

Use of duplex stainless steels at low temperatures: A new way to present toughness – temperature - thickness data

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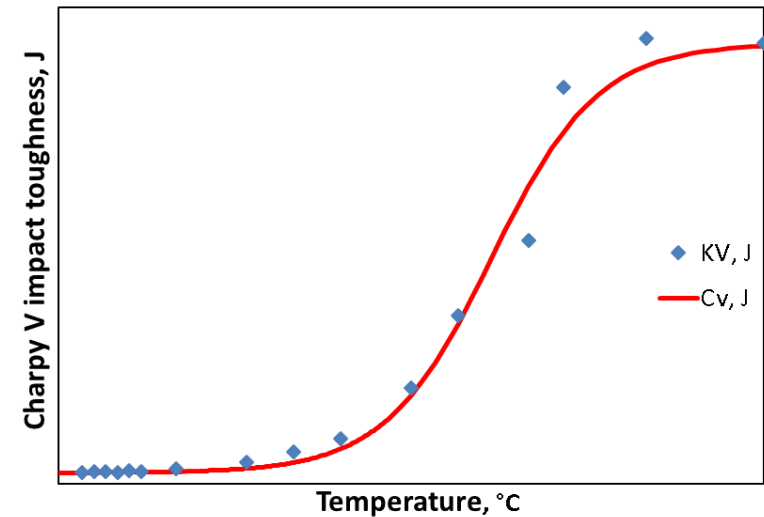


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Introduction

- The duplex stainless steels have a ductile-to-brittle transition temperature.
 - Due to this, safe design against brittle failure at low temperatures has to be considered for low temperature applications.
 - Common material toughness requirements:
 - Min. 40 J at – 40 °C
 - Min. 40 J at -46 °C
- A more balanced view of the temperature limitation for the duplex stainless grades



The ductile-to-brittle transition temperature

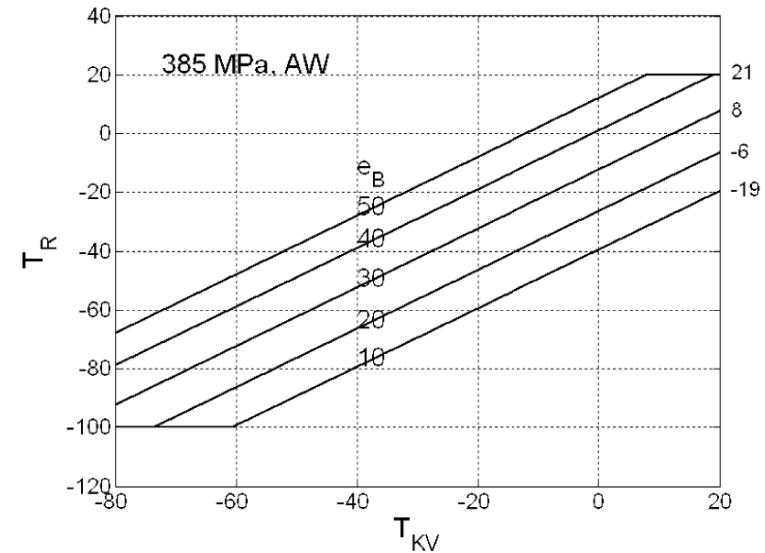
Mechanical properties at RT and impact energy at -40 °C

Grade	R _{p0.2} (min) [MPa]	R _m (min) [MPa]	A ₅ [%]	KV [J] {L(RT)/T(RT)/T(-40 °C)}
Forta DX 2304 (1.4362)	385 (L)	630	25	120/90/40
Forta DX 2205 (1.4462)	445 (L)	640	25	150/100/40
Forta SDX 2507 (1.4410)	515 (L)	730	20	150/90/40
Forta SDX 100 (1.4501)	515 (L)	730	25	150/90/40

For duplex in the solution annealed condition (min values) for plate.
From EN 10028-7:2007 - Flat product made of steels for pressure purposes

EN 13445-2:2014+C2:2015

- Design against brittle failure –
EN 13445-2: Unfired pressure vessels –
Part 2: Materials
- Nomograms are used for e.g. the duplex
- The nomograms: based on fracture
mechanical principles, e.g. including:
 - Semi-elliptical surface crack
 - Primary and secondary stresses
 - Master Curve approach
- The idea: use the nomogram for displaying
the low-temperature "window" for duplex
stainless steels



