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TITLE

Assessment of the Fracture Toughness of Pipeline Girth Welds

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Assessment of the Fracture Toughness of Pipeline Girth Welds

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ABSTRACT

The crack-tip-opening displacement (CTOD) fracture toughness and Charpy absorbed energy of the base metal, weld metal and heat-affected zone (HAZ) of a pipeline girth weld were measured for several notch orientations, as well as for simulated HAZ regions produced using a Gleeble 2000 thermal-mechanical simulator. The results show that the CTOD toughness variability can be described by a weakest-link model and Weibull statistics. The present work illustrates how the toughness variability associated with girth welds in pipelines may be quantified for use in engineering critical assessment procedures.

Assessment of the Fracture Toughness of Pipeline Girth Welds

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Background

- Fracture toughness assessments of weld metal and HAZ regions are used for:
- Pre-qualification testing and defect assessments.
- As input parameters for ECA and fracture mechanics analysis.
- A major concern is the high degree of variability (scatter) in cleavage fracture toughness, especially in the ductile-to-brittle transition region
- Micromechanical and statistical modeling procedures are used to characterize the toughness variability

Objective

To establish the degree of scatter in different regions (base metal, HAZ and weld metal) of a multipass pipeline girth weld.

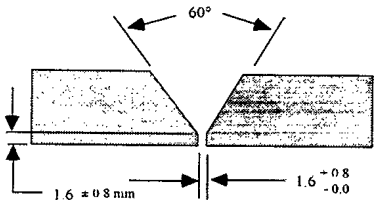
Linepipe Steel - NPS-36 Grade X52

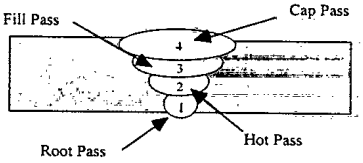
- **914 mm dia. Grade 359 MPa 10.4 mm W.T.**
- **1960's C-Mn hot-rolled steel**
- **Properties**

• Transverse Yield Strength	370-390 MPa
• Transverse Ultimate Strength	550-560 MPa
• Longitudinal Yield Strength	360-380 MPa
• Longitudinal Ultimate Strength	550-570 MPa
• Charpy Impact Energy	16 J at –5°C and 5 J at –45°C
• Drop Weight Energy	270 J at –5°C with 5% shear

Girth Welding Procedures

- Two field girth welds were made by NGTL.
  - SMAW E55010-G cellulosic electrodes
  - Vertical down welding technique.
  - Minimum preheat = 100°C
  - Energy input range = 0.56-2.33 kJ/mm





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Chemical Composition

Material	Element wt %						
	C	Mn	Si	S	P	Cr	Ni
BM	0.19	1.0	0.017	0.037	0.027	0.02	0.04
Weld 1	0.16	0.91	0.08	0.007	0.011	0.12	0.78
Weld 2	0.15	1.1	0.16	0.007	0.011	0.12	0.78

Note: Cu<0.04; Mo<0.03; Ti, Nb and V <0.01; Al<0.006

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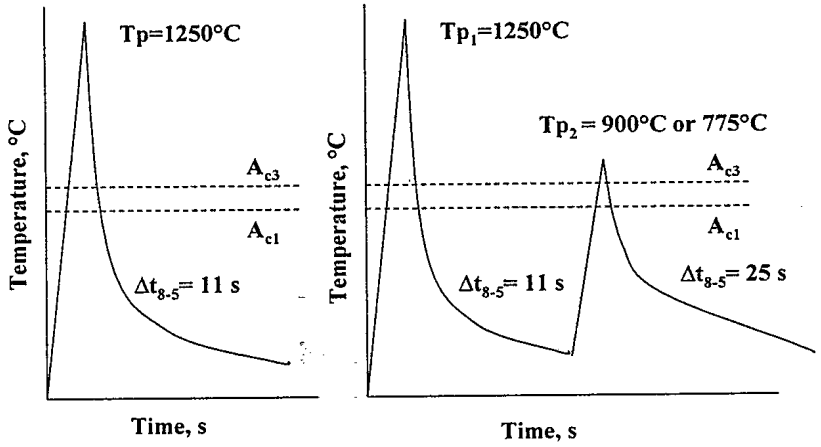
Schematic Simulation Cycles



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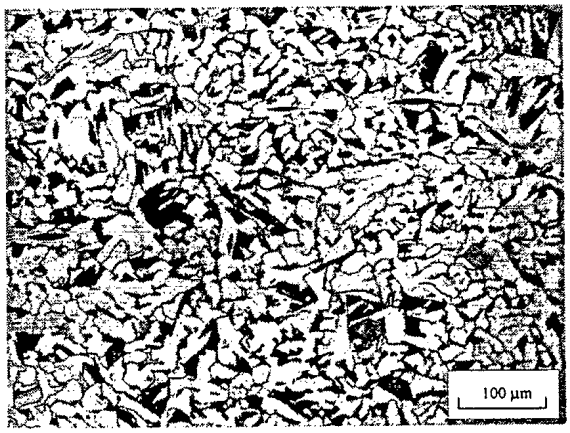
Base Metal Microstructure



