ULTRA LOW Nb

Reducing cost & GWPe in S275 and S355 commodity grade structural steels

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On behalf of CBMM Technology
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OPENING QUESTIONS...?

What is Ultra Low Nb (ULNb)...?

The use of niobium (Nb) at VERY low levels ≤100 ppm Nb (i.e., 0.010wt.%Nb)

Typically, between 60-90ppmNb, based on the final product

What are the two main benefits...?

Cost savings by using less manganese (Mn) and/or vanadium (V) in the alloy design

Lower final product GWPe values for Environmental Product Declarations (EPDs)

What type of steels are we looking at...?

Typically, commodity and structural grade steels (i.e., 275–355 MPa YS)

And even rebar grades (i.e., ≥420MPa YS)

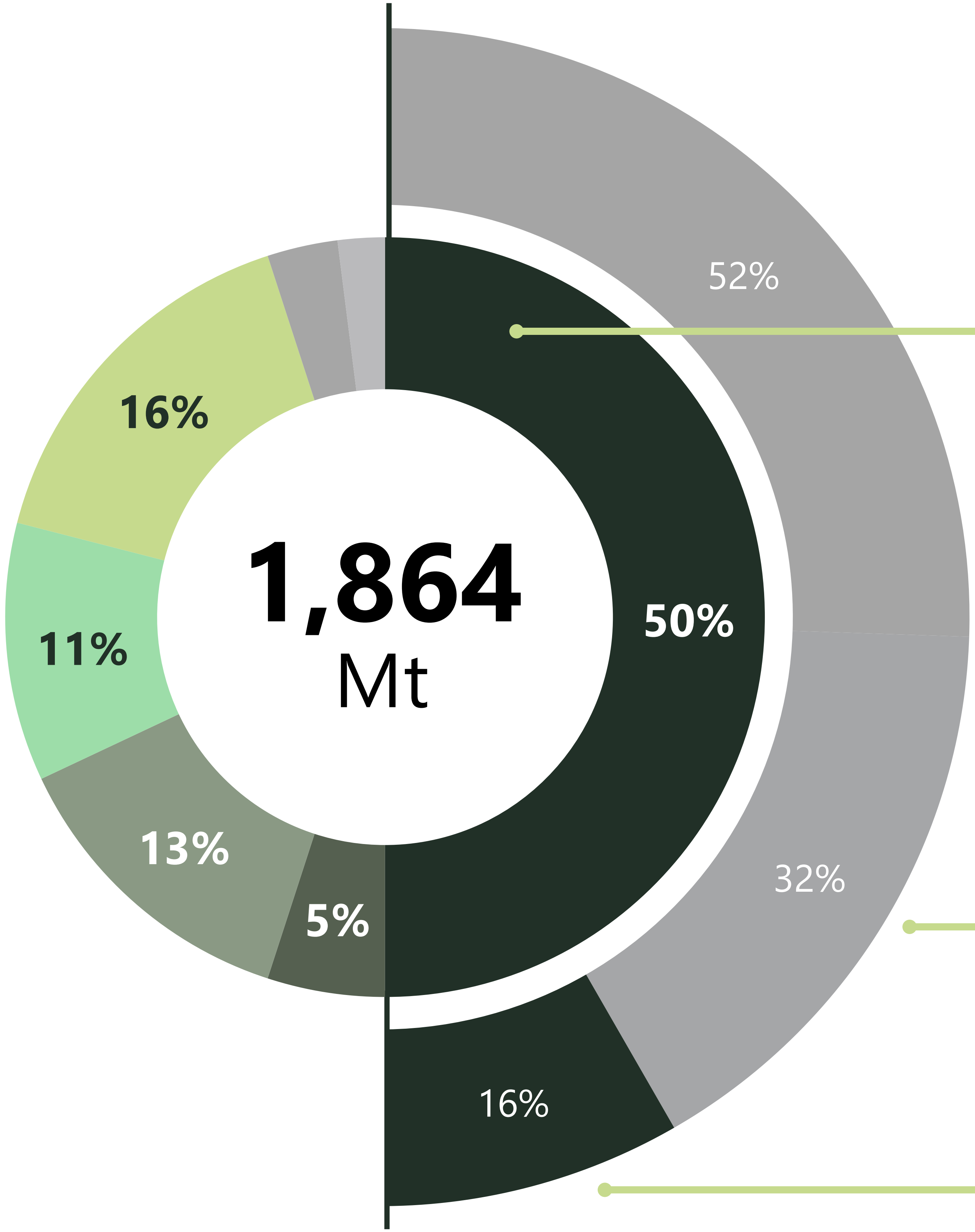
ULNb solution can be applied in strip, plate and long products

Are there any changes required in my process...?

No!

The addition of Nb is so low, there is very little effect on the production process itself

GLOBAL STEEL MARKET



- Construction
- Other Transport
- Auto
- Metal Products
- Mechanical Machinery
- Electrical Equipment
- Domestic Appliance

Source: World Steel Association for chart

50% of global crude steel is used in the construction sector.

Mainly low strength commodity steel grades

Value circa:
USD$850bn
in revenue (p.a.)

Circa 300Mt, circa USD:
$200-220bn (p.a.)
Rebar

140-150Mt, circa USD:
$130-140bn (p.a.)
Beams & Sections

COMMODITY & STRUCTURAL GRADES…

The chemical composition of all these steels are based on a plain CMnSi alloy design, with the content steadily increasing with strength.

As the final steel product thickness or weight is increased, the alloy design is often supplemented by the addition of more Mn and microalloys, such as vanadium, to achieve the final strengths.

However, there are costs **associated with these extra additions…**

235 MPa YS

275 MPa YS

300 MPa YS

++ Carbon

++ Manganese

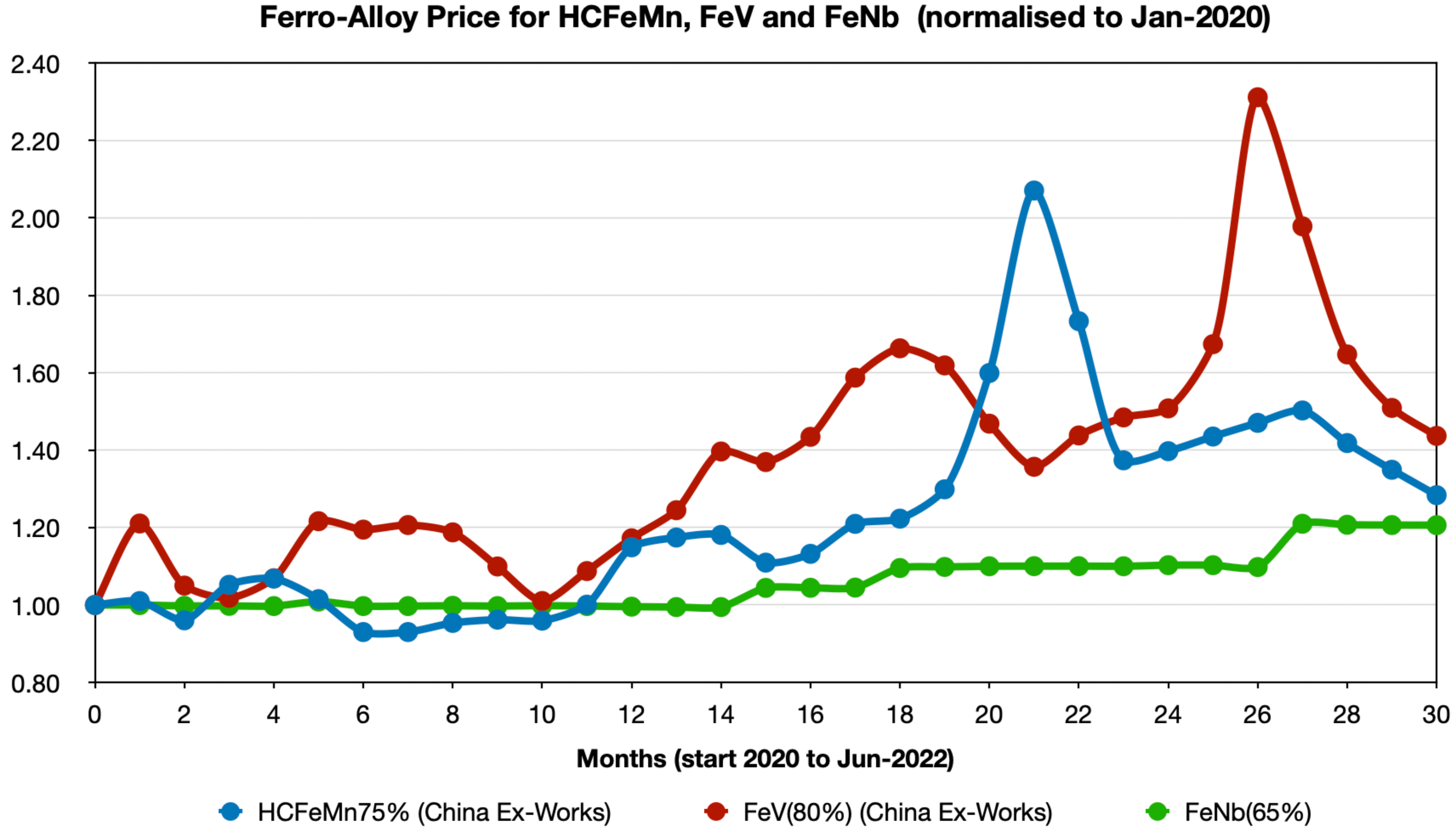
+ Microalloy(s)

++ Manganese

Medium to Heavy Sizes

≥355 MPa YS

PRICE OF FERRO-ALLOYS



PRICES FROM JAN 20 – JUN 22

The plots show the price China ex-works (normalized to base Jan 2020) of ferro-manganese, ferro-vanadium and ferro-niobium for 30 months at the end Jun-2022.

