Hydrogen Piping and Pipelines

Pressure Boundary Integrity and Material Considerations

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Overview of the Presentation

- Features of hydrogen and hydrogen transportation
- Status of ASME B31.12 Piping and Pipeline Codes
- Hydrogen effects on material properties
  - Tensile
  - Ductility/deformability
  - Toughness
  - Fatigue
- Arresting running fracture in hydrogen pipelines
- Considerations for modern high strength linepipes and welds
- Status of hydrogen piping and pipelines
- Gaps and research needs

- Acknowledgment:

  Parts of the material came from the Hydrogen Forum held at the International Pipeline Conference (IPC), September 2006, Calgary, Canada.

Hydrogen and Safety

- Hydrogen pipelines in service for over 50 years
- Several hundred miles of hydrogen pipelines worldwide
- No reported injuries due to hydrogen pipelines
- Fire test on hydrogen and gasoline cars, below

- Ref: Jim Campbell, Air Liquide, Hydrogen Forum, IPC 2006

H_2 Service: Safety and Challenges

- H_2 Advantages:
  - Non-toxic
  - 14 times lighter than air- rapidly dissipates
  - H_2 flame emits 10% of the radiant heat of a hydrocarbon fire
  - No smoke or emissions
  - Requires a constrained volume to explode
  - H_2/air mixture must be twice as rich as natural gas to explode
  - Explosive power is 22 times less than gasoline vapor
- Challenges:
  - Odorless, but no odorant suitable for hydrogen yet
  - Leaks very easily
  - More care needed with mechanical joints
  - Very low ignition energy, therefore:
    - "Spontaneous" combustion
    - Very hard to extinguish hydrogen fires
  - Flame is invisible in daylight

- Ref: Jim Campbell, Air Liquide, Hydrogen Forum, IPC 2006

Current ASME Codes for Hydrogen Service

- **Piping and pipelines:**
  - **B31.1 - Power piping**
  - **B31.3 - Process piping**
  - **B31.4 - Liquid pipelines**
  - **B31.8 - Gas pipelines**
  - **B31.8S - Managing gas pipeline integrity**
- **Valves, flanges, and fittings:**
  - **B16.34 - Valves**
  - **B16.5 - Pipe flanges and fittings**

