41th SENAFOR

CBMM

IMPROVEMENT OF THE QUALITY OF FLAT STRUCTURAL STEEL PRODUCTS THROUGH PARTIAL REPLACEMENT OF MANGANESE BY NIOBIUM

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Introduction

- **Requirements** to be satisfied by a **steel alloy design**:

  ✓ Meet **specified requirements** as **cost-effectively** as possible.

  ✓ **Refining, rolling and application steps** as simplified, economical and consistent as possible.

  ✓ Use **alloy elements** readily available on the market, with **low and stable quotations over time**.

  ✓ Present **minimal carbon footprint** and **high recyclability**.

Introduction

- The focus of this work is to **rethink** the use of manganese in structural steels:

  ✓ Established alloy element due to its largely favorable **cost:benefit ratio** for decades.

  ✓ It promotes **solid solution hardening**, an increase in the **pearlite fraction** in the microstructure and **discrete grain refinement** due to the lowering of A_{r3}.

  ✓ It combines with the sulfur in the steel, preventing the **formation of iron sulfide** which is liquid at the usual hot working temperatures of steel and promotes embrittlement.

Introduction

- But the use of Mn presents some **drawbacks**:

  - ✓ Manganese contents above 0.8% require the addition of large amounts of FeMn, requiring an **increase in the BOF tapping temperature**, reducing the life of the refractory linings and intensifying liquid steel rephosphorization.

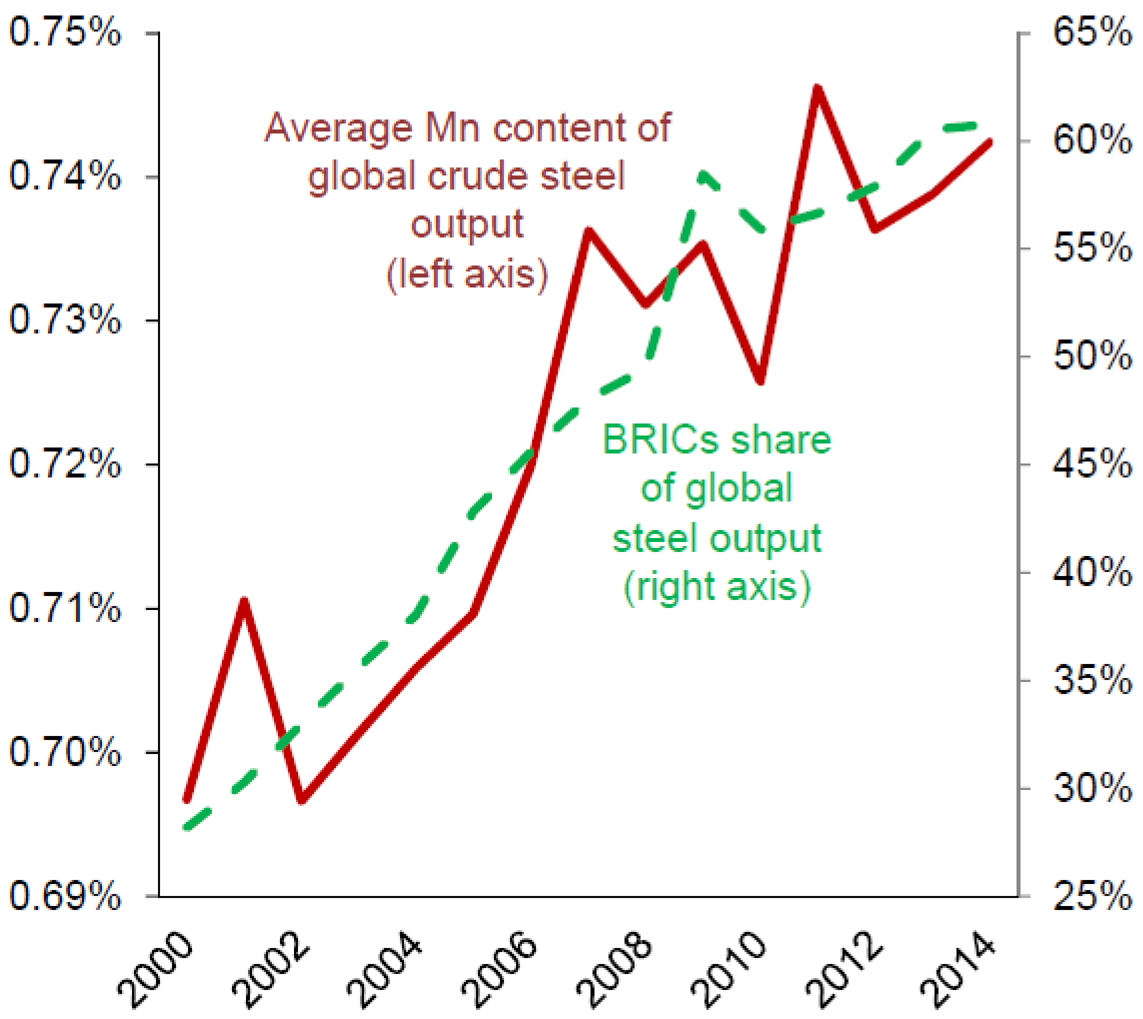
  - ✓ This problem can be avoided by adding FeMn in a **ladle furnace**, but the associated electricity costs are considerable, besides production restrictions.

  - ✓ Manganese **segregates intensely in the center** of the thickness of the slabs produced by continuous casting, impairing the quality of the final product.

  - ✓ Increased **microstructure banding**, affecting toughness.

  - ✓ Increase in **carbon-equivalent**, affecting weldability.

