Improved Wear Resistance of Martensitic Stainless Steel

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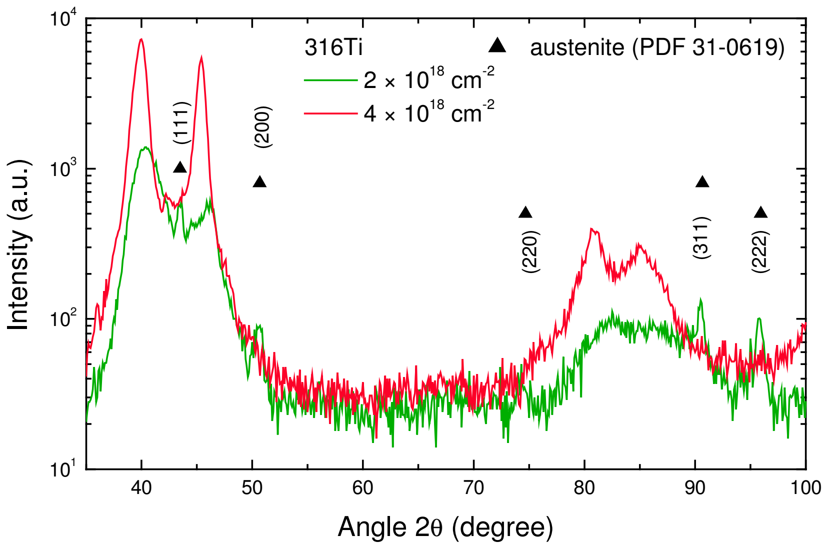
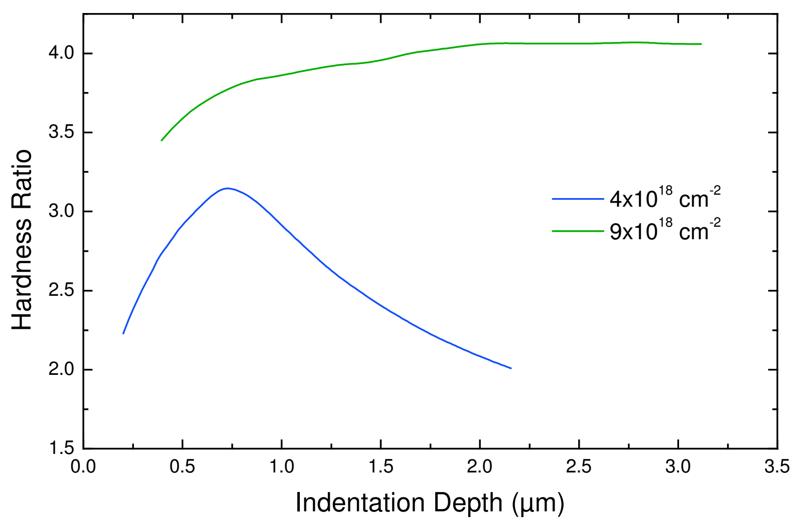
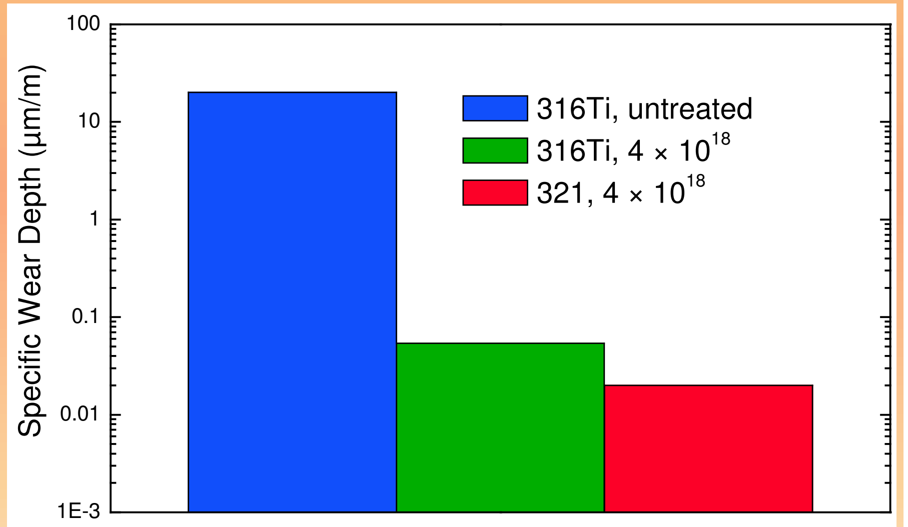
Motivation

Austenitic Stainless Steel





- Formation of expanded austenite characterised by anisotropic lattice expansion and concentration dependent diffusion coefficient.
- Hardness increases to 1000 - 1200 HV after nitrogen insertion (PIII, low energy implantion or plasma nitriding).
- Large wear reduction of 2 - 3 orders of magnitude.