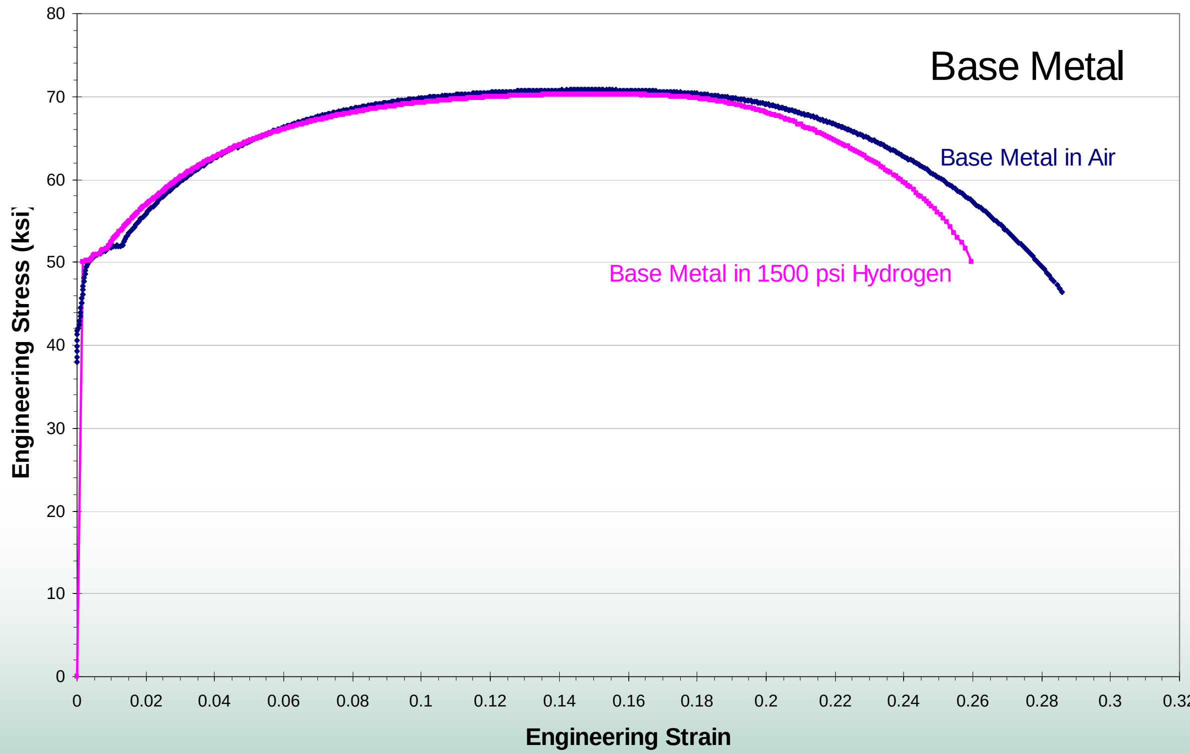
- **Ref: Lou Hayden, ASME**

ASME B31.12 Codes

- Chaired by Lou Hayden
- 75-80% complete. Meeting next week in Los Vegas
- Anticipated publication date: 2007
- Divided into four subsections:
  - Part G : General reference material
  - Part A: Industrial piping
  - Part B: Pipelines and distribution piping
  - Part C: Residential piping
- Part B: Pipelines and distribution piping
  - Requirements specific to hydrogen service
  - Reference and incorporation of applicable sections of B31.8, B31.8S, and other recognized standards (ASME, API, CGA, etc.)
  - Anticipated operating ranges:
    - Pressure: full vacuum to 3,000 psig
    - Temperature: - 40˚F to 300˚F

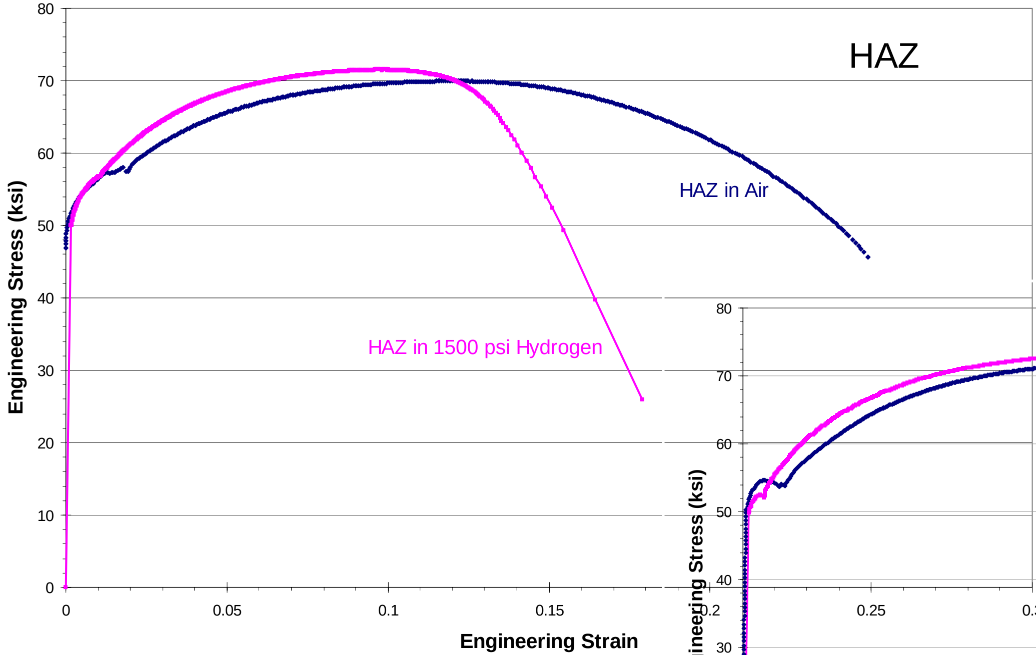
Tensile Properties in Hydrogen

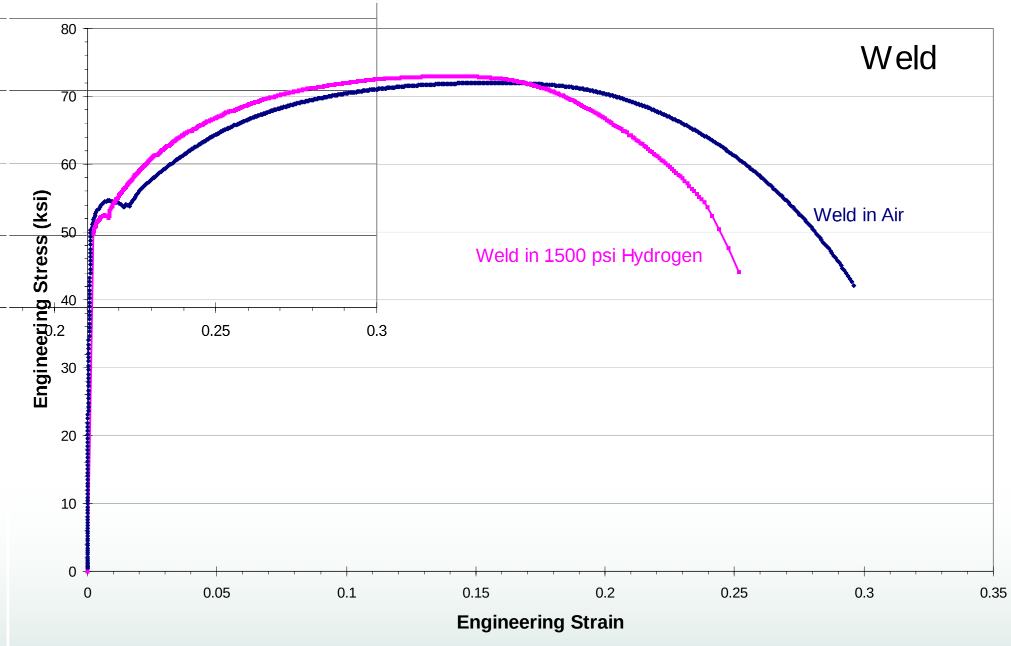
Alloys	**A106 Grade B Carbon Steel**
Orientation:	**Crack perpendicular to rolling direction (L-C)**
Atmosphere:	**100 ATM (H_2), 1 ATM (Air)**
Strain Rate:	**10^{-4} /sec**



