SCI
Steel Knowledge

Properties and specification of higher strength steels

How are HSS made?

Key properties (strength, ductility, impact strength & weldability) derived from a combination of:

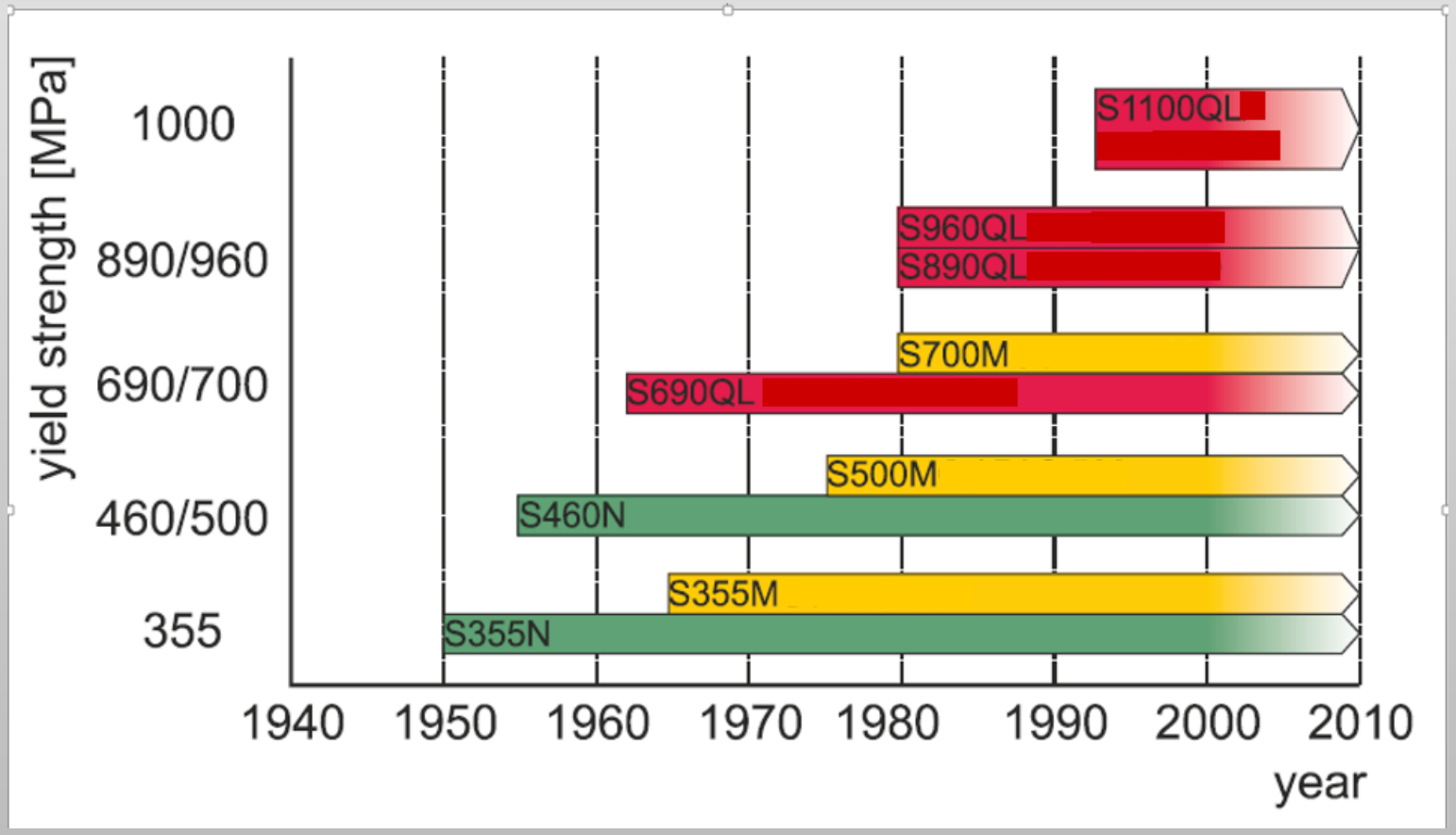
- chemical composition
- manufacturing processes (controlled heat treatment, rolling temperatures, cooling rate)

Steel producers use a wide range of different concepts to achieve the required balance of properties.

