Fatigue fracture assessment of high carbon steel components

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Abstract
Fractographic assessment of fatigue fractures may be difficult if they occur in metallic components characterized by low ductility complex microstructures. In these cases, reconciliation of known fatigue rupture mechanisms with fractographic appearance of fatigue-fractured surfaces is challenging. Special techniques assisted by theory development may be necessary. Pearlitic steels fatigue fractures are visited.

1. Introduction

High carbon steels find their way in technological applications owing to their resistance to wear and tear, extreme hardness, as well as to their ability to achieve very high tensile strength when extruded into wire. Furnace annealed or normalized high carbon steels have an almost fully pearlitic microstructure. A classical use of high carbon steels is in the fabrication of rails, which call for elevated compression strengths.

Fatigue failures in pearlitic steels, such as rail steels, are difficult to analyze and clearly identify, due to the metallographic microstructure that shows alternate lamellae of ductile ferrite and brittle cementite. Moreover, the task is challenging since their fracture surfaces at room temperature have ductile features, more characteristic of high temperature ruptures. In fact, if we examine a brittle to ductile Charpy-V transition curve (Fig. 1) for rail steels (≈ 0.7% C), we can recognize that brittle rupture predominates at the lower shelf, which extends up to 40°C ca. Fully ductile upper shelf fracture is reached only at 220°C. Features of the above fatigue surfaces are clearly not brittle, but rather ductile, although not fully ductile. Thus, striations, that usually characterize ductile fatigue failures, are not clearly visible because they cannot appear on the brittle carbides, but only on the ductile ferrite lamellae.

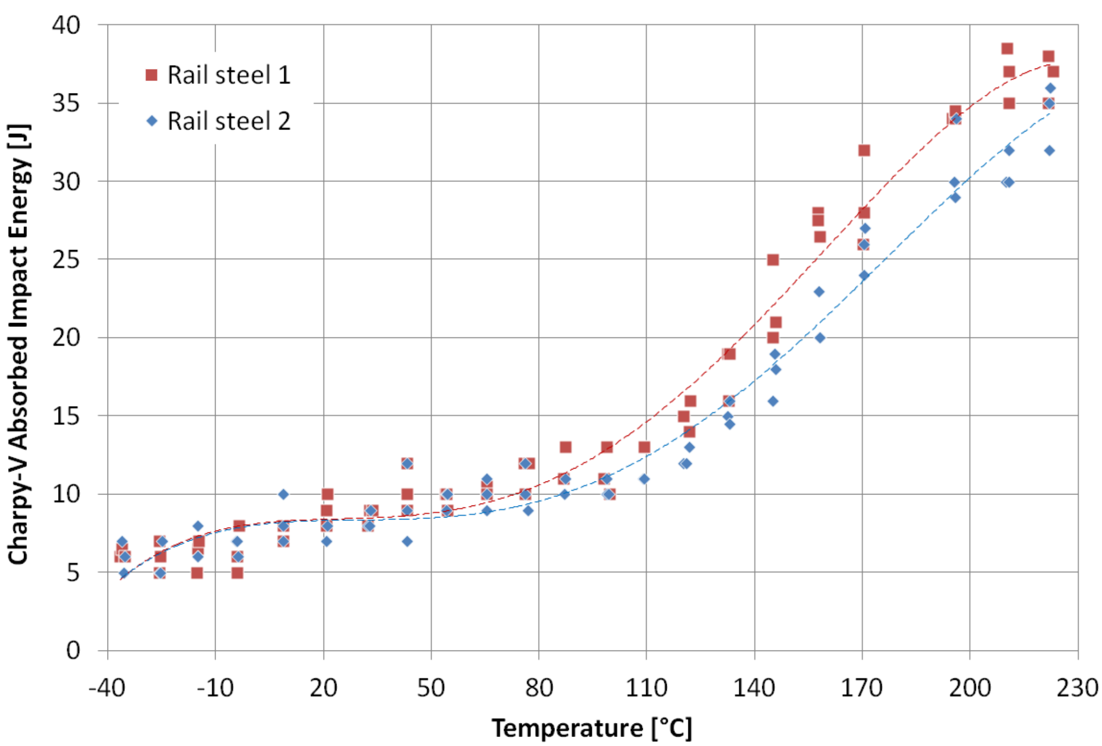

Fig. 1 - Rail 260 steel Brittle-to-ductile transition curves; rail steels 1 and 2, 0.68% and 0.73% C, respect.

Careful SEM exams of fracture surfaces of EN 13674-1 R260 pearlitic rail steels specimens tested under controlled crack growth fatigue rates have been performed to ascertain the presence of striations on the top of broken ferrite lamellae, as suggested by a micro-mechanical model previously developed by the authors.

