Influence of Vanadium Microalloying on the Microstructure of Induction Hardened 1045 Steel Shafts

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TIMKEN

ASPPRC Advanced Steel Processing & Products Research Center

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

FLUXTROL Centre for Induction Technology

With Additional Support From

GERDAU

FCA FIAT CHRYSLER AUTOMOBILES | NORTH AMERICA

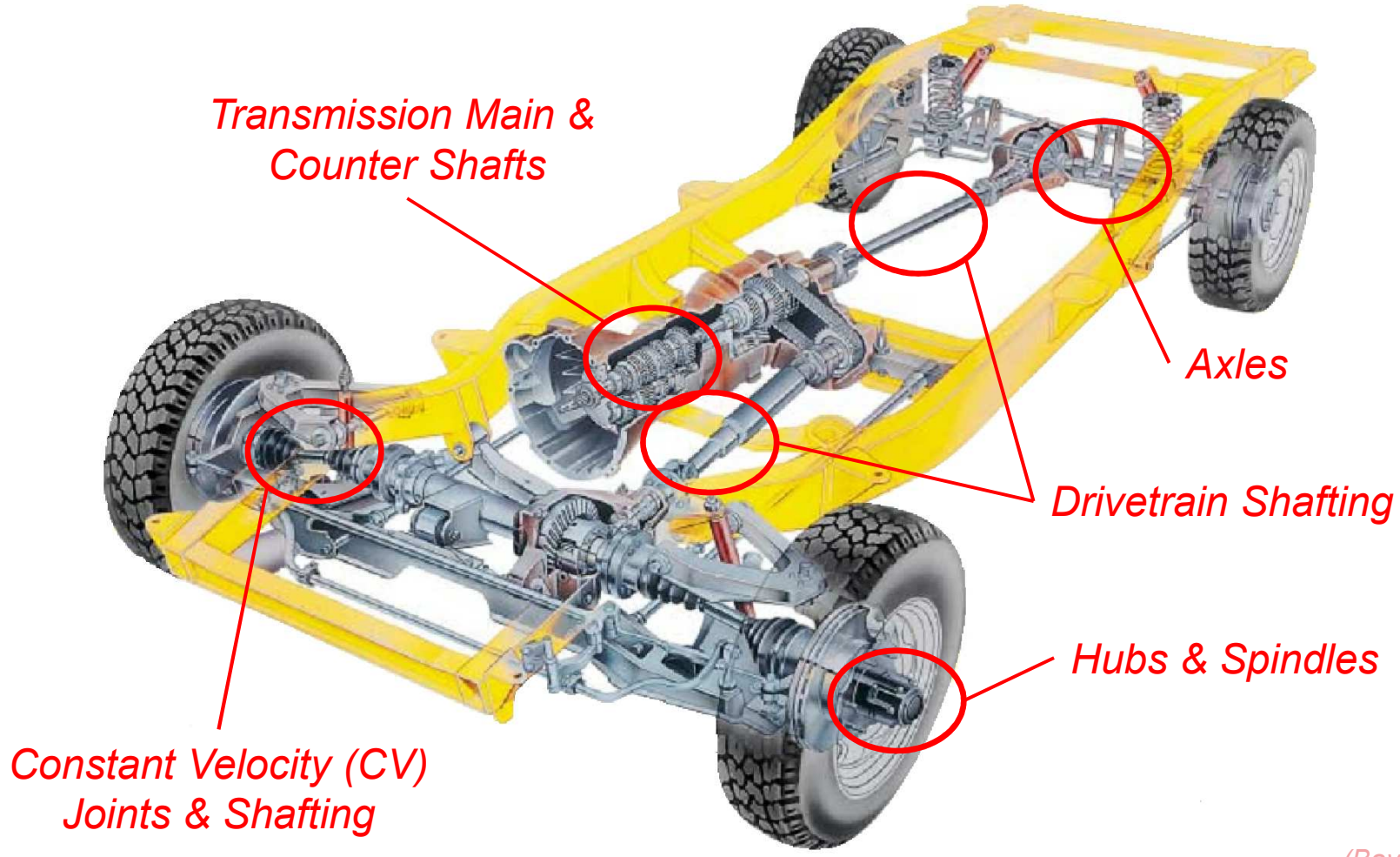
INDUCTOHEAT An Inductotherm Group Company

HTS Heat Treating Society ASM INTERNATIONAL

ASM INTERNATIONAL

Motivation

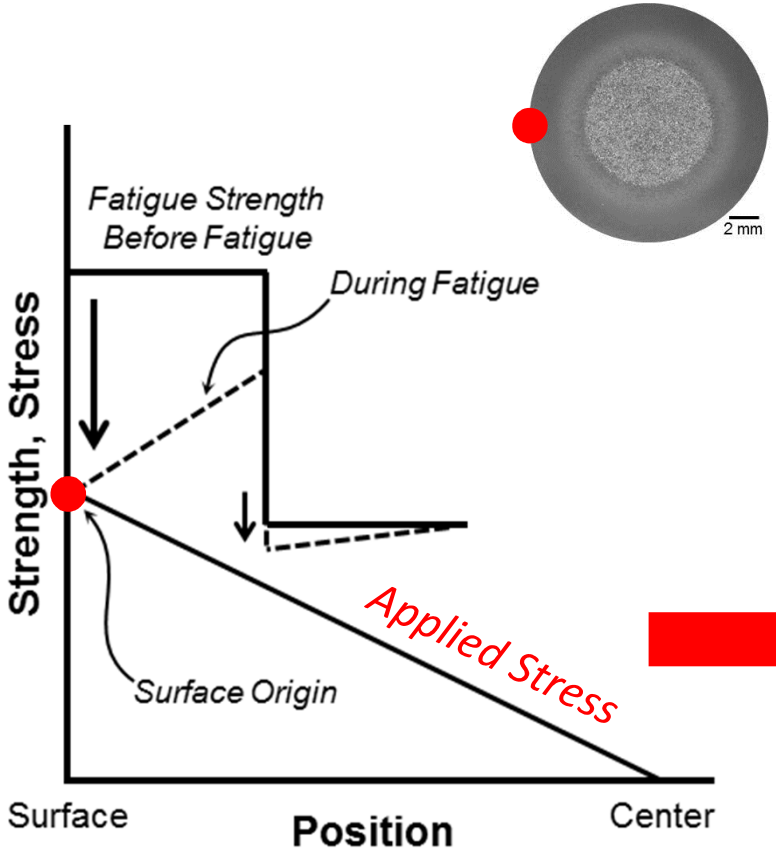
Applications of Induction Hardened Medium-carbon Steels



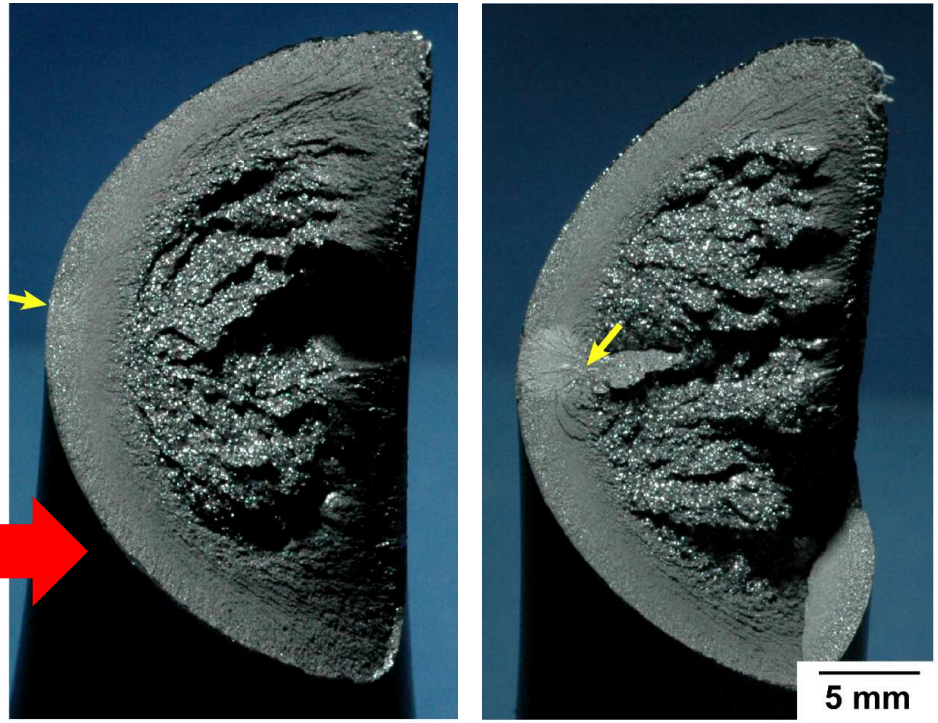
(Bayer, 2003)

Motivation

Improving fatigue performance…



Torsional Fatigue Failures
(550 MPa, R=0.1)



