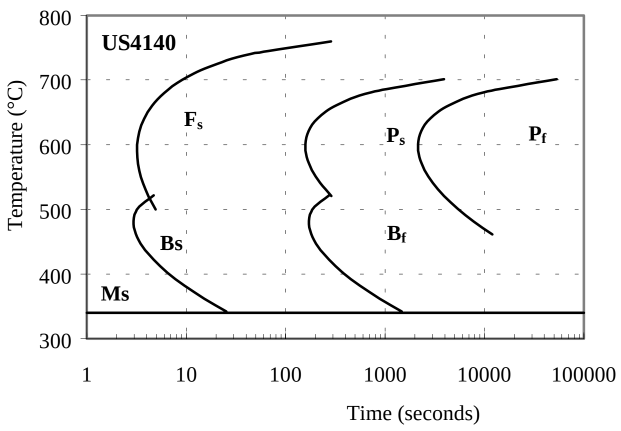
# JMatPro for HSLA Steels

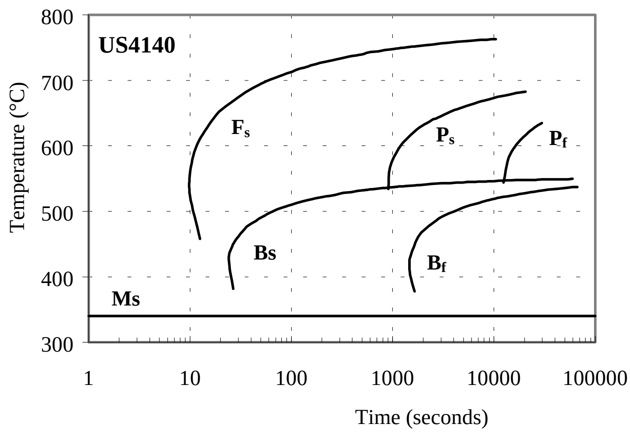
## Technical Background and Validation

The basis for the HSLA calculations lies in the calculation of the various critical temperatures, such as the Ae3 and the pearlite transformation temperature. The method used here is based on the well established CALPHAD approach (Saunders & Miodownik 1998) and utilises a thermodynamic database that has been well tested for steels (Saunders 2000). The martensite and bainite temperatures are after Stevens and Haynes (1956) and Kirkaldy & Venugopolan (1984)

For the case of transformation diagrams in HSLA steels, we have adopted a slightly modified approach following Kirkaldy and co-workers (Kirkaldy et al. 1978, Kirkaldy & Venugopolan 1984). This has proved a reliable method for calculating TTT and CCT diagrams for such alloys and the Figures below show calculated TTT and CCT diagrams for US4140 as examples. Use of the Materials Browser will allow TTT and CCT diagrams for a variety of other alloys to be accessed.




*Calculated TTT diagram for a US4140 steel*




*Calculated CCT diagram for a US4140 steel*

The hardenability of an HSLA steel can be calculated from the CCT curve for a Jominy bar. Firstly, cooling rates as a function of temperature and Jominy bar depth are calculated and the main equation is (Kirkaldy & Venugopolan 1984):

$$\dot{T} = -(T_a - 297)\frac{4\eta}{\sqrt{\pi x^2}}\Phi^3\exp(-\Phi^2) \qquad (1)$$

Where

$$\Phi = \sqrt{\frac{\pi}{2}}\left(\frac{T-297}{T_a-297}\right) + 0.4406\left[\frac{T-297}{T_a-297}\right]^{3.725} \qquad (2)$$

