INVESTIGATIONS ON THE FATIGUE CRACK GROWTH RATE IN 10HNAP STEEL AFTER SINGLE OVERLOADING BY THE AMPLITUDE WHILE TENSION

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The paper contains the results of the tests of fatigue crack growth rate under tension in 10HNAP steel subjected to uniaxial overloading when the overload coefficient is $k_j = 1.1 \div 1.624$. Plane specimens with the central symmetric concentrators of stresses (circular slots with side notches) were tested. The obtained results are expressed by the analytical relation which takes into account the retardation parameter of the fatigue crack growth and allows to determine life of the tested element made of 10HNAP steel.

INTRODUCTION

Many elements of structures work under irregular loadings which can include single or multiple instantaneous loadings of different signs, transitions from one loading level to another one, Wanhill (1). Thus, a suitable method of prediction of the fatigue crack growth under irregular loading should be used for estimation of permissible damages and general life of the elements, Gasiak and Grzelak (2).

Under irregular loadings the fatigue crack growth is accompanied by kinetic effects of loading interaction. Namely, retardation or acceleration of the fatigue crack growth can be observed. Their occurrence depends on a sequence in which loadings of various amplitudes are applied, Newman (3). Single tensile overloadings with transition from a high level to a lower one cause visible retardation of the fatigue crack growth (2), Pantelakis et al (4).

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MODEL OF THE FATIGUE CRACK GROWTH AFTER OVERLOADING

After application of tensile overloads the fatigue crack is characterized by a number of cycles of its retardation, N_{di}. Height of the applied overloading is the most important factor influencing value of N_{di}. The overloading is characterized by $k_j = P_p / P_{max}$(Fig.1), where P_p is the maximum loading in a overloading cycle and P_{max} is the maximum loading for a regular cycle.

A number of retardation cycles of the fatigue crack growth, N_{di}, increases together with increase of k_j as a result of formation of a system of residual stresses, intensification of the crack closing degree and plastic blunting of the crack tip (2). Increase of the residual stress area and increase of a crack closing level after application of loading cause decrease of the efficient range of the stress intensity coefficient, ΔK. As the fatigue crack increases after overloading, the range of ΔK increases again and approaches its stationary value. The stationary value occurrs at the maximum value of the stress intensity factor range, ΔK_{max} under a regular loading cycle.

The authors proposed a model of micromechanism of the fatigue crack growth after one-cycle overloading with the amplitude for 10HNAP steel. The model, based on the test results, can be expressed by a relation between the fatigue crack rate, $d(2\ell)/dN$, and the stress intensity coefficient range, ΔK

$$\frac{d(2\ell)}{dN} = \frac{C_2[(1-C_{di})\Delta K]^{m_2}}{(1-R)\sqrt{J_c E} - \Delta K} \tag{1}$$

where:

$$C_{di} = n(R_m^2 - R_e^2)\frac{2\ell_i - 2\ell_p}{N_{di}(K_p^2 - K_{max}^2)} \tag{2}$$

After integration of relationship (1) we can obtain an expression for determination of specimen life, N_k

$$N_k = \int_{2\ell_o}^{2\ell_p} \frac{(1-R)\sqrt{J_c E} - \Delta K}{C_1(\Delta K)^{m_1}} d(2\ell) + \int_{2\ell_p}^{2\ell_k} \frac{(1-R)\sqrt{J_c E} - \Delta K}{C_2[(1-C_{di})\Delta K]^{m_2}} d(2\ell) \approx$$

$$\approx \sum_{i=1}^{i=i_p} \frac{(1-R)\sqrt{J_c E} - \Delta K_i}{C_1(\Delta K_i)^{m_1}} \Delta(2\ell_i) + \sum_{i=i_p}^{i=i_k} \frac{(1-R)\sqrt{J_c E} - \Delta K_i}{C_2[(1-C_{di})\Delta K_i]^{m_2}} \Delta(2\ell_i) \tag{3}$$

where the first term (3) expresses life of the element up to application of one-cycle overloading ($C_{di} = 0$), and the second one - from overloading to the moment when the slot reaches its critical length, $2\ell_k$.