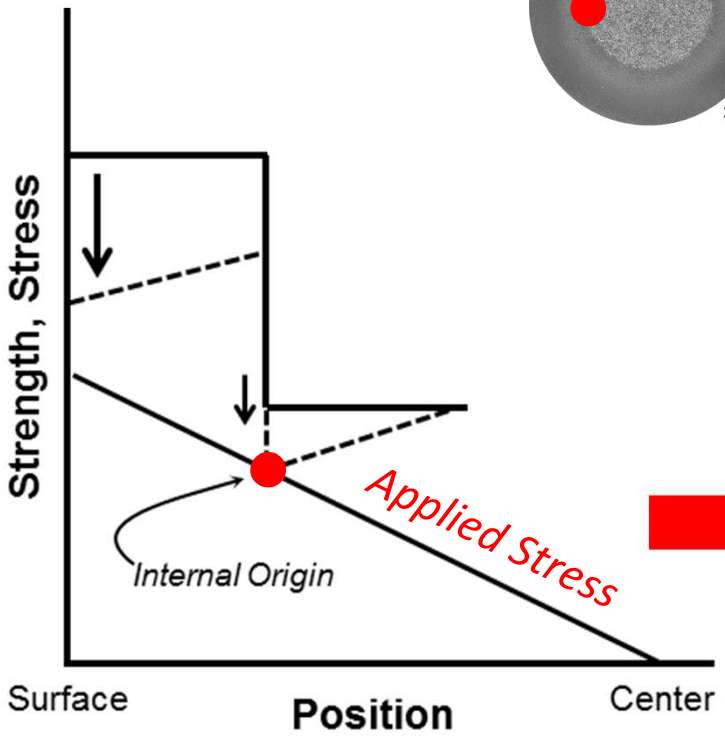
Surface ***Sub-surface***

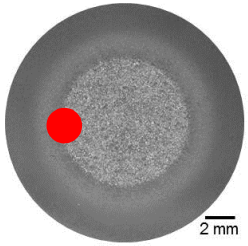
(Ochi et al. 1999)

(Rothleutner et al. 2015)

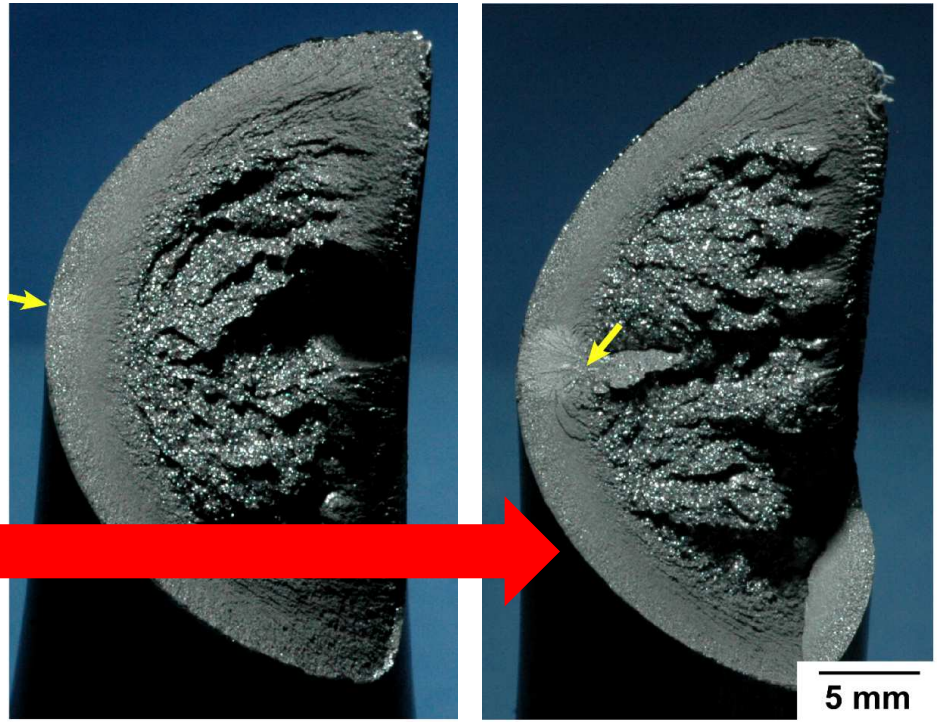
Motivation

Improving fatigue performance…





Torsional Fatigue Failures
(550 MPa, R=0.1)



Surface

Sub-surface

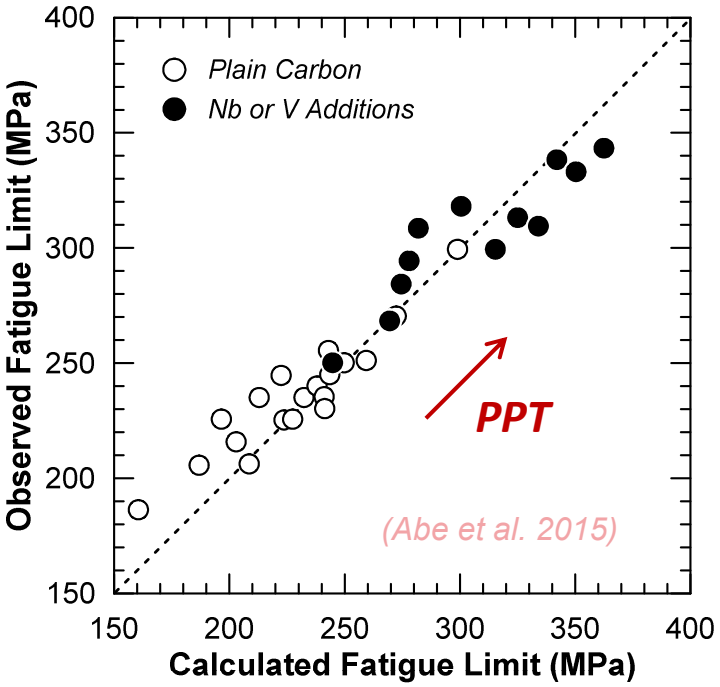
(Ochi et al. 1999)

(Rothleutner et al. 2015)

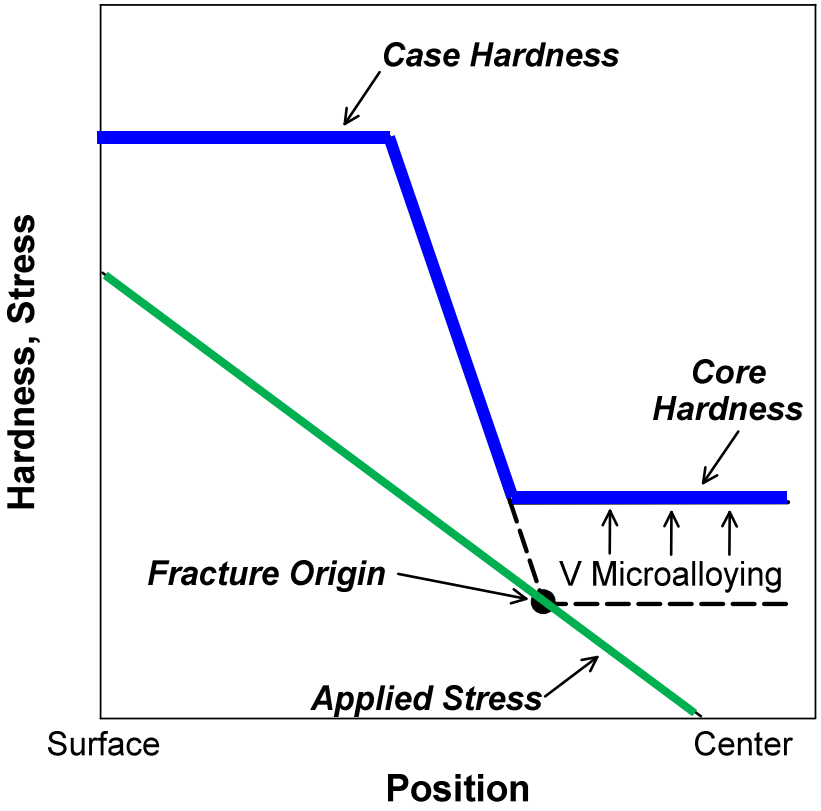
Motivation

How will vanadium microalloying influence fatigue life?

