

Rapid Induction Heating for Sustainable Manufacturing of Advanced High Strength Sheet Steels for Automotive Applications

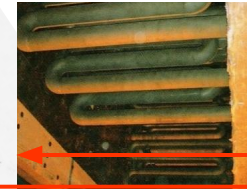
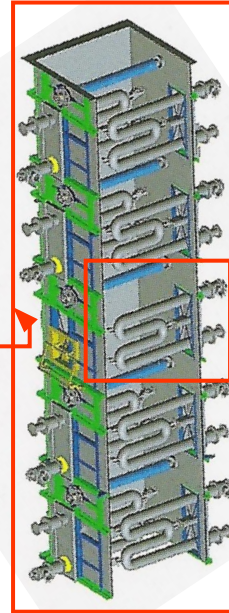
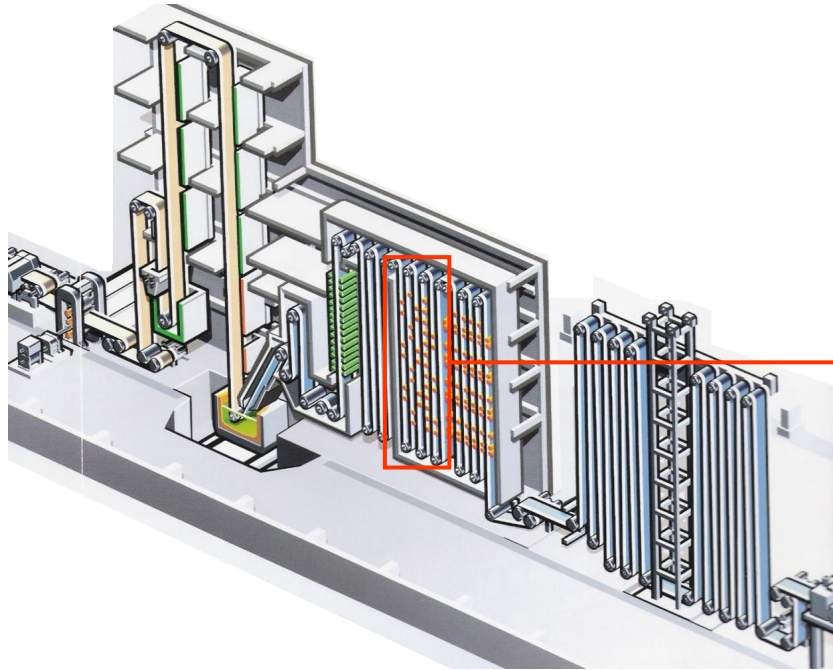
Fluxtrol Student Research Competition

Wednesday October 22nd

Alec Williamson, Samuel Findley, Dominic Piccone, Colton Brown,
Sam Nikolai, David Ulrich, Garrison Hommer, Rob Goldstein, Matthew McCosby,
David Barbier, Laurent Lesne, Eliseo Hernandez, Malavikha Rajivmoorthy,
Emmanuel De Moor, Lawrence Cho

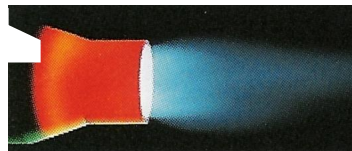


Continuous Annealing Line and Combustion Heat



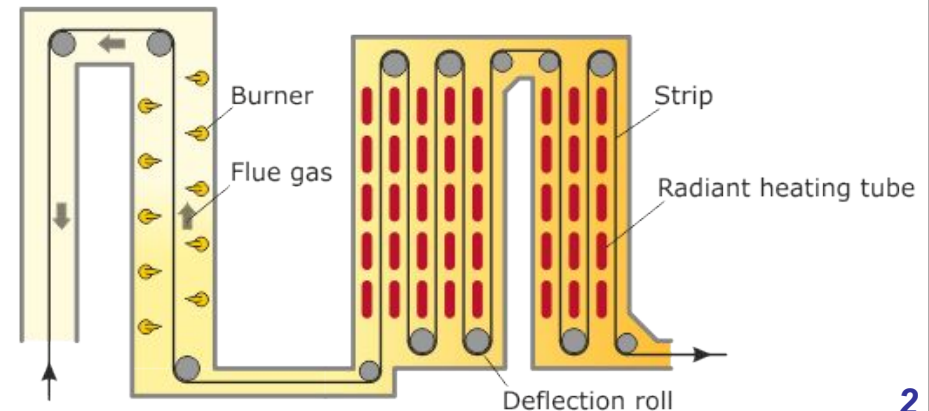
***Current Use of
Gas Fired Furnaces***

Direct Fired Furnace + Radiant Tube Furnace



Direct-fired furnace

Indirect-fired furnace



ELTA Simulation: Energy Efficiency

**Martensite-Starting Microstructure
Entire Longitudinal Flux (LFX)**



**Martensite-Starting Microstructure
Longitudinal to Transverse Flux (TFX)**

Scenario 1						
	LFX	LFX	LFX	LFX	LFX	LFX
	Stage 1	Stage 2	Stage 3	Stage 3	Stage 3	Stage 4
Ti	50	650	725	725	725	800
Tf	650	725	800	800	800	880
time	1.5	1.5	1.5	1.5	1.5	1.5
Power Total (MW)	6.3	1.19	27.46	7.9	3.5	3.99
Power Strip (MW)	6.04	1.16	2.18	2.28	2.1	1.62
Coil Loss	0.26	0.03	25.28	5.62	1.4	2.37
Electrical Eff.	95.9%	97.5%	7.9%	28.9%	60.0%	40.6%
Thermal Eff.	99.0%	86.0%	84.3%	80.9%	81.7%	86.7%
Current	1600	570	16000	6000	2340	3050
Frequency	60000	60000	60000	150000	400000	400000
Note - should increase insulation thickness						

