Introduction to High Strength Structural Steels

Products, Properties & Process Metallurgy

Dr Jitendra Patel
Eng.D, MBA, C.Eng. IMechE, FIMMM
International Metallurgy Ltd.
Email: jp@imetallurgy.co.uk

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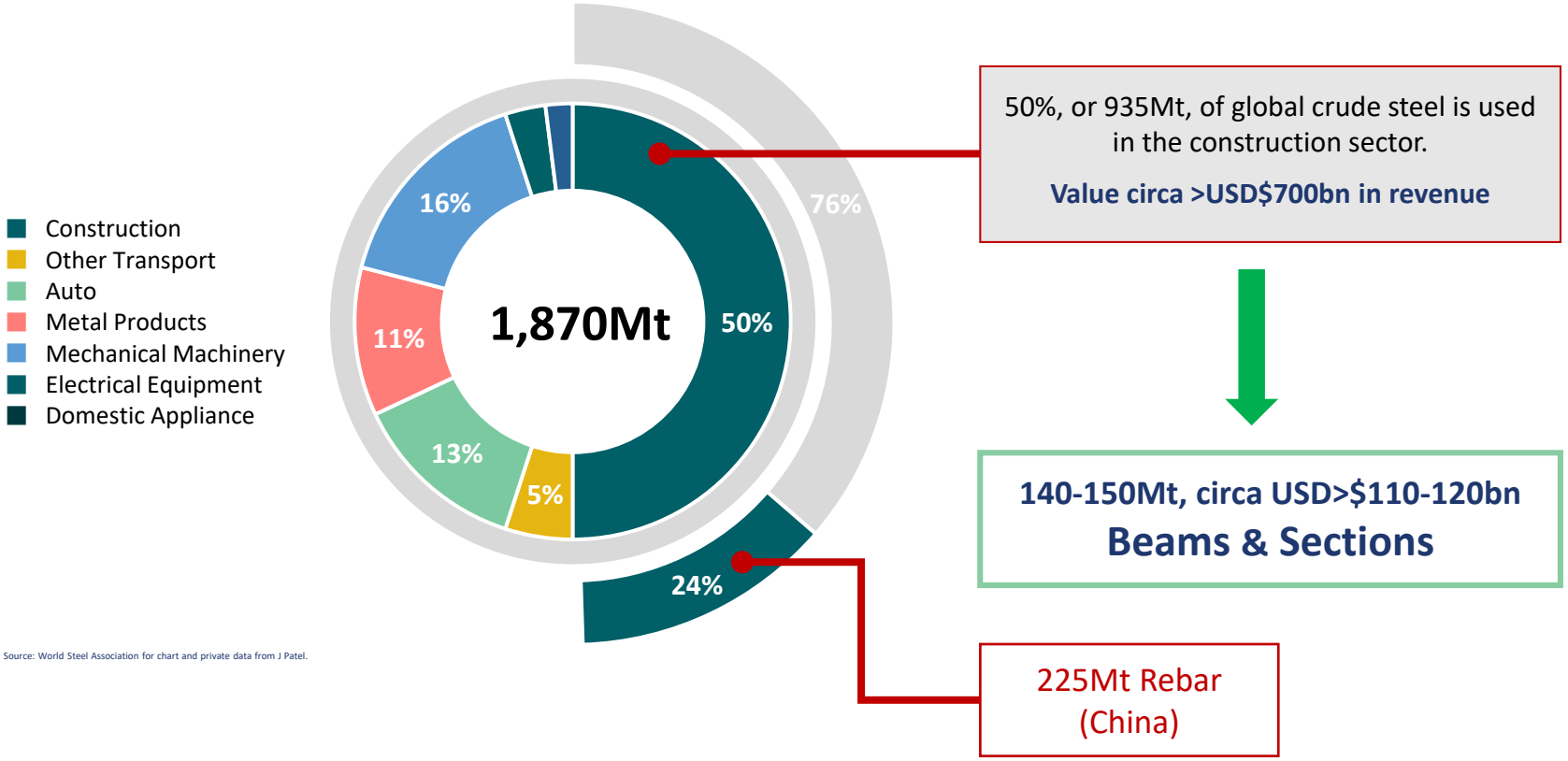
Content

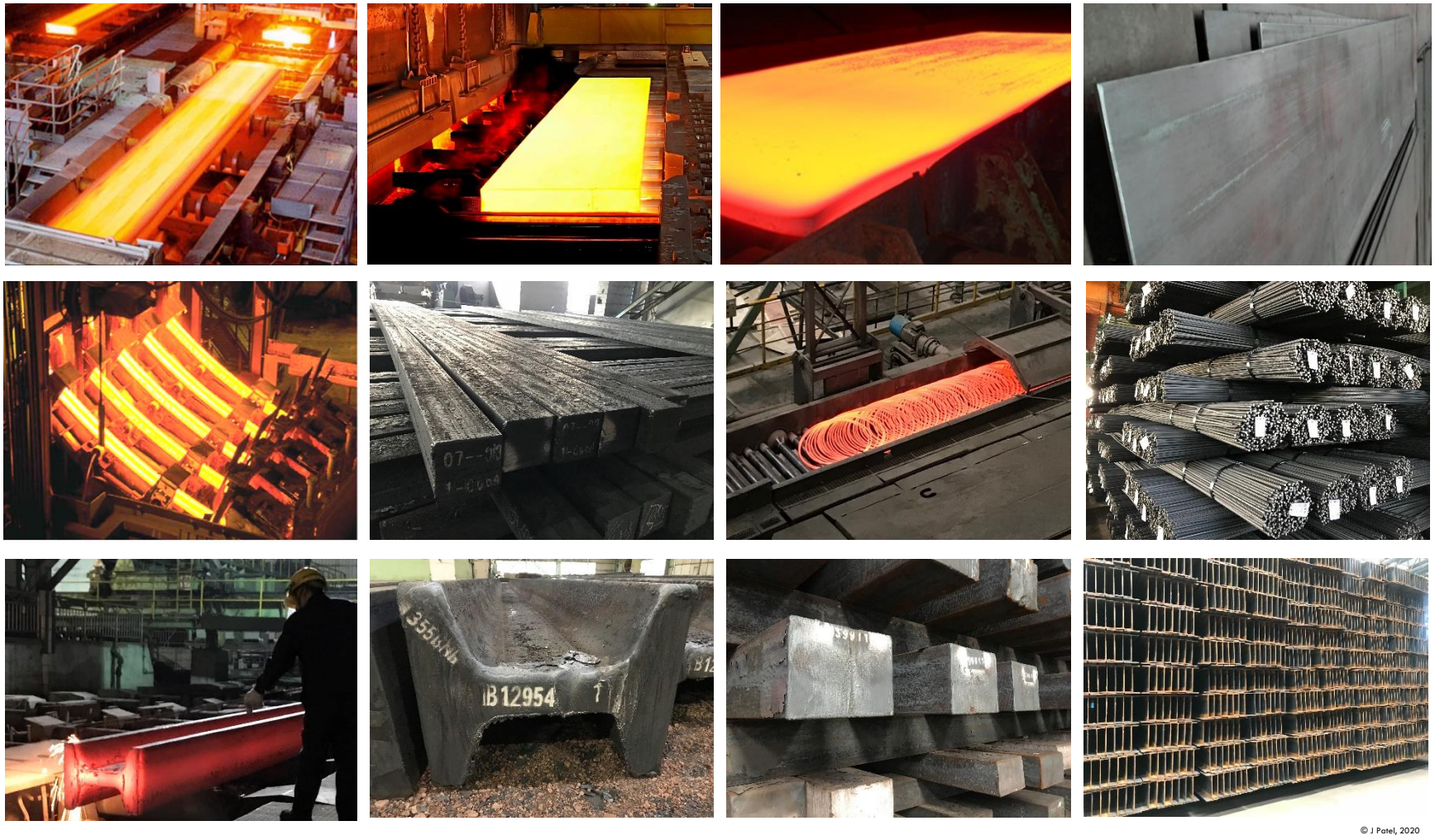
- To provide a brief introduction into high strength structural steels
- Market and evolution
- Specification, products and grade availability
- Properties performance and metallurgical approach
- The effect of steel chemistry and processing routes

