Effects of Process Variables on HAZ Hardness

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The art of qualifying CROs

• Qualification of welding procedures to satisfy ASME, API and NACE requirements can be a challenge, especially when applied to heat-treatable (hardenable) steel alloys.

• When applying the first layer, must balance between use of a low heat input rate to minimize dilution and prevention of high hardness in the heat-affected zone (HAZ).
Understanding the metallurgy

• HAZ properties dependent on
  – Base metal chemistry \( \text{carbon equivalent (CE)} \)
  – Base metal thickness
  – Welding process variables affecting cooling rate
    • Heat input rate
    • Preheat temperature

• Once understood the process variables affect the outcome, use of automated welding will guarantee success
Base metal chemistry

• Composition of steel will determine its reaction to heat treatment
• Various alloying elements will increase steel’s hardenability
• Carbon content has the dominant effect, but other elements also contribute
  • Manganese
  • Chromium
  • Nickel
  • Molybdenum
• Calculation of carbon equivalent (CE) is a means of factoring the effects of all alloying elements in relation to carbon content

• Numerous CE formulas exist, but the one below was adopted by IIW in 1967 and is widely recognized

\[
CE = \%C + \frac{\%Mn}{6} + \frac{(\%Cr + \%Mo + \%V)}{5} + \frac{(\%Ni + \%Cu)}{15}
\]
CE for 4130

• Based on minimum and maximum chemistries for AISI 4130, a range of CE
  – Min  0.537
  – Max  0.700
Test results - HAZ hardness

• CE for 4130 test coupon / 500° F preheat
  – 0.637
  – HAZ hardnesses (HV$_{10}$)
    – 4hr PWHT 245/250/248
    – 12hr PWHT 238/240/238

• CE for 4130 test coupon / 500° F preheat
  – 0.676
  – HAZ hardnesses (HV$_{10}$)
    – 3hr PWHT 247/249/249
    – 6hr PWHT 225/230/243
• Relationships
  – For given CE: \( \uparrow CR \Rightarrow \uparrow HAZ \) hardness
  – \( \downarrow HIR \Rightarrow \uparrow CR \Rightarrow \uparrow HAZ \) hardness

• However
  – Need to keep HIR low to minimize dilution to make chemistry
  – So, to make chemistry (which requires low HIR) and meet hardnesses in HAZ, need to somehow slow down cooling rate
Potential solution

• One way to slow down cooling rate is to increase the preheat temperature
• To better understand the behavior of this material and how it reacts to heating and subsequent cooling is to review the continuous cooling diagram
4130 CCT diagram

Chromium-Molybdenum Steels: 4130

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Overlay test welds were applied to 4130 material using GTAW-HW.

Base metal CE = 0.656

Preheat temperatures: 400° F, 500° F, 600° F, and 700° F

Checked hardnesses in as-welded and PWHT condition (4hr holding time at 1175° F)
• Tested hardesses of HAZs both with single and double layers of overlay
  - To determine the degree of tempering realized from the second layer
• Tested both “peaks” and “valleys”
• Used Knoop microhardness testing (500g load) to allow for more localized determination of hardesses
Hardness testing

1 Pass Peak

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2 Pass Peak

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Hardness testing

1 Pass Valley

2 Pass Valley

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Detailed hardness results

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Detailed hardness results

1 Pass Valley

- HK 500gf 15sec
- 250 HV10

WI - .25mm, -.50 mm, -.75mm, -1 mm, -1.5 mm, -2 mm

Graph showing hardness results for different conditions.
Detailed hardness results

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Summary

• Base metal carbon equivalent (CE) important
  – If maximum CE material used for qualification, production welding on lower CE material will yield acceptable results
• To achieve the required HAZ hardness, preheat temperature is the most critical variable
• Tempering effect of second layer critical as well
• Preheating at 600° F or above could provide acceptable results, even without PWHT
  – PWHT effects on HAZ hardness secondary
  – Per ASME Section IX, production welding can be performed using 500° F minimum preheat temperature