Low cycle fatigue behavior and damage mechanisms of work-roll material

W. Zhang, C. Krempaszky, E. Werner

Abstract

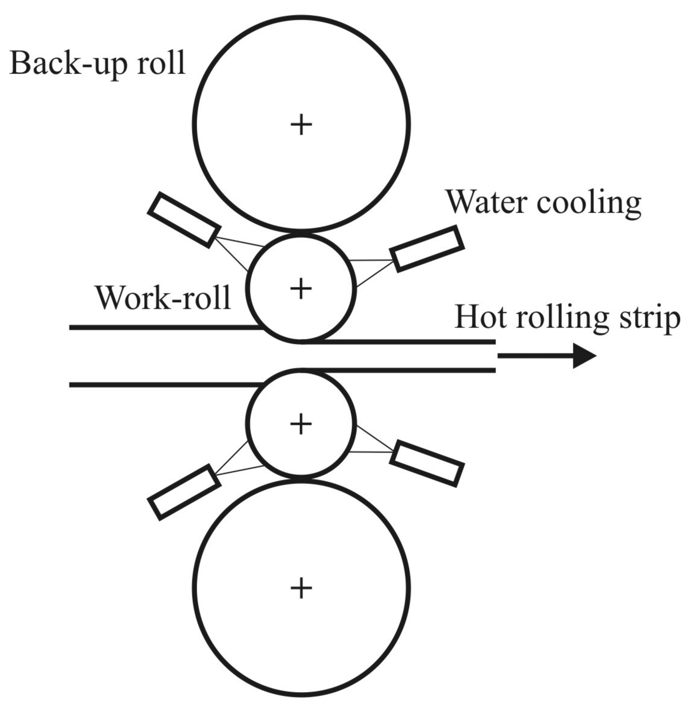
A special cyclic loading path with mixed load/displacement control modes is employed to simulate the thermo-mechanical behavior of the work-roll material used in hot rolling mills. The loading path is designed according to the characterization of the complex thermomechanical loads acting on the work-rolls by a semi-analytical thermomechanical modeling approach. A series of laboratory low cycle fatigue (LCF) tests was performed isothermally at room temperature on the high chromium iron samples taken directly from industry work-rolls. It is found that the maximum tensile stress at zero displacement of each individual cycle increases with cycle numbers. The LCF specimen fails due to the combination of accumulated damage and the increasing tensile stress. Based on these laboratory tests, the damage mechanisms and the critical thermomechanical loading conditions causing surface deterioration can be identified.

Hot rolling strip mill

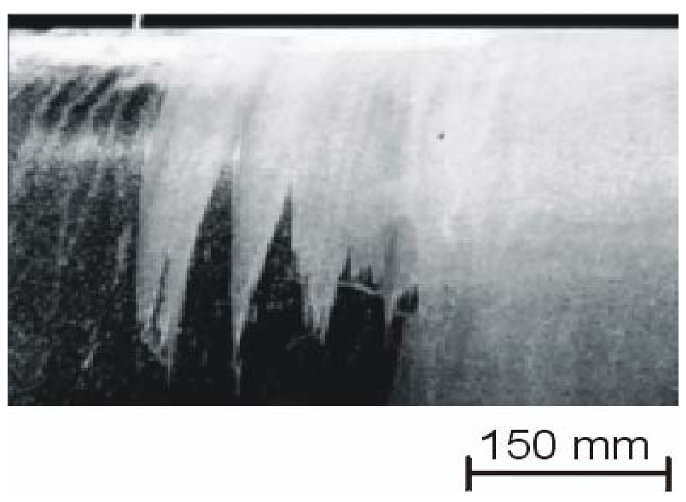
Background:

Surface deterioration of work-rolls determines their life-time and strongly influences the surface quality of the strip. The performance of the work-rolls depends on the coupling of several degradation phenomena: mechanical fatigue, wear, thermal fatigue, and oxidation etc.. It is demonstrated that thermal fatigue is the most critical factor affecting roll surface deterioration at the first stands in finishing train.

