U.S. Department of Transportation

Pipeline and Hazardous Materials Safety Administration

Emerging Packaging Research Session

High Strength Steel Cylinders for Transporting Hydrogen-Bearing Gases

HazMat R&D Forum
May 16, 2018
Washington DC

Applied Chemicals & Materials Division

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DOT

Safe Transportation of Hydrogen-Bearing Gases

This started back in the 1960s, doesn't happen anymore, and it only happened in Europe, as far as I know

from ISO DTR 10783

Safe Transportation of Hydrogen-Bearing Gases

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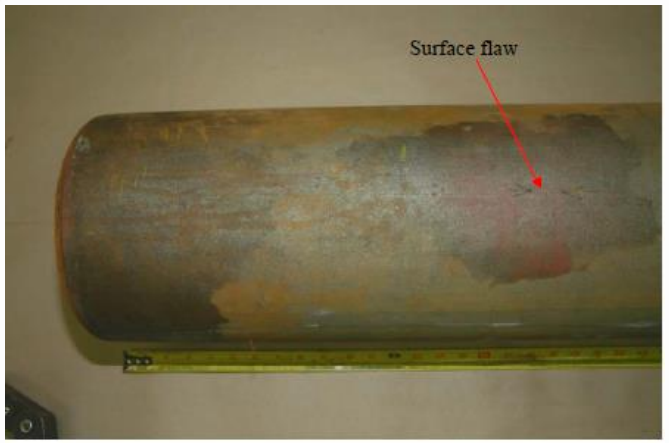

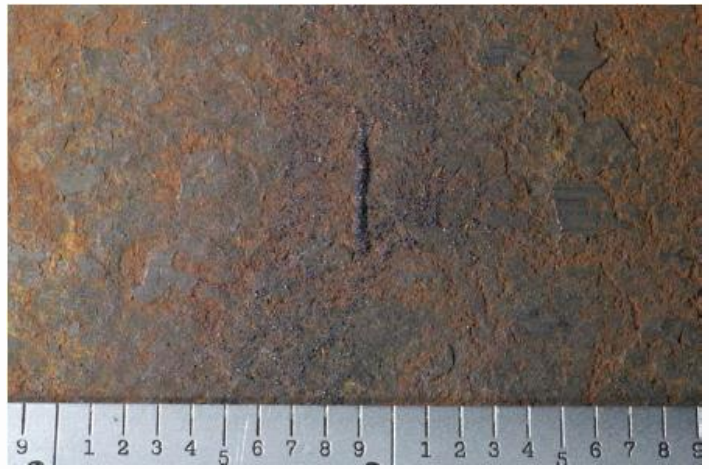

From DTPH56-07-P-000007

Safe Transportation of Hydrogen-Bearing Gases

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Can higher-strength steels be used?

- Strain-Life measurements
- Modeling of full elastic and plastic effects
- Fatigue results from SNL?

How "safe" are each of the three test methods in ISO 11114-4?

- Strain-Life measurements
  - Baseline material (UTS=724 MPa)
  - High-strength material (UTS – 1040 MPa)
- Modeling
  - Elastic effects
  - Accumulated inelastic strain
  - Comparison of A, B, C methods
  - Microstructure
- Crack-tip mechanics

Safe Transportation of Hydrogen-Bearing Gases: accepted test methods

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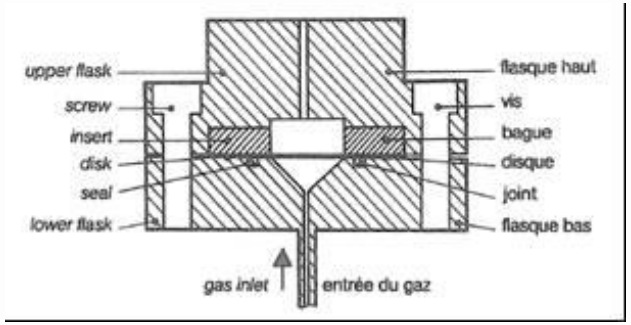
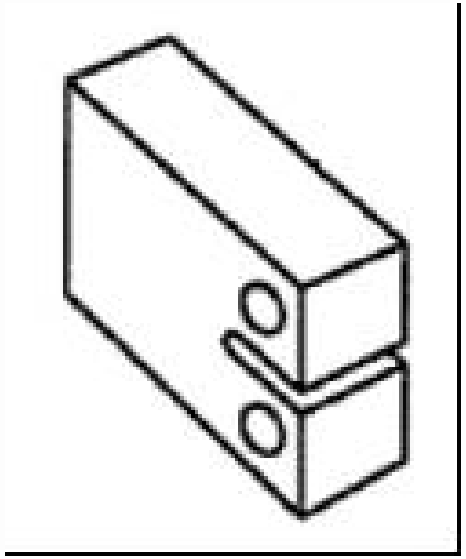
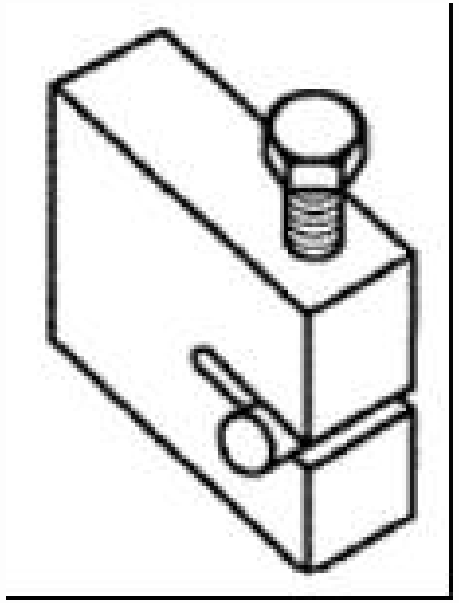
Method A: Rupture Disc





Method B: Rising-load, fracture threshold



Method C: Wedge-opening load, fracture arrest

Strain-Life Measurements: 4130 steel

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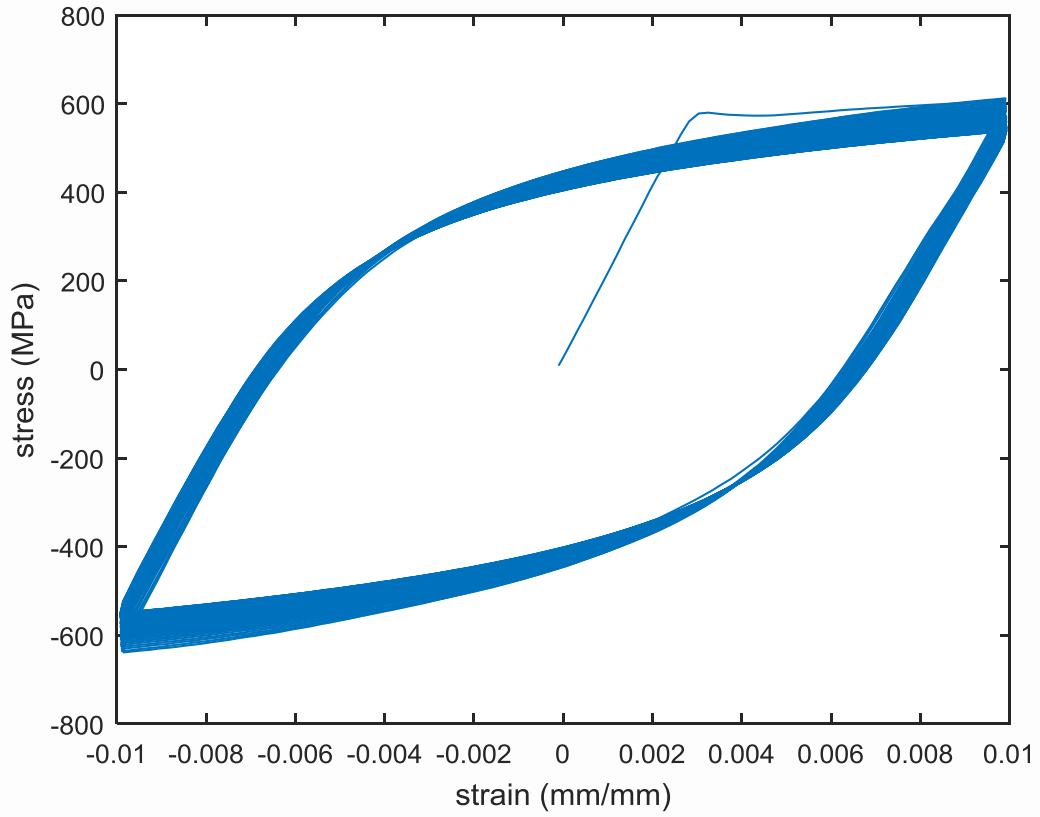
Raw Data
strain rate 0.008 for
all measurements
ε=0.0098
f=0.2Hz
R=-1
air