Market perspective

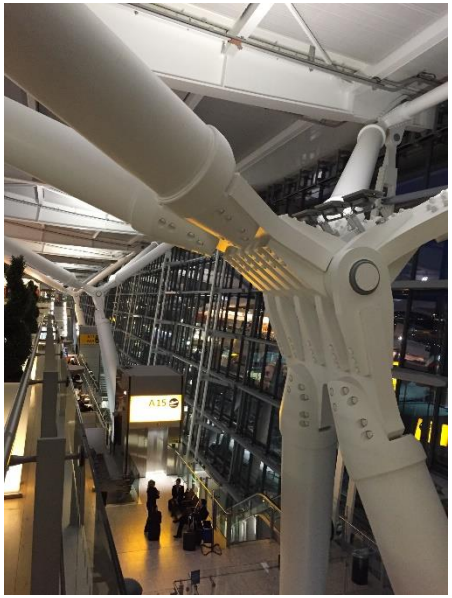


Source: World Steel Association for chart and private data from J Patel.

Structural steel products



HSS structural elements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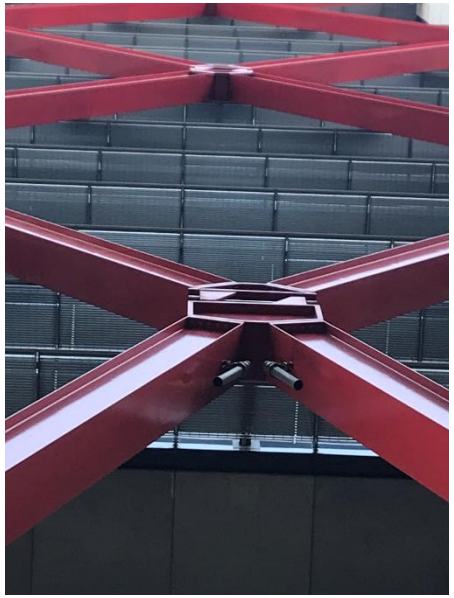
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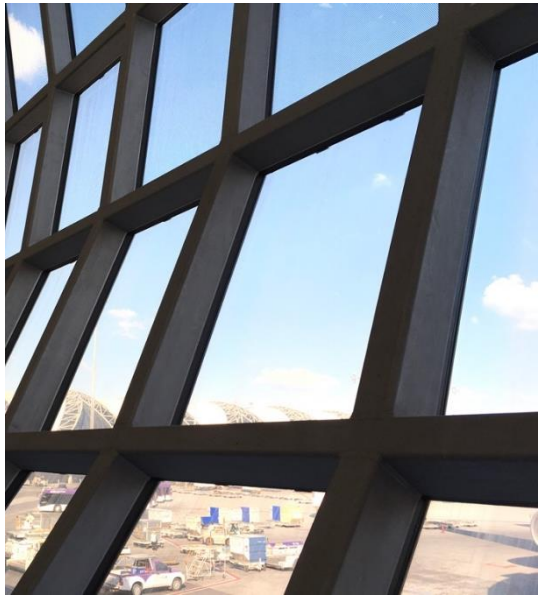
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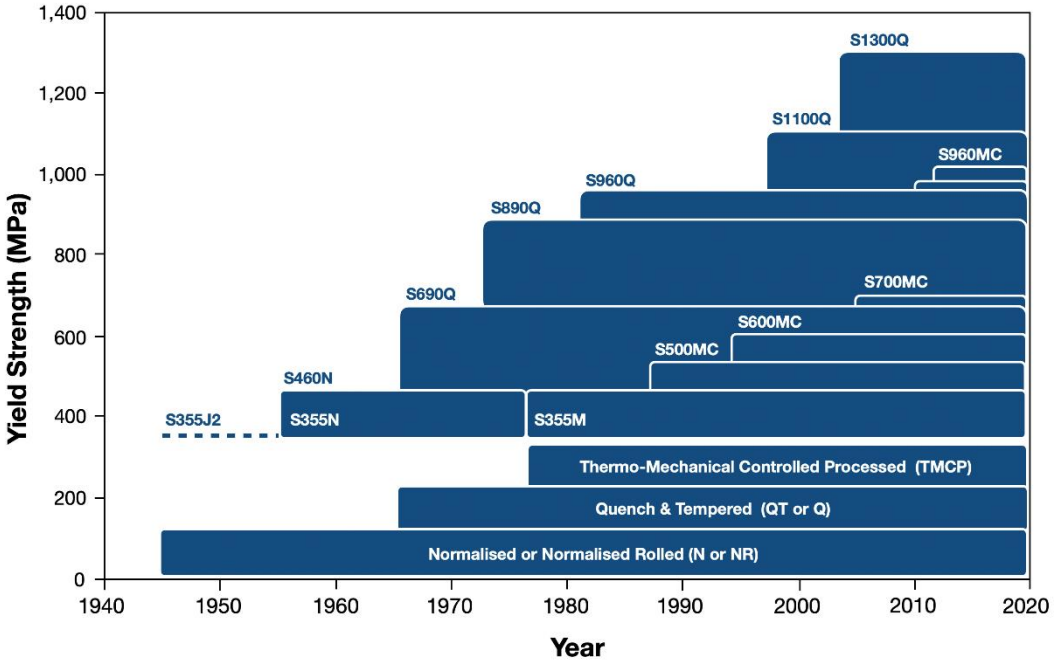
Evolution of High Strength Structural Steels