A nomogram in EN 13445-2

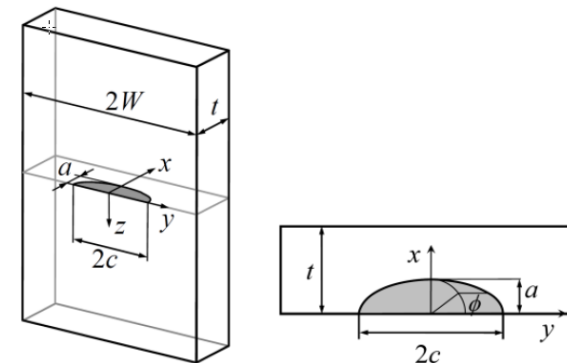
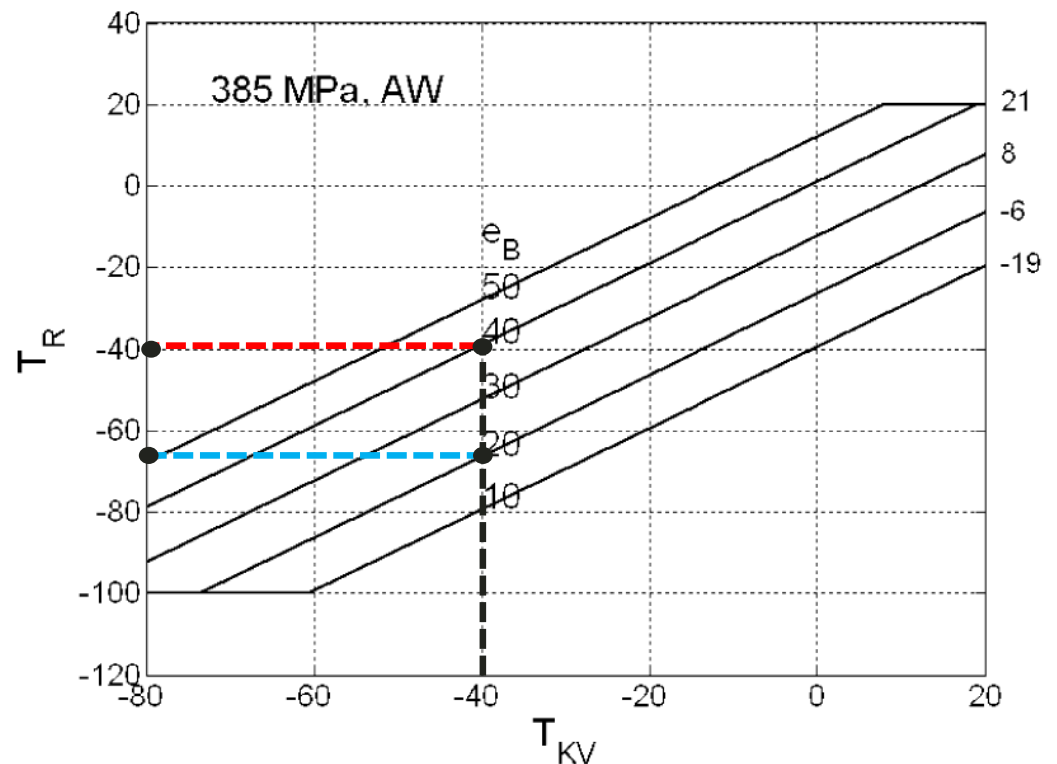