Martensitic Steel

Very good wear resistance

Moderately good corrosion resistance

Applications

Turbine blades, tools, knives

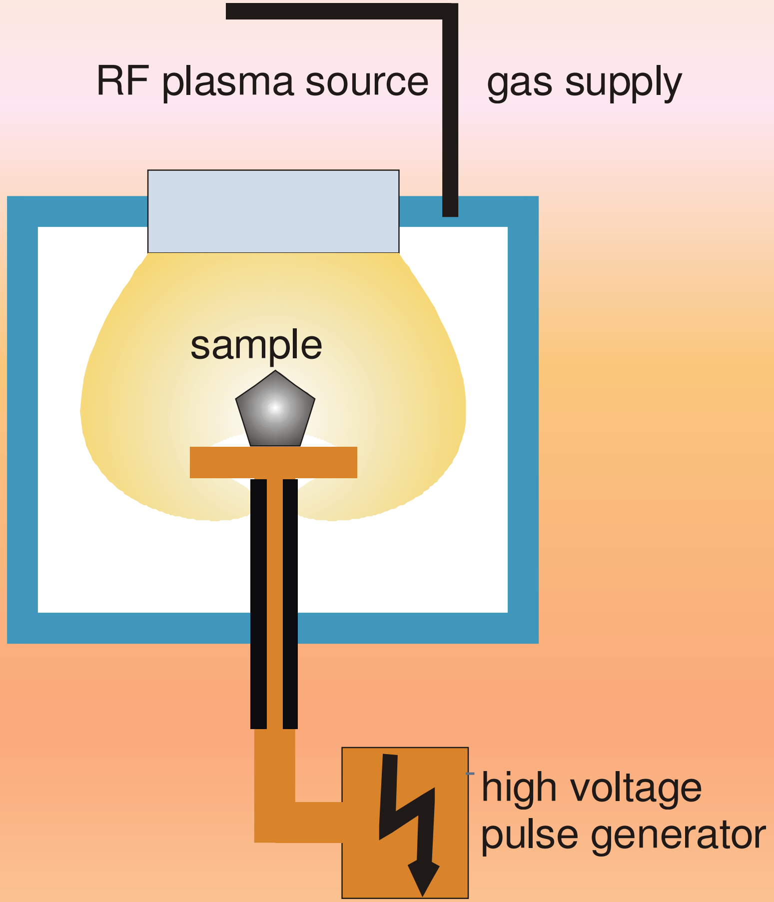
Bearings, structural aircraft parts

Orthopaedic surgery, bone saws

Dental surgery

***Possibility of hardening with energetic nitrogen implantation*?**

Experiment



PIII into martensitic stainless steel

1.4542 (X5CrNiCuNb17.4), 1.4021 (X20Cr13),1.4034 (X46Cr13), 1.4057 (X20CrNi17.2), 1.4104(X12CrMoS17)