Principal steel production processes

- As-rolled (AR)
- Normalized/Normalized-rolled (N)
- Thermomechanically rolled (M, TMR, TMCP)
- Quenched & tempered (Q, Q&T)

Development of high strength steels



Wegmann, H., & Gerster, P. (2003). *Schweißtechnische Verarbeitung und Anwendung hochfester Baustähle im Nutzfahrzeugbau*

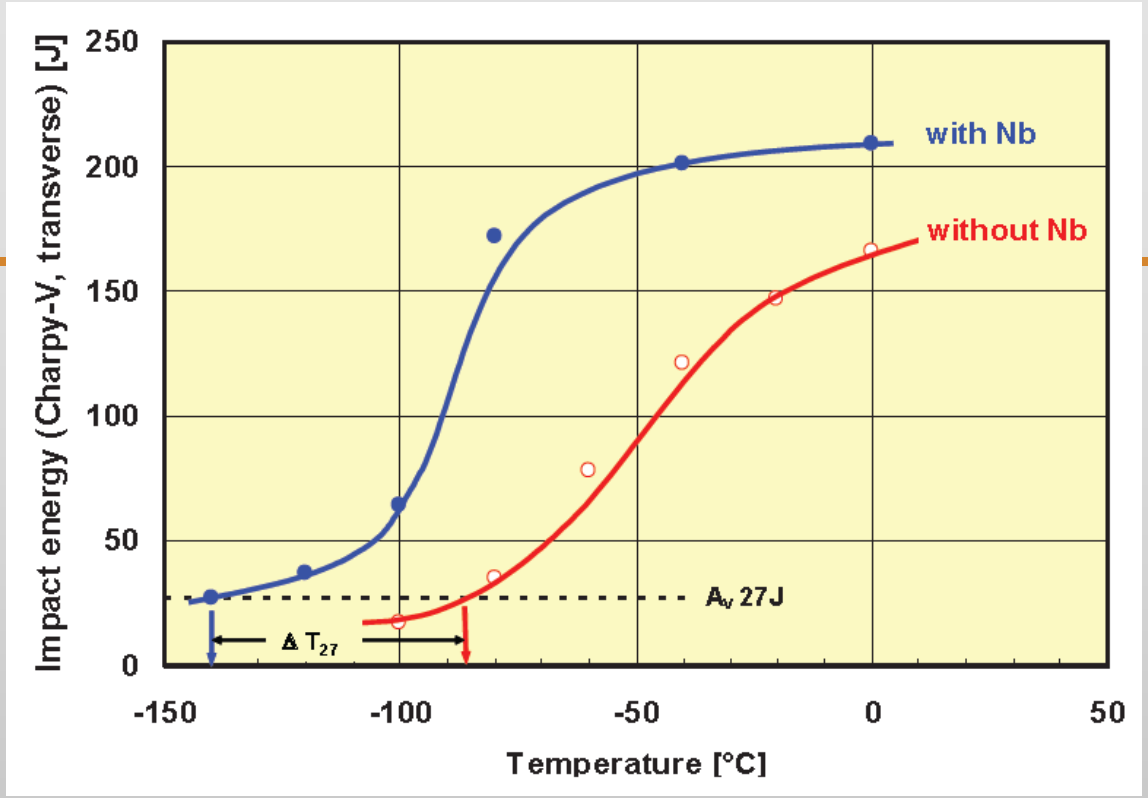
Chemical composition

Careful balance to achieve desired properties

- Increase strength by adding more carbon (but this reduces ductility, toughness, weldability)
- Microalloying with elements like niobium, vanadium, titanium or molybdenum in amounts below 0.1 wt % (1000 grams/tonne) is a cost-effective method of achieving a balanced combination of properties.

