GREAT DESIGNS IN STEEL

# PROCESS CONSIDERATIONS FOR NIOBIUM IN A TRIP-ASSISTED DP STEEL

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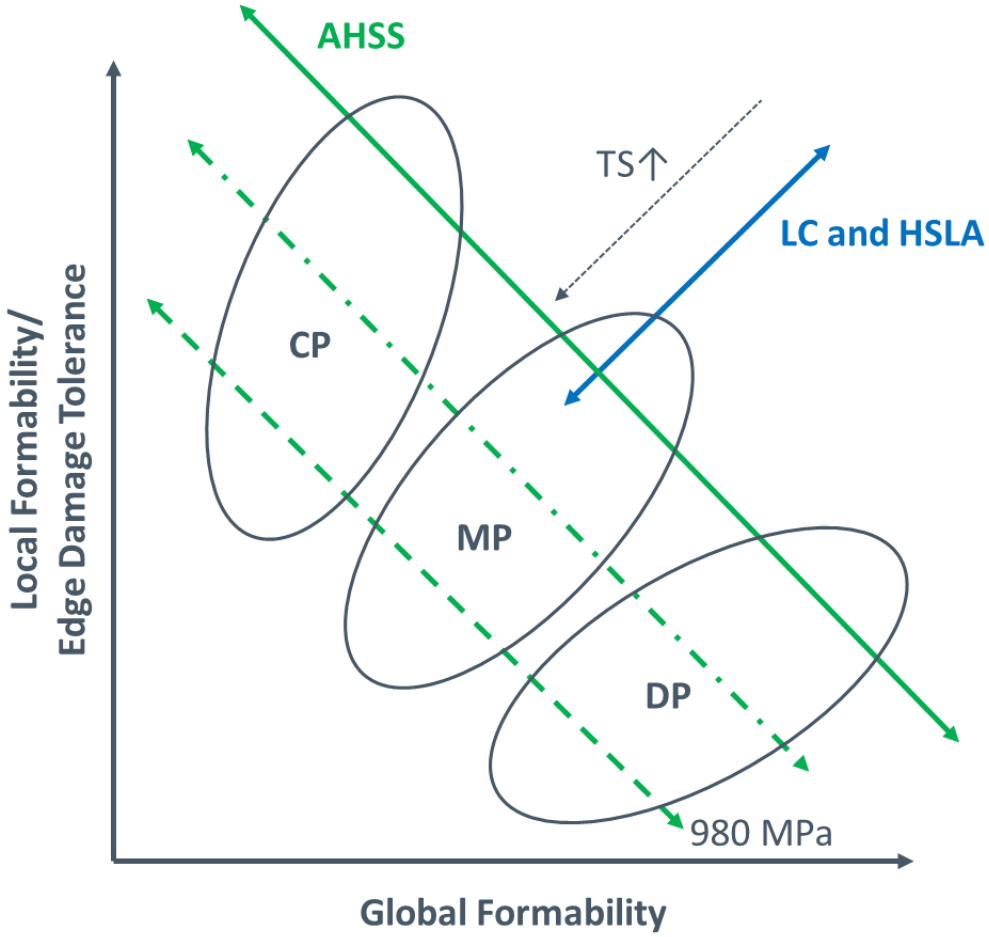
# OUTLINE

- Background & Motivation
  - Formability Challenges in AHSS
  - Microalloy Effects in AHSS
  - DH Steel Development
- Materials & Methods
  - Alloy Design
  - Process Design
  - Metallurgical Analyses
- Results & Discussion
  - Microstructural Evolution
  - Evolution of Niobium Precipitation
  - Mechanical Performance
- Conclusions

# BACKGROUND & MOTIVATION

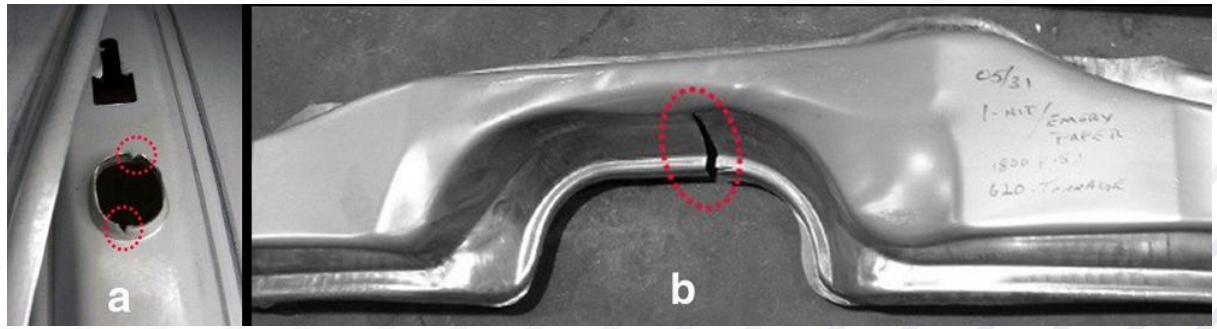
# FORMABILITY CHALLENGES IN AHSS




Formability Balance Remains a Challenge in Multiphase Steels

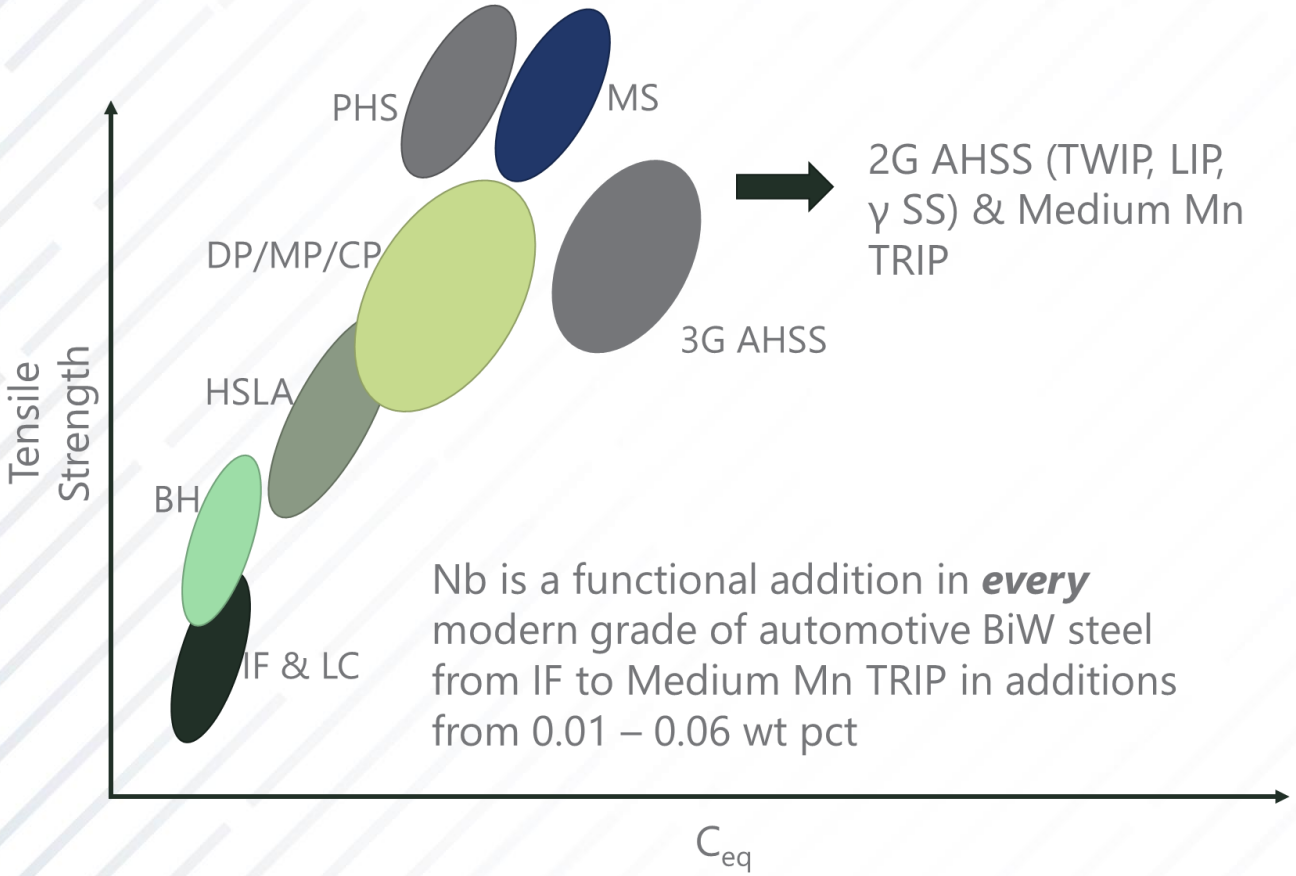
For Conventional Ferritic Steels, Global and Local Formability are Positively Correlated (Shown in Blue)