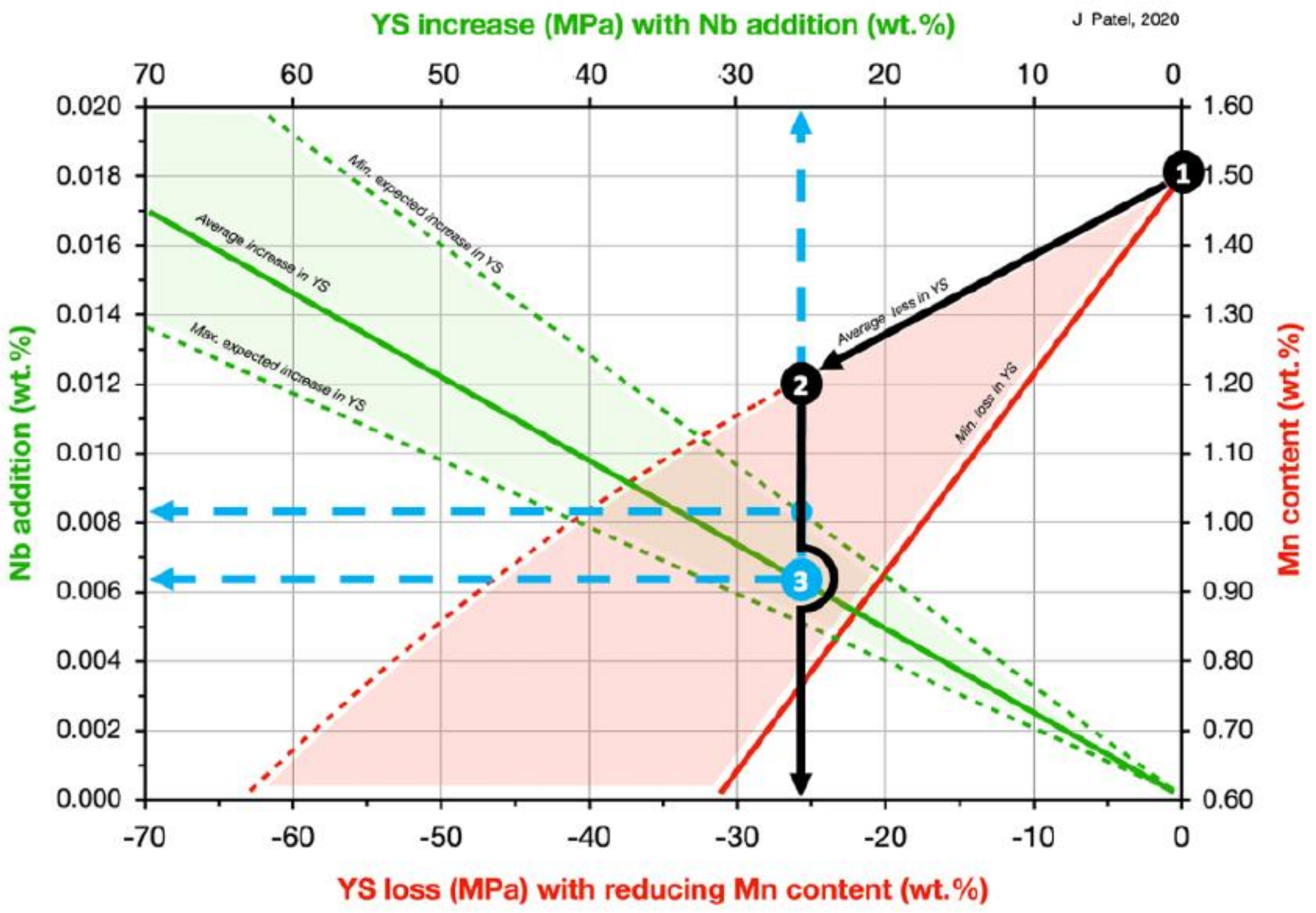
Introduction



Even so, the use of Mn in structural steels has been increasing rapidly, both **due to the increase in its content** in steels and to the **increase in production**, especially in developing countries.

Fowkes, 2015

Equivalence Between Niobium and Manganese



Patel 2021

Ultra-Low Nb Concept Applied to Industrial Structural Steels

Standard	Thickness [mm]	Alloy Design	C [%]	Mn [%]	Nb [%]	CEq	LE [MPa]	LR [MPa]	A [%]	CVN @0°C [J]
ASTM A36	2,3	CMn	0.07	0.80	-	0.20	301	435	35.4	-
		ULNb	0.07	0.50	0.012	0.15	321	420	34.8	-
EN S355	12,0	CMn	0.15	1.20	-	0.35	356	499	26.0	-
		ULNb	0.15	0.80	0.010	0.28	359	481	27.0	-
Q345	≤ 30	CMn	0.16	1.40	-	0.39	383	525	27	164
		ULNb	0.16	0.90	0.010	0.31	387	514	26	170

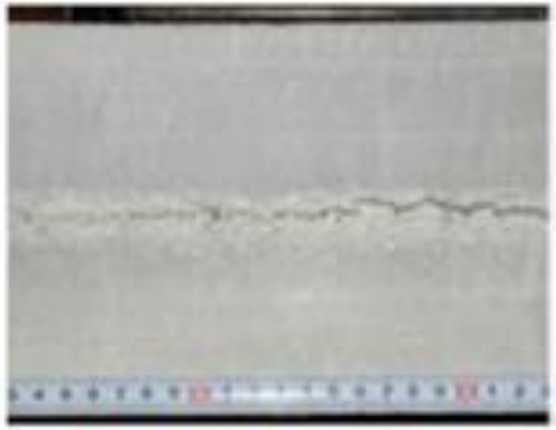
- The swap of **0.3% Mn by 0.010% Nb** promotes **a mean reduction of 34 kg $CO2_e$/t** associated with steel production.

- A typical **passenger car** emits about **4.6 tons of $CO2_e$/year** (12.6 kg/day).

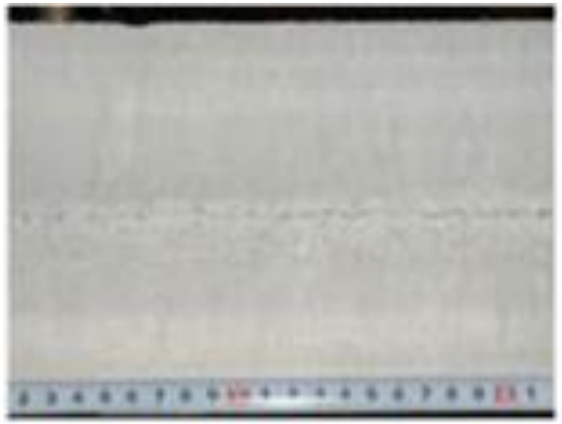
- So, **1 ton of ULNb steel** causes a **reduction of carbon footprint** that corresponds to **2.7 days of car use**!