Niobium

41
Nb
Niobium
92.906



Impact energy vs transition temp. of N-A-XTRA 700

Courtesy: H Mohrbacher

Adding Nb to steel causes the formation of Nb carbide and Nb nitride within the structure of the steel which improves the grain refining, retardation of recrystallization, and precipitation hardening of the steel leading to better toughness, strength, formability, and weldability.

Molybdenum

42
Mo
Molybdenum
95.94

- Mo enhances strength, hardenability, weldability, toughness, elevated temperature strength, and corrosion resistance in steels
- Typically used when f_y > 550 MPa at thicknesses >20 mm, or a particular microstructure is required.

EN 10025: 2004 Hot rolled products of structural steels

Standard	Yield strength (MPa)	Max thick. (mm)	Elong. (%)	Sub-grade	Impact Energy	Test temp
EN 10025-2 Non-alloy structural steels	235 275 355 450	400 400 265 150	26 23 22 17	JR J0 J2 K2	27 J 27 J 27 J 40 J	20 °C 0 °C -20 °C -20 °C
EN 10025-3 normalized/normalized rolled weldable fine grain structural steels	275 355 420 460	250 250 250 200	24 22 19 17	N NL	40 J 27 J	-20 °C -50 °C
EN 10025-4 thermomechanical rolled weldable fine grain structural steels	275 355 420 460	120 120 120 120	24 22 19 17	M ML	40 J 27 J	-20 °C -50 °C
EN 10025-6 high yield strength structural steels in the quenched & tempered condition (2009 amendment)	460 500 550 620 690 890 960	150 150 150 150 150 100 50	17 17 16 15 14 11 10	Q QL QL1	30 J 30 J 30 J	-20 °C -40 °C -60 °C

Normalized/Normalized-rolled (N)

- Normalized
  Heating up to 900ºC and allowing it to cool naturally
- Normalized rolled
  Controlling the temperature during rolling so that all rolling is above about 900ºC and then cools naturally

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Thermomechanically rolled (M, TMR, TMCP)

- Slightly lower alloy steel (less carbon and impurities)
- Rolled in a carefully controlled manner down to a finishing temperature of 700-800ºC
- No further heat treatment required

Pipelines, bridges, ships, lifting equipment, tanks and pressure vesels ……

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				ML	27 J	-50 °C
EN 10025-6 high yield strength structural steels in the quenched & tempered condition (2009 amendment)	460 500 550 620 690	150 150 150 150 150	17 17 16 15 14	Q	30 J	-20 °C
				QL	30 J	-40 °C
					30 J	-60 °C

For long products, t ≤ 150 mm

Quenched & tempered (Q, Q&T)

1. Heated above 900ºC, and then cooled rapidly by immersion in a bath of water or a spray → high strength but low toughness
2. Tempered (heated to 600-700ºC) to restore toughness

Much higher strengths can be achieved but subsequent heating, e.g. during welding, may effect properties.

Pressure vesels, penstocks, jack-up platforms, submarine hulls ……

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EN 10025-2 non-alloy structural steels	235 275 355 450	400 400 265 150	26 23 22 17	JR	27 J	20 °C
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				QL	30 J	-40 °C
				QL1	30 J	-60 °C

EN 10225: 2009 Weldable structural steels for fixed offshore structures

Yield strength (MPa)	**Grade**	**Delivery Condition** (thickness limit)	**Min. elongation**	**Impact Strength J** (avg)	**Test temp**
S355	G7, G8, G9, G10	N (*t*<150 mm) M (*t*<100 mm)	22%	50	-40 °C
S420	G1, G2	M and QT (*t*<100 mm)	19%	60	-40 °C
S460	G1, G2	M and QT (*t*<100 mm)	17%	60	-40 °C