Global and Local Formability are Negatively Correlated for Multiphase AHSS (Shown in Green)



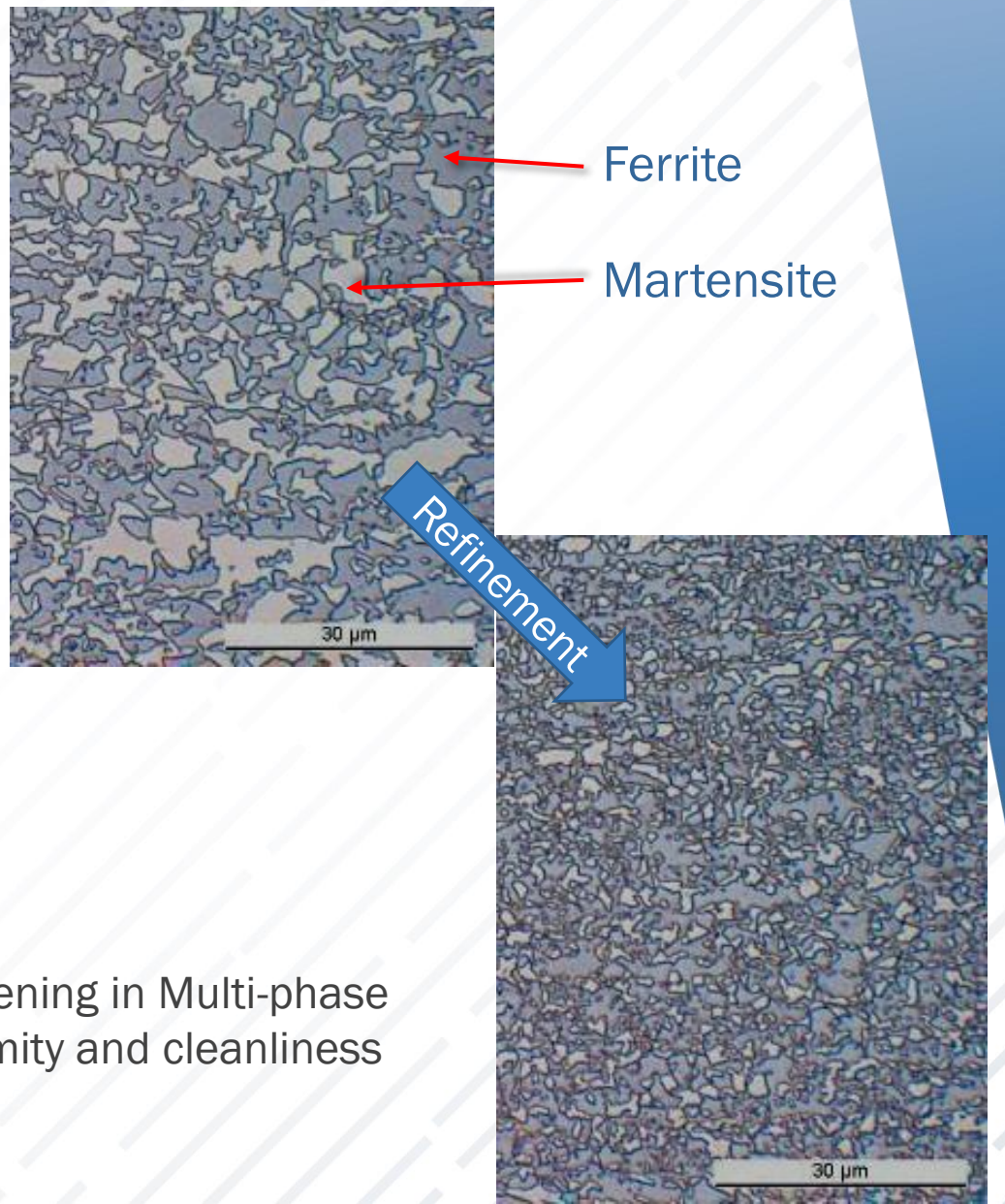

Coryell, GDIS 2016

# MICROALLOY EFFECTS IN AHSS




2G AHSS (TWIP, LIP, γ SS) & Medium Mn TRIP

Nb is a functional addition in ***every*** modern grade of automotive BiW steel from IF to Medium Mn TRIP in additions from 0.01 – 0.06 wt pct

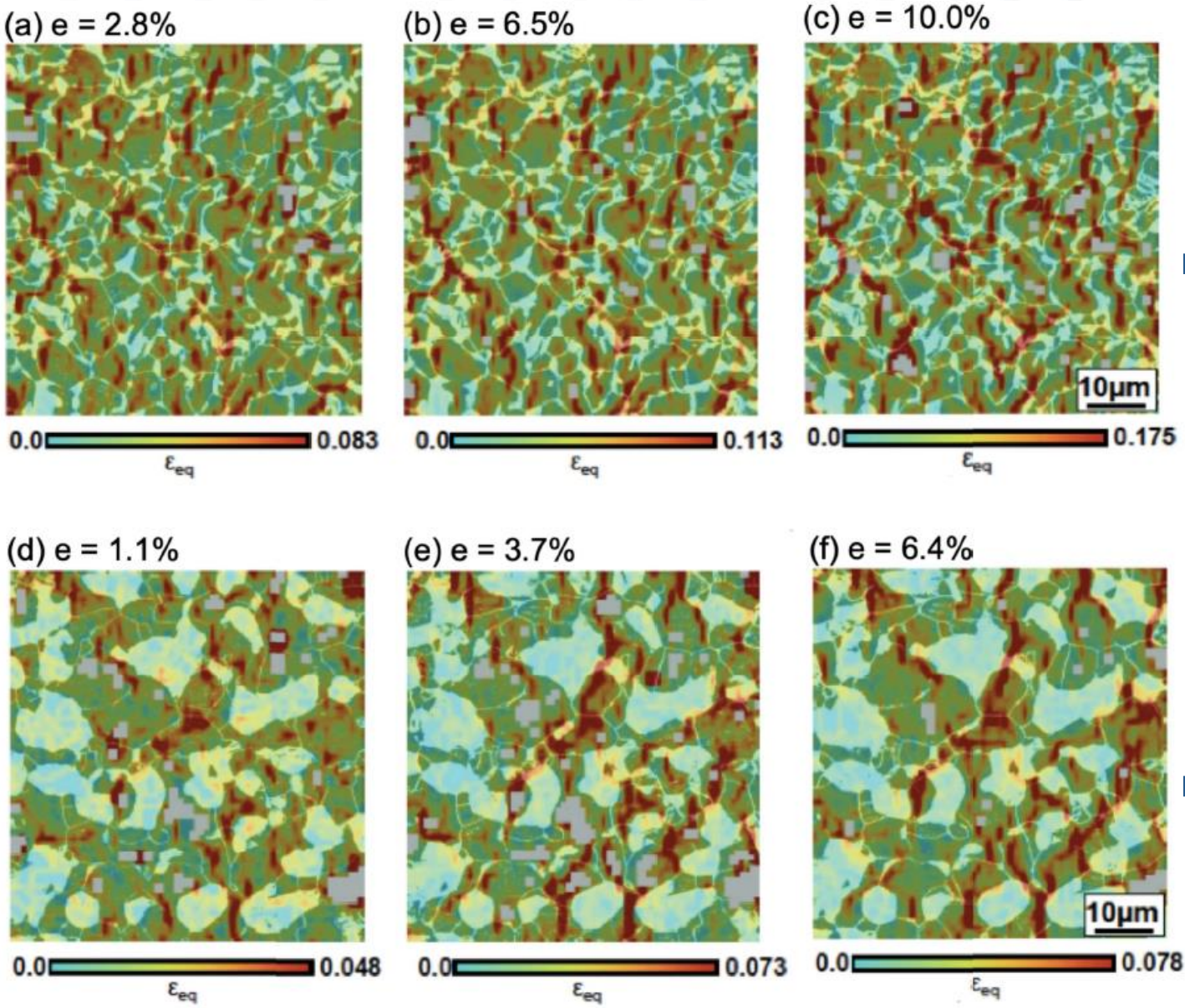



The Effect of Nb: Structural Refinement and Ferrite Strengthening in Multi-phase Steels Improves Formability Balance. Microstructural uniformity and cleanliness remain similarly important to prevention of local fracture.