- **Ref: "Hydrogen Regional Infrastructure Program in Pennsylvania," David Moyer, IPC 2006 Hydrogen Forum.**

Tensile Properties in Hydrogen (Cont’d)

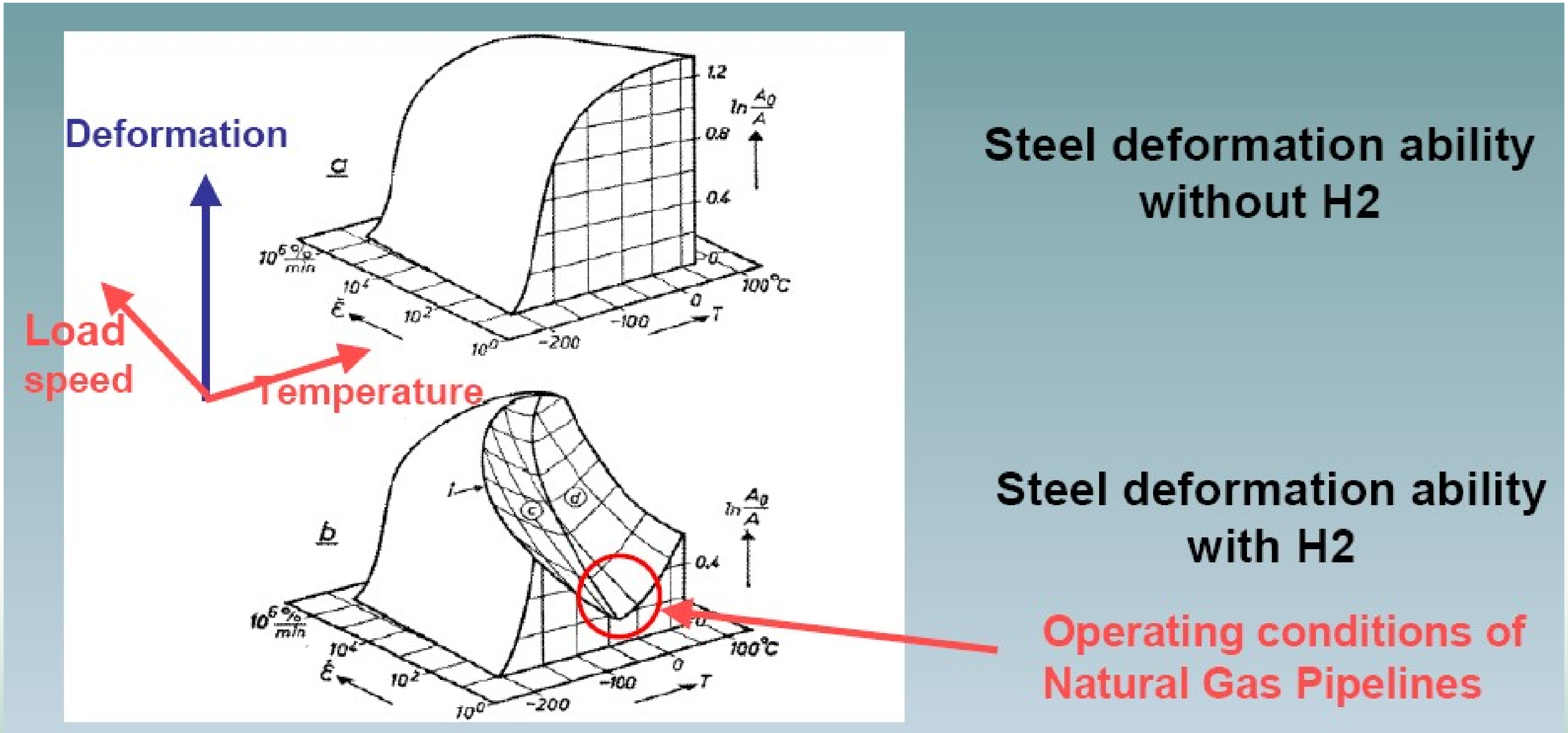




Hydrogen affects HAZ and weld metal more than base metal
The effects on HAZ is the strongest.