Stalheim 2018

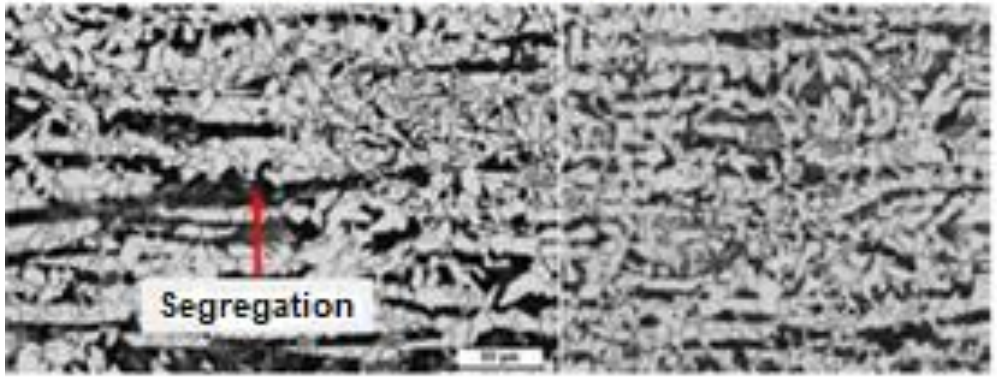
Segregation Minimization through Replacement of Mn by Nb