# MICROALLOY EFFECTS IN AHSS

- Strain Distributions more homogeneous in refined structure.

- Strain more localized at F/M interfaces in coarse structure.

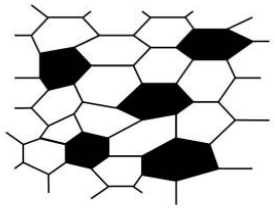



Terada et al., 2017 IOP Conf. Ser.: Mater. Sci. Eng., 219, 012008

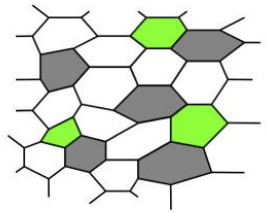
# DEVELOPMENT OF HD DP STEELS

**1st generation AHSS (TS: 450 – 980 MPa)**

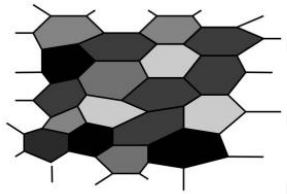
**Dual Phase**



**TRIP**

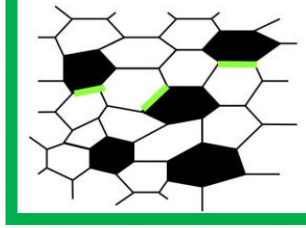


**Complex Phase**

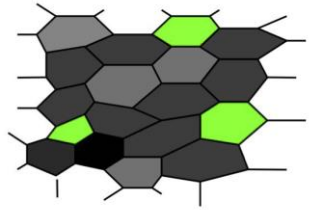


**3rd generation AHSS (TS: 780 – 1180 MPa)**

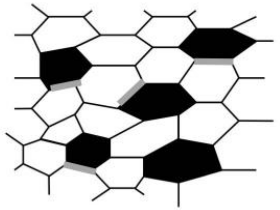
**Dual Phase HD**
- Ferrite
- Harder martensite
- Retained austenite



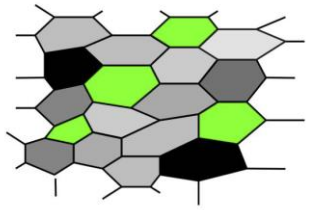
**Q&P steel**
- Martensite
- Martensite (tempered)
- Retained austenite



**Microstructural refinement**



**Low-C Dual Phase**
- Ferrite
- Softer martensite
- Bainite



**TBF steel**
- Bainitic ferrite
- Bainite
- Retained austenite

"High Ductility" (HD) DP steel variants provide increased drawability aided by a small share of austenite retained in the microstructure

This study investigates the microstructural evolution and progress of niobium precipitation during industrial processing of high-ductility DP 980

| Stahlgüte / Steel Grade | Streckgrenze / Yield Strength | Zugfestigkeit / Tensile Strength | Bruchdehnung / Elongation | | | n | | $BH_2$ |
|---|---|---|---|---|---|---|---|---|
| | $R_{p0,2}$ MPa | $R_m$ MPa | Type 1 $A_{50\ mm}$ % | Type 2 $A_{80\ mm}$ % | Type 3 $A_{50\ mm}$ % | $n_{4-6}$ | $n_{10-20/Ag}$ | MPa |
| CR440Y780T-DH | 440 – 550 | 780 – 900 | ≥ 19 | ≥ 18 | ≥ 19 | ≥ 0,18 | ≥ 0,13 | ≥ 30 |
| CR700Y980T-DH | 700 – 850 | 980 – 1180 | ≥ 14 | ≥ 13 | ≥ 14 | - | - | ≥ 30 |

# MATERIALS & METHODS

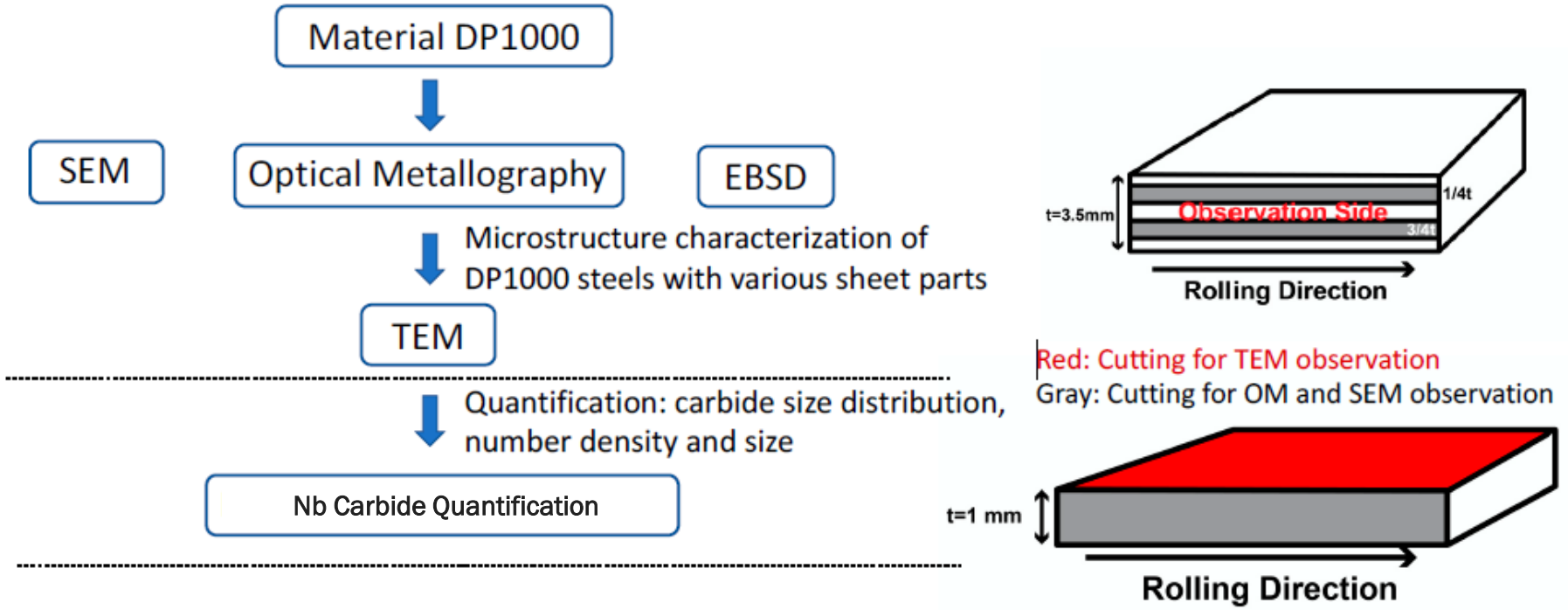
# STEEL PRODUCTION PARAMETERS

- C, Mn, and Si increased relative to DP for austenite retention
- Nb included for structural refinement and ferrite strengthening.
- Not TMCP-Rolled
- Batch anneal included following hot rolling to soften for CR (70%) and to spheroidize cementite
- PMT of 850 °C prior to galvanizing

| Alloy (Mass%) | C | Mn | Si | Cr | Nb | Ti | B |
|---|---|---|---|---|---|---|---|
| DP980 HD: | ≈0.2 | 2.2–2.6 | 0.5–1.0 | <0.7 | 0.03 | <0.02 | <0.003 |
| Processing Stage | Slab Soaking | Finish Rolling | Coiling | | Batch Annealing | Continuous Annealing | |
| Temperature: | 1240 °C | >900 °C | ≈600 °C | | 580 °C/10 h | 850 °C | |