Strain-Life Measurements: 4130 steel

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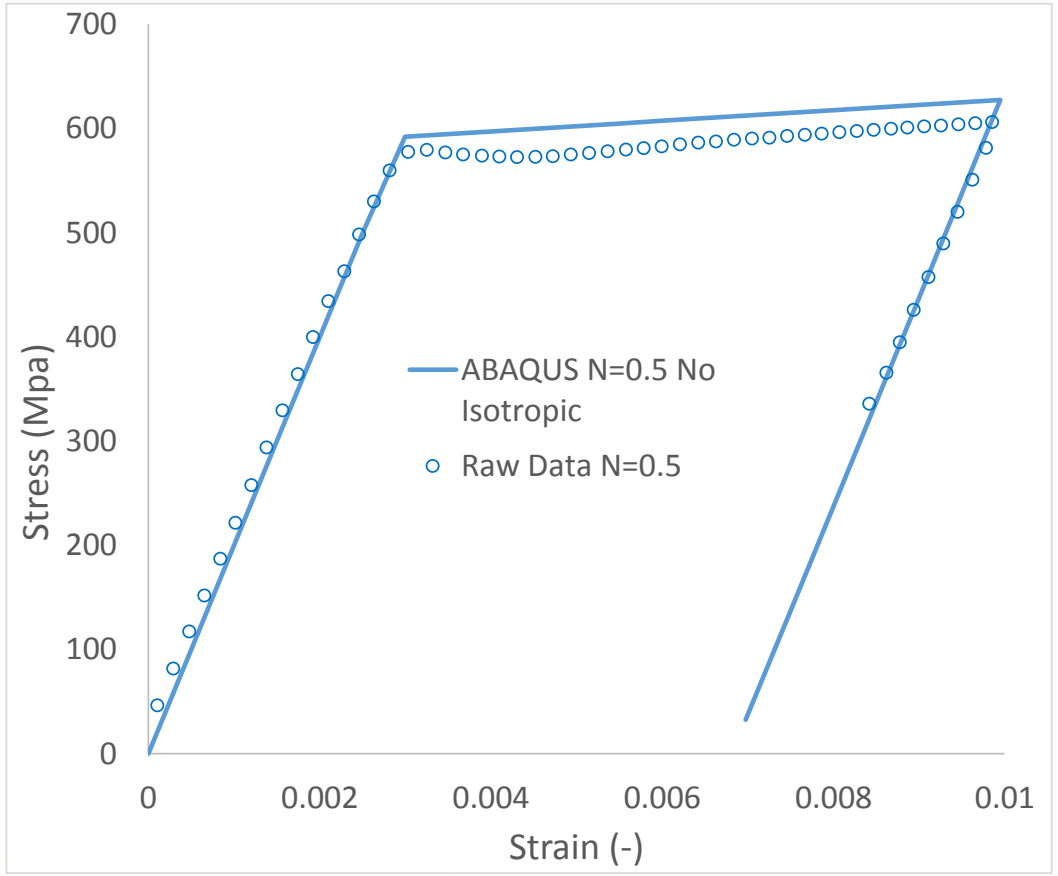
Air
First Cycle- Monotonic
Elastic-perfectly plastic
behavior is ignored



Strain-Life Measurements: 4130 steel

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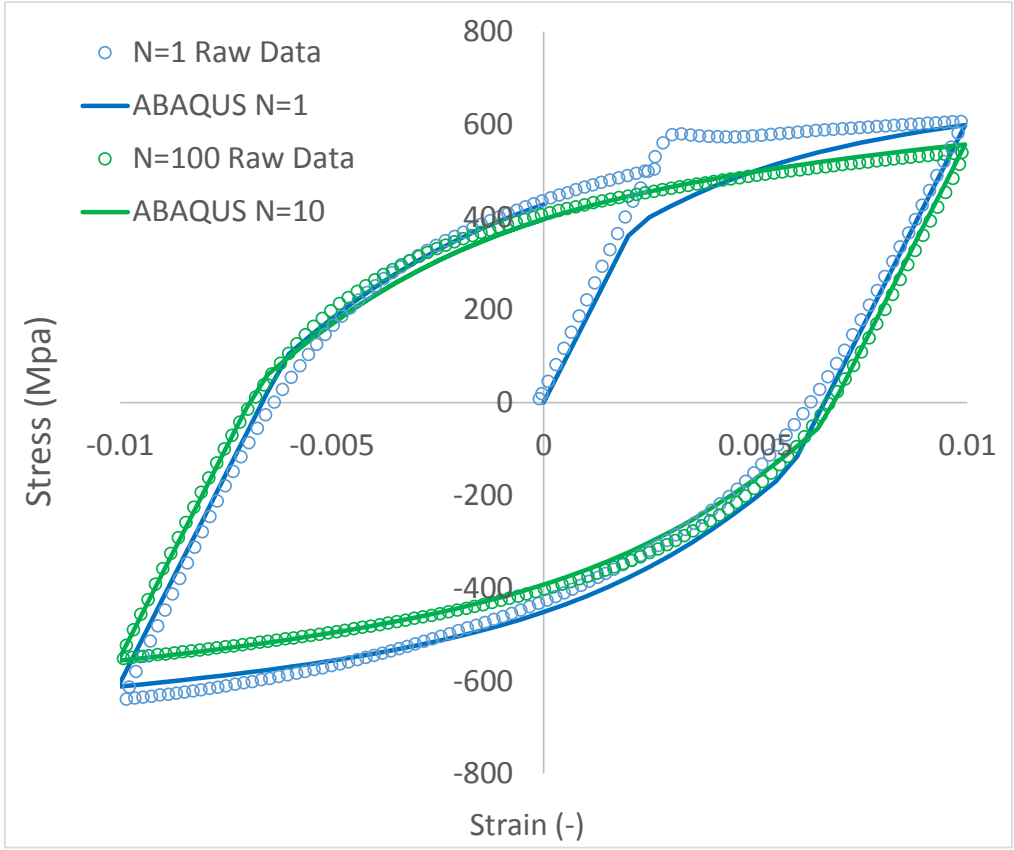
Air