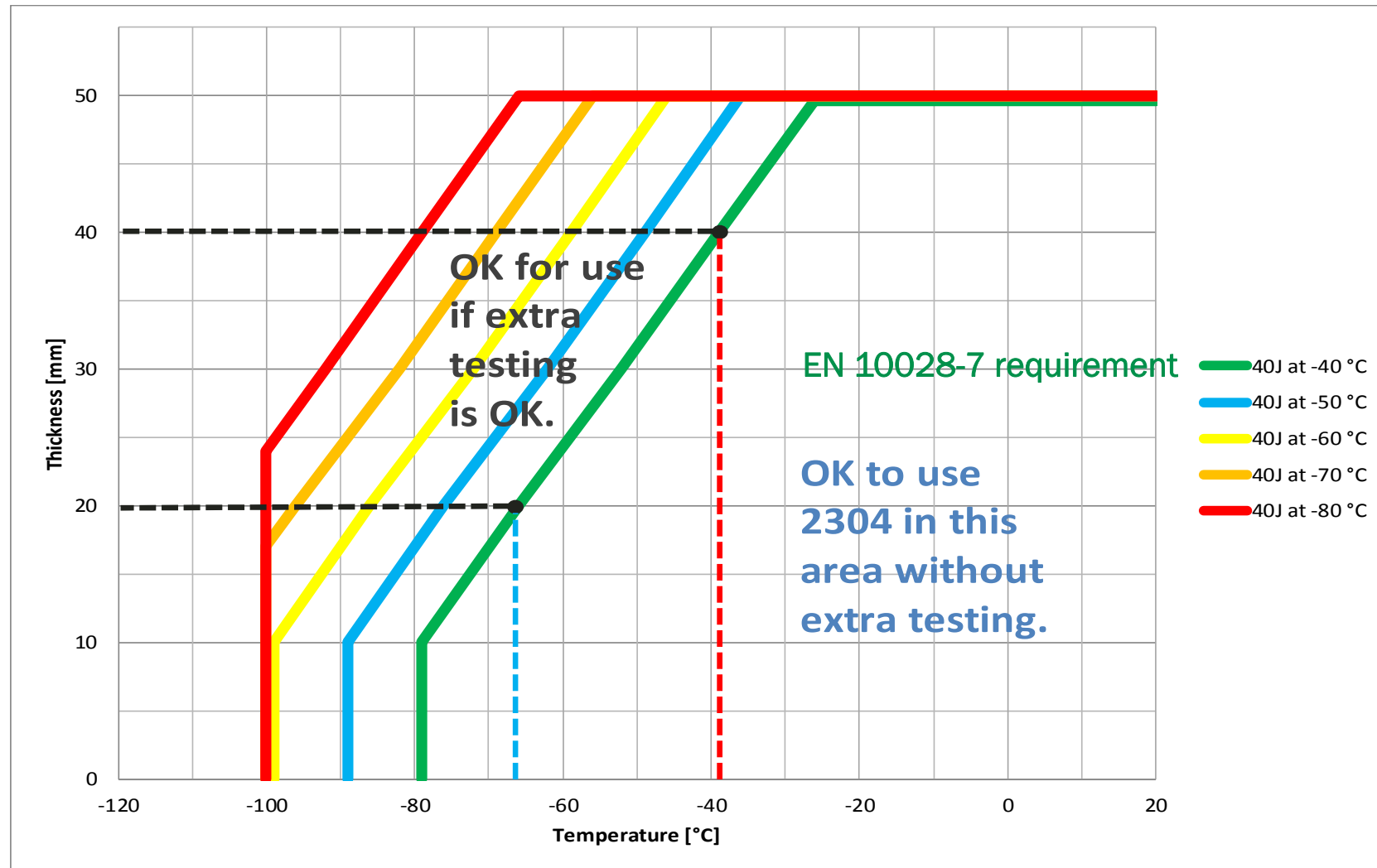
Plate with a semi-elliptical surface crack

Nomogram: How to use

- T_R , design reference temperature
 - $T_R = T_M + T_S$
 - T_M , min. metal temperature.
 - T_S , temp. adjust. term. 0 °C for as welded condition.
- T_{KV} = temperature for min. 40 J Charpy V.
- Depending on the min. specified yield strenght.
- In this case:
 - 40 J @ -40 °C $\rightarrow T_R \sim -40$ °C for **40 mm** plate
 - 40 J @ -40 °C $\rightarrow T_R \sim -67$ °C for **20 mm** plate