# CHARACTERIZATION

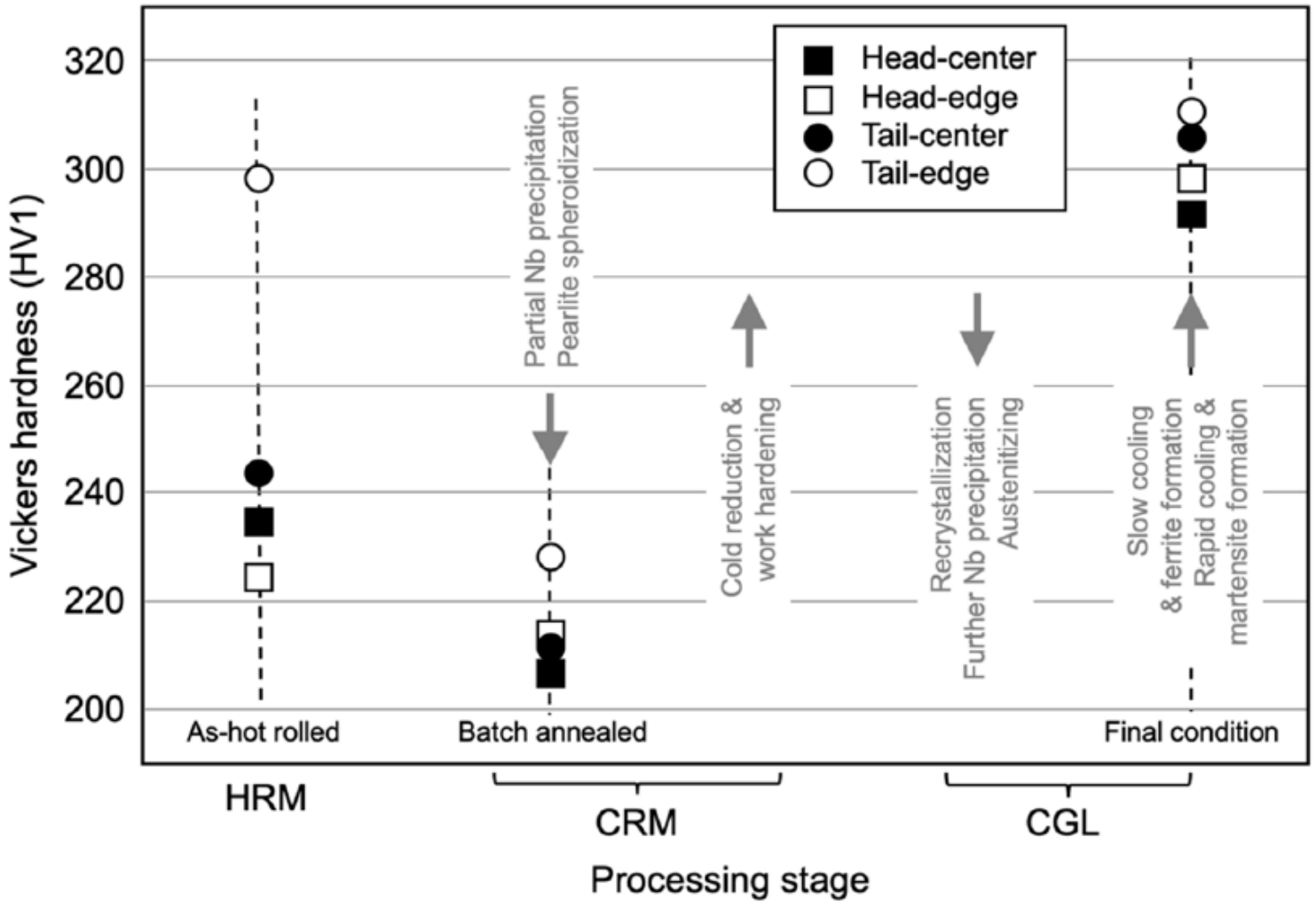
Samples extracted from head and tail, center and edge of hot band, batch annealed, and finished galvanized product.



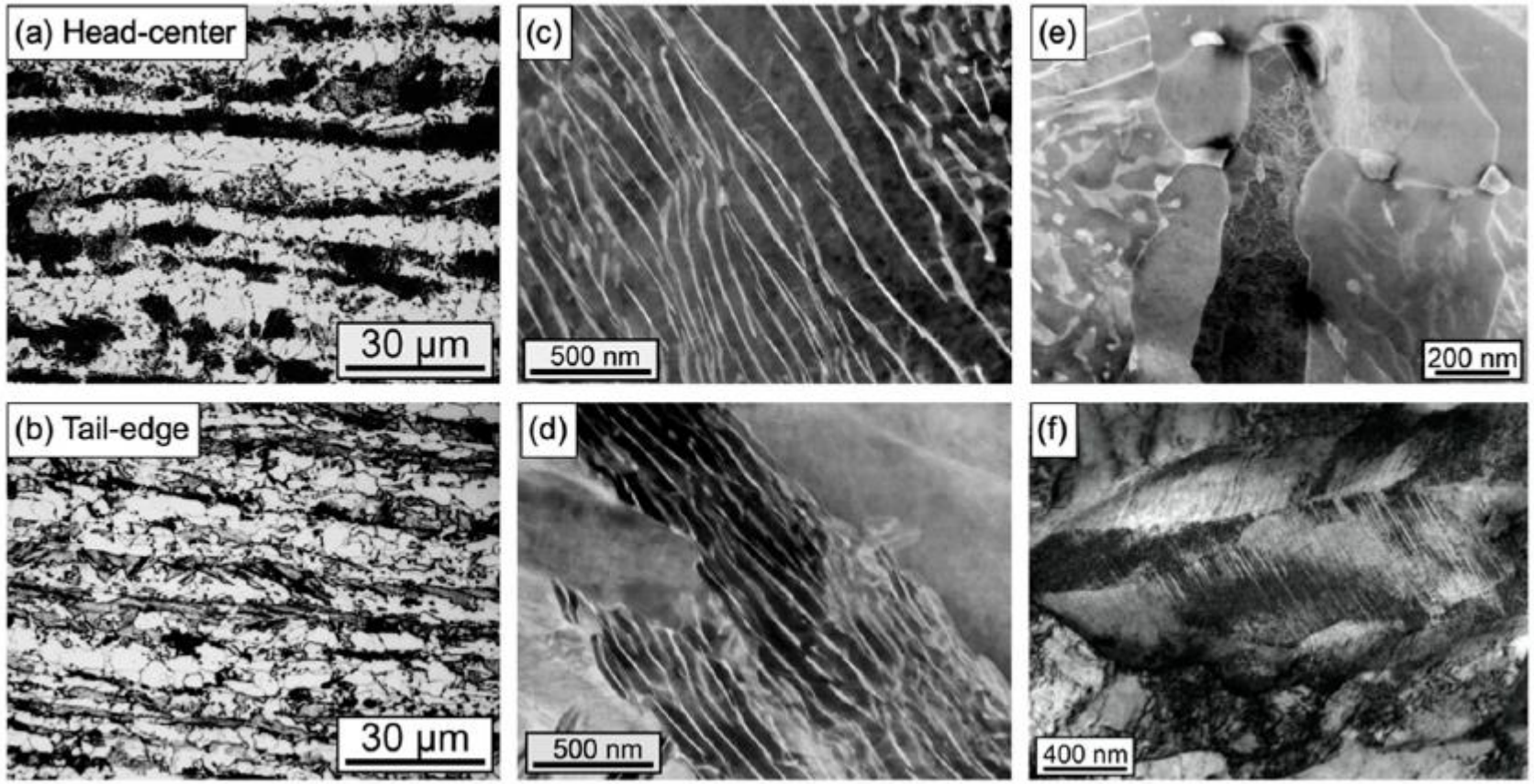

Mechanical evaluations were also conducted to obtain Vickers hardnesses and uniaxial tensile properties.