FeMn and Fe(MnSi) are often regarded as "cheap" ferro-alloys.

However, as they are used in the production of ALL steels, any price volatility will have a direct impact on the overall production costs and thus realized margin per ton of steel.

MARKET PROPOSITION WITH ULTRA LOW Nb (ULNb)

What if there is a way to reduce overall alloying costs, reduce exposure to ferro-alloy price fluctuations and ultimately improve profitability?

Add 50 ppm to **100 ppm Nb**

235 MPa YS → (++Carbon, +Manganese) → **275** MPa YS → (++Carbon, ++Manganese) → **355** MPa YS

≤100 ppm Nb:

- ✓ Low reheating temperatures
- ✓ Suitable for weak / old mills
- ✓ Full use of Nb addition during rolling & precipitation strengthening
- ✓ Cost savings vs Mn and/or V additions
- ✓ Lower GWPe per tonne of steel
- ✓ No major, if any, changes to existing operating practices

+Niobium (0.0050–0.0080 wt.%) → **275** MPa YS

Reduce manganese

+Niobium (0.0080–0.0100 wt.%) → **355** MPa YS

Reduce manganese and/or reduce vanadium

Nb Niobium

BACKGROUND METALLURGY

ROLE OF MANGANESE

Is added to plain carbon structural steels for a number of reasons:

- To combine with sulfur / act as a deoxidizing agent
- **Solid Solution Strengthening**
- Lowering the decomposition temperature of austenite

As shown in the chart, Mn will tend to provide a linear increase in strength by means of solid solution strengthening. As a guide:

Approximately 1.0%Mn = 32 MPa towards the YS

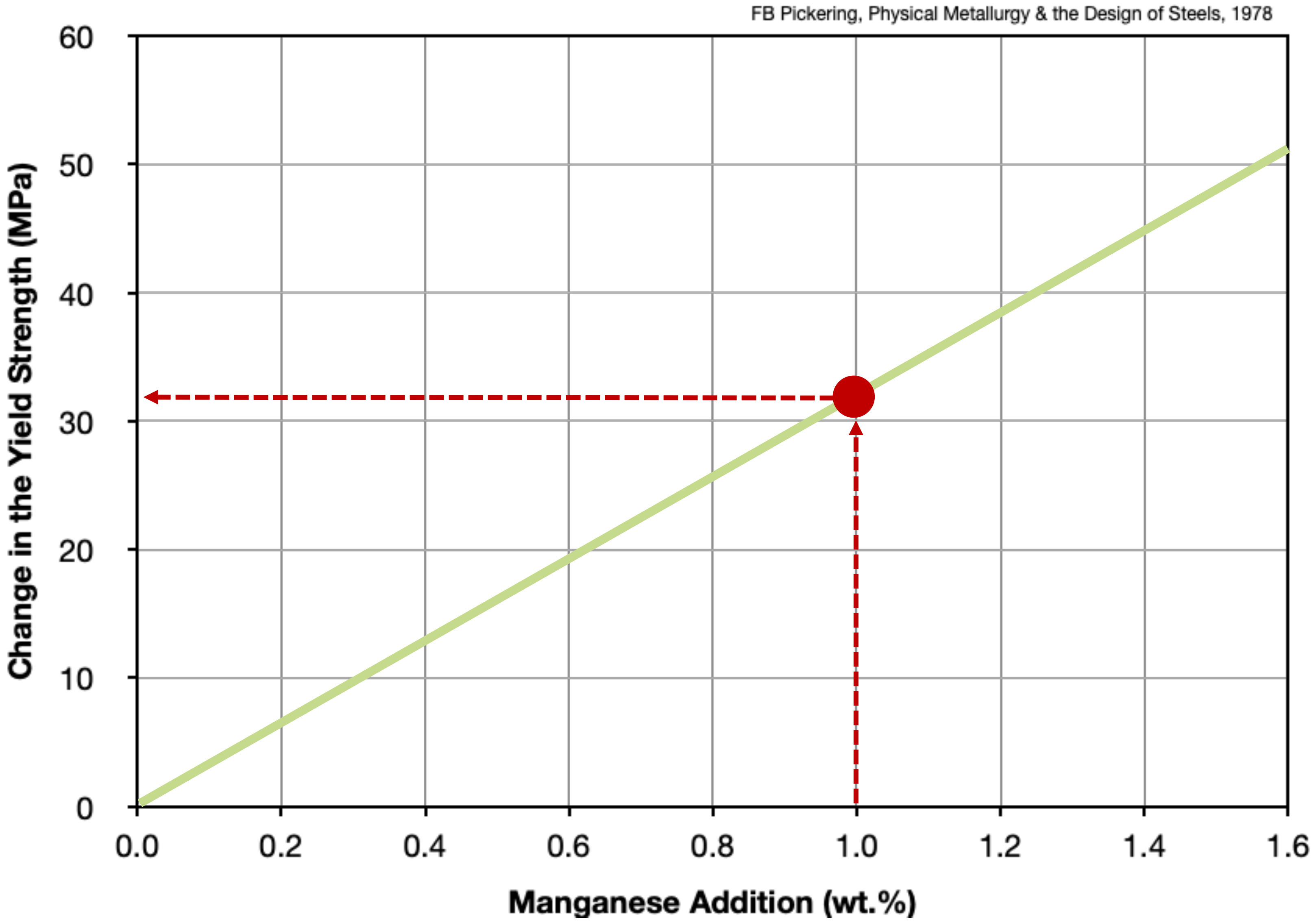
This relationship has been established through the study of a range of steel compositions developing the following semi-empirical relationship for the yield (YS) and tensile (TS) strengths respectively:

YS (MPa) =

$53.9 + \mathbf{32.3\%Mn} + 83.2\%Si + 354\%N_f^{1/2} + \mathbf{17.4d^{-1/2}}$

TS (MPa) =

$294 + \mathbf{27.7\%Mn} + 83.2\%Si + \mathbf{3.85\%\ Pearlite} + 7.7d^{-1/2}$



ROLE OF MANGANESE

Is added to plain carbon structural steels for a number of reasons :

- To combine with sulfur / act as a deoxidizing agent
- Solid Solution Strengthening
- **Lowering the decomposition temperature of austenite**

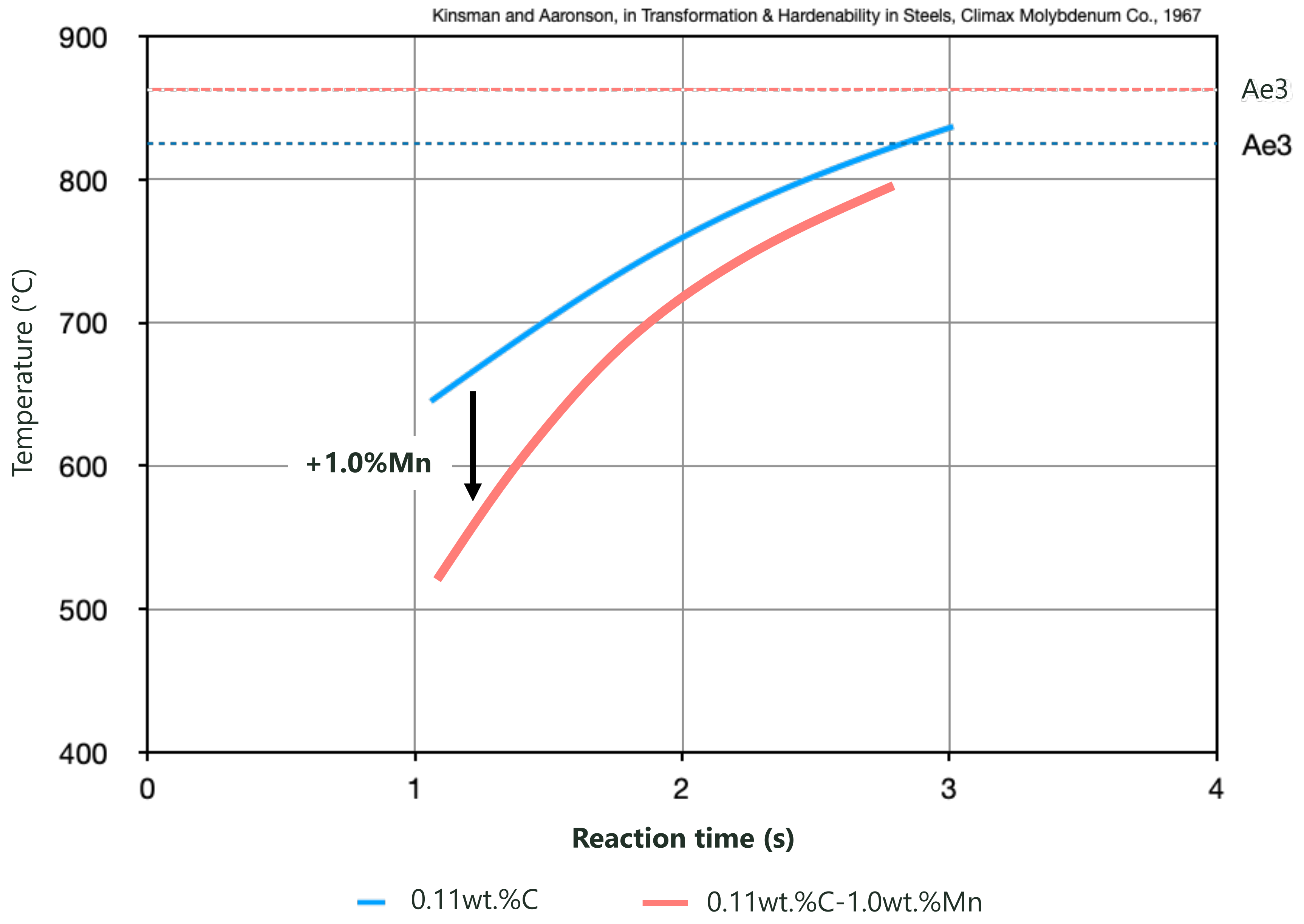
Classed as an austenite stabilizer, Mn will depress the austenite to ferrite (Ar_3) transformation temperature as it will partition to the austenite phase during transformation.