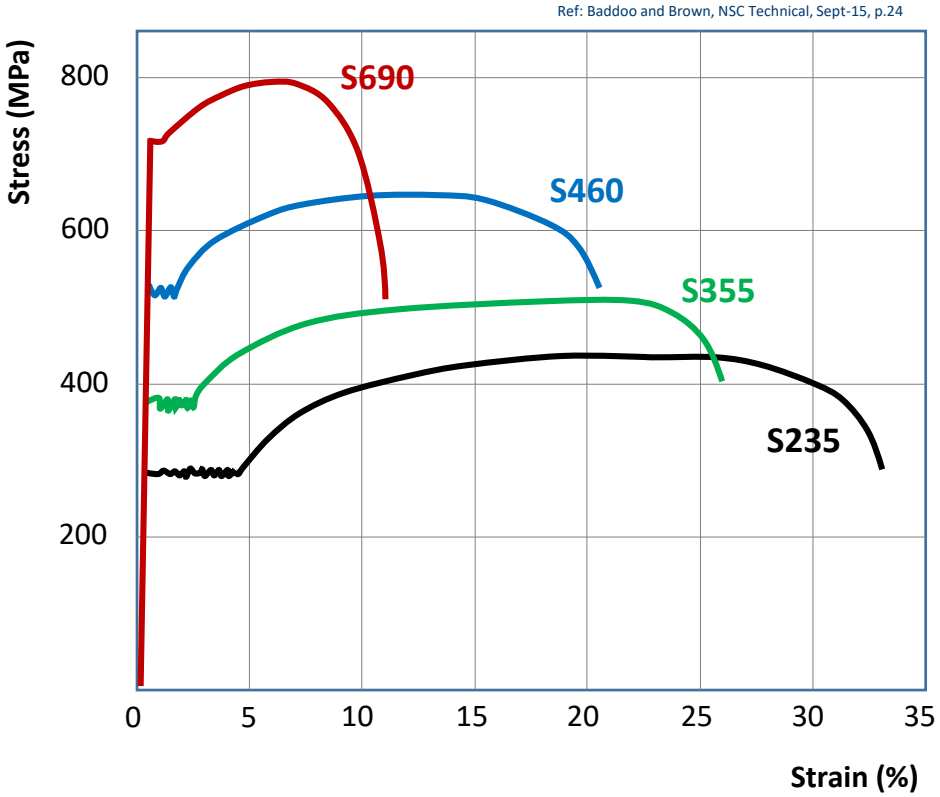
- Today high strength steels are classed as steels with yield strengths (YS) greater than 355MPa.
- As shown, HSS with a minimum YS of 1,300MPa are available in the market today.
- The vast majority of structural steels remain between 275-355MPa, however, there is growing use of 460MPa steels for beams and built-up sections, and even higher strengths for specific structural elements.
- For steel reinforcement bars in concrete, typical strengths range from 400-500MPa YS, but now 600MPa and even 700MPa are being used.
- HSS design up to S700 are now covered in EN 1993-1-12 (EC3).
- EN 10210-3:2020 (Hot Finished Hollow) includes steels with strengths up to S960 (via QT) and up to S500 weathering grade.

Main requirements for structural steels

- **Strength** - *load*
- **Stiffness** - *resist deflection*
- **Ductility** - *sustain deformation*
- **Toughness** - *fracture resistance*
- **Weldability** - *ease of joining*

Grade	YS min (MPa)	TS min (MPa)	TS_{min} / YS_{min}	Total $El._{min}$ ($\%_{A5}$)
S275	275	430	1.56	22
S355	355	510	1.44	22
S460	460	540	1.17	17
S500	500	590	1.18	17
S550	550	640	1.16	16
S620	620	700	1.13	15
S690	690	770	1.12	14
S890	890	940-1100	1.06	11
S960	960	980-1150	1.02	10
S1100	1100	1250-1550	1.14	8
S1300	1300	1400-1700	1.08	8

HSS performance



- The stress-strain behaviour of HSS will change with increasing strength.
- As the strength increases, the ratio of ultimate to yield strength reduces, and the ductility also reduces.
- Although the reduction is not significant enough to affect the design of the majority of structures.
- Due to these differences in stress-strain characteristics, a few design rules require modification for the higher strength steels.
- **In particular, there isn't too much difference when moving from S355 to S420 or S460.**

Developing mechanical properties

Steel Performance

- Tensile Strength
- Yield Strength
- Lüders Plateau (YPE)
- Elongation
- Formability
- Work-hardening rate
- Low Temp Toughness
- Corrosion Resistance
- Weldability