Pulse voltage 10 and 25 kV,

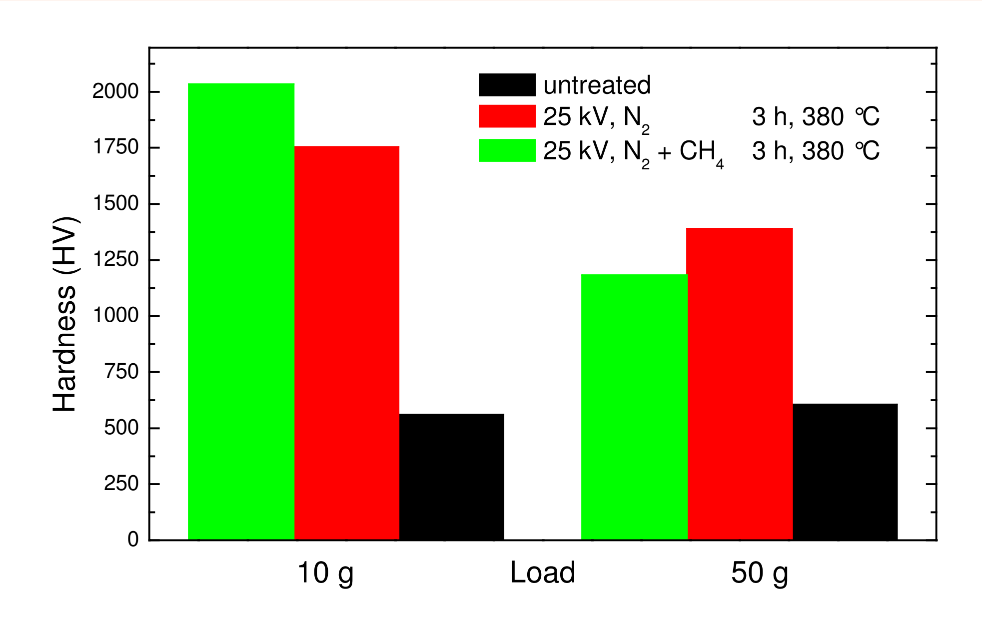
Nitrogen or nitrogen/methane atmosphere

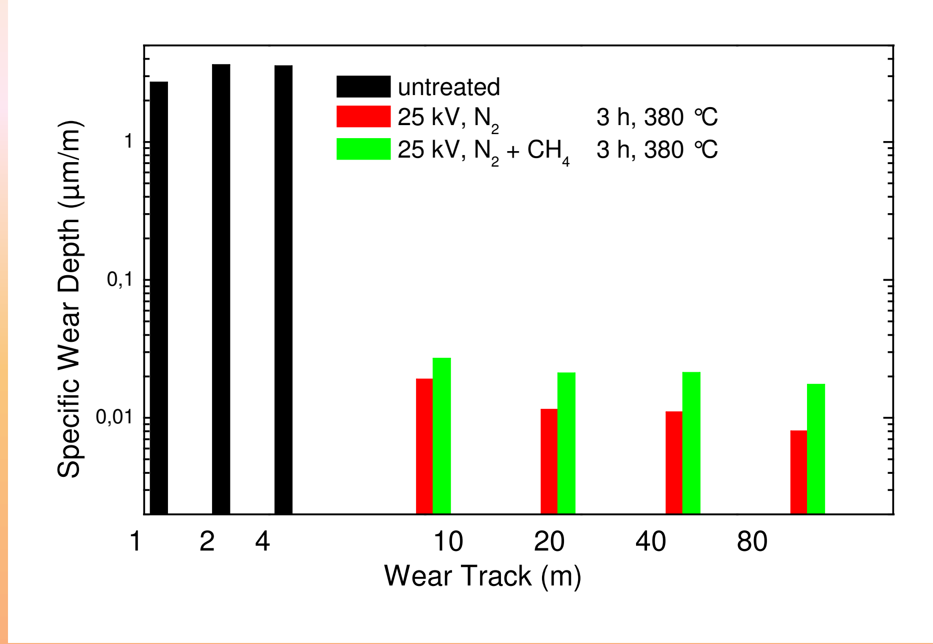
380 ℃°, 1 - 6 h implantation time.

Analysis: XRD + glow discharge optical spectroscopy (GDOS).

Hardness measurements, wear resistance measurements

Martensitic Steel Grade 1.4542





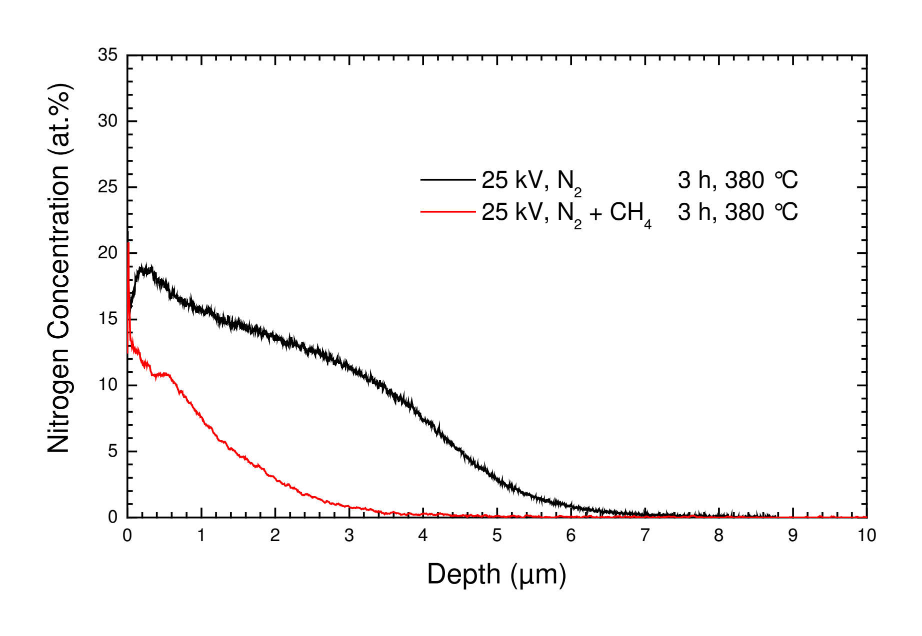
No hardness variation with load for non-implanted sample