As shown, this this has a marked effect on the kinetics of the ferrite reaction which will support refinement of the ferrite grain size via greater nucleation sites and thus an increase in the yield strength.

Published equations propose:

Approximately 1.0%Mn = a drop of 80°C in the Ar_3 temperature

Furthermore, as the spacing of the pearlite lamellae is also sensitive to changes in the transformation temperature, Mn additions will also result in smaller interlamellar spacings and thus support an increase in the tensile strength.



ROLE OF

NIOBIUM

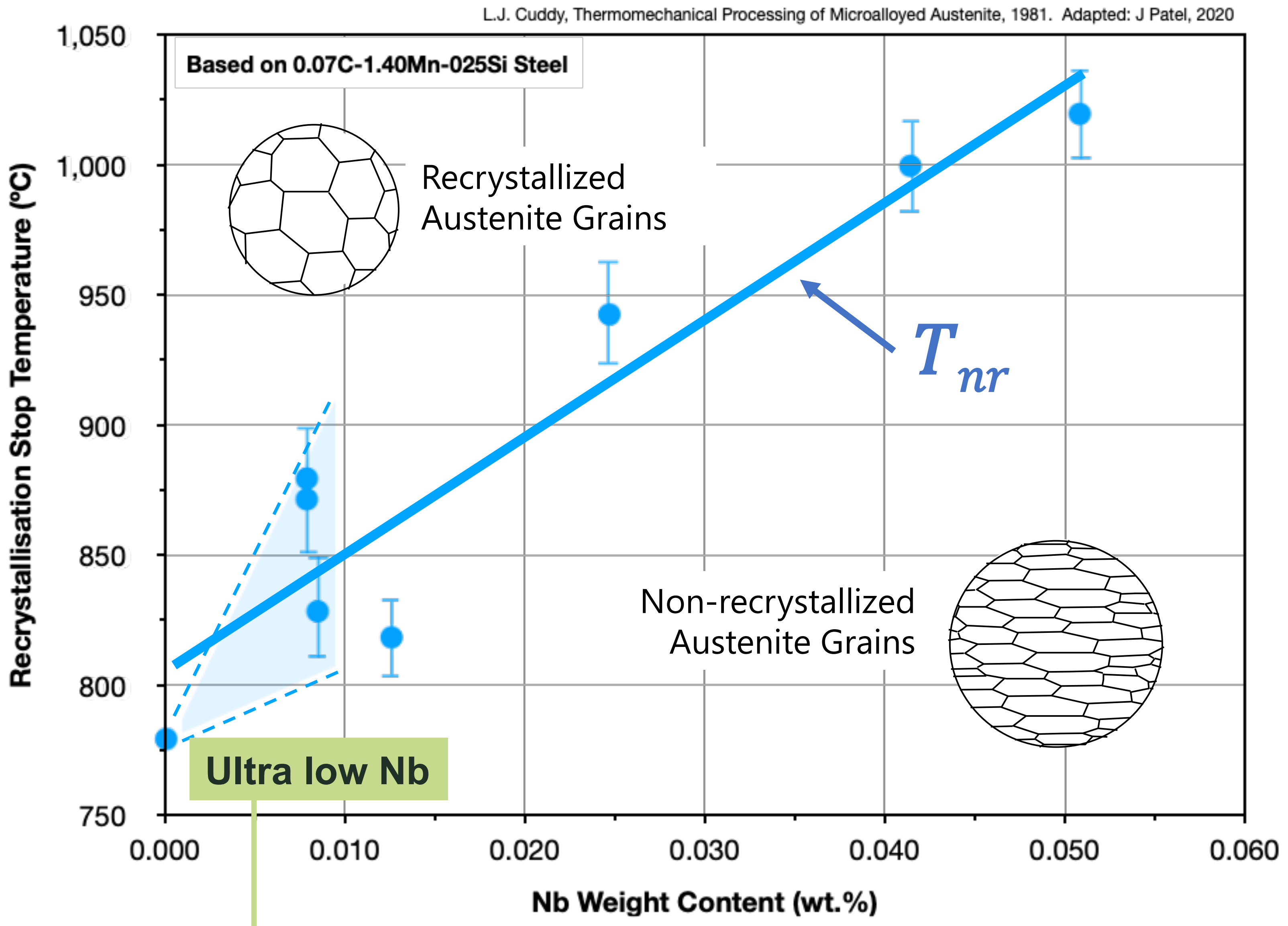
Effect of Nb on recrystallization

- Niobium delays the process of austenite recrystallisation during hot rolling.
- As the amount is increased this occurs at a higher temperature and the effect is more pronounced.

$$T_{nr} = 887+464C+980Ti+363Al-357Si + 6455Nb-644\sqrt{Nb}+732V-230\sqrt{V}$$

Boratto et.al., 1988

Smaller ferrite grains = Higher strength + improved toughness + better homogeneity



Note : It can be seen that at ultra low additions (≤100 ppm), Nb may have a more powerful effect

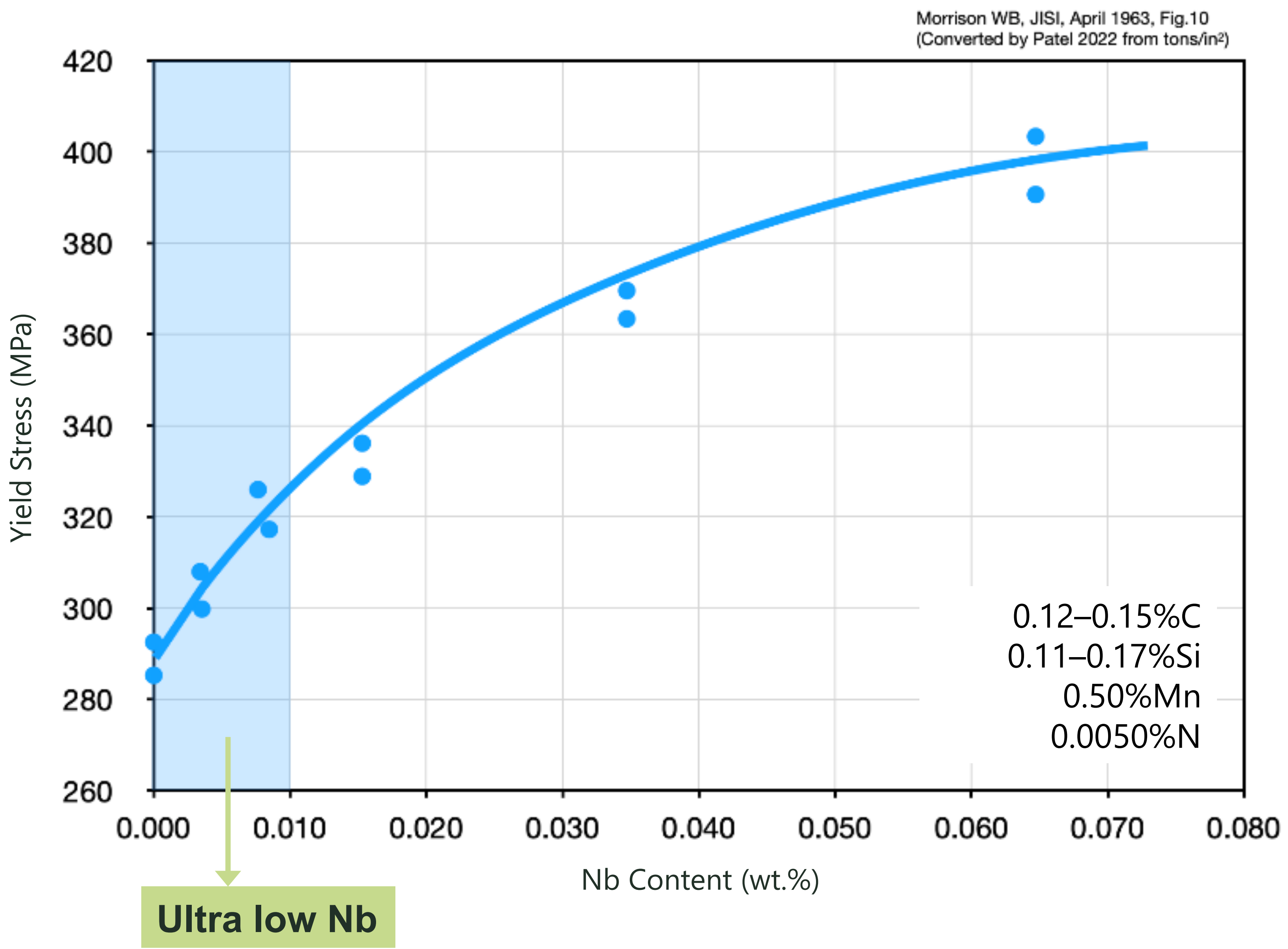
ROLE OF NIOBIUM AT ULTRA LOW LEVELS (ULNb)

Effect of Nb on yield strength

Due to effect of Nb on the recrystallization-stop temperature (T_{nr}) and subsequent refinement of the transformed ferrite grain size, Nb contribution to the yield strength is well established. This is all well demonstrated and published in the literature.

