GREAT DESIGNS IN STEEL

PERFORMANCE ENHANCEMENT OF ADVANCED HIGH STRENGTH STEELS BY NIOBIUM MICROALLOYING

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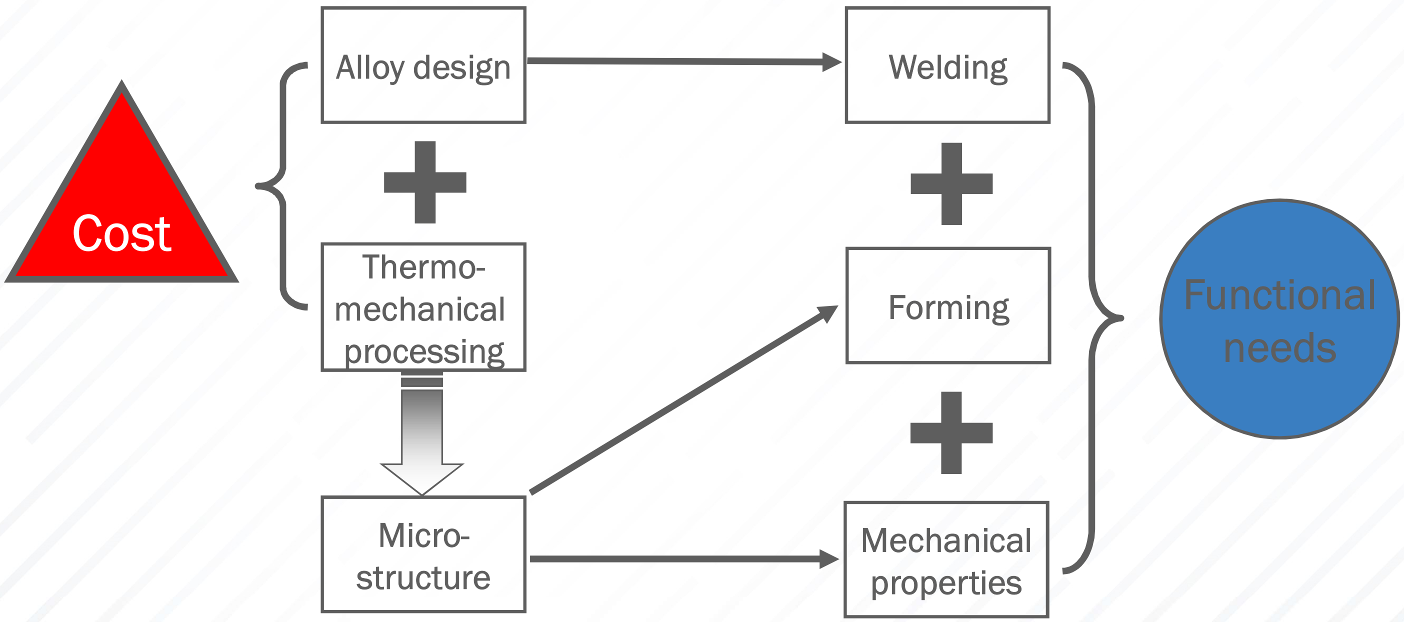
OUTLINE

- Introduction
- Conventional Role of Nb in HSS
  - Precipitation Strengthening
  - Grain Refinement
- Nb Metallurgy in AHSS
  - Multiphase Steels (DP, MP, CP)
  - TRIP-Aided Steels (CFB, Q&P)
- Nb Effects on Delayed Fracture
- Conclusions

INTRODUCTION – FUNDAMENTALS OF Nb



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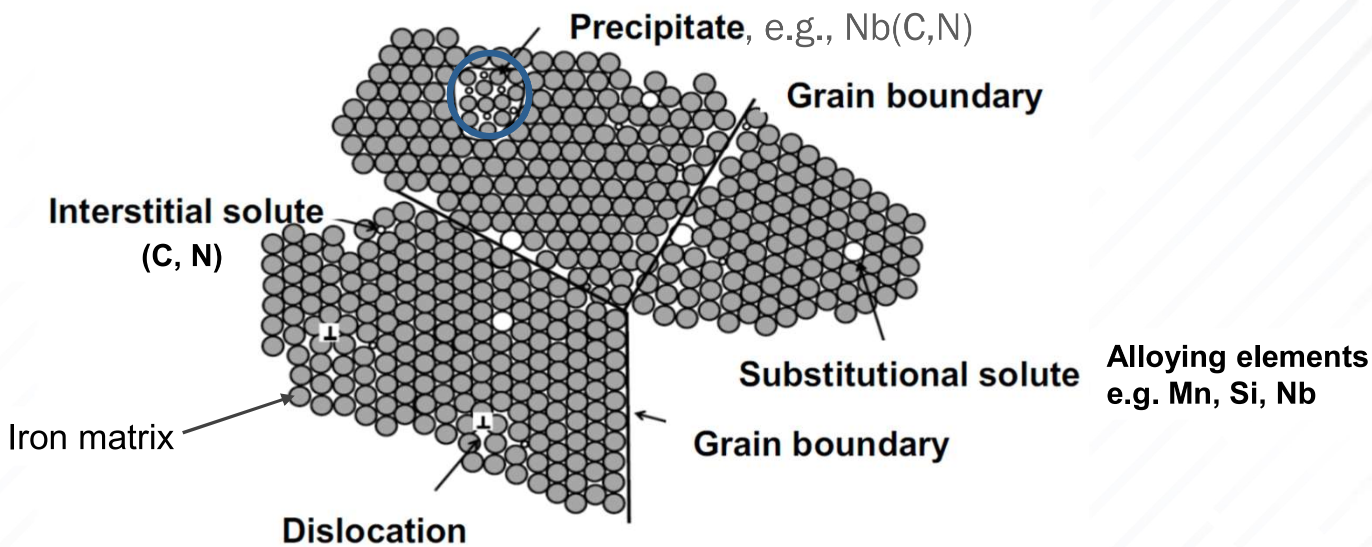
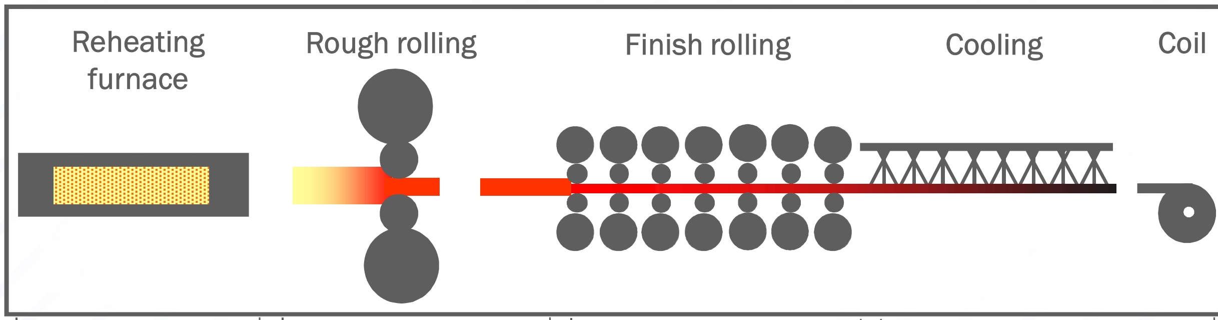


- Small atoms such as carbon or nitrogen reside on interstitial lattice sites.
- Large atoms such as manganese, silicon, niobium, etc., substitute iron atoms in the lattice.
- Carbon form carbides with iron and several alloying elements (e.g. niobium, titanium, vanadium).

INTRODUCTION – FUNDAMENTALS OF Nb

MAJOR PROCESS STEPS IN THE HOT ROLLING MILL (STRIP)

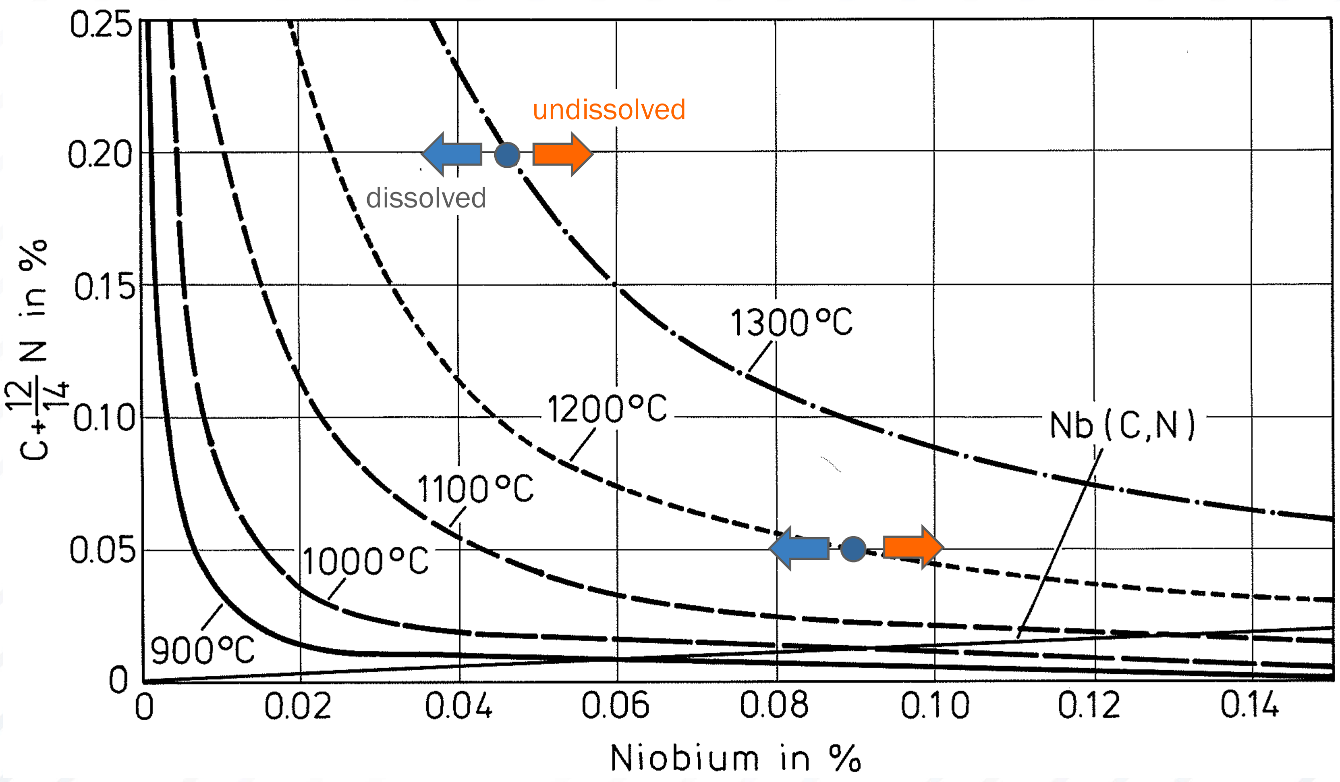


Finishing

Austenitizing (1200-1250 °C) Dissolution of alloying elements	Thickness reduction 200 → 25-50 mm Multiple static recrystallizations (1150-1000 °C)	Thickness reduction 25-50 → 5-2 mm Potentially without recrystallization (TMCP) (1000 °C-820 °C)	Cooling to coiling temperature (700-500°C) γ → α transformation

