This research work was carried out in cooperation between the Metals Technology Group at Tampere University and the Institute of Iron and Steel Technology at Technische Universität Bergakademie Freiberg, Germany.

Quenching and partitioning: A novel process to improve the cavitation erosion resistance of AISI 420 stainless steel

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Abstract

Stainless steels are commonly used in hydraulic components where they may be susceptible to cavitation erosion. In this study the cavitation erosion resistance of AISI 420-type stainless steel is examined after novel quenching and partitioning (Q&P) heat treatment. Q&P-samples were prepared with varying heat treatment parameters, while reference samples were prepared with quenching and tempering and quenching without partitioning. The samples were eroded for 6 h with an ultrasonic cavitation erosion device, and their mass losses were measured. The mass losses were then compared to the measured hardness and retained austenite fractions of the samples. To evaluate the damage mechanisms, the eroded areas were examined with scanning electron microscopy and optical profilometry.

Q&P Heat Treatment

Quenching and Partitioning is a heat treatment process in which the steel is first austenitized and then quenched between the martensite start and finish temperatures. The temperature is then raised to enable carbon partition to the austenite phase, resulting in presence of retained austenite at room temperature. The resulting retained austenite fraction is dependent on the initial quenching temperature.

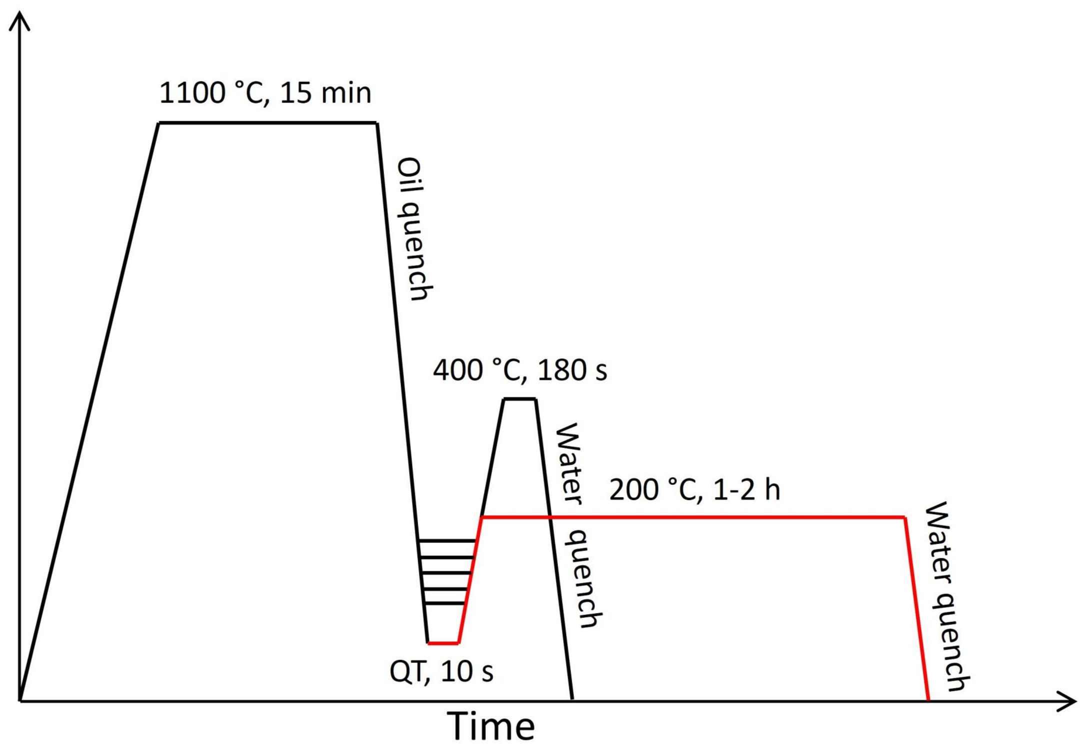
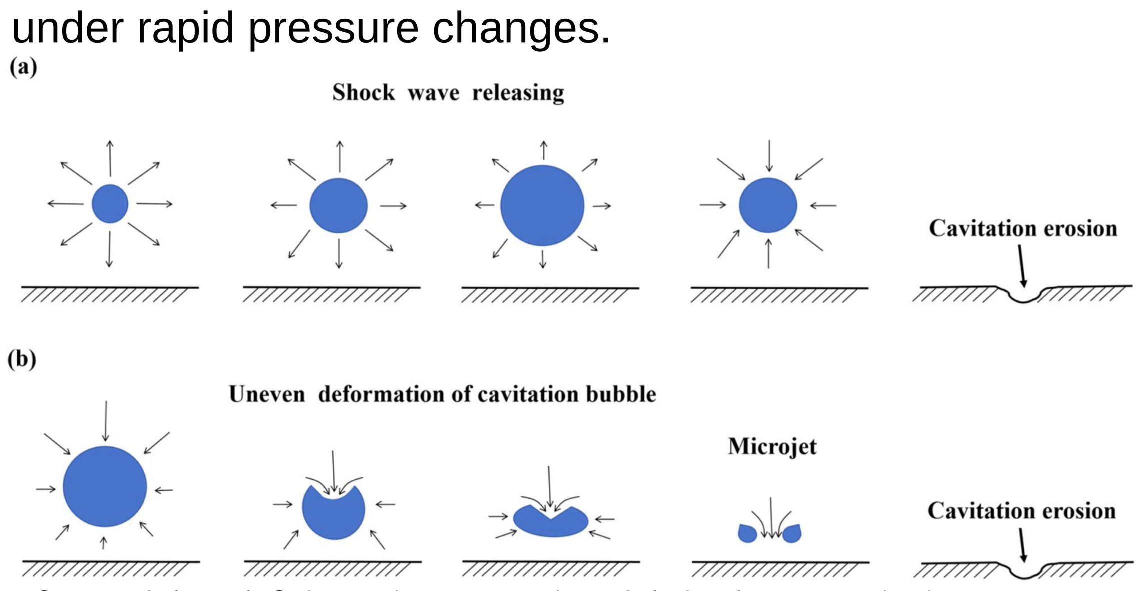