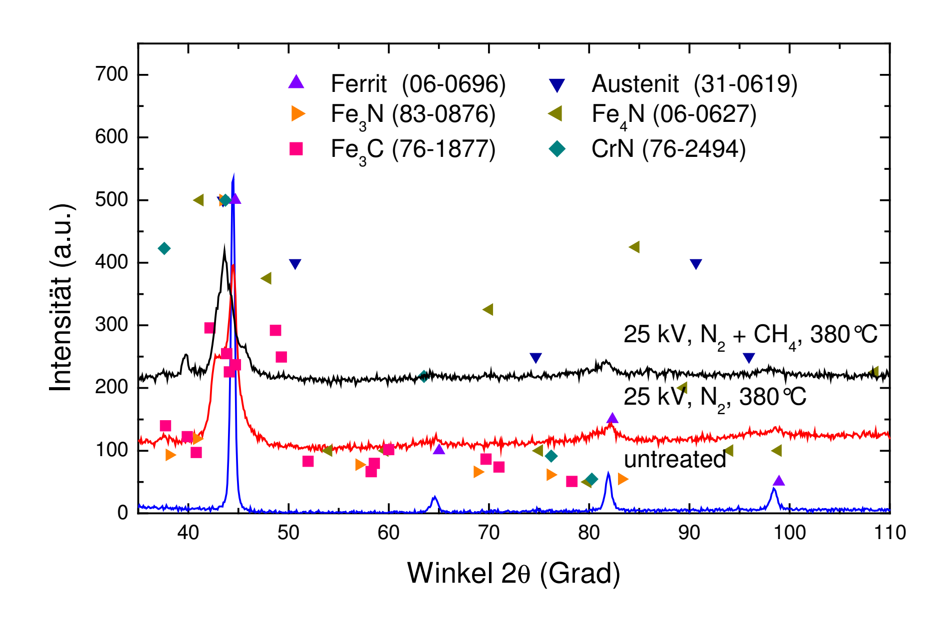
Increased hardness up to 2000 HV, significantly decreasing for higher load, thus indicating a layered system

Highly reduced wear by two orders of magnitude (contact pressure 1.0 GPa, low speed)

No breakthrough through layer even up to 80 or 400 m wear track length

Martensite Steel Grade 1.4542





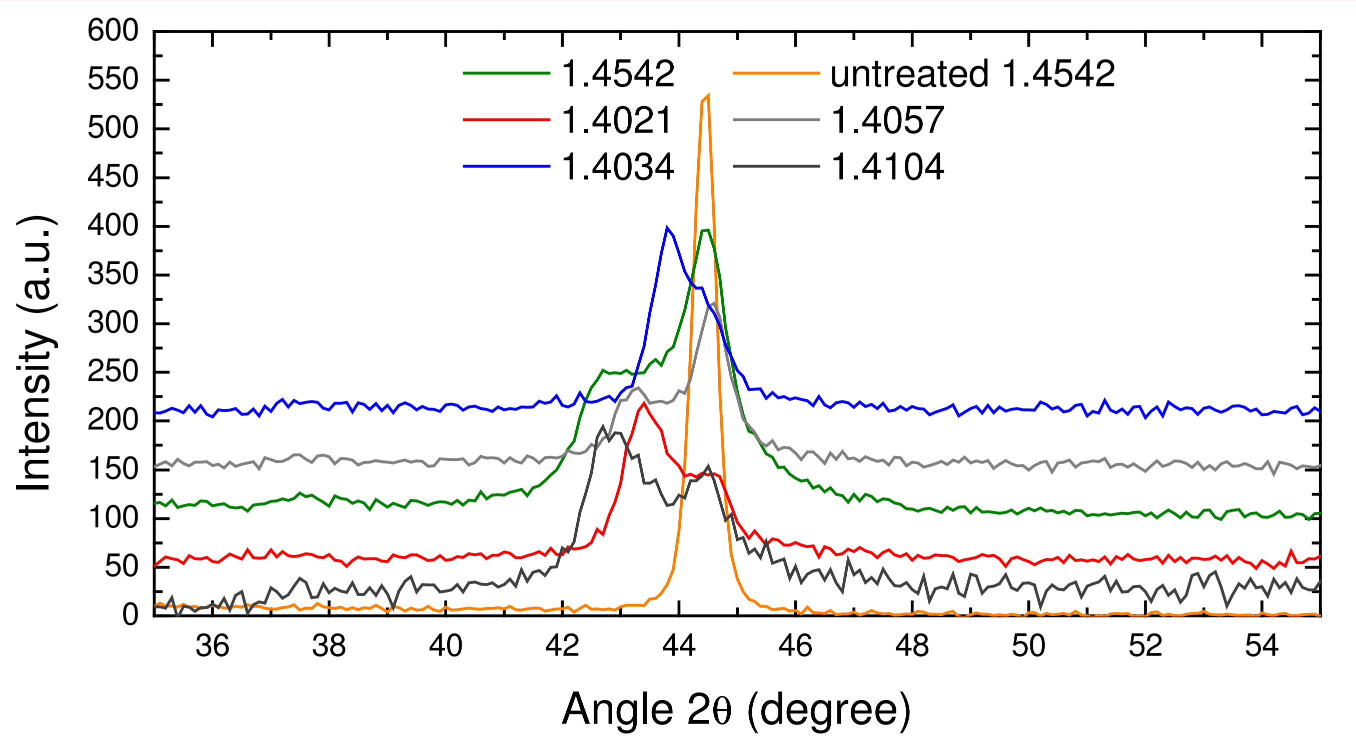
Fast nitrogen diffusion (slowed by additional carbon)