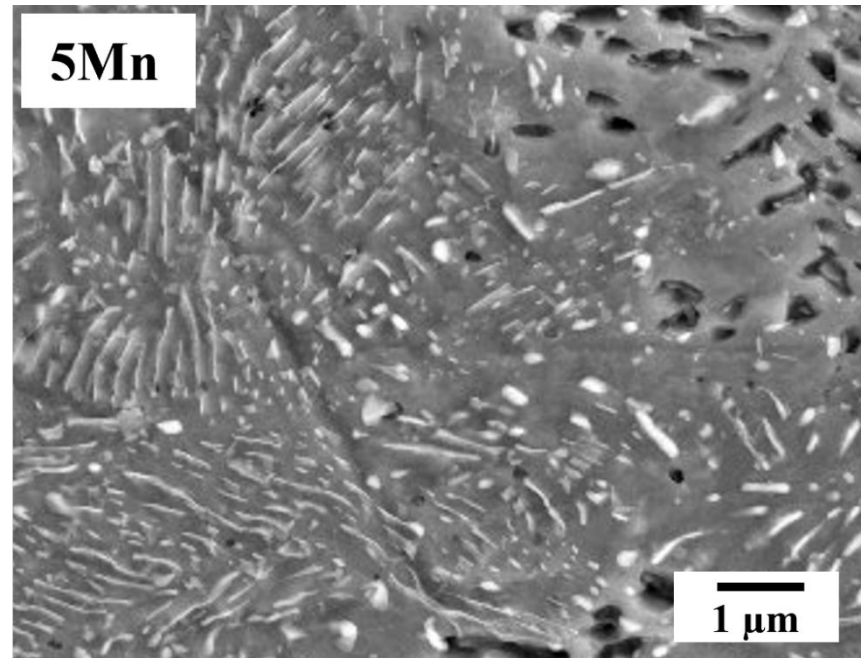
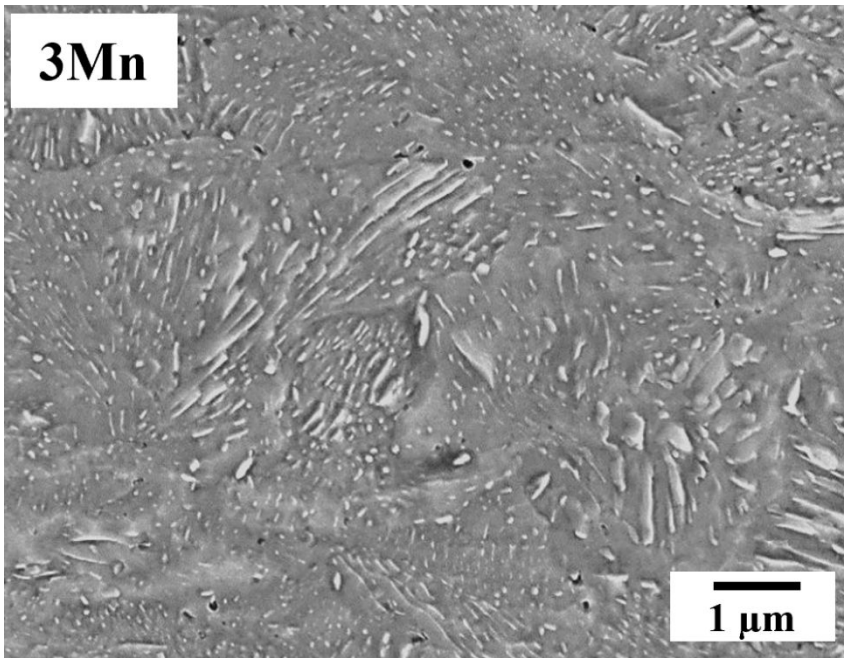
Scenario 2				
	LFX	TFX	TFX	TFX
	Stage 1	Stage 2	Stage 3	Stage 4
Ti	50	650	725	800
Tf	650	725	800	880
time	1.5	1.5	1.5	1.5
Power Total (MW)	6.3	1.19	2.23	1.65
Power Strip (MW)	6.04	1.16	2.18	1.62
Coil Loss	0.26	0.03	0.05	0.03
Electrical Eff.	95.9%	97.5%	97.8%	98.2%
Thermal Eff.	99.0%	86.0%	84.3%	86.7%
Current	1600	2360	3000	2500
Frequency	60000	1000	1000	1000
Note - should increase insulation thickness				

- **Efficiency loss near/above Curie temperature**
- **TFX can maintain high electrical efficiencies for thin strip heating.**