Hot-rolled



Induction Hardened

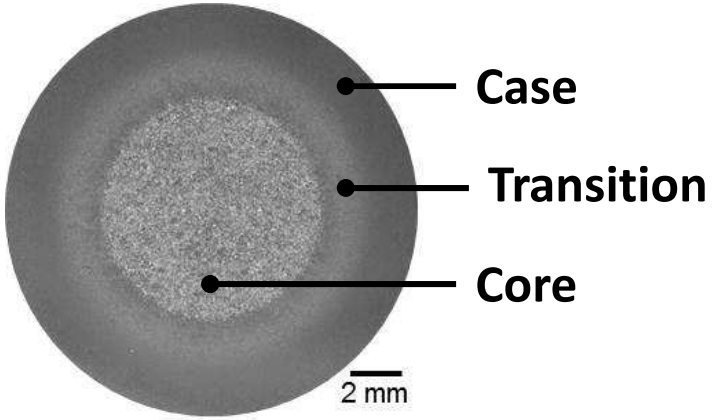


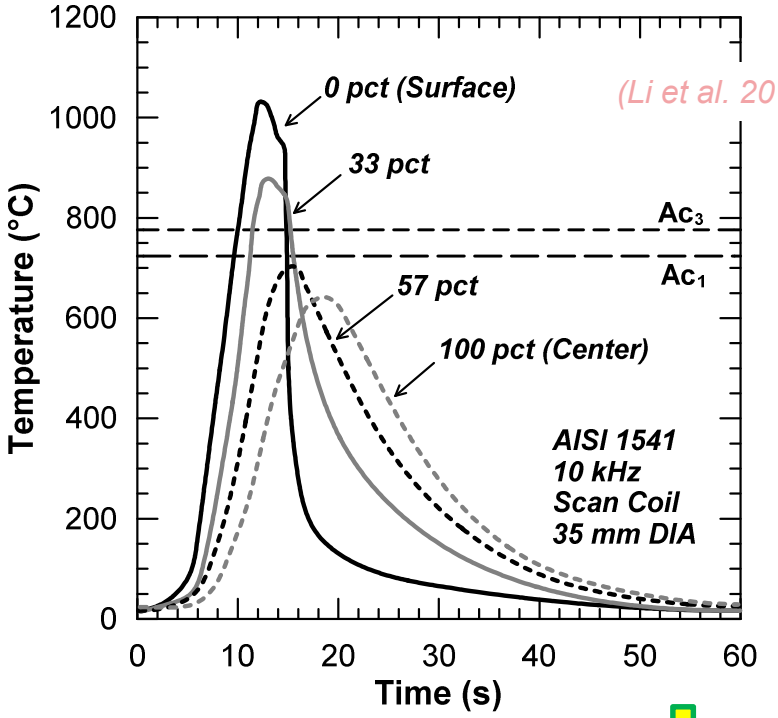
(Rothleutner, 2015)

$$\sigma_w = 8.4 + 0.92\,\sigma_{ss} + 0.70\,\sigma_{ppt} + 0.53\,\sigma_{prlt} + 0.43\,\sigma_{gr} + 0.23\,\sigma_{dis}$$

Background

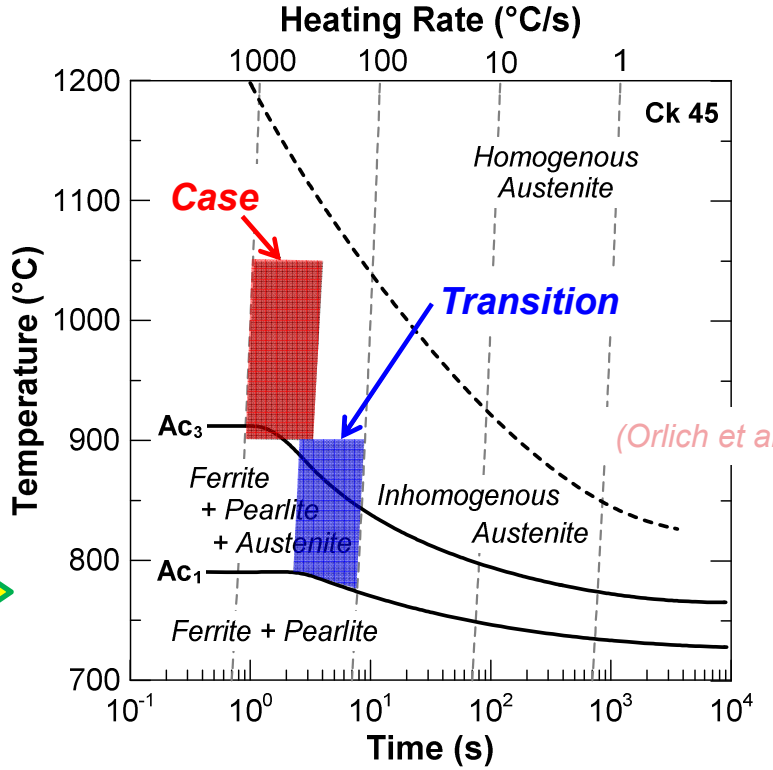
Induction Hardening





(Li et al. 2014)

Heating rate and peak temperature are a function of distance from center.



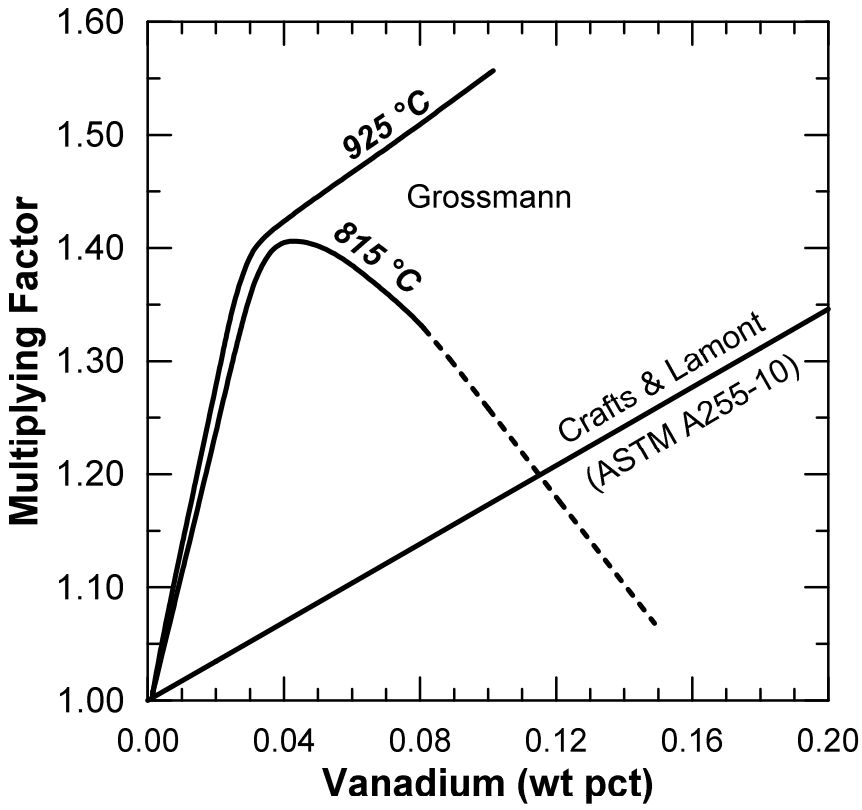
(Orlich et al. 1973)

Background

Effect of Vanadium on Hardenability

Magnitude depends on state of vanadium in the steel.

- Precipitate vs. Solid-solution

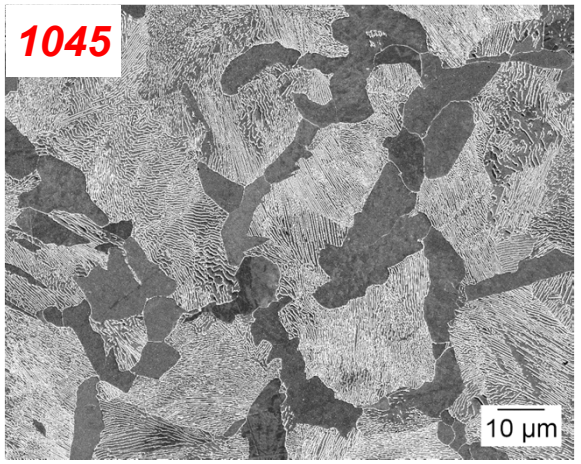


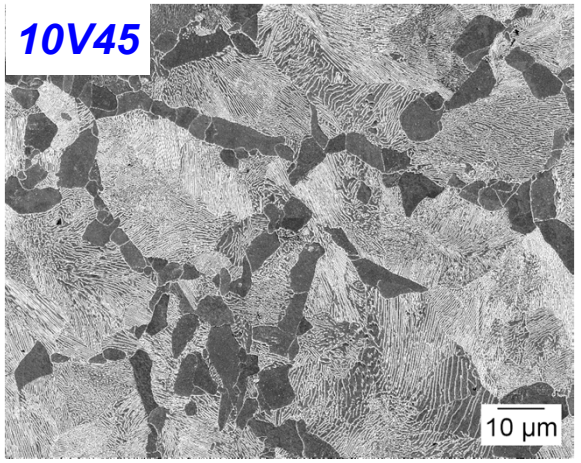
(Rothleutner, 2015)

Materials

Chemistry & Microstructure

	1045	10V45	Δ (pct)
Ferrite (%)	14.9 - 18.9	12.0 - 15.0	-25
Ferrite Grain Size (μm)	5.0 - 5.7	2.7 - 3.1	-85
Microhardness (HV_{1kg})	217 ± 5	281 ± 9	+23