Concentration dependent diffusion constant (deviation from erfc shape)

Formation of “expanded martensite”

Anisotropic lattice expansion

XRD – different steel grades



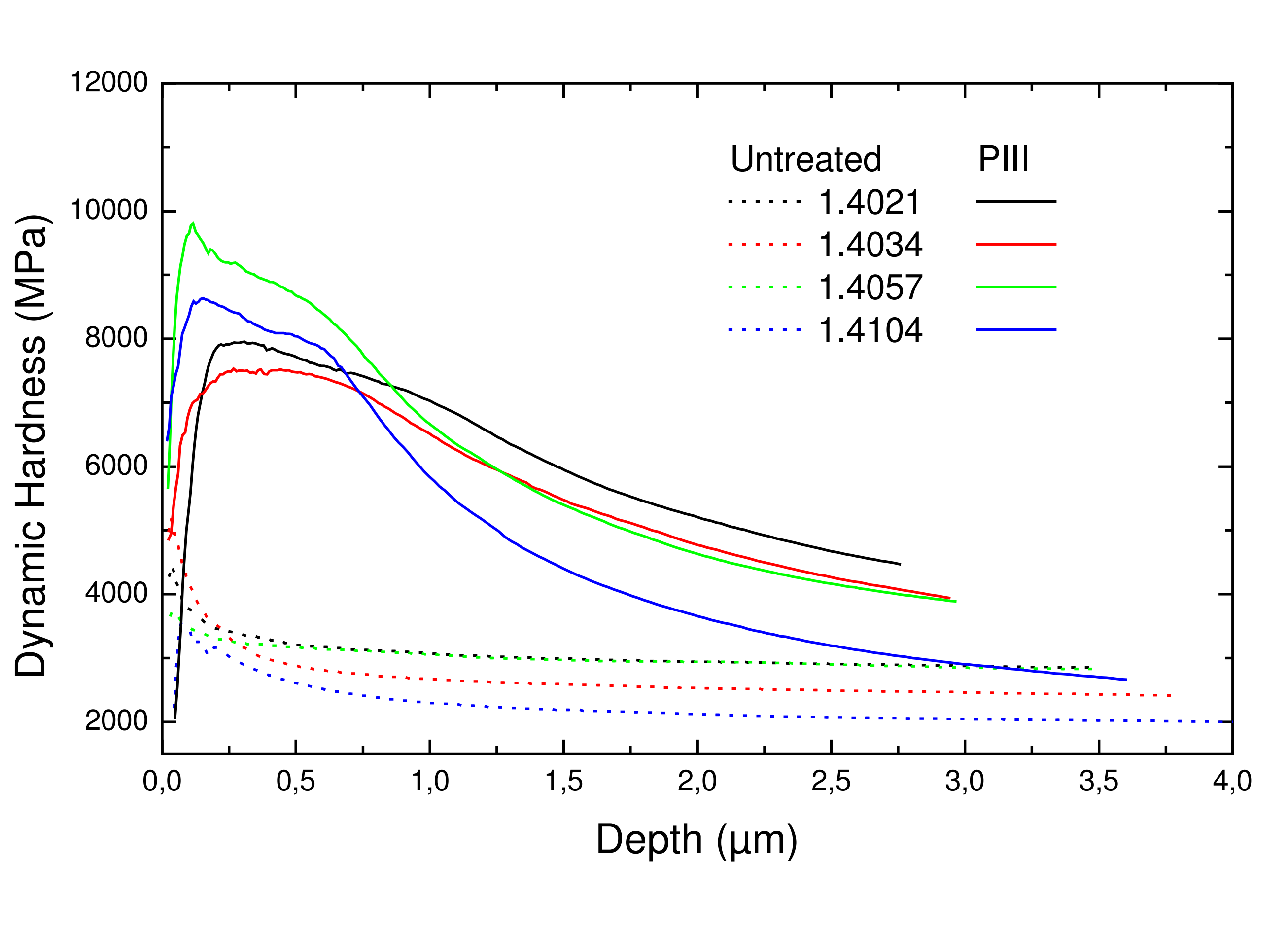
Expanded lattice after nitrogen PIII for all investigated grades

Lattice expansion depends on steel grades

No other phases in XRD spectra (range 30° - 90°)

Layer thickness varying between steel grades at identical treatments (smallest for 1.4542)