Cyclic- Strain Hardening

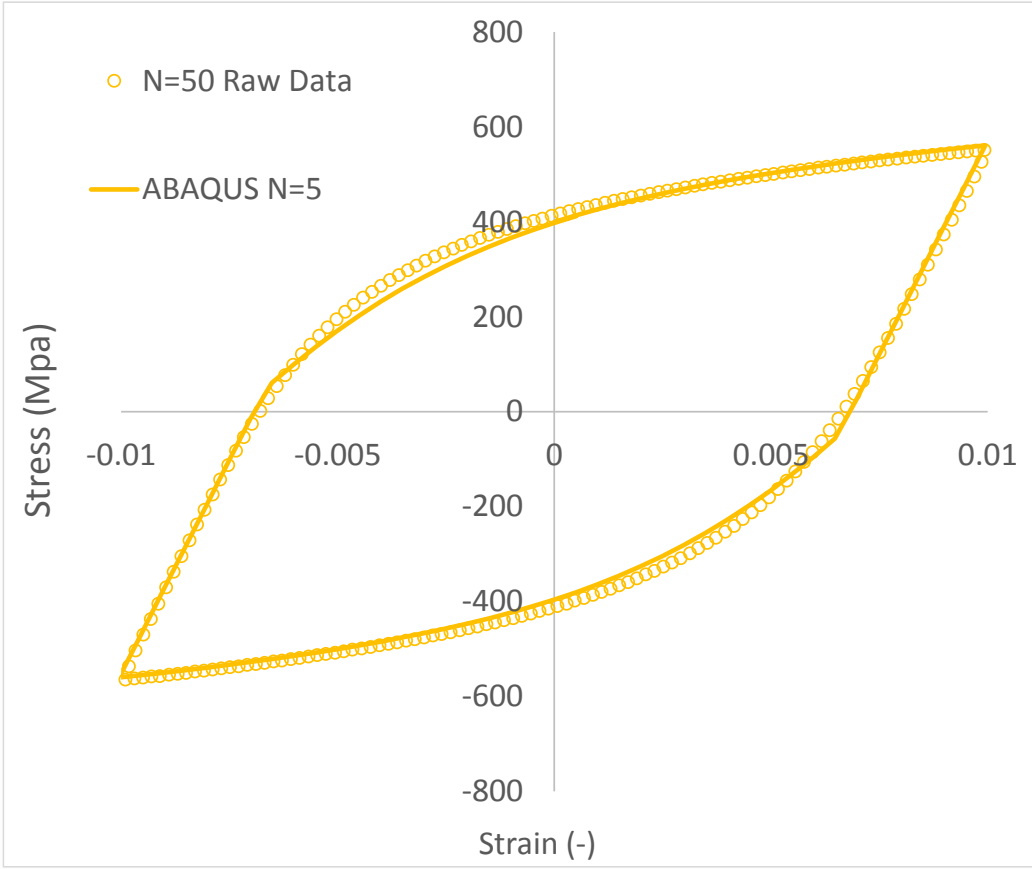


Strain-Life Measurements: 4130 steel

Applied Chemicals & Materials Division

Air

Cyclic- Strain Hardening



Strain-Life Measurements: 4130 steel

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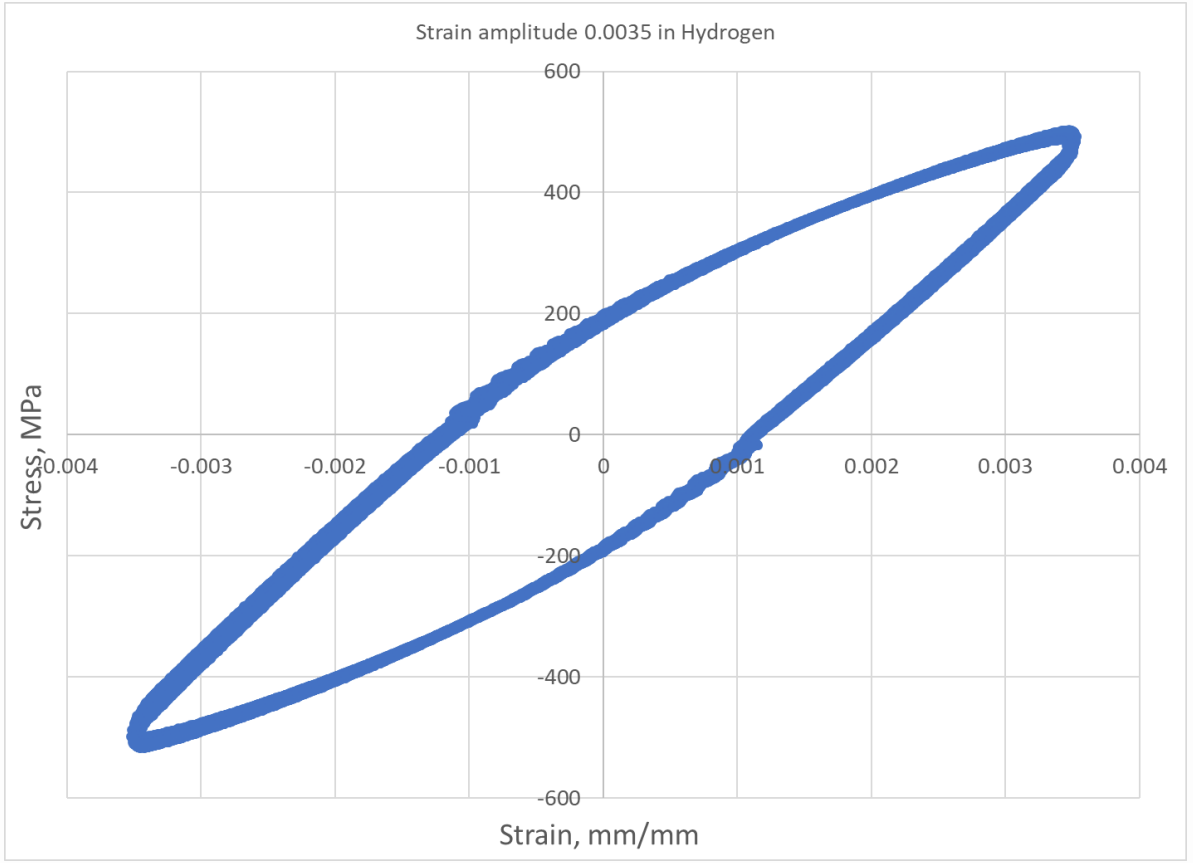
Hydrogen (18 MPa, 2600 psi)
Cyclic- Strain Hardening



Strain-Life Measurements: 4130 steel

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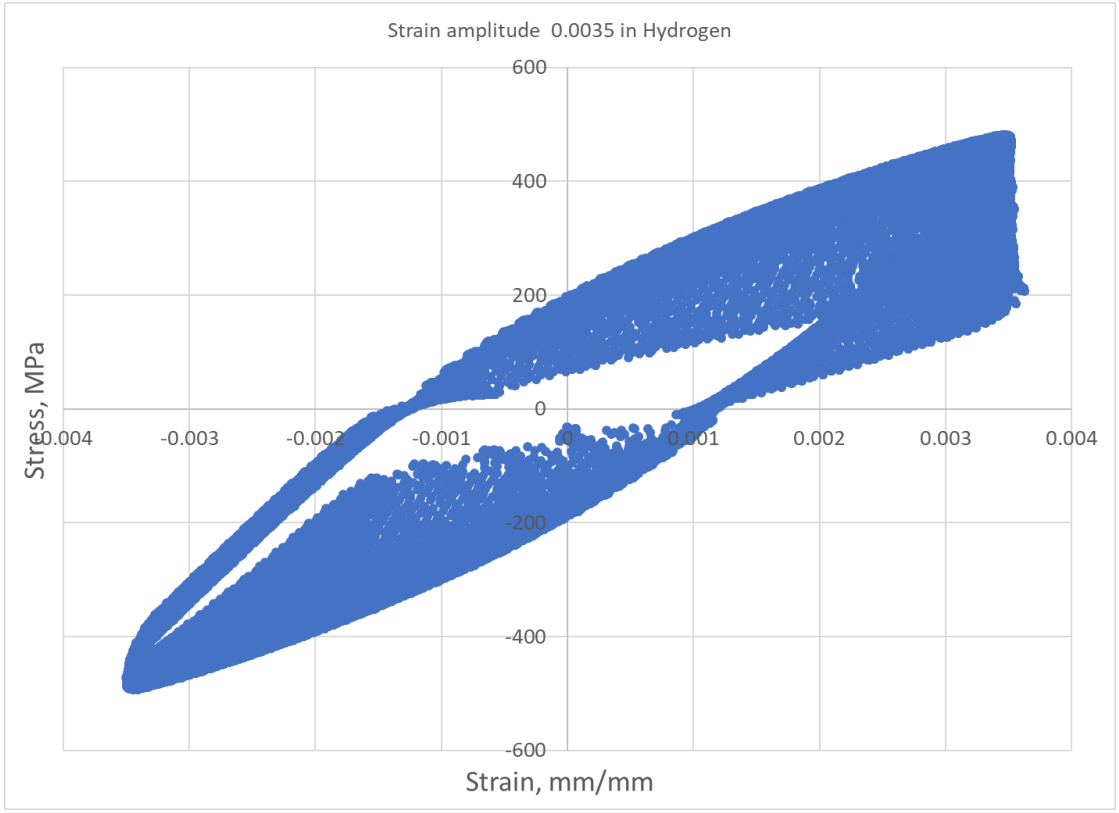
Hydrogen (18 MPa, 2600 psi)
Fatigue



Modeling: Deformation Response for 4130 Steel at 2600 psi

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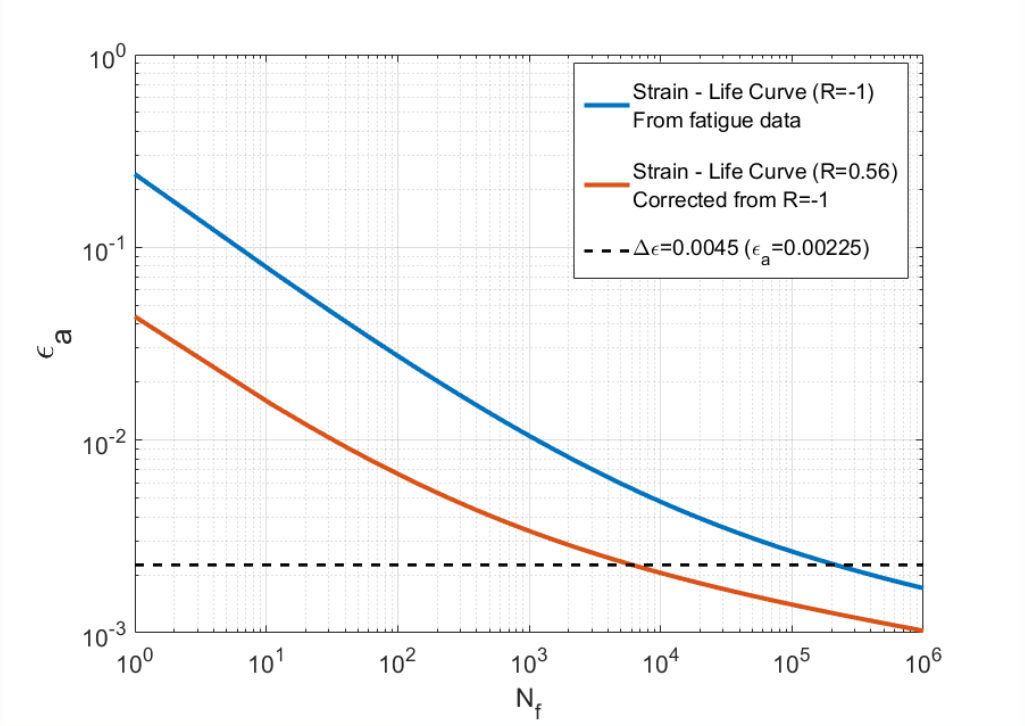
- Chaboche cyclic plasticity model
- isotropic and kinematic hardening or softening
  - calibrated separately



Modeling: Comparison of 3 Methods in ISO 11114-4

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This example given for testing and modeling in air

Inelastic Strain (Air)							
		TO					
		Burst Disc	CT-LC	CT-DC	IS	tensile	
FROM	Burst Disc	1.000	12.639	4.546	44.823	2.432	Multiply By
	CT-LC	0.079	1.000	0.360	3.546	0.192	
	CT-DC	0.220	2.781	1.000	9.861	0.535	
	IS	0.022	0.282	0.101	1.000	0.054	
	tensile	0.411	5.198	1.869	18.433	1.000	

