Assessment of hydrogen-induced cracking (HIC) susceptibility of V micro-alloyed wire rod steel with different heat treatments

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Abstract

Different quenching and tempering heat treatments were applied on a vanadium micro-alloyed wire rod steel, to reach a tensile strength (Rm) of min. 1400 MPa for enhanced high strength screw production. SEM and TEM microstructural analyses showed high density of two precipitate types, i.e. needle-shaped M_3C and vanadium rich, globular MX. MatCalc simulations were performed for calculating the precipitation kinetics, the size, number density and phase fraction. The validation showed good agreement in the case of M_3C, while the size of MX is underestimated by MatCalc. To evaluate the relative susceptibility against HIC, notched tensile specimens were charged with hydrogen (H) by cathodic polarization at -1.1V vs. Ag/AgCl electrode in an electrochemical cell containing a 3.5% NaCl - 0.1% thiourea solution during the Incremental Step Load Test according to ASTM 1624-12.

Introduction

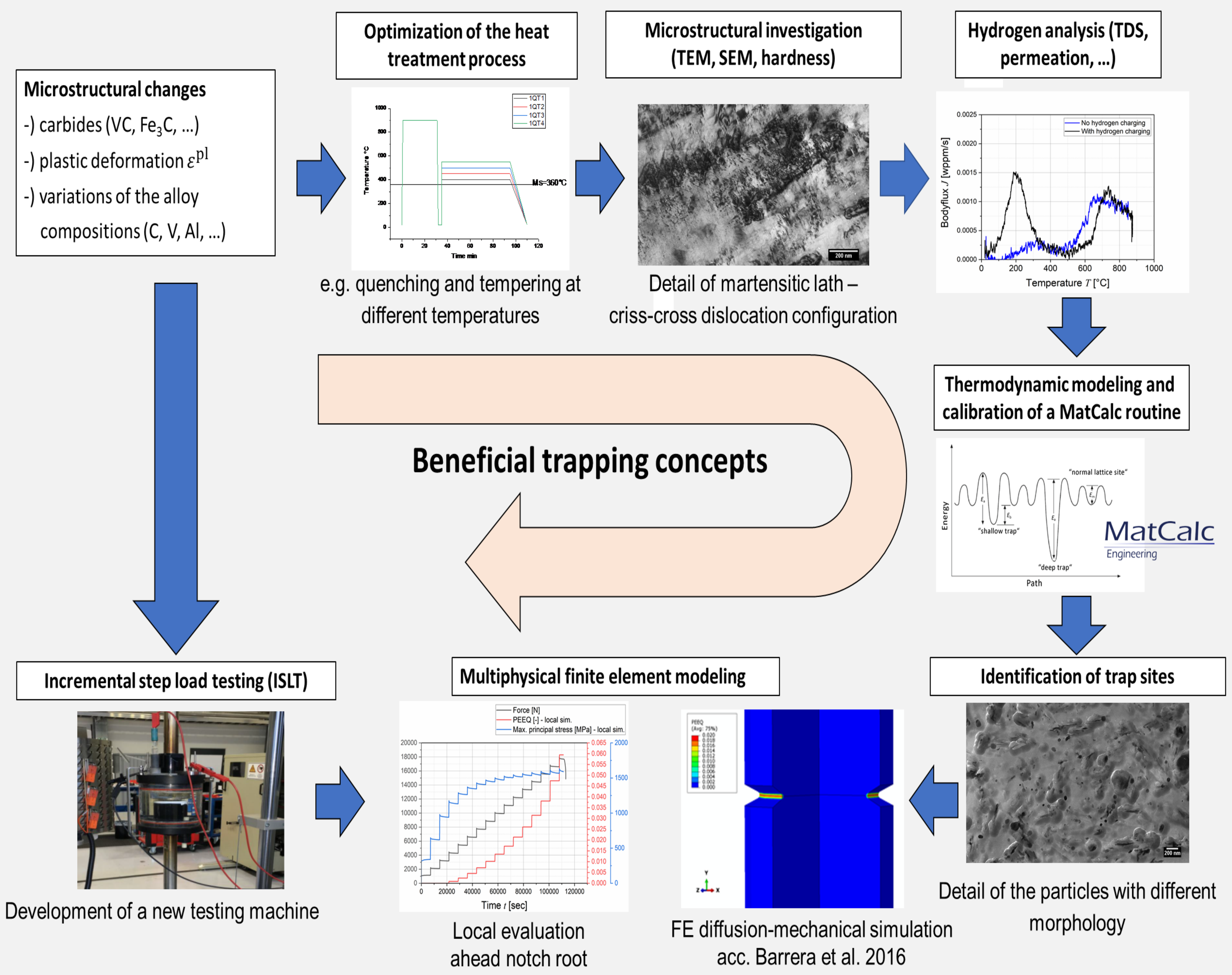
Ultra-high strength steels (UHSS) of a tensile strength higher than 1400 MPa are the current choice to manufacture fasteners and other components in automobile industries [1]. The main advantage of using UHSS is the ability to reduce the fastener diameter for downsizing, which is a continuing trend for mobility industries to improve fuel efficiency and environmental friendliness [2]. However, the UHSS structural integrity is at risk due to premature failures caused by HIC during operation, as the uptake of atomic hydrogen even in a few ppm from the environment could cause unpredictable fractures [3].