# RESULTS & DISCUSSION

# HARDNESS EVOLUTION

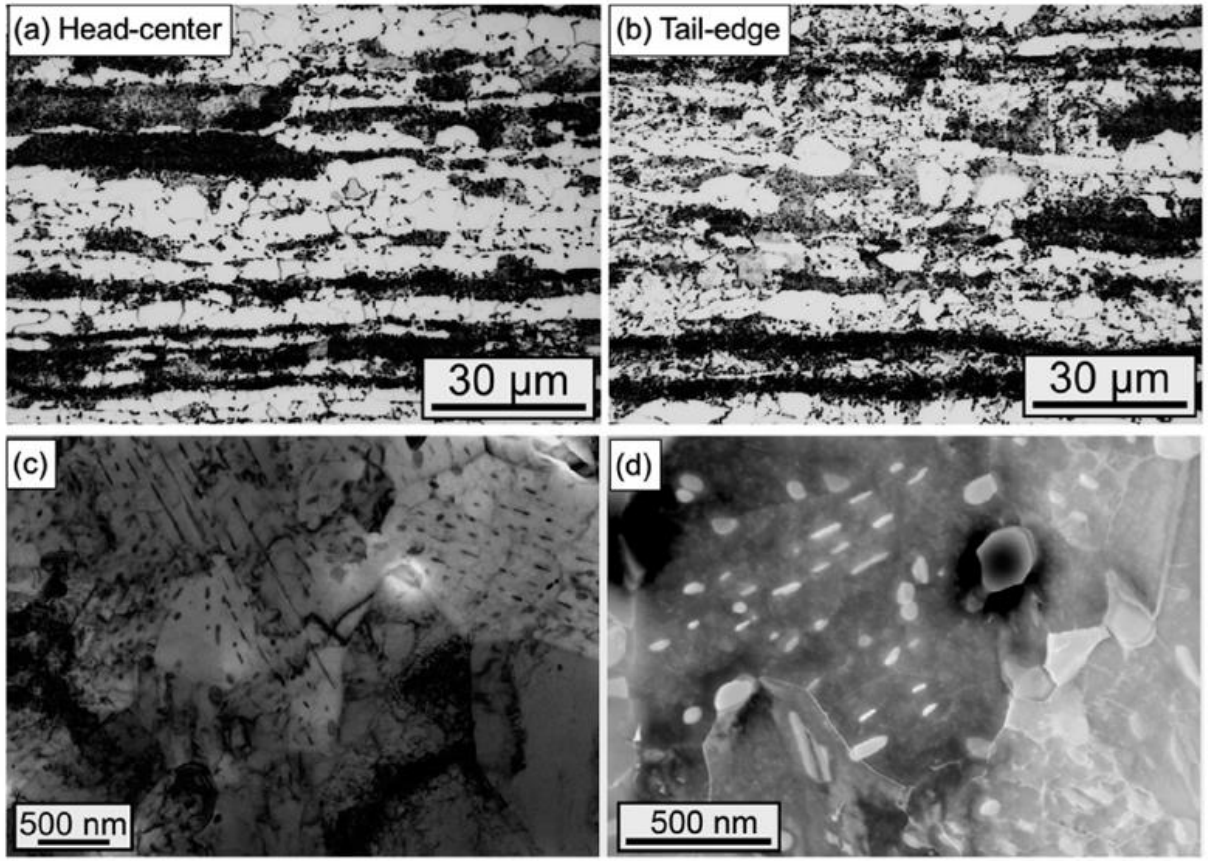


# HOT ROLLED MICROSTRUCTURE




Microstructure in as hot rolled condition: (a,b) light optical microscopy; (c,d) TEM (Transmission electron microscope) details of lamellar pearlite; (e,f) TEM details of martensitic phases.

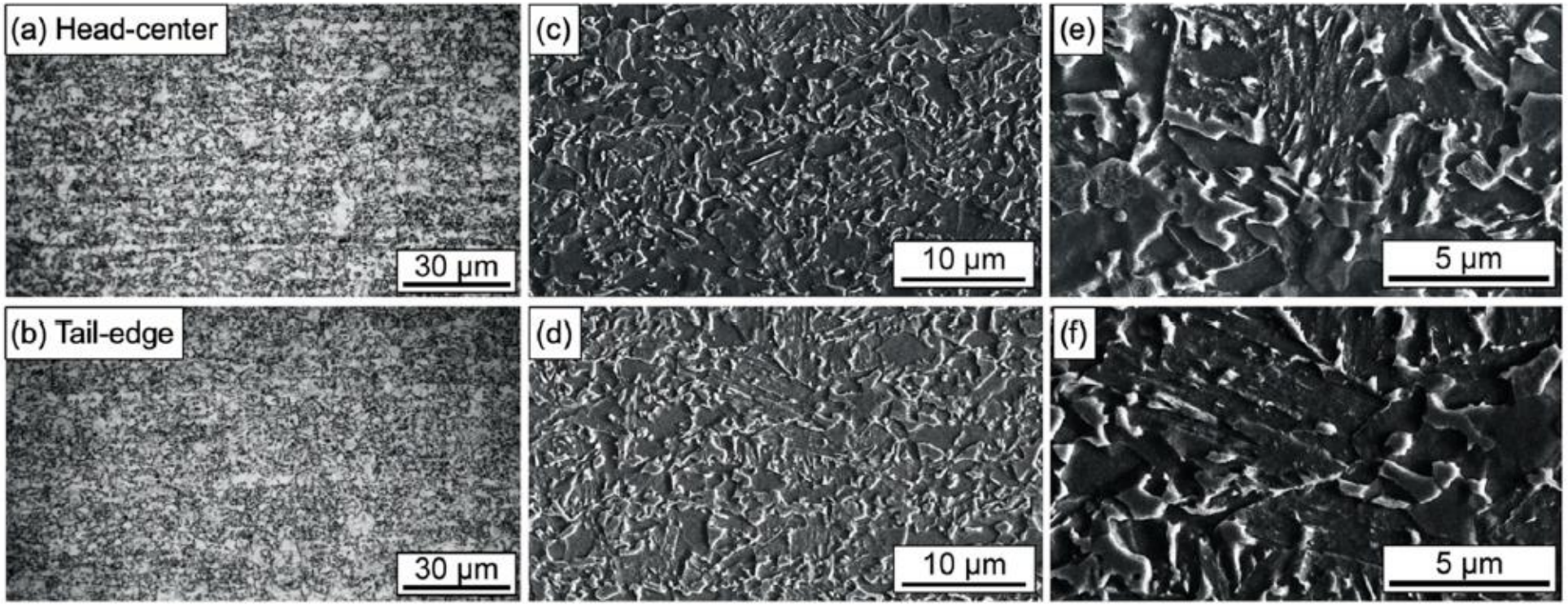
# BATCH ANNEALED MICROSTRUCTURE




Microstructure of the subject steel in batch annealed condition: (a,b) light optical microscopy; (c,d) transmission electron microscopy.

Note retention of highly non-uniform structure in conjunction with spheroidization.