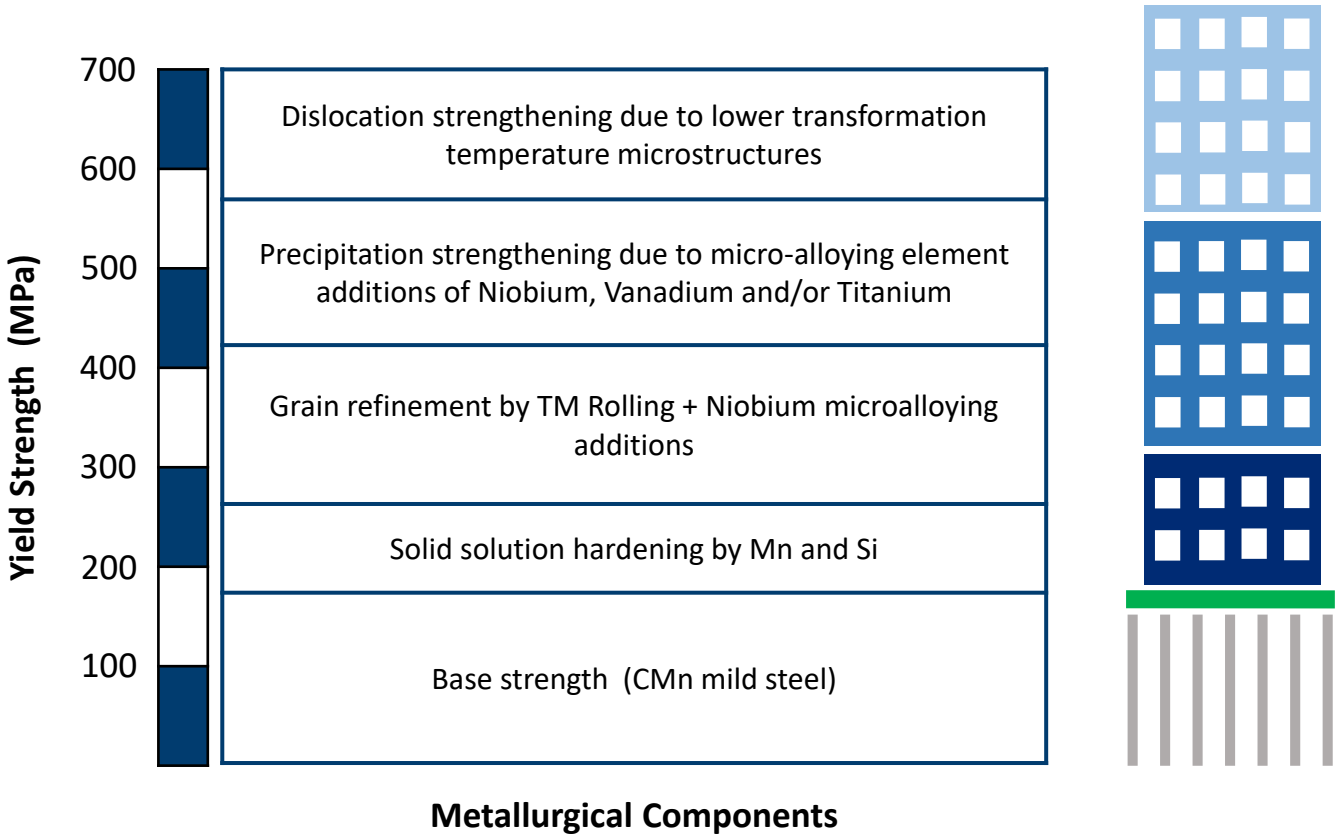
Microstructure

- ✓ Grain size
- ✓ Second Phase (e.g. pearlite)
- ✓ Solid solution strengthening
- ✓ Precipitates
- ✓ Dislocations

Process Control

- ✓ Steel chemical composition
- ✓ Processing route

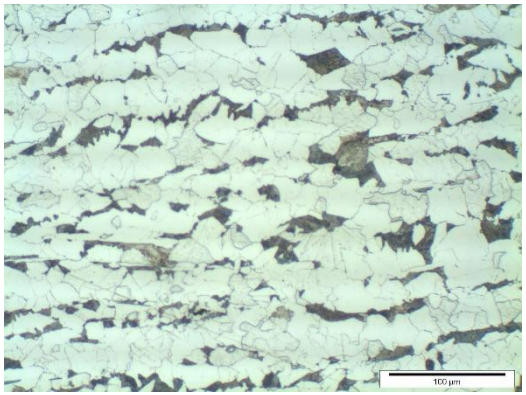
Metallurgical components



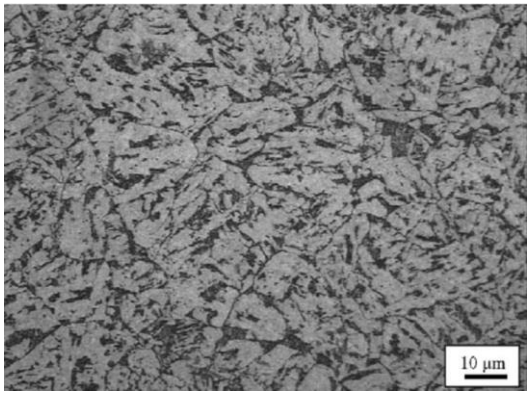
Importance of microstructure type

Examples of microstructures:

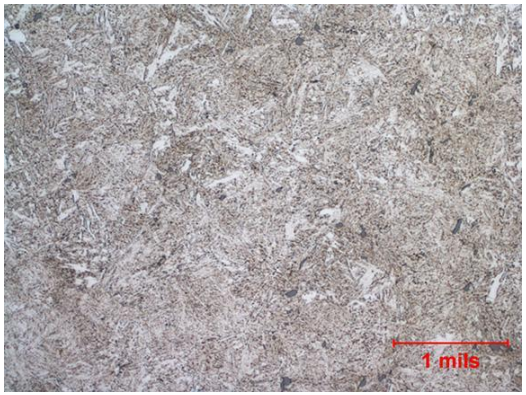
Ferrite-Pearlite



Bainite



Martensite



Lower strengths
Greater ductility
Good toughness

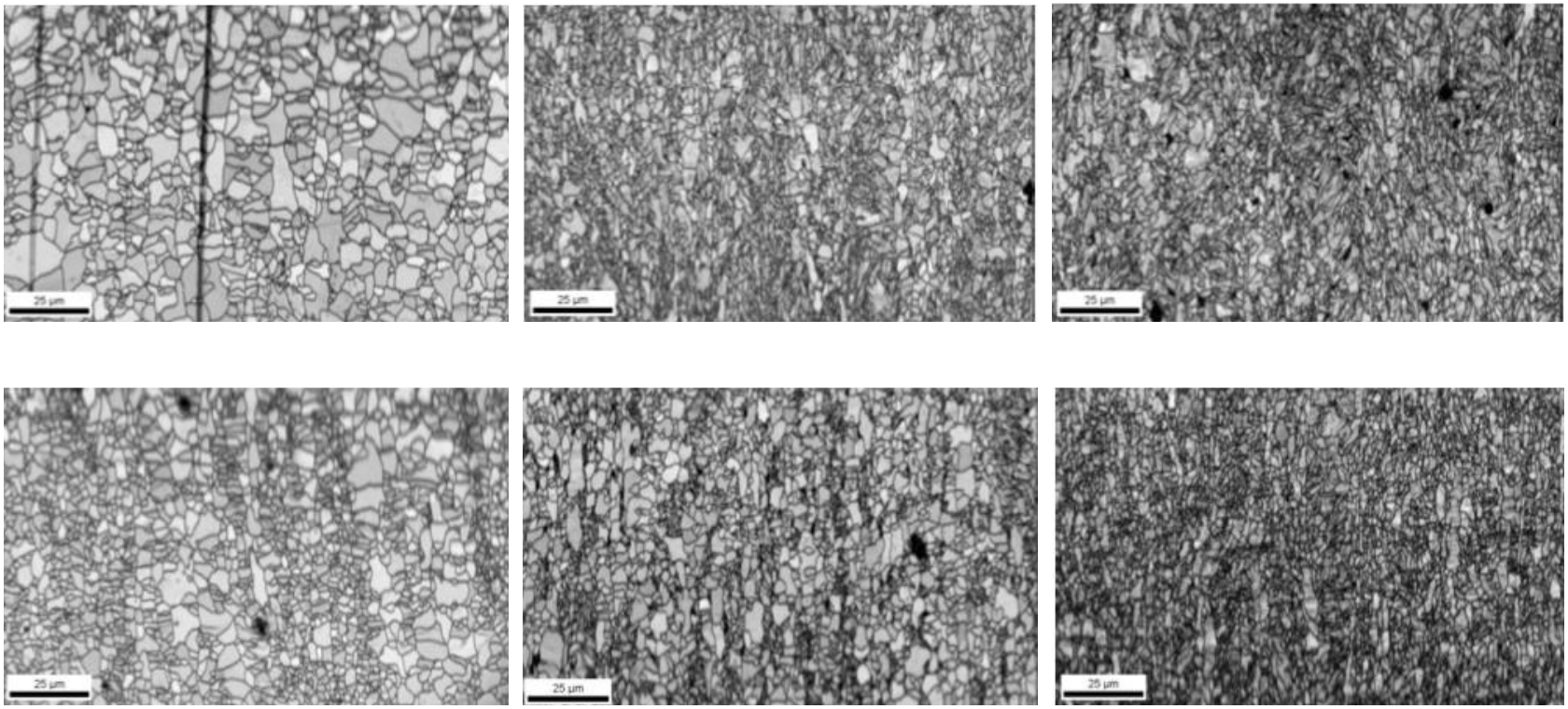
Higher strengths
Reduced ductility
Poor toughness

Each type of microstructure constituent *(or phase)* will behave differently and will impart different degrees of influence based on volume fraction and location within the structure.

Therefore, via steel chemistry and processing conditions, steel producers can develop and make different grades of HSS. However, this will depend on the capability of the steelmaker!

Process metallurgy

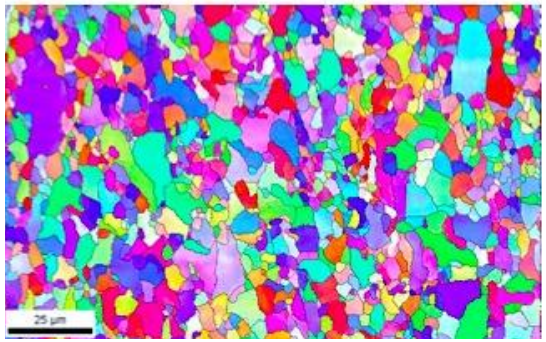
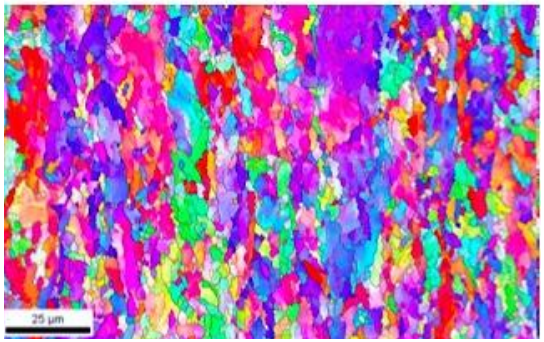
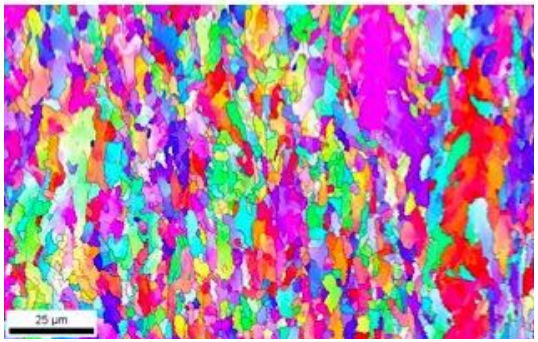
Same steel chemistry and final rolled plate thickness, but different starting thickness applying different hot rolling and cooling practises!



Consequently, each has different microstructural components and thus mechanical properties.

Process metallurgy

Same steel chemistry and final rolled plate thickness, but different starting thickness applying different hot rolling and cooling practises!

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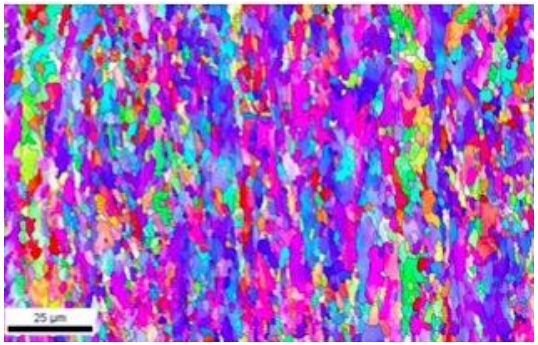


Consequently, each has different microstructural components and thus mechanical properties.

Structural steel specification EN 10025

- Harmonised European structural steel specification for most steelwork in building and civil engineering applications.
- A very wide range of plates and open sections such as I-sections, channels and angles are made from these steels.
- HSS from S420 to S960 are specified to EN 10025-3, EN 10025-4 and EN 10025-6, depending on the delivery conditions of the material.
- N and M steels are available in strength grade S420. N, M and Q steels are available in strength grade S460.
- The very high strength grades above S690 to S960 are only produced via the QT process route.

EN 10025-2 Non-alloy structural steels

EN 10025-3 Normalized/normalized rolled weldable fine grain structural steels

EN 10025-4 Thermomechanical rolled weldable fine grain structural steels

EN 10025-5 Structural steels with improved atmospheric corrosion resistance

EN 10025-6 Flat products of high yield strength structural steels in the quenched and tempered condition

Think beyond EN 10025-2 !