Fig. Illustration of the used heat treatment parameters. Tempering is highlighted in red color.

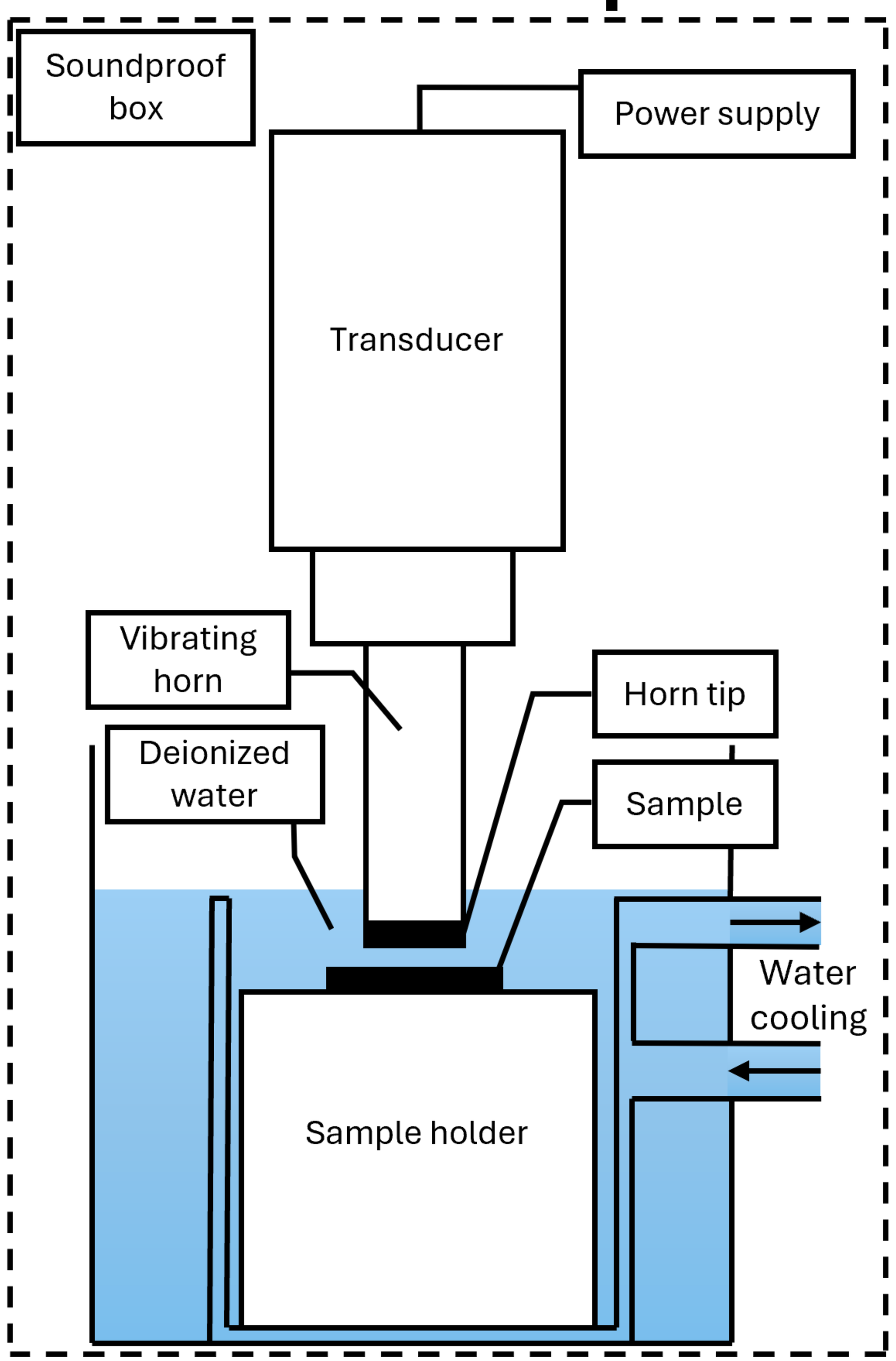
Cavitation erosion

Cavitation erosion is a form of impact fatigue caused by the formation and collapse of vapor bubbles in a fluid under rapid pressure changes.