Effects of Nb Present at Each Stage of Process – Precipitation is Strain Dependent

INTRODUCTION – FUNDAMENTALS OF Nb



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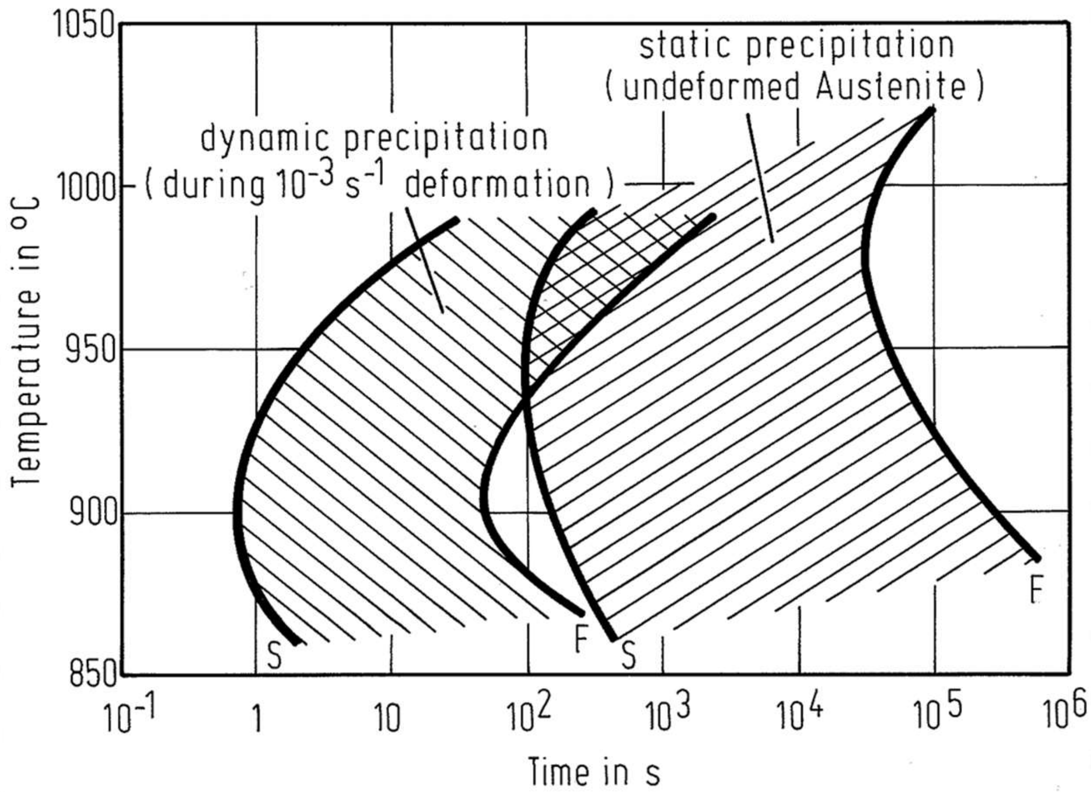

Precipitation of Nb during steel rolling is nucleation dependent – kinetics matter.

CONVENTIONAL ROLE OF Nb IN HSS

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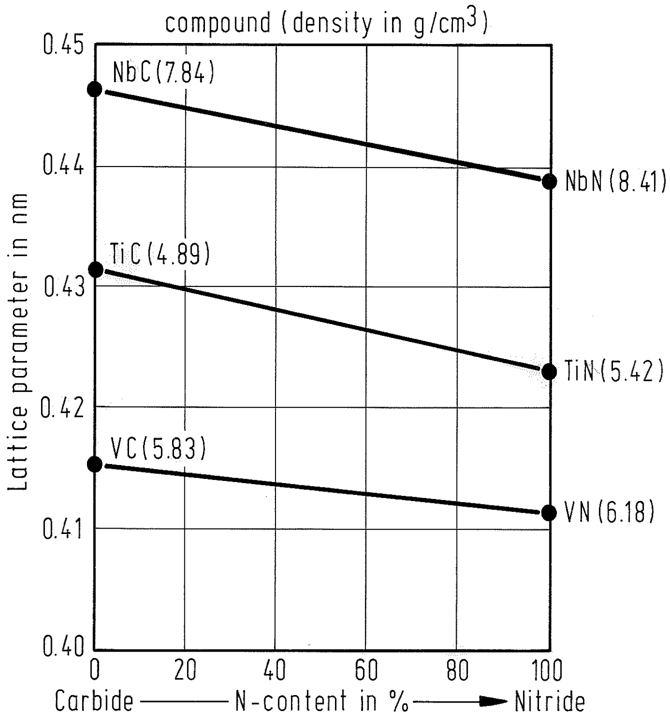
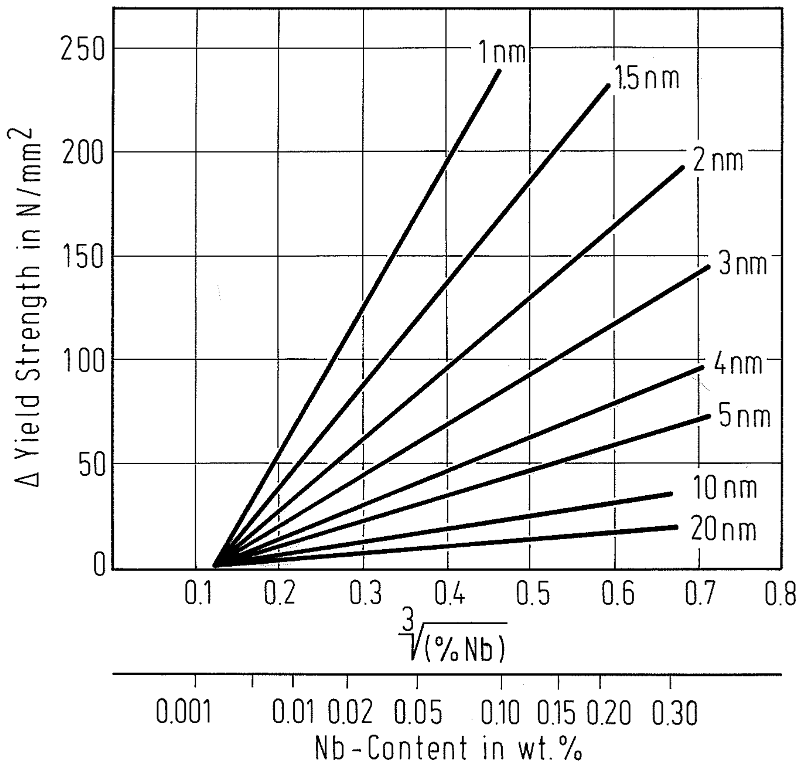
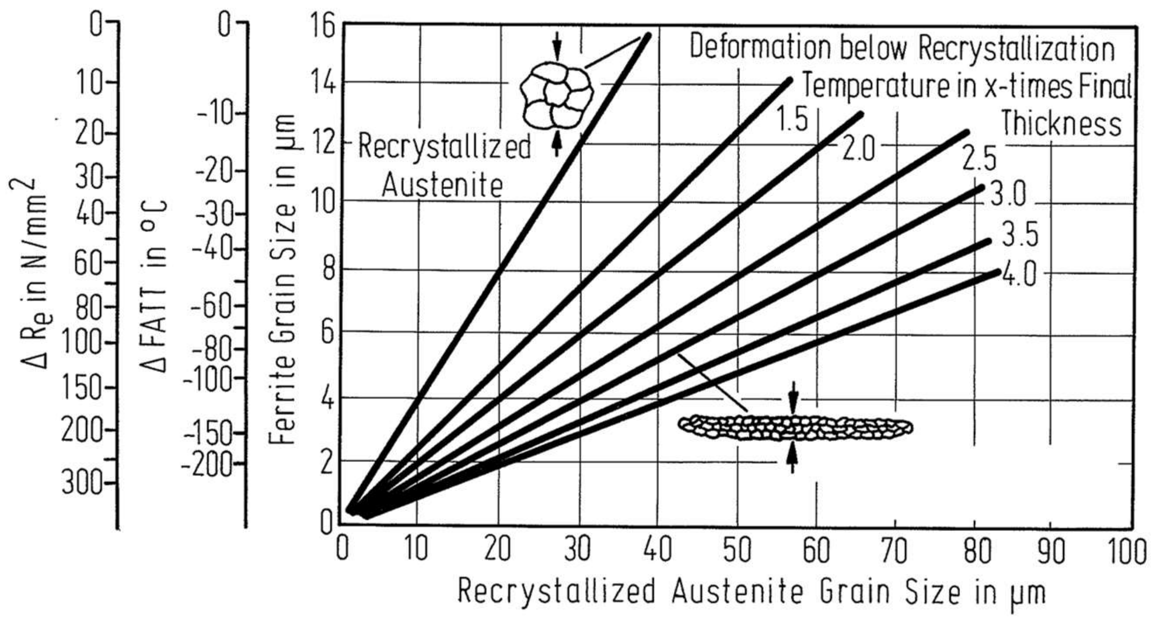
- Nb carbonitride precipitates strengthen ferrite through traditional mechanisms





CONVENTIONAL ROLE OF Nb IN HSS

- Nb as solute or in carbonitride precipitate acts to delay austenite recrystallization during hot rolling
- Similar effects occur in reheating following cold rolling
- The result is ferritic grain refinement



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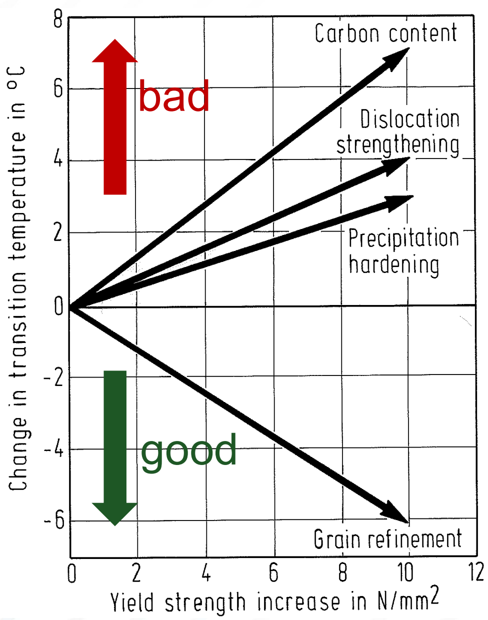