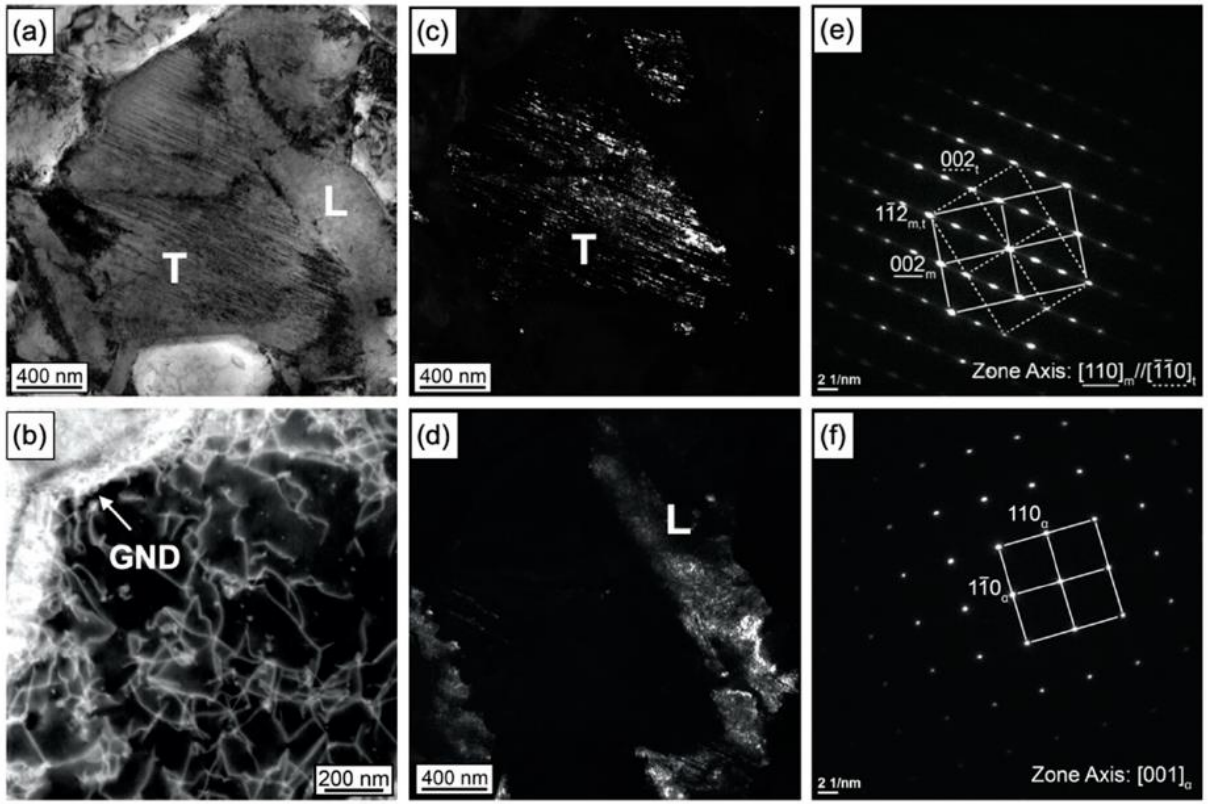
# FINAL MICROSTRUCTURE




Microstructure of cold rolled steel after final continuous annealing: (a,b) light optical microscopy; (c-f) scanning electron microscopy.

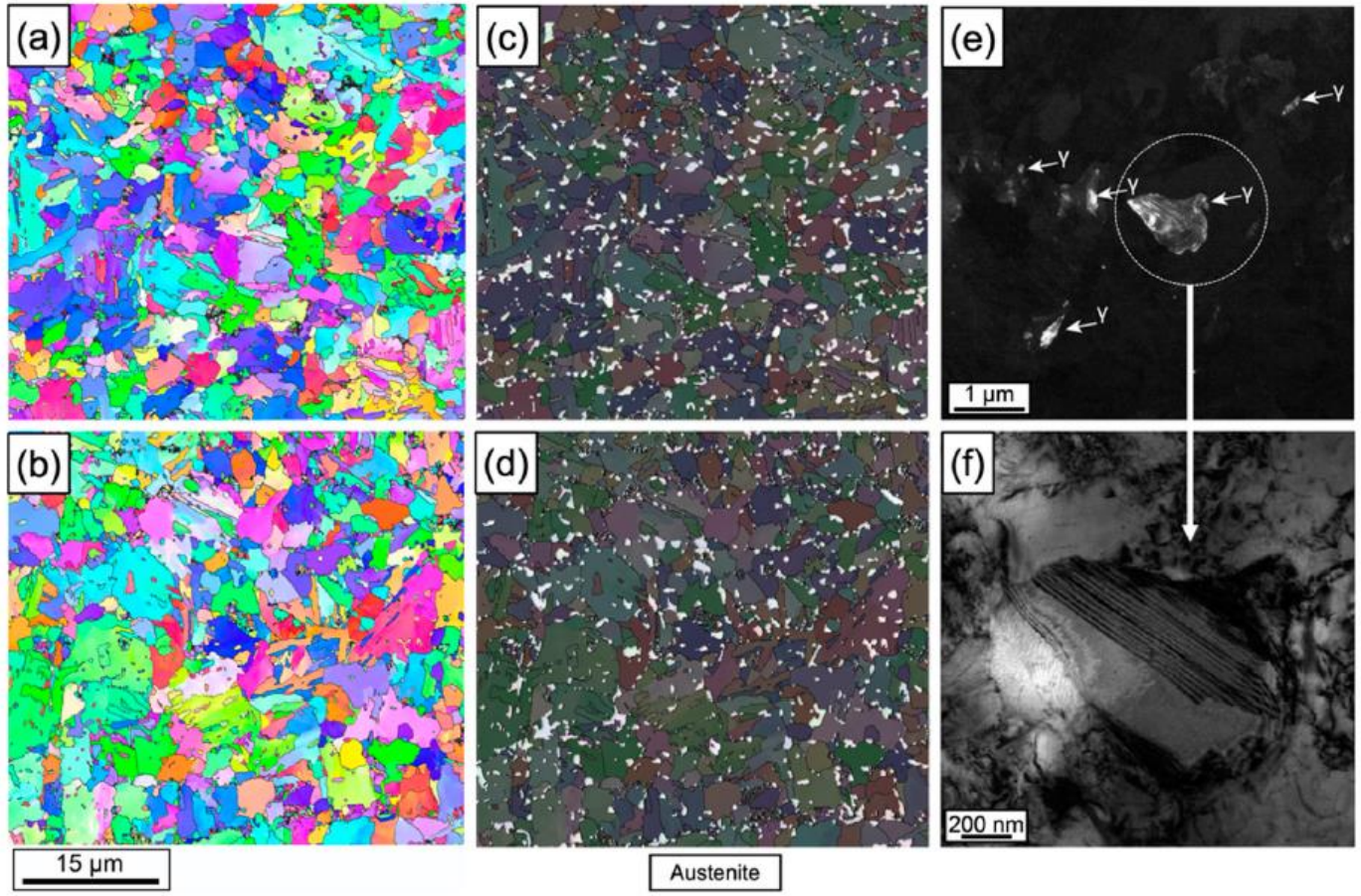
Homogeneity is recovered!

# FINAL MICROSTRUCTURE




Identification of microstructural details after final conditioning by TEM: (a) co-existence of lath (L) and twinned (T) martensite; (b) geometrically necessary dislocations (GND) at boundary between ferrite and martensite; (c,e) twinned martensite; (d,f) lath martensite.