Gao et al. (2024): Schematic presentation of a) shock wave cavitation and b) microjet cavitation. DOI: 10.3390/ma17051007

Test Setup



Results

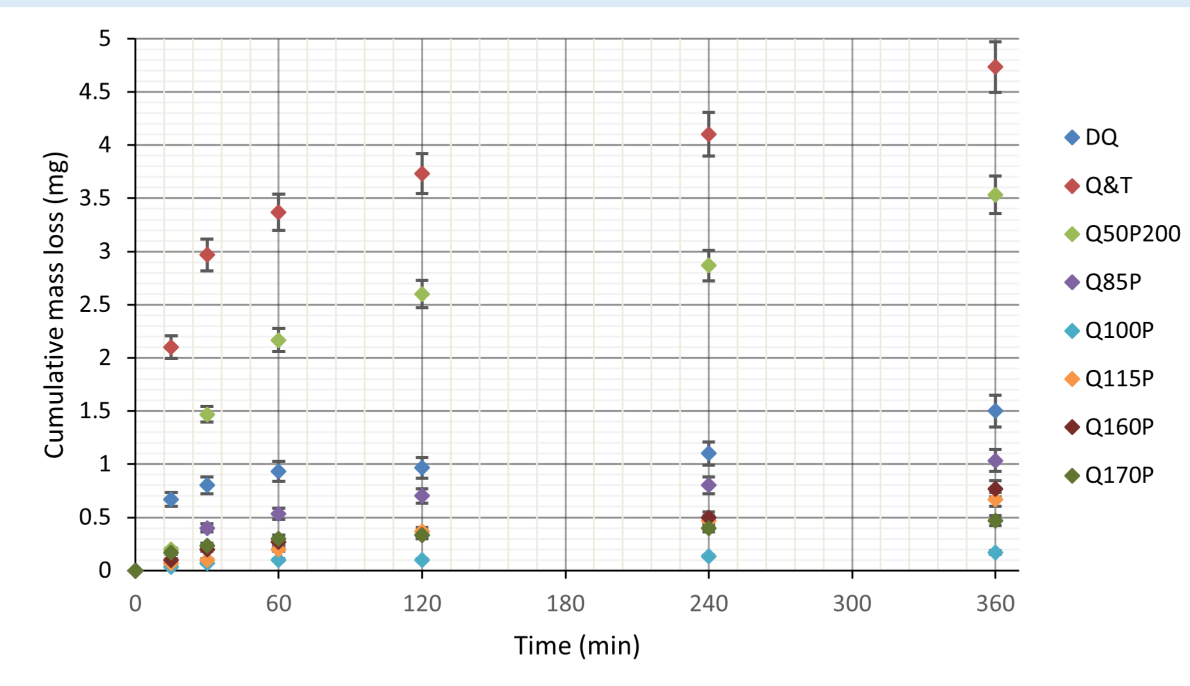


Fig. Cumulative measured mass losses of the eroded samples as a function of time.