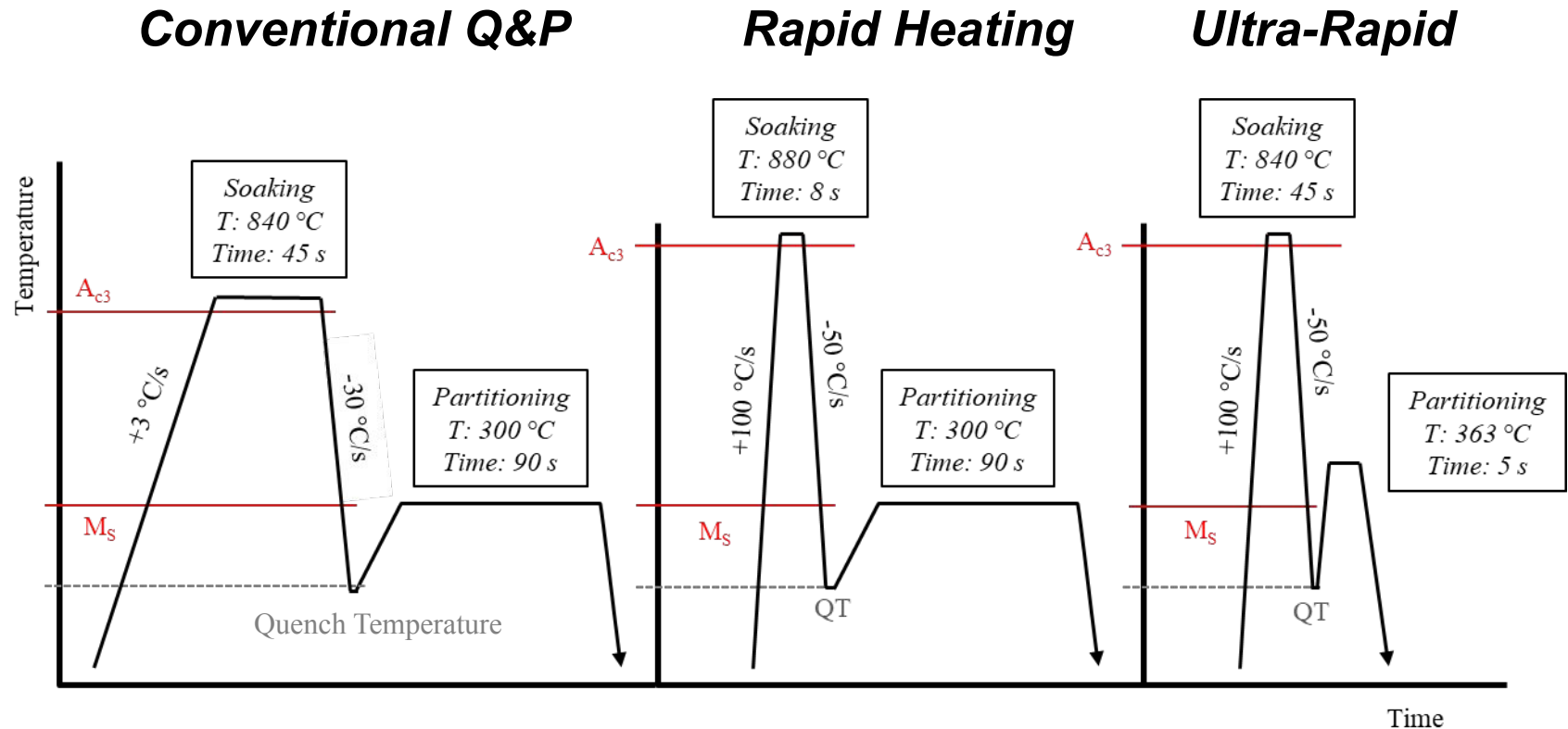


As-Received Microstructures

- *Cold-rolled conditions consist of deformed pearlite/martensite and fine cementite.*
- *Two alloy compositions: Fe-0.3C-(3-5)Mn-1.6Si-1.0Cr*



