Title	Additional Note on the Report "Quench Hardening and Cracking in Electron Beam Weld Metal of Carbon and Low Alloy Hardenable Steels"
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Additional Note on the Report "Quench Hardening and Cracking in Electron Beam Weld Metal of Carbon and Low Alloy Hardenable Steels"†

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In the previous report[1], the hardenability was investigated for the electron beam weld metals of the various carbon and low alloy hardenable steels, then a generalized prediction equation for the hardness in the electron beam weld metals was established. The equation obtained is given by

$$H_v = \left[\frac{840}{\tau^{0.22}} \cdot C_{eq} + 58\right] \pm 66 \qquad (1)$$

$$C_{eq} = [C] + \frac{[Mn]}{2.4} + \frac{[Si]}{24} + \frac{[Ni]}{14} + \frac{[Cr]}{16} + \frac{[Mo]}{60} \qquad (2)$$

$$\tau = 3.8 \times 10^{-2} \cdot \left(\frac{0.8 \cdot V_b \cdot I_b}{v_b \cdot t}\right)^2 \times \left\{\frac{1}{(500-T_0)^2} - \frac{1}{(800-T_0)^2}\right\} \qquad (3)$$

where, H_v: Vickers hardness of weld metal with load of 10 Kg, τ: cooling time from 800 to 500°C which is estimated by eq. (3), C_{eq}: carbon equivalent, [C], [Mn], [Si], [Ni], [Cr] and [Mo]: wt. % of carbon, manganese, silicon, nickel, chromium and molybdenum, V_b: anode voltage (kv), I_b: welding current (mA), v_b: welding speed (cm/sec), T_0: preheat temperature (°C), t: plate thickness or penetration (=hp) (cm).

Eq. (1) is reliable on the carbon and the low alloy steels, the chemical compositions of which are within the limits of 0.1 to 0.55 % C, 0.4 to 0.9 % Mn, 0.2 to 0.3 % Si, less 3.5 % Ni, less 3.0 % Cr, less 0.5 % Mo and less 0.2 % Cu.

Moreover, the hardnesses predicted with the generalized prediction equation were nearly equal to the actual hardnesses measured in the electron beam weld metals by several researchers. Therefore, authors have considered that the generalized prediction equation in the previous report is fairly valid to predict the hardness of weld metal in electron beam welding of hardenable carbon and low alloy steels whose chemical compositions of the materials to be welded are within the applicable limits for the generalized prediction equation.

Now, however, in a point of view for industrial application of the generalized prediction equation, the value of the standard deviation of the generalized prediction equation, which is ±66, is comparatively large. Moreover, as it is understood from **Fig. 1**[1], the predicted hardnesses for the plain carbon steels (white circle) independently deviate to some extent.

It is considered that the reason in the above is that the index numbers of the cooling time (τ) for the plain carbon and low alloy steels are different each

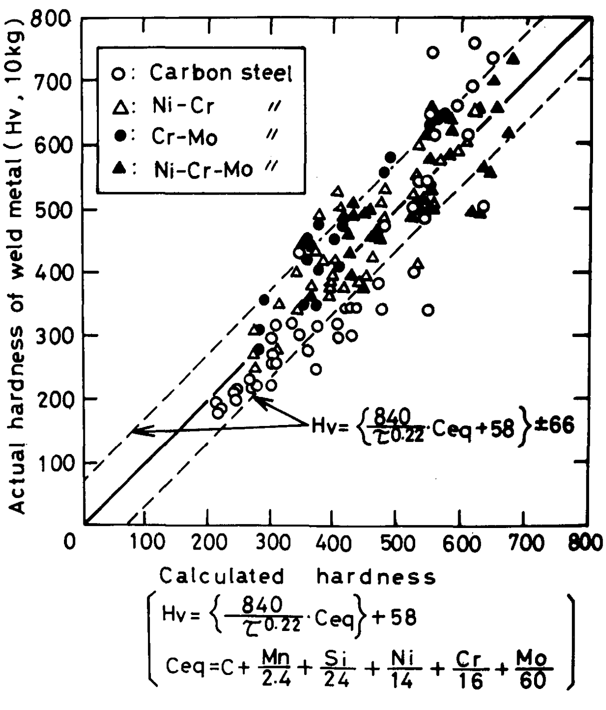

Fig. 1. Comparison of the Actual Hardness with the Calculated Hardness for Electron Beam Weld Metal of Various Steels in the Previous Report.

