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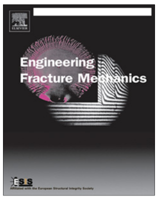

Fatigue crack growth rate of two pearlitic rail steels

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ABSTRACT

A study of fatigue crack growth rate was conducted in two pearlitic rail steels, namely R260 and R370CrHT. Two crack plane orientations with respect to the rolling direction were tested and separate experiments were performed to cover a wide variation in fatigue crack growth, from the fatigue threshold (circa 10^{-9} m/cycle) to rapid fracture conditions. The fracture surfaces were examined and some correlations between microstructural features such as interlamellar spacing and mechanical properties were made.

1. Introduction

The pearlitic carbon steels are commonly used in applications in which high strength, high wear resistance and low cost are desired, being rail–wheel pairs and reinforcements in pre-stressed concrete typical examples. In particular, rail steels are subjected to demanding conditions since the high loads and low contact areas lead to local stresses that easily exceed the yield strength of the material. When preventing the plastic deformation and cracking is unable, it is important to focus on how cracks form and how quickly they grow. For years, the breaking of railway axles, wheels and rails has caused accidents with disastrous consequences for life and property. This encouraged the development of fracture mechanics and new research fields of materials testing and fatigue [1].

Some investigations compare the wear rates and the Rolling Contact Fatigue (RCF) of different rail steels in fully scale tracks [2,3] and laboratory tests [4,5] The RCF covers all rail phenomena that appear on rails due to overstressing the rail material. Important exponents of the RCF family are (beside others) spalling, squats, and mainly head checks. Other studies focus on the fracture toughness [6–9] but just a few measure the fatigue crack growth (FCG) of pearlitic steels [10]. Hassani and Ravaee reported fracture toughness of 30.4 MPa $\sqrt{m}$ for premium rail steel tested at $-20\,^{\circ}C$ [7]. C. Kammerhofer et al. reported a K_{Ic} around 33 MPa $\sqrt{m}$ for a R260 steel [9]. Wetscher et al. studied the effect of large shear deformation on the

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Nomenclature

a	crack length, crack size, estimated crack size (mm)
a_o	initial crack size after pre-cracking (mm)
B	specimen thickness (mm)
Δa	estimated crack extension (mm)
$\Delta a/\Delta N$	estimated fatigue-crack-growth rate (mm/cycle)
ΔK	stress-intensity-factor range (MPa $\sqrt{m}$)
ΔK_{th}	fatigue-crack-growth threshold (MPa $\sqrt{m}$)
E	Young's modulus (GPa)
K_I	stress-intensity factor, in Mode I (MPa $\sqrt{m}$)
K_{Ic}	plane-strain fracture toughness, in Mode I (MPa $\sqrt{m}$)
K_Q	conditional fracture toughness (MPa $\sqrt{m}$)
$K_{\max}$	maximum stress-intensity factor (MPa $\sqrt{m}$)
$K_{\min}$	minimum stress-intensity factor (MPa $\sqrt{m}$)
N	number of fatigue cycles
P	force (kN)
$P_{\max}$	maximum force (kN)
$P_{\min}$	minimum force (kN)
R	force ratio ($=P_{\min}/P_{\max}$)
S	specimen span (mm)
W	specimen width (mm)

mechanical properties of a rail steel grade R260. In these experiments the measured fracture toughness (K_Q) of the undeformed material change from ≈53 to 42 MPa $\sqrt{m}$, after one pass in the equal channel angular pressing (ECAP) [6]. This shows the effect of plastic deformation but as their samples were very thin ($B = 2$ mm), were in a plane-stress state and therefore the true K_{Ic} is unknown. Hohenwarter et al. also showed that the fracture toughness is highly influenced by the degree of deformation and orientation, decreasing for cracks oriented with regard to the aligned lamellae microstructure and increasing for cracks perpendicular to them [8].

Studies carried out by Ganesh and Kitsunai and Wilson in A533B steels addressed the inclusions, and their orientation, influence on the FCG [11,12]. Today the rail steels are very clean but the cementite lamellae orientation has similar effect. Wetscher et al. exposed a considerable increment of crack growth rate after three passes of ECAP [6].

The purpose of this paper is to present complete plots of stress-intensity factor range (ΔK) versus cyclic crack growth rate of two rail steels, in which an experimental approximation to the *Paris–Erdogan Law* is obtained. The *Paris' Law* relates the Irwin stress intensity factor range to characterize the range of crack advance per cycle under a fatigue stress regime [13]. These results allow the optimization of maintenance tasks in modern railway systems given that the FCG rate can be estimated more accurately. In addition, the material characterization and the inspection of the fracture surfaces were performed to understand the material response under fatigue conditions. The implications of some test parameters in a good accuracy in the measure of the crack length are discussed in the paper.

2. Materials and methods

All the samples for the present investigation were extracted from sections of R260 and R370CrHT rails manufactured by *Voestalpine Schienen GMBH-Austria* for the Metro system of *Medellín–Colombia*. The rail heads were cut as shown in Fig. 1 and single edge crack bending specimen [SE(B)] were machined and notched according to the ASTM E1820-11 standard with $W = 24$ mm. In agreement to ASTM E399-09 standard the crack plane orientations are L–S for the cracks that grow from the top of the rail head to the rail web, and L–T for those that grow from one flange of the rail to the other. In both cases the cracks grow transversal to the rolling direction. Three replicas of the L–S samples and four of the L–T ones were tested. The chemical composition measured by optical emission spectrometry and the mechanical properties of the rails, in accordance with EN 13674-1:2011 standard, are shown in Tables 1 and 2 respectively.

2.1. Metallographic characterization and hardness measurements

For the metallographic analysis the samples were grinded using emery paper followed by polishing using 12.5 μm alumina followed by 1 μm diamond. The analysis of non-metallic inclusions was performed in accordance with the ASTM E45-13 standard by using an Optical Microscope. Picral etching (100 ml ethanol + 4 g picric acid) was used to reveal the microstructure. The SEM was performed using a JEOL 5910LV system.

A Universal hardness testing equipment Wolpert DIA TESTOR was used in the Vickers scale with a load of 31.25 Kgf. Eight hardness measurements were made for each sample (four per side), as shows Fig. 1.