Modeling: microstructure

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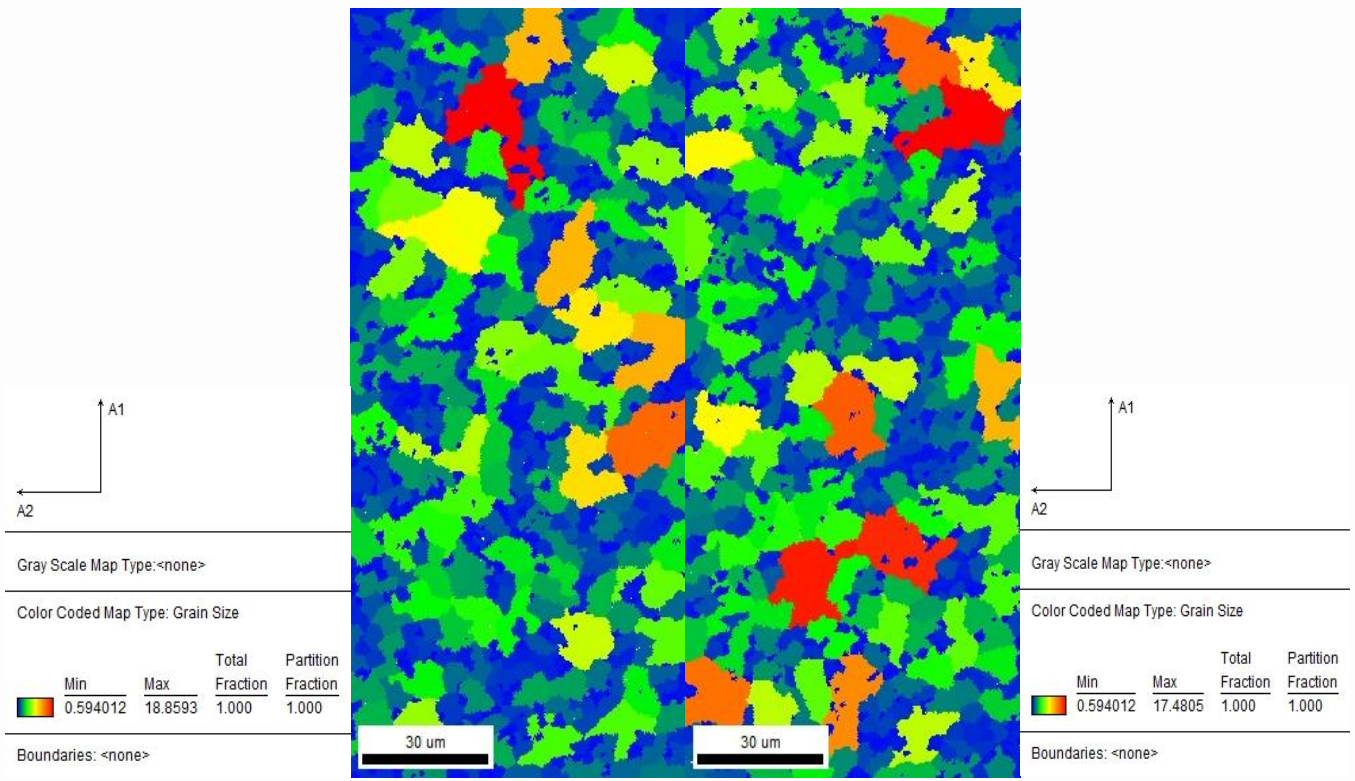
Alloy D
tessellated grains



Modeling: microstructure

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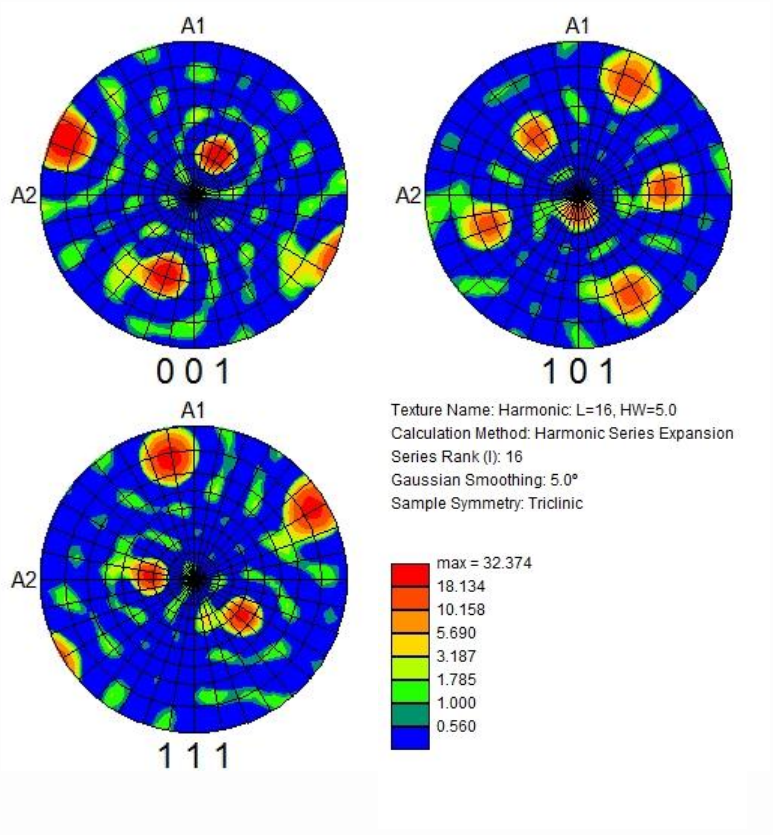
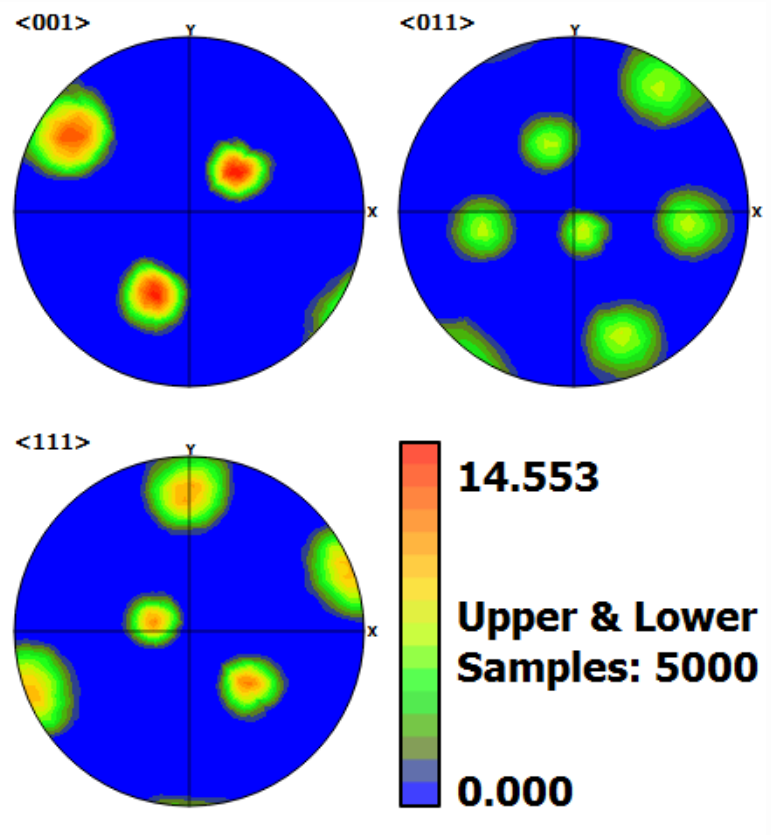
Alloy D
EBSD

