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Influence of microstructure on fatigue process in a low carbon steel. Analysis and modelling

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ABSTRACT

Fatigue in a low-carbon steel is investigated through observation on surface crack propagation and on growth of cracks in preliminary notched specimens. Testing uses three groups of specimens. For surface crack observation there are two groups of samples consisting of cylindrical specimens subjected to tension-tension and rotating-bending fatigue; in this case surface microstructurally-short crack propagation is monitored by acetate-foil replica technique. For crack growth observation (in situ) in notched specimens there is a third group of samples including flat specimens preliminary notched by FIB-technique and then subjected to pure-bending fatigue. Here microstructurally-short crack propagation is examined at interruptions of each test at a given equal number of cycles for detailed observation of specimen surface by optical- and SEM-microscopy. The study is focused on examining of crack paths in terms of interaction between the propagating short cracks and the microstructure, and on a suitable mathematical description of crack growth in the investigated microstructure. The obtained data for pure-bending fatigue show higher crack growth rates (dominated by the interaction with ferrite and pearlite grain boundaries and interfaces, ferrite grains, pearlite colonies and non-metal inclusions) and shorter fatigue lifetimes than those found for rotating-bending fatigue. In comparison, the registered tension-tension fatigue data present the lowest crack growth rates, due to much lesser loading than that applied at rotating-bending and pure-bending fatigue. Based on data obtained, a Parabolic-linear model "Crack growth rate – Crack length" is used for describing and predicting adequately short crack propagation under the specified three types of fatigue. The model is supported by a comparison between the predicted and the actual fatigue lifetimes.

1. Introduction

In the present work investigations on microstructurally-short fatigue crack growth are performed in order to clarify the relationship between the typical features of the studied microstructure and the specific behavior of cracks propagating through it.

Short cracks are recognized to have considerable influence on fatigue strength of a large number of engineering components and structures. The standard approach usually uses the Paris relation to describe crack growth data in terms of crack growth rate versus stress intensity factor range. But it does not describe the propagation of sub-critical cracks which control a large part of the fatigue lifetime of a component. These cracks grow at stress intensity ranges, smaller than the threshold value of the stress intensity factor and show a specific behavior, with a widely fluctuating crack growth rates higher than those of long cracks, described by the standard LEFM-procedure at the same nominal driving force. In order to understand mechanics, mechanisms and microstructural effects on short fatigue crack propagation, the mentioned specific crack growth behavior has been examined in many different metallic

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Table 1
Chemical composition, mechanical and microstructural properties of ROLCLAS 09Mn2.

Chemical composition									
C, %	Si, %	Mn, %	Cr, %	Ni, %	P, %	S, %	Cu, %	Al, %	As, %
0,09	0,28	1,63	0,05	0,04	0,017	0,026	0,13	0,12	0,014

Mechanical and microstructural properties				
Tensile strength σ_B, MPa	Proof strength $\sigma_{0,2}$, MPa	Cross section contraction, ψ, %	Hardness HB, MPa	Average grain size, [μm]
482	382	62,3	148	25,6

materials. It is well known that usually there is a change of crack growth direction and considerable slowdown in crack growth rate when cracks propagate across grain boundaries and in the vicinity of an interface between phases with different mechanical properties. These microstructural features can act as stress raisers or can cause shielding effect at the crack tip. The barriers can reduce the effective driving force for crack propagation and that is why short crack growth is so microstructurally sensitive; all the variations in the microstructure surrounding the crack tip are responsible for its specific growth behavior [1,2].

In the present work short fatigue crack propagation behavior is investigated under tension-tension, (**T**-**T**), rotating- bending (**RB**) and pure-bending (**PB**) loading conditions [3–10]. Three different groups of specimens are used: for surface crack observation – two groups of hour-glass specimens for **T**-**T** and **RB** fatigue tests [3]; and for crack growth observation (in situ) in notched specimens – a group of flat samples notched by Focused Ion Beam (FIB) technique, tested under **PB** [4,5,10]. A plastic-foil replication is used for short fatigue-crack growth monitoring at **T**-**T** and **RB** fatigue and direct observation by optical- and SEM-microscopy at **PB** fatigue. The obtained data are presented by microstructural photos, and plots “Crack length – Cycles” and “Crack growth rate – Crack length”; some comparisons between them are made. A mathematical model of fatigue crack propagation “Parabolic-Linear Model”, **PLM**, is proposed in [6] and employed for mathematical propagation description of data obtained.

2. Material, specimens and testing

A **ro**lled **l**ow-**c**arbon, **l**ow-**a**lloyed **s**teel, ROLCLAS, marked as 09Mn2 Steel (according to the Bulgarian Construction Steel Standard), used mostly for offshore applications and in shipbuilding, was subjected to tension-tension, rotating-bending and pure-bending fatigue.

The chemical composition of ROLCLAS and its mechanical and microstructural characteristics are given in Table 1.

ROLCLAS was available in sheets of 8 mm thickness. Its microstructure revealed a sequence of long and uniform pearlite and ferrite bands, as shown in Fig. 1a. The bands are wider in the middle of the sheet but loose and thinner close to the surface. Two groups of hour-glass specimens were under investigation: **Group A** consisting of specimens for **T**-**T** fatigue with geometry shown in

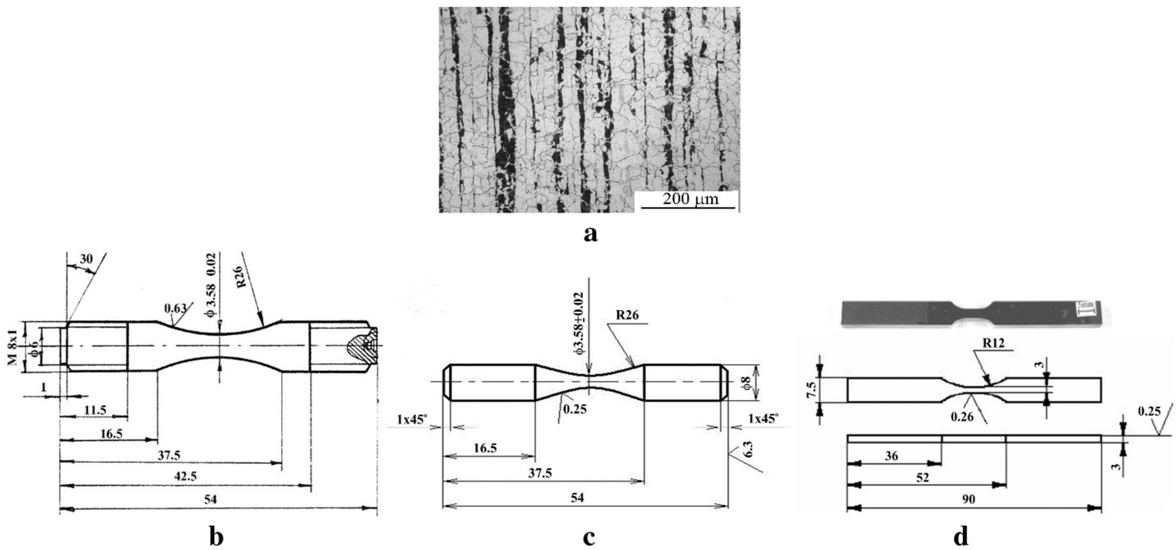

Fig. 1. Microstructure of cross section of ROLCLAS specimens (a), hour-glass fatigue specimens for **T**-**T** (b) and **RB** fatigue (c), flat fatigue specimen for **RB** fatigue (d); all dimensions are in mm.

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