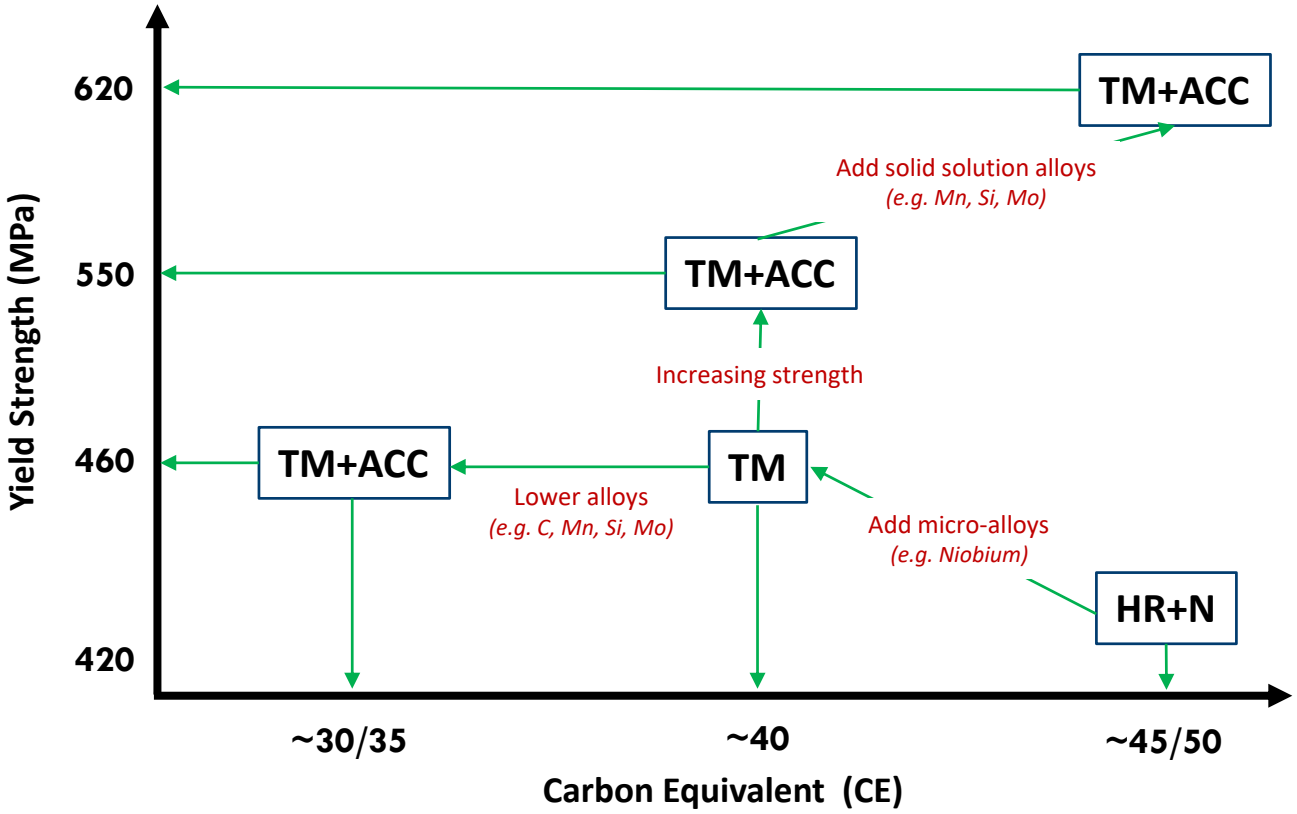
There is 3, 4, 5 and even 6 !

Delivery conditions and quality

Often used abbreviations:

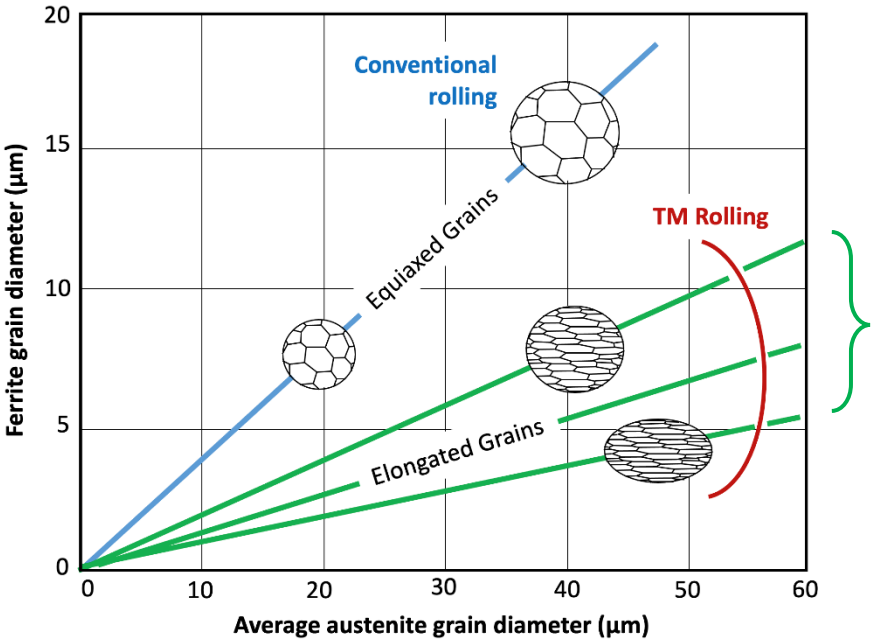
S	=	Structural steel
+AR	=	Supplied in the As Rolled condition
+N	=	Supplied in the Normalized or Normalised Rolled condition
+CR(NR)	=	Controlled Rolling (Normalized Rolled)
TM	=	Thermo-Mechanically Rolled
M	=	Longitudinal Charpy V-notch impacts at a temperature not lower than -20ºC
ML	=	Longitudinal Charpy V-notch impacts at a temperature not lower than -50ºC
N	=	Normalised or Normalised Rolled with longitudinal Charpy V-notch impacts at a temperature not lower than -20ºC
NL	=	Normalised or Normalised Rolled with longitudinal Charpy V-notch impacts at a temperature not lower than -50ºC
DQ	=	Direct Quenched
Q	=	Quenched and Tempered with longitudinal Charpy V-notch impacts at a temperature not lower than -20ºC
QL	=	Quenched and Tempered with longitudinal Charpy V-notch impacts at a temperature not lower than -40ºC
QL1	=	Quenched and Tempered with longitudinal Charpy V-notch impacts at a temperature not lower than -60ºC
QST	=	Quench and Self-Tempered