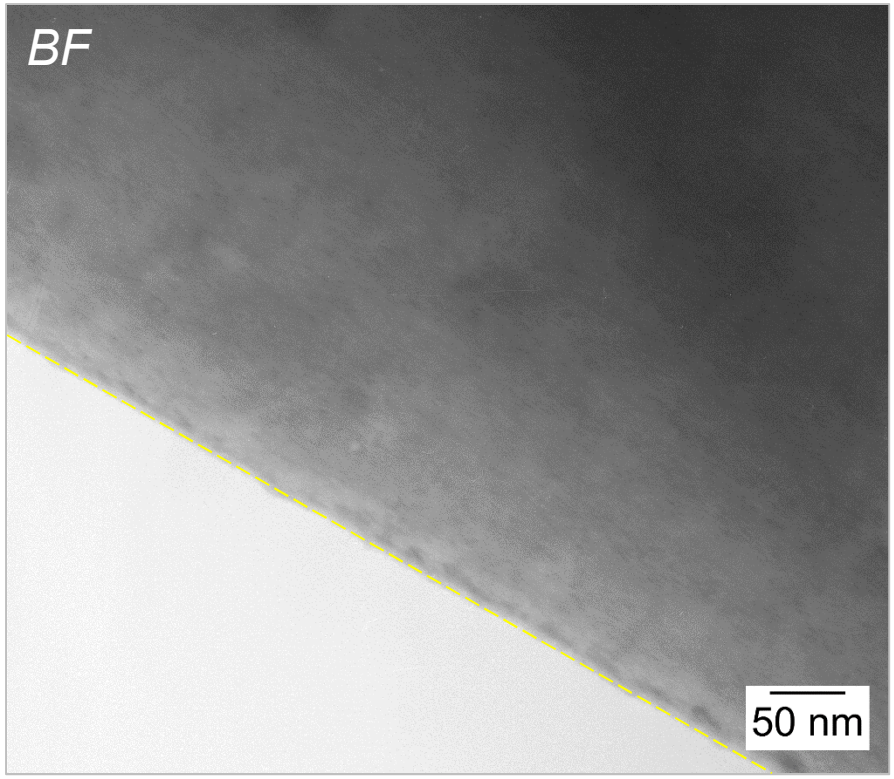


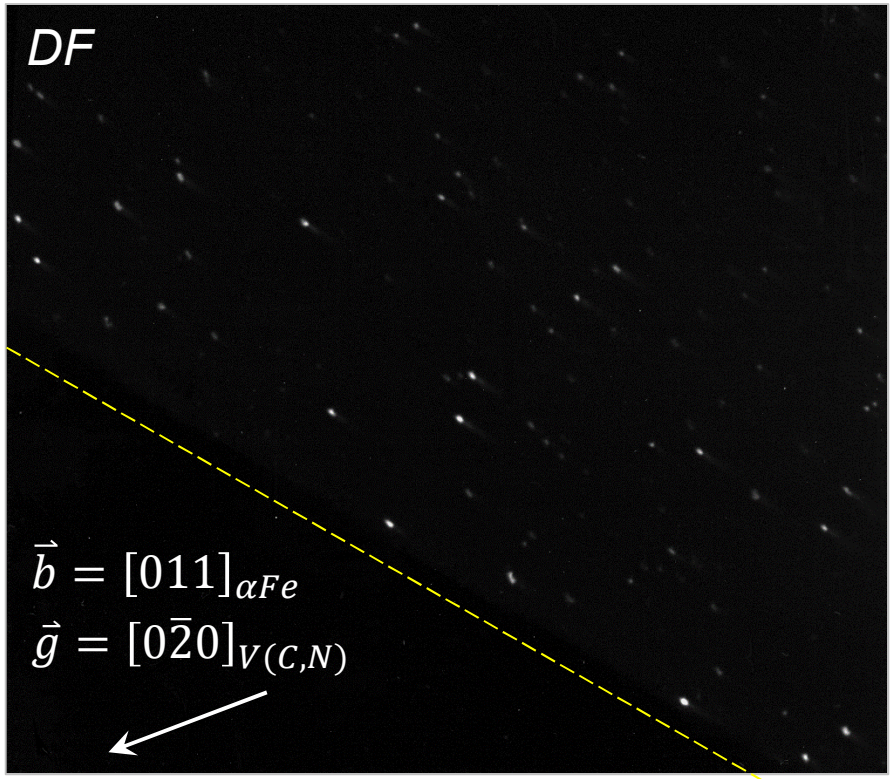
wt.%	C	Mn	Si	Ni+Cr+Mo	V	Al	N	P	S	Cu	DI[a] (mm)
1045	0.44	0.74	0.23	0.25	0.002	0.016	0.0068	0.010	0.006	0.26	35.6
10V45	0.47	0.82	0.28	0.24	0.080	0.007	0.0100	0.007	0.009	0.22	45.5