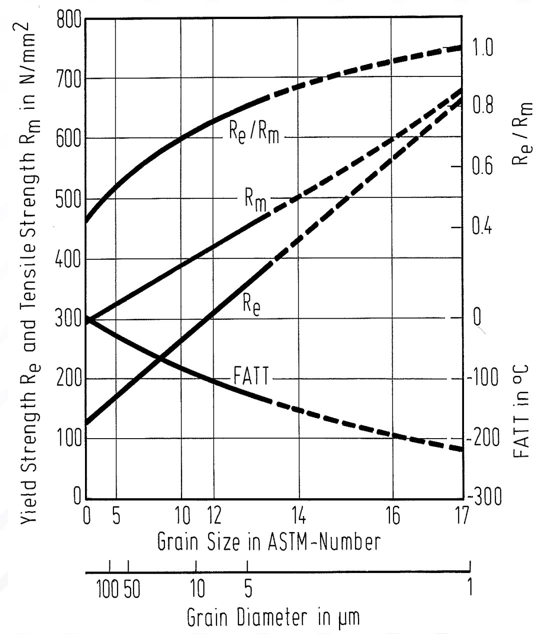

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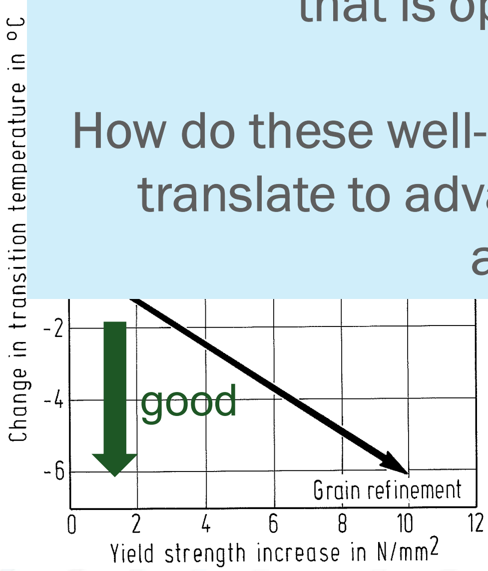
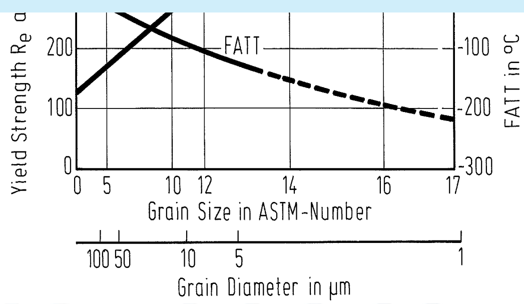
For strength - energy related optimizations in HSS, grain refinement should be the first mechanism that is optimized/maximized.

How do these well-proven and understood effects translate to advanced steels for automotive applications?





NIOBIUM (Nb) MICROALLOYING IN AHSS

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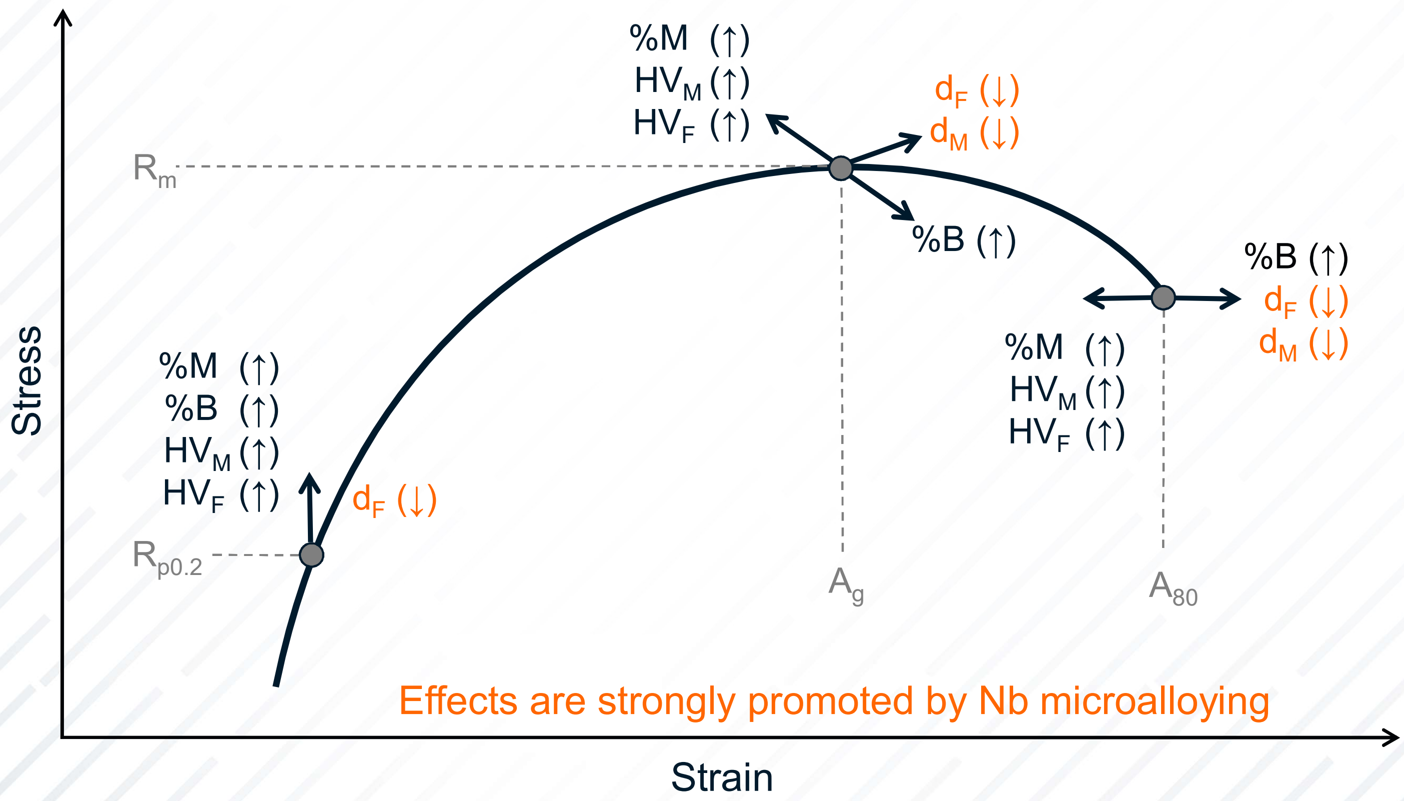


NIOBIUM (Nb) MICROALLOYING IN AHSS

MICROSTRUCTURAL INFLUENCES ON THE MECHANICAL PROPERTIES OF DP/MP/CP STEEL

Control of DP microstructure through prior hot band microstructure:

- Fine ferrite grain size
- Fine pearlite distribution
- Achievable by addition of microalloy + controlled rolling

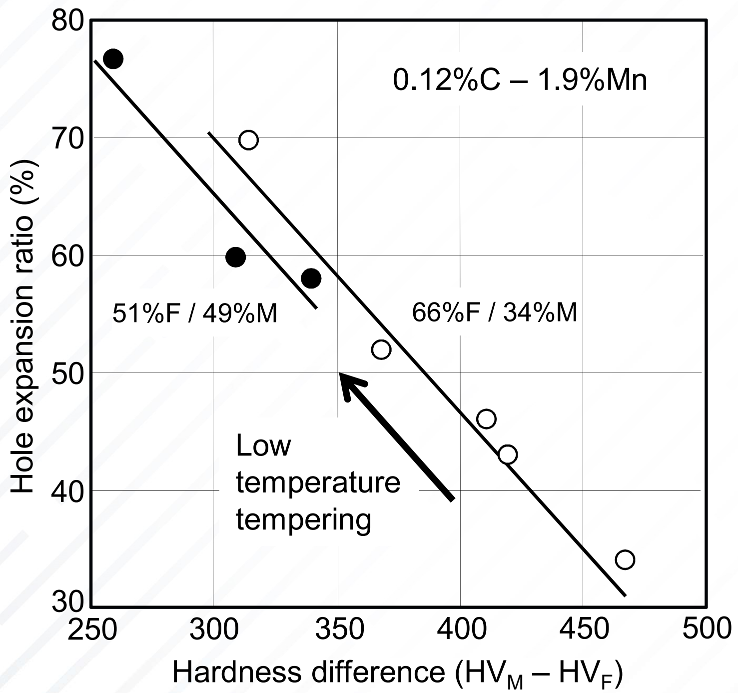
Optimization of DP/MP/CP Properties Will Require Resistance to Strain Partitioning to Enhance Local Formability with Maintenance of Uniaxial Tensile Properties

This is Achievable Through:

- Structural Refinement
- Reduction in Martensite/Ferrite Hardness Differences

NIOBIUM (Nb) MICROALLOYING IN AHSS

INFLUENCES ON HOLE-EXPANSION BEHAVIOR



During hole-expanding, micro-cracks propagate mostly along the phase interfaces in dual-phase steel in case of low stretch-flange-formability.

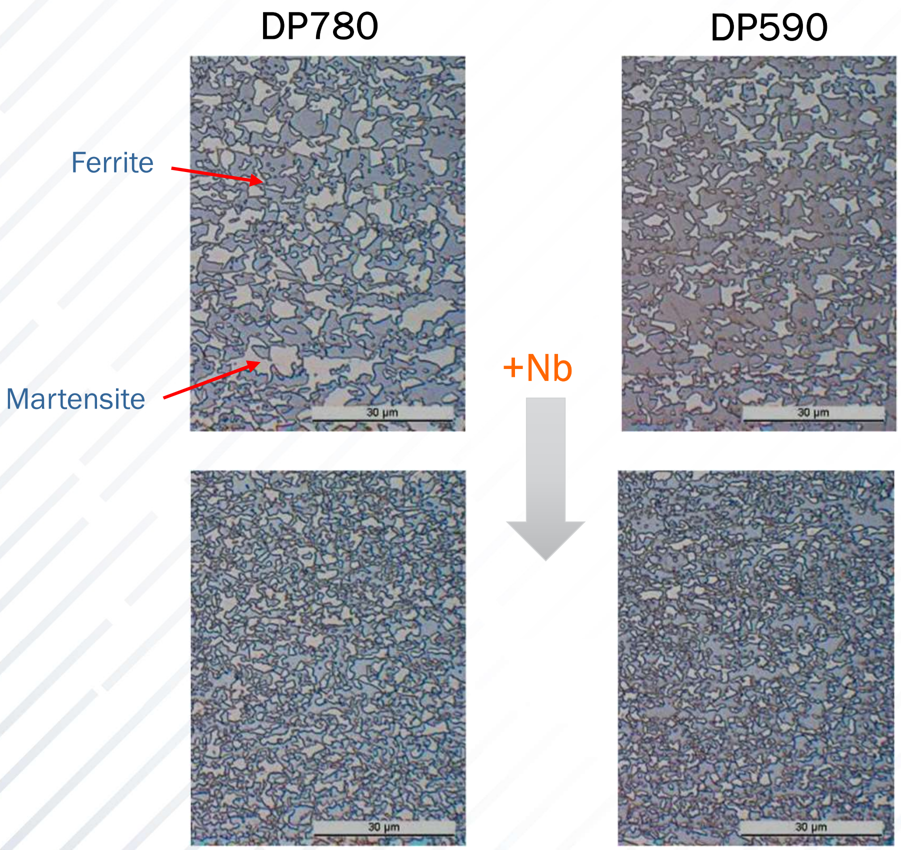
Microcracks tend to propagate through ferrite or martensite phase in dual-phase steel in case of high stretch-flange formability.

