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Fatigue crack propagation in cold drawn steel

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Abstract

This paper deals with the fatigue crack growth in pearlitic steel wires in the form of hot rolled bar and cold drawn wire. The progress of crack front was analysed by means of the evolution of the aspect ratio with the relative crack depth, and this latter was evaluated during the tests by a compliance method. Results show that cold drawing is beneficial from the point of view of crack growth rate, i.e., cracking is slower in the cold drawn wire (final commercial product) than in the hot rolled bar (base material). In spite of the oriented pearlitic microstructure of the cold drawn steel, fatigue crack propagation develops in mode I, i.e., cracking takes place by maintaining its original plane. A materials science reasoning is proposed to explain this behaviour on the basis of the pearlitic microstructure of the steel and the large geometry changes in the vicinity of the crack tip.

Keywords: Pearlitic steels; Steelmaking; Cold drawing; Strength anisotropy; Crack deflection; Crack tip blunting

1. Introduction

High-strength cold-drawn pearlitic steel is widely used in the prestressed concrete technique in the form of wires, cables and strands, and it is frequently subjected to cyclic (fatigue) loading able to produce the growth of cracks.

There are studies in the scientific literature about fatigue crack propagation in wires from the analytical-numerical [1–3] or experimental [4,5] points of view, although the fatigue phenomenon in wires is far from being totally understood.

In this paper the differences, with regard to fatigue crack growth, between a hot rolled bar and a cold drawn wire (commercial prestressing steel) are studied, since the strain hardening process to make prestressing steel produces, apart from a clear improvement of mechanical properties (the final aim of manufacturing) a change in the fatigue performance.

2. Experimental procedure

The material used was a pearlitic steel with eutectoid composition. It was analysed in two forms: firstly, as a hot rolled bar (steel E0), and secondly, as a commercial prestressing steel wire after cold drawing the hot rolled bar in seven passes (steel E7).

The main mechanical properties of the steel are summarized in Table 1, where E is the Young's modulus, σ_Y the yield strength and σ_R the ultimate tensile strength. Their stress–strain curves are plotted in Fig. 1.

The specimens for the fatigue tests were circular rods of 11.0 and 5.1 mm diameter (respectively the hot rolled bar and the prestressing steel wire) and a mechanical notch was produced to initiate fatigue cracking. Tests were performed at room temperature, step by step under load control, the load being constant in a step and decreasing from one to another step. Samples were subjected to tensile cyclic loading with an R factor equal to zero, and a frequency of 10 Hz. The maximum load in the first loading stage corresponded to a value of about half the yield strength in the smooth wire and was reduced between 20 and 30% from one to another step (cf. Fig. 2).

The crack front was modelled as an ellipse with its centre located at the periphery of the rod (Fig. 3). It was defined from a set of real points taken form the actual crack front and using a least squares fitting technique to adjust the theoretical (modelled) crack front to the real one.

The crack length was evaluated by means of the compliance of the samples, cf. Fig. 4 showing the dimensionless compliance (1/CED) *versus* the dimensionless crack length (a/D) for both steels. The compliance (C) for each test was obtained from the

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Table 1
Mechanical properties of the steels

Steel	E (GPa)	σ_Y (GPa)	σ_R (GPa)	ε_R	R_A (%)
E0	202	0.70	1.22	0.068	31.24
E7	209	1.48	1.82	0.059	23.05

ε_R: ultimate strain; R_A: reduction of area at fracture.

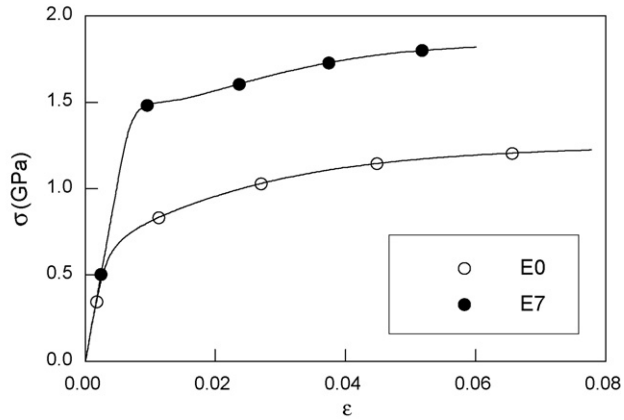

Fig. 1. Stress–strain curves of the steels.