[a] *ASTM A255-10: Standard Test Methods for Determining Hardenability of Steel*

Materials

V(C,N) Precipitation in 10V45 – Proeutectoid Ferrite



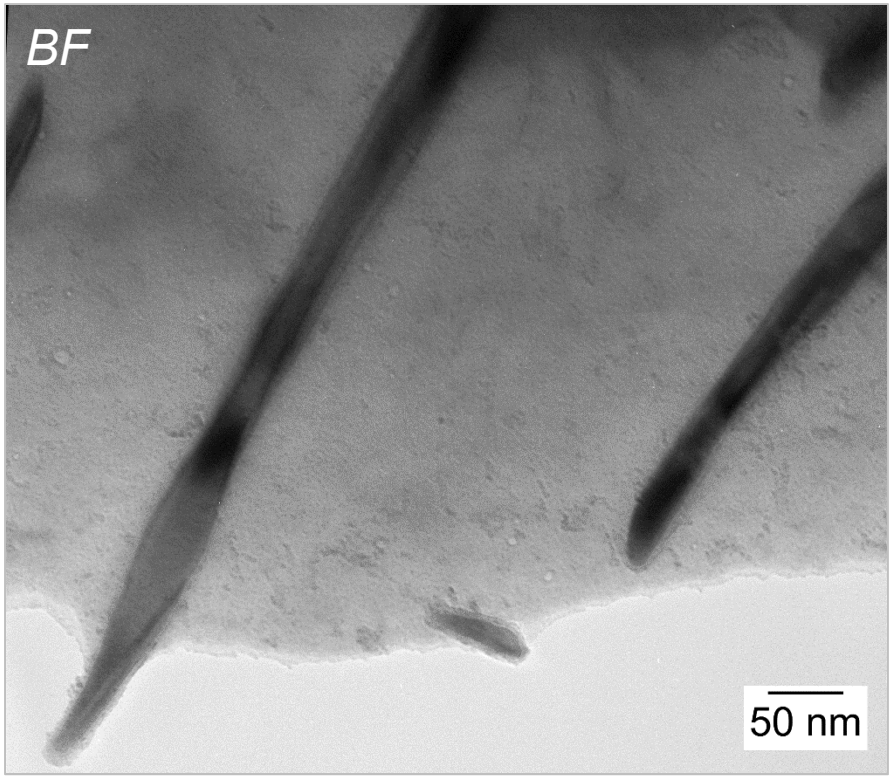


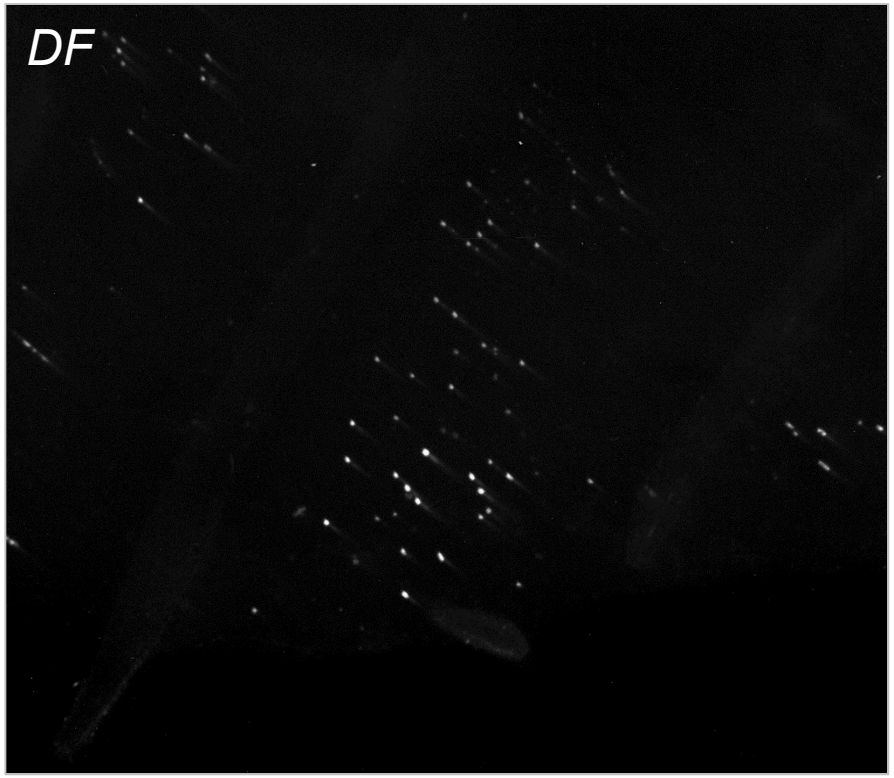
V(C,N) diameter

4.5 ± 0.3 nm

Materials

V(C,N) Precipitation in 10V45 – Pearlitic Ferrite





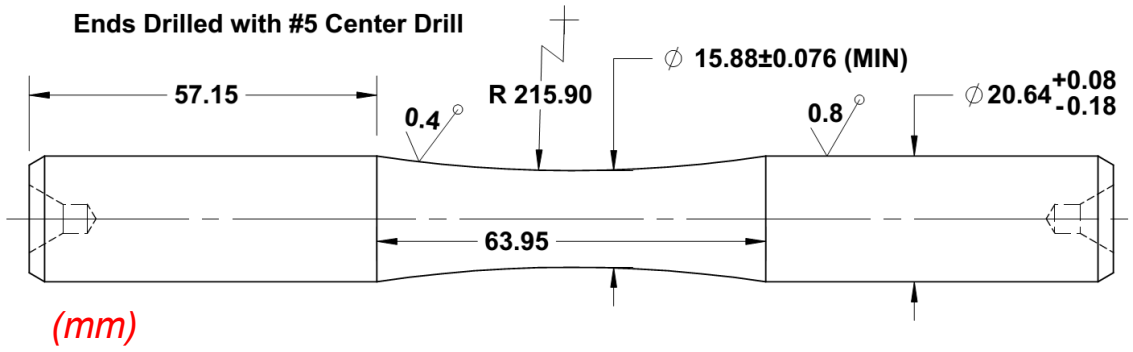
V(C,N) diameter

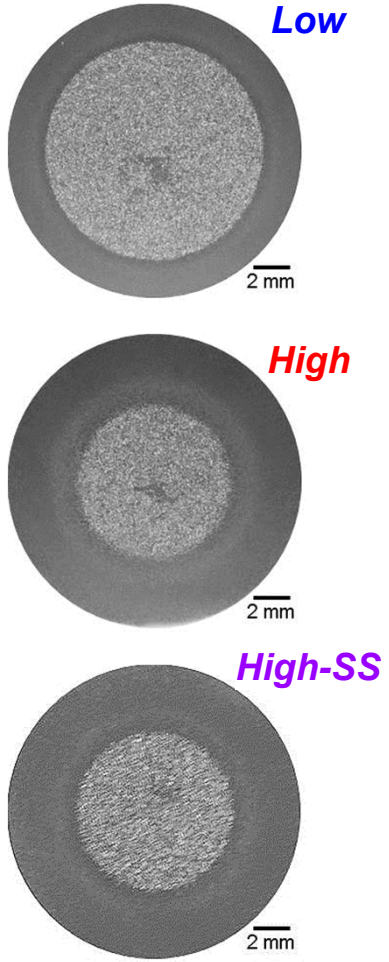
3.3 ± 0.3 nm

Induction Hardening

Processing Parameters for Torsional Fatigue Samples

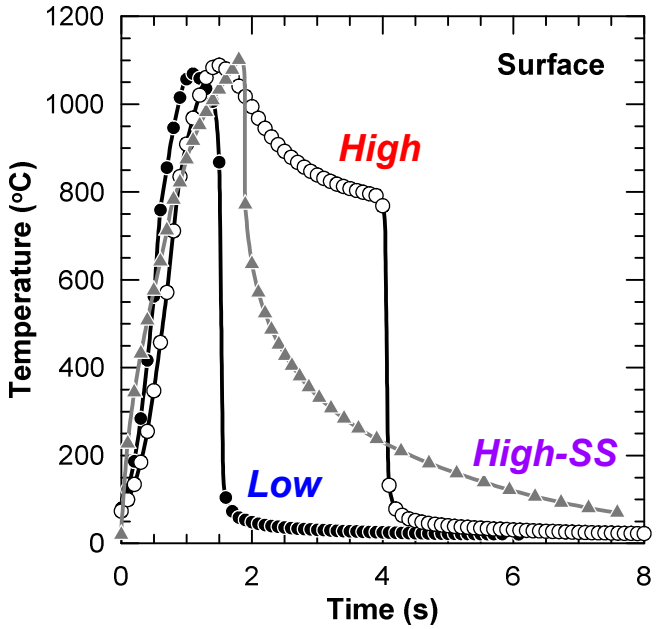
	Low	High	High-SS
Power (kW)	72	72	128
Frequency (kHz)	196	196	31
Scan Rate (mm/s)	22.9	17.3	---
UCON A Conc. (%)	6	6	2
Flow Rate (L/min)	75	75	173
Eff. Case Depth (%)	25	44	44