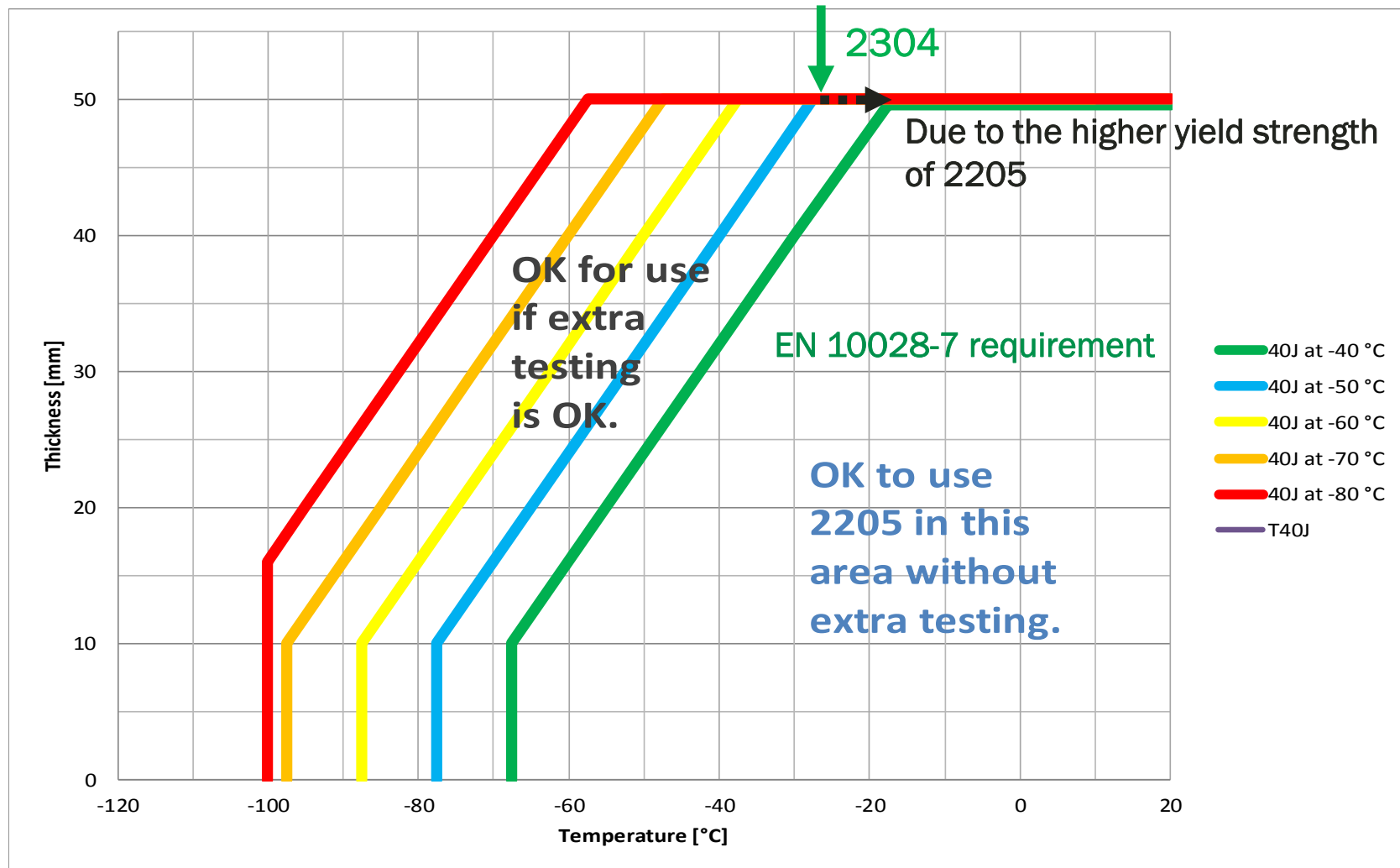


New Nomograms – Forta DX 2304, 385 MPa



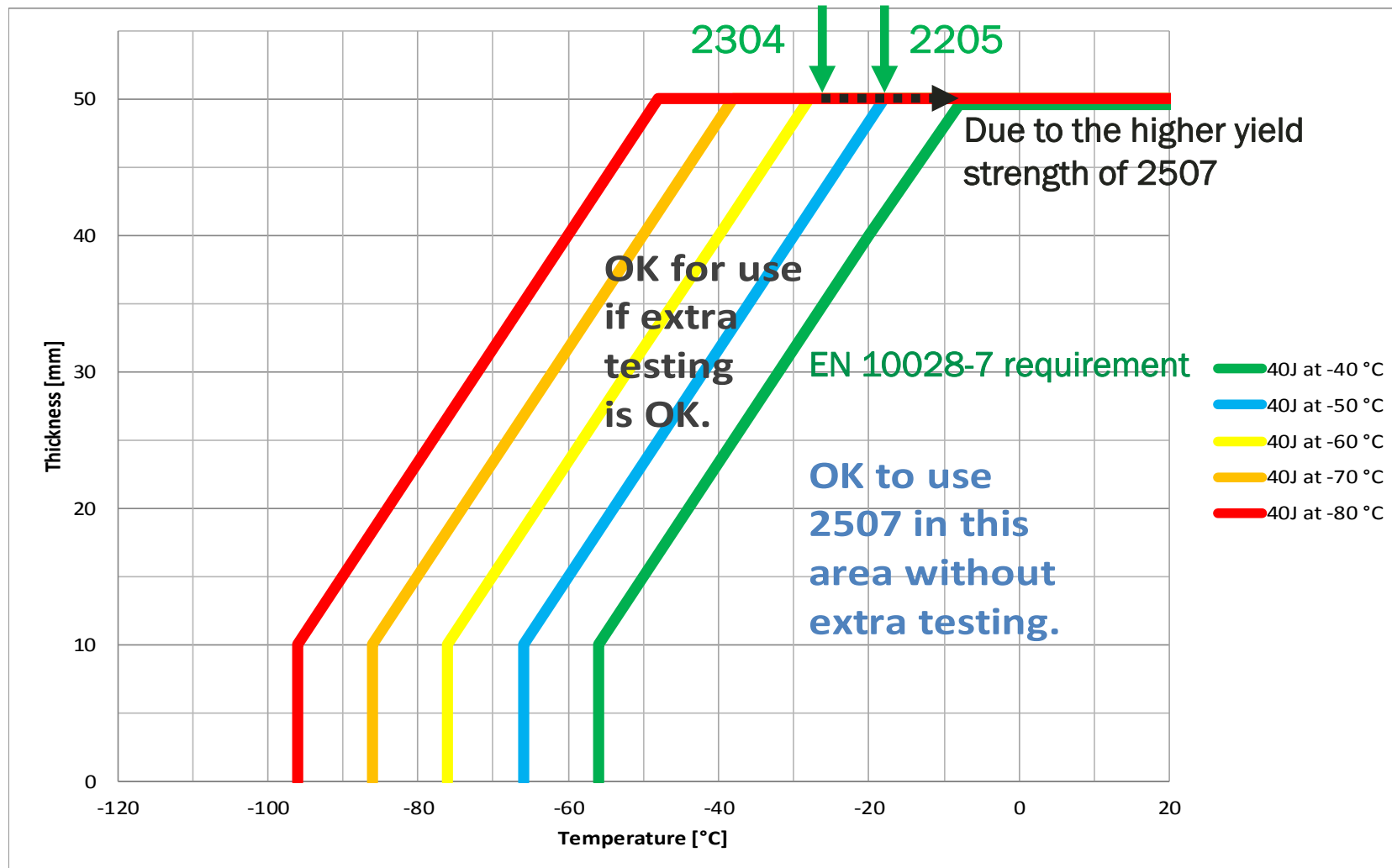
Temperature - thickness map for Forta DX 2304 as derived from Method 2.

New Nomograms – Forta DX 2205, 465 MPa



