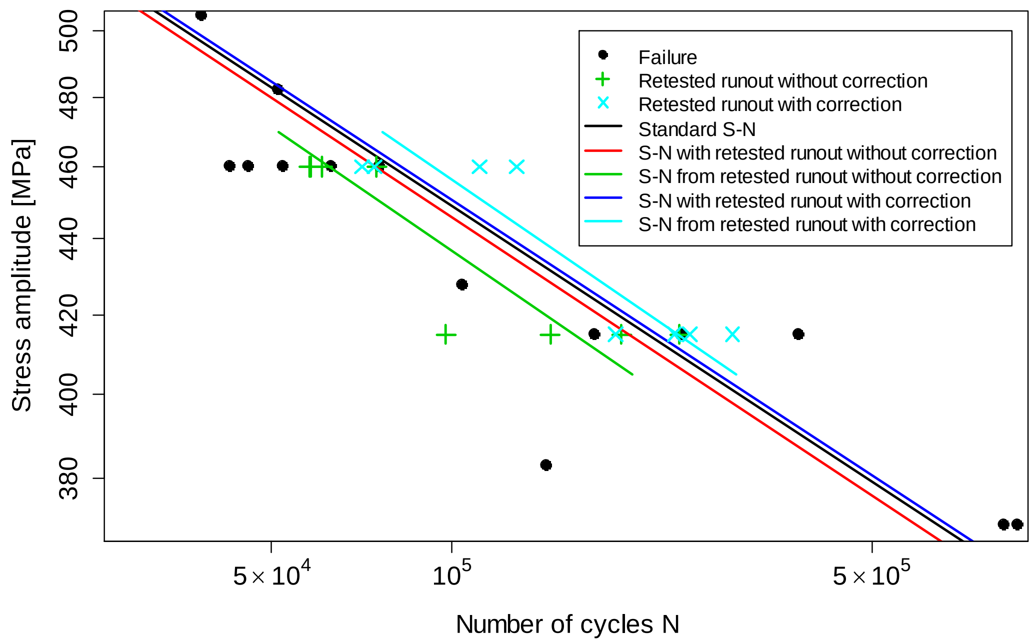

Fig. 2: S-N curves for S355J2+C steel with retested runouts.

Tab. 2: Coefficients of regression for standard test results and with retested runouts.

Type of data	Coefficient of regresssion	
	m	***c***
Standard tests	9.523	30.25
Standard tests + retested runout without correction	9.455	30.04
retested runout without correction	9.128	29.10
Standard tests + retested runout with correction	9.533	30.30
retested runout with correction	9.128	29.27

3. Conclusions

Cycle number adjustment according to formula (3) for the not broken and repeatedly tested samples gave a satisfactory result. Fig. 2, shows that the obtained characteristics for the repeatedly tested samples with adjustment, and those tested in the standard way are close to each other, compared to the other ones. The fact that the characteristics obtained for samples repeatedly tested without cycle number adjustment is shifted to the left (which effects in lowered number of cycles) results in that is located on the safe side. Such characteristics is useful for applying for calculations of structural element fatigue life. It must be remembered, however, that different construction materials may hardening or weakening, causing this statistical method not to apply.

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