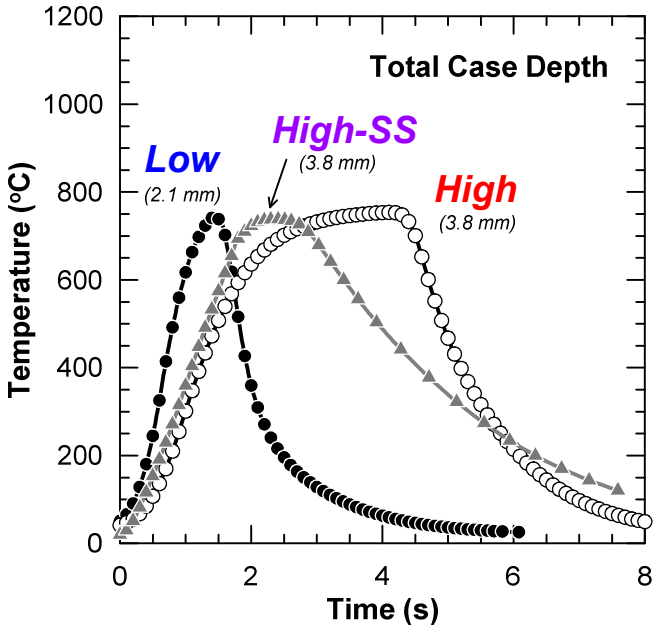


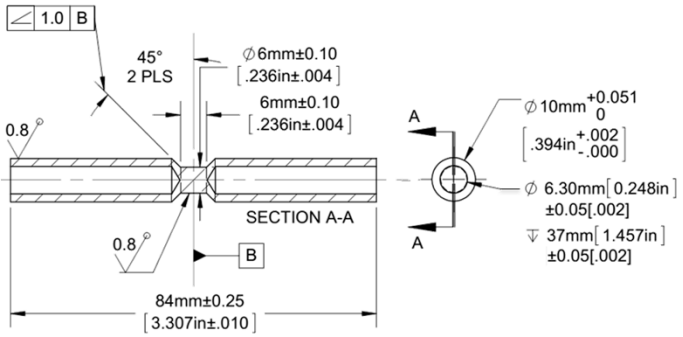


Simulation of Induction Hardening

Thermal Profiles for Gleeble Testing



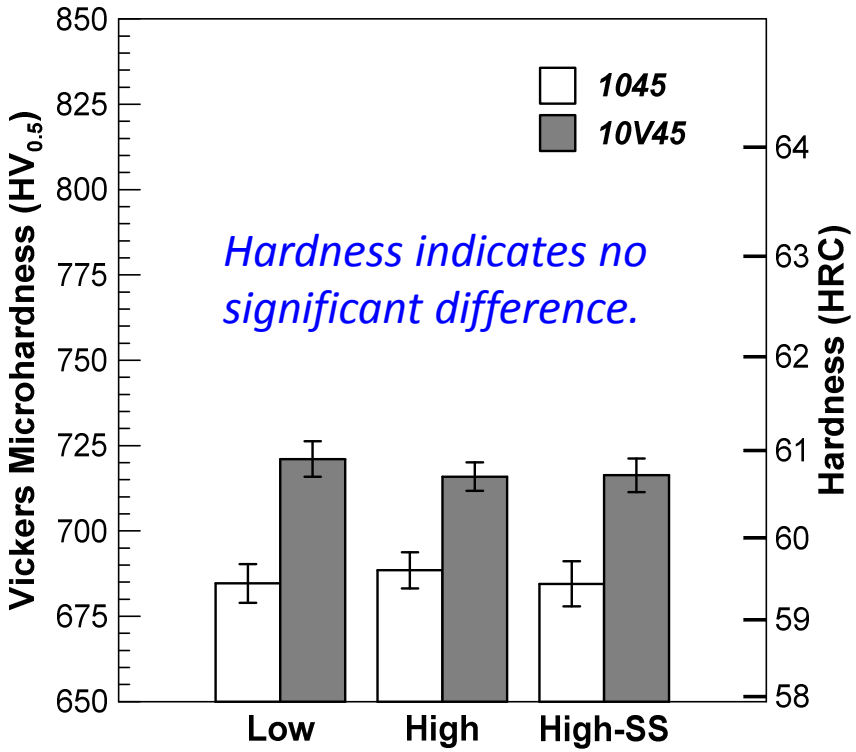


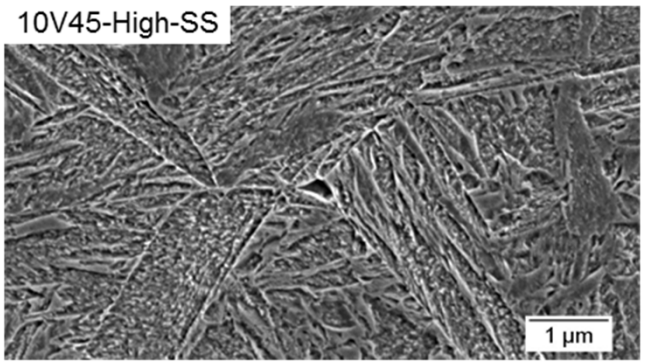


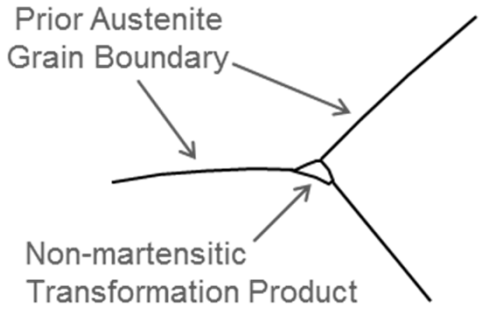
Condition	Software	Location Description	Distance from Surface (mm)
Low	Flux 2D	Surface	---
		Total Case Depth	2.10
High	Flux 2D	Surface	---
		Total Case Depth	3.80
High-SS	ELTA	Surface	---
		Total Case Depth	3.80

Simulation of Induction Hardening

Gleeble Testing Results – Surface



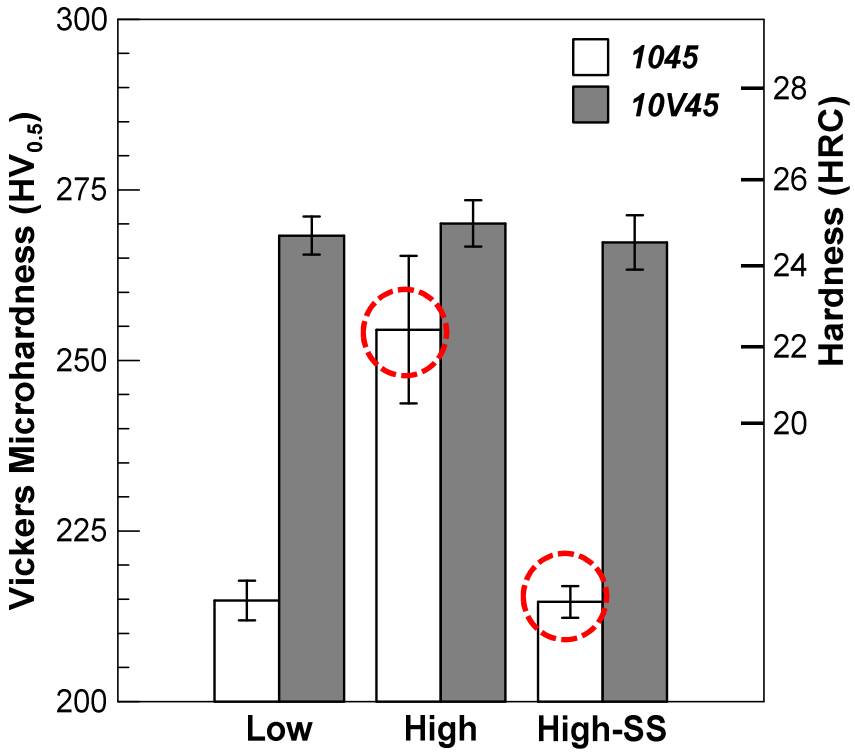




<1%

Simulation of Induction Hardening

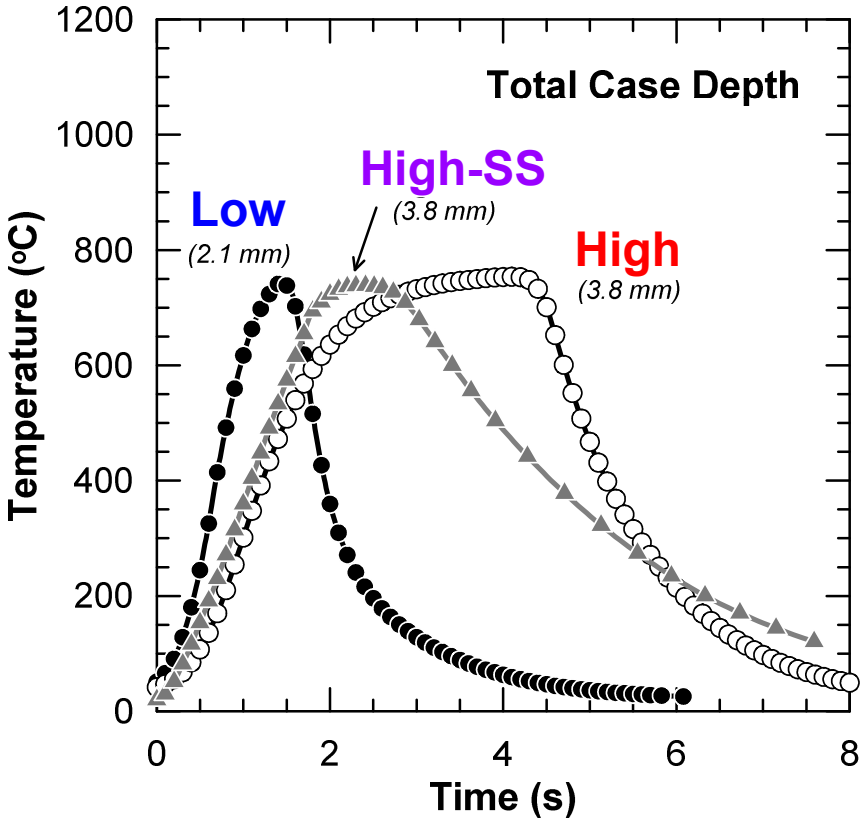
Gleeble Testing Results – Total Case Depth

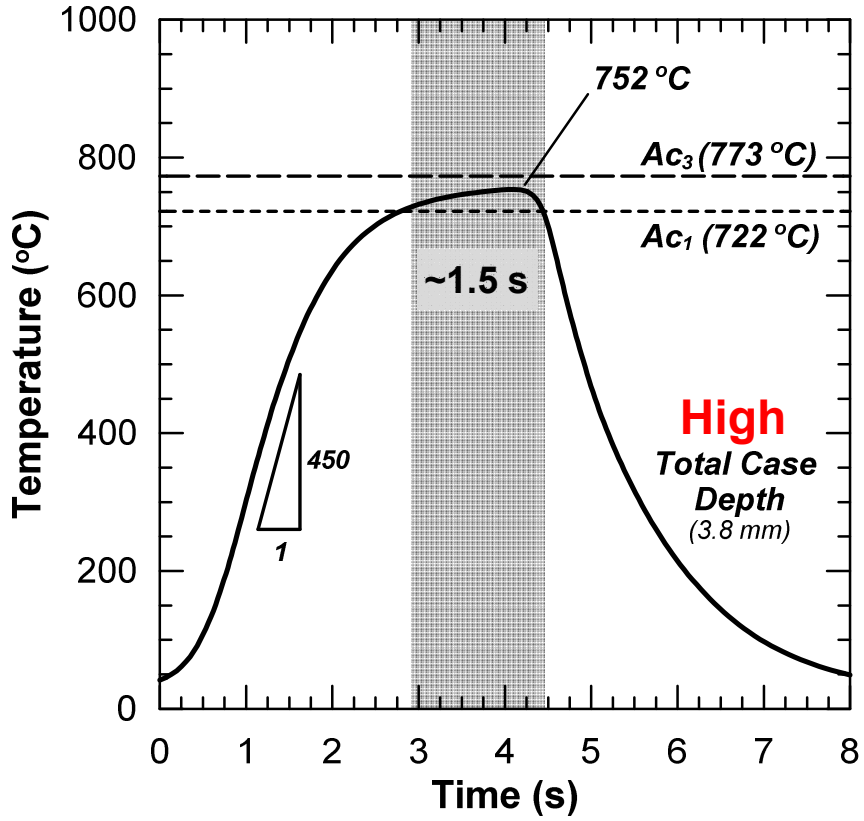


Significant difference between the 1045 High and High-SS conditions.