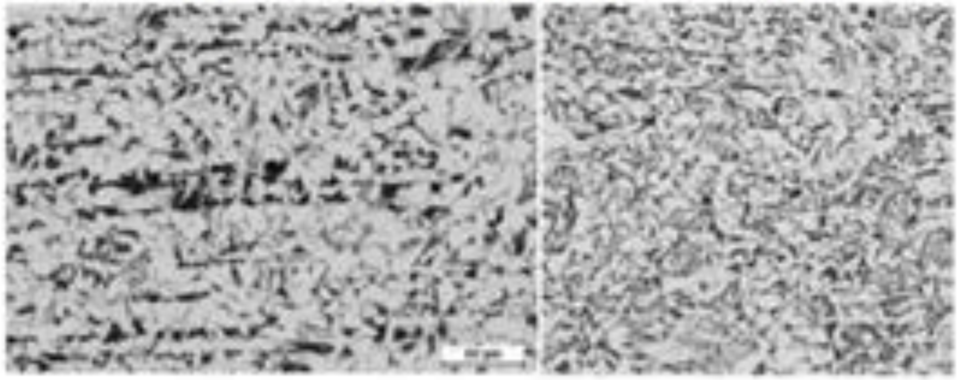


0.16% C, 1.30% Mn



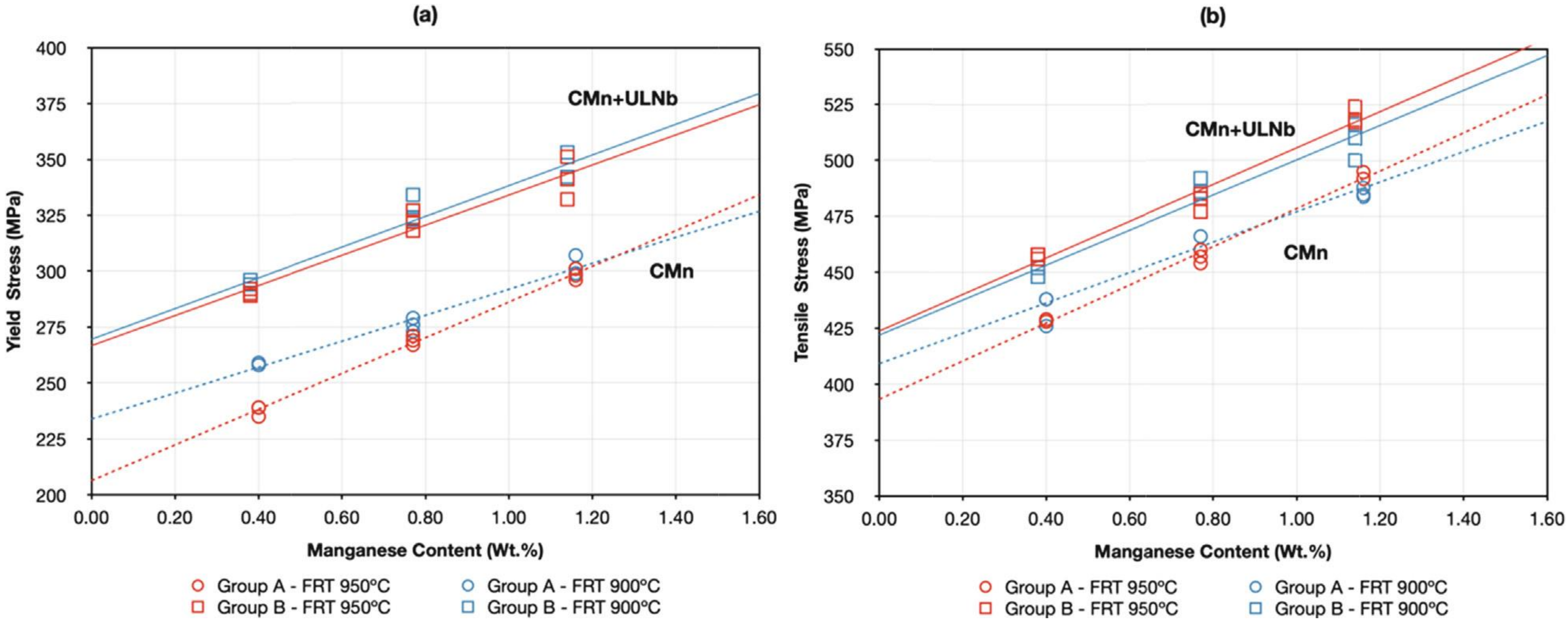
0.16% C, 0.90% Mn, 0.010% Nb





Stalheim 2018

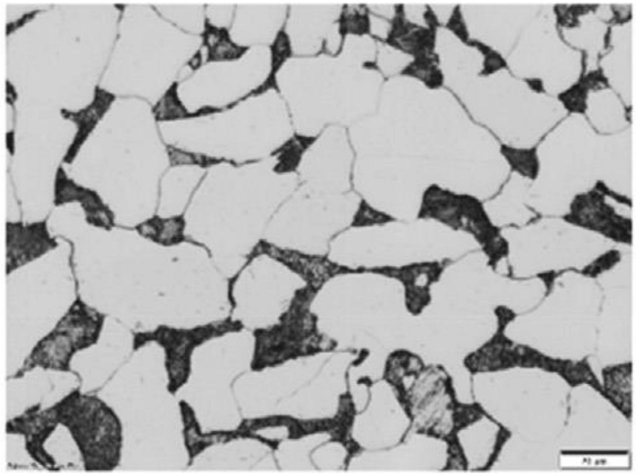
Comparison: CMn x ULNb Steels

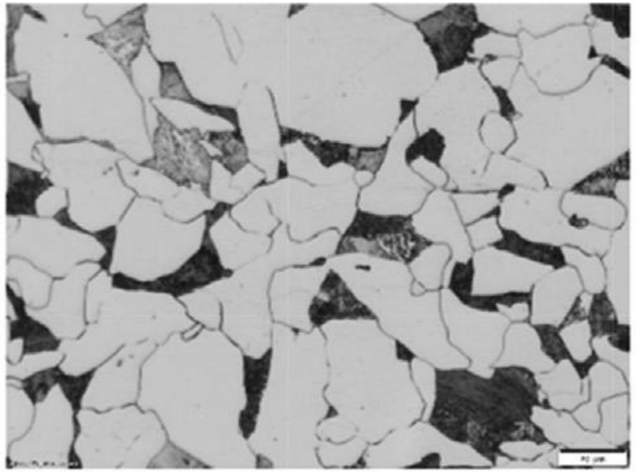


Patel 2022

Comparison: CMn x ULNb Steels

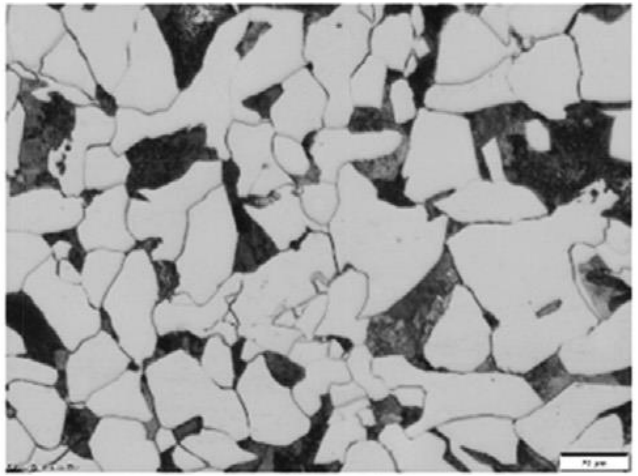
0.18C-0.77Mn-0.19Si
18.2µm; 20% Pearlite
YS = 269 MPa
TS = 457 MPa
TS/YS = 1.70
CVN@0ºC = 217J

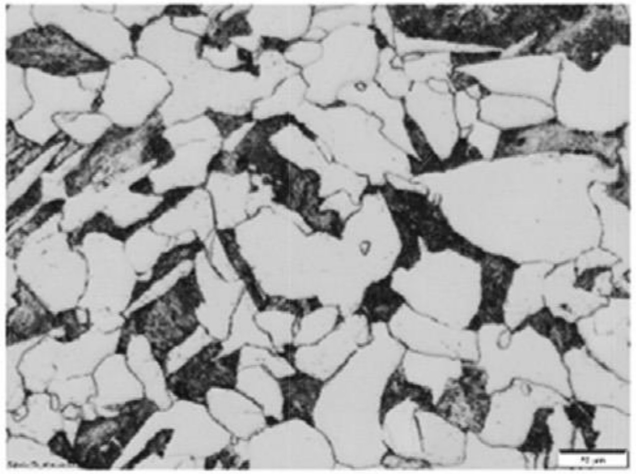




0.18C-0.77Mn-0.19Si+72ppmNb
15.2µm; 15% Pearlite
YS = 322 MPa
TS = 482 MPa
TS/YS = 1.50
CVN@0ºC = 190J

0.18C-1.16Mn-0.20Si
13.3µm; 25% Pearlite
YS = 298 MPa
TS = 493 MPa
TS/YS = 1.65
CVN@0ºC = 235J