However, looking back at the original work of Morrison (1963), based on laboratory made and rolled steels, the contribution of Nb at very low levels is also seen to be greater within this range, matching the observations for the T_{nr}. But this part has not been widely investigated for commodity grade carbon structural steels

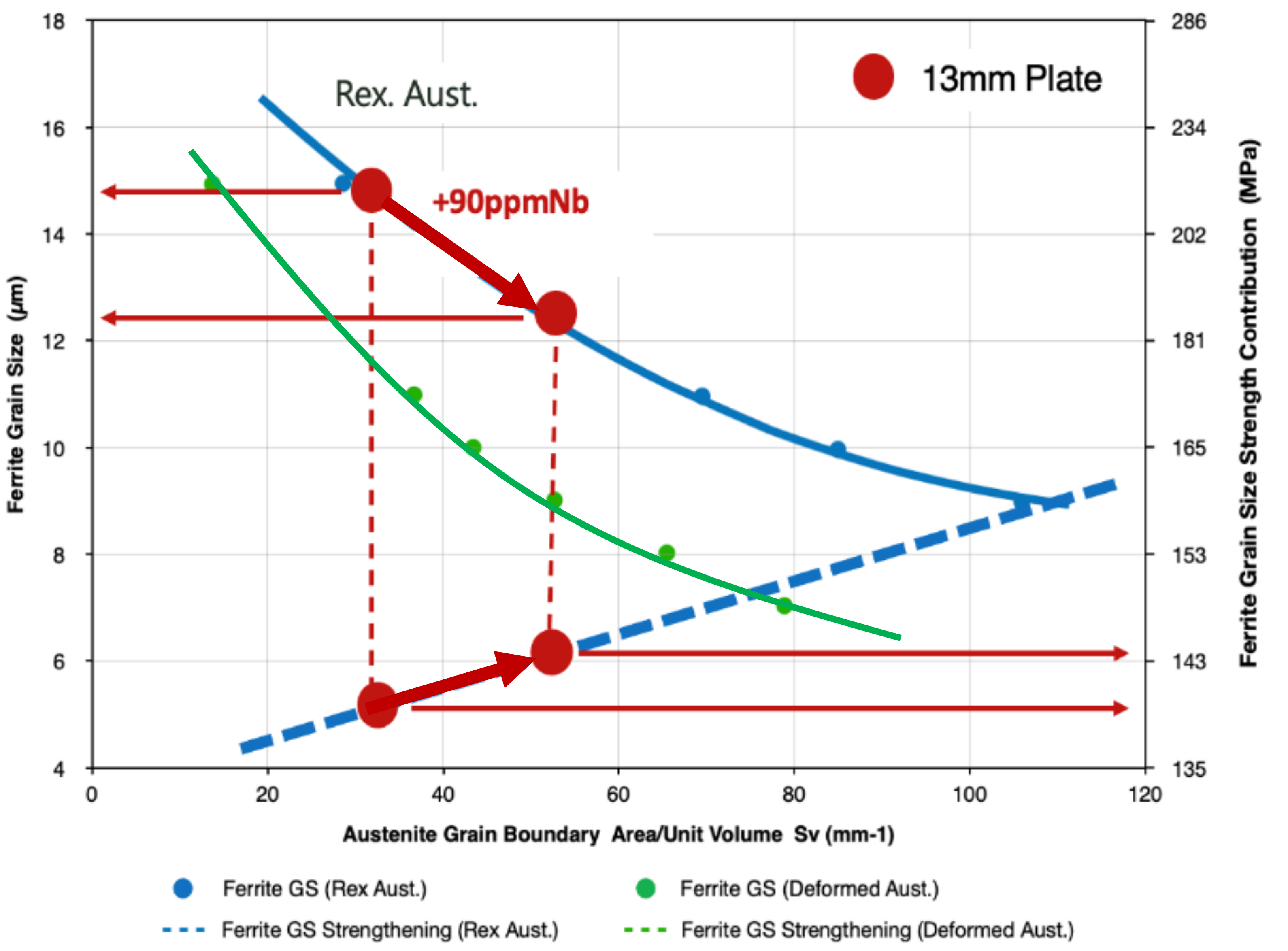
Note : Refer to the original paper to find details of the actual heat treatment and rolling conditions applied



Note : it can be seen that at ultra low additions (≤100 ppm), Nb gives a much higher strengthening contribution.

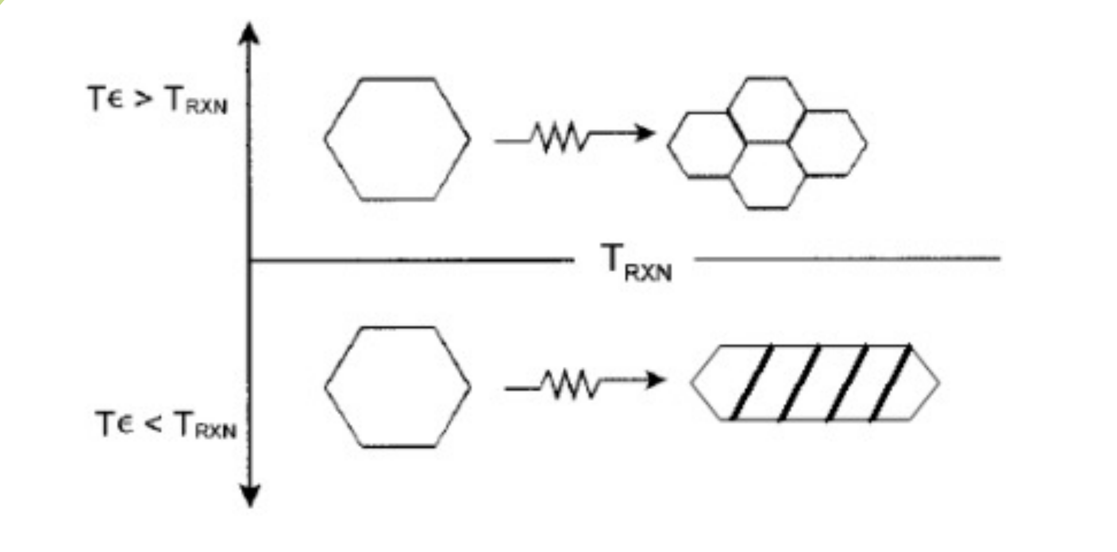
DEVELOPING A SMALLER RECRYSTALLIZED AUSTENITE GRAIN WITH ULNb

Sandberg A. and Roberts W., Swedish Institute for Metals Research Report No. IM-1439, 1980. Further developed by J Patel, 2020.



Ferrite grain refinement with Nb

The variation of the resultant ferrite grain size with the effective austenite interfacial area shows a difference whether the austenite was developed from a recrystallization or non-recrystallization state (i.e., below the T_{nr}). The latter producing a finer grain even with the same S_v value as it benefits from deformation bands within the grain



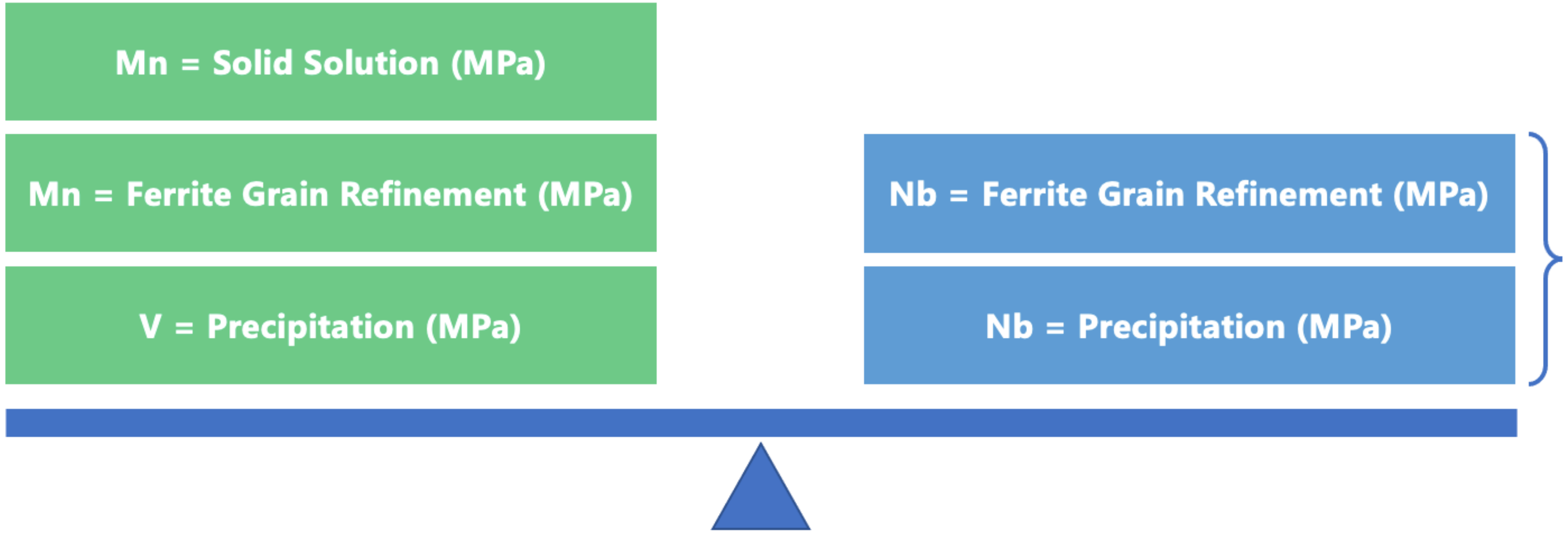
A.J. DeArdo, Proc. of the Int. Sym. Niobium 2001, USA, Dec 2–5, 2001, TMS, p. 427–500.

Solute drag effect of Nb coupled with the addition of strain (i.e., deformation) will introduce some strain induced Nb precipitates which should develop a smaller austenite grain.

That is, the aim is to move further down the blue line whilst remaining in the fully recrystallized austenitic state. This should keep more Nb available in solute form to precipitate post rolling.