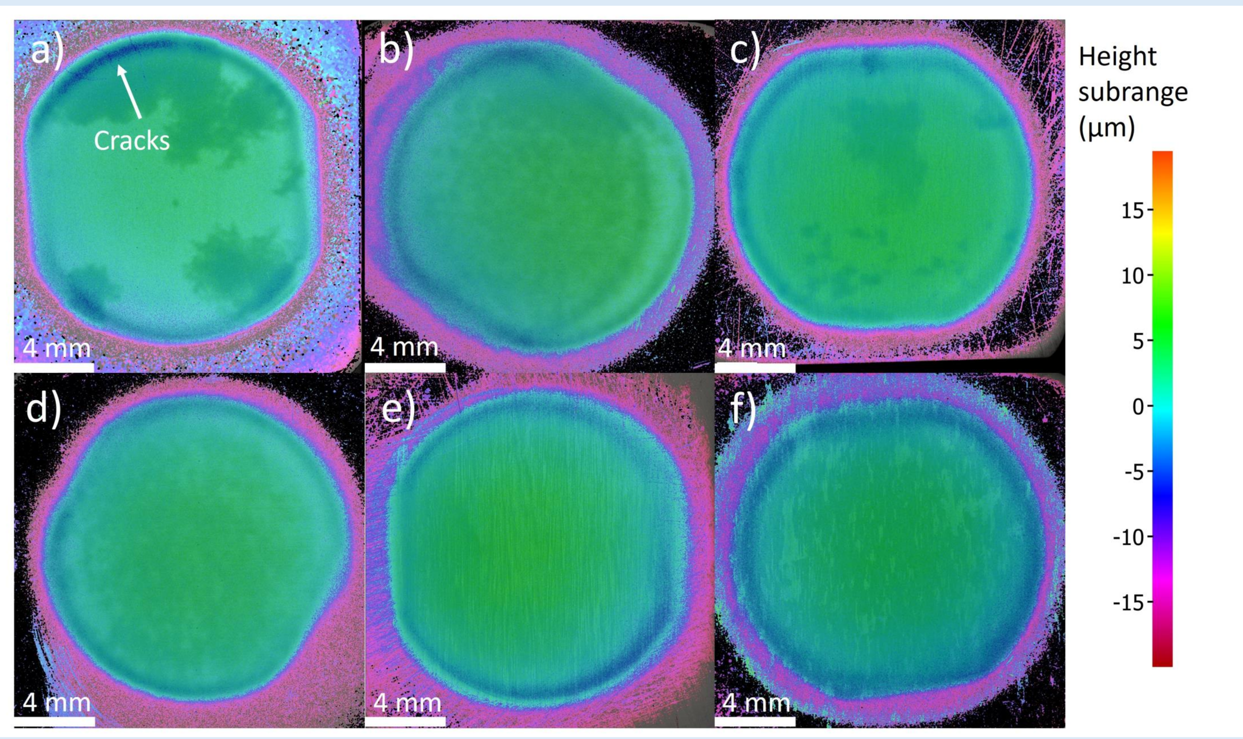


Fig. Optical profilometry of samples after 6 h of cavitation a) DQ, b) Q85P, c) Q100P, d) Q170P, e) Q50P200, and f) Q&T.