EN 10210: 2006 Hot finished structural hollow sections of non-alloy and fine grain steels

	Yield strength (MPa)	Max thick. (mm)	Elong. (%)
Non-alloy	235 275 355	120 120 120	26 23 22
Fine grain	275 355 420 460	65 65 65 65	24 22 19 17

Sub-grade	Impact Energy	Test temp
JRH	27 J	20 °C
J0H	27 J	0 °C
J2H	27 J	-20 °C
K2H	40 J	-20 °C
NH	40 J	-20 °C
NLH	27 J	-50 °C

Next revision in 2016 will cover up to S960 and M steels

EN 10219: 2006 Cold formed welded structural hollow sections of non-alloy and fine grain steels

	Yield strength (MPa)	Max thick. (mm)	Elong. (%)
Non-alloy	235 275 355	40 40 40	24 20 20
Fine grain	275 355 420 460	40 40 40 40	24 22 19 17

Sub-grade	Impact Energy	Test temp
JRH	27 J	20 °C
J0H	27 J	0 °C
J2H	27 J	-20 °C
K2H	40 J	-20 °C
NH/MH	40 J	-20 °C
NLH/MLH	27 J	-50 °C

Other EN standards for HSS

EN 10149

Hot-rolled flat products made of high yield strength steels for cold forming (S420, 460, 500, 550, 600, 650, 700, 900, 960 but only for $t < 20$ mm) NC and MC

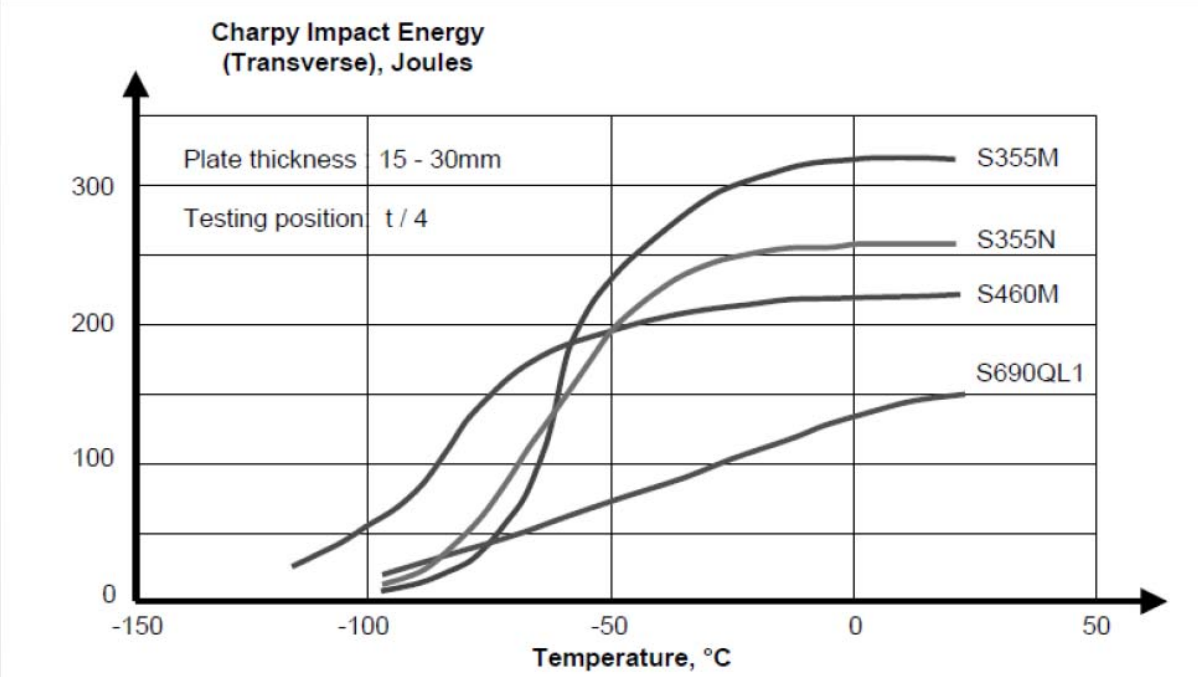
Agricultural machinery, automotive components, containers, cranes and crane booms, earth-moving equipment, industrial silos, lightweight towers, racking and shelving