The **difference in hardness of ferrite and martensite is the dominant factor** of the stretch-flange formability in dual-phase steel. In addition, the volume fractions of phases also influence the formability.

Kohei HASEGAWA, Kenji KAWAMURA, Toshiaki URABE and Yoshihiro HOSOYA
ISIJ International, Vol. 44 (2004), No.3, pp. 603-609

NIOBIUM (Nb) MICROALLOYING IN AHSS

MICROSTRUCTURAL REFINEMENT OF DUAL PHASE STEEL

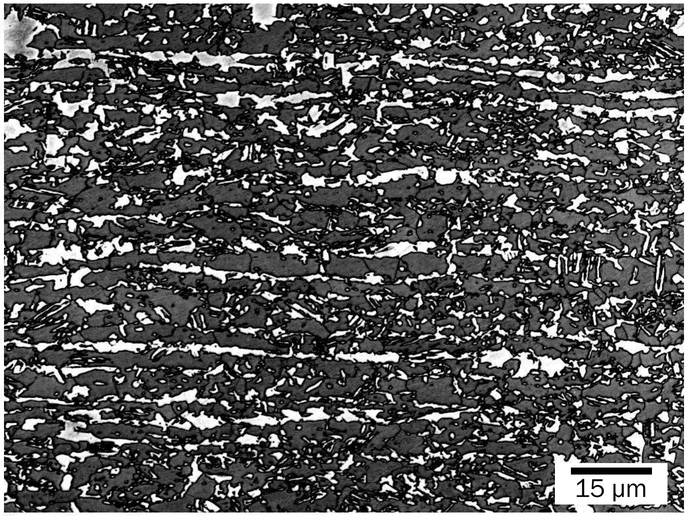


- Martensite islands with variable C content.
- Martensite clustering.
- Greater potential for crack propagation under local straining.

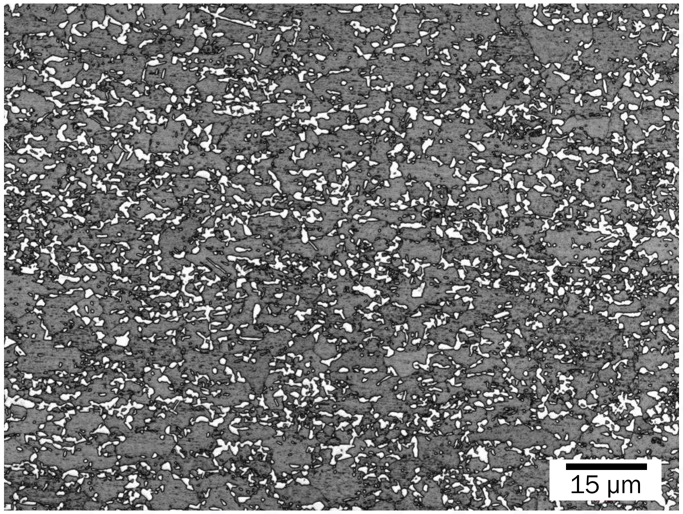
- Smaller martensite islands
- Reduced martensite clusters.
- Increased YS and TS.
- Improved hole expansion ratio and bendability.
- Lower C necessary to Achieve UTS

NIOBIUM (Nb) MICROALLOYING IN AHSS

MICROSTRUCTURAL REFINEMENT OF DUAL PHASE STEEL



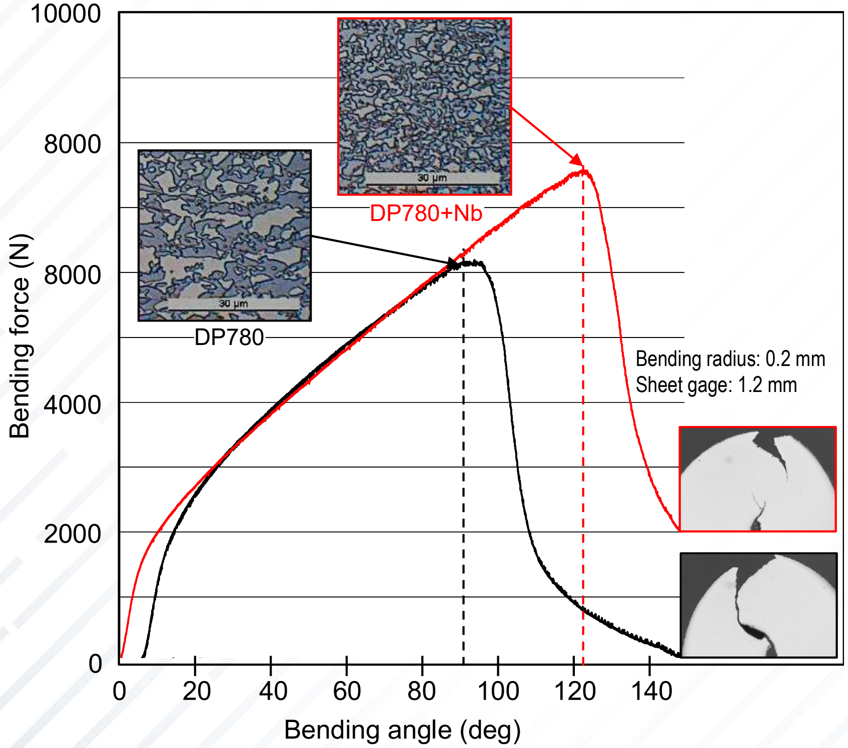
Standard DP780



DP780 + Nb

NIOBIUM (Nb) MICROALLOYING IN AHSS

MICROSTRUCTURAL REFINEMENT OF DUAL PHASE STEEL



Optimized Alloy Concepts Will Utilize:

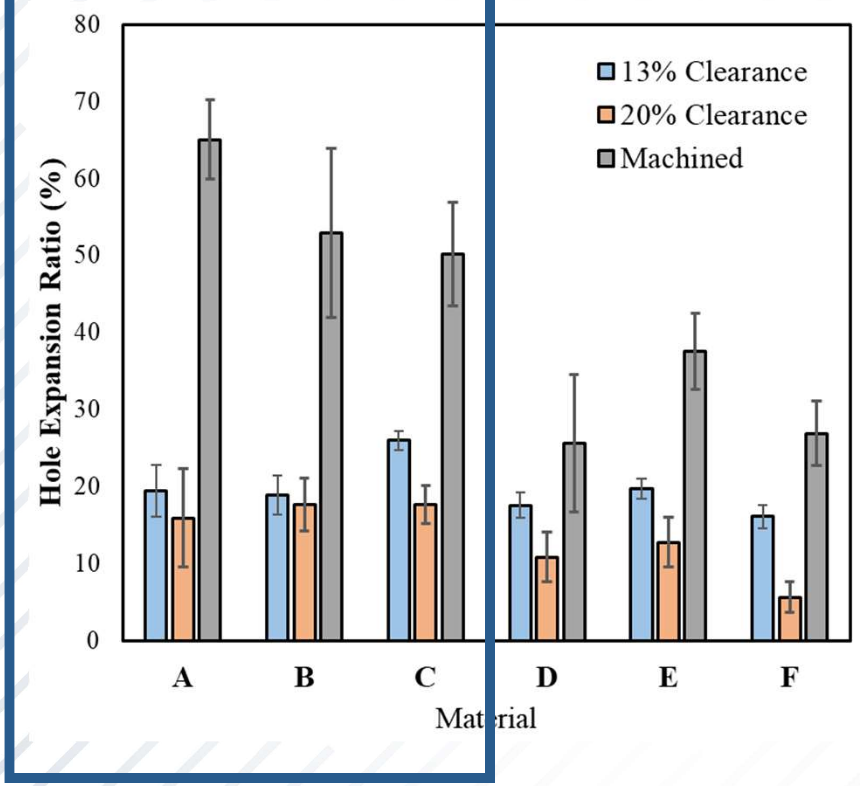
- Grain Refinement
- Minimization of C Content (MP and DP980 Grades Achievable at Sub-Peritectic C Levels).
- Continued or Greater Emphasis on Clean Steel Practices (low S)

Modular Concepts Exist and Have Been Demonstrated to Achieve Balanced Global and Local Formability for DP/MP/CP 590-980 MPa

NIOBIUM (Nb) MICROALLOYING IN AHSS

MICROSTRUCTURAL REFINEMENT OF DUAL PHASE STEEL

Nb-Added Chemistry



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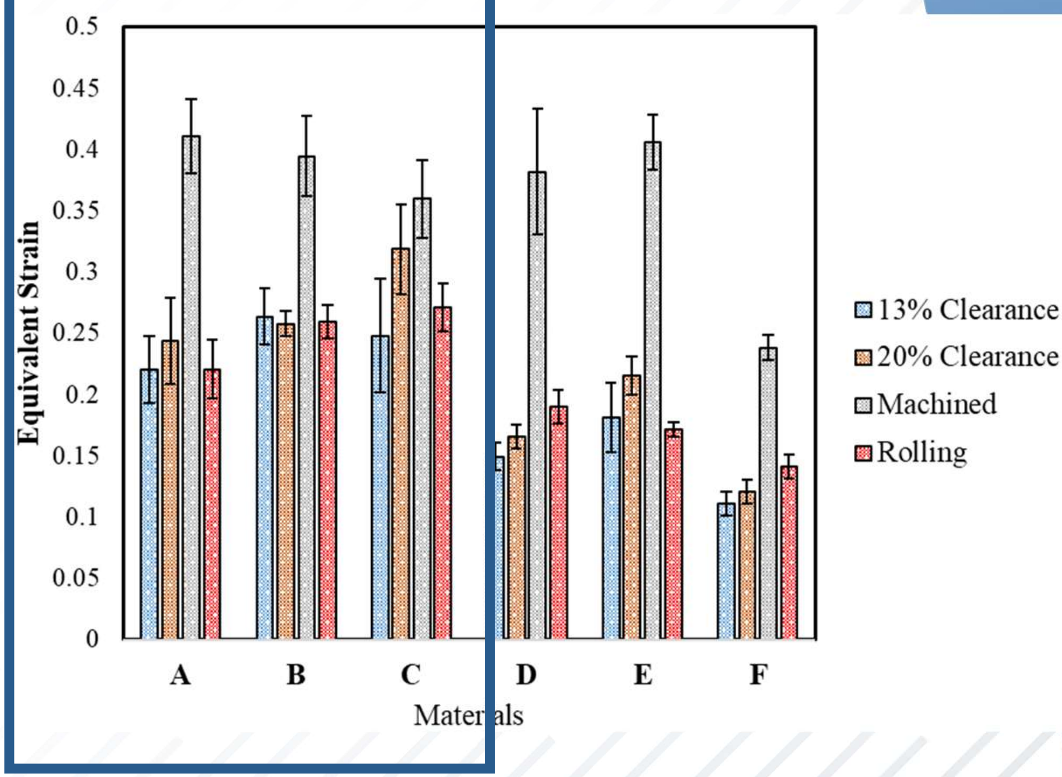
Nb-Added Chemistry