The materials HIC susceptibility is determined by microstructural features, like grain size, phases, dislocations, precipitates, inclusions etc., which control the H diffusion to stress concentrated areas [4]. Several studies report the important role of the fine dispersed (V-Mo-Cr-Nb) carbides throughout the microstructure, which provides both H trapping and strengthening by grain refinement [5]. Due to the increase of the HIC susceptibility with the strength, strength class 10.9 (R_m≈1000MPa minimum and $R_{p0,2}$≈0,9*R_m) is considered as the critical strength of fasteners below which the susceptibility is acceptable [3].

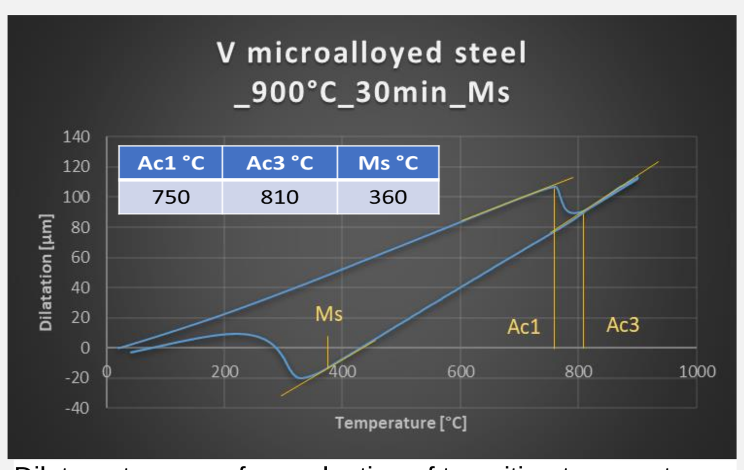
Aim of the current work

- Evaluation of the HIC susceptibility of V micro-alloyed UHSS steel in using the Incremental Step Load Tensile Test (ISLT).
- Alloy modifications and microstructural optimization for different heat treatments by MatCalc simulation and LOM/SEM/TEM analyses.
- Test of electrochemical parameters on H-loading and corrosion mechanisms
- Effect of H content and H trapping energies on HIC