Ductility in Hydrogen Environment

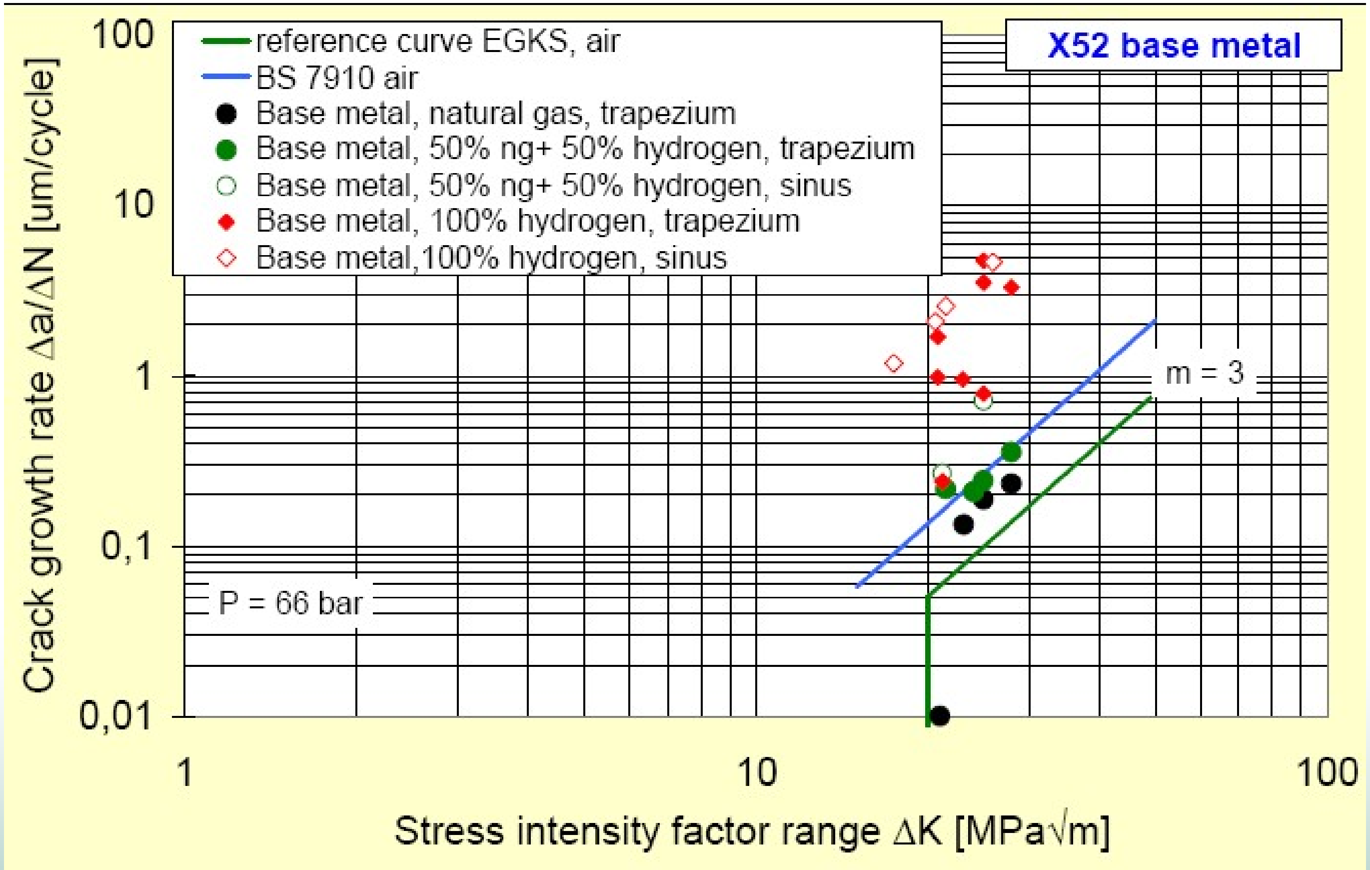
Steel deformability is decreased in hydrogen environment.
Implications:
- **tolerance to mechanical damage**
- **design requirements for ductility, impact energy, fracture arrest, etc.**



Ref: "The Naturaley Project," Onno Florisson and Isabelle Alliat, Hydrogen Forum, IPC 2006.

Fatigue in Hydrogen Environment

Fatigue performance is not affected when H_2 is as high as 50% in mixture.
Presence of o_2 increases the acceptable H_2 level.
Unknows: (1) welds, (2) new steels



Ref: "The Naturaley Project," Onno Florisson and Isabelle Alliat, Hydrogen Forum, IPC 2006.