Changing the process route



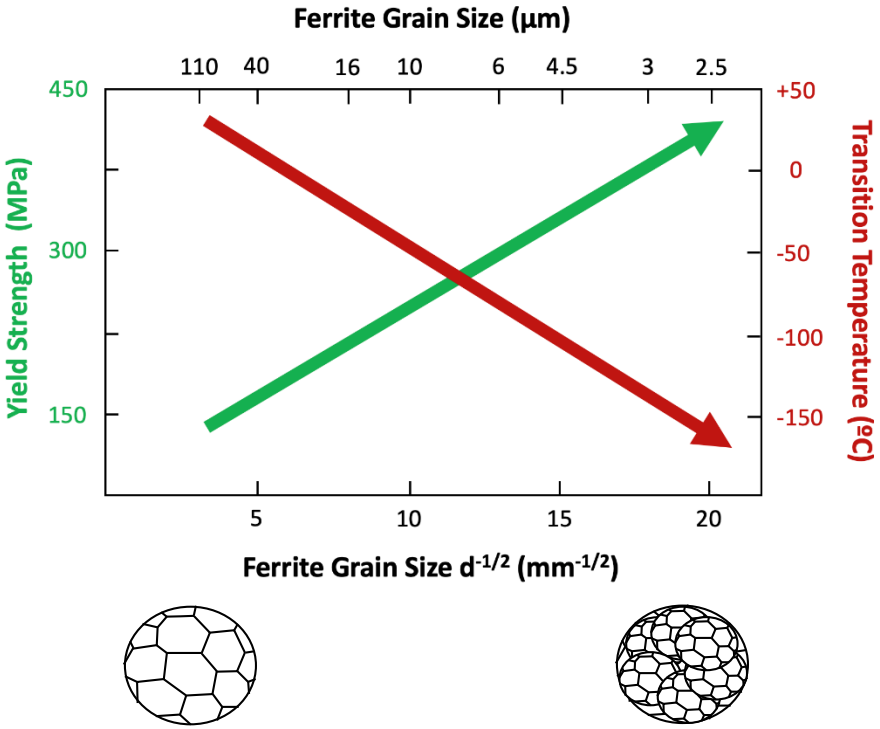
Microalloyed steels

EN 10025-4 Thermomechanical rolled weldable fine grain structural steels



- Typically microalloyed steels contain small additions of niobium (Nb), vanadium (V) and titanium (Ti), either singly (~0.010wt.%) or in combination (≤0.015wt.%).
- These elements readily form nano-sized precipitates (i.e. particles) during hot rolling and cooling of the steel which support the development of higher strengths.
- In particular, for TM rolled steels, the addition of niobium is often made as it is refines the grain structure of the steel.
- *Note, Aluminium provides limited grain refinement and is mainly used in lower strength steels.*

The importance of grain refinement



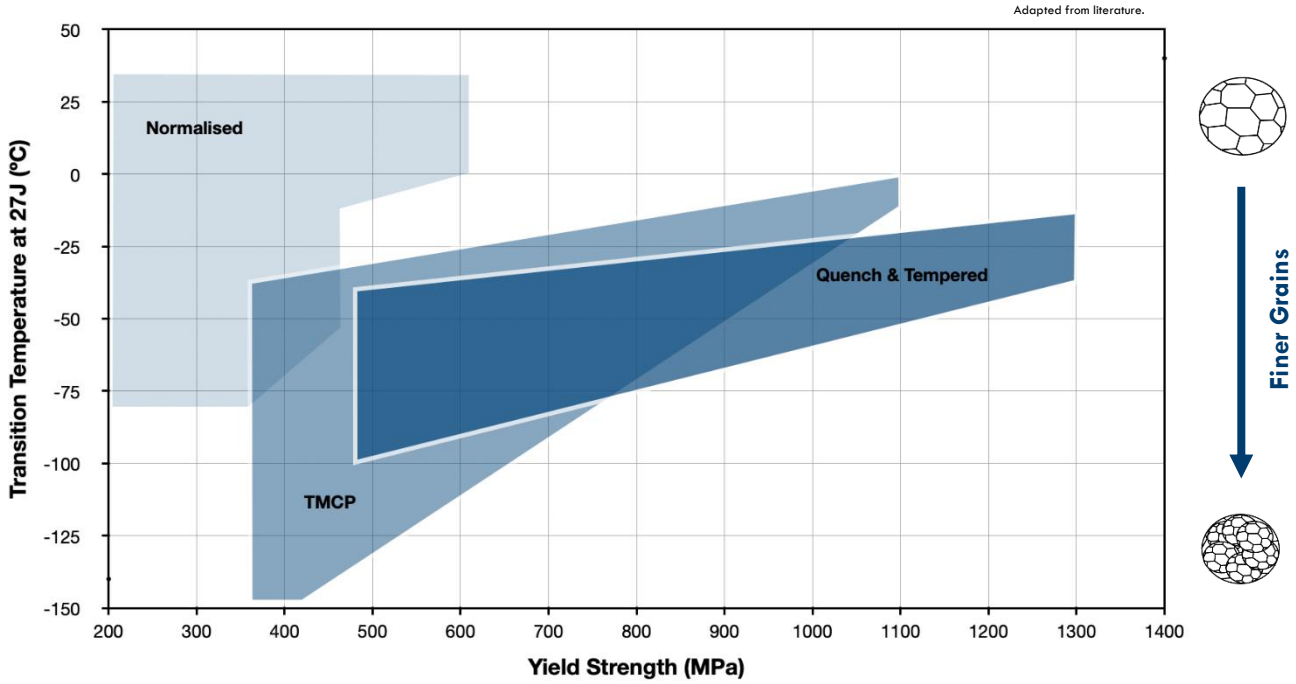
The ability to produce a small (finer) grain structure is highly beneficial towards the production of HSS:

1. It is the best way to increase the yield strength.
2. Simultaneously, it also significantly enhances low temperature toughness properties.

The primary route to achieve this is via Thermo-Mechanical (TM) rolling which itself relies on the use of niobium (Nb) microalloying.