Half Dome Edge Stretch - DIC

NIOBIUM (Nb) MICROALLOYING IN RA AHSS

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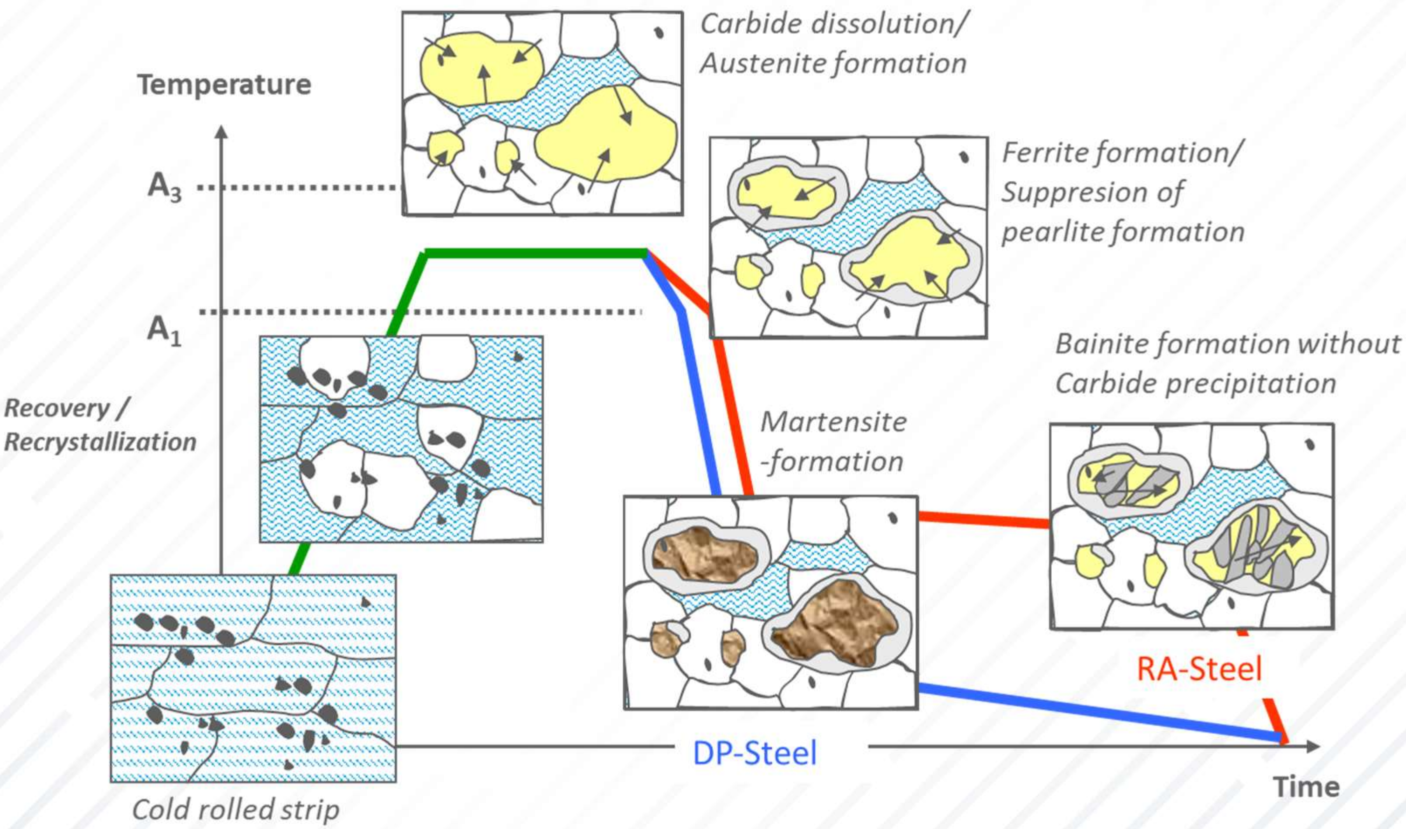
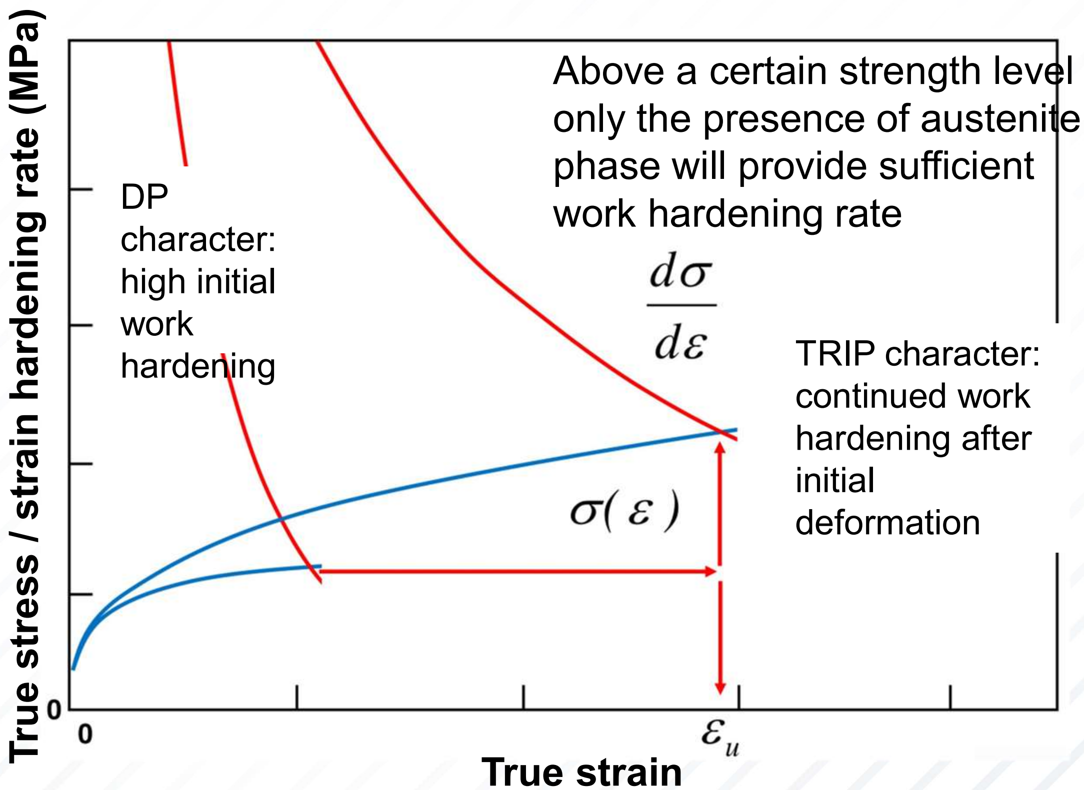
PRODUCTION OF CLASSIC AND RA MULTIPHASE STEELS