Fracture Testing: Sustained Load and Toughness

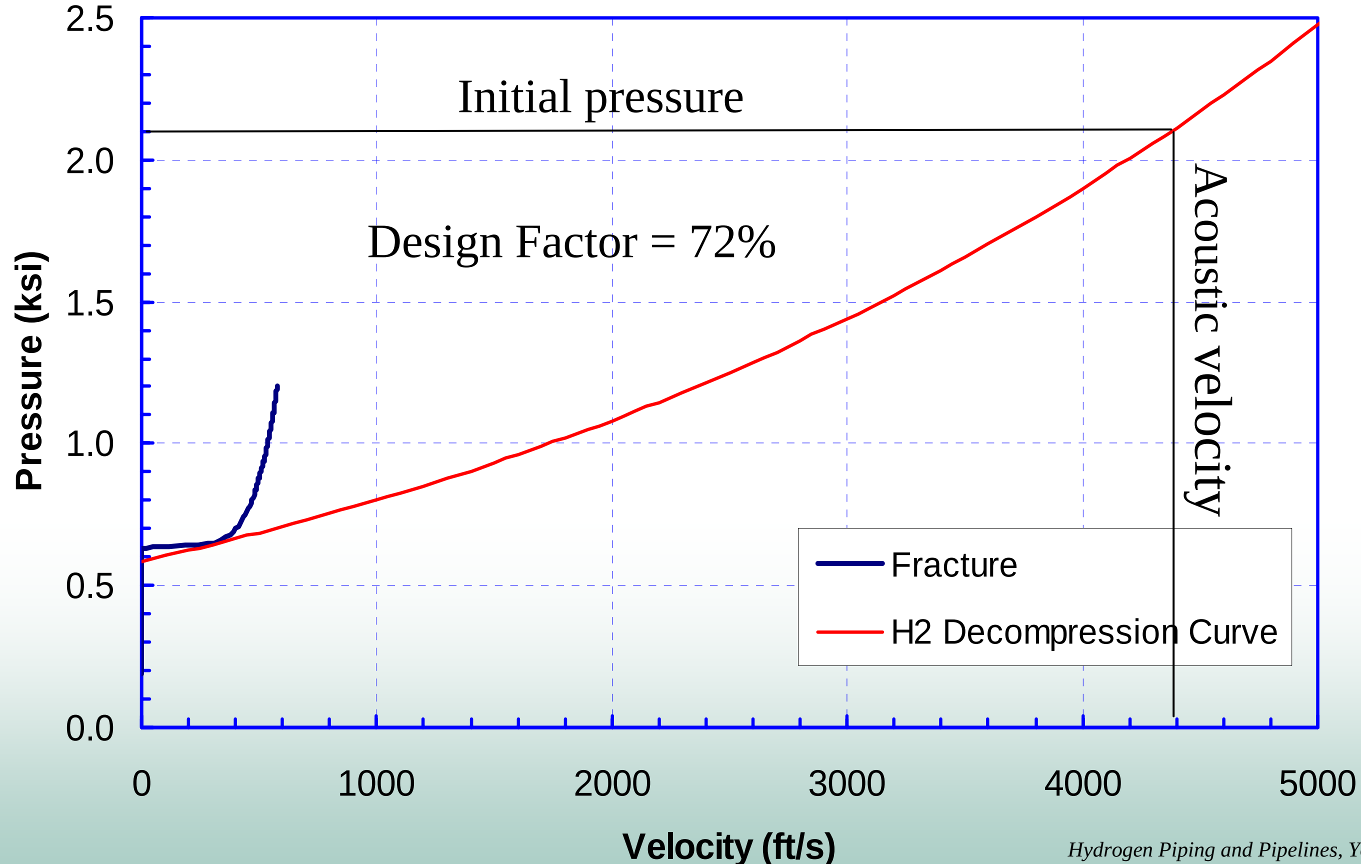
- Welds and HAZ may crack more easily in hydrogen environment than the base metal under sustained loads.
- Fracture toughness testing in hydrogen environment can be more difficult than in air environment.
  - Specimen validity requirements (e.g., crack front straightness) may be difficult to meet.
  - Embrittlement effects on material properties used to compute fracture toughness

Arresting Propagating Cracks, Concept

- Modern pipelines are required to be able to arrest a running crack.
- Crack arrest occurs when the decompression velocity is greater than the fracture propagating velocity, i.e., diminishing driving force.
- The measured brittle fracture speeds generally range from 1500 to 3000 ft/sec.
- The highest measured ductile fracture speed is about 1100 ft/sec, most within the range of 400-700 ft/sec.
- The measured acoustic velocity of natural gas ranges approximately from 1250 to 1450 ft/sec.
- The acoustic velocity of gaseous hydrogen is approximately 2.8 times of the lean natural gas.