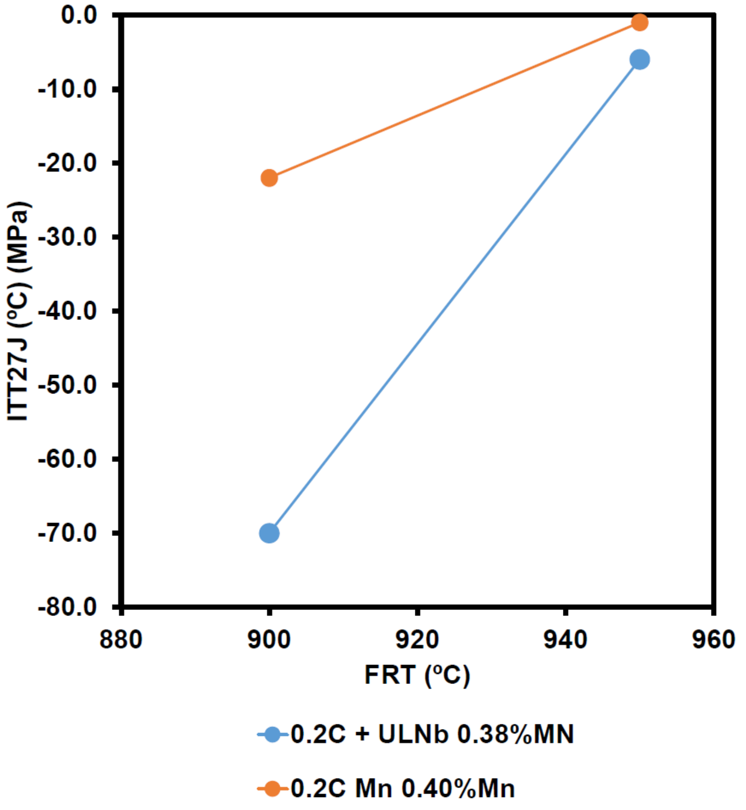


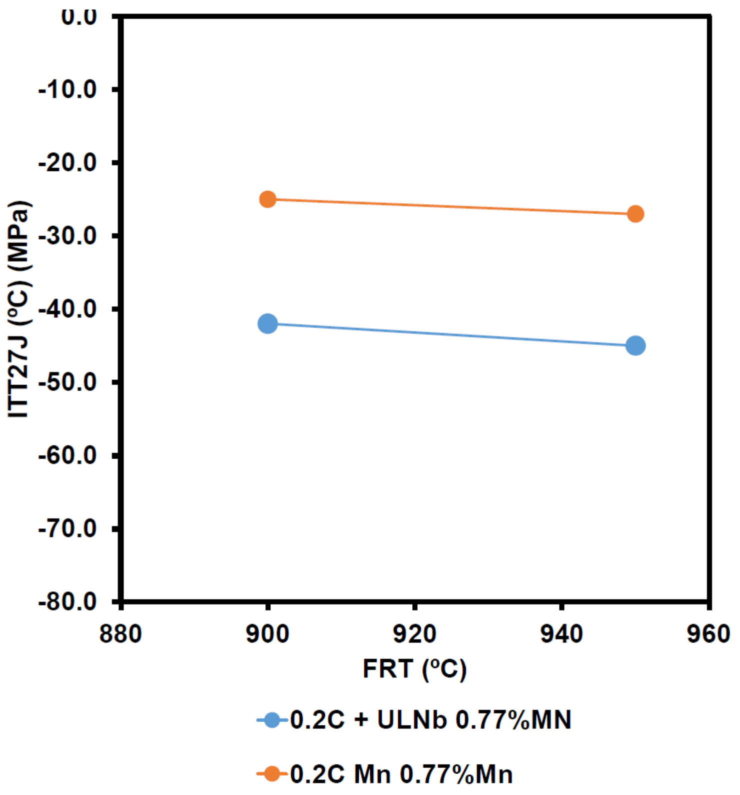


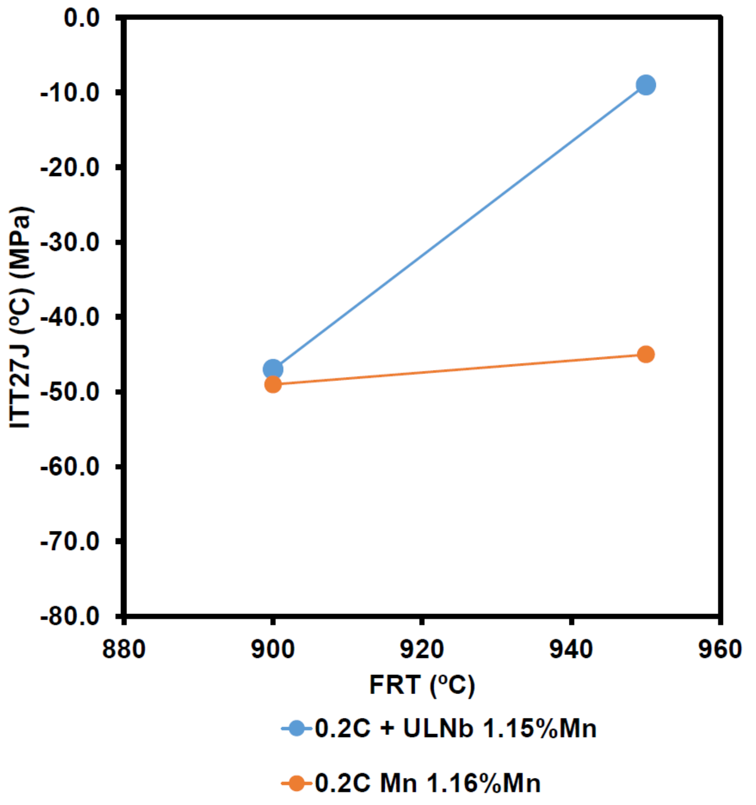
0.18C-1.14Mn-0.20Si+81ppmNb
12.8µm; 20% Pearlite
YS = 341 MPa
TS = 520 MPa
TS/YS = 1.53
CVN@0ºC = 227J