Temperature - thickness map for Forta DX 2205 as derived from Method 2.

New Nomograms – Forta SDX 2507, 550 MPa



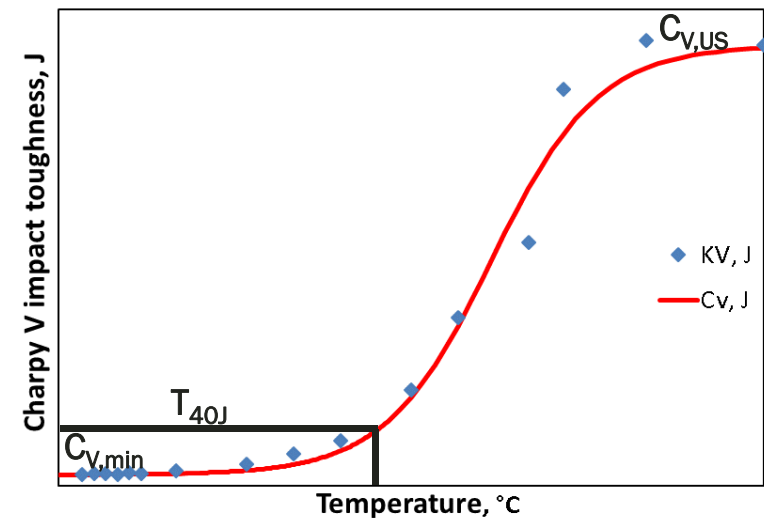
Temperature - thickness map for Forta SDX 2507 as derived from Method 2.