MARKET PROPOSITION
WITH ULTRA Low Nb (ULNb)

So, knowing these established facts, can we use ultra low levels of Nb to effectively substitute some additions of Mn without changing any operational processes



Solute drag + strain induced precipitates = a slightly smaller recrystallised austenite = slightly smaller ferrite grain size.

Remaining solute Nb = precipitation strengthening

TO DEMONSTRATE THE EFFECT OF ULNb A SIMPLE RESEARCH STUDY WAS PERFORMED...

CBMM study on strengthening contribution from ferro-alloys

0.18C + Mn variation → The effect of Mn

0.18C + Mn variation + 70/80ULNb → The effect of ULNb on varying levels of Mn

Low carbon + Mn variation + 70/80ULNb → The effect of ULNb on varying levels of Mn in Low Carbon

0.18C +1.00Mn + Nb variation → The effect of varying levels of Nb

0.18C +1.00Mn + V variation → The effect of varying levels of V

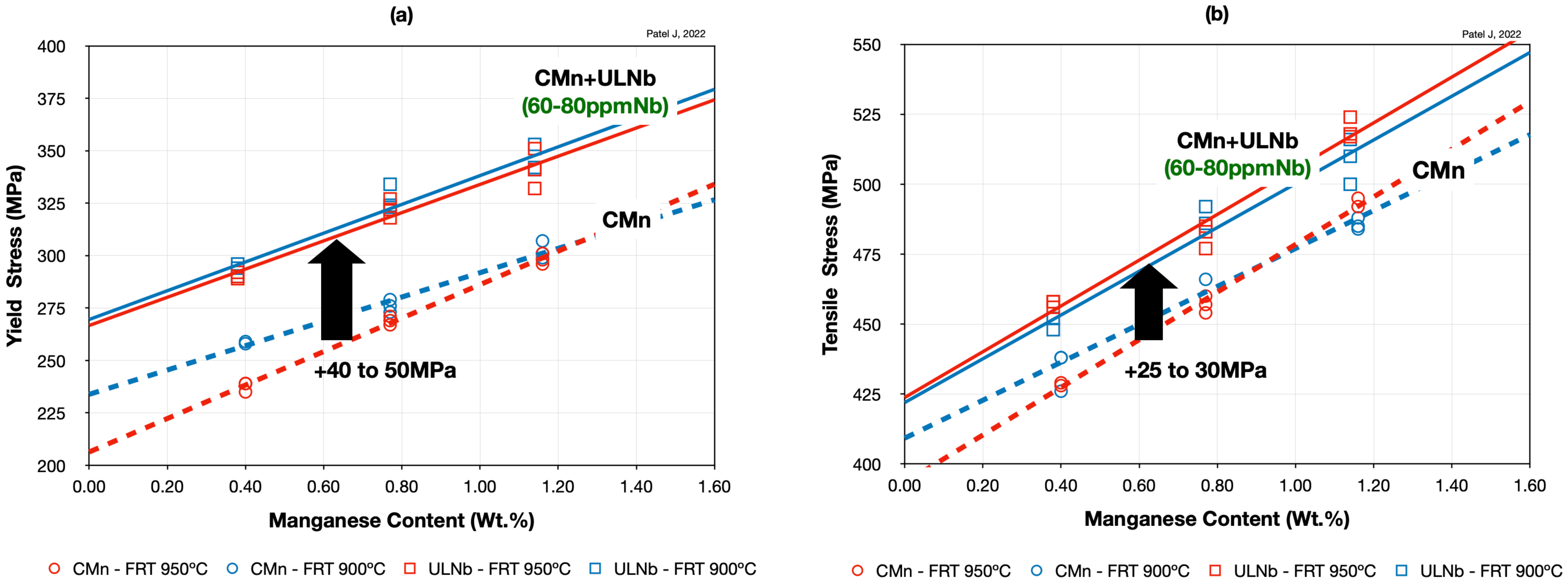
0.18C +1.00Mn + V variation + ULNb → The effect of ULNb on varying levels of V

MAIN FINDINGS

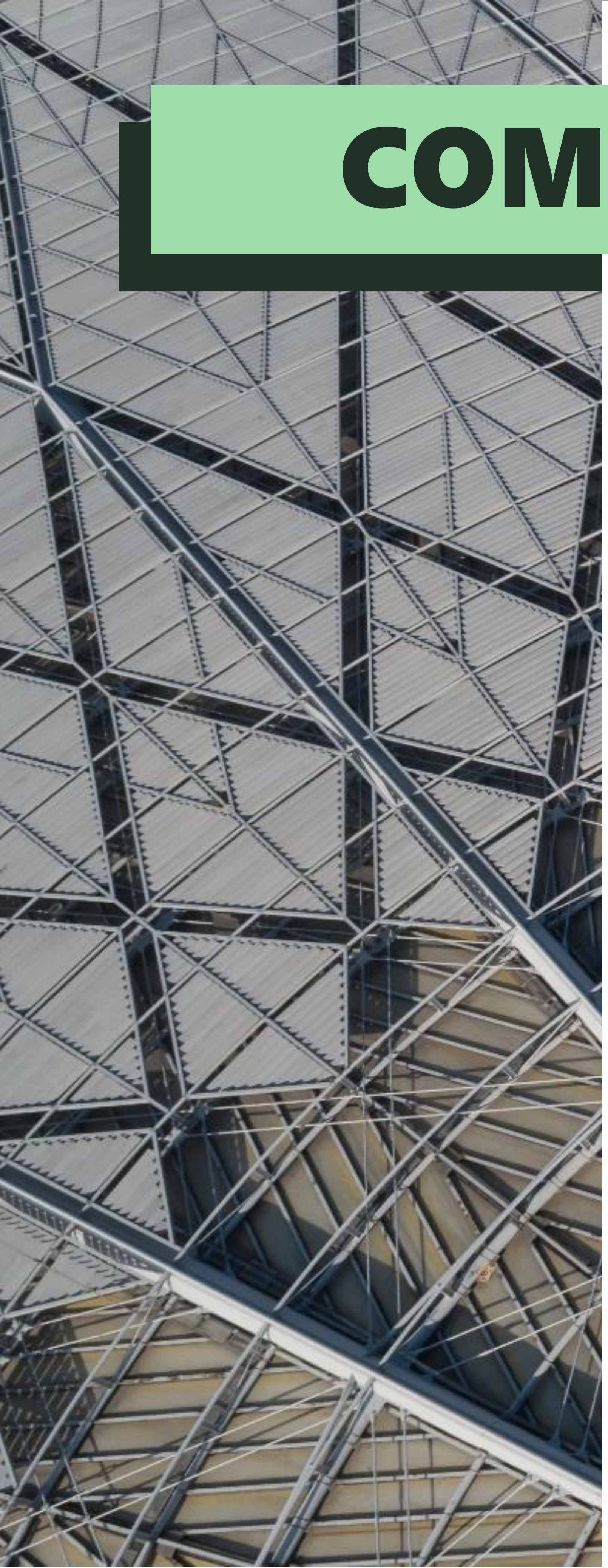
	Per Wt.% Addition (MPa)	Per 0.010wt.% (MPa)	Comparison Ratios [X : Nb]	Comments
Plain CMn	35	0.35	**49 : 1**	Only solid solution
	34	0.34		Only ferrite grain size
Vanadium (CMnV)	1,190	11.9	**2.52 : 1 ***	At content up to 0.042wt.%V
Niobium	3,000	30	**---**	At content between 0.010 to 0.020wt.%
ULNb	5,500	55	**0.55 : 1**	ULNb has a greater effect at these Ultra Low levels

* When using a semi-empirical analysis approach the ratio is found to be 3 : 1

- **0.45wt.%Mn can be replaced by 100ppmNb**
- **The V:Nb ratio is 2.52 : 1**
- **Confirmation that Nb at Ultra Low additions (≤100ppm) has far greater potency !**

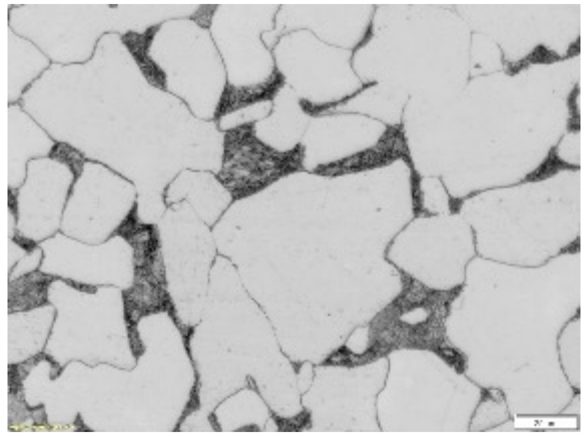


THE EFFECT OF ULNb ADDITIONS ON A PLAIN CMn STEEL



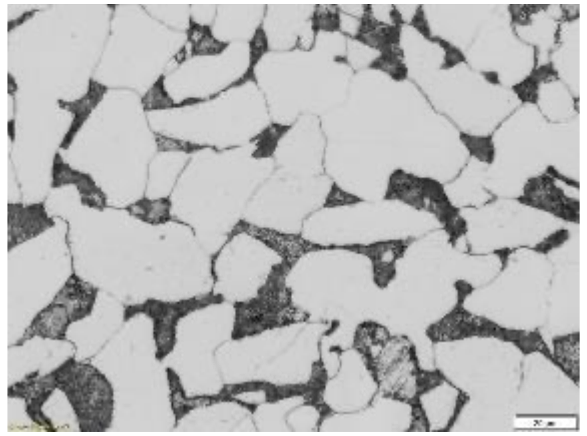
COMPARISON OF CMn AND ULNb STEELS

CMn (14 mm)