Patel 2022

Comparison: CMn x ULNb Steels







Increasing Mn Contents

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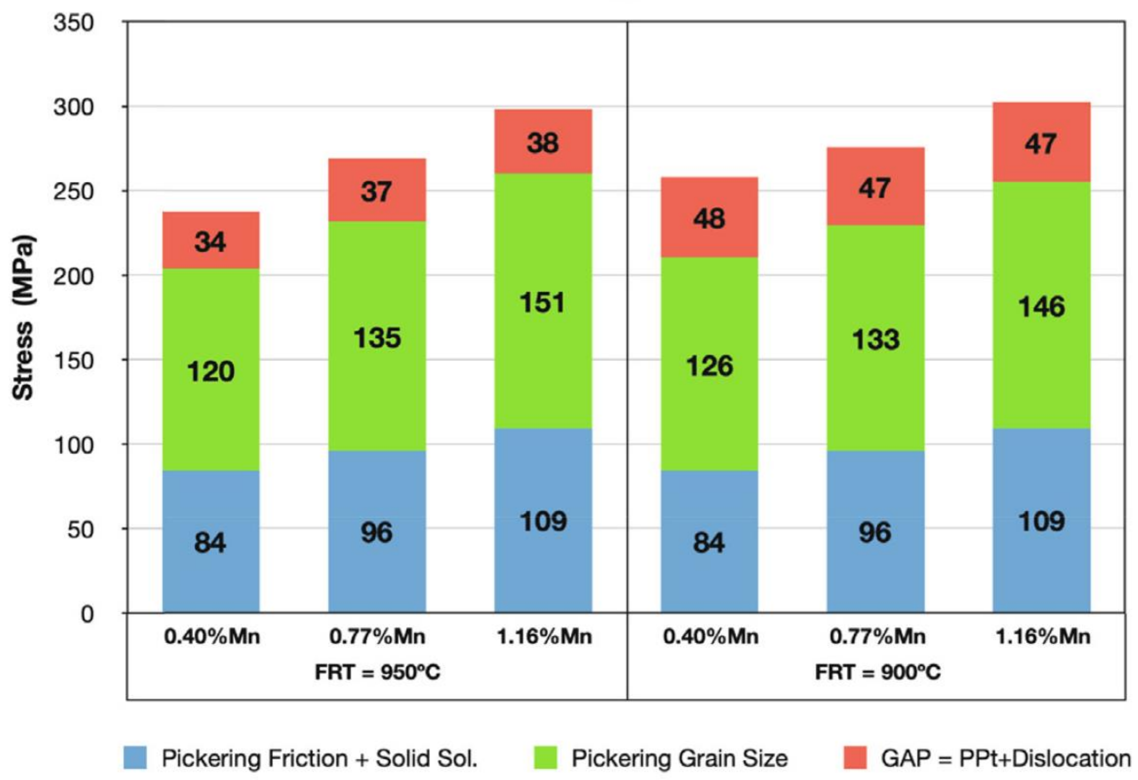
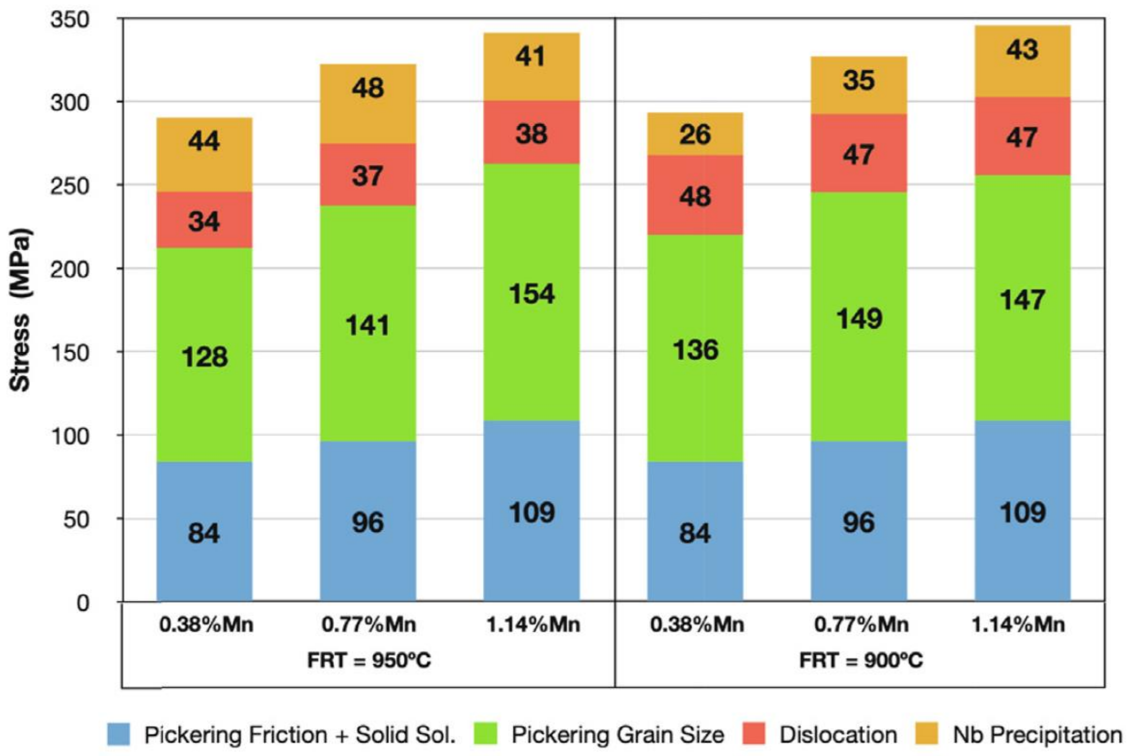
Comparison: CMn x ULNb Steels



(a)



(b)

