Specifications Dilemma Posed by Ultra High Toughness Line Pipe Steels

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Outline

• Introduction
  – why high toughness? – avoid / limit propagating shear failure
  – why is it a concern? – consequences unacceptable

• Issues Caused by Increased Toughness
  – Sub-size Specimens
  – Implications of Unbroken Specimens

• Summarize / Conclusions

Focus on what steel composition & processing must achieve in terms of Specifications & related Properties Tests
What concerns drive higher toughness?

- Toughness controls the fracture initiation pressure & critical length
  - Consequences of Initiation = Leak & related events that for some scenarios can be problematic
- Inadequate toughness leads to rupture & chance of propagating failure
  - Consequences of rupture for NG & multi-phase fluids (HVPLs/CO₂/etc) & impact on toughness

for NG / MPF Pipelines & Adequate Toughness = Controlled but Full-Bore

AS 2885.1 recognizes this and provides a basis for control

But there are some aspects of Specifications & Acceptance Testing that pose concern

origin -- mechanical damage induced crack that grew in service -- initially just 0.25 mm deep gouge!!

So, design for “control” & Target Leak not Rupture via adequate toughness

Much energy but contained

Shear propagation in a full-scale test

typical view along fracture path
Understanding Propagating Shear Failures

Bottom line is that high toughness can be essential to avoiding propagating shear failures.
Some Trends with Increasing Toughness

Shift from propagation to deformation control, so high CVN values ≠ cracking resistance

Shift from steep slope to a shallow one, so high CVN values ≠ deformation/flow resistance

So, significant changes occur in the response of a CVN sample as toughness increases...
Issues in Qualification & Acceptance Testing

3-point impact-bend specimens (CVN & DWTT) introduced decades ago, to deal with much different steels than today (chemistry, processing, flow & fracture response, ...)

CVN for failure “resistance”

DWTT for “failure mode”

Both suffer major issues as toughness increases
High Toughness & Sub-Size CVNs

- Some codes require testing full-size (FS) CVN specimens, but high toughness can lead to issues with machine capacity.
- Alternatively, when dealing with thinner skelp you can’t get to full size:
  - leads to the need for scaling rules for energy & FATT
  - specifications don’t address scaling rules & full-size equivalence (FSE)
  - next few slides consider issues that emerge dealing with rising upper shelf (RUS) steels and scaling rules
CVN Resistance: RUS & Implications for MPQT

- **What is a RUS??** (illustrated here for Australian 2011 X70 production)
  - All results reflect “valid” testing (E ≤ 80% of the machine capacity)
  - RUS develops under fully ductile conditions (i.e., ~100% shear)

- Curves show typical CVN behavior:
  - a lower shelf, a transition, & an upper shelf (US) or plateau

- RUS leads to a high upper-shelf energy (USE) & low fracture appearance transition temperature (FATT)

- However:
  - onset (‘CV100’) here occurs at ~136 J
  - the ‘plateau’ reflects a RUS at ~270 J
  - the reported USE depends on the MPQT temperature – & so can vary with that temperature
Implications of the Rising Shelf Energy

- CVN Testing for Development, Acceptance, or Comparative Evaluation

- Modern X80 – typical TMCP / Pacific-rim production
Possible Rising Shelf Implications: Aussie focus

• Consider now some “ultra pipe” – Australian data circa 2008

  • A nonlinear scaling rule led to a very good fit when targeting average CVN USE:
    – but, the scatter is huge relative to typical plateau / CV100 response !!

  • Good correlations ≠ Large scatter:
    – what exponent values are needed to offset this significant scatter ??

  • Quite large swings in the exponent are necessary to offset the scatter:
    – suggests other factors might be involved
    – a RUS can promote significant scatter
    – modern steels tend to show a RUS
    – perhaps further understanding is needed for cases where propagating shear failure is a potential concern
Summary for RUS & CVN Width: MPQT Implications

- Effect of width & RUS for recent Pacific-Rim Production

Observations

- ¾-size data show a clear RUS as did full-size results
- RUS was ‘heat’ specific for nominally identical steels
- ½ & ⅓-data show a diminishing RUS

Observations / Questions

- RUS is effected by the TM rolling history
- Sub-size results can serve as benchmarks for other sizes only at CV100
- RUS leads to a nonlinear scaling rule except where CV100 data are employed
- ?? Is energy dissipated in the RUS equally effective in controlling propagating shear failures (splits)?
- ?? What temperature is appropriate for MPQT?
Full vs Sub-Size CVN Correlation

- Effects of specimen width & a RUS (at CV100)

1950s/60s Era
~prior to control-rolling/TMCP

Post 60s Era
and RUS @ CV100

Observations
- In the ⅓-size CVN era when the BTCM was developed the sub-size energy scaled linearly.
- CV100 trends linearly even for very tough RUS steels.
Issue: High Toughness & Unbroken CVNs

- Current standards permit the use of unbroken CVN energy results provided that the test energy is ≤ 80% of the machine capacity
- All results to be considered satisfy this requirement & so are “valid data”
- So broken & unbroken energies can be comingled per ASTM E23

Quite different looking unbroken CVN Specimens
Issue: High Toughness & Unbroken CVNs

• All results shown here satisfy the requirements for “valid data”

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<th>Frequency of occurrence</th>
<th>Contrasting energies for broken vs unbroken specimens</th>
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<th>Averaged CVN energy per heat, J</th>
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Observations

• “Valid” data for broken and unbroken specimens comprise two distinct populations.
• Energy components in the unbroken population reflect deformation and initiation not fracture.
• Specifications need to be modified to distinguish this behavior, and exclude unbroken energy that currently can be comingled with the broken results.
• Very high CVN resistance has little practical significance.
Are current tests adequate to qualify today’s pipe?

CVN for failure "resistance"

Industry needs to accept the challenge to replace outdated practices

DWTT for failure "mode"
Summary & Conclusions

- Inadequate line-pipe specifications can lead to field failures and costly repair or replacement programs.
- To affect competitive bidding the Operators require at least:
  - a comprehensive MPS that can be responded to by many pipe mills
  - MPQTs that can effectively establish acceptance of pipe that will be fit for service, with a level of safety matched to the risk
- DWTT and CVN used in MPQTs can be inadequate for some advanced-design pipelines
- Steels showing a significant RUS pose issues in the use of sub-size specimens
- Unbroken specimens can lead to a non-conservative measure of resistance
- Advanced design pipelines pose a specifications dilemma