Hardness- different steel grades

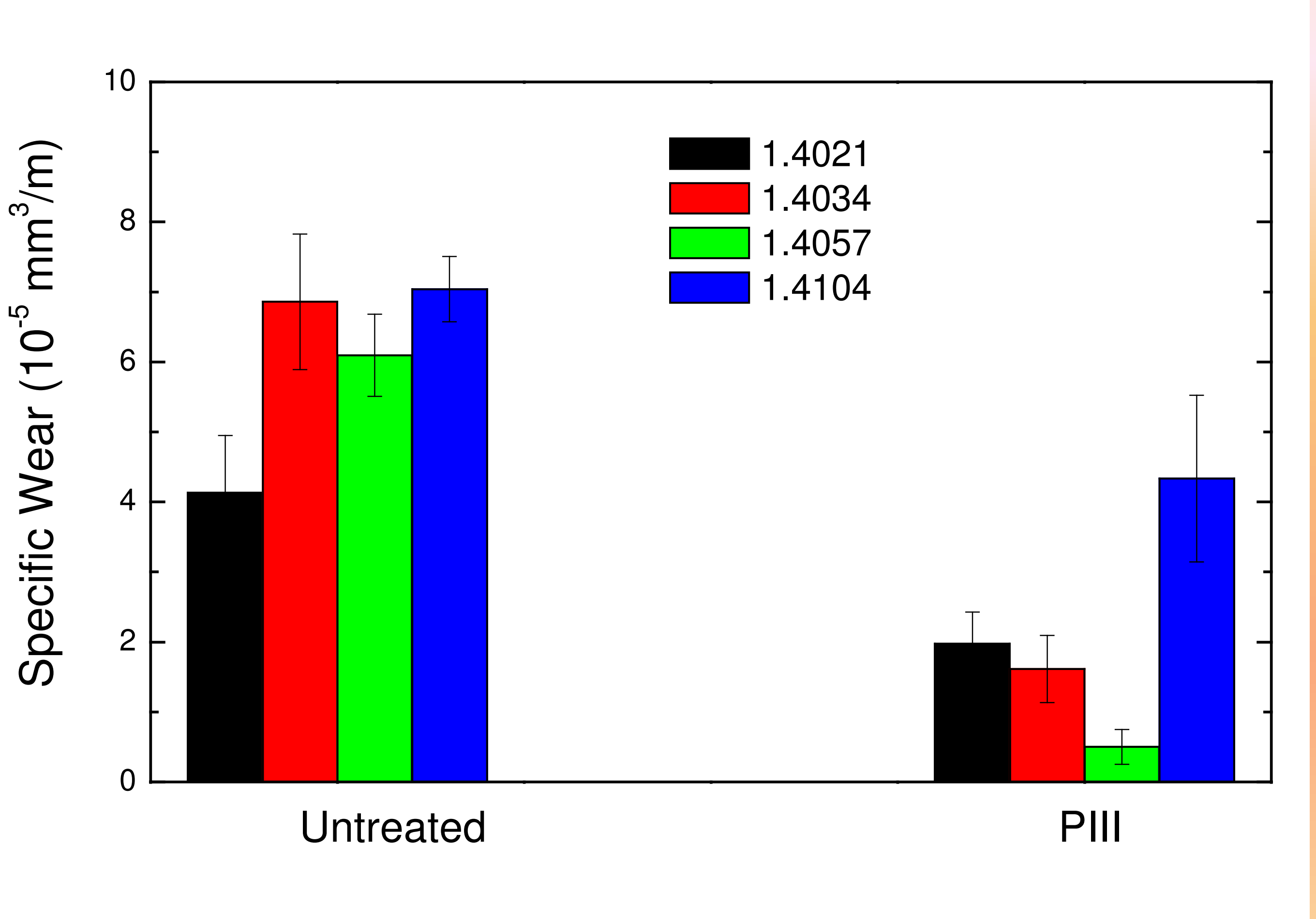


Significantly improved hardness for all steel grades up to 9810 MPa (≡ 1000 HV)

Absolute and relative increase depends on steel grade / chemical composition

No correction for elastic deformation, i.e. corrected values are about 15 - 20% higher

Wear resistance – different steel grades



Experimental conditions: contact pressure 1.4 GPa, high speed

High variability in wear reduction

Not identical wear mode as for the high performance steel 1.4542

Discussion

Lattice expansion of steel after interstitial atom insertion at 330 – 400 °C

Formation of expanded austenite/martensite independent of

Chemical nature of ions (nitrogen or carbon)

no formation of nitride or carbide detected

Energy range of ions (method of nitriding)

austenites √ / martensites (??)