CMn Steel

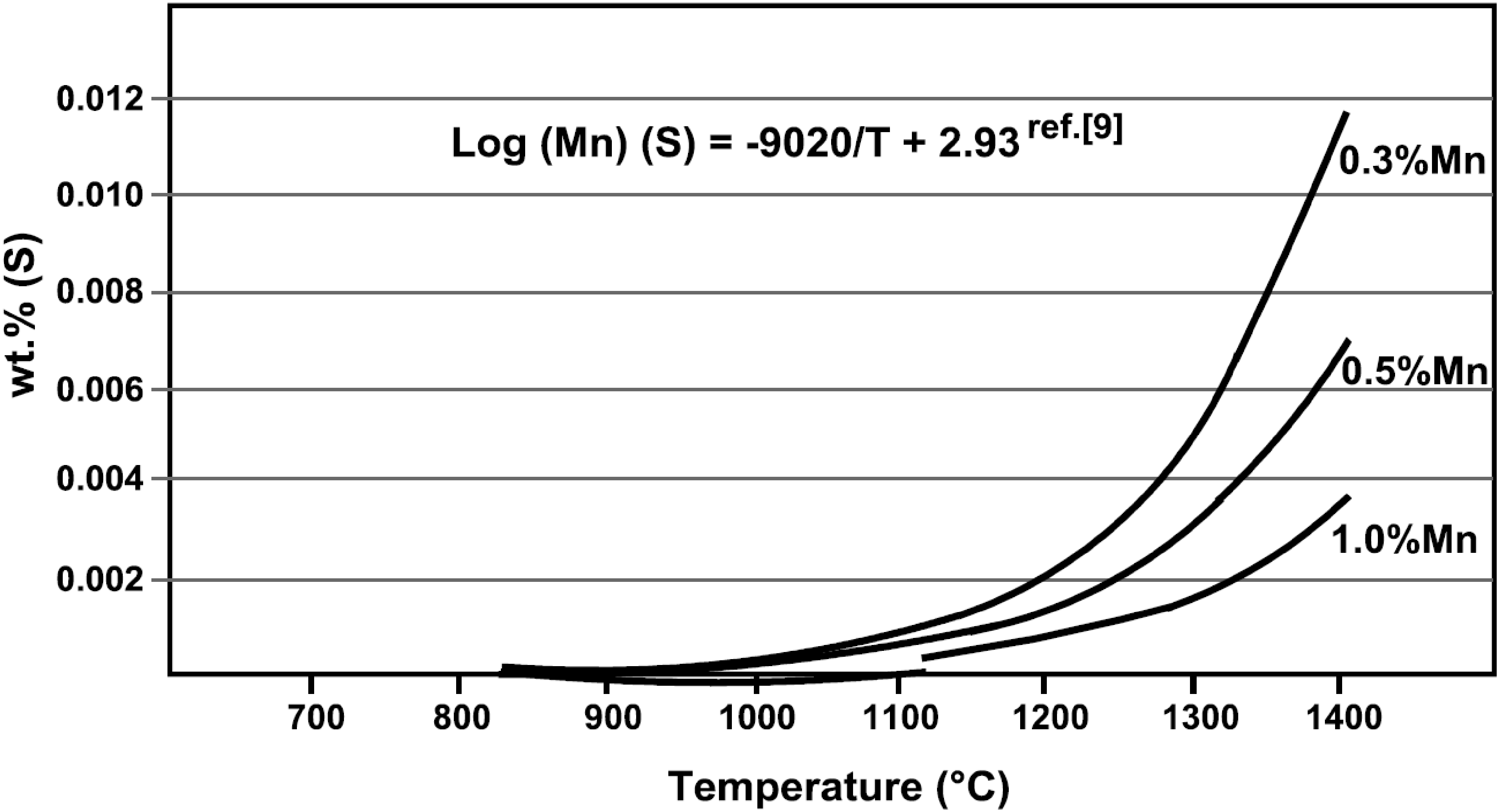
ULNb Steel

Patel 2022

Low Mn HTP Steel for Sour Service Pipes

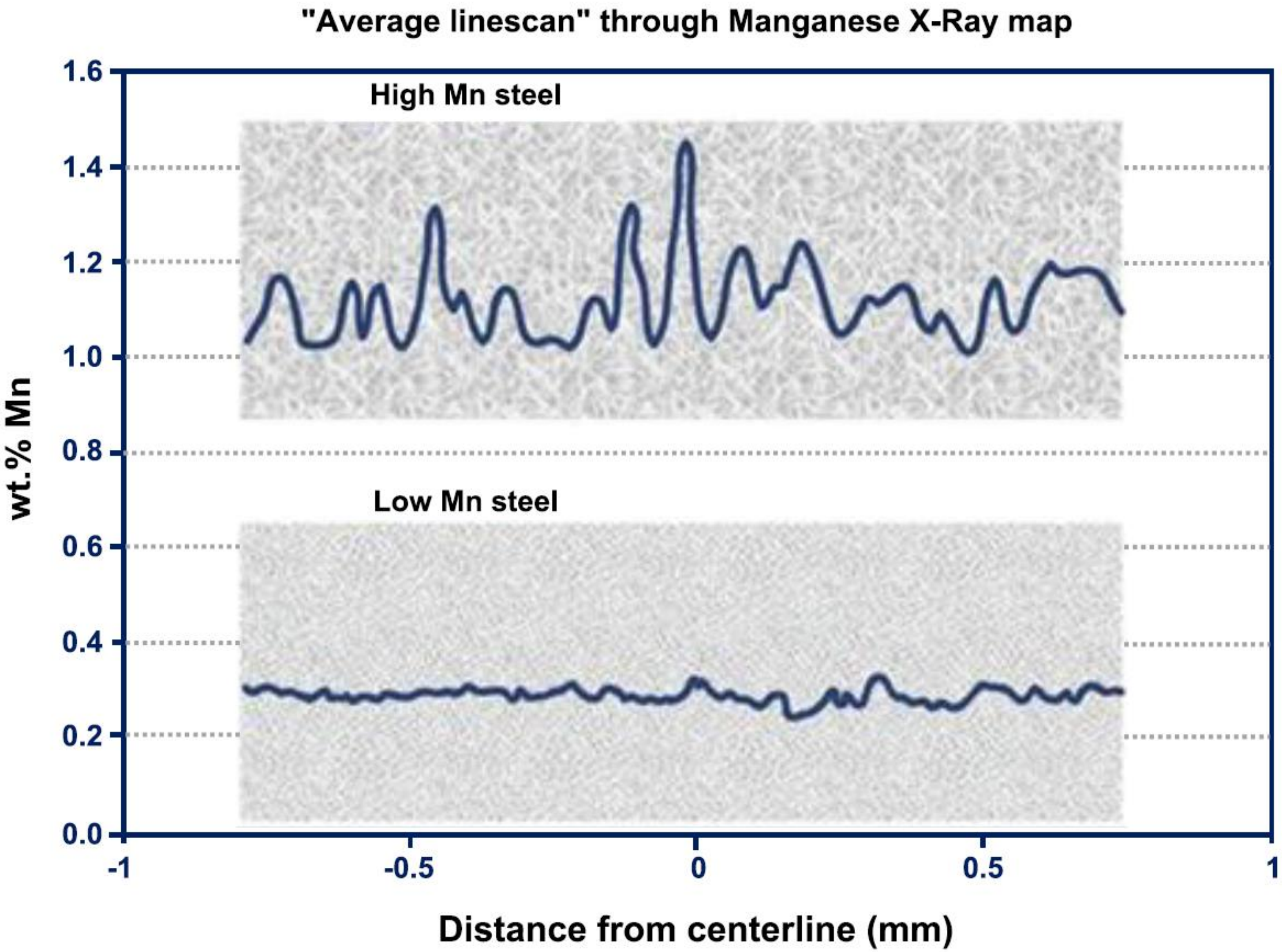
- Pipes for sour service generally are made with **microalloyed steel with Mn amounts tipically in the 0.90-1.20% range**.
- Such **Mn values are relatively high** when compared to the **rather low S amounts** required for this application, typically below 0.001%.
- Under such conditions there is the formation of **elongated inclusions of MnS**, which increase the susceptibility of the steel to HIC.
- In this case it is necessary to **globulize such inclusions** through the treatment of liquid steel with higher amount of Ca, leading to higher consumption of this material, steel projections and formation of excessive amount of inclusions.
- Therefore, the **partial substitution of Mn by other alloying elements** presents potential advantages.