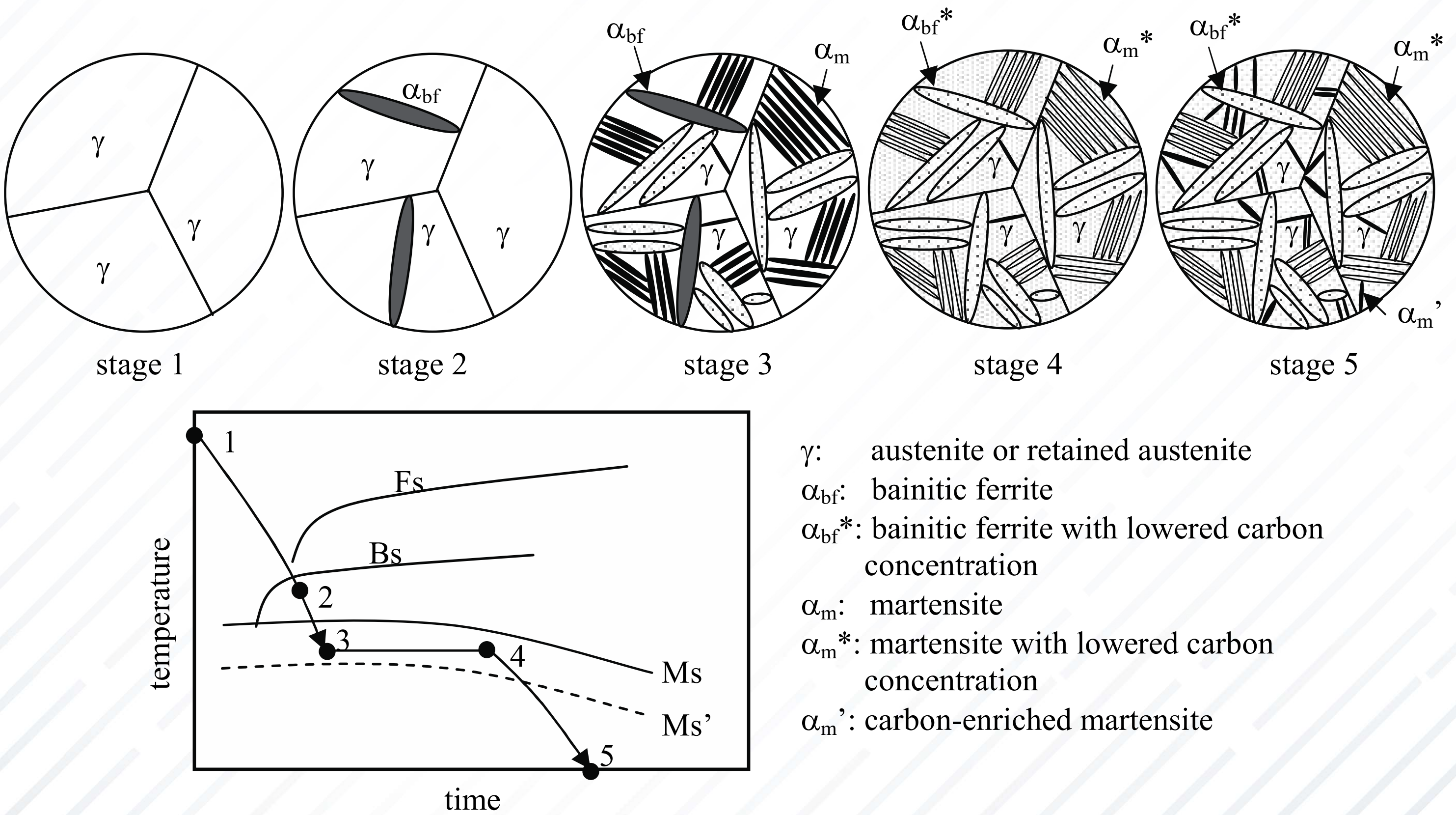
NIOBIUM (Nb) MICROALLOYING IN AHSS

THE CONSIDÉRE CRITERION: IMPROVING ELONGATION AT HIGH STRENGTH



NIOBIUM (Nb) MICROALLOYING IN AHSS

STAGES IN FORMING A RETAINED AUSTENITE MICROSTRUCTURE



γ: austenite or retained austenite

α_{bf}: bainitic ferrite

α_{bf}*: bainitic ferrite with lowered carbon concentration

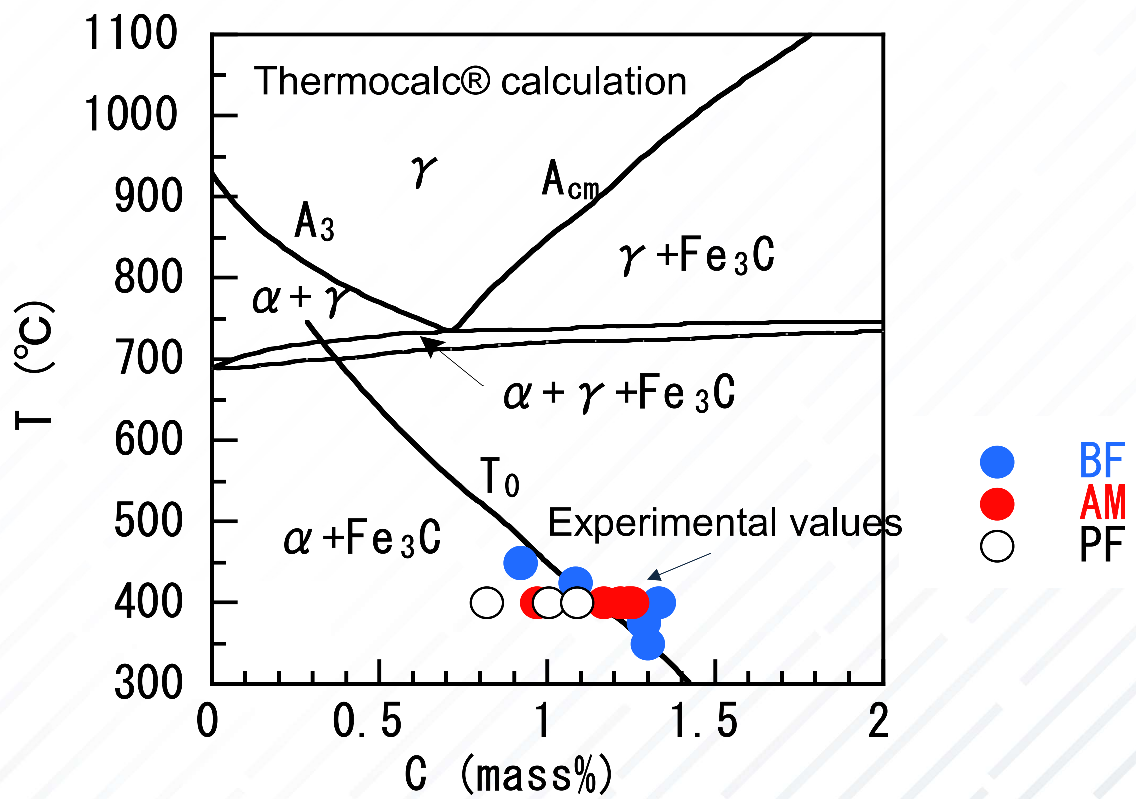
α_m: martensite

α_m*: martensite with lowered carbon concentration

α_m': carbon-enriched martensite

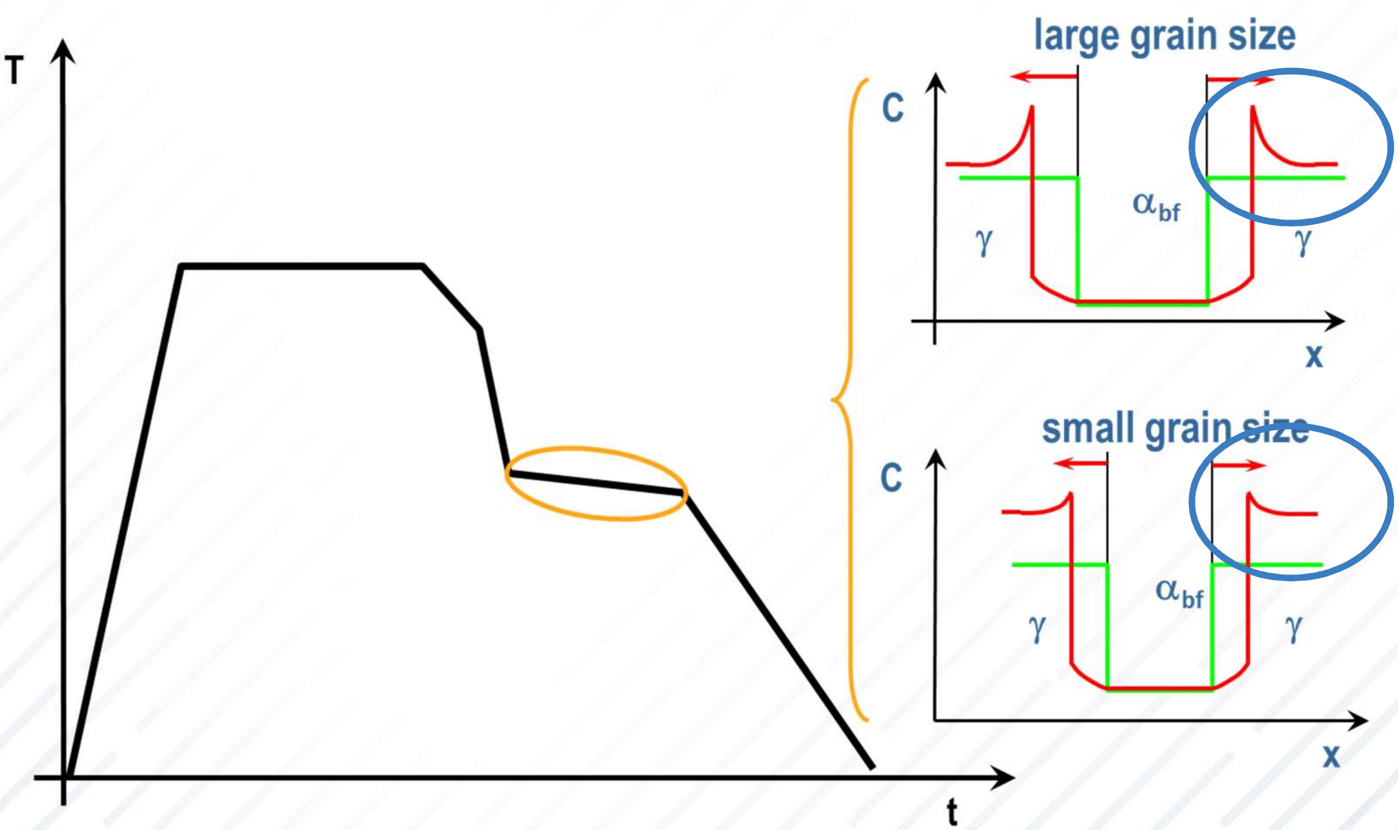
NIOBIUM (Nb) MICROALLOYING IN AHSS

EQUILIBRIUM DIAGRAM OF FE-C-1.5SI-1.5MN AND RA CARBON CONCENTRATION



NIOBIUM (Nb) MICROALLOYING IN AHSS

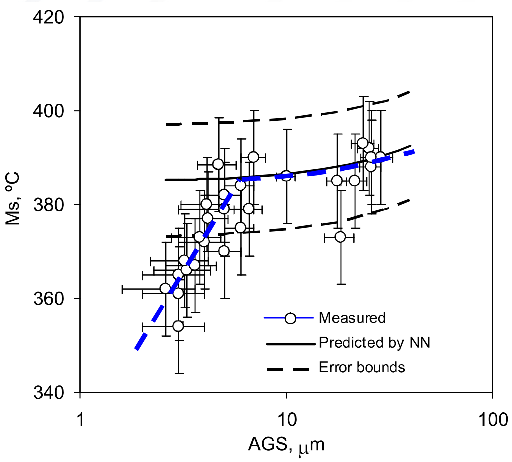
CARBON PARTITIONING: EFFECT OF GRAIN SIZE



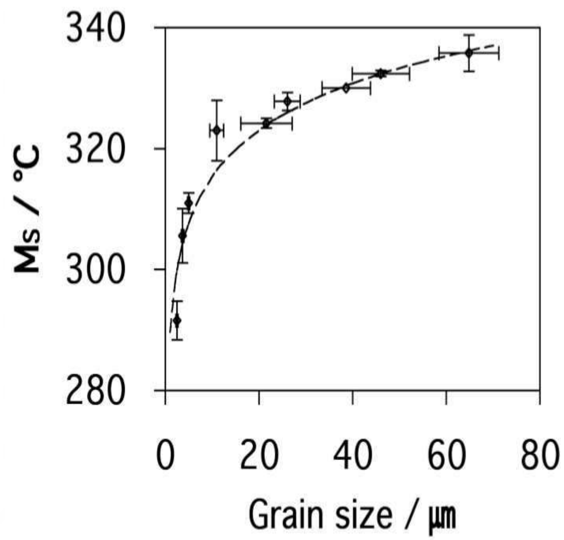
NIOBIUM (Nb) MICROALLOYING IN AHSS

PAGS EFFECT ON M_S TEMPERATURE

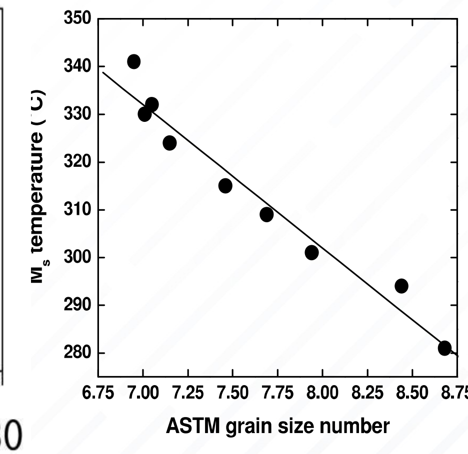
Ref.: A. García-Junceda, C. Capdevila, F.G. Caballero, C. García de Andrés



Ref.: Hong–Seok Yang and H. K. D. H. Bhadeshia



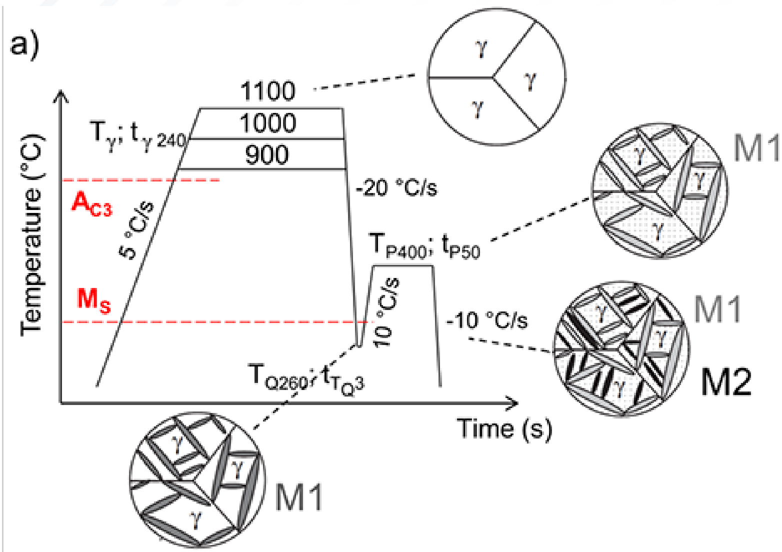
Ref.: Seok-Jae Lee and Young-Kook Lee



- Niobium is very efficient in controlling PAGS (Zener Pinning).
- This can help to enhance robustness of Q&P process.