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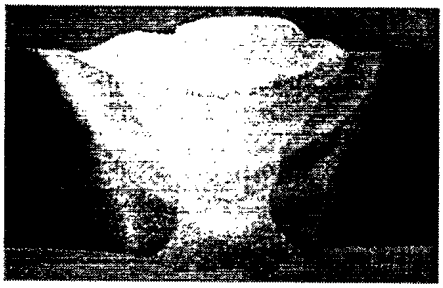
Girth Weld Macrostructures

12 o'clock

3 o'clock



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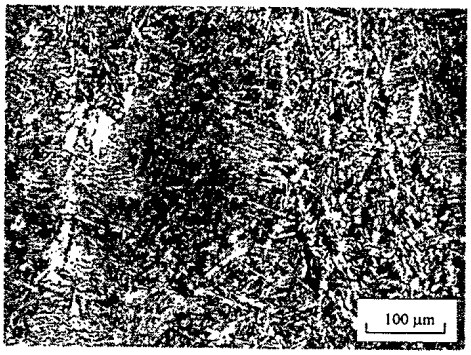
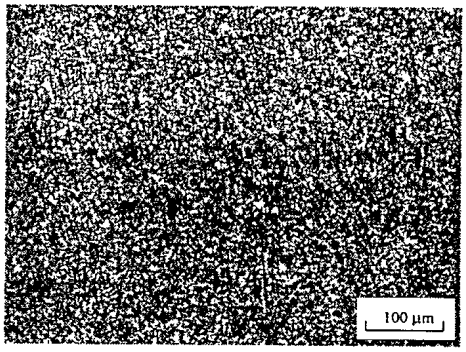
Weld Metal Microstructures

As-deposited



Reheated



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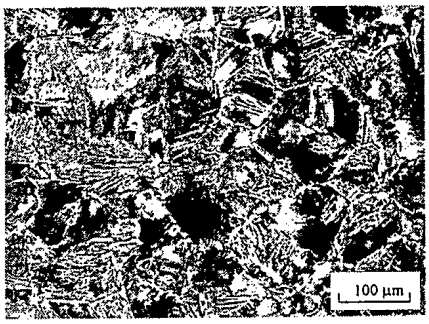
HAZ Microstructures

GCHAZ



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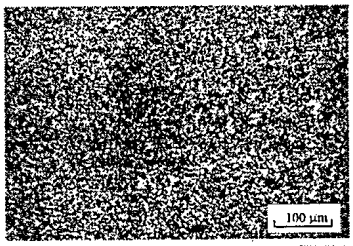

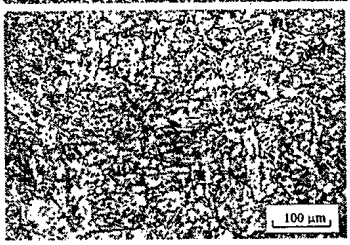

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Microhardness (VHN)

Location	12 o'clock	3 o'clock
Weld Metal Centerline	171 (157-208)	190 (164-242)
GCHAZ	193 (188-197)	196 (191-200)
Mid-Thickness Reheated HAZ	166 (165-168)	173 (170-177)
Root Region Reheated HAZ	161 (160-161)	165 (157-169)

Note: Base Metal = 170 (159-183)

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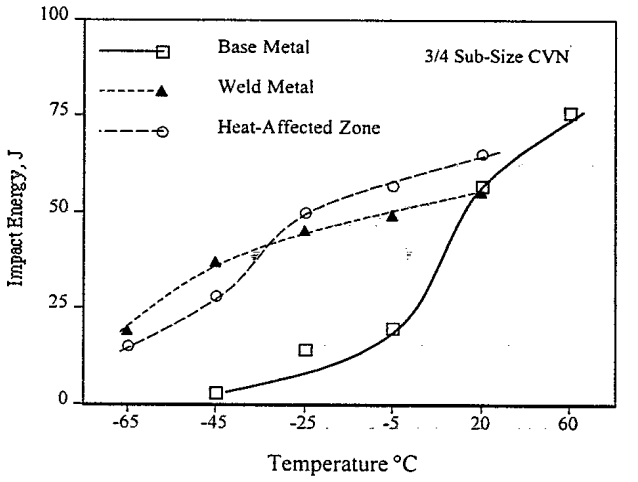
Charpy Impact Transition Curves