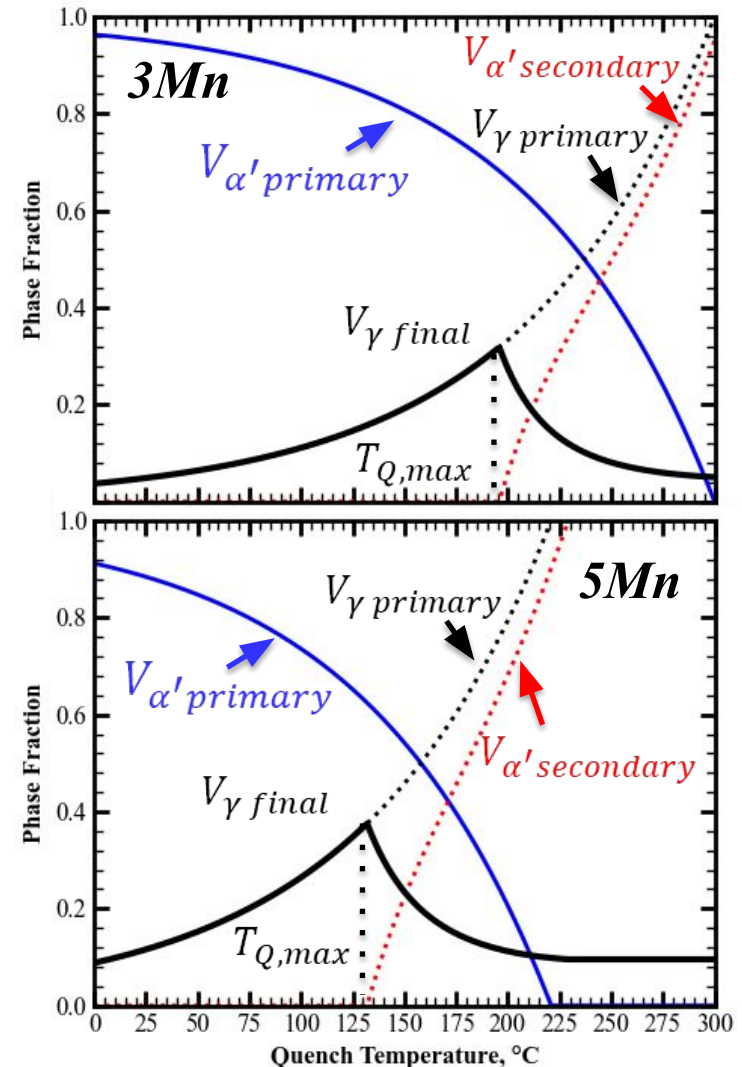
Conventional Q&P versus Q&P Involving Induction Heating



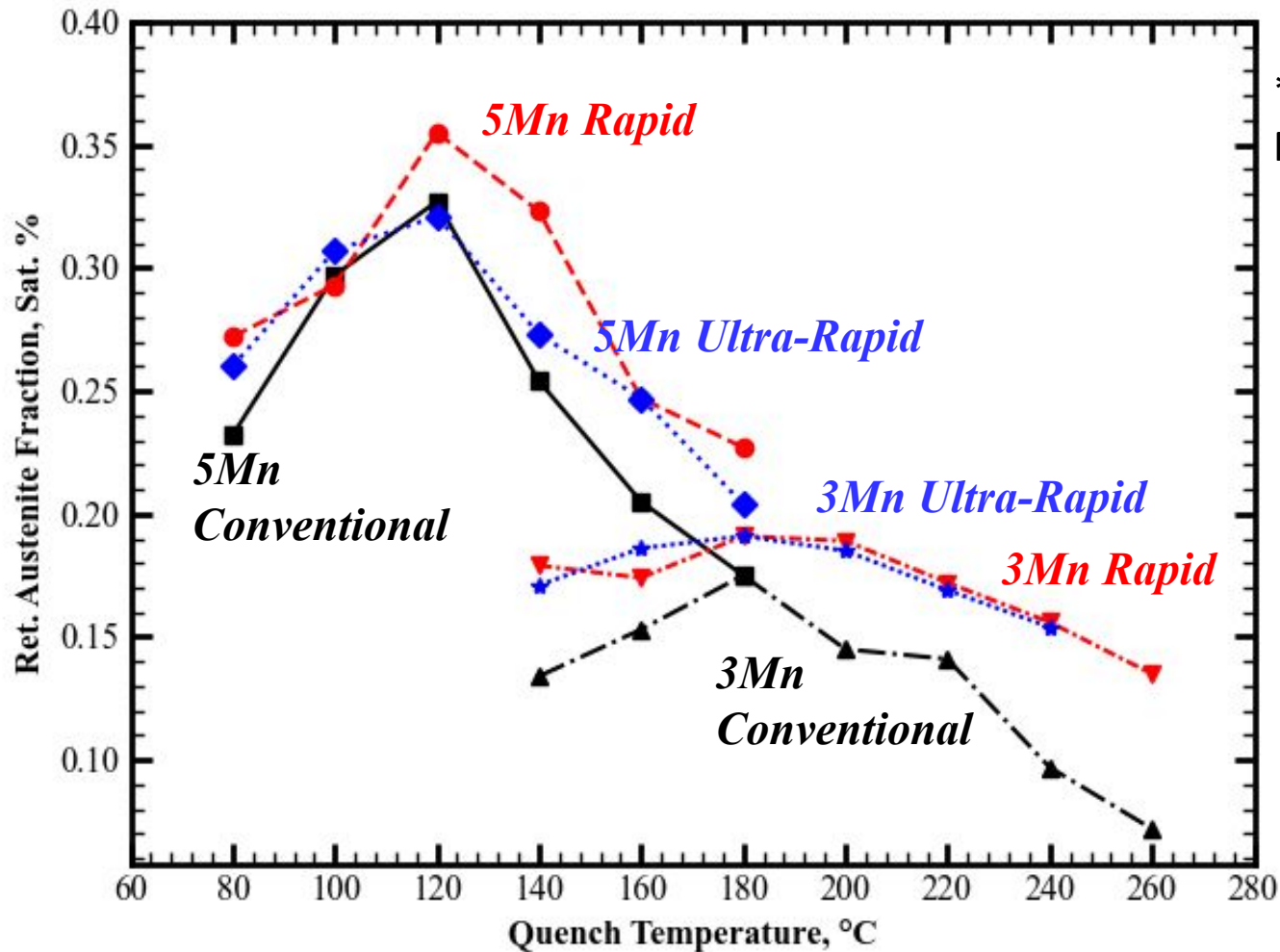
- **Critical temperatures A_{c3} and M_s were determined through dilatometry experiments with varied heating rates.**
- **Critical temperatures shown are for the 3Mn alloy.**