FATIGUE TESTS

Plane specimens made of higher strength and higher corrosion-resisting steel (10HNAP), Gasiak and Grzelak (5). Chemical constitution and mechanical properties of the material are given in Tables 1 and 2.

TABLE 1 - Chemical constitution of 10HNAP steel (%).

	C	Mn	Si	P	S	Cr	Ni	Cu	Al
Min.	-	0.4	0.25	-	-	0.5	0.3	0.25	-
Max.	0.12	0.9	0.6	0.06	0.04	1.0	0.6	0.5	0.02

TABLE 2 - Mechanical properties.

Re [MPa]	Rm [MPa]	δ_5 [%]	E [MPa]	J_c [N/mm]	n
402	494	22	$2\cdot10^5$	131.2	0.28

The specimens were subjected to variable tension under constant mean loading $P_m = 7500$daN and constant amplitude of regular loading, $P_a = 2350$daN ($R = 0.523$). The range of one-cycle overloading coefficient, $k_j = P_p / P_{max}$, was changed from $k_1 = 1.1$ to $k_s = 1.624$. The tests were carried out on a hydraulic pulsator and the regular loading frequency was 14 Hz. One-cycle overloading was once applied to each specimen at a given fatigue crack length $2\ell_p$.

Figure 2 shows fatigue crack in the specimen just after overloading ($k_j = 1.5$, $2\ell_p = 13$mm). The crack tips are blunt and the areas of plastic strain can be seen.

TEST RESULTS AND THEIR DISCUSSION

During tests it has been proved that retardation of the fatigue crack growth can be observed after application of one-cycle overloading. It is caused by a new, secondary fatigue crack which initiates and develops from the bottom of the blunt crack under the influence of repeated cycles of regular loading after an overloading cycle. After its formation the primary fatigue crack grows again but with a sharp tip.

Exemplary courses of the fatigue crack growth rates as functions $d(2\ell)/dN = f(\Delta K)$ for $k_j = 1.624$, $2\ell_p = 11.04\,mm$ are shown in Fig.3. Retardation of the fatigue crack growth begins from the broken line 3, corresponding to the start of the specimen overloading. The results obtained before overloading (denoted as O) were approximated by line 1, described with relation (1) for $C_{di} = 0$ and $C_1 = 3.765 \cdot 10^{-16}$, $m_1 = 10.875$. The results obtained after overloading (denoted as ●) were approximated by line 2 described with relation (2) for $C_{di} \neq 0$ and $C_2 = 1.983 \cdot 10^{-7}$, $m_2 = 2.965$.

CONCLUSIONS

Basing on the test results we can draw the following conclusions:

1. The applied analytical relationship of the fatigue crack growth rate versus the stress intensity coefficient range, including the retardation parameter is sufficiently conforming with the experimental results for a wide range of the overload coefficient.
2. After application of one-cycle overloading retardation of the fatigue crack growth occurs. It is caused by plastic blunting of the crack tip and formation of internal compressive stresses.
3. While determination of fatigue life of the elements under variable loadings with one-cycle overloadings we should take into account the parameter of the fatigue crack growth retardation.

SYMBOLS USED

C_{di} = parameter of retardation of the fatigue crack growth
$2\ell_i$ = actual crack length (mm)
$2\ell_p$ = crack length corresponding to overloading (mm)
K_p = maximum stress intensity coefficient for an overloading cycle $(MPa \cdot m^{0.5})$
K_{max} = maximum stress intensity coefficient for regular cycles of loadings $(MPa \cdot m^{0.5})$
R_m = tensile strength (MPa)
R_e = yield point (MPa)
n = parameter of the material hardening,
J_c = Rice integral (N/mm)
E = longitudinal modulus of elasticity (MPa)
C_2, m_2 = constants determined from tests of the fatigue crack growth rate.