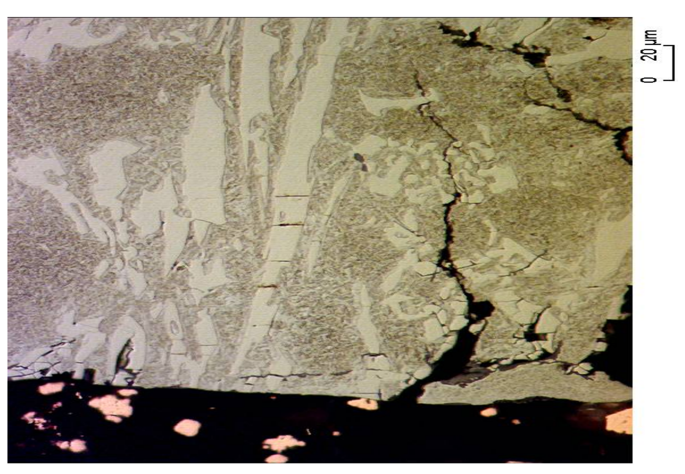
Rolling pass and the In situ observation:



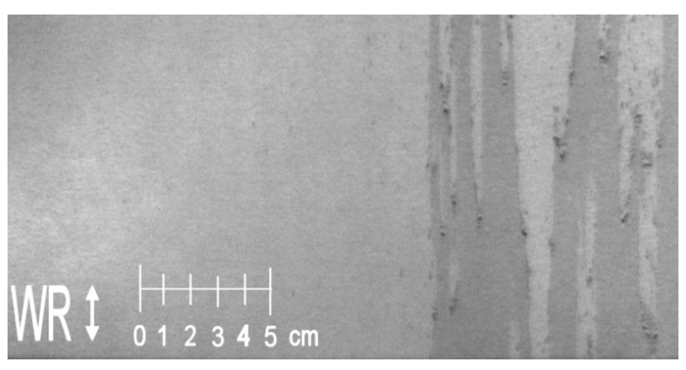
Schematic illustration of a rolling pass, where work-rolls subjected to complex cyclic thermo-mechanical loads



Surface deterioration of a used industry work-roll



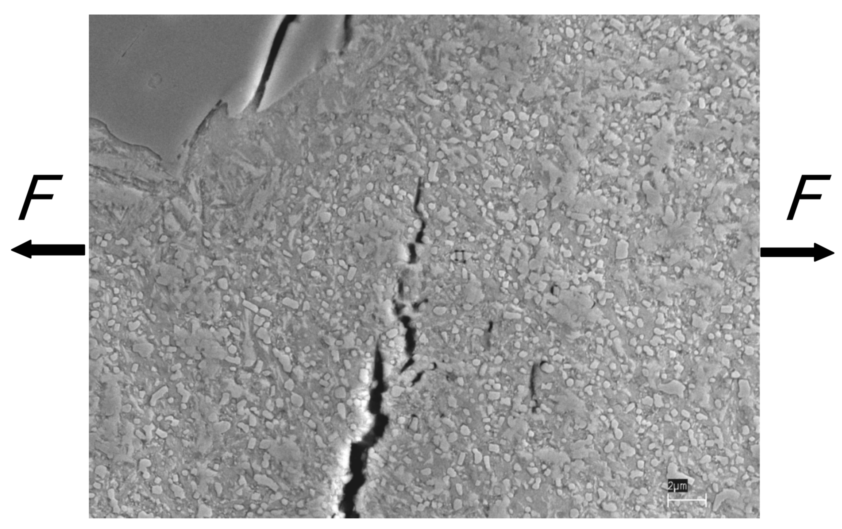
Optical micrograph taken near the surface of a used industry work-roll shows short cracks in carbides and long cracks in the martensitic matrix