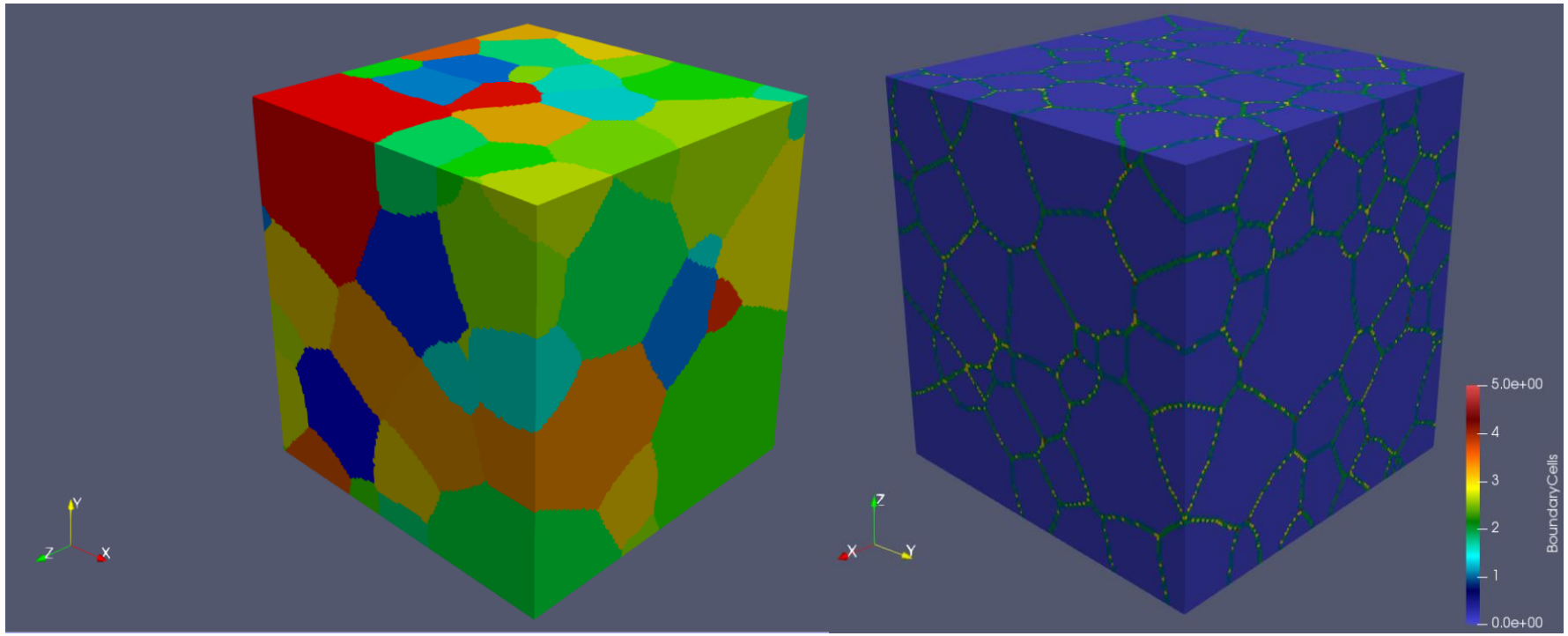




Modeling: microstructure

Applied Chemicals & Materials Division

Alloy D synthetic



Modeling: microstructure and Diffusivity

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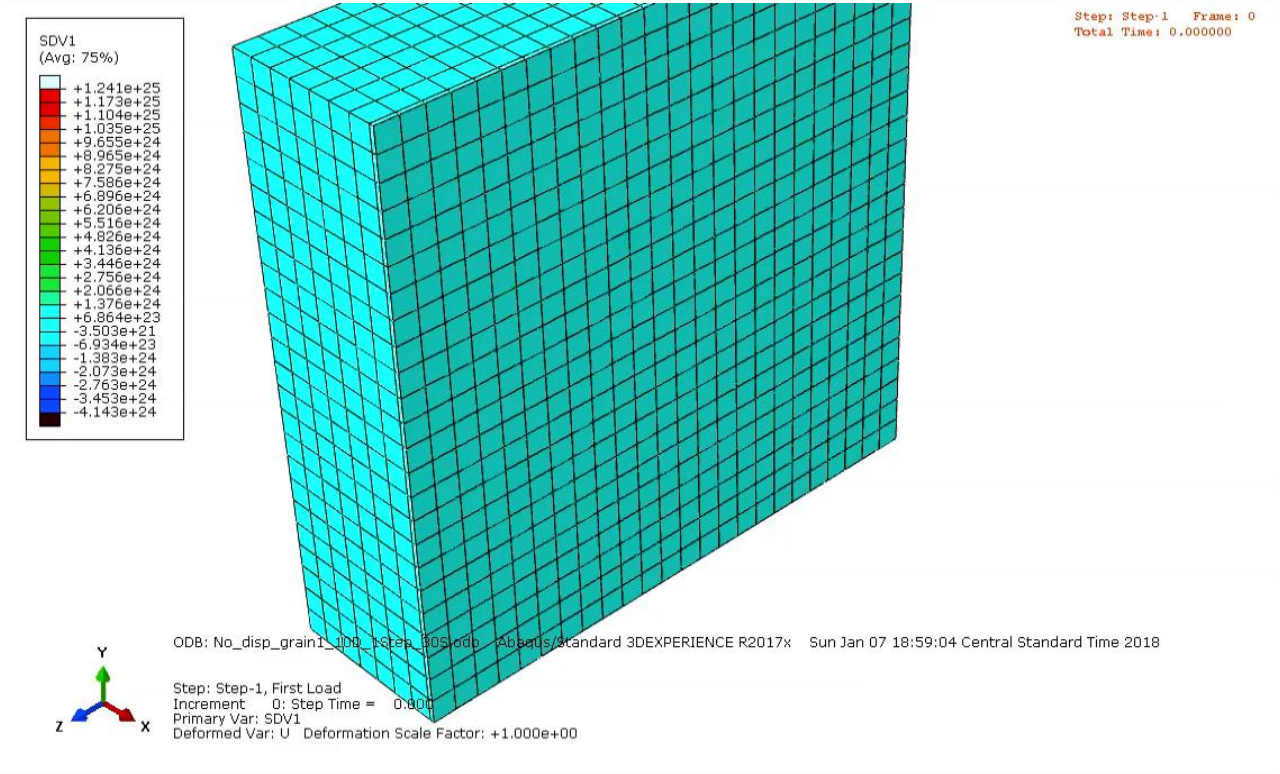
Synthetic Alloy D in ABAQUS- Grain 9

BC: 2000 psi

Hydrogen



Fatigue Results on High-Strength Steel

Applied Chemicals & Materials Division

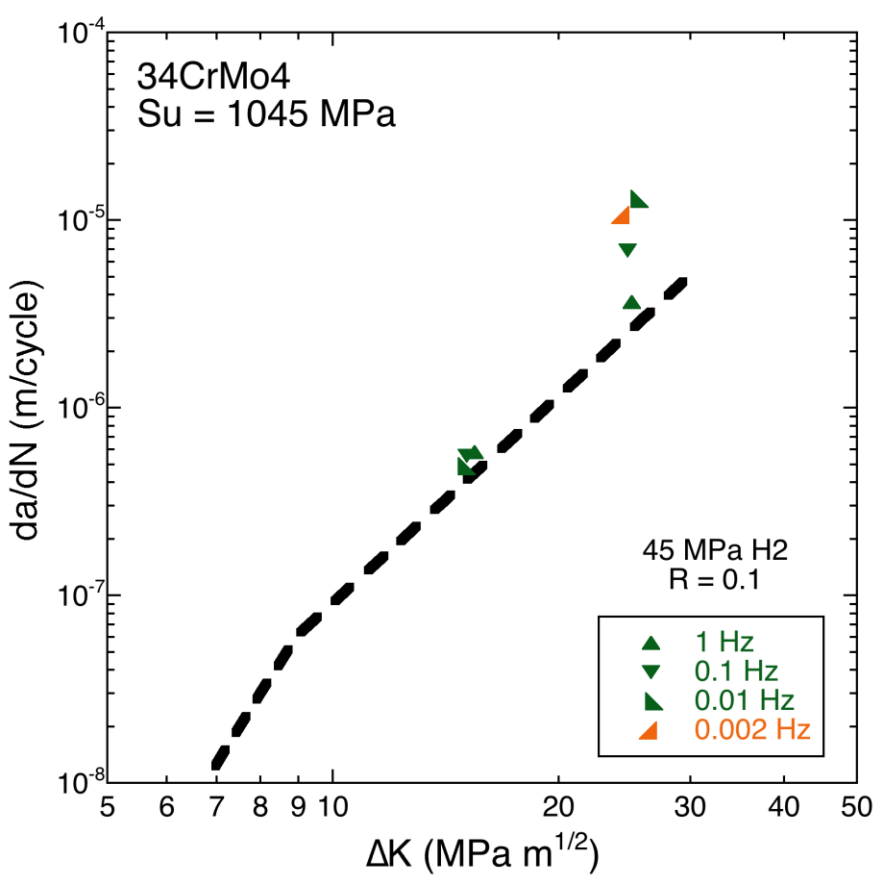
Done at Sandia National Laboratories

Su = 1045 MPa

- **Gaseous hydrogen at pressure of 45 MPa (6500 psi)**
- **R = 0.1**
- **Frequency between 0.002 and 10 Hz**
- **Data from PVP2015-45424:**

Optimizing Measurement of Fatigue Crack Growth Relationships for Cr-Mo Pressure Vessel Steels in Hydrogen Gas