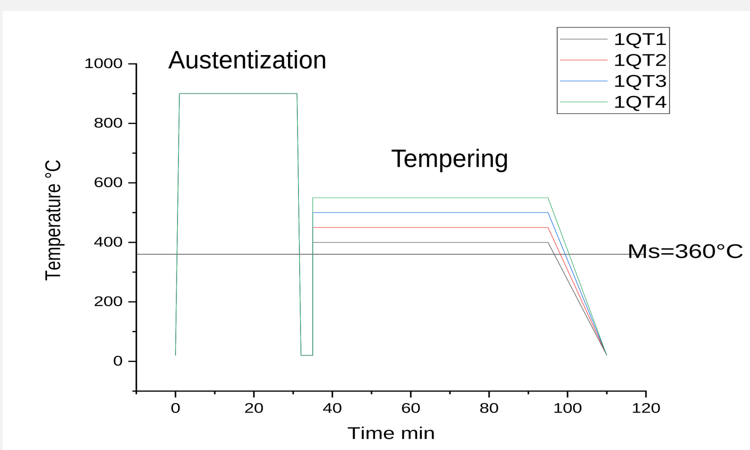
Methodological approach



Heat treatments

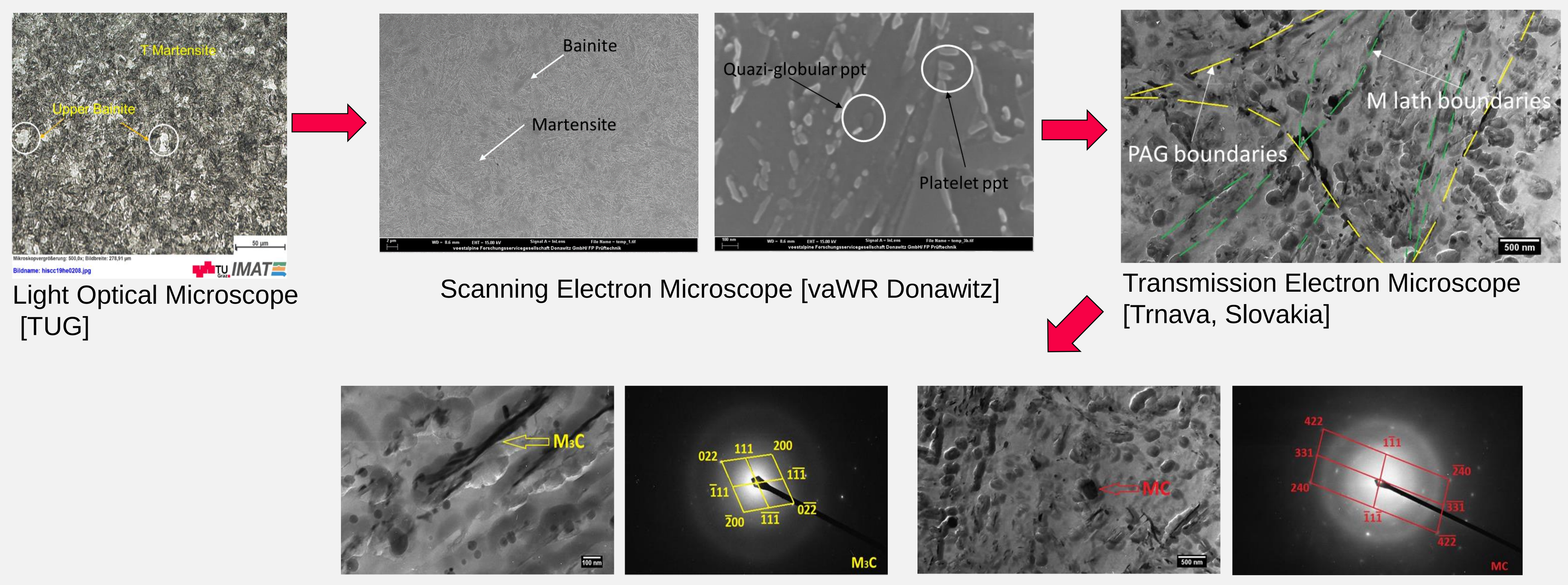


Dilatometer curve for evaluation of transition temperatures



Applied heat treatments - quenching and tempering.

Microstructure characterization



Light Optical Microscope [TUG]

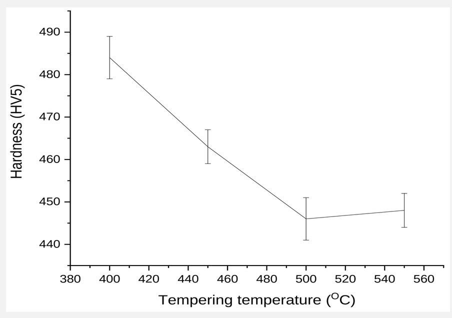
Scanning Electron Microscope [vaWR Donawitz]