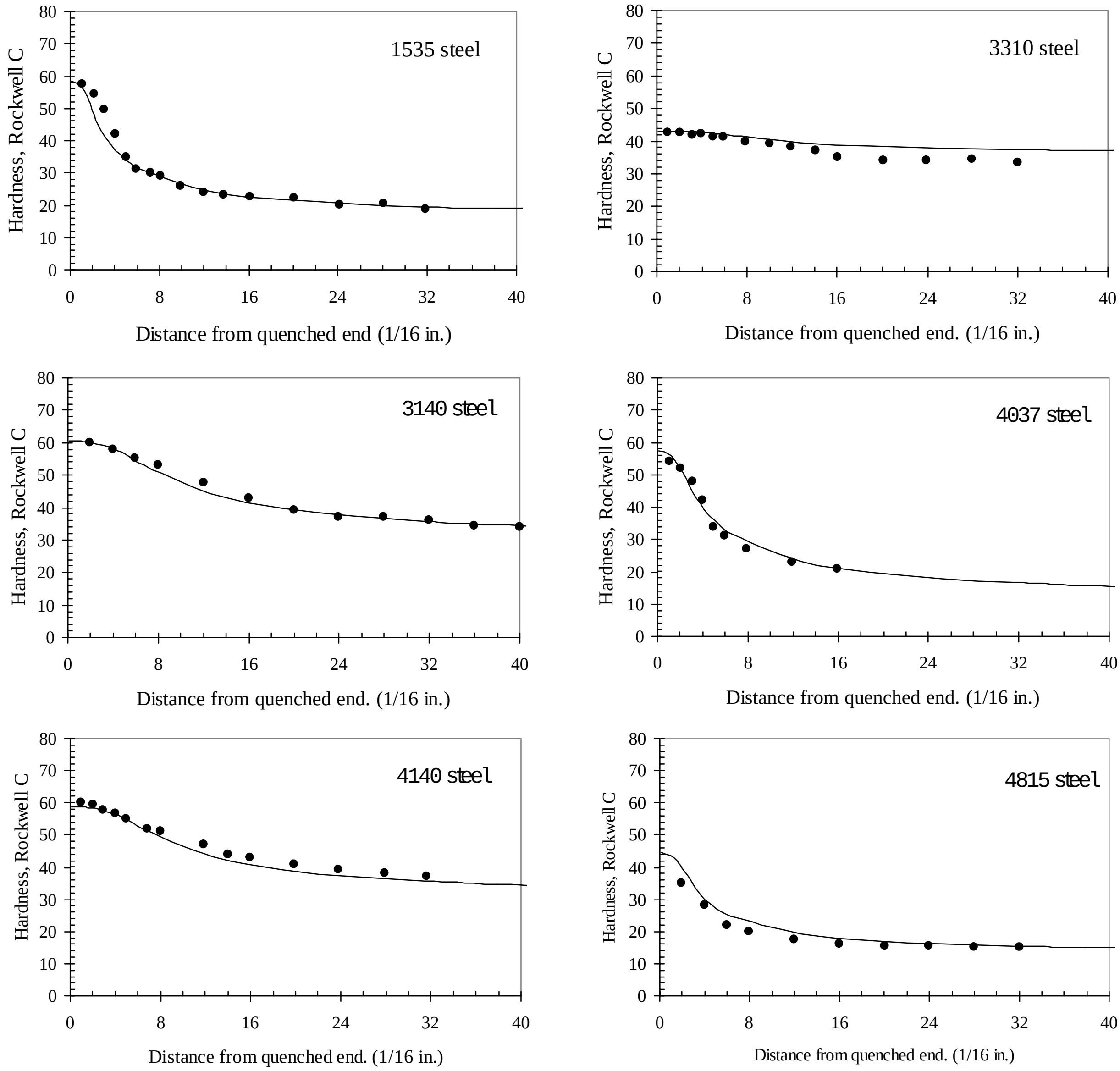
$\eta$ is the thermal diffusivity at distance x (in cm) along the Jominy bar, T is the temperature and $T_a$ is the austenisation temperature. The next step is to calculate the inflection point from the corresponding TTT and CCT curves, which is associated with the Jominy bar depth $X_0$. The Vickers Pyramid Number (VPN) is given by:

$$VPN = Y1 - \frac{(Y1 - Y2)}{3X_0^{2}} x^{2}; \qquad x < X_0 \qquad (3)$$

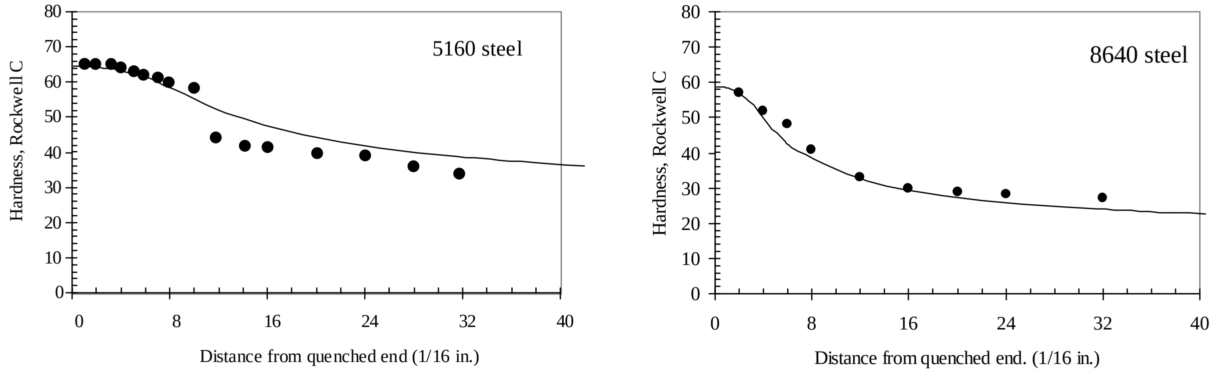
$$VPN = Y2 + \frac{2}{3}(Y1 - Y2)\frac{X_0}{x}; \qquad x >= X_0 \qquad (4)$$

Where Y1 and Y2 are the hardness values of martensite and pearlite in the alloy of interest, which can be calculated by formulae proposed by Honeycombe (1980) and Kirkaldy and Venugopolan (1984).

Based on the above equations, the Jominy hardenability curves of different types HSLA steels have been calculated and the Figures below show comparisons between experiment (ASM 1977, Kirkaldy et al. 1976, Kirkaldy & Venugopalan 1984) and calculations.




*Comparison between calculated and experimentally measured Jominy hardenability for various HSLA steels*




***Comparison between calculated and experimentally measured Jominy hardenability for various HSLA steels***

Once the hardness is obtained, both the 0.2% proof and ultimate tensile stress (UTS) can be calculated using a well tested approach (X. Li et al. 2000). Quantitative relationships between hardness and tensile properties were developed by Tabor (1956) based on the relationship between stress, σ, and the (true) strain, ε, by Ludwig's Law

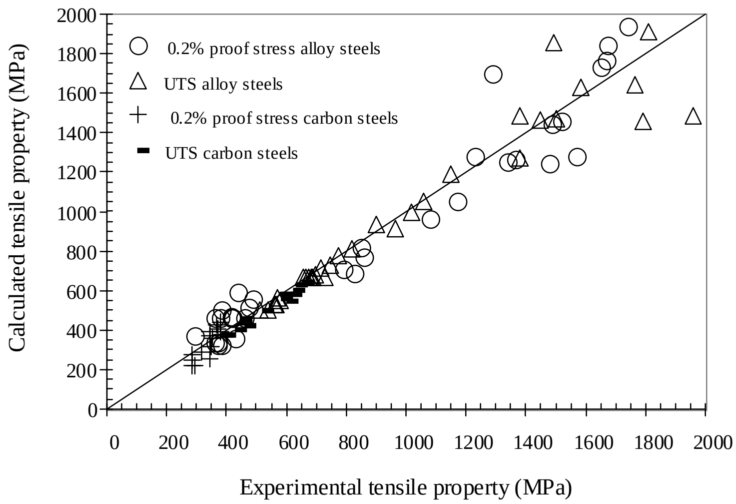
$$\sigma = A\varepsilon^{n} \qquad \text{...(1)}$$

Where n is the work-hardening coefficient A is a constant. By determining the pressure under a hardness indentor of a given geometry, it is possible to derive equations for the relation between the hardness, proof stress ($\sigma_{PS}$) and the ultimate tensile strength (UTS).

$$H_v = C\,\sigma_{PS}\left(\frac{\varepsilon_1}{\varepsilon_2}\right)^{n} \qquad \text{...(2)}$$

$$\frac{UTS}{H_v} = (1-n)C^{-1}\left(\frac{12.5n}{(1-n)}\right)^{n} \qquad \text{...(3)}$$

C, is a materials constant, $\varepsilon_1$ is the average strain under the indentor, and $\varepsilon_2$ is the strain chosen for the Proof Stress. The Figure below shows a comparison between experimental values of 0.2% $\sigma_{ps}$ and UTS and those calculated from hardness values.




***Comparison between experimental values of 0.2% $\sigma_{ps}$ and UTS and those calculated from hardness values***

## References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