

# **Identification of behavior and damage mechanism in fatigue of ferrite-pearlite steel with microstructure gradient.**

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## **Points of interest.**

- The microstructure gradient of ferrite-pearlite in railway gears (i.e., wheels and axles) displays a continuous variation in constituent size and fraction.
- Cylindrical samples extracted from different regions of a railway wheel were mechanically tested to investigate the influence of microstructure heterogeneity.
- This study aims to investigate the effects of these gradients on fatigue life by developing an experimental method to observe strain localizations and microcrack initiation during cyclic loading.

## **1 Introduction.**

Railway components, such as axles and wheels, require careful consideration of steel grades and manufacturing processes to ensure fatigue resistance. Ferrite-pearlite or pearlite grade steels are commonly used, and their manufacturing processes involve heat treatments and severe plastic deformations during operations, leading to microstructural gradients [1, 2, 3] in areas that may be prone to fatigue. These gradients have been shown to confer superior mechanical properties, including high elastic limit, ductility, and surface resistance to fatigue cracks. Nonetheless, the mechanisms underlying the impact of these gradients on fatigue crack initiation and propagation remain unclear, except for the residual compressive stresses [4, 5] they induce. To enhance the accuracy of residual life prediction, maintenance operations, and microstructure optimization, it is necessary to gain a comprehensive understanding of the effects of these gradients. In this study, we carried out microstructural and mechanical characterization to obtain valuable insights into the behavior of ferrite-pearlite gradients. Our findings can contribute to the development of prediction models and improve fatigue life management practices.

## **2 Material and method.**

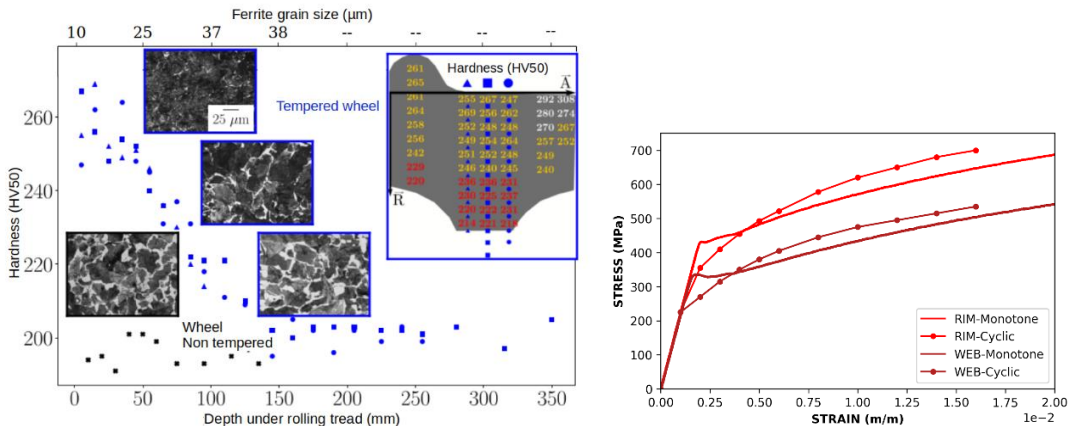
The ER7 alloy material from a railway wheel supplied by MG Valdunes was characterized, revealing its microstructure and composition. The wheel was made via press forging, with austenitization at 900°C, annealing at 500°C for 4 hours, and quenching via water spraying. The material has a ferrite-pearlite microstructure, with increasing ferrite grain size and ferrite surface fraction with depths (*Figure 1*). The microstructure is isotropic in the rim but anisotropic in the web, with banded microstructure in radial and circumferential directions of the wheel, and equiaxial in the axial direction. Interlamellar spacing, which decreases with depth below the wheel's tread, is also important, with finer spacing resulting in higher strength [6] in pearlite.

To address the issue of microstructure heterogeneity in ferrite-pearlite alloys and their potential impact on their mechanical behavior, a preliminary mechanical testing campaign was conducted on cylindrical samples extracted from different regions of a wheel, i.e. rim and web, with a radial orientation of the

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specimen's axis. The specimens subjected to monotonic tensile and cyclic hardening tests to assess variations in their mechanical properties had a gauge length of 35mm and a diameter of 8mm at gauge length. In the cyclic hardening tests, a strain-controlled loading protocol was employed, consisting of successive cyclic strain amplitude starting from 0.1% to 1.6% or failure. Each increment of strain was applied for 50 cycles, based on the number required to stabilize the load. The applied strain was monitored using an INSTRON clip-on extensometer with a gauge length of 25mm.



**Figure 1.** (a) Evolution of Microstructure and hardness with depth, (b) Monotonic and Cyclic stress-strain plot of RIM and WEB samples.

## 2 Results.

The results revealed that the Ultimate Tensile Strength and yield strength values were higher in the rim samples compared to web samples. Additionally, the pearlite content decreased with depth while interlamellar spacing increased (*Figure 1*). All samples exhibited Yield Point Elongation (YPE), with different characteristic lengths. YPE and plateau length were observed to decrease with depth due to the presence of a higher proportion of ferrite. Moreover, the cyclic hardening tests showed that all samples exhibited hardening after yielding (*Figure 1*), with the stabilized stress value decreasing with depth. Overall, the findings of this study provide valuable insights into the microstructure heterogeneity and mechanical behavior of ferrite-pearlite alloys. The investigation is anticipated to enhance the comprehension of material behavior and damage mechanisms under cyclic loading conditions.

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