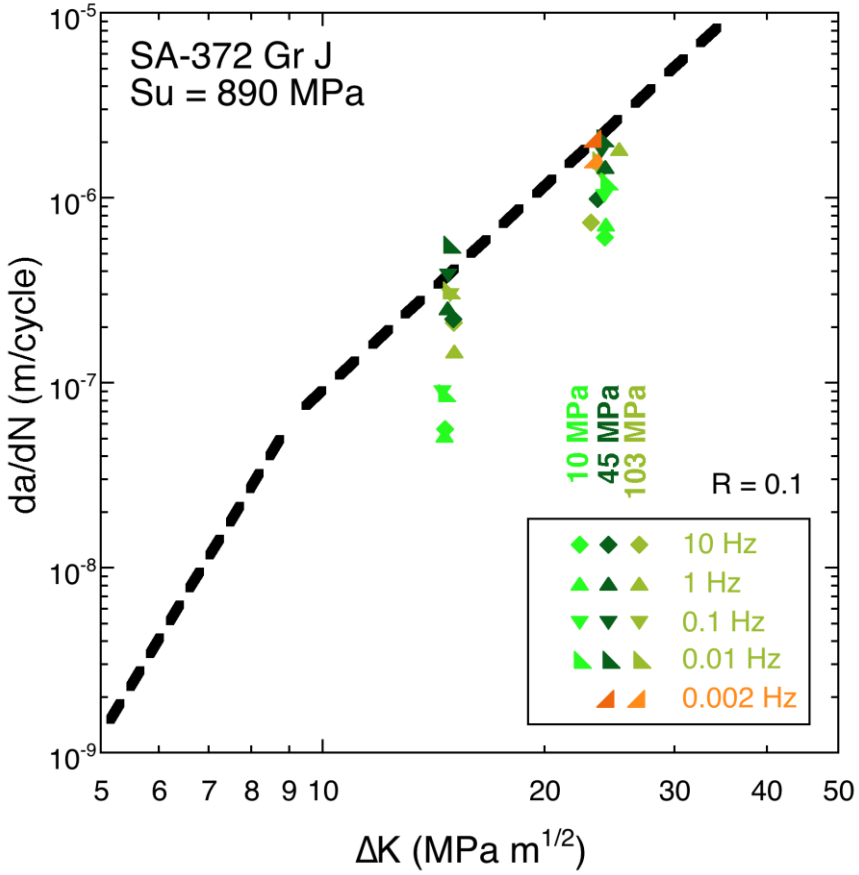
Brian Somerday, Paolo Bortot and John Felbaum



Fatigue Results on High-Strength Steel

Applied Chemicals & Materials Division

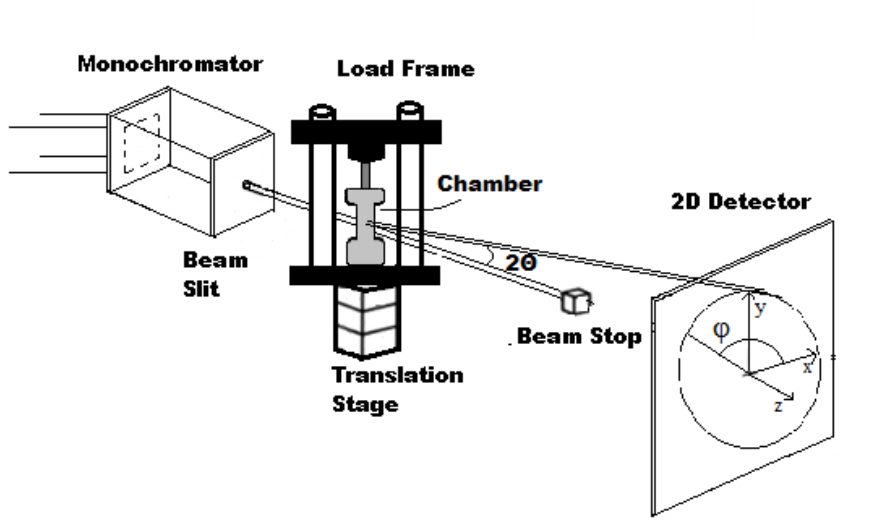
Done at Sandia National Laboratories
Gaseous hydrogen at pressure between 10 and 100 MPa (1450 to 15,000 psi)
- **R = 0.1**
- **Frequency between 0.002 and 10 Hz**
- **Data from PVP2015-45424**



Crack-Tip Mechanics

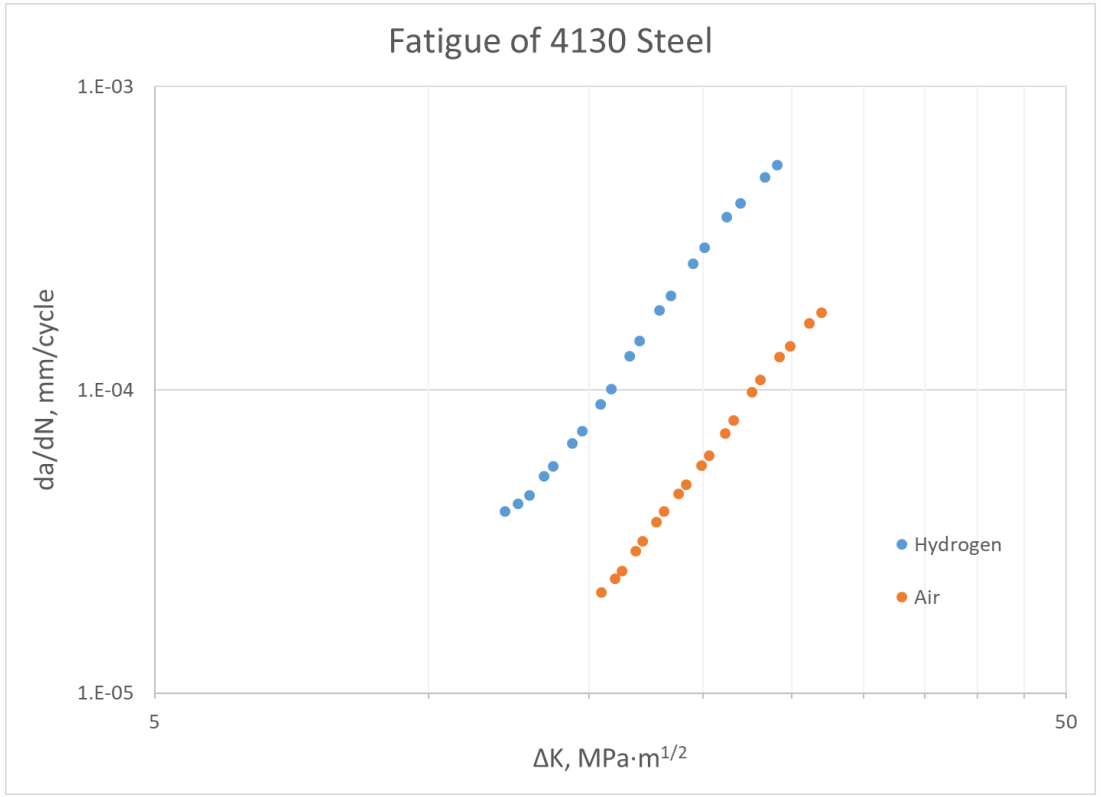
Applied Chemicals & Materials Division

HEXRD: high-energy x-ray diffraction



Yield Strength (MPa)	Ult. Tensile Strength (MPa)	Young's Modulus (GPa)	Elon. to Failure (%)
696 ± 19	777 ± 14	213 ± 9	24.3 ± 0.3