Arresting Ductile Cracks, Sample Cases

- X70, 36” OD and ¾” W.T.
- <u>Charpy energy at the postulated failure time</u>
- 72% DF, maximum pressure = 2,100 psi, required Charpy = 37.0 ft-lb
- 50% DF, maximum pressure = 1,458 psi, required Charpy = 17.5 ft-lb

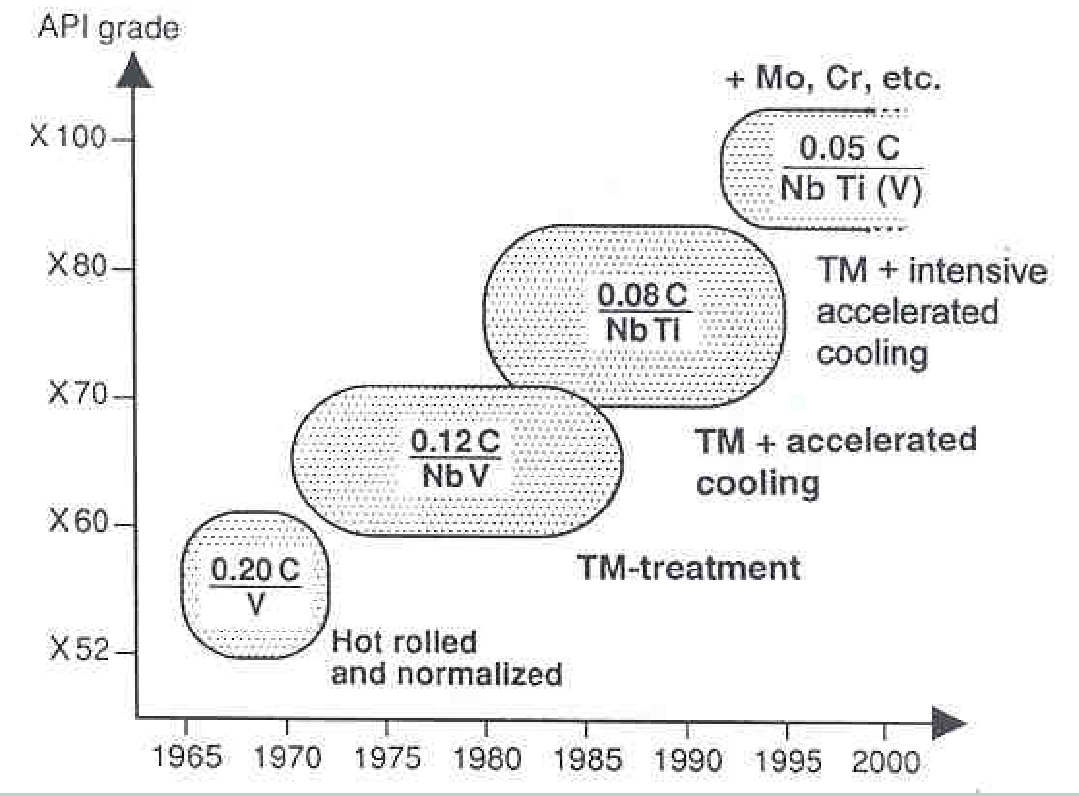


General Observations about Fracture Arrest

- High acoustic velocity of gaseous hydrogen makes arresting propagating fracture easier than for natural gas.
- Modern linepipes, at the time of construction, should have little difficulty in meeting the Charpy impact energy requirements.
- The high acoustic velocity of gaseous hydrogen makes arresting brittle fracture a possibility.
- The hydrogen embrittlement over the lifetime of pipelines, if occurs, can affect fracture arrest.
- Experimental validations are needed.

Evolution of Linepipe Steel Production

- Until late 1960's, Grade up to X60 were made using hot rolled and normalized plates
- From the late 1960's, thermal-mechanically process, accelerated cooling, and microalloying have allowed the production of grades up to X100.