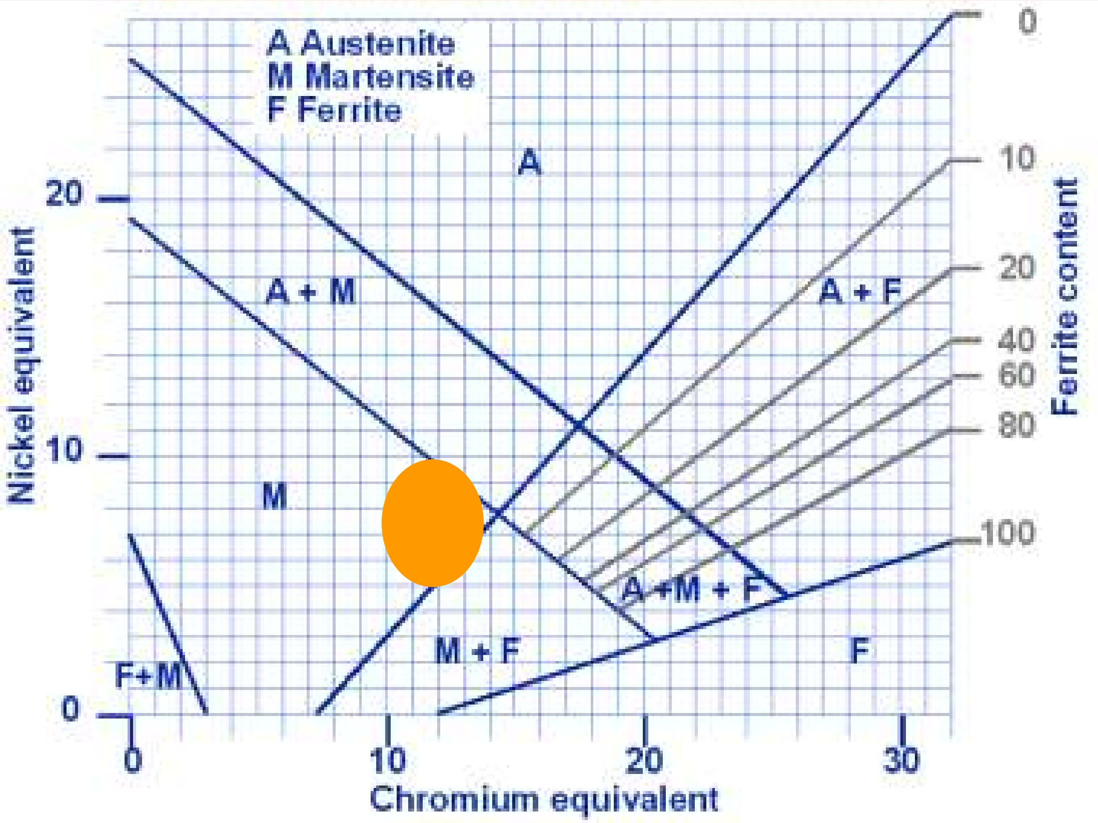
Composition of Steel

Apparently no access to investigate and identify the mechanism

No chemical path!

Metallurgical path?

Schäfflerdiagramm



Ni = 30(C+N) + 0.5 Mn + Ni + 0.5 (Cu+Co)

Cr = 1.5Si + Cr + Mo + 2Ti + 0.5 Nb

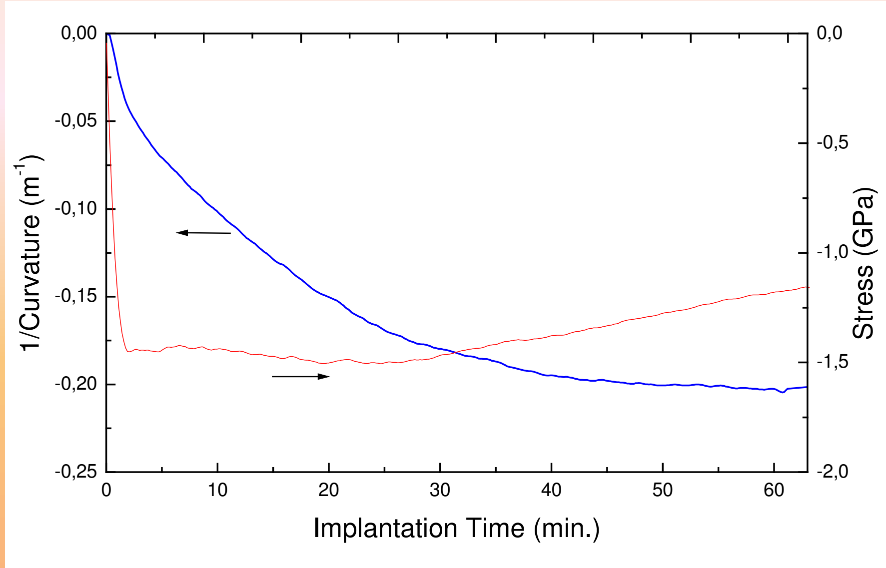
Introduction of nitrogen into steel should lead to increase of nickel equivalent

However, no austenitic phase found in XRD spectra even for high-Ni alloys

⇒ Expected phase transition from martensite to austenite is not observed

⇒ Formation of expanded martensite not related with metallurgical phase transition!