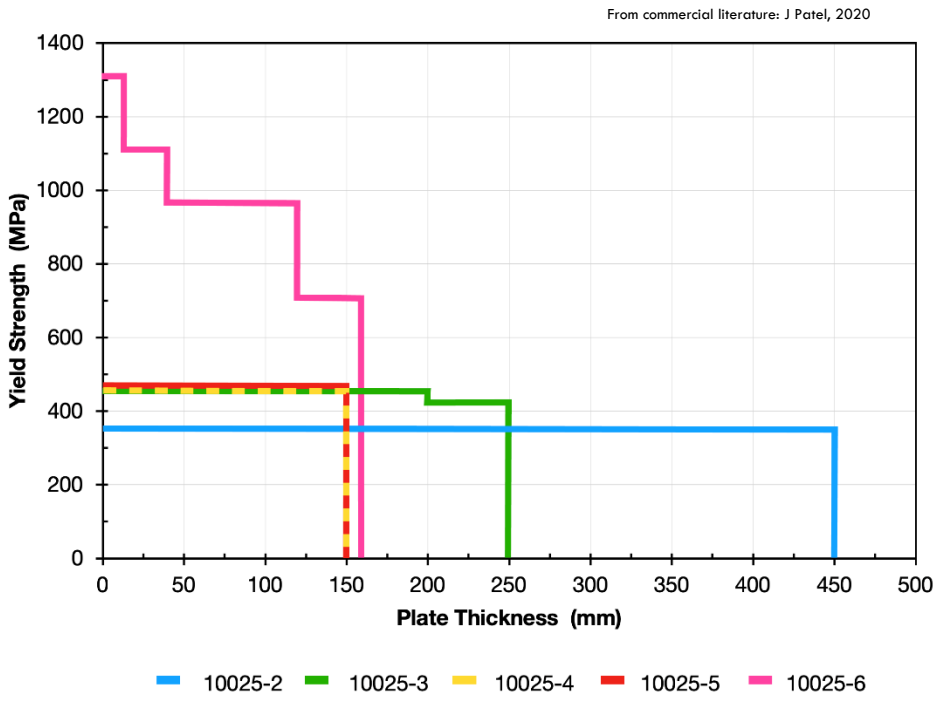
- Niobium is a key steel alloying element enabling both grain refinement and better toughness.
- Consequently, this allows less reliance on other elements such as carbon which is detrimental to toughness and weldability.

Toughness



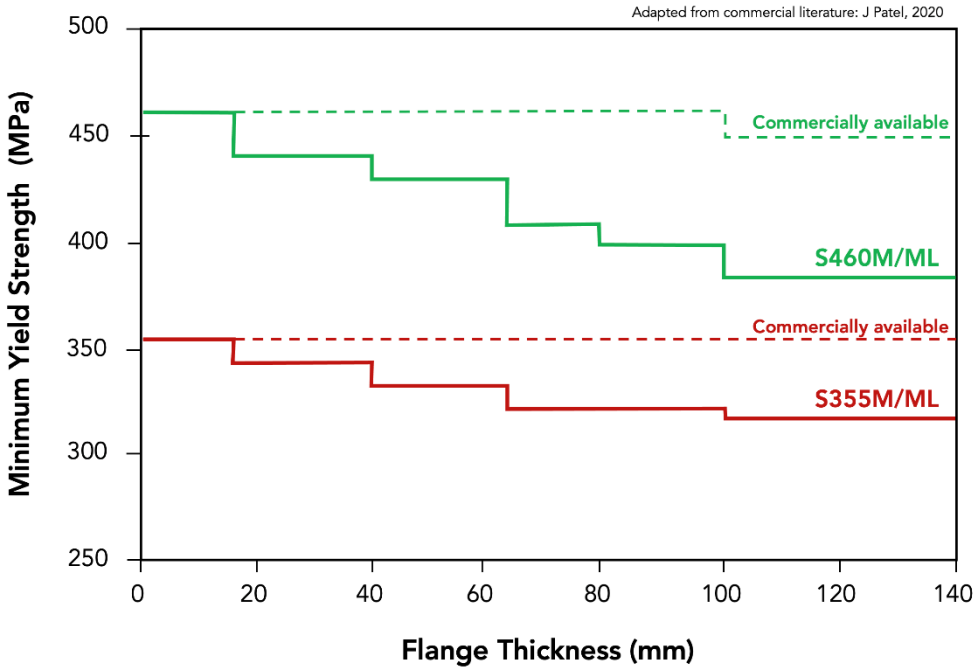
- Today Modern TMCP *(i.e. TM Rolling + Accelerated Water Cooling)* steels are more than capable of matching the performance of Normalised (N) and some Quench & Tempered (QT) steels.

HSS plate product availability



- In recent years, the operational capability of many of the world leading plate mills has significantly improved.
- In particular the ability to cast and roll much thicker starting steel slabs.
- This has opened up the possibility to produce much heavier (thicker) plates with improved low temperature Charpy V-notch impacts and higher strengths.
- Furthermore, with the installation of upgraded online direct quenching facilities, there are more plate mills capable of supplying a wider range of QT plates.

HSS H-beam product availability



- In recent years, the operational capability of many of the world leading beam and sections mills has also significantly improved.
- In particular the ability to cast and roll much thicker beam blanks has meant much heavier sections are now in the market.
- As shown some producers can make S460M or ML with flange sizes up to 140mm thick without any significant reduction in strength levels due to increased thickness.

Transitioning to HSS

- Not so long ago Grade SS275 used to be the steel choice for structural engineers.
- Today, if you order this Grade most UK/EU steelmakers will charge an extra cost on this, as it will be considered a “special order” as it is not routinely made.
- This is because S355MPa has become the main workhorse structural grade.

Extra costs on basis

EN10025-2	£/tonne
S275JR*	+ 30
S275J0*	+ 40
S275J2*	+ 80
S355JR	Basis
S355J0	10
S355J2	40
S355K2	80

- Today, HSS and product types are much more widely available in the global market from steelmakers and stockholders.
- Especially Grades S420, S460 and S690 in plate form and up to S460 in as-rolled beams.
- Plate thickness in excess of 200mm are possible and thicker microalloyed TM rolled plates are replacing “N” grades.
- And there are more jumbo and super jumbo (>1000kg/m) as-rolled beam producers in the world making S460.
- So, in the future with increasing call from engineers, S460 will share the load with S355!

Further support

Contact

Dr Jitendra Patel

Eng.D, MBA, C.Eng MIMechE, FIMMM

International Metallurgy Ltd.

Oxford, UK

jp@imetallurgy.co.uk

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