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
**H₂ Service: Safety and Challenges**

- **H₂ Advantages:**
  - Non-toxic
  - 14 times lighter than air - rapidly dissipates
  - H₂ flame emits 10% of the radiant heat of a hydrocarbon fire
  - No smoke or emissions
  - Requires a constrained volume to explode
  - H₂/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 (H₂), 1 ATM (Air)
Strain Rate: 10⁻⁴ /sec

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.

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

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 ⅜” W.T.**
- **Charpy energy at the postulated failure time**
- **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.

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HAZ Softening, X100 Seam Weld

![Image of HAZ Softening](image-url)

- **Temperature Ranges:**
  - 310-330
  - 290-310
  - 270-290
  - 250-270
  - 230-250
  - 210-230
HAZ Softening, X100 Girth Weld
General Observations: Hydrogen Piping and Pipelines

- Hydrogen has been transported safely 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.
- “Life time” management
- Material property testing in high pressure hydrogen environment, including suitable testing techniques
- Need full documentation of material and testing conditions