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Machine Learning Structure-Property Model for Carbon Steels

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Carbon steels were historically widely used for steam pipes in petrochemical and power generating plants. The microstructure consists of alternative bands of ferrite and pearlite aligned with the rolling direction. During long-term service above 420°C the lamellar cementite structure either breaks up into spheriodite or converts into its thermodynamical stable phase, graphite, leading to a decrease in the mechanical properties.

Small-punch creep (SPC) rupture testing is currently used to evaluate the creep-rupture properties of steels used in the petrochemical and power generating industries. This study explores microstructure-property relationships for service-exposed carbon steels using machine learning (ML). The reduced order models can be used to rank the different microstructural features in terms of their importance on the SPC-test and potentially be used to prioritise/reduce SPC testing requirements.

An experimental dataset consisting of 120x3 steel microstructures and their associated SPC-rupture times was collected. *WeldCore*® a novel sampling and repair technique for in-situ sampling of high-pressure steam lines, turbines and related components was used to remove site specific plug samples for the investigation. The creep-rupture properties were evaluated using Small Punch Creep (SPC) testing. A 2 mm diameter ceramic ball is forced (296 N) into the steel disk (8 mm diameter and 0.5 mm thickness) at a temperature of 500 °C. The time-to-rupture was used as the target variable for this study.

Optical 2D micrographs were taken from the etched surfaces of the tested samples. These optical micrographs were segmented and quantified using various feature extraction methods including traditional image segmentation, 1- and 2-point statistics, and convolutional neural networks. The extracted microstructural features were then reduced using principle component analysis (PCA) and used as inputs for training various regression models using different ML techniques. The samples were then investigated using secondary electron imaging at a higher resolution to incorporate the finer pearlite sub-structures into the models.

The microstructurally based model can predict the SPC rupture time approaching the variability in the testing platform (Testing RMSE = 79 hours). The pearlite phase fraction, degree of spheriodisation, and pearlite banding were the most important microstructural features for predicting the SPC rupture times. This machine learning approach can be adapted to different material systems if sufficient microstructural and mechanical property data are available.

Apply to be considered for a student ; award (Yes / No)?

No

Level for award;(Hons, MSc, PhD, N/A)?

N/A

Primary authors: Dr WESTRAADT, Johan (Nelson Mandela University); Mrs WESTRAADT, Lindsay (Nelson Mandela University)

Presenter: Dr WESTRAADT, Johan (Nelson Mandela University)

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