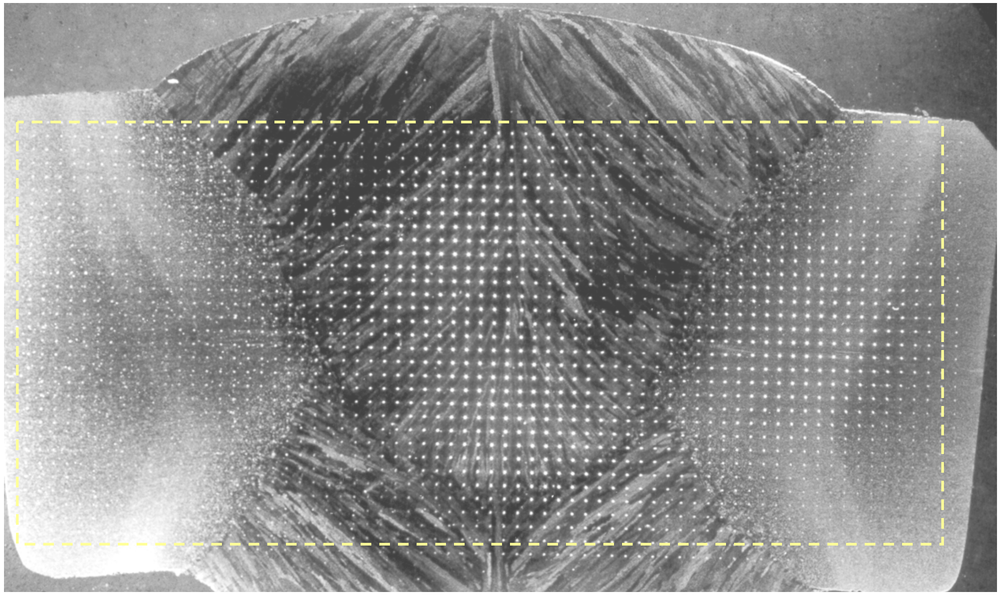
- *Ref:* Hillenbrand, H., et al., 2000

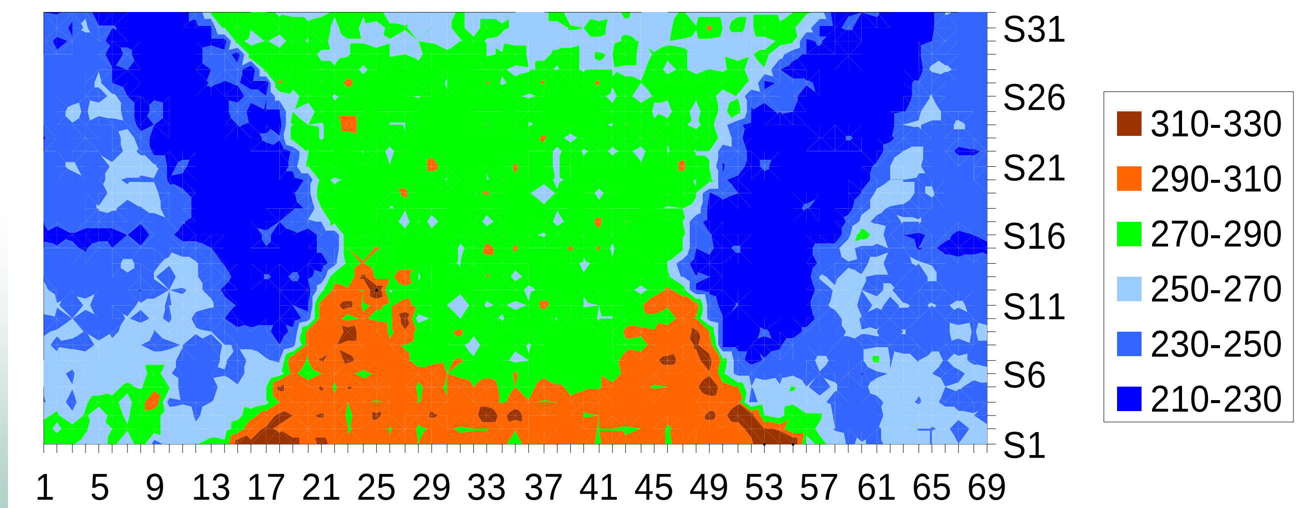
New Microalloyed Steels vs. Older Steels

- **Chemical composition has changed over time.**
- **Microalloyed steels**
  - **Addition of vanadium, niobium, titanium, boron**
  - **sulfide-shape control**
- **Microalloyed steels have significantly improved toughness while achieving high strength. Achieving balanced strength and toughness requirements for high strength welds can be a challenge.**

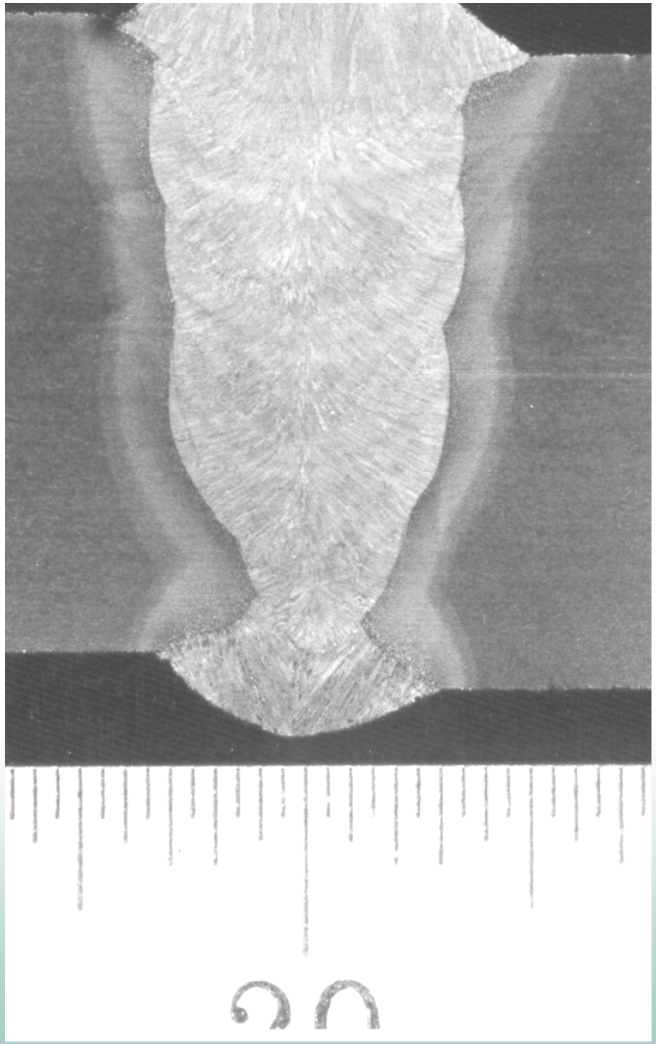
	C	Mn	P	S	Si	Ni	Cu	Cr	Mo	V	Nb	Al	Ti	N	O	Ca	B	CE (IIW)	Pcm
X100, New	0.058	1.960	0.007	0.002	0.223	0.30	0.210	0.020	0.180	0.00	0.045	0.003	0.014	0.003	0.002		0.000	0.459	0.192
X70, New	0.060	1.500	0.010	0.007	0.280	0.023	0.017	0.033	0.004	0.062	0.037	0.044	0.016				0.001	0.332	0.154
X60, Glover 1987 report	0.200	1.160	0.008	0.007	0.440					0.086	0.025							0.411	0.281