0.18 C-0.40 Mn
22.0 µm; 15% Pearlite

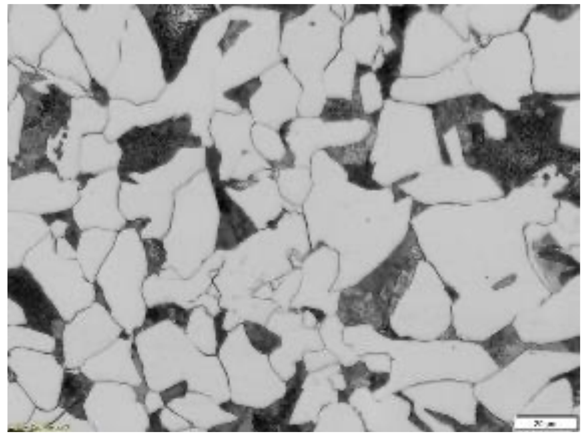
YS = 238 MPa
TS = 428 MPa



0.18 C-0.77 Mn
16.6 µm; 20% Pearlite

YS = 269 MPa
TS = 457 MPa

CVN@0ºC = 217 J

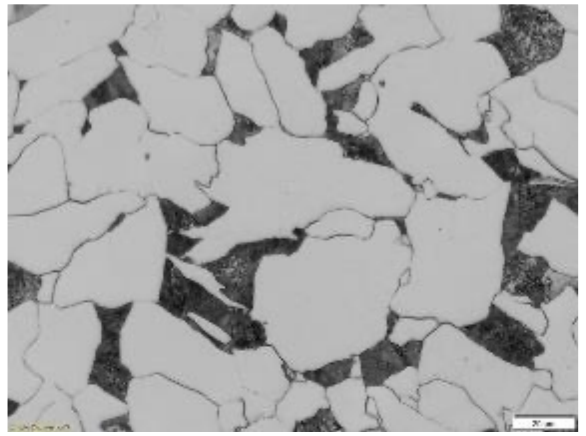


0.18 C-1.16 Mn
13.5 µm; 20% Pearlite

YS = 298 MPa
TS = 493 MPa

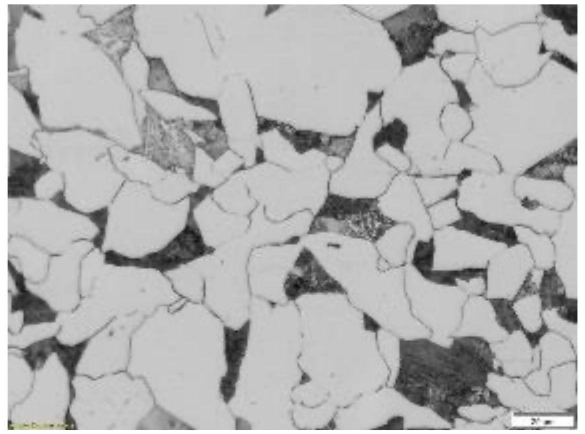
CVN@0ºC = 235 J

CMn+0.010%Nb (14 mm)



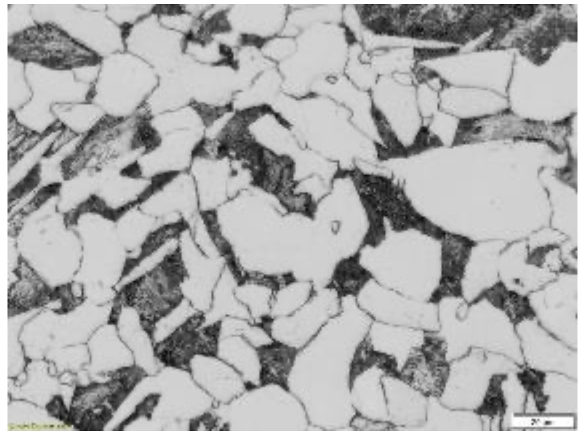
0.18 C-0.38 Mn +63 ppmNb
17.6 µm; 15% Pearlite