Transmission Electron Microscope [Trnava, Slovakia]

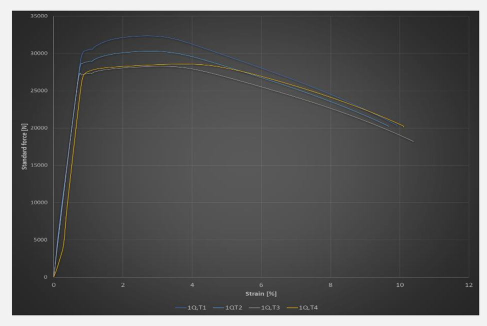
M3C platelet and diffraction pattern

Globular MC and diffraction pattern

Mechanical testing

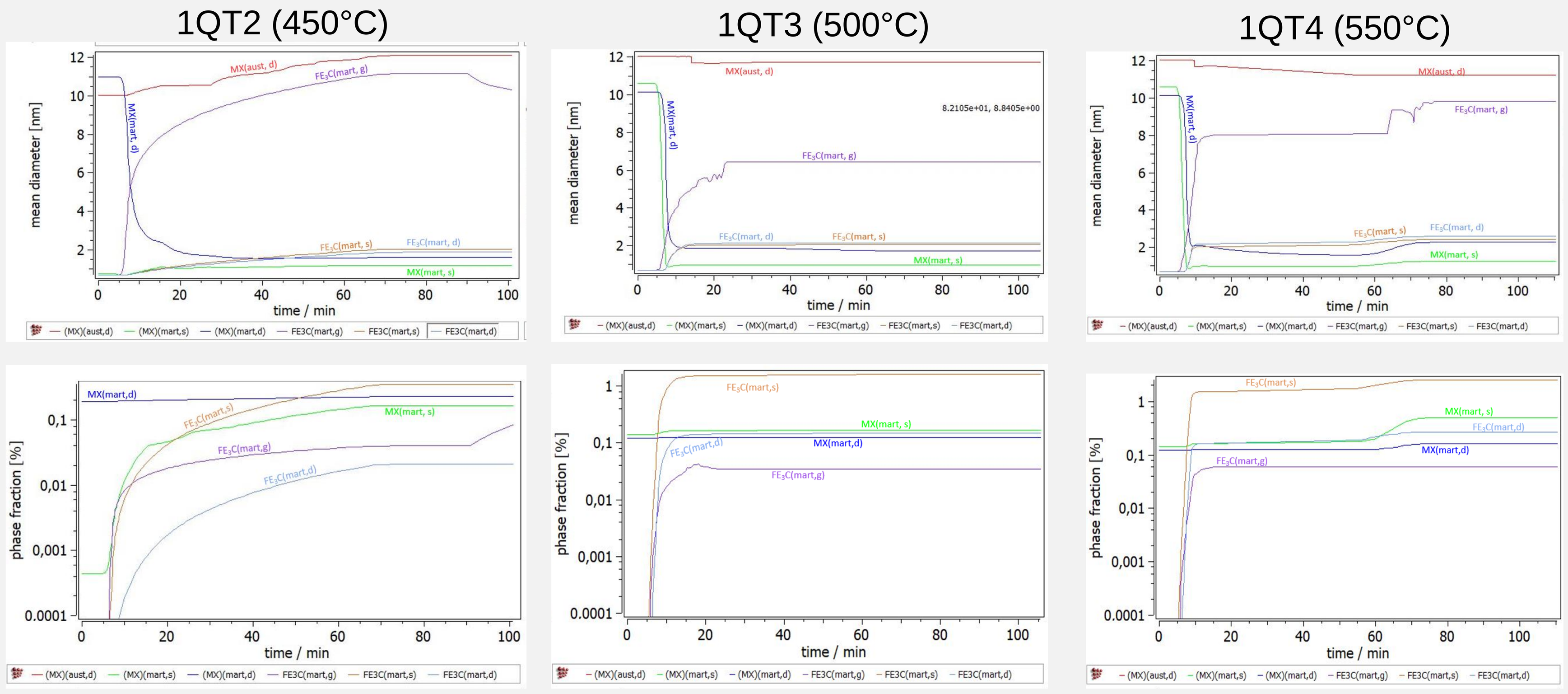


Heat treatment	Hardness HV5	Rm (MPa)	R_{p02} (MPa)	R_{p02}/Rm (%)
1QT1	484 ±5	1647	1548	94
1QT2	463 ±4	1561	1476	95
1QT3	446 ±5	1439	1387	96
1QT4	448 ±4	1454	1440	99