Simulation of Induction Hardening

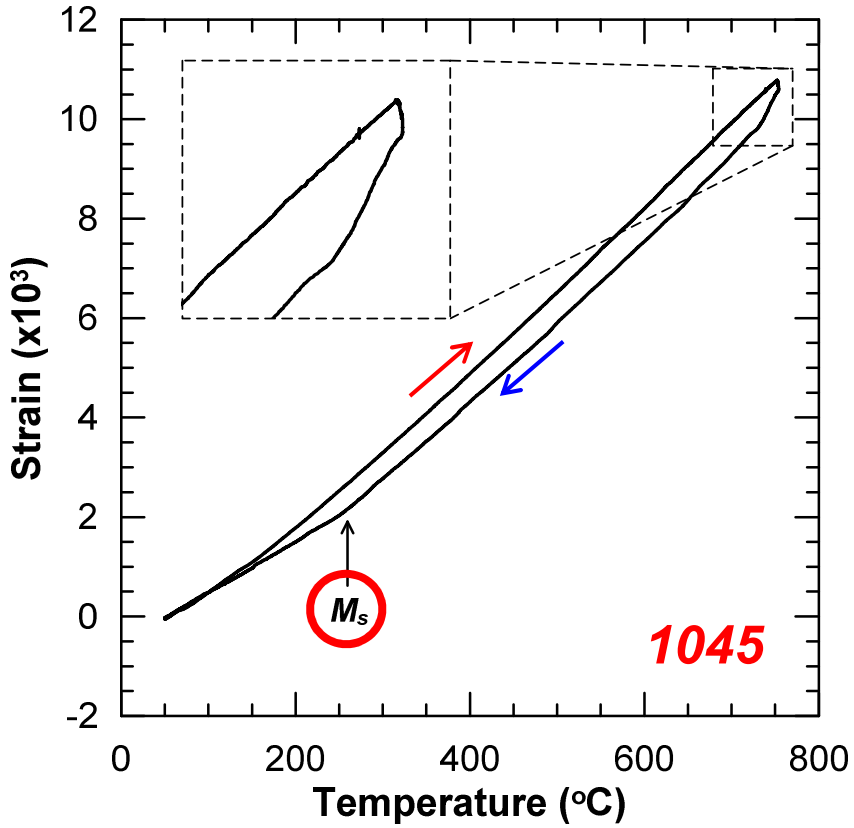
Gleeble Testing Results – Total Case Depth

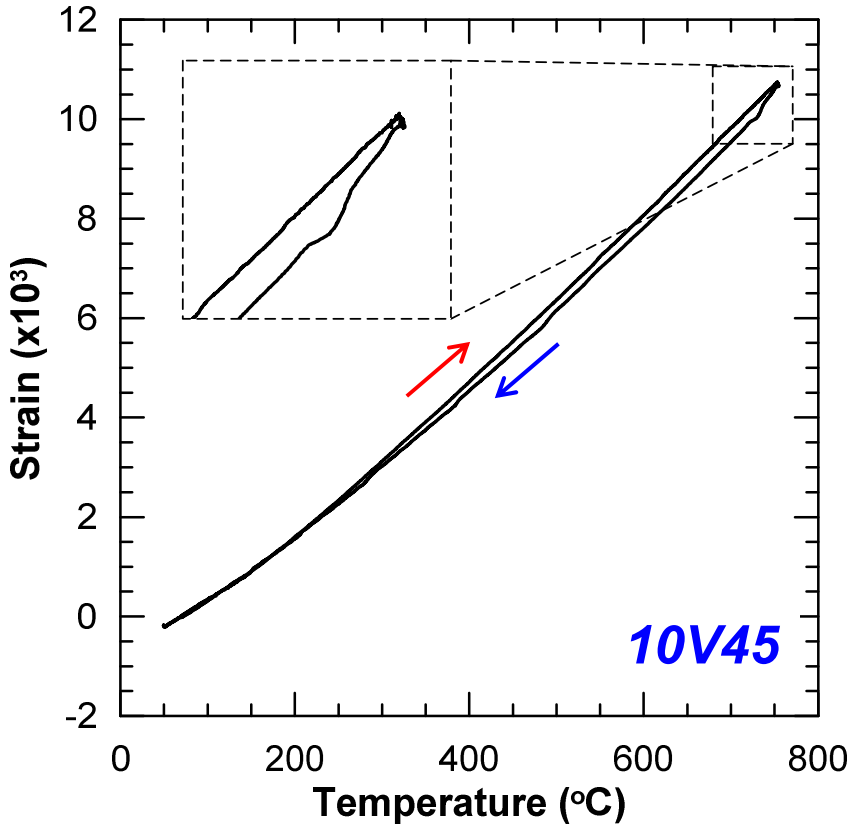




Simulation of Induction Hardening

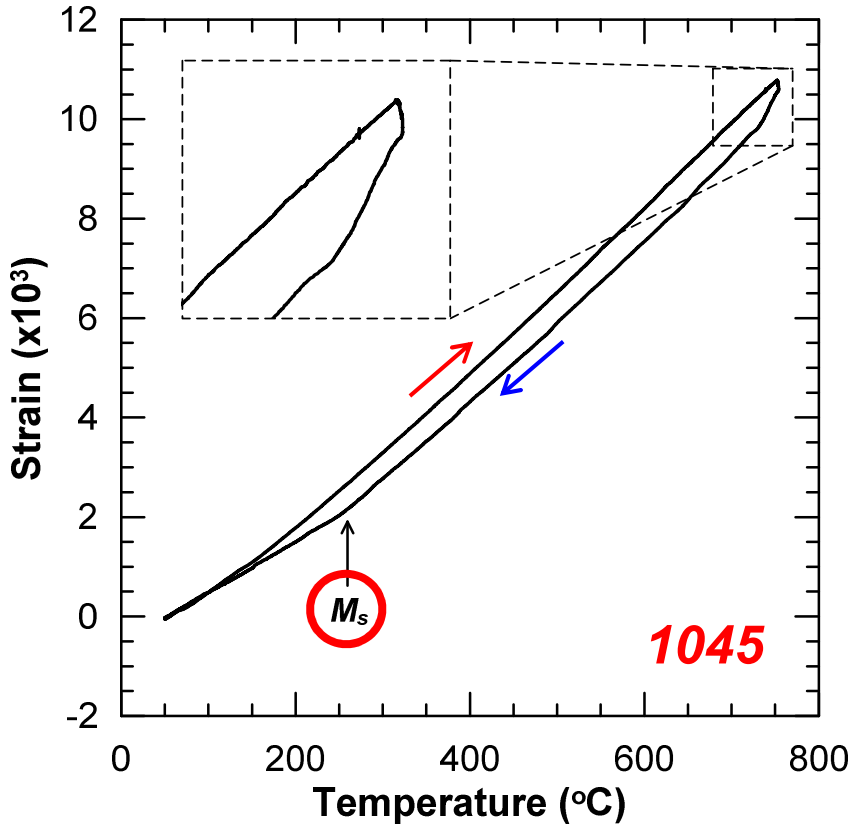
Gleeble Testing Results – Total Case Depth for High Condition