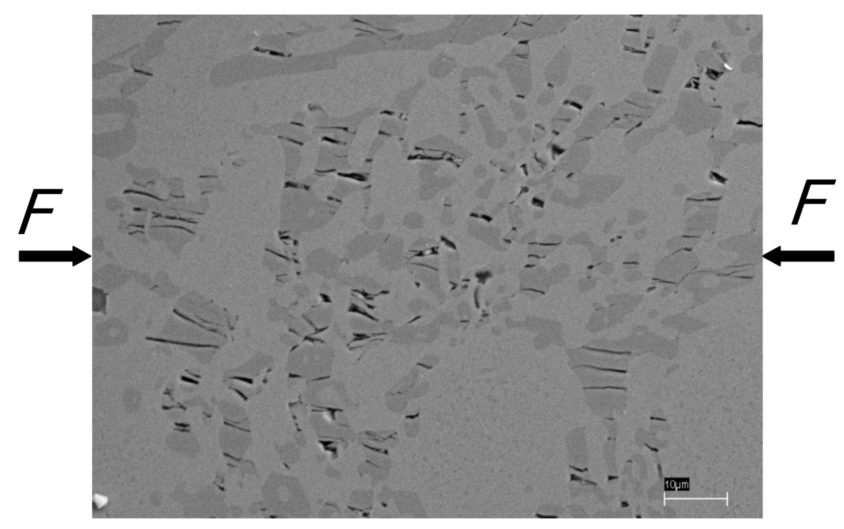
Hot rolled strip with defects (rolled-in scale) caused by oxide layer breaking and embedding

Experimental results

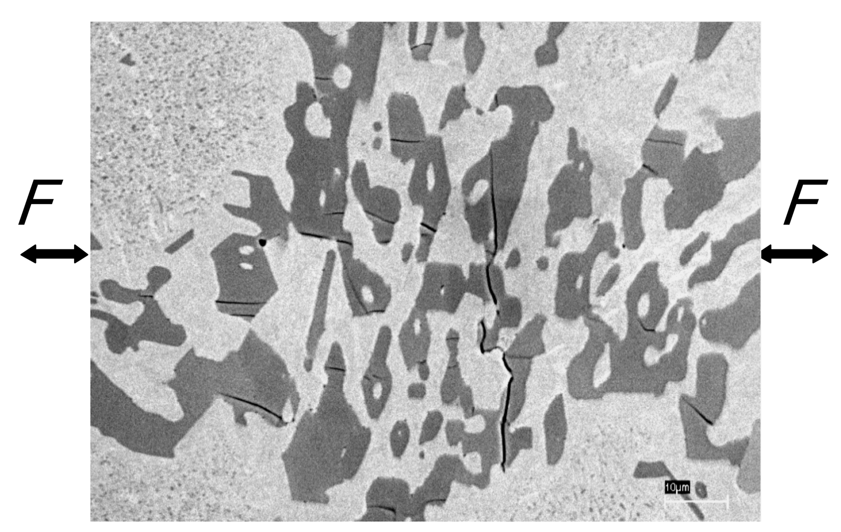
Microscale:



Monotonic tension: long cracks in the martensitic matrix perpendicular to the loading direction

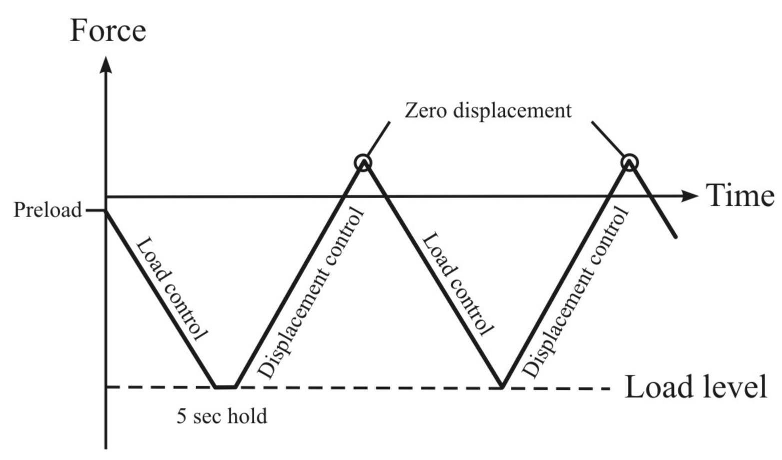


Monotonic compression: short cracks within the carbides parallel to the loading direction

