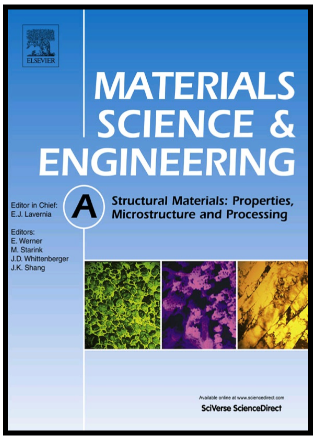

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Evaluation of local strength via microstructural quantification in a pearlitic rail steel deformed by simultaneous compression and torsion

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Abstract

Pearlitic steels are commonly used for railway rails because they combine good strength and wear properties. During service, the passage of trains results in large accumulation of shear strains in the surface layer of the rail, sometimes leading to crack initiation. Knowledge of the material properties versus the shear strain in this layer is therefore important for fatigue life predictions. In this study, fully pearlitic R260 rail steel was deformed using a bi-axial torsion-compression machine to reach different shear strains. Microstructural parameters including interlamellar spacing, thickness of ferrite and cementite lamellae and dislocation density in the ferrite lamellae, as well as hardness were quantitatively characterized at different shear strain levels. Based on the microstructural observations and the quantification of the microstructural parameters, the local flow stresses were estimated based on boundary strengthening and dislocation strengthening models. A good agreement was found between the estimated flow stresses and the flow stresses determined from microhardness measurements.

Keywords: Pearlitic rail steel, TEM, hardness, strengthening mechanisms, dislocation density

1. Introduction

The most common material type for manufacturing of rails nowadays are carbon steels with a predominantly pearlitic microstructure. Pearlite is a lamellar microstructure consisting of colonies of similarly oriented cementite lamellae embedded in a softer ferrite matrix. Steels with this microstructure exhibit a very good combination of wear and strength properties suitable for railway applications. In this paper the grade R260 is studied, which is one of the most common rail steel grades in Europe.

The surface layers of rails are subjected to very high rolling contact loads during their service life, which lead to large plastic deformation due to accumulation of large shear strains close to the running surface [1, 2]. These surface layers have typically position-dependent thickness from several micrometers to a few tens of millimeters and thus varying strain gradients, which limits the possibilities for a systematic study of the mechanical response of the layers. To understand the material behavior and enable large scale testing of the material, specimens with a fairly uniform microstructure within the test volume are required. If the microstructure observed in field including the gradient microstructure, could be recreated artificially in the lab, it would be possible to perform a thorough investigation of how the microstructure evolves with loads and of how the microstructure affects the mechanical properties.

To this end a method was developed to pre-deform test bars using a bi-axial test frame by combining compression and torsion, so that a sufficient strain level in the bars was achieved [3]. The comparison between the field samples and the test bars in the above study was performed by macroscopic 2D strain calculations such as the flow line method (see more details in [3]). However, the full picture such as the relationships among shear strain, microstructure, and strength, which can provide the baseline for the understanding of mechanical properties in the lab/field, is still unclear.

For the understanding of the mechanical properties such as flow stress/strength in deformed pearlitic steel [4-6] and other metals and alloys [7-9], microstructural characterization and quantification by scanning electron microscopy (SEM) and transmission electron microscopy (TEM) followed by computations of mechanical properties have been reported as powerful tools. A similar strategy will therefore be applied in the present study.

The main goal of the investigation is to characterize the artificially produced microstructure of pre-deformed test bars using SEM and TEM, to quantify the microstructural parameters such as interlamellar spacing (ILS), thickness of ferrite and cementite lamellae, and the dislocation density in the ferrite lamellae, and to correlate these parameters to the shear strains and the mechanical properties. The shear strains will be theoretically calculated at the different positions in the test bars from where the samples were extracted.

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