YS = 290 MPa
TS = 457 MPa



0.18 C-0.77 Mn +72 ppmNb
15.2 µm; 15% Pearlite

YS = 322 MPa
TS = 482 MPa
TS/YS = 1.50
CVN@0ºC = 190 J



0.18 C-1.14 Mn +81 ppmNb
12.5 µm; 20% Pearlite

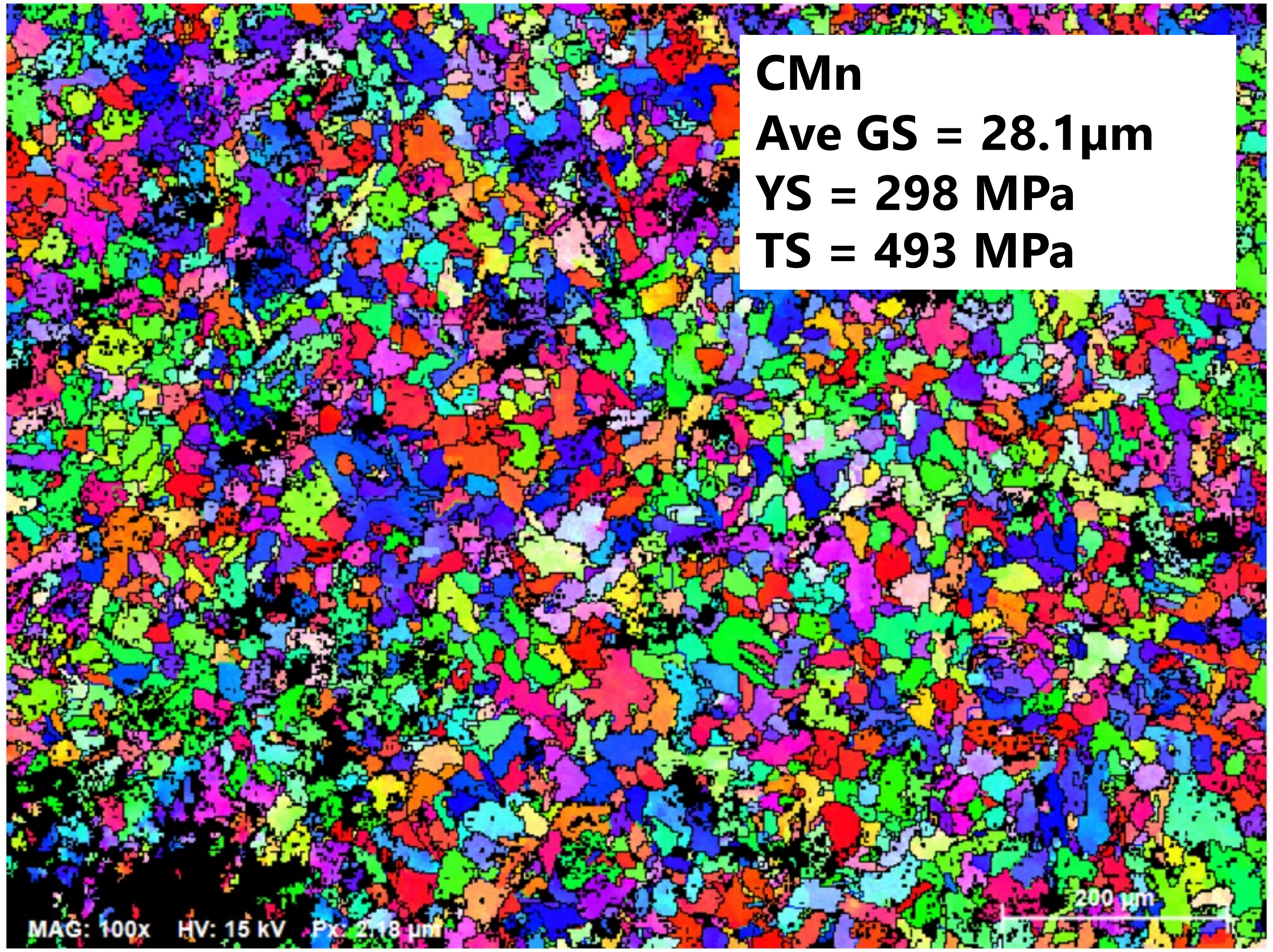
YS = 341 MPa
TS = 520 MPa

CVN@0ºC = 227 J

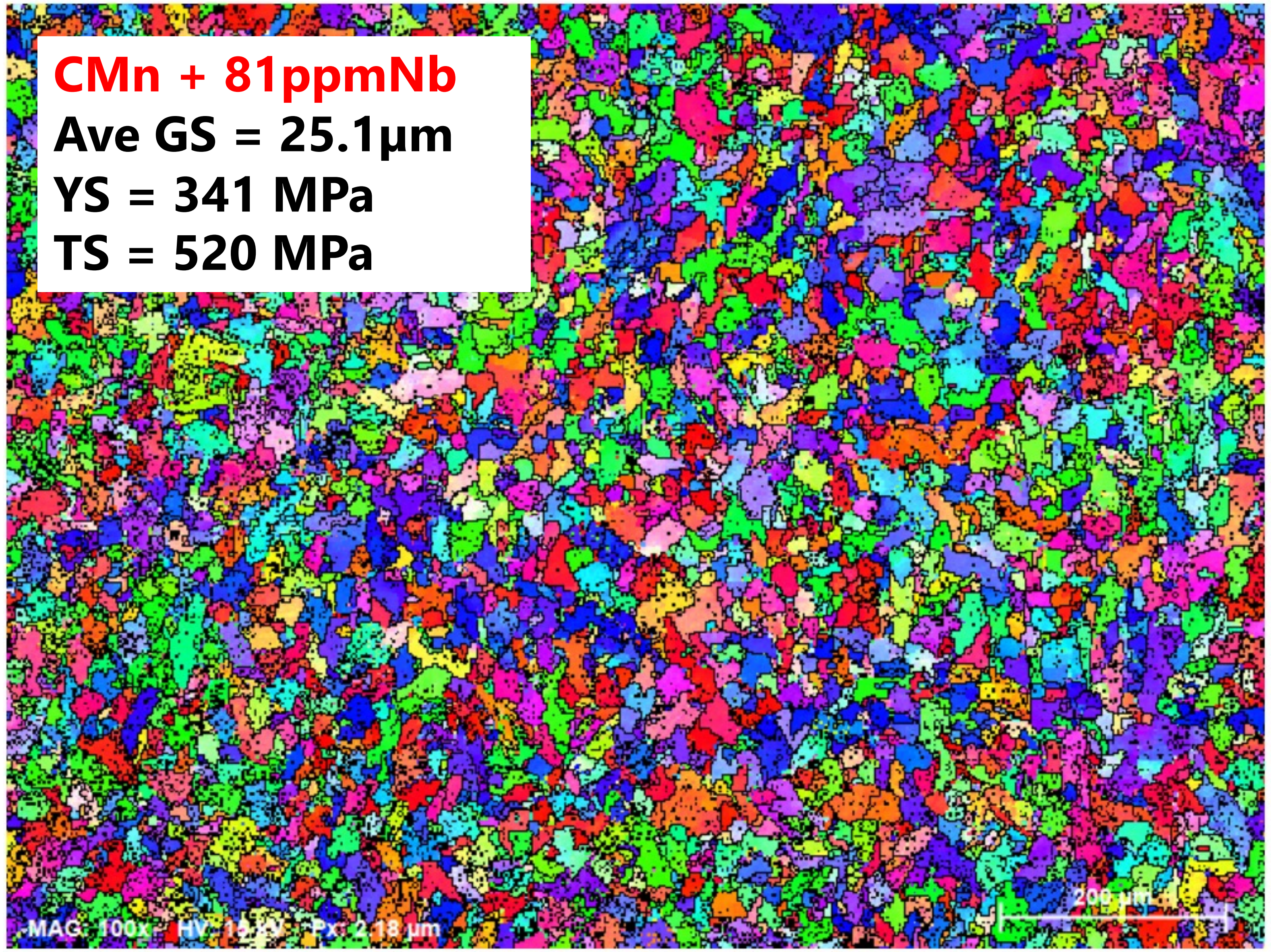
Finer & more homogenous

FERRITE GRAINS

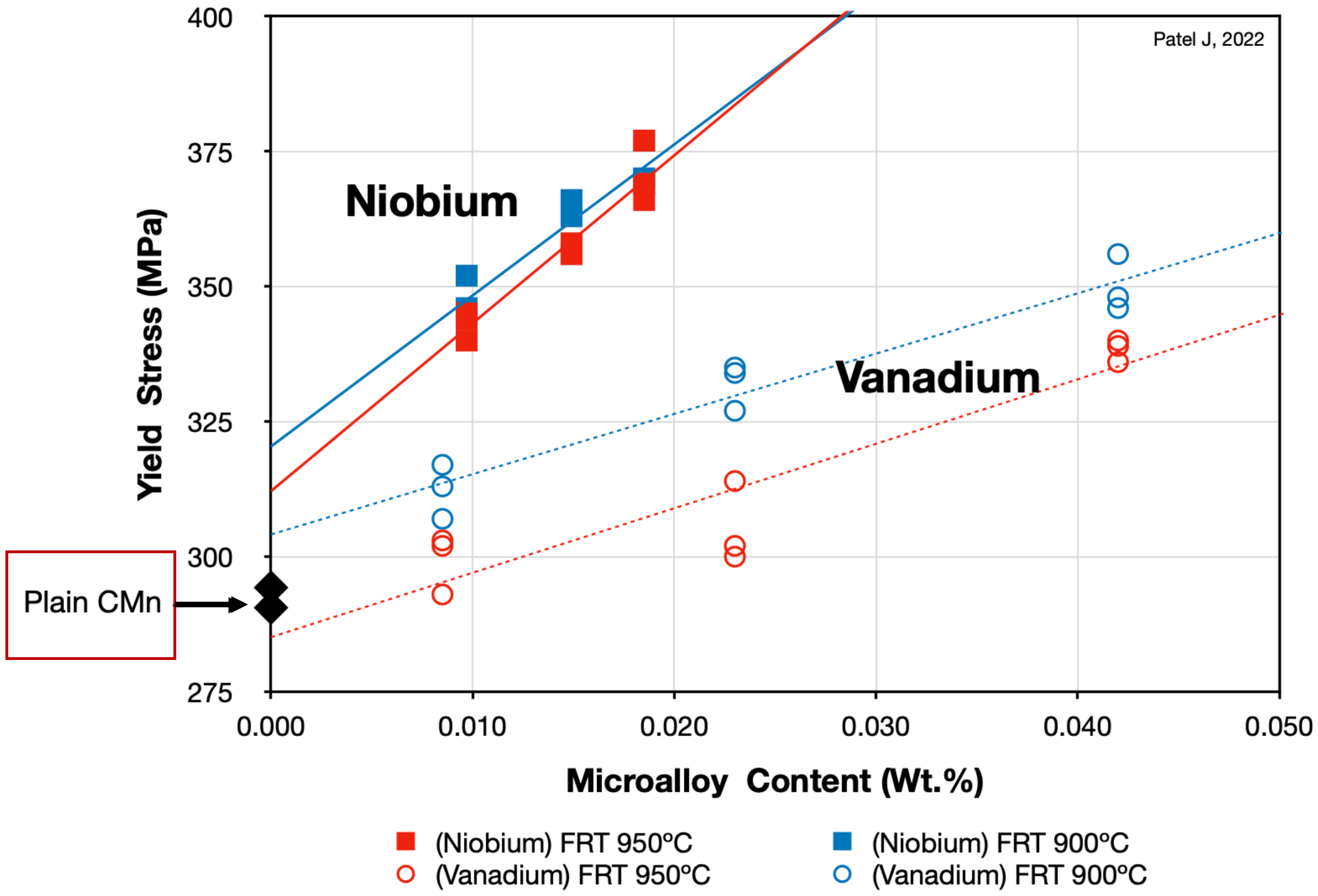
Patel J, 2022



Patel J, 2022



VANADIUM TO NIOBIUM RATIO



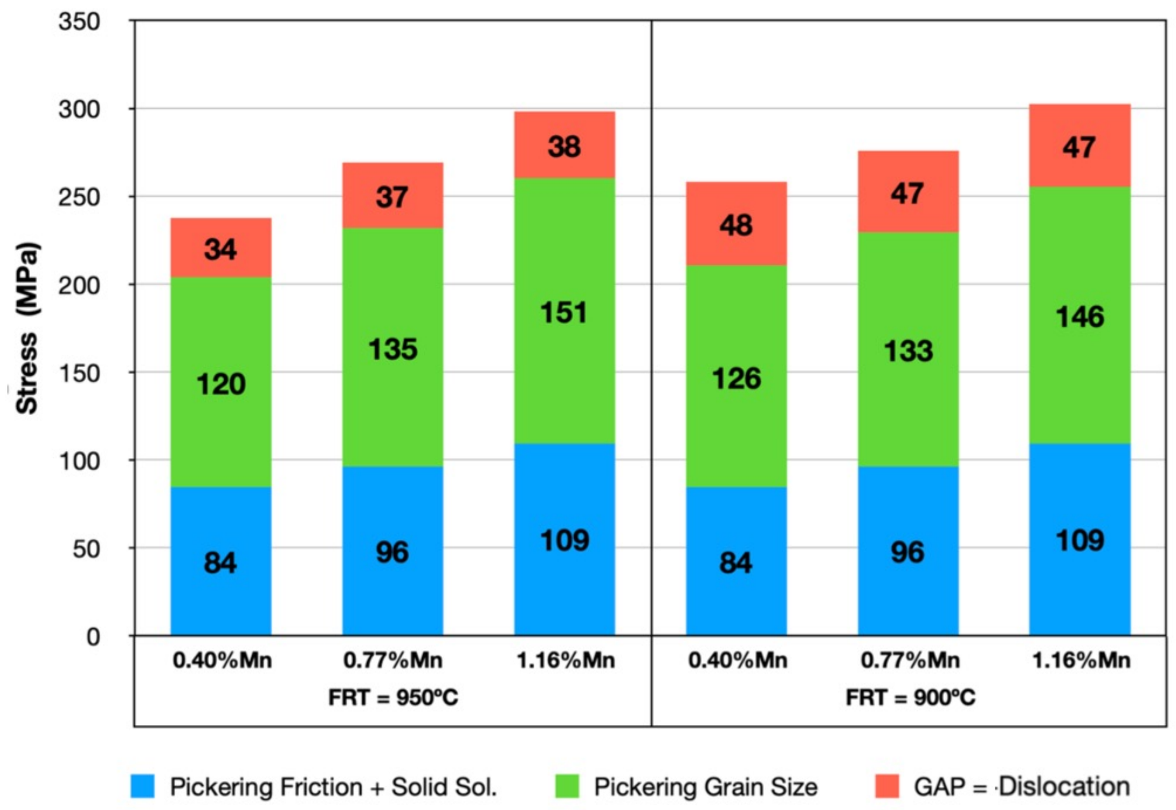
Recent studies by CBMM has established that the V:Nb ratio can be as high as 2.5 to 1

This will vary depending on the final steel product dimensions and cooling rates post rolling