Prediction of Phase Fractions after Q&P

- Quench temperature (T_Q) < $T_{Q,max}$:
Retained austenite volume fraction increase with increasing T_Q as less primary martensite is formed upon initial quenching
- $T_Q > T_{Q,max}$:
The austenite stability before final quenching decreases, resulting in a higher volume fraction of secondary martensite with increasing T_Q .



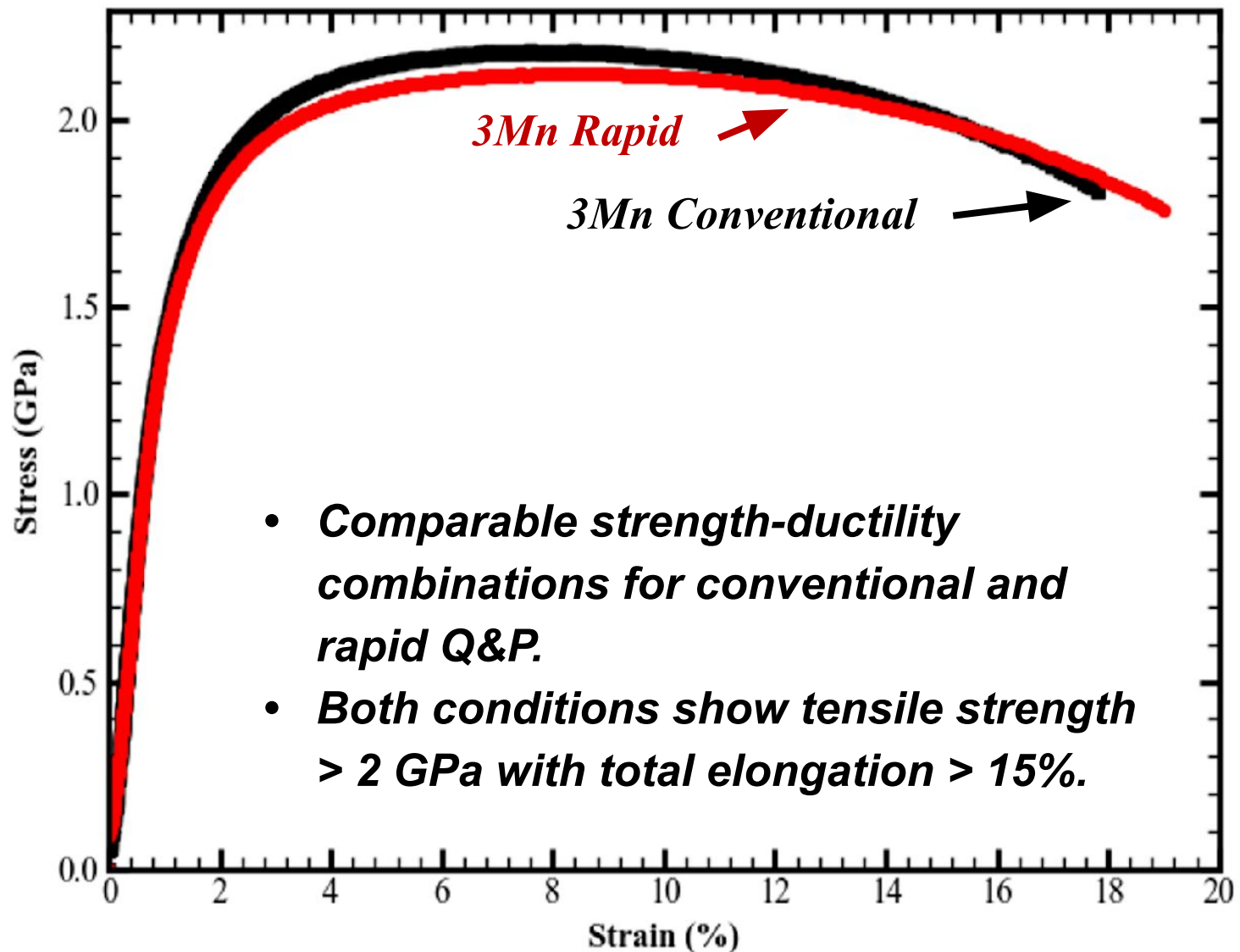
Retained Austenite Fraction



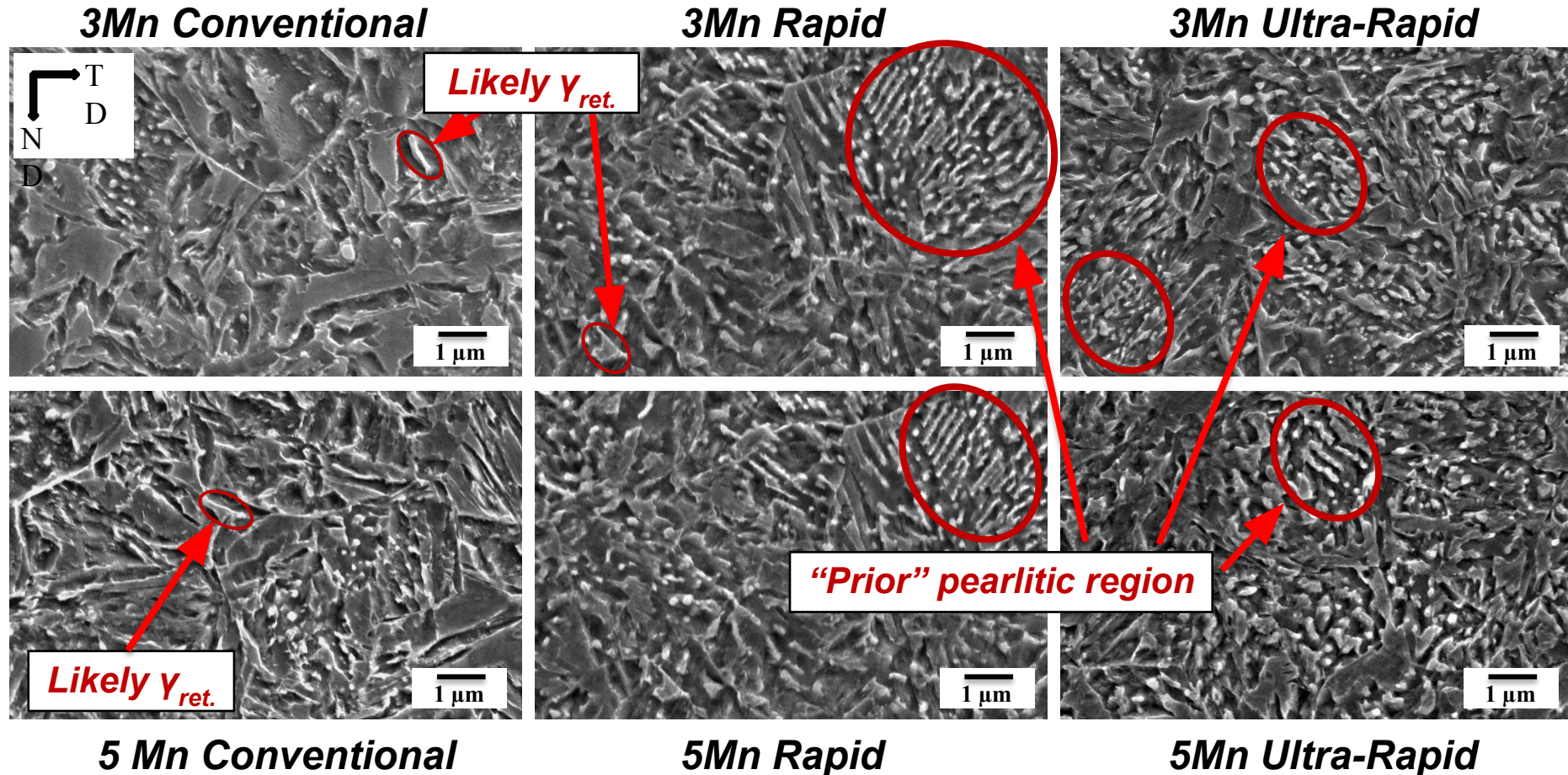
*Dilatometry and
Magnetic Saturation

Higher Mn content and rapid heating result in increased retained austenite fractions.