NIOBIUM (Nb) MICROALLOYING IN AHSS

EFFECT OF PAGS ON MARTENSITE CHARACTER



T_γ, °C	900	1000	1100
PAGS, µm	14±1	24±1	67±1
f_{M1}	0.62	0.73	0.81
f_{RA}	0.16	0.15	0.14
f_{M2}	0.22	0.12	0.05

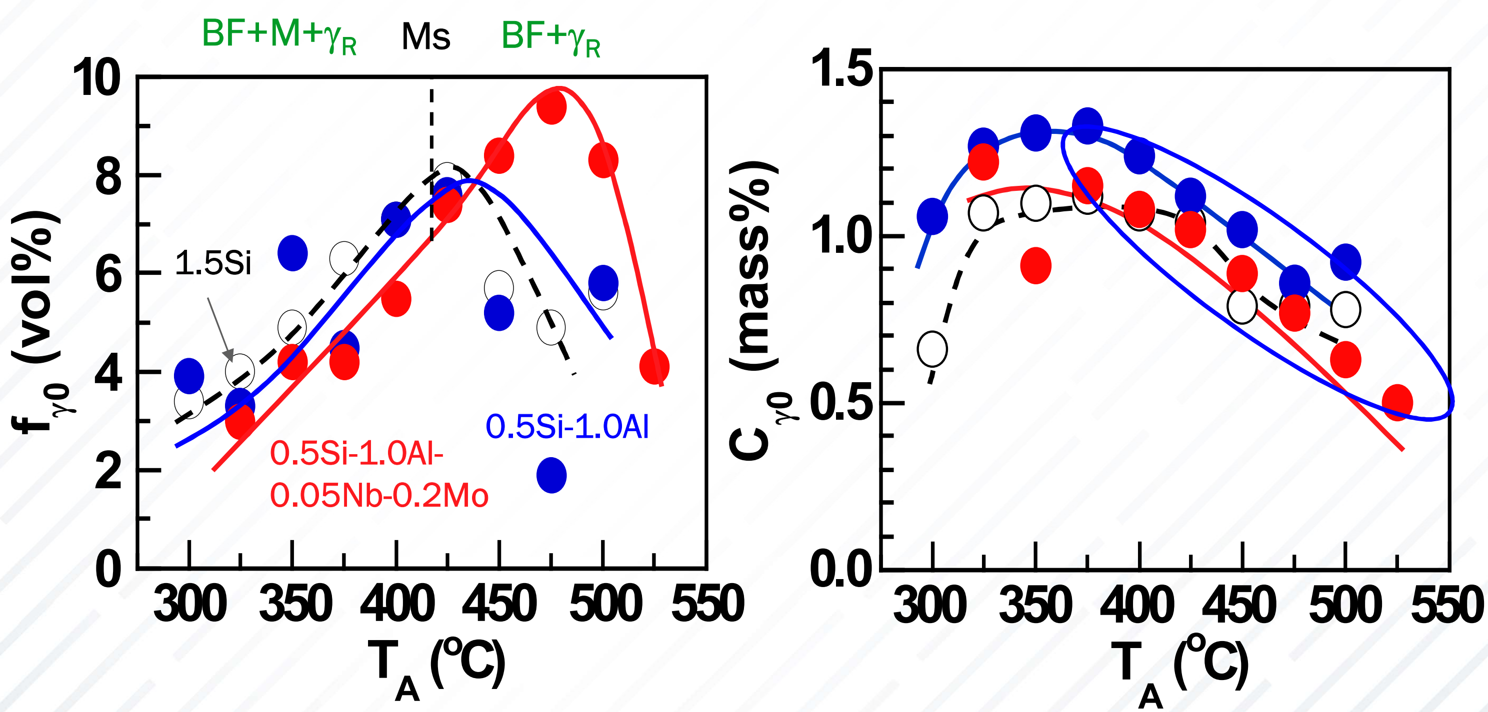
M1 is carbon depleted martensite (softer).
M2 is carbon enriched martensite (harder).

Mechanical stabilization of austenite phase due to a reduction of its grain size causes a reduction in M_s – C kinetics reduce at same fraction.

Lower f_{M1} implies lower carbon content available for diffusion into the adjacent austenite during partitioning.
This leads to more f_{M2} resulting in higher strength for a given austenite character.

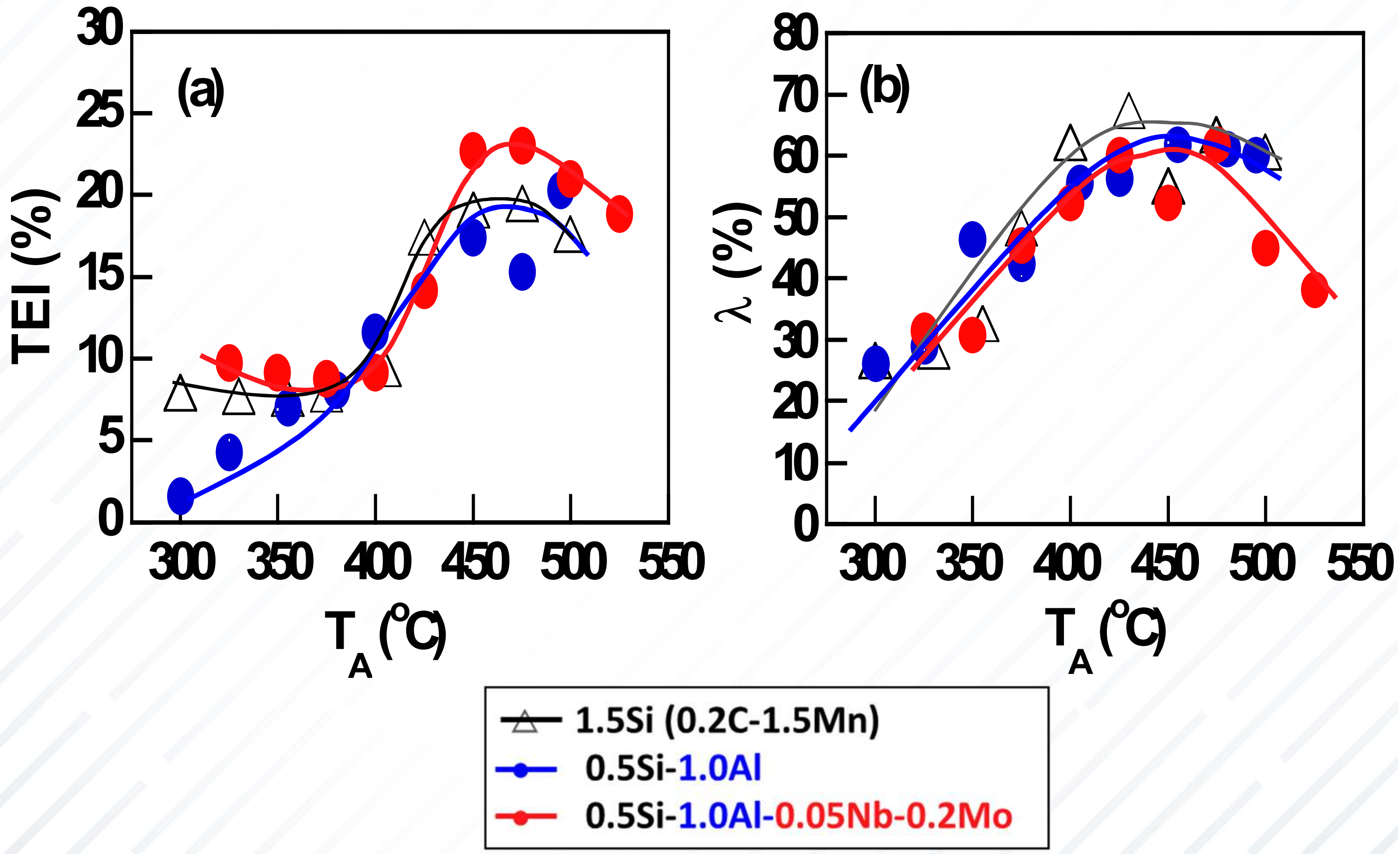
NIOBIUM (Nb) MICROALLOYING IN AHSS

EFFECT OF OVER-AGING TEMPERATURE AND ALLOYING CONCEPT ON RETAINED AUSTENITE IN RA (CARBIDE FREE BAINITIC) STEEL



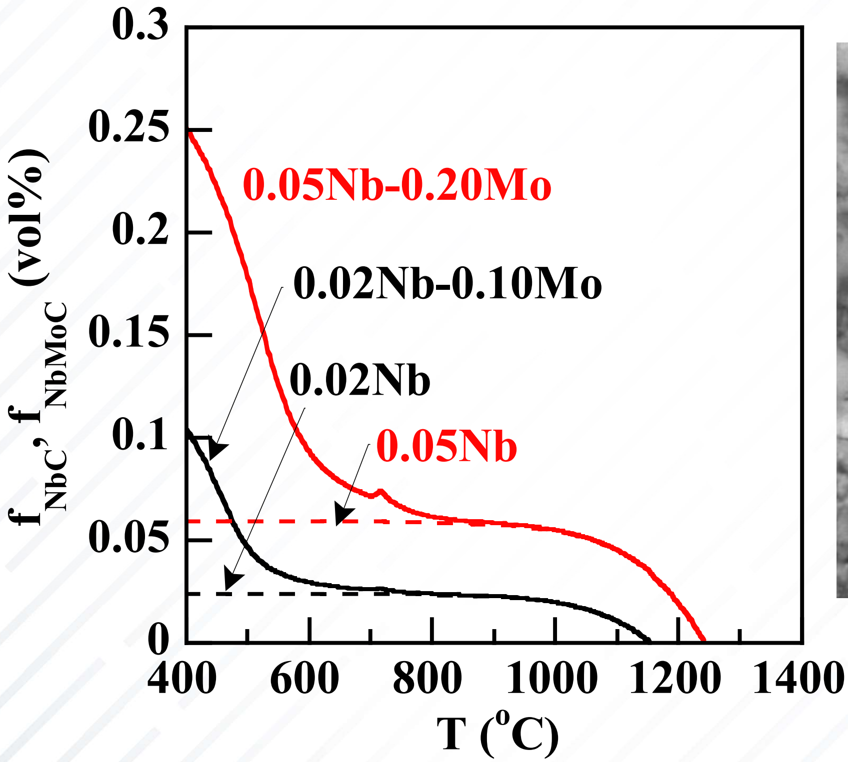
NIOBIUM (Nb) MICROALLOYING IN AHSS

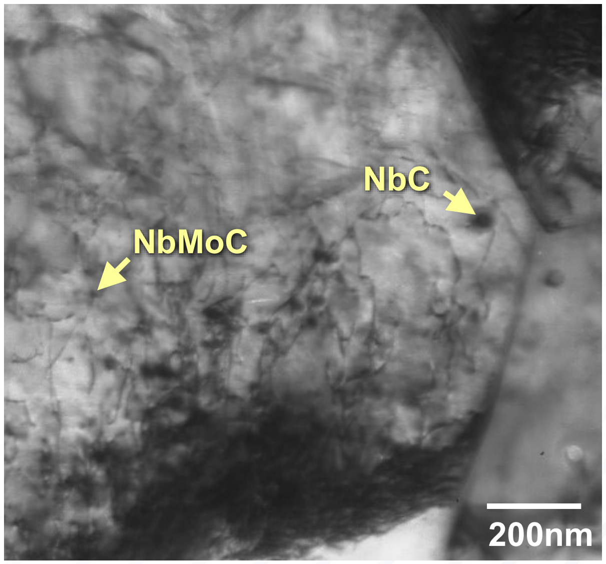
EFFECT OF Al, Nb AND Mo ADDITIONS TO 0.2% C-1.5% Mn CFB STEEL