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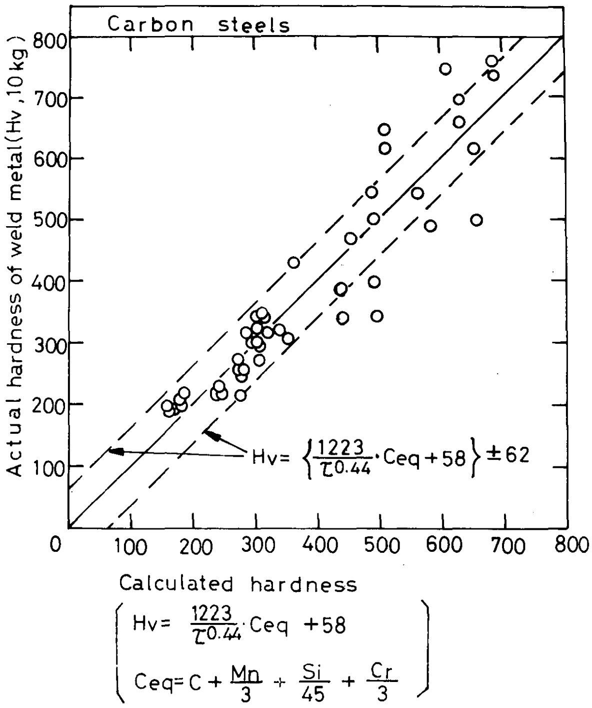

Fig. 2. Comparison of the Actual Hardness with the Calculated Hardness for Electron Beam Weld Metal of the Plain Carbon Steels.

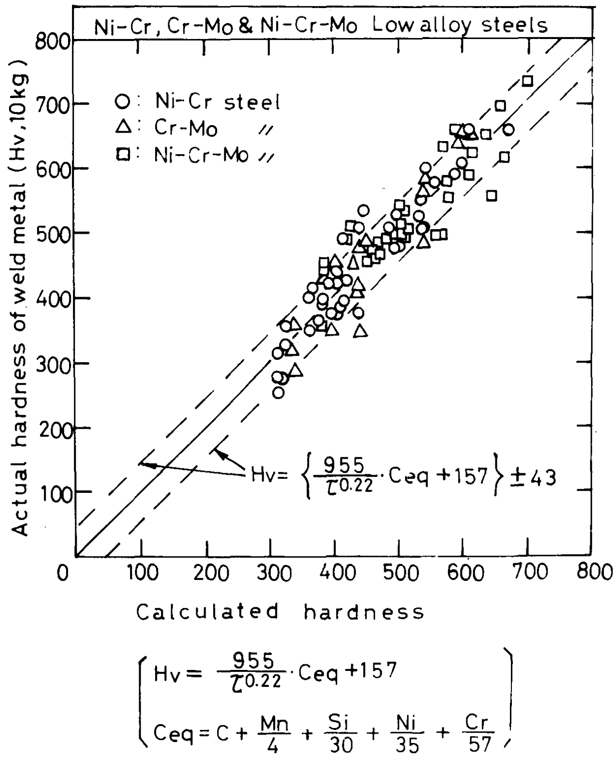

Fig. 3. Comparison of the Actual Hardness with the Calculated Hardness for Electron Beam Weld Metal of the Ni-Cr, Cr-Mo, Ni-Cr-Mo Low Alloy Steels.

other, especially the value for the plain carbon steels is fairly different.

Then, authors have divided the actual hardness data in the weld metals in the previous report into the two groups, that is, of carbon steels and of low alloy steels. Subsequently, for each group new prediction equation for the hardness of the electron beam weld metal was established in the same method utilized in the previous report.

The two new prediction equations obtained are as follows. For the carbon steels (whose chemical compositions are within 0.18 to 0.53 % C, 0.45 to 0.81 % Mn, 0.23 to 0.29 % Si, 0.01 to 0.02 % Ni and 0.01 to 0.14 % Cr),

$$H_v = \left[\frac{1223}{\tau^{0.44}} \cdot C_{eq} + 58\right] \pm 62 \tag{4}$$

$$C_{eq} = [C] + \frac{[Mn]}{3} + \frac{[Si]}{45} + \frac{[Cr]}{3} \tag{5}$$

For the Ni-Cr, Cr-Mo and Ni-Cr-Mo low alloy steels (whose chemical compositions are within 0.12 to 0.46 % C, 0.48 to 0.74 % Mn, 0.24 to 0.31 % Si, 0.03 to 3.15 % Ni, 0.37 to 2.66 % Cr and less 0.51 % Mo),

$$H_v = \left[\frac{955}{\tau^{0.22}} \cdot C_{eq} + 157\right] \pm 43 \tag{6}$$

$$C_{eq} = [C] + \frac{[Mn]}{4} + \frac{[Si]}{30} + \frac{[Ni]}{35} + \frac{[Cr]}{57} \tag{7}$$

The experimental relations between the actual hardness of the weld metal and the predicted hardness by eq. (4) and eq. (6) are shown in **Fig. 2** and **Fig. 3,** respectively.

The values of the standard deviation of the both eq. (4) and eq. (6) became smaller than that of the generalized prediction equation as described in eq. (1). Especially in the eq. (6) for the low alloy steels, this is more notable.

To conclude, it is considered that using the eq. (4) or eq. (6), the hardness in electron beam weld metal can be predicted more correctly than using the generalized prediction equation established in eq. (1).

Reference

1) Y. ARATA, F. MATSUDA, K. NAKATA: "Quench Hardening and Cracking in Electron Beam Weld Metal of Carbon and Low Alloy Hardenable Steels", Trans. JWRI, **1** (1972), 1, p. 39~p. 51.