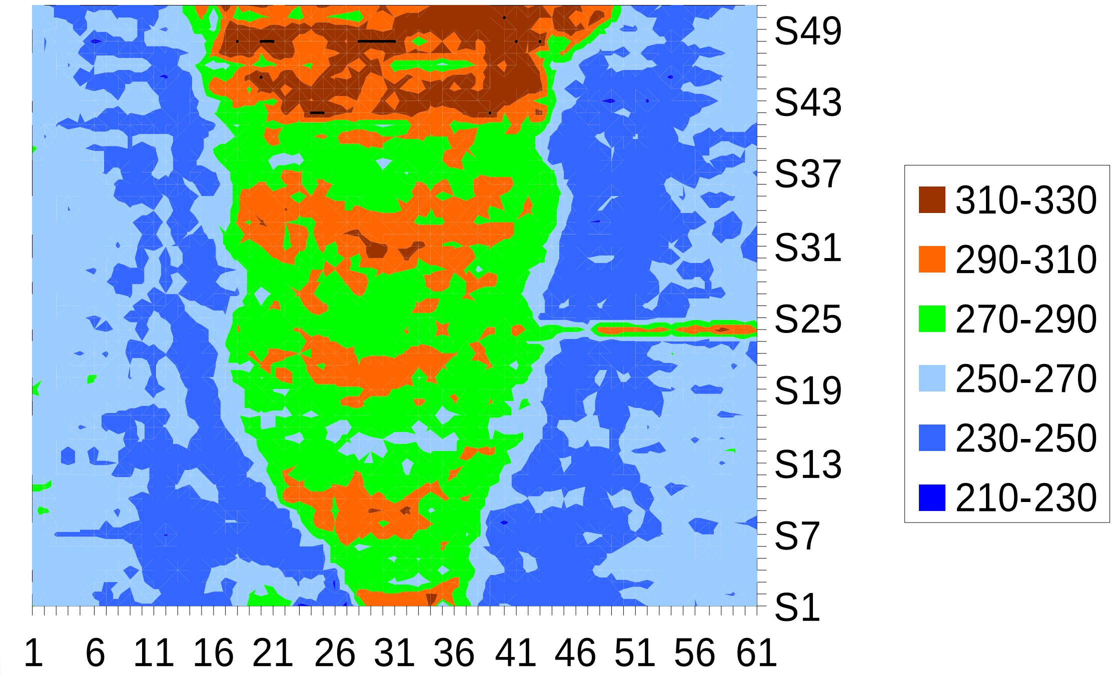
HAZ Softening, X100 Seam Weld





HAZ Softening, X100 Girth Weld





General Observations: Hydrogen Piping and Pipelines

- Hydrogen has been transported safety over many decades.
- Most service experience has been with lower grade linepipes (e.g., API X42 and X52), small diameter (e.g., ≤12”), and relatively low design factor (hoop stress / SMYS < 0.50)
- Future long distance transportation of gaseous hydrogen will require:
  - Higher strength linepipes
  - Higher pressure
  - Probably microalloyed linepipes
- Very limited information available on the new materials for long distance hydrogen transportation.

Gaps and Research Needs

- **Coordinated efforts**
- **Public awareness**
- **Connecting basic test data with integrity assessment**
  - **Involvement of end users in the beginning**
  - **Welds are generally more vulnerable.**
- **<u>“Life time” management</u>**
- **Material property testing in high pressure hydrogen environment, including suitable testing techniques**
- **Need full documentation of material and testing conditions**