NIOBIUM (Nb) MICROALLOYING IN AHSS

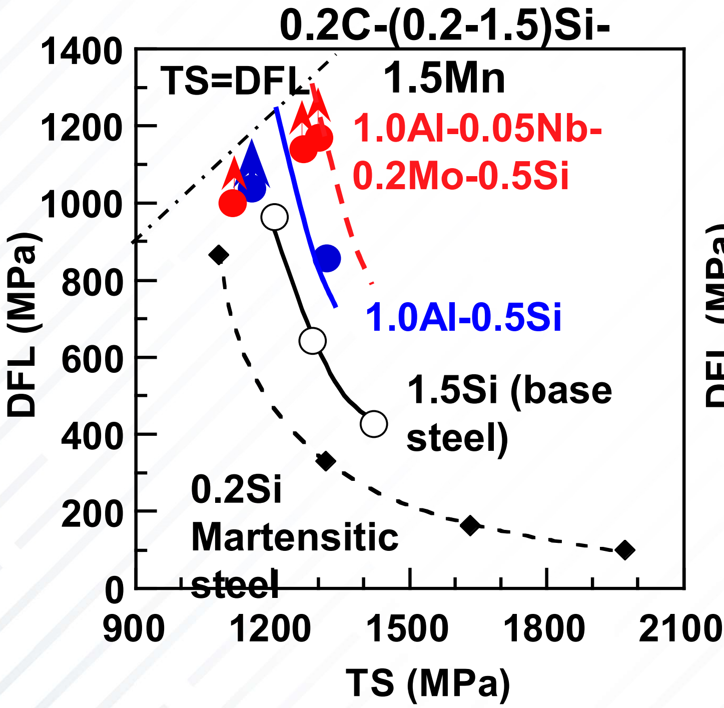
PRECIPITATION BEHAVIOR OF NB AND/OR MO BEARING 0.2C-1.5SI-1.5MN STEELS

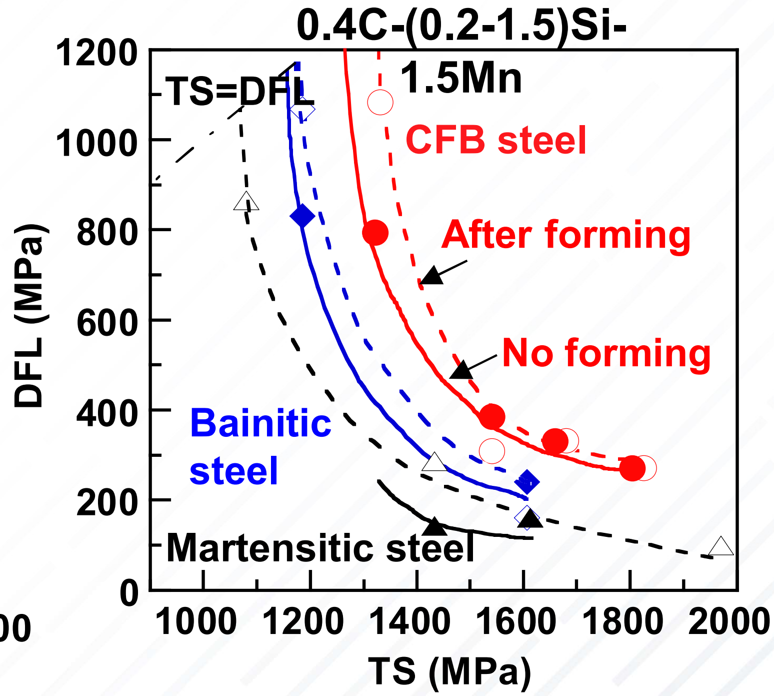




NIOBIUM (Nb) MICROALLOYING IN AHSS

DELAYED FRACTURE LIMIT (DFL) OF CFB STEELS

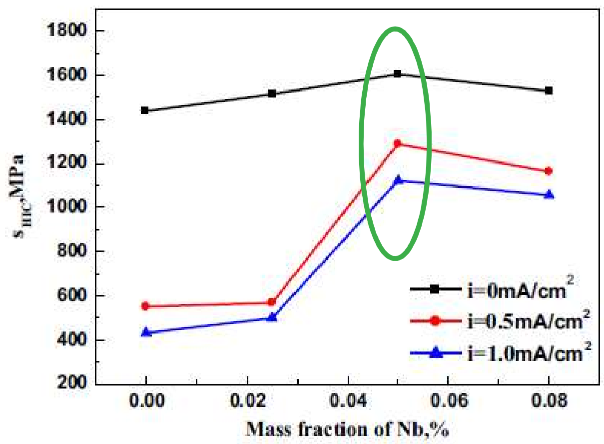


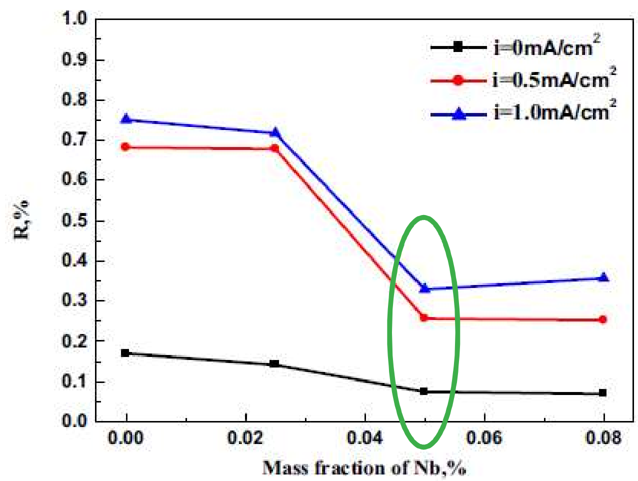


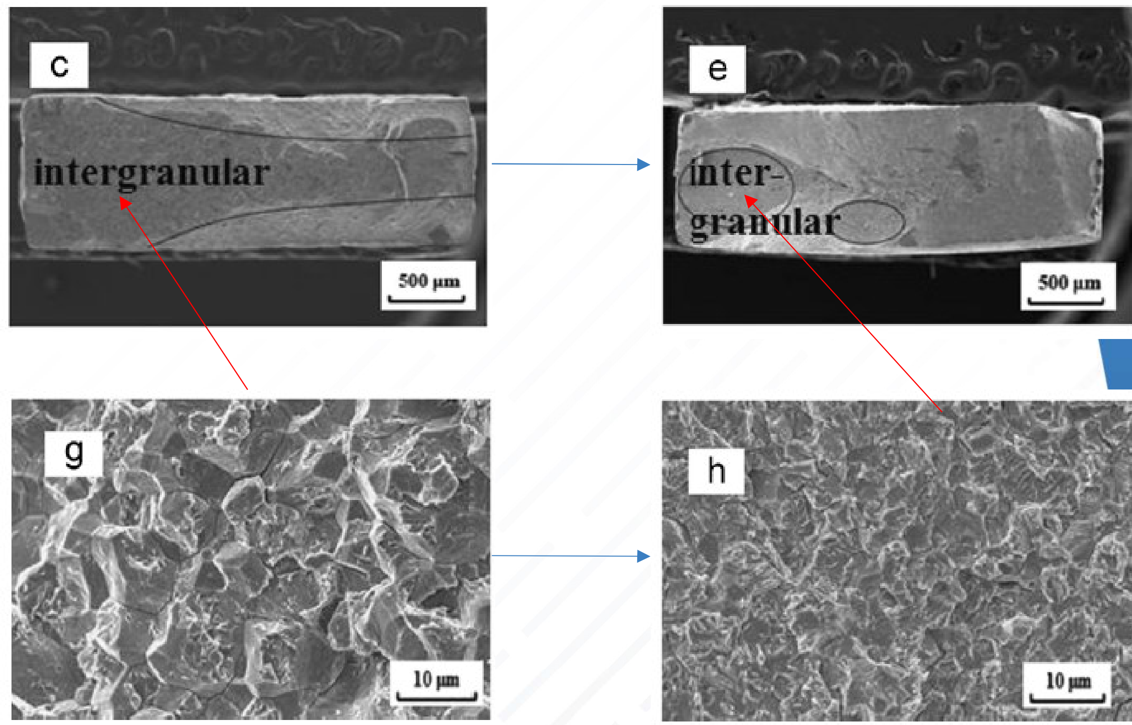
Sugimoto, et al., Materials Science and Technology, 2009, Vol 25, No 9

NIOBIUM (Nb) MICROALLOYING IN AHSS

HYDROGEN EMBRITTLEMENT RESISTANCE IN PHS STEELS







0 Nb

0.05 Nb

Zhang et al., Materials Science & Engineering A, 2015, Vol 626

CONCLUSIONS

- Nb strengthens conventional low carbon ferritic high strength steel by conventional mechanisms of grain size refinement and precipitation hardening.
- Grain size refinement may be considered the "basis" of strengthening mechanisms due to its positive influence on fracture toughness (resistance to crack propagation) – others require trade-off
- Nb additions in AHSS are considered for optimization of the primary strengthening mechanisms, namely the multiphase structure created. The demonstrated benefits of Nb in this regard include:
  - Refinement and Homogeneity of Microstructure for Local Formability in MP
  - Precipitation Hardening of Ferritic and Bainitic Constituents by NbC
  - Modification of Martensite / Austenite Characters in RA Steels for Better Property Balance of Process Robustness
  - Precipitates Act as H-trapping Sites

THANK YOU!

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