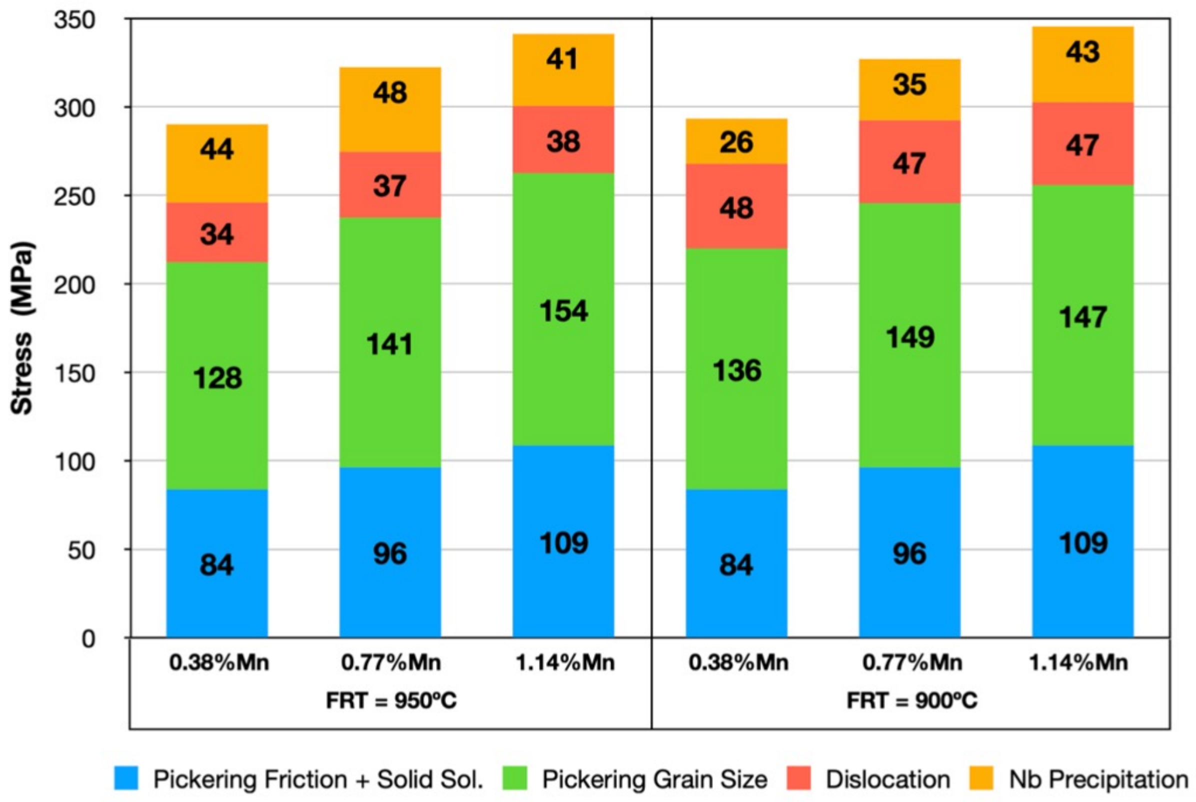
SEMI-EMPIRICAL ANALYSIS

$$YS = 53.9 + 32.34\ Mn + 83.2\ Si + 678\ P + 354.2\ N_f + 17.4\ d^{-1/2}$$

CMn Only Steels

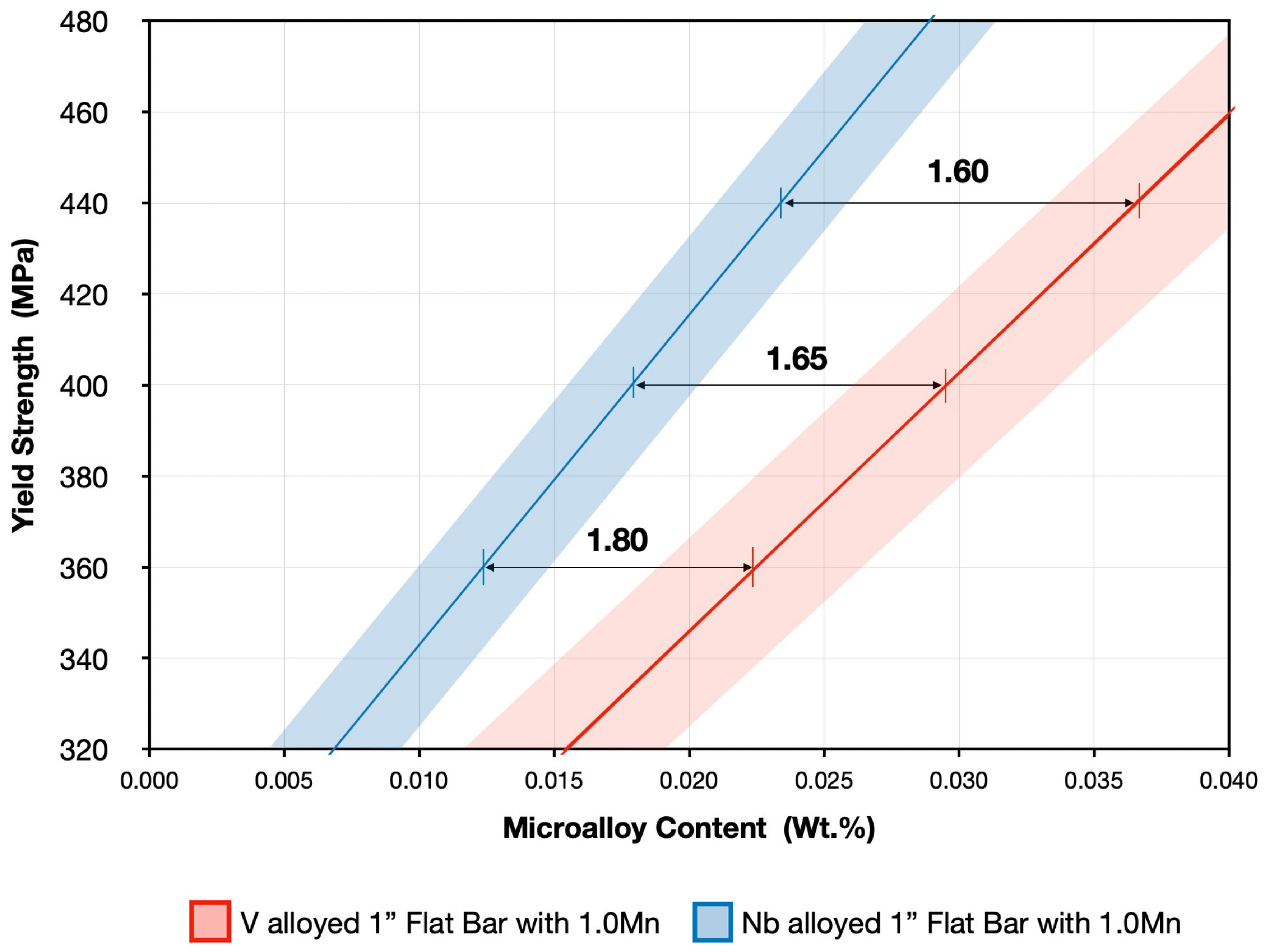


CMn + ULNb Steels



- **ULNb does support refinement of the final ferrite grain size (a few microns)**
- **Main strengthening contribution is attributed to precipitation**

Comparison of flat structural merchant bar



Vanadium vs Niobium

For 1" thick bars, using <u>conservative</u> guidance, vanadium to niobium ratio (V : Nb) ranges from:
1.80 : 1 to 1.60 : 1

For Grade 50 (355MPa) Average V:Nb Ratio = 1.75 : 1

INDUSTRIAL TRIALS

S275JR and S355JR

(H-Beams 15-mm flange @ 95kg/m)

S275 JR	C	Mn	Si	Nb		YS	TS	T.EL.	TS/YS
Original	0.20	0.65	0.19	---	Ave.:	345	485	29	1.41
ULNb	0.20	0.69	0.21	95 ppm	Ave.:	380	505	28	1.34
					Improvement:	+35 MPa	+20 MPa		

S355 JR	C	Mn	V	Nb		YS	TS
Original	0.20	1.43	0.0120	---	Ave.:	375	550
ULNb	0.20	1.47	---	80 ppm	Ave.:	>400	>570
					Improvement:	+25 MPa	+20 MPa

Based on the achieved results:

(1) 1.0wt.% Mn = 70MPa in YS

(2) 0.025wt% V ≈ 40MPa in YS

(3) 100ppm Nb ≈ 40MPa in YS

As these savings are a direct consequence of reduced consumption in raw materials, there also will be an saving in Scope 3 Global Warming Potential (GWP) equivalent emissions.

Taking conservative values:

~ 0.40%Mn = 40MPa = 18 kg.CO_2e / t steel

~ 0.020%V = 40MPa = 8.7 kg.CO_2e / t steel

100 ppmNb = 40MPa = 0.83 kg.CO_2e / t steel

WHAT COULD THIS MEAN FOR STEELMAKERS?

For every 100,000 tonnes of commodity grade steel	Applying ULNb solution	Mn	V
		Saving 1,700 t of CO2e	Saving 780 t of CO2e
		Saving USD 446,000	Saving USD 137,00

Applied factors:
HCFeMn(75%)=USD1.50/kg; FeV(80%)=USD30/kg; FeNb(65%)=USD47/kg
FeNb and FeV recovery rates=95% HCFeMn recovery rates=85%
GWP (kg $CO2_e$/kg): HCFeMn75%=2.91; FeV80%=33.1 and FeNb65%=5.1
(Sources: CBMM, GaBi database)

WHAT COULD THIS MEAN FOR
STEELMAKERS?

CBMM | Niobium Nb

World leader in the production and commercialization of Niobium products, CBMM has more than

500 customers in over **50** countries.

With headquarters in Brazil and offices and subsidiaries in China, Netherlands, Singapore, Switzerland and the United States, the company supplies products and cutting–edge technology to the infrastructure, mobility, aerospace and energy sectors. CBMM was founded in 1955 in Araxá, Minas Gerais, and relies on a strong technology program to increase Niobium applications while growing and diversifying this market.

Further information can be obtained at ***www.niobium.tech***