ASME PWHT PROJECT

Assessment of Materials
Whose Toughness is Degraded
by Post-Weld Heat Treatment (PWHT)

O’Donnell Group
Degradation of Toughness by PWHT

- **Members:**
  - W. D. Doty
  - W. J. O’Donnell
  - C.E. Spaeder

Comment on Dor Doty

- Many of you recognize that Dr. Doty was a major contributor to the NBIC rules for many years.
- He served as my mentor since 1960.
- This presentation is dedicated to Dor Doty.

Presentation Format

- Background of present code rules.
- Overview of PWHT Issues.
- Stress Relieving (PWHT) ASTM A212.
- Flaw Size vs. Fatigue Life per Barsom.
- PWHT of Modern Steels.
- Review of Selected Documents.
- ID items that need to be reconsidered by the Code.

Terms Used Interchangeably

- Reheat Cracking
- PWHT
- post weld heat treatment (PWHT)

Project Background

- PWHT reported as highly desirable in the early 50s.
- Beneficial notion became ingrained in common "in-house" welding programs.
- PWHT can be detrimental for certain steels.
- PWHT has no benefit for some modern steels.
- Need to apply technology from other industries; example: fracture control plan as applied to bridges.

Overview of PWHT Effects

Beneficial Effects

- Improve toughness of certain steels; especially steels with relatively high carbon.
- Mitigate SCC in some Service.
- Outgas hydrogen. (Need can be mitigated by strict low hydrogen practices).
- Reduce residual stresses; important in SCC service and for dimensional control after machining.

Overview of PWHT Effects

<u>Detrimental Effects</u>

- Degrade toughness for some steels.
- Introduce micro cracks not readily found by routine NDE.
- It is difficult to rule out reheat cracking because of the complexity of the HAZ.

Pellini on Residual Stress in Structures

- Residual Stress is important in terms of brittle fracture only with low toughness.
- When a PWHT is undesirable, elastic-plastic toughness corresponding to the presence of stresses equal to yield strength values should be required. This toughness value allows the omission of a PWHT in the absence of issues such as SCC and dimensional considerations.