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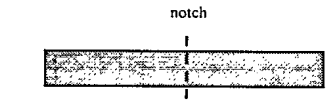
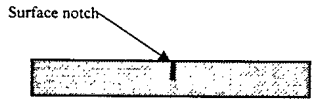
CTOD Notch Orientation

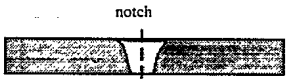
Specimen Size = 9 x 9 x 75 mm



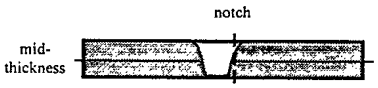
Base Metal- Notched through-thickness at centerline



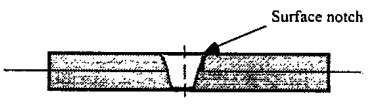
Simulated HAZ-Surface Notched



Weld Metal- Notched through-thickness at centerline



Heat-Affected Zone-
Through-thickness notched within 0.5 mm of the fusion line.



Heat-Affected Zone-
Surface notched within 0.5 mm of the fusion line.

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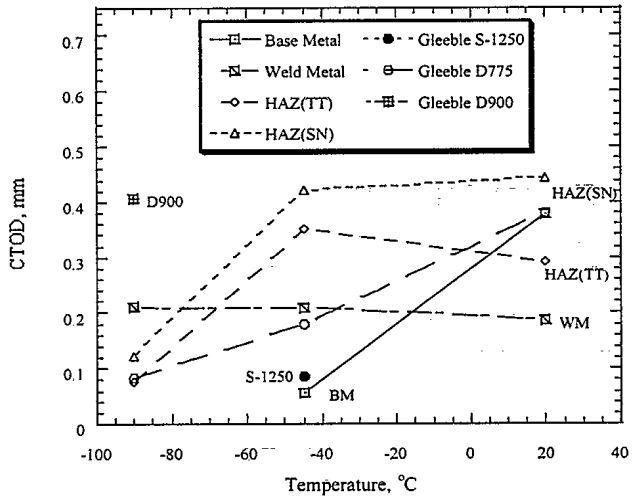
CTOD Transition Curves



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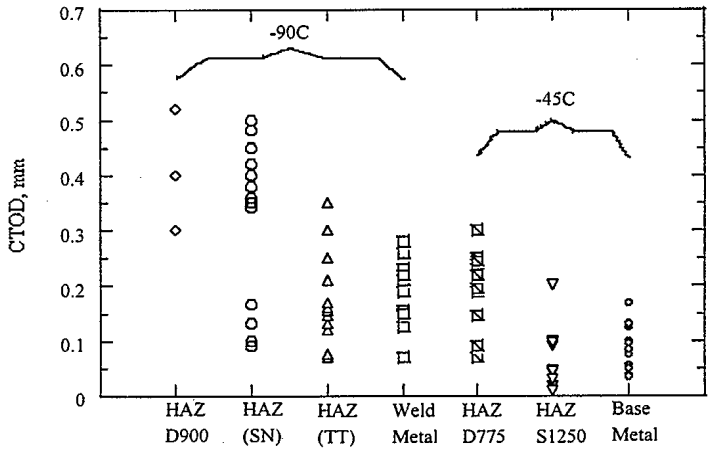
CTOD Data



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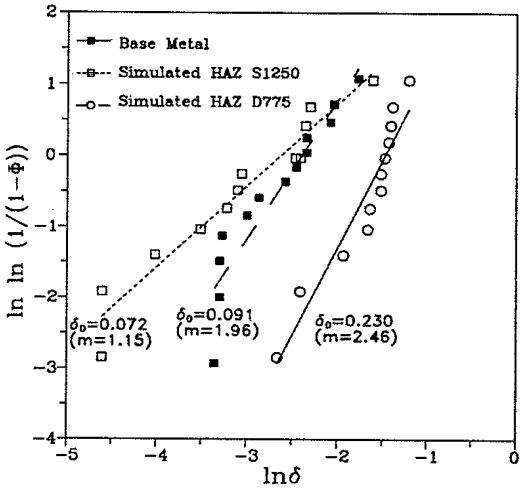
Weibull Plot for CTOD tests at -45°C



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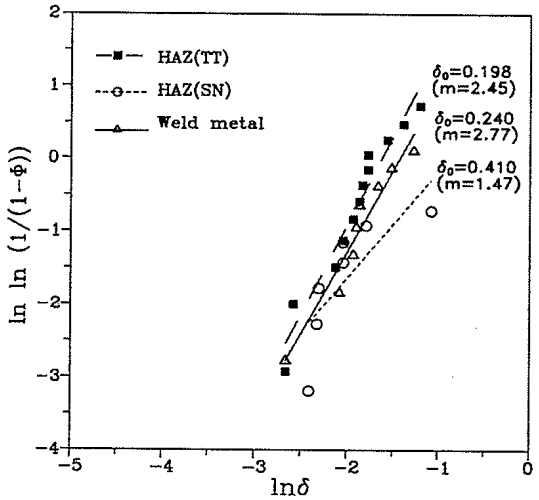
Weibull Plot for CTOD tests at -90°C