Strength and ductility

- Q&T steels for strengths above about S460 (can get M steels up to 500 MPa in lower end of thickness range)
- N/M steels have better ductility in thicker sections than non-alloy steels

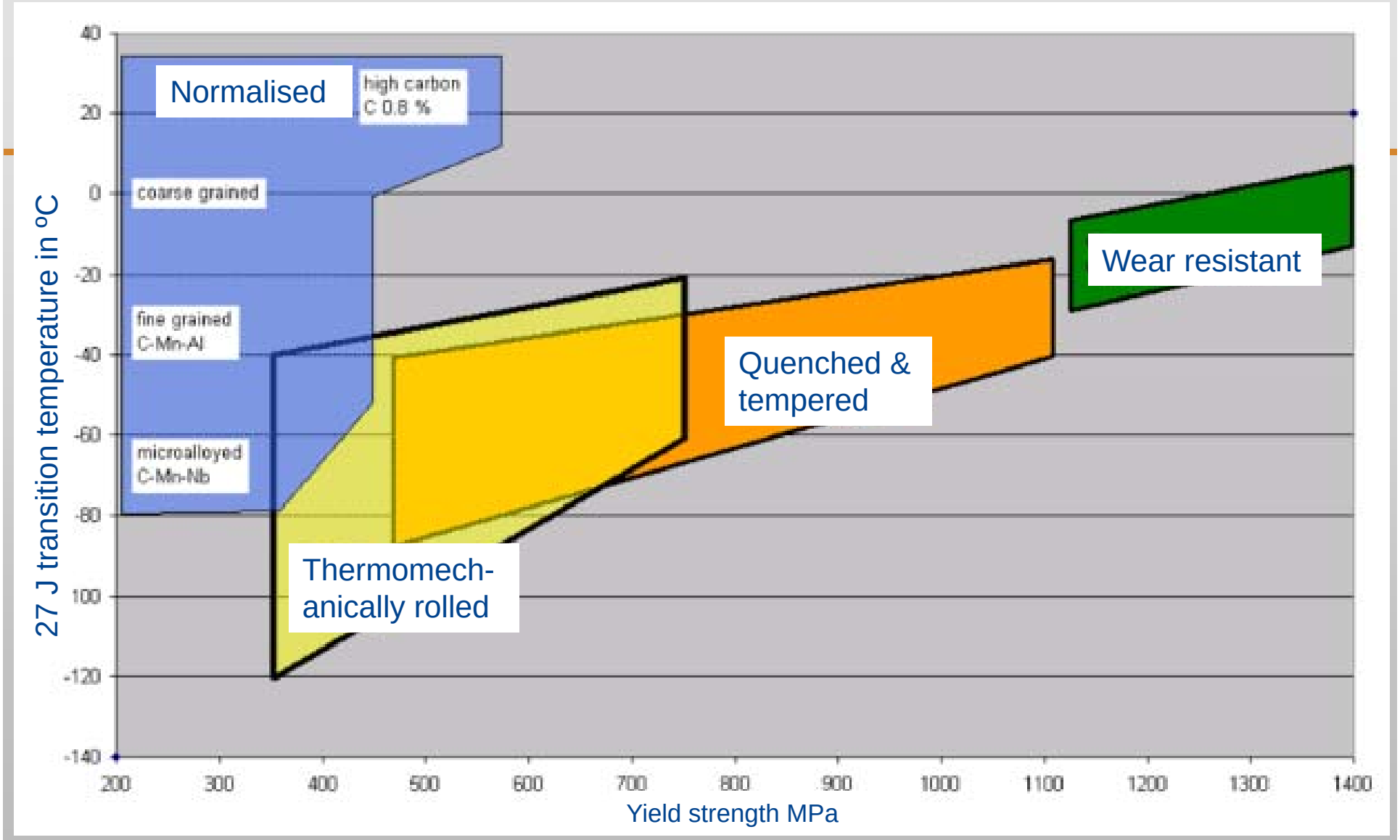
Toughness