Stress Relieving (PWHT) ASTM A212

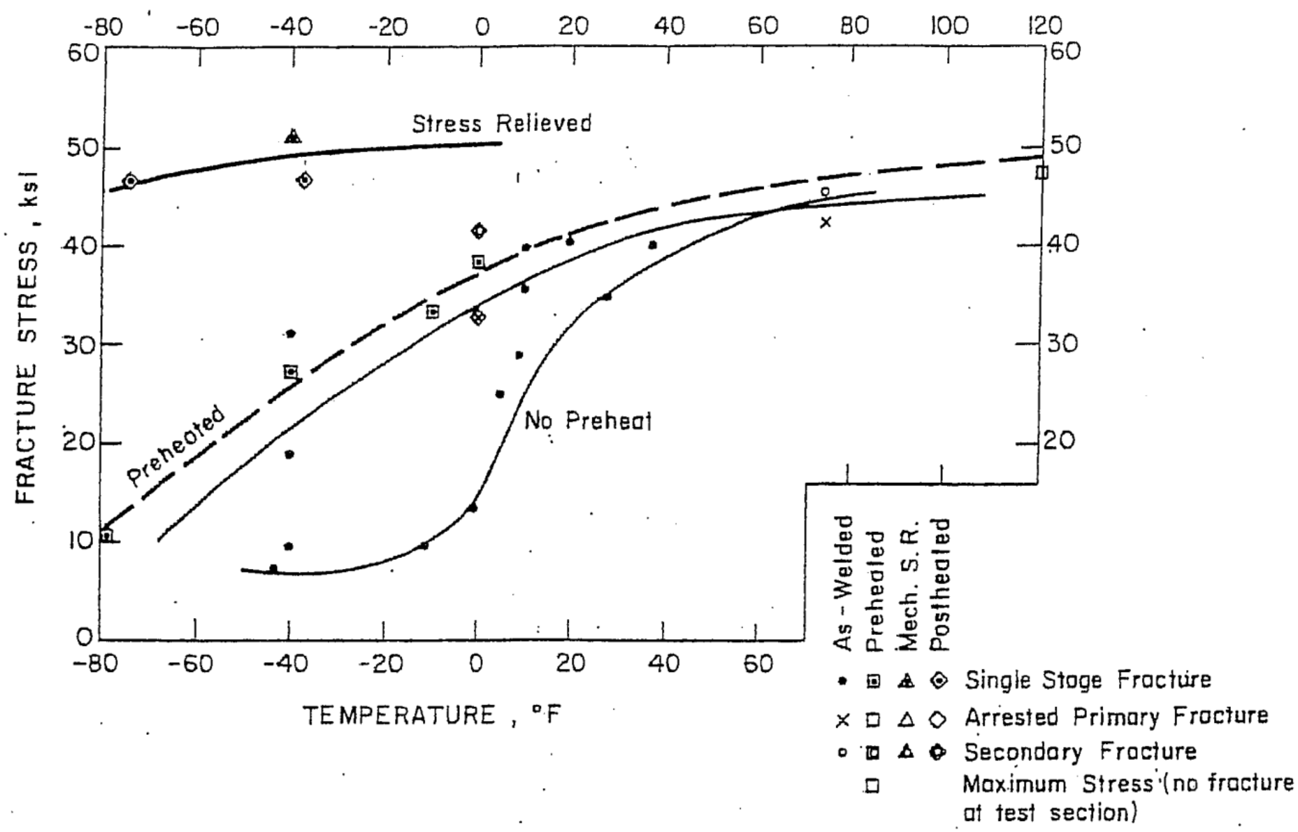

FIG. 8.12 Fracture Stress Variation with Temperature in A212 Grade B Wide-Plate Weldments Notched After Welding.

Flaw Size vs. Fatigue Life

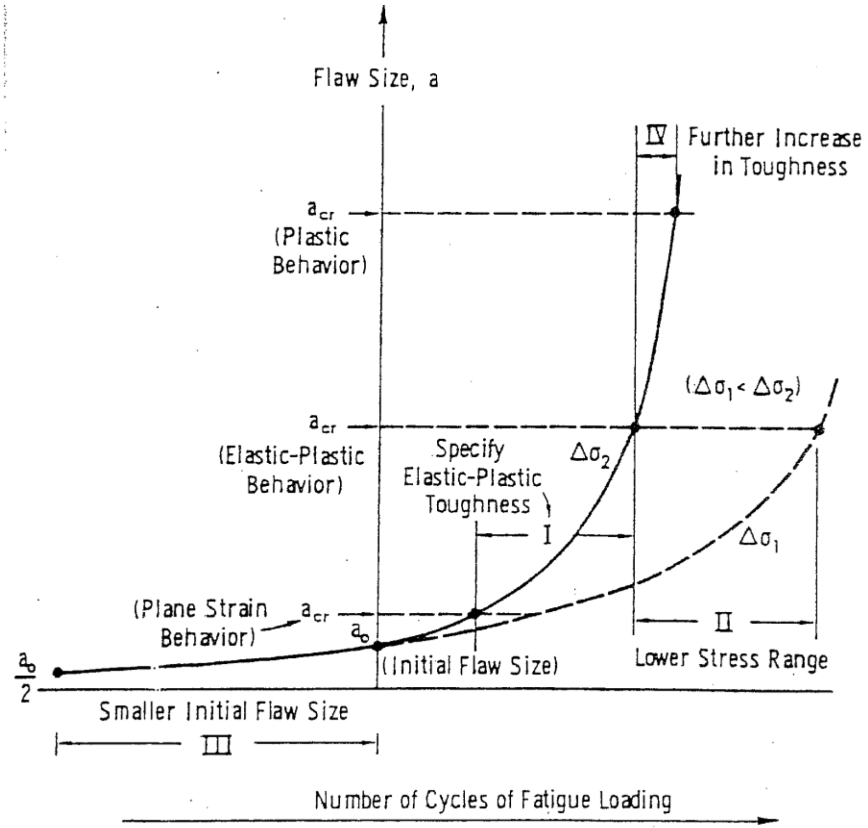

FIG. 15.11 Schematic showing flaw size–fatigue life relations for various critical crack sizes.

Comments on Previous Slide

Briefly:

1. Very important in understanding the role of notch toughness and inter relationships among cracks and crack-like flaws, stress range, and fatigue life. (on cover of Barsom book)
2. Stress range is critical because crack growth rate is proportional to the power 3.
3. Role of stress concentration effects needs to recognized.
4. Elastic-plastic behavior in desirable in most ASME applications.
5. Crack arrest can be achieved with some steels that exhibit very high toughness.
6. Some low carbon high strength steels exhibit toughness approaching that of austenitic stainless steels such as Type 304.

PWHT on Modern Steels

ASTM 709 –(High Performance Steel)

- Designed for ease of welding.
- Toughness similar to austenitic steel.
- Exhibits yield strengths as high as 100 ksi.
- Low carbon martensitic steels similar to ASTM A517 steel except carbon is kept low.
- These types of steel can be susceptible to PWHT cracking.