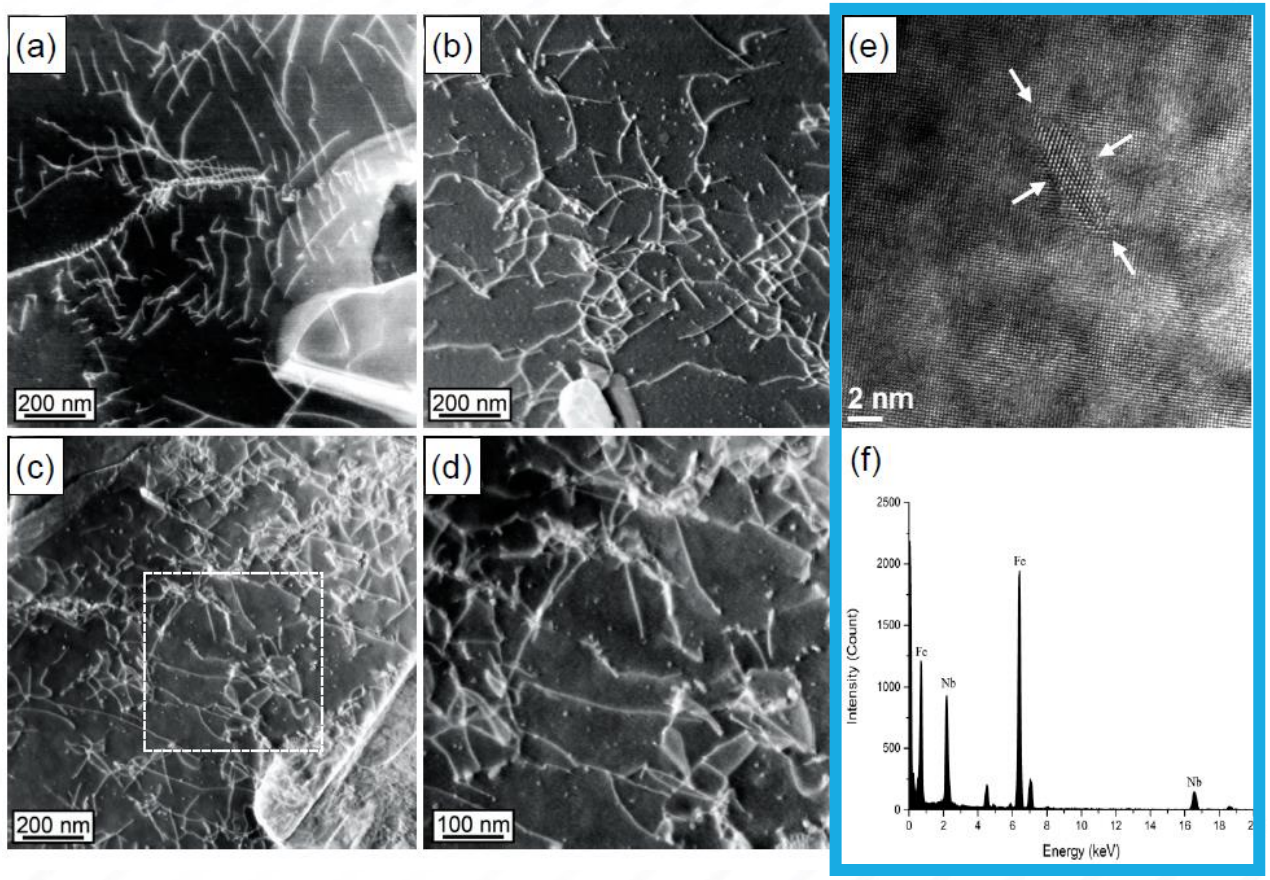
# PHASE FRACTION EVALUATION




| Position in Strip | Phase Share (%) | | |
|---|---|---|---|
| | Ferrite | Martensite | Austenite |
| Head-center | 44 | 48 | 8 |
| Head-edge | 46 | 46 | 8 |
| Tail-center | 45 | 48 | 7 |
| Tail-edge | 42 | 52 | 6 |

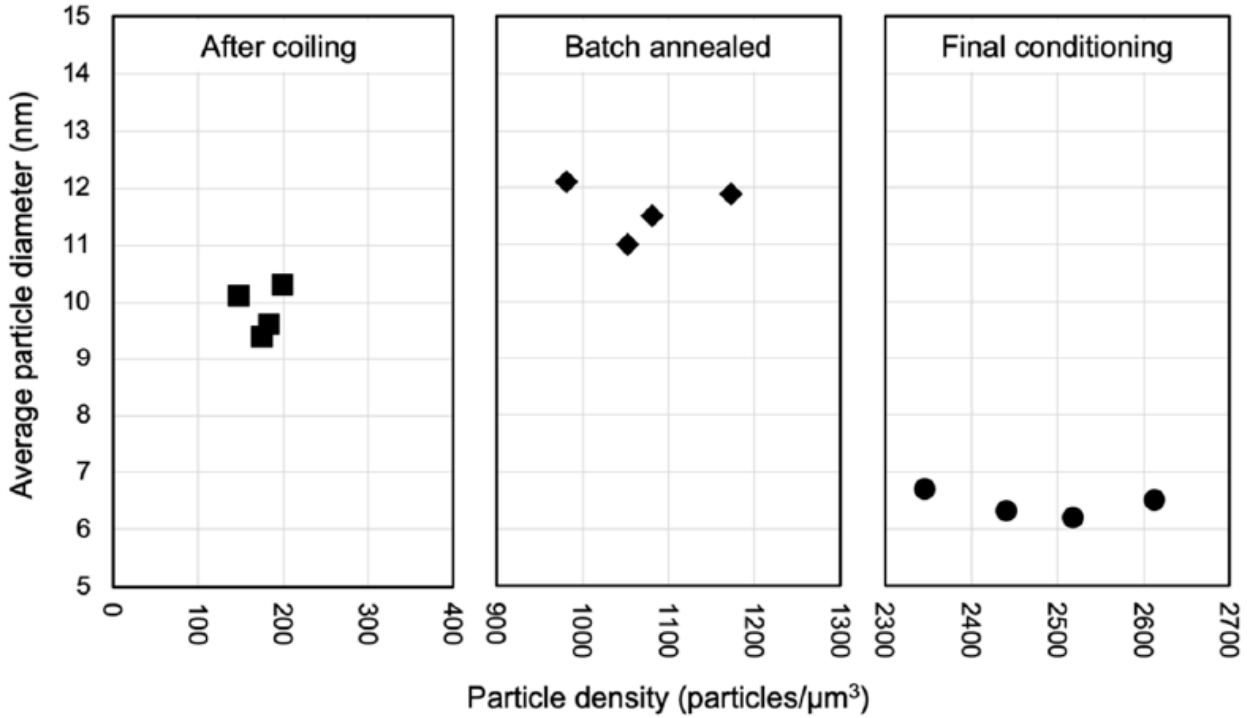
Characterization of final DP microstructure: (a,c) head-center, (b,d) tail-edge and identification of the retained austenite phase (white colored grains on the EBSD background (c,d)); TEM characterization of austenite grains: (e) dark field image, (f) bright field image of detail in (e).

# NIOBIUM PRECIPITATE EVOLUTION




Evolution of niobium precipitation during processing stages characterized by TEM: (a) as hot rolled; (b) after batch annealing; (c) after hot dip galvanizing; (d) higher magnification of dashed area marked in (c); (e) representative high-resolution image of NbC precipitate in ferrite matrix after batch annealing; (f) EDX spectrum indicating a high level of Nb in the precipitates