Tensile Properties: Rapid vs. Conventional

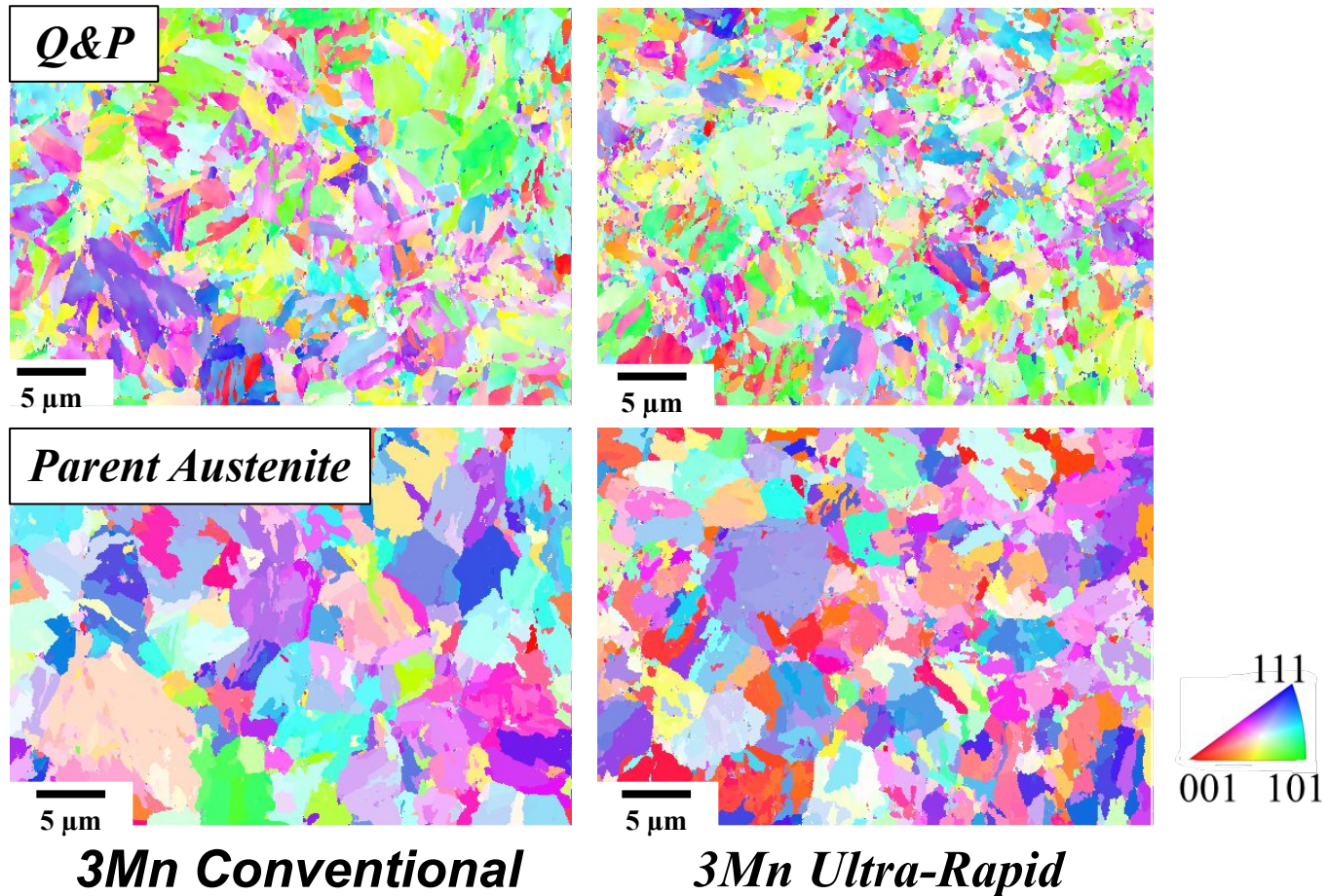


Rapid Heating Effects on Q&P Microstructure



- **Microstructural and chemical heterogeneities originated from the prior pearlitic structure exist due to short soaking times.**

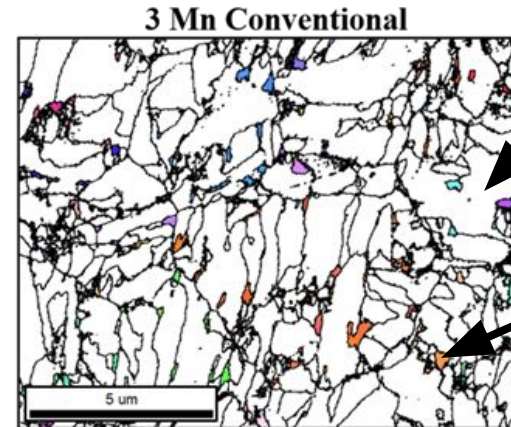
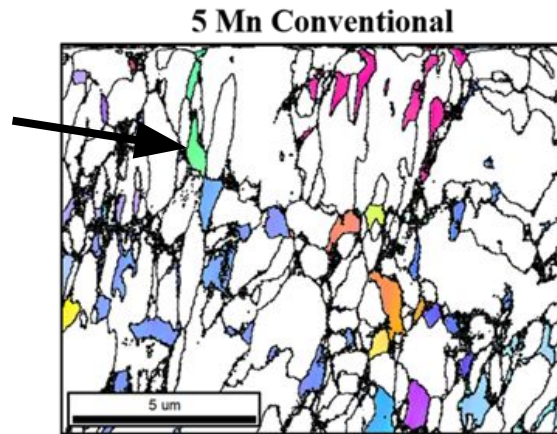
Parent Austenite Grain Reconstruction (EBSD)



EBSD IPF maps of Q&P microstructure and reconstructed parent austenite grain orientation maps display refined microstructure from rapid heating.

Retained Austenite Morphology (EBSD)