Tempering temperature dependent mechanical values / hardness, yield & tensile strength and strain

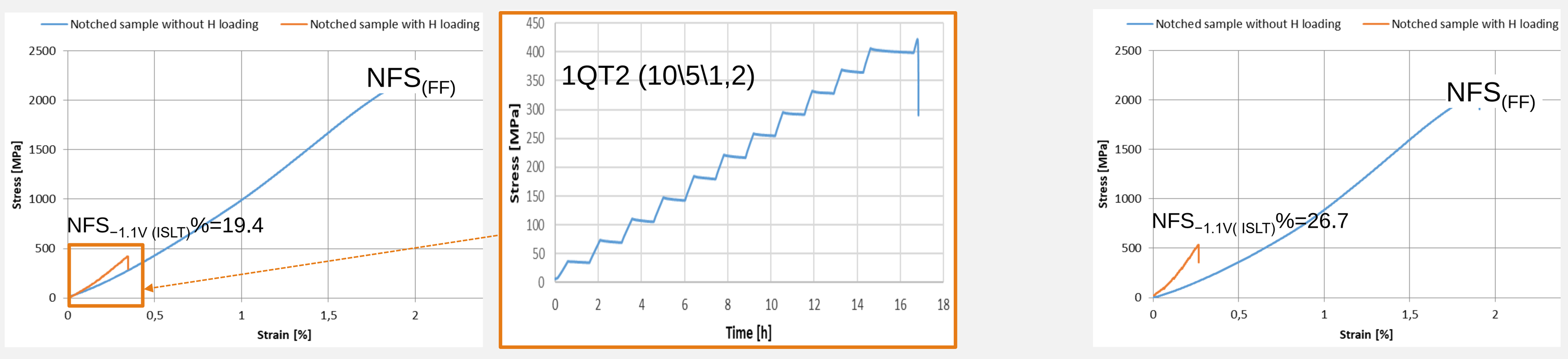
MatCalc simulation



Time development of mean diameter and phase fraction of precipitates for different tempering temperatures

Incremental Step Load Test (ISLT)

For ISLT according to ASTM F1624-12 [6], a special electrochemical cell was built to be used with a potentiostat for cathodic H charging. The time and loading increment dependent HIC susceptibility is expressed by relative notch fracture strength at an imposed potential of -1.10V ($NFS_{-1.1V\ (ISLT)}$) divided by the fast fracture load in the air ($NFS_{(FF)}$). Specimens are tested at progressively decreased loading rates, until the threshold stress at which no HIC occurs, is determined.



Stress strain curves for notched tensile samples 1QT2 (left, with ISLT parameters) and 1QT3 (right) with and without H charging

$$\text{Notched Fracture Strength } NFS_{-1.1V}\% = \frac{NFS_{-1.1V\ (ISLT)}}{NFS_{\ (FF)}} * 100 \ldots [1]$$

Results summary

Different heat treatments were done for V micro-alloyed steel to investigate its influence on the HIC susceptibility. The gained microstructure was characterized by using LOM, SEM, and TEM and consisted of tempered martensite with intensive precipitations of needle-shaped M_3C and globular MX. EDX analyses showed that M_3C has a high content of Fe, whereas MX has a high content of V. The results of MatCalc simulation are in good agreement with TEM results in the case of M_3C, while the size of the MX was underestimated by MatCalc, where we still need further analysis (TEM resolution limit). The phase fraction of Fe_3C (cementite) increases by a factor of about 10 with raise of tempering temperature from 450 to 500°C but does no increase further when raising to 550°C and no change in the phase fraction of MX was found. The results of ISLT showed an improved HIC susceptibility of the sample which was tempered at the higher temperature 1QT3.

References

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