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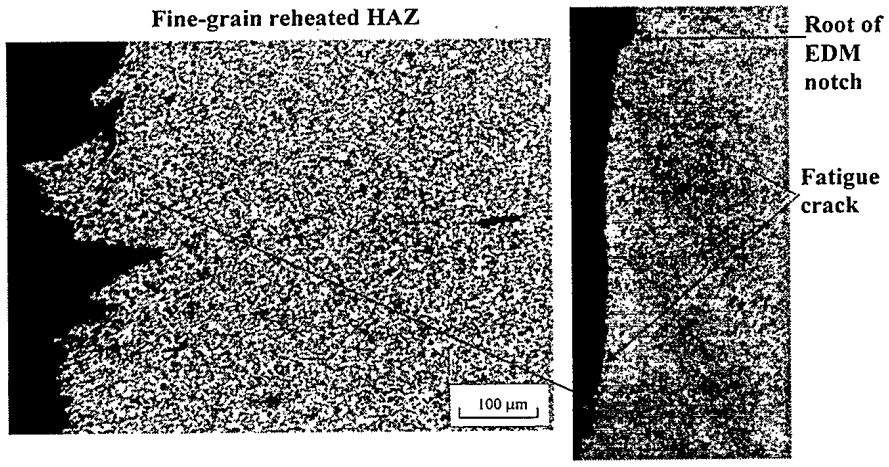
High CTOD Toughness HAZ(SN)



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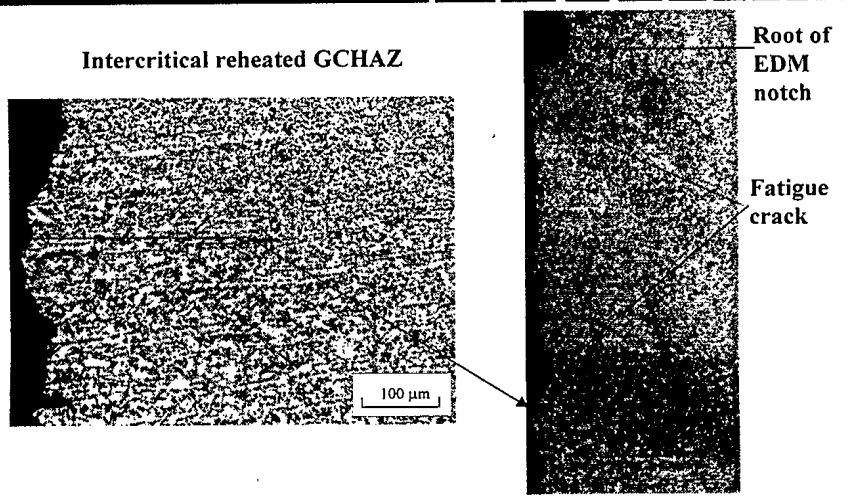
Low CTOD Toughness HAZ(SN)



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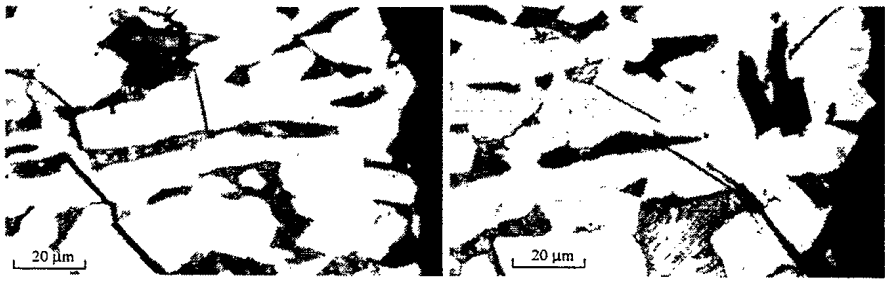
Secondary Microcracks

Base Metal



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Secondary Microcracks

Simulated GCHAZ

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Conclusions

1. The CTOD fracture and Charpy impact toughness of a girth weld produced in a 1960's NPS 36, X52 linepipe steel were characterized, along with simulated HAZ regions, in terms of their cleavage fracture resistance and variablity.

2. A Weibull statistical model based on weakest-link theory characterized the cleavage fracture toughness. Greater variability was observed for the simulated GCHAZ region and surface-notched real weld HAZ(SN) than for either the base metal, through-thickness notched HAZ(TT) or weld metal regions.

3. High toughness correlated with a relatively high proportion of fine-grained polygonal ferrite present near the central region of the crack tip.

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