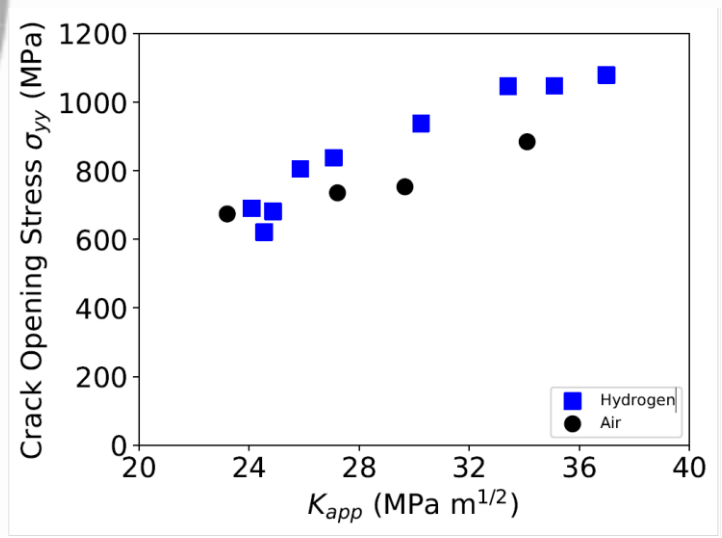
1.7 MPa (250 psi), 1 Hz



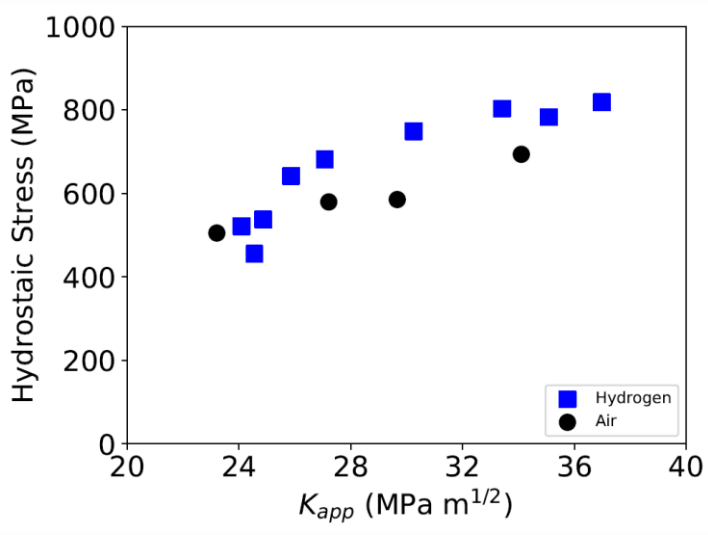
Crack-Tip Mechanics

Applied Chemicals & Materials Division

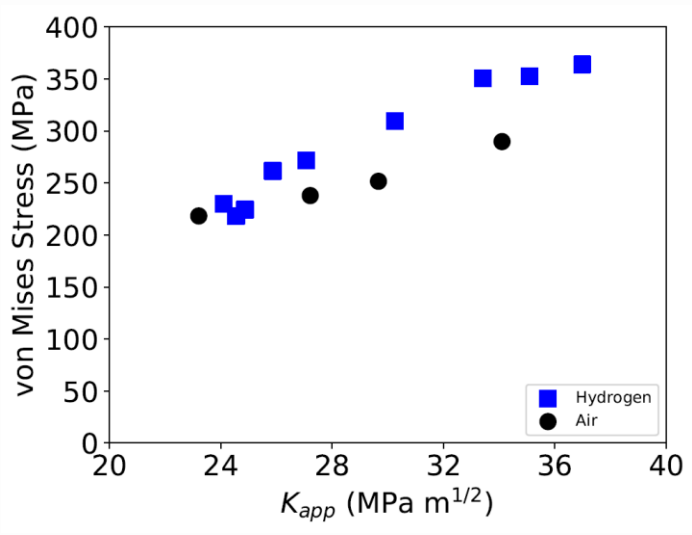
Maximum stresses in hydrogen and in air



crack-opening stress



Hydrostatic stress



von Mises stress

Crack-Tip Mechanics

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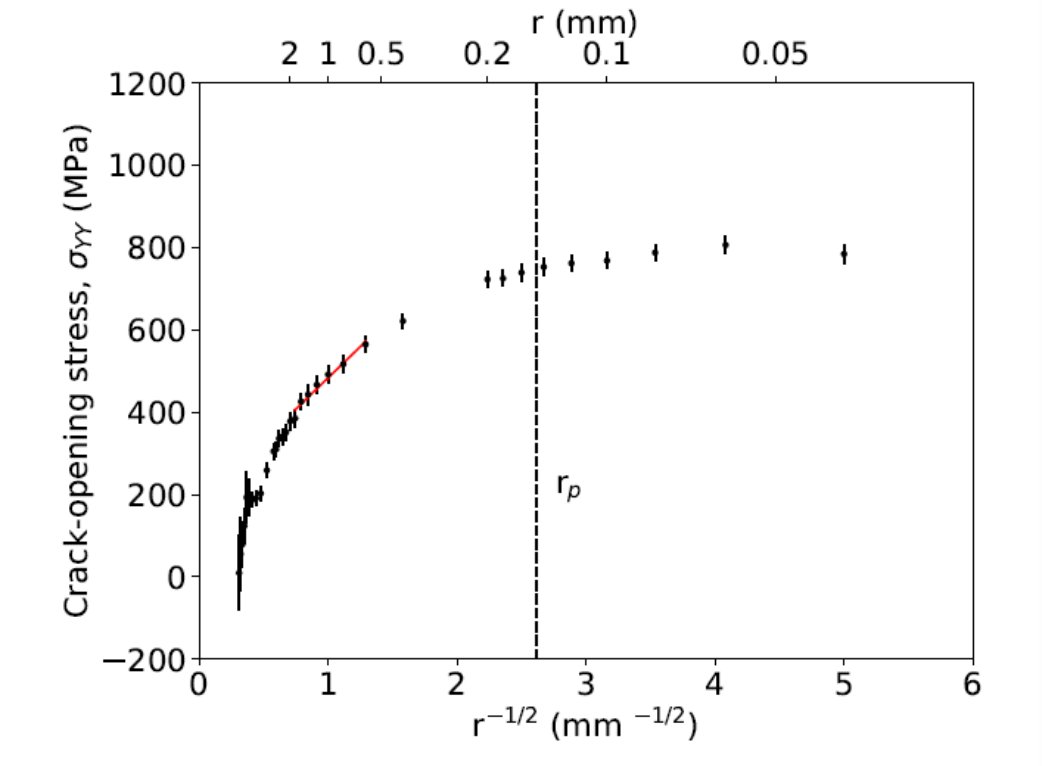
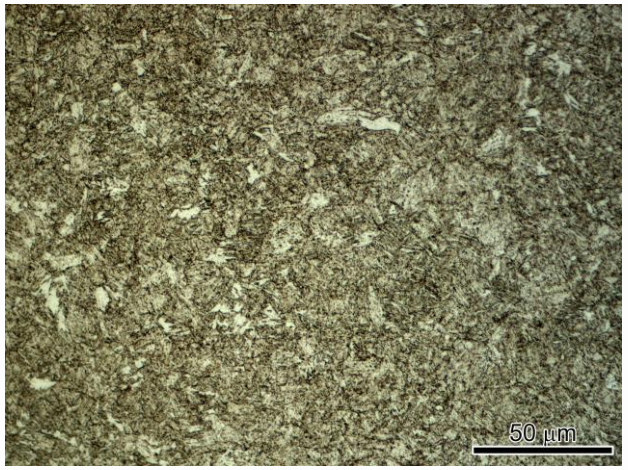
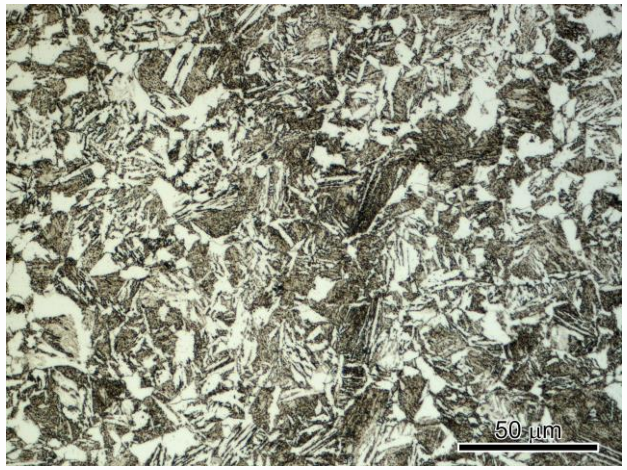
Determination of K_{eff} where the red line shows the range of the linear *K*-dominant region. The crack tip plastic zone is closer than this to the crack tip. The vertical dashed line shows the analytic prediction of the plastic zone size.

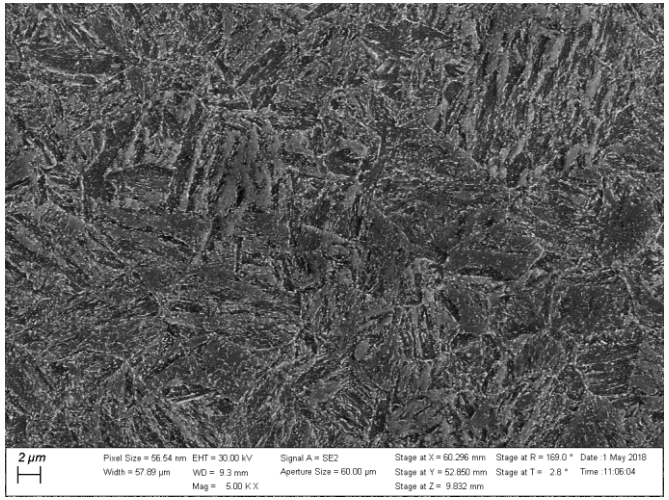


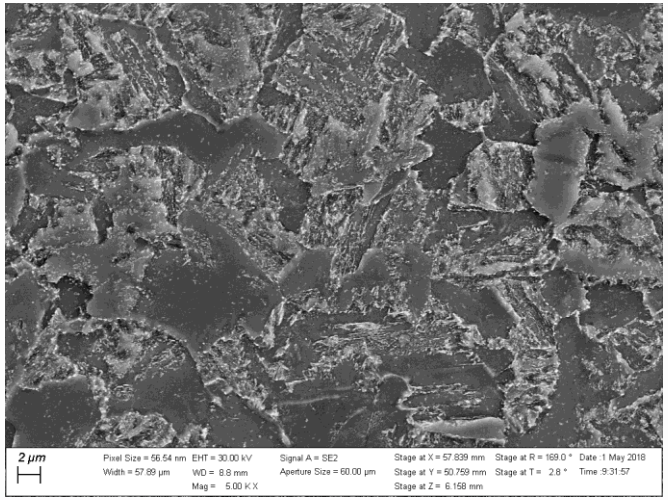
High-Strength Steel comparison





- Used for hydrogen
- UTS=792 MPa
- Elongation to failure 24.2%





- New from Faber in Italy
- UTS=1042 MPa
- Elongation to failure 17.4%

Next Steps

- Complete strain-life tests in hydrogen
- Adjust model for hydrogen effects
- Ask collaborators about definition of in-service conditions
- Begin tests on high-strength steel
- Determine whether there is a pressure effect?
- Develop a model that will be used for selecting steel intended for hydrogen pressure vessels

Fiber-Reinforced Polymer Materials for Cargo Tank Motor Vehicles

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Emerging Packaging Research
PHMSA Research and Development Forum
May 16-17, 2018