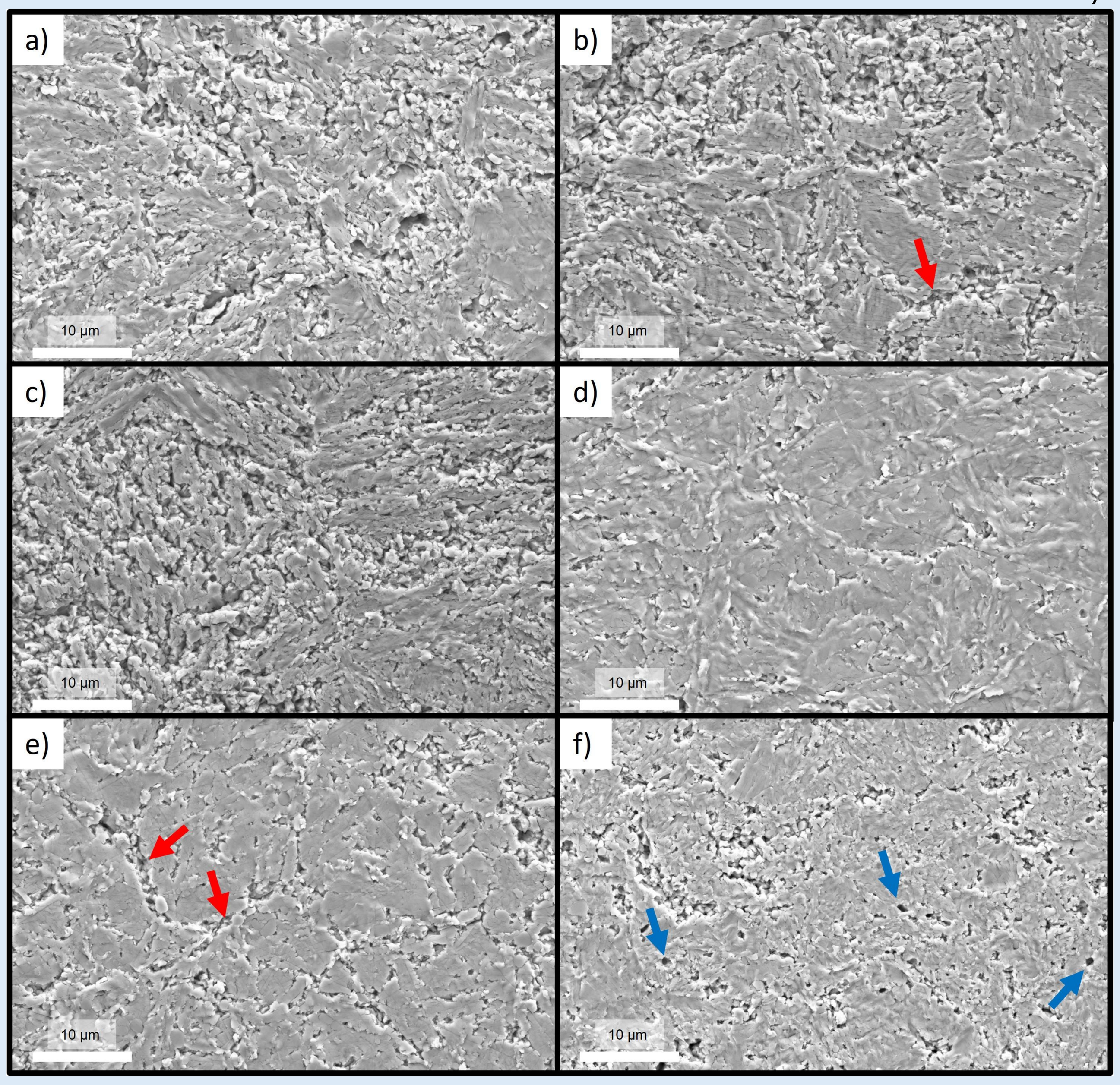


Fig. Eroded surfaces in SEM after 6 h of cavitation a) DQ, b) Q50P200, c) Q&T, d) Q100P low wear, e) Q100P high wear, and f) Q170P.