- N/M steels have better low temp toughness (down to -50ºC) compared to non-alloy (values down to -20ºC)



- Q&T steels where high strength and very high toughness requirements (values given down to -60ºC)

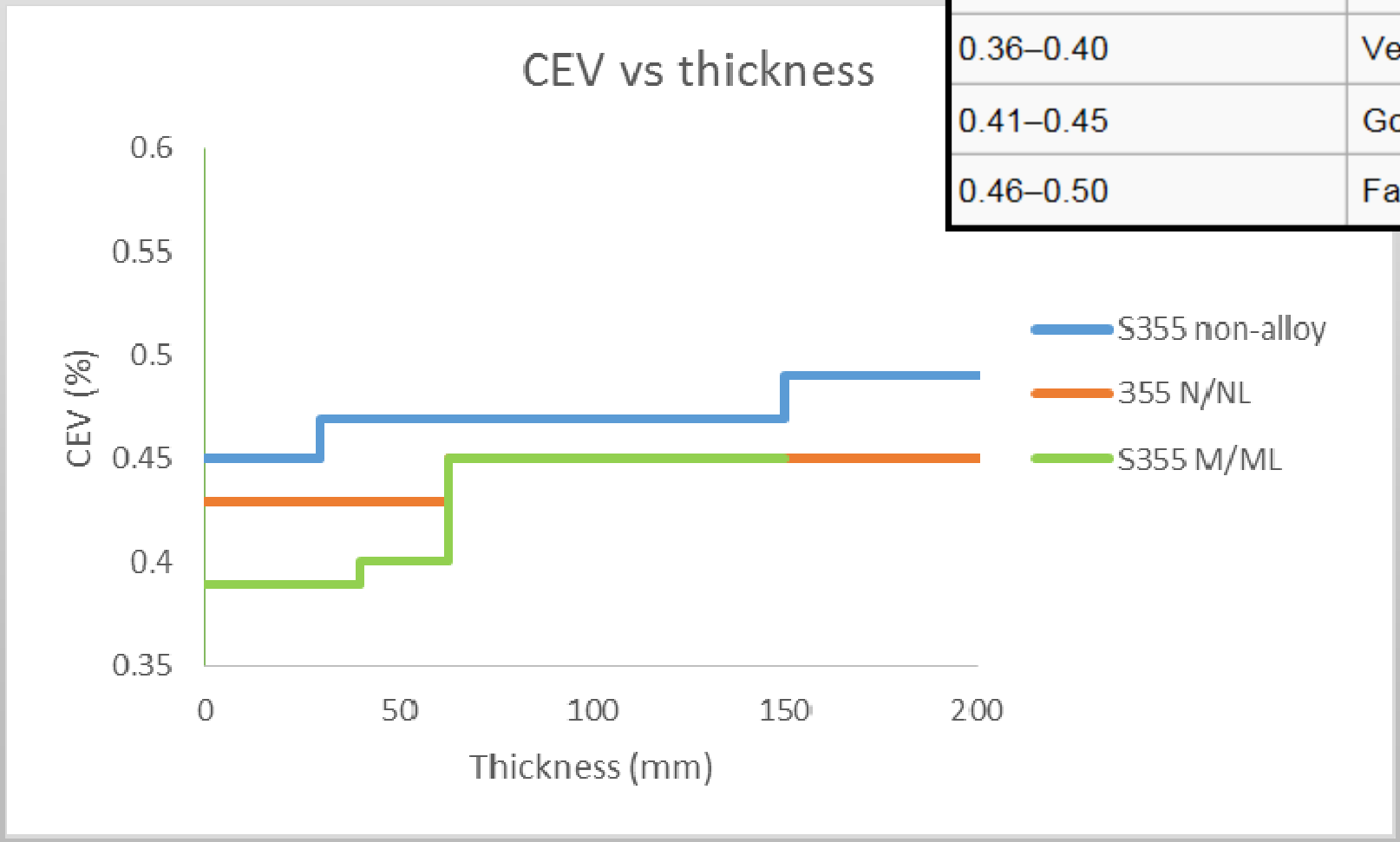
Most steel manufacturers can agree enhanced toughness requirements with customers at extra cost