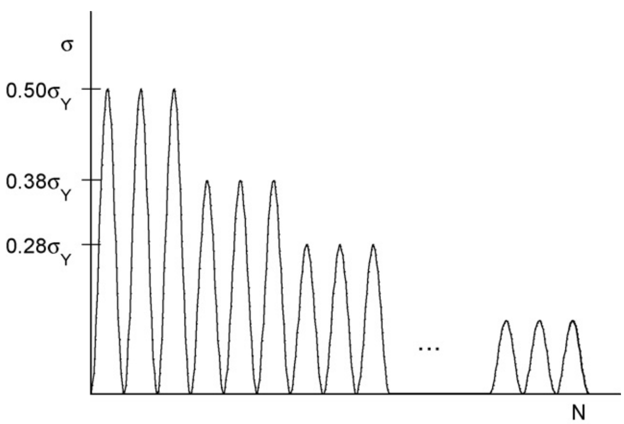

Fig. 2. Loading scheme during the tests.

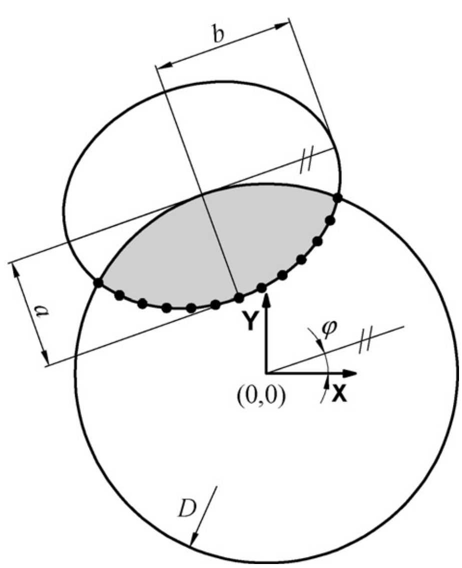

Fig. 3. Crack front modelling.

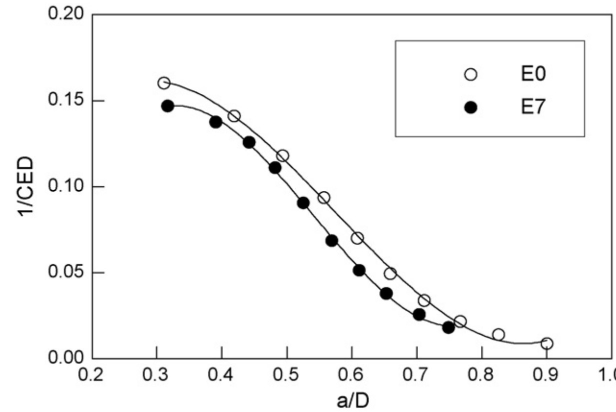

Fig. 4. Dimensionless compliance for both steels.

last loading step at which the relationship between the applied load (F, measured by means of the load cell) and the relative displacement between two reference points in the sample (u, evaluated by means of a dynamic extensometer located in front of the crack mouth) allows the computation of the compliance $C = u/F$. Finally, the compliance was related to the crack geometry (relative crack depth a/D and crack aspect ratio a/b, see Fig. 3), these geometric parameters being obtained by optical microscopy after fracture (Figs. 5 and 6).

The slight differences can be attributed to the different evolution of crack shape during fatigue in both steels, since the specimen dimensions were taken as proportional to guarantee the geometric similarity and thus a theoretically unique plot in dimensionless compliance is obtained if the same crack aspect ratio a/b is achieved.

3. Experimental results

3.1. Crack aspect evolution

In the fractographs obtained by fatigue and posterior fracture of the wires, the crack front evolution was observed during the different steps (Figs. 5 and 6). The fatigue surfaces of the hot rolled bar and the cold drawn wire are developed in mode I, although a certain 3D aspect is observed in some local areas,

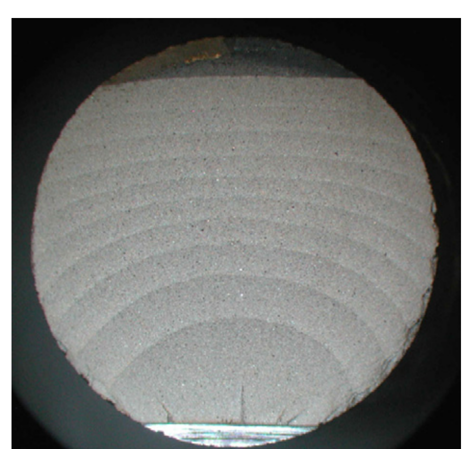

Fig. 5. Fatigue surface (hot rolled steel E0).