2. Experimental

6 series of 3 single edge notched beam rail steel specimens have been precracked and fatigue tested with a load ratio $R = 0.5$, each series having been fabricated by a single rail coming from a different heat. For the selected steel, valid Paris law ΔK values are comprised between 7 and 20 MPa√m ($\Delta K_{th} \approx 4$ MPa√m). Two different average values of ΔK have been aimed at, namely, 10 and 13.5 MPa√m. Measured average crack growth rates, da/dN have resulted as being 9 and 20 nm/cycle, respectively. Further fatigue crack growth brought to fast unstable final fracture. Metallographic and fractographic analyses were performed.

3. Results

An almost full pearlitic microstructure having been ascertained, low and high temperature fracture surfaces were examined (Figg. 2 and 3). The fatigue fracture surfaces (Fig. 4) shew striations on top of broken, previously necked, ferrite lamellae, thus proving the capability of the proposed model of being a valid tool in pearlitic steels fatigue failure analysis.

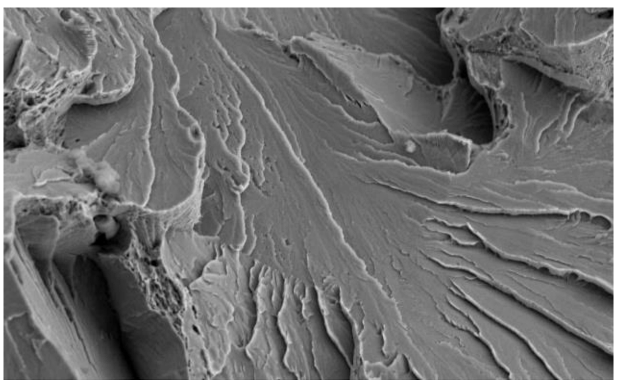

Fig. 2 - Charpy-V impact broken sample,20°C;5KX

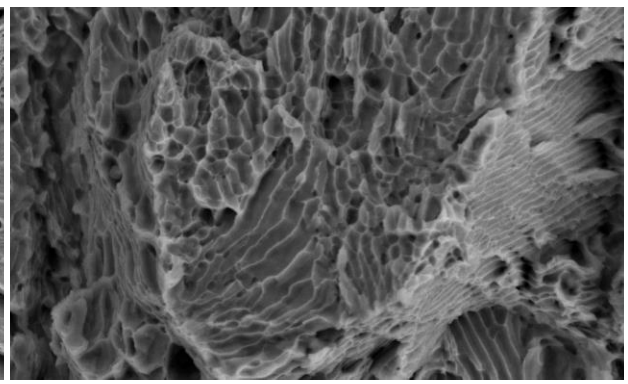

Fig. 3 - Charpy-V impact broken sample, 220°C;15KX

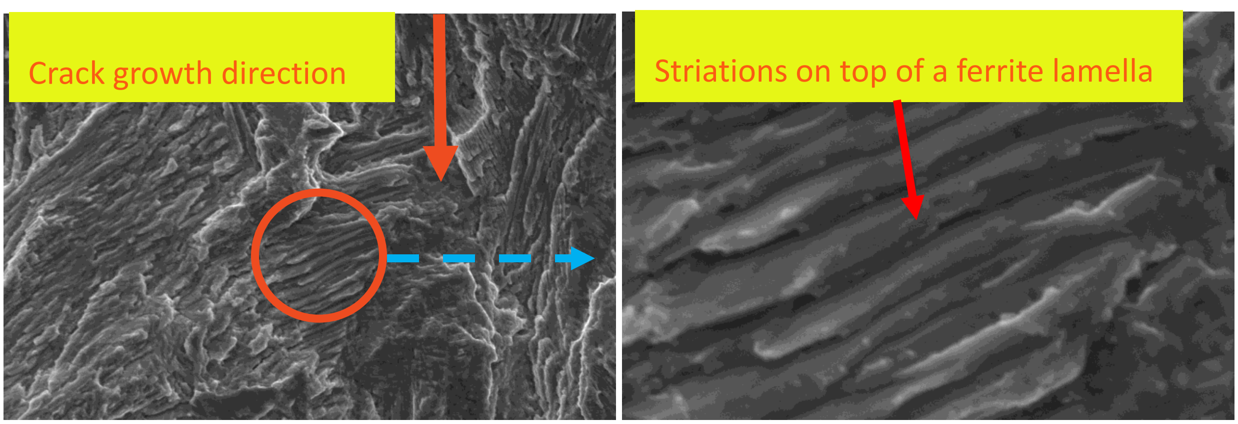

Fig. 4 - 20°C Fatigue fracture surfaces of a rail steel. da/dN = 8.0 nm/cycle; 5 and 25 KX;

By comparing the above reported fatigue surfaces with similar fractographs obtained on the overload portions of the same specimens, it was possible to pinpoint to the fine differences between the two types of fracture surfaces. The fractured surfaces of upper shelf AISI 1085 steel Charpy-V specimens have also been taken into account and found similar to those of upper shelf rail steel samples.

4. Conclusions

The developed methodology readily allows distinguishing between fatigue and overload fractures in rails and other high carbon steels components.