Background Documents

- Documents considered in following order:

1. WRC Bulletins.

2. Doty Papers

3. TWI documents-March 2006 Welding Journal.

Stout Bulletin 302

- Good overview of PWHT issues:
  1. Benefit of PWHT for 0.25% carbon steels.
  2. Marginal benefit for 0.15% carbon steels.
  3. V bearing steels often degraded by PWHT.
  4. PWHT not a universal good.
  5. Not required if residual stress can be dealt with successfully.
  6. Little benefit with respect to fatigue.

Konkol Bulletin on Long-Time Effects

- Studies on ASTM A36, A537 Class 1, A612, A588 Grade A, A572 Grade 50, A663 Grade C, and A633 Grade E show:
  1. Base metal strength and notch toughness are generally degraded by long PWHT.
  2. HAZ and Weld Metal toughness are affected by welding parameters.
  3. HAZ sometimes benefit from PWHT and sometimes degraded.

WRC Bulletin 395

- Lehigh studies on V and Cb additions show:
  1. These additions degrade the CVN of normalized and tempered base metal and HAZ properties.
  2. The level of degrading is a function of specific composition and welding paramters.

WRC Bulletin 407

- Spaeder-Doty Interpretive report shows:
  1. The ASME Code permits the elimination of a PWHT when the steel exhibits high notch toughness at the intended service temperature.

  2. The use of a PWHT is likely to degrade the service performance at the intended service temperature.

  3. The above criteria has been applied generally in code cases; exception is P8 steels.

Needs Identified in WRC 407

- Need for Rules for eliminating PWHT when it can be justified on the basis of notch toughness in the as welded condition.
- Need to eliminate PWHT when reheat cracking is a distinct possibility. Note: Reheat cracks can be missed in routine non destructive examination.

WRC Bulletin 481

- Orie and Upitas Studies show:
  1. Base metal notch toughness of SA516 degraded by PWHT.
  2. PWHT follows Larson Miller relationship.
  3. Reinforce earlier studies that show that a PWHT is not a universal good.

Steels Exhibiting Reheat Cracking per Doty

TABLE 1 CLASSIFICATION OF STRUCTURAL AND PRESSURE VESSEL STEELS

Composition Type	Thermal History	Minimum Yield Strength (or Point) ksi (MN/m^2)
Carbon[a]	Nonheat-treated	30–50 (207–345)
	Normalized	30–50 (207–345)
	Quenched and Tempered	50–100 (345–689)
Low-Alloy[b]	Nonheat-treated	40–70 (276–482)
	Normalized	50–60 (276–413)
	Quenched and Tempered	60–100 (413–689)
Alloy[c]	Normalized	35–50 (241–345)
	Normalized and Tempered	50–80 (345–552)
	Quenched and Tempered	50–180 (345–1241)

[a] 0.33% max C, C–Mn, C–Mn–Si, and C–Mn–Si with certain alloying elements.
[b] 0.26% max C with up to about 1% total Cu, Ni, Cr, V, and Cb.
[c] 0.25% max C with 0.5% or more of Ni, Cr, or Mo.

Welding Technology of Heat Treated Steels

- Doty-Szekeres paper:
    1. This paper details the experience with T-1, 9% nickel steel, and HY-80 steel and reports that these steels generally do not require a PWHT.
    2. These steels are used successfully in non-stress relieved conditions in bridges, storage vessels, and military applications.

TWI Studies Reported in WJ March 2006

- The paper references work to justify exemptions from Code rules requiring a PWHT.
- The TWI view is that fracture mechanics can be used to justify departure from Code rules by showing that the steel has sufficient notch toughness.

ASME CODE RULES in Need of Reconsideration

- There is a compelling need to revise the rules for “lethal” service.
- Presently the Code requires a PWHT even if the PWHT degrades notch toughness and possibly introduces reheat cracks that are likely to go undetected under routine non-destructive inspection.

More On Proposed Revisions

- Add rules to the Code that eliminate a the PWHT provided a fracture mechanics analysis confirms that weldment exhibits sufficient notch toughness to preclude brittle fracture over the life of the vessel.

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- Lethal service should be expanded to include vessels that contain large quantities of liquefied flammable gases where a vapor cloud explosion is a possibility in the event of major leak.
- A vapor cloud explosion can cause a number of injuries and deaths if the event occurred in a populated area.

GOING FORWARD

- The report in written form is being considered by the various Code Committees in meetings this week.
- The most important observation is that it is very difficult to say that a specific steel is fully immune to reheat cracking because of the complex nature of multi-pass welding.