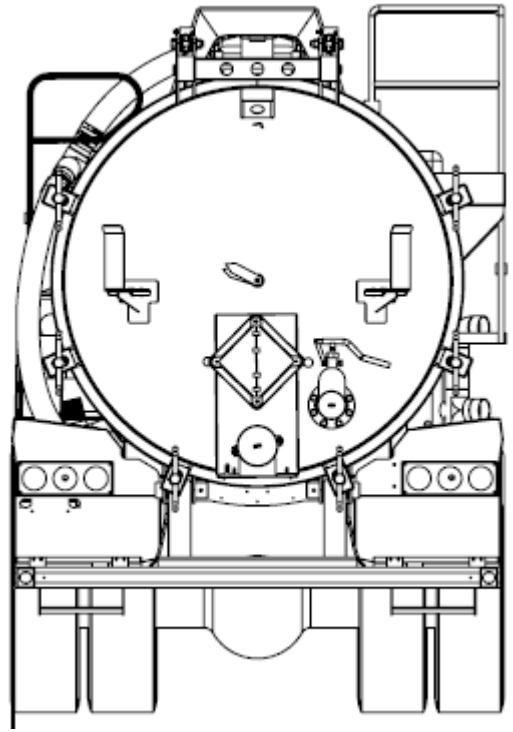
Acknowledgement of PHMSA Team

- Rick Boyle (Program POC)
- Victor Casillas (Project/Technical POC)
- Cheryl Freeman
- Satyaveda Bharath
- Eva Rodezno

Overview

- PHMSA regulates the construction, testing and inspection of highway cargo tank motor vehicles (CTMVs) within the Hazardous Materials Regulations (HMR)

- The HMR only allows the construction of metallic tanks
  - Manufacturers desiring lighter, more corrosion resistant tanks are requesting special permits for tanks constructed of fiber-reinforced polymers (FRP)



Problem Statement

- FRP manufacturers must request special permits from PHMSA because the HMR does not currently allow non-metallic CTMVs
- There are currently 6 manufacturers in the US and Canada constructing FRP CTMVs with special permits
  - Special permits are granted on an individual basis, and may have varying conditions and restrictions
- Differing regulations in Canada and Europe already exist for CTMVs constructed of FRP

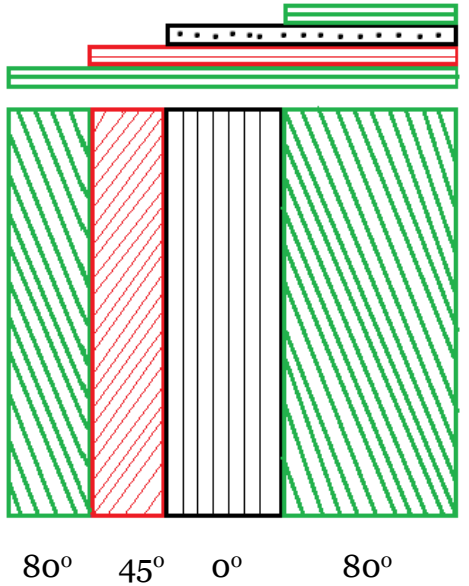
FRP Considerations

- Key advantages
  - Low density
  - High specific stiffness and specific strength
  - Good fatigue endurance
  - Excellent corrosion resistance
  - Outstanding thermal insulation
  - Low thermal expansion

- Areas of concern
  - Through-the-thickness mechanical properties
  - Impact damage tolerance
  - Fire performance

Challenges with FRP Construction

- Material properties are directional and can depend on a number of factors
  - Glass Fiber or Carbon Fiber
  - Polymer Selection
  - Fiber Orientation
  - Method of Construction
    - Single wall
      - Hand lay-up
      - Filament wound
    - Sandwich layers
      - Balsa, foam, honeycomb



Project Objectives

- Establish experimental testing procedures and develop a finite element (FE) analysis framework for evaluating the performance and determining the specifications of FRP cargo tanks for highway HM transportation

- Provide performance data and technical parameters for PHMSA to develop uniform performance evaluation criteria and procedures for FRP CTMVs

Procurement of FRP Specimens – Task 1

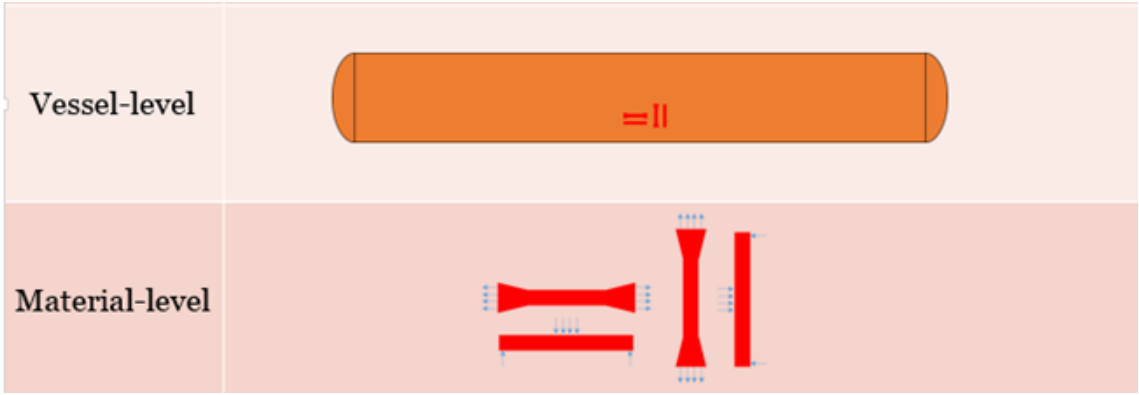
- Review of manufacturers of FRP CTMVs currently operating under a special permit
  - Discussion of manufacturing materials
  - Discussion of type of manufacture
  - Discussion of current characterization methods employed by the manufacturer

Material and Component-Level Testing – Task 2

- Establish a test matrix
  - Review tests recommended in existing guidance documents
    - Current CTMV requirements in HMR
    - Relevant ASME Boiler and Pressure Vessel Code Sections
    - Existing Canadian and European requirements
    - Existing Special Permits
  - Determine which mechanical properties will be required for modeling

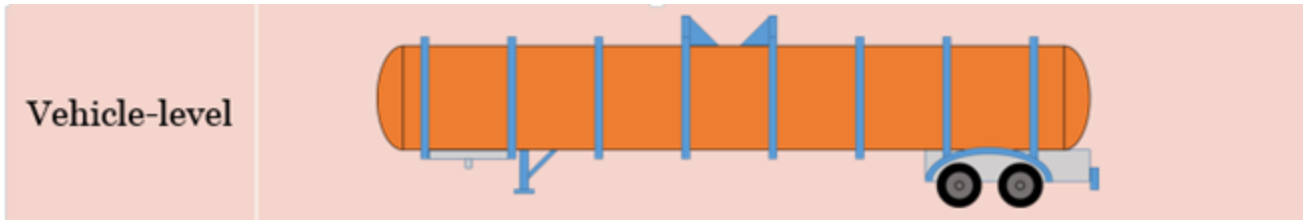
Material and Component Level Model Development – Task 3

- Develop FE models for each level of characterization
  - Static/dynamic anisotropic elasticity and strengths, including impact strength and toughness
  - Fire resistance and/or thermomechanical properties
  - Performance under fatigue loading



Full Scale FRP Cargo Tank Model Development– Task 4

- Develop FE model of a representative CTMV
  - Make assumptions about accident damage protection
  - Capacity and dimensions subject to constraints of weight and space that apply to existing trailers



Full Scale FRP Cargo Tank Performance Simulations– Task 5

- Develop a simulation matrix for the development of uniform performance evaluation for FRP CTMVs
- Conduct FE simulations using the full scale FRP cargo tank models developed
  - Performance under extreme dynamic loading
  - Susceptibility to rollover accident
  - Thermal performance
  - Fatigue performance

Data Synthetization and Technical Parameter Development – Task 6

- Final report expected to include
  - Material test reports for each level of material testing
  - Review of existing FRP, CTMV, and FRP CTMV criteria and procedures
  - Description of model development and verification/validation procedures

Tentative Project Schedule

Task		Schedule
1	Project Management	FY18, FY19 & FY20
2	Procurement of FRP Specimens	FY18
3	Material and Component Level Testing	FY18 & FY19
4	Material and Component Level Model Development, Calibration and Validation	FY19 & FY20
5	Full Scale FRP Cargo Tank Model Development	FY19 & FY20
6	Full Scale FRP Cargo Tank Performance Simulations	FY20
7	Data Synthetization and Technical Parameter Development	FY20

Current Project Status

- Outreach to Manufacturers
  - Method of manufacture
  - Material properties for existing constructions

- Determine testing requirements
  - From existing standards
  - To provide sufficient data for model input and validation

Current Project Status

- Samples being obtained
  - Filament wound
  - Hand lay-up
  - Balsa
  - Foam
  - Honeycomb
- Test Matrix
  - Strength and elasticity
  - Impact
  - Thermal properties

Questions?

Thank You!

- For more information please visit us at https://www.phmsa.dot.gov/research-and-development/hazmat/research-development-forum-may-16-17-2018

Shaped Charge Packaging Research

"Classification of Conical Shaped Charges"

Southwest Research Institute