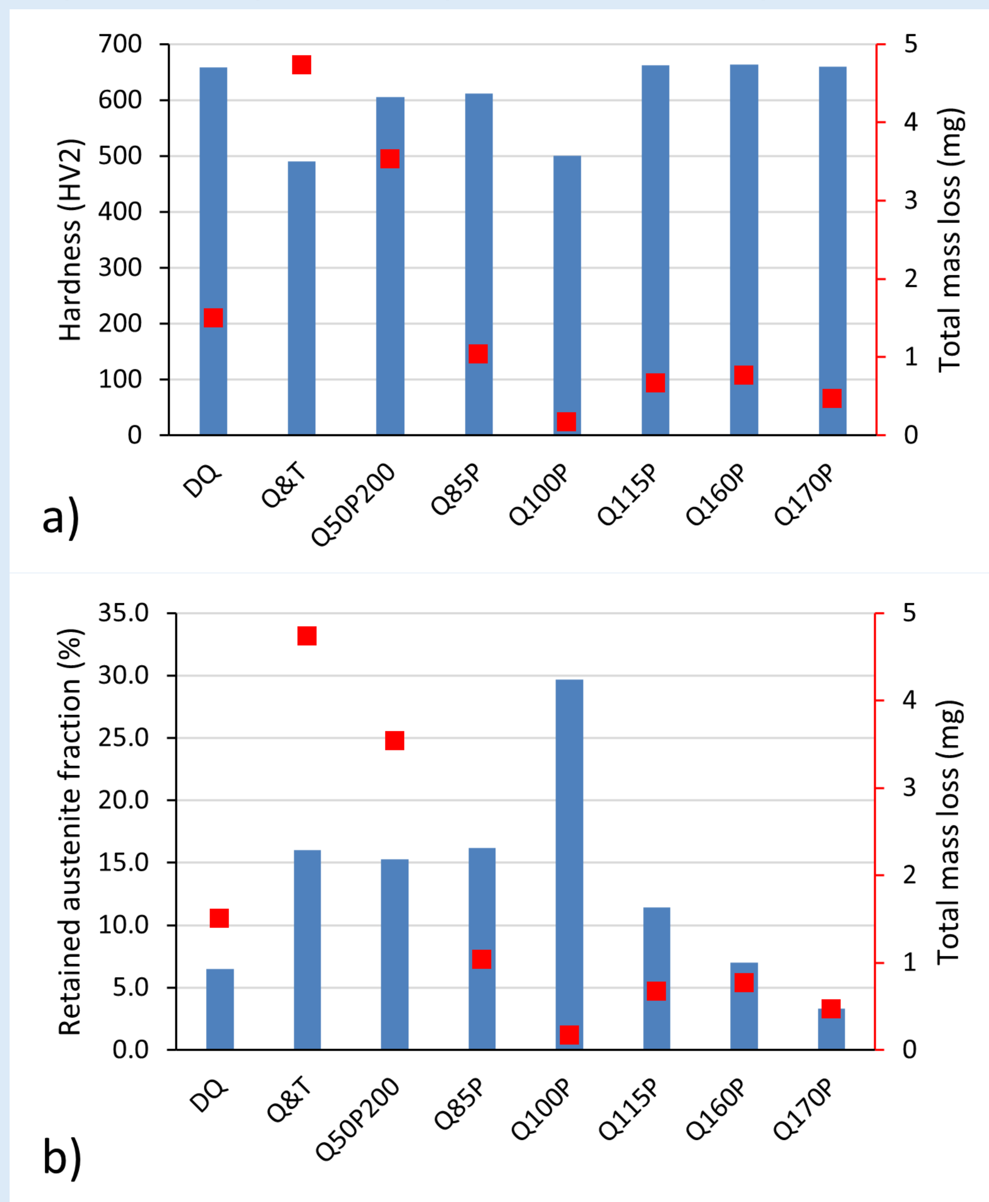


Fig. Correlation between the measured mass losses and a) hardness and b) retained austenite fraction.

Discussion

The measured mass losses were relatively low for all samples, indicating that the acceleration stage may not have been reached within the 6 hours of cavitation. Further research is needed to understand the long-term cavitation erosion mechanisms.

Based on the SEM micrographs the cavitation erosion damage initiates and propagates at the grain boundaries. In samples with low partitioning or tempering temperature the erosion has proceeded into the grains, resulting in increased mass losses.

Optical profilometry shows that the eroded surfaces have expanded in volume resulting in increased surface height. This expansion is caused by strain induced martensitic transformation, which results in expansion of the lattice. The resulting compressive internal stresses hinder the propagation of grain boundary fractures, which increases the cavitation erosion resistance.

Although increasing the hardness of the steel generally enhances the cavitation erosion resistance, the presence of retained austenite is also favorable due to TRIP-mechanism. As austenite is transformed into martensite during cavitation erosion, the surface hardness increases while cavitation damage is absorbed by the phase transformation.

Conclusions

- Q&P-treatment enhances the cavitation erosion resistance of the steel compared to conventional quenching and tempering.
- Cavitation erosion resistance depends on the hardness and retained austenite fraction of the steel.
- Cavitation damage initiates at grain boundaries and advances to the grains.
- High retained austenite fraction is favorable as strain induced martensitic transformation absorbs cavitation damage and hinders propagation of grain boundary cracks.

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