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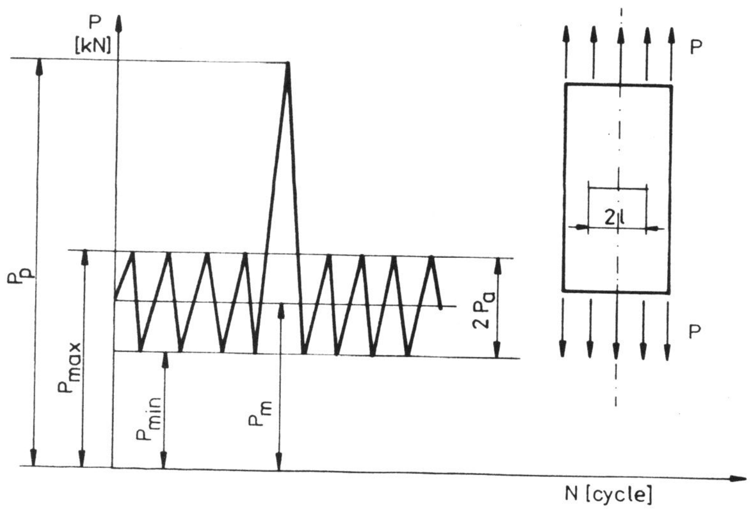

Fig.1 Scheme of the specimen overloading

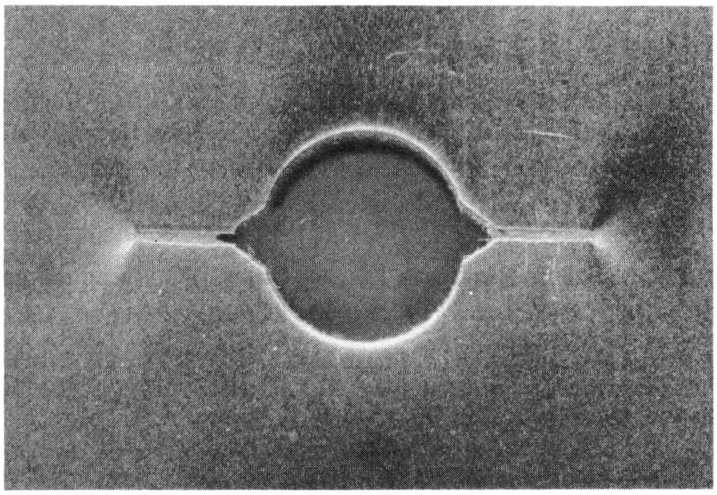

Fig.2 Fatigue slot in the specimen after overloading with a half-cycle of amplitude for $k_j = 1.5$

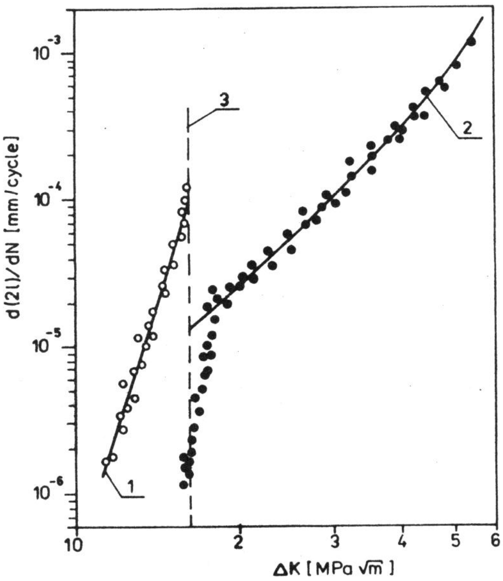

Fig.3 Course of the fatigue crack growth rate versus the stress intensity coefficient for the overload coefficient $k_j = 1.624$