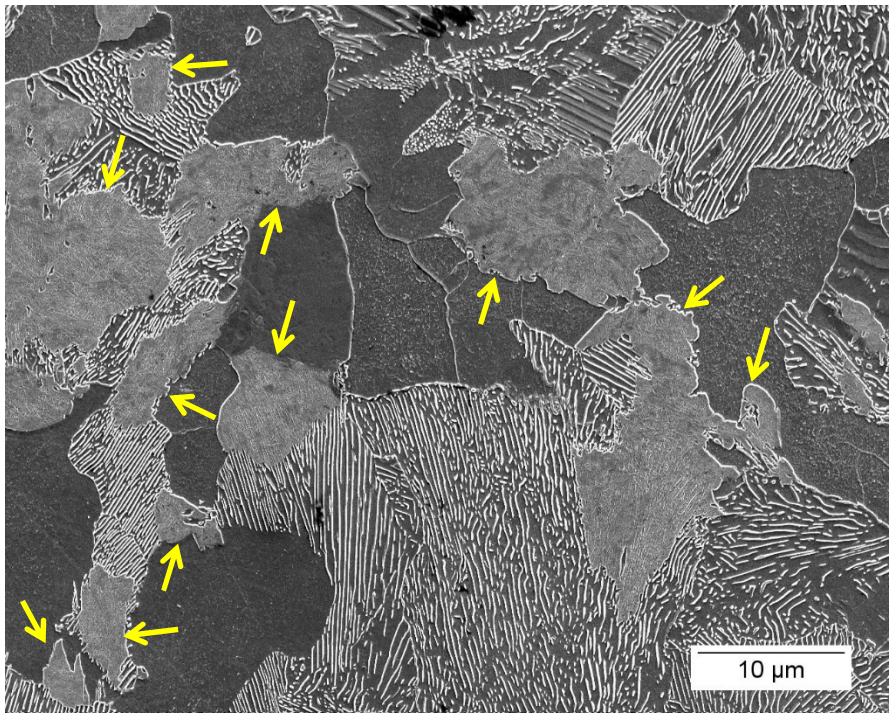




Simulation of Induction Hardening

Gleeble Testing Results – Total Case Depth for High Condition

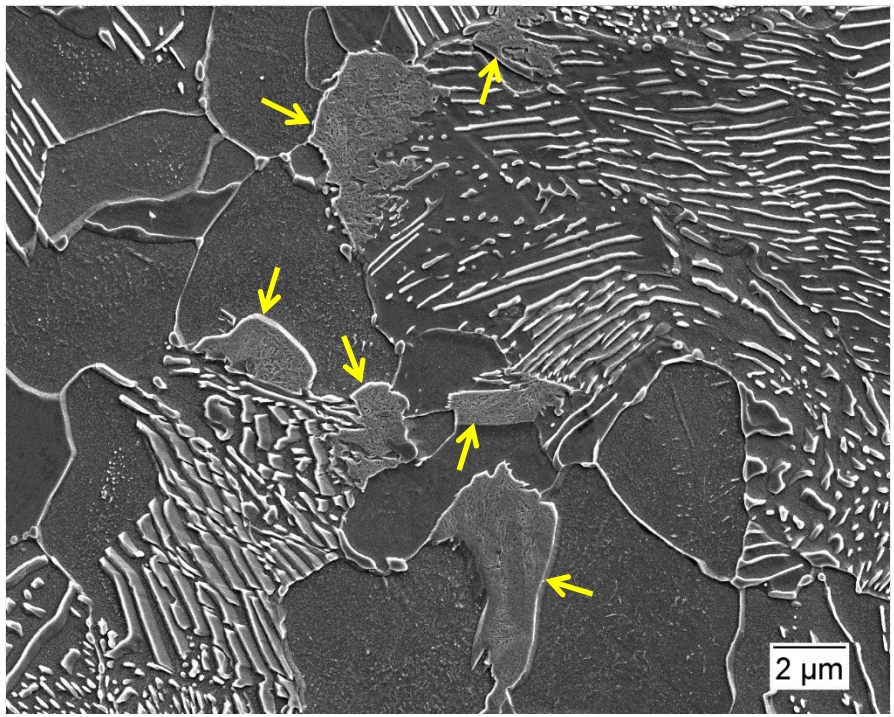




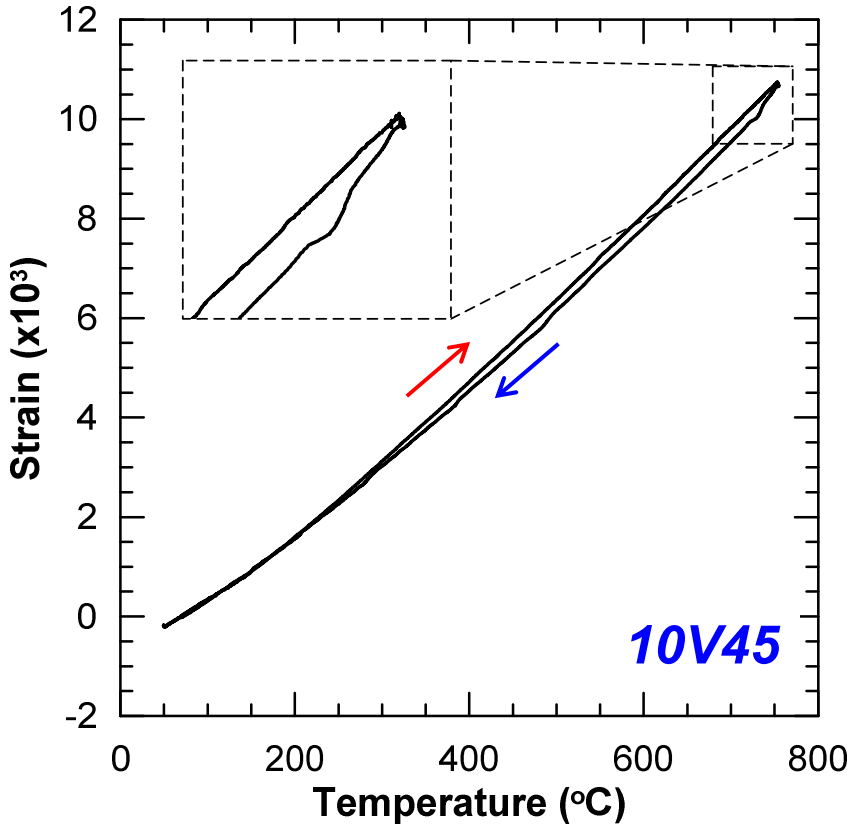
13.5 ± 0.6 pct

Simulation of Induction Hardening

Gleeble Testing Results – Total Case Depth for High Condition

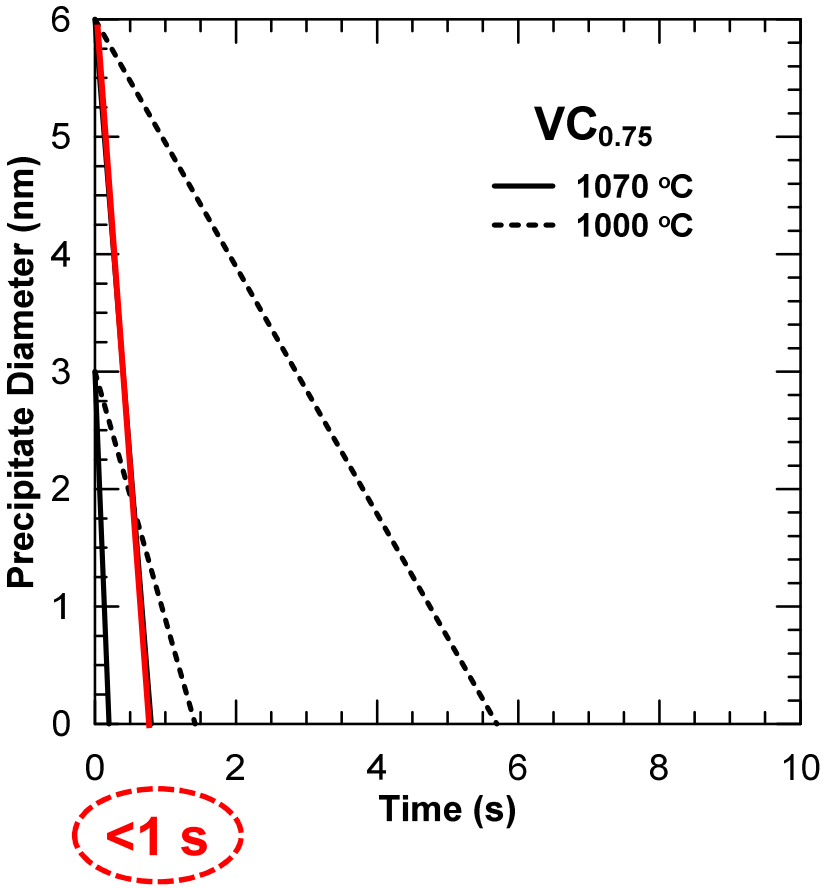


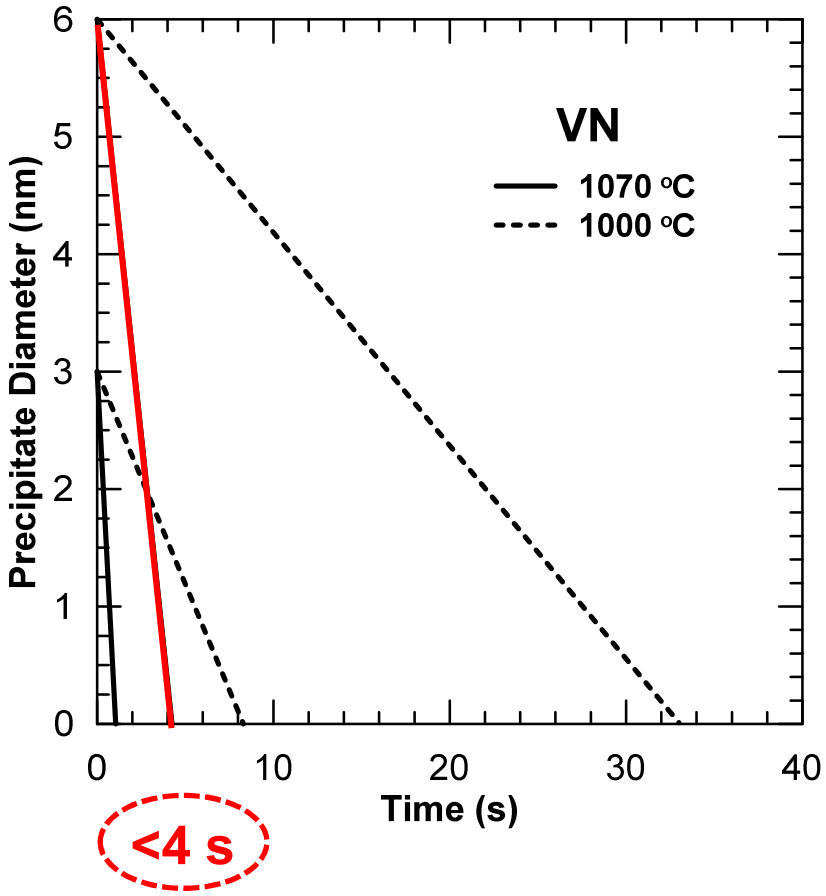
1.1 ± 0.5 pct



Materials

V(C,N) Precipitate Dissolution





(Whelan 1969)

Conclusions

Microalloying of induction hardened medium carbon steels with vanadium may result in...

1) *Increased non-martensitic transformation products in the case.*

2) *Reduction in total case depth at higher case depths.*

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