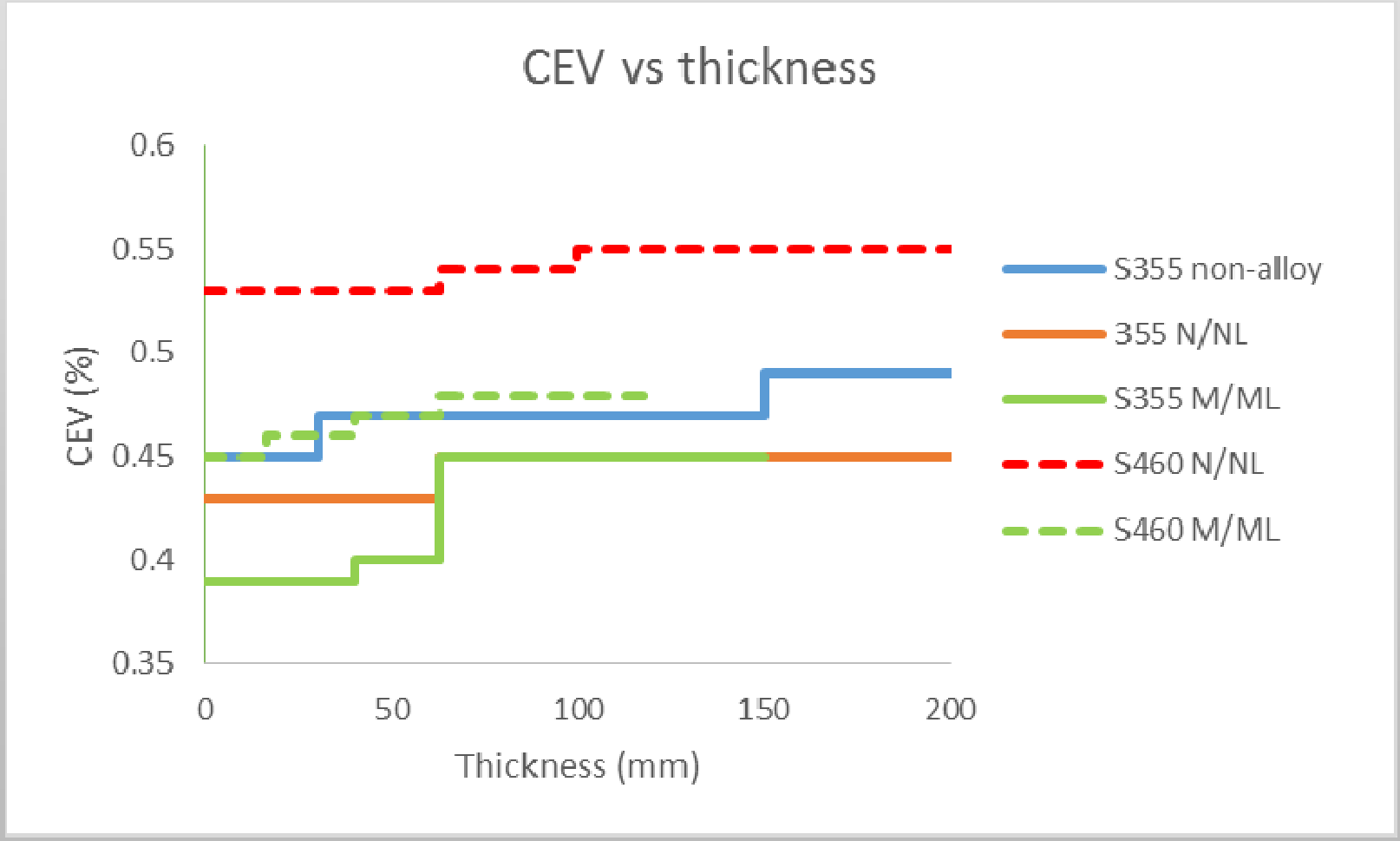
Courtesy: Dillinger

Weldability

Carbon equivalent (CE)	Weldability
Up to 0.35	Excellent
0.36–0.40	Very good
0.41–0.45	Good
0.46–0.50	Fair



Weldability



Lead times

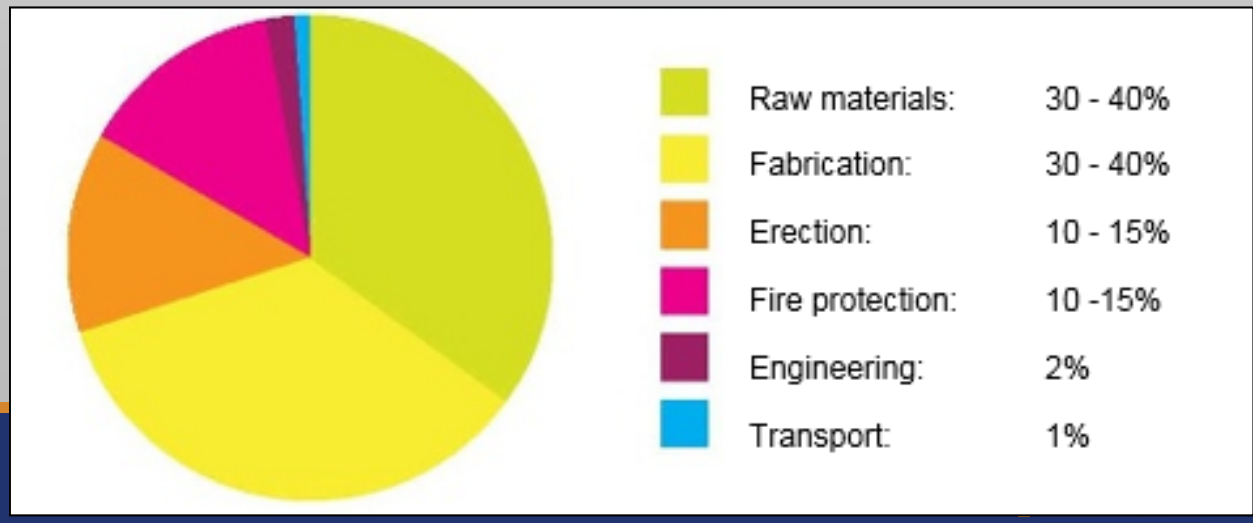
- Fast lead time is required, M steels may be the best choice (N and Q steels require additional heat treatments)
- Depend on how much is required and what is stocked
- May be necessary to order from steel producer, not stockholder

- Open sections in S460….
- Hollow sections in S420, S460 and higher strength
- Sheet, strip and plate in a wide range of high strengths

Cost

- Increases with increasing strength
- Varies with thickness (thinner plates need more mill time and therefore energy to roll)
- Cost of S460 compared to S355? 10-15%
- Cost of S690 compared to S355? 40-70%

Combined cost of materials, fabrication and erection is more relevant



Summary

- HSS are not new!
- Gradual but clear worldwide trend towards greater use
- Properties continue to improve due to advances in metallurgy & steel production processes