Discussion



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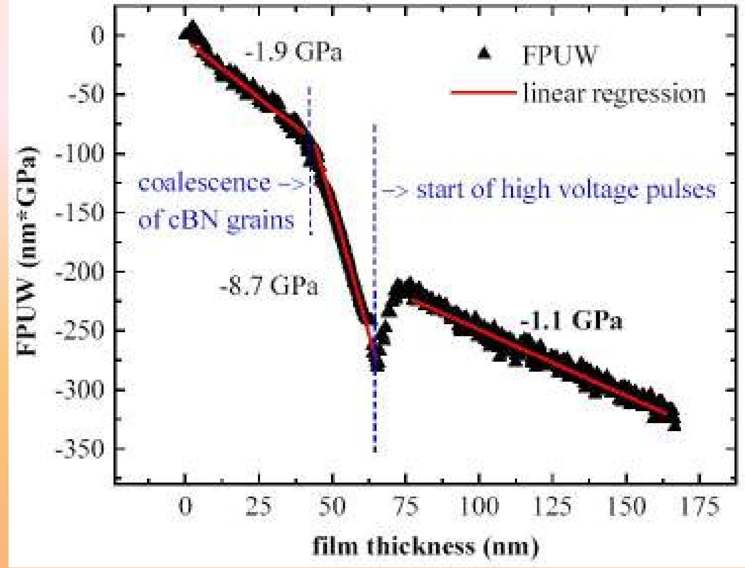


B. Abendroth, A. Kolitsch, Annual FZR Report 2002

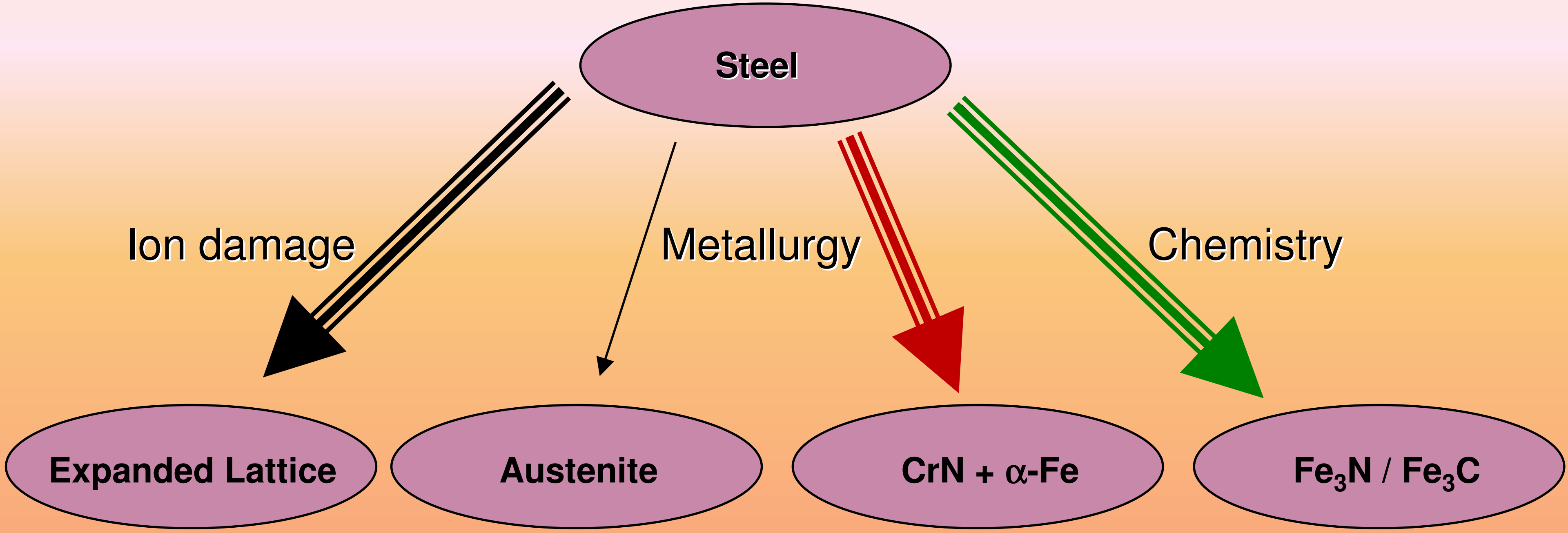
Very fast increase of stress in the begining of austenite nitriding

Accumulation of stress for BN leads to phase transition h-BN to c-BN

Same cause for austenite and BN: accomodation of stress necessary for transition?

However: Inward ⇔ Outward growth

Discussion & Conclusions



Additional reaction path: influence of deposited energy

Low energy limit for expanded martensite formation!

Temperature dependence: $<$ 330 °C $<$ 400 °C $<$

Thermal activation energy, reaction enthalpy, potential barrier?

Acknowledgements

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