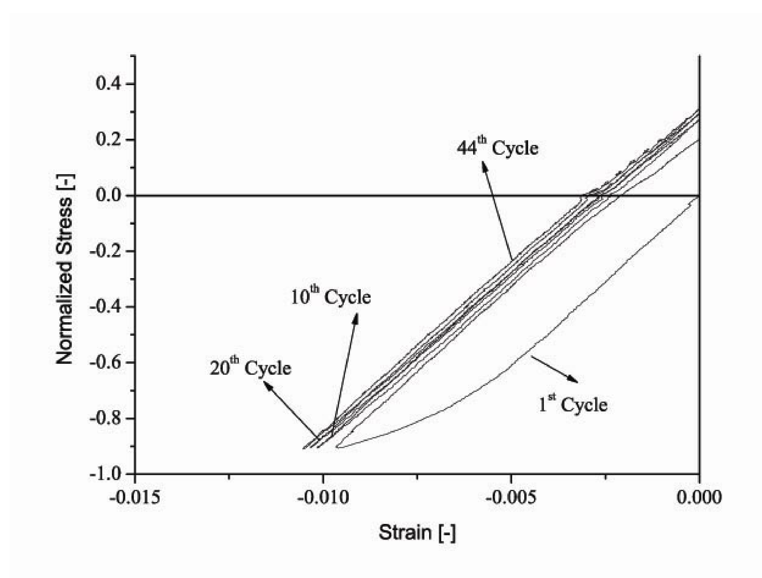


LCF specimen: long cracks perpendicular, short cracks parallel to the loading direction

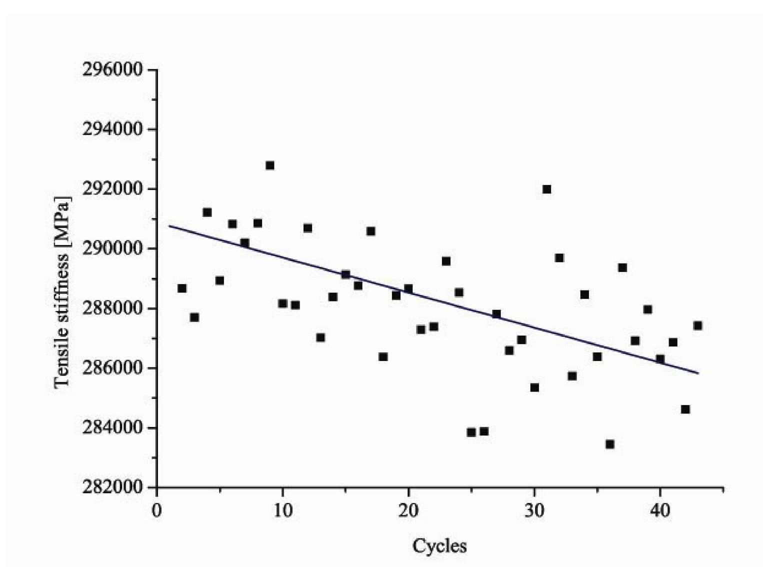
Macroscale:



A special LCF loading path with mixed load/displacement controlled modes, where the load level is chosen between the yield strength and the ultimate strength in compression



Cyclic stress-strain response in the LCF test



Overall tensile stiffness reduction during the test

Summary

Uniaxial tests are proposed to simulate the cyclic thermomechanical loading acting on the surface-near region of work-rolls. Analysis of the material response shows that the plastic deformation as well as the maximum tensile stress increase with the number of cycles. The decrease of the overall Young's modulus is 1.0% to 2.5% at the final failure stage. Fractographical analysis confirms that the governing damage mechanisms are adequately reproduced in the laboratory experiment.

Lehrstuhl für Werkstoffkunde und Werkstoffmechanik

MPA MASCHINENBAU TU MÜNCHEN
Materialprüfamt für den Maschinenbau

Christian Doppler Laboratorium für Werkstoffmechanik von Hochleistungslegierungen