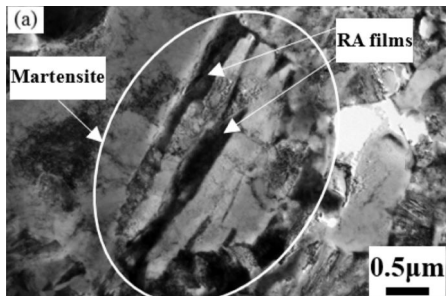
**“Blocky”
retained
austenite**



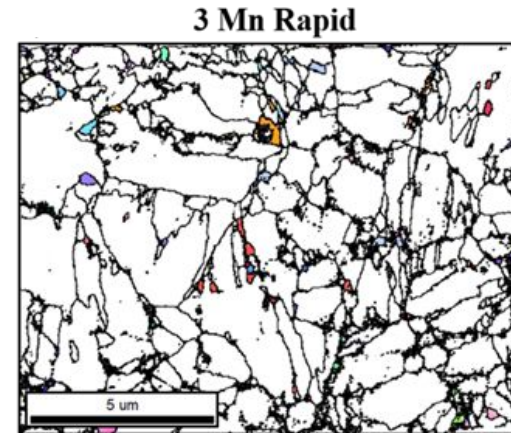
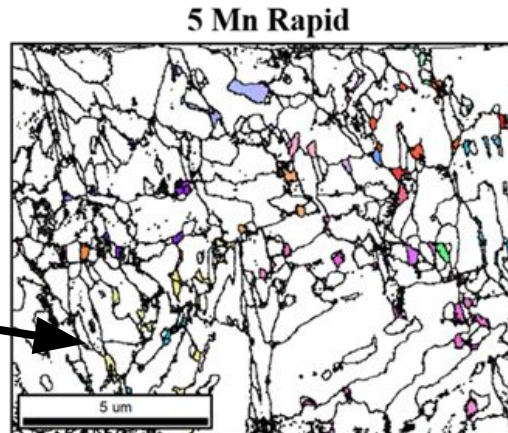
Martensite

**Retained
Austenite**

Thin Film Morphology

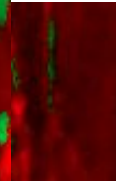
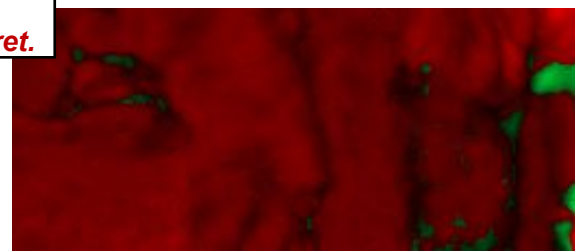
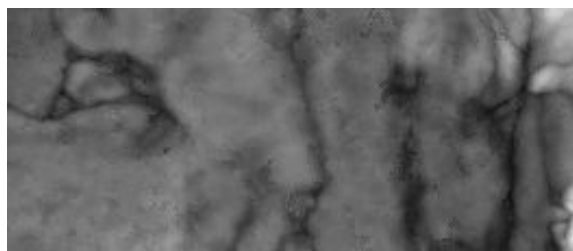
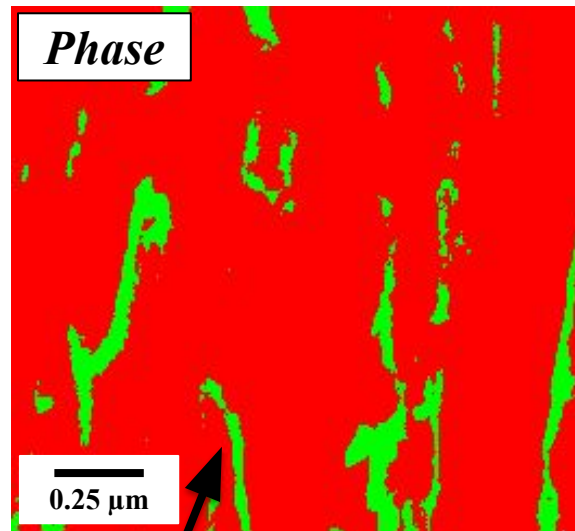
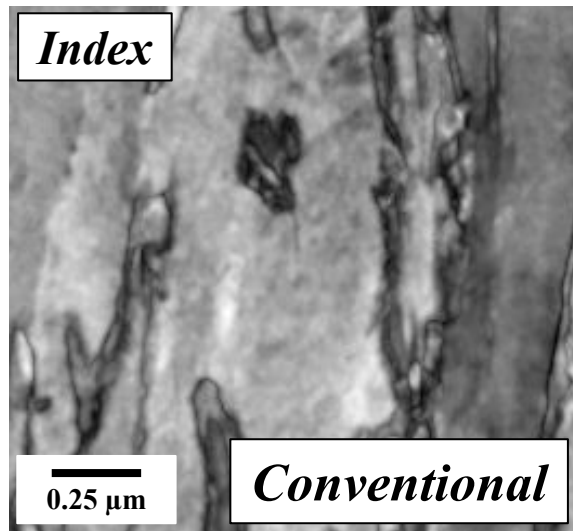


Song, Chenghao, et al. *Materials Science and Engineering: A* 670 (2016): 326-334.



- **Higher Mn content leads to increased retained austenite fractions.**
- **Rapid Q&P produces finer retained austenite grains.**

Crystallographic Orientation Mapping Using Precession TEM (ASTAR Technique)



Nano-sized $\gamma_{\text{ret.}}$

Thin $\gamma_{\text{ret.}}$ film

Conclusions

- Induction heating represents a viable alternative to conventional gas-fired furnaces in AHSS continuous annealing.
- Q&P involving rapid induction heating **stabilizes higher fractions of retained austenite** compared to conventionally continuous-annealed microstructures.
- Rapid, higher-temperature partitioning stages can stabilize **retained austenite fractions comparable** to conventional partitioning treatments.
- Rapid heating produces **refined, heterogeneous microstructures** with **finer retained austenite grains**.

Acknowledgements

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