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EVOLUTION OF DAMAGE FOR P91 STEEL UNDER CYCLIC LOAD

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1. Introduction

Damage evolution law for materials subject to monotonic load was used in its simplest form by many researchers, e.g. [1]. This simplest form can be written as follows:

$$dD = \frac{1}{\bar{\varepsilon}_f} d\bar{\varepsilon}_P \,, \tag{1}$$

which means that damage is liner function of accumulated plastic strain. Calculation of accumulated plastic strain in general case requires integration of the plastic strain intensity increment along the deformation path

$$\bar{\varepsilon}_P = \int d\bar{\varepsilon}_P \,. \tag{2}$$

For monotonic, proportional loading accumulated plastic strain equals strain intensity at the given instant. Final value of accumulated plastic strain (at the moment of material failure) is denoted as $\bar{\varepsilon}_f$. For general case of non-proportional, complex loading this calculation, however much more difficult, can be performed easily by most commercial FEM codes.

Uniaxial, cyclic load that is used in most of low and high cycle fatigue testing, e.g. [2] can be considered special case of proportional loading. Reported tests were stress controlled, fully reversible ($R = -1$) load cycles were applied with the frequency 20 Hz. Typical strain response for such program of loading is shown in Fig. 1 [3].

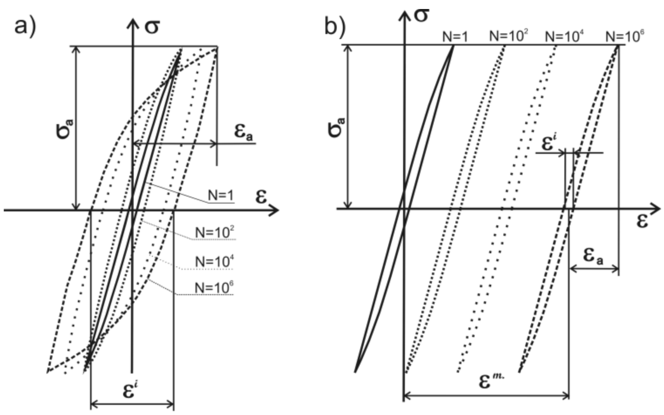

Fig. 1. Strain response for stress controlled, fully reversible load.

For each cycle of the load accumulated plastic strain intensity is composed of double inelastic response ε^i shown in Fig. 1a and ratcheting strain ε^m – see Fig. 1b. For N elapsed cycles of load we can write that accumulated plastic strain intensity is:

$$\bar{\varepsilon}_P = \sum_{n=1}^{N} \left[2|\varepsilon_n^i| + |\varepsilon_n^m - \varepsilon_{n-1}^m| \right]. \tag{3}$$

2. Experimental results

Most of experiments in the framework of presented experimental program was performed in high-cycle regime. Due to this fact, local observation of the damage had to be introduced in the manner described in [2]. Transversal strains were measured instead longitudinal, typically employed in the case of low-cycle fatigue. Since in the case of high-cycle fatigue it is inconvenient to record and analyze each load cycle, formula (3) was slightly modified to calculate damage indicator parameter using data recorded for selected cycles:

$$\varphi_N = \sum_{n=1}^{N} \left[|\varepsilon_n^i - \varepsilon_{n-1}^i| + |\varepsilon_n^m - \varepsilon_{n-1}^m| \right], \tag{4}$$

where n stands for sequential number of the recorded load cycle. Finally, value of damage parameter D was calculated using simple formula:

$$D = \frac{\varphi - \varphi_0}{\varphi_f - \varphi_0}. \tag{5}$$

Results of fatigue tests, obtained as the result of experimental program [3] are show in Fig. 2.

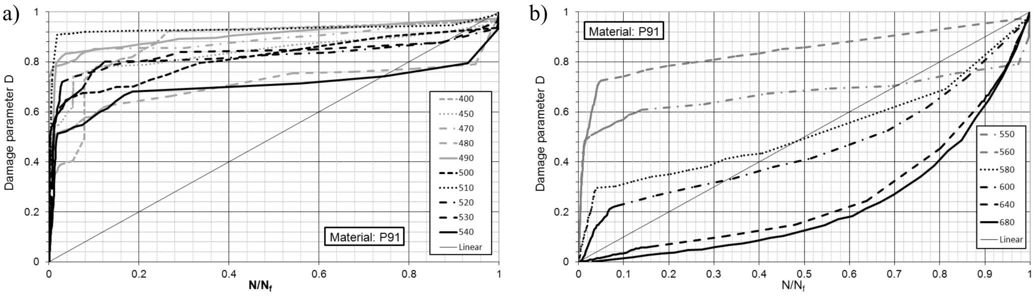

Fig. 2. Damage evolution for P91 steel: a) for low stress amplitudes (400–540 MPa), b) for high stress amplitudes (550–680 MPa).

Evolution of the damage parameter is shown in these plots as the function of the life fraction N/N_f for low (Fig. 2a) and high (Fig. 2b) stress amplitudes. Such kind of plot, usually referred as Damage Curve unambiguously describes damage evolution. Additionally, in Fig. 2a and b continuous line illustrates most popular damage evolution low – linear damage accumulation. In such a case damage is assumed to be linear function of the life fraction. As it can be easily noticed, evolution of damage for the material in question doesn't follow linear damage accumulation rule and more sophisticated, nonlinear model has to be applied in numerical simulations.

References

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