Low Mn HTP Steel for Sour Service Pipes



Gray, J.M. Microalloyed Pipe Steels for the Oil & Gas Industry. CBMM, Moscow, April 2013, 14 p.

Low Mn HTP Steel for Sour Service Pipes



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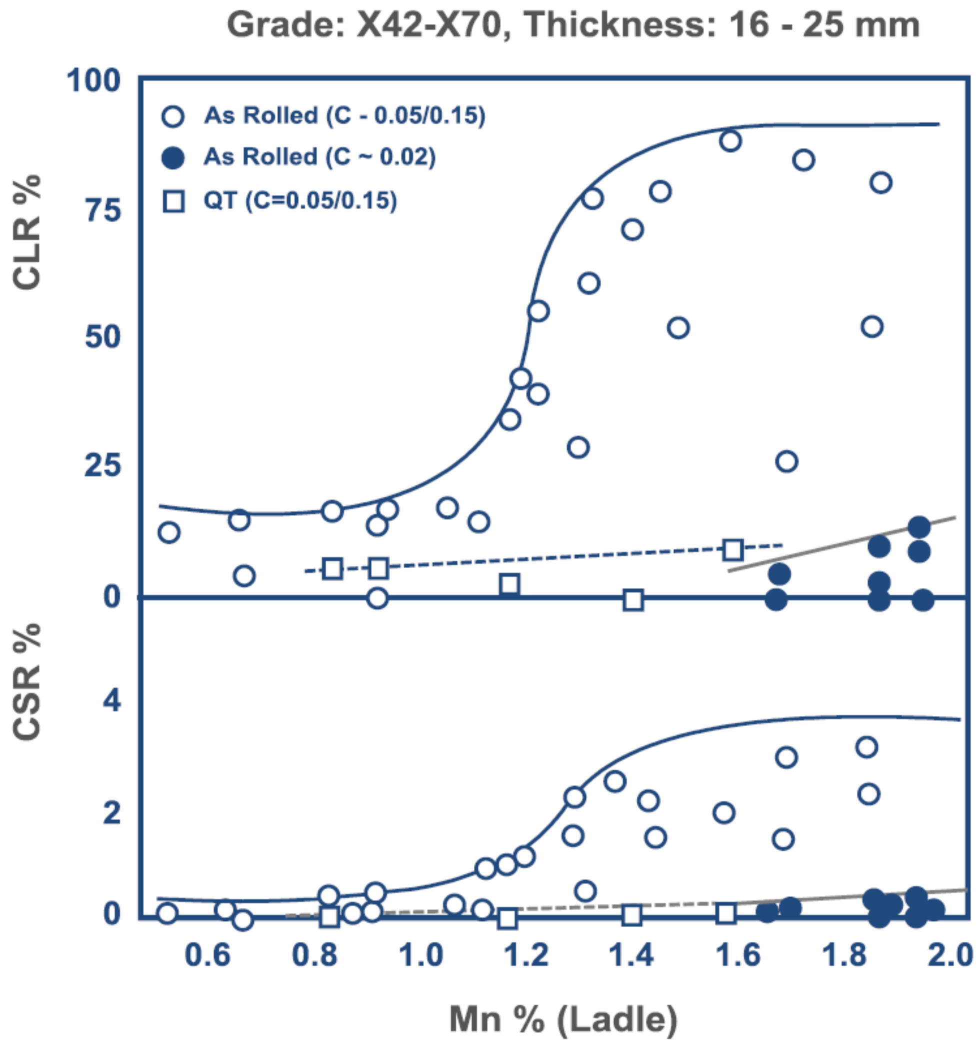

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Low Mn HTP Steel for Sour Service Pipes

- From these findings it was proposed a **new concept of alloy design** for heavy plates intended for the manufacture of sour service pipes:
  - ✓ **Reduction of slab central segregation**:
    - Reduced Mn amount;
    - C < 0.06% + Cr to promote solidification in the delta ferrite range, where the diffusion of alloy elements is fast;
    - Low casting speeds;
    - Use of soft reduction.
  - ✓ **Solubility increase of MnS** through reduction of Mn and S amounts;
  - ✓ **Plasticity decrease of MnS** through reduction of Mn:S ratio;
  - ✓ **Addition of Nb and Cr** to compensate Mn amount reduction.

Gray, J.M. Microalloyed Pipe Steels for the Oil & Gas Industry. CBMM, Moscow, April 2013, 14 p.

Conclusions

- The **world steel market is extremely competitive**, requiring a continuous search for opportunities to **reduce costs** and ensure the **competitiveness** of the plants.
- One of them arose from the **large increase in demand for Mn** that occurred in recent years, which was reflected in the **magnitude** and **volatility of the prices** of its ferroalloys.
- The **replacement of 0.30-0.50% Mn by 0.010-0.020% Nb** in structural steels proved to be a **viable alternative** in technical, economic and environmental terms.
- Other steel grades, as those used in **sour service linepipes**, also can benefit from the **partial substitution of Mn by Nb** and other alloy elements.

Niobium | High Strength Steel | Light Weight & Weldable | Lean & Competitive Design | Environmentally Sustainable Structure

THANK YOU FOR YOUR ATTENTION! QUESTIONS?

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