# NIOBIUM PRECIPITATE EVOLUTION

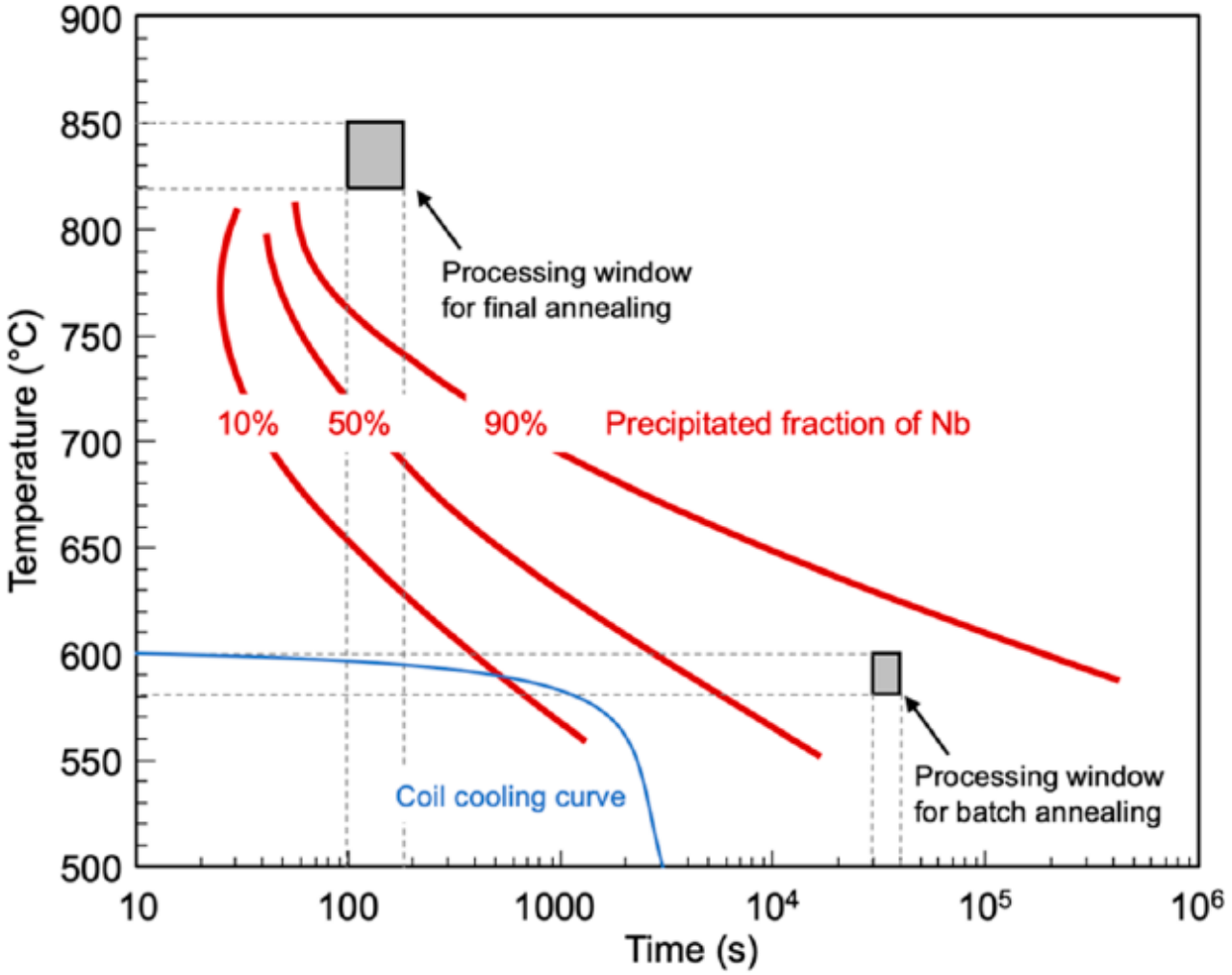



Size and particle density analysis of niobium precipitates for the different processing conditions at four strip positions.

| Processing Stage | Particle Size (nm) | Particle Count ($\mu m^{-3}$) | Particle Volume Fraction (%) | Amount (ppm)/Share (%) of Precipitated Nb |
|---|---|---|---|---|
| Hot rolled | 9.6 | 188 | 0.004 | 35/10% |
| Batch annealed | 11.6 | 1072 | 0.023 | ~200/~70%[1] |
| Final conditioning | 6.5 | 2480 | 0.034 | 303/100% |

[1] estimated value based on observed particle diameter-to-thickness ratio

# NIOBIUM PRECIPITATE EVOLUTION & STRENGTH INCREMENT




Adapted form Perrard et al.

Precipitation kinetics of niobium in the ferrite phase; various time-temperature scenarios applied during processing of DP steel in the current study are indicated. Final A-O calculation of NbC contribution to ferrite strength is ≈ 80 MPa.

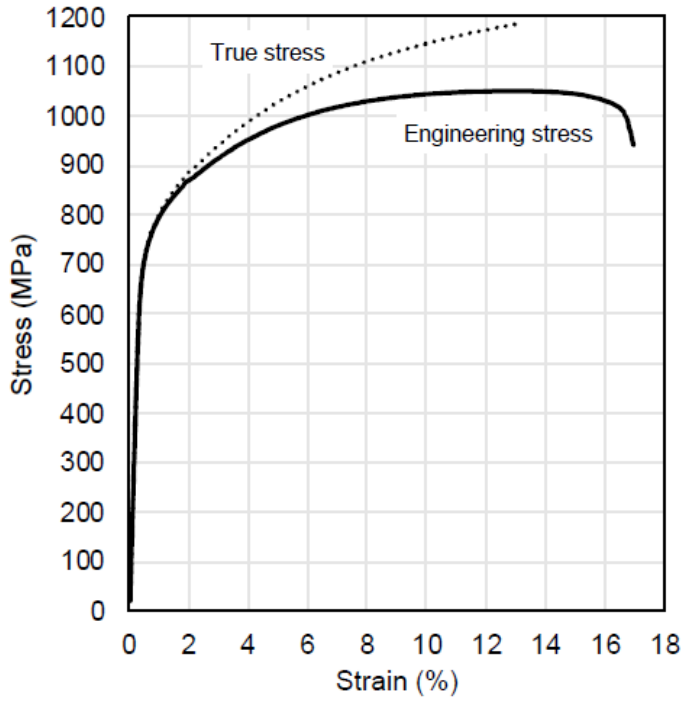
$$\sigma_{\text{Ashby-Orowan}} = \frac{0.8 \cdot M \cdot G \cdot b}{2\pi \cdot L\sqrt{1-\nu}} \cdot \ln\left(\frac{x}{2b}\right)$$

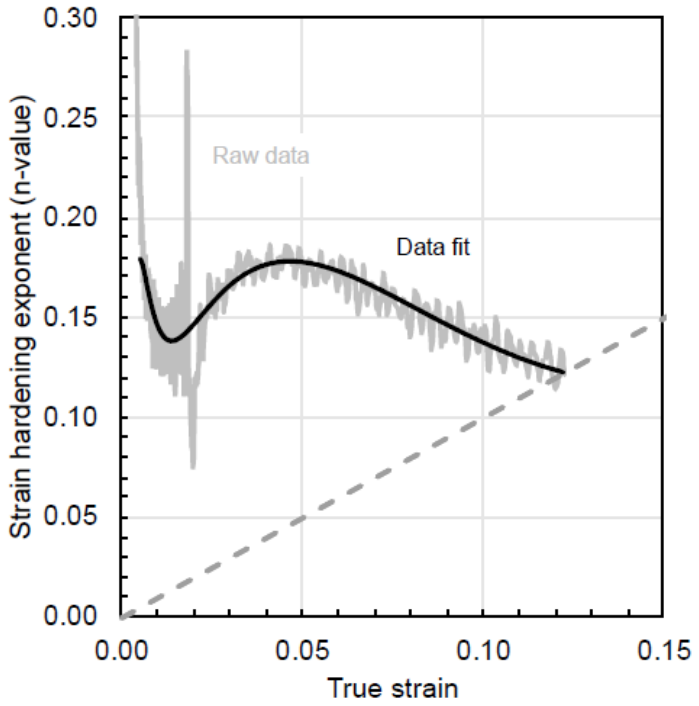
# MECHANISTIC DISCUSSION

- Batch annealing coarsens both NbC and cementite and alters recrystallization/austenitization sequence relative to standard processing.
  - Classic recrystallization kinetics asserts that iron carbide dissolution/coarsening is limiting process (Bunge et al.)
  - Austenite nucleation preferentially occurs at ferrite and cementite boundaries
- Concurrent austenitization / recrystallization results from a strong suppression of ferrite recrystallization and reduction of Ac temperatures due to C and Mn additions.
- High ferrite defect density drives high austenite nucleation density and carbides assist in pinning subsequent growth.
- Retained austenite distribution is dictated by distribution of former cementite particles, and batch annealing further assists in localization of C and Mn for austenite retention upon cooling.

# MECHANICAL PROPERTIES

| Steel Grade | Yield Strength $R_{p0.2}$ (MPa) | Tensile Strength $R_m$ (MPa) | Elongation at Fracture $A_{80}$ (%) | n-value | |
|---|---|---|---|---|---|
| | | | | $n_{4\text{-}6}$ | $n_{10\text{-}20\,/\,Ag}$ |
| CR440Y780T-DH | 440–550 | 780–900 | ≥18 | ≥0.18 | ≥0.13 |
| CR700Y980T-DH | 700–850 | 980–1180 | ≥13 | - | - |
| Current production (typical values) | 740 | 1030 | 15 | ≥0.14 | ≥0.12 |



# CONCLUSIONS

# CONCLUSIONS

- Niobium microalloying to dual phase steels significantly contributes to strength by both precipitation of ultrafine particles and microstructural refinement. A pronounced refinement of the DP microstructure is related to a strong recrystallization delay of the cold rolled ferrite matrix by NbC. The precipitates further restrict grain growth during the soaking phase of the final annealing cycle.

- In addition, properties relevant to formability are being improved due to known mechanisms of strain partitioning.

- Intermediate annealing results in both further fine NbC distributions and cementite spheroidization.  Carbon and Mn localization as a result of the intermediate annealing is asserted as beneficial for subsequent austenite retention.

# FOR MORE INFORMATION

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