Experimental data & Influence of welding

- Temperature at 40 J, T_{40J} from:

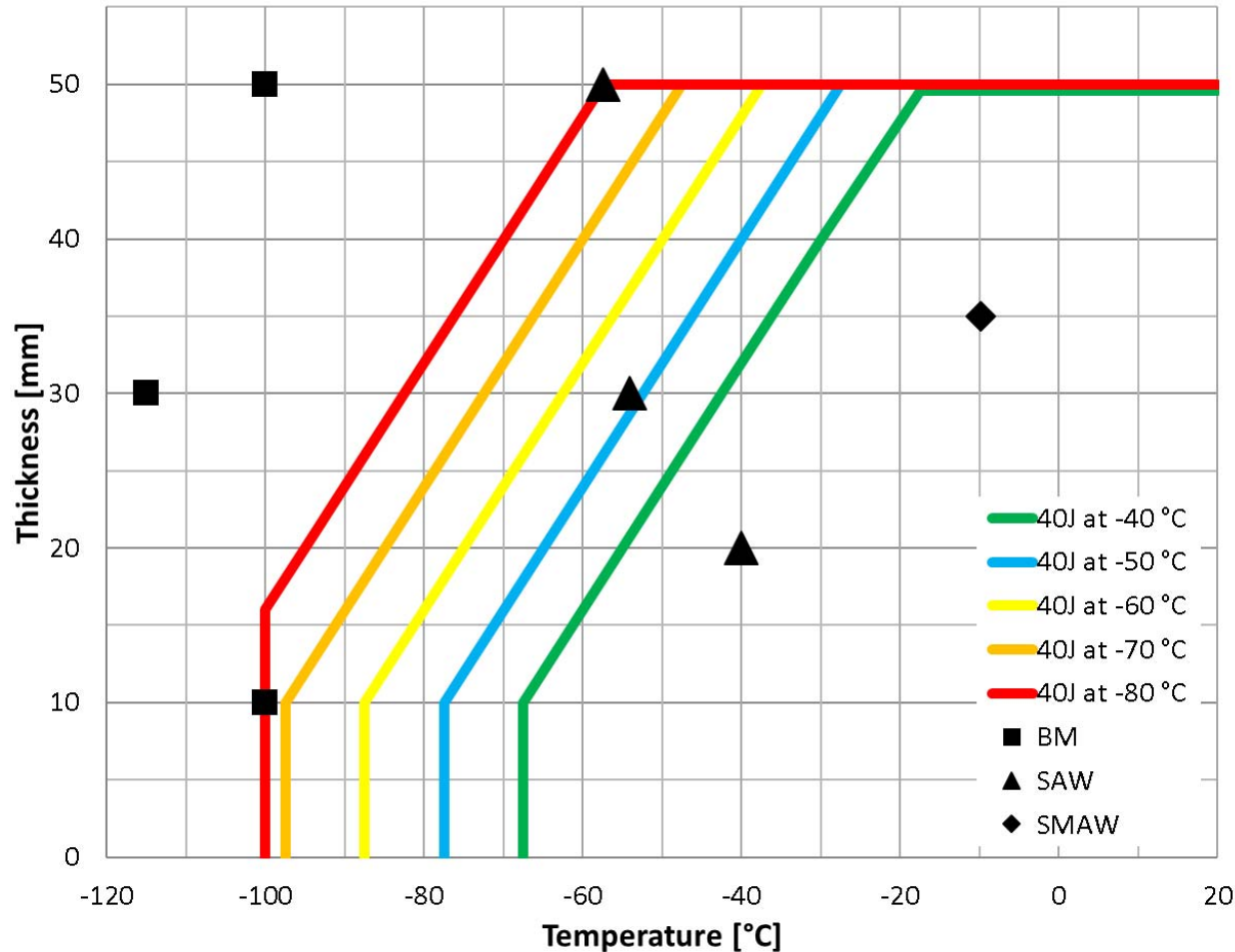
$$C_V(T) = \frac{C_{V,US} - C_{V,min}}{2} \left(1 + \tanh \left(\frac{T - T_{50}}{C} \right) \right) + C_{V,min}$$

- T_{40J} data from the ECOPRESS project together with unpublished data from Outokumpu for Forta DX 2205.
- Base metal
- Weld metal



The ductile-to-brittle transition temperature

Base material & Influence of welding



Temperature - thickness map for Forta DX 2205 with T_{40J} for base material and weld metal for two different welding conditions.

Summary

- The presented approach has the possibility to open up for new low temperature duplex applications.
- The way of presenting the thickness – temperature – toughness relation shown in the new type of nomogram is a good way to illustrate the use of the duplex stainless steels at lower temperatures.
- For base material of Forta DX 2205, the present approach shows large potential for expansion of applications into low(er) temperature applications.
- For Forta DX 2205 it is the weldments that gives the lower temperature limit.
- This approach is derived from the European pressure vessel code, which is a strict design code in Europe. For other applications, demands may not be as strict as for pressure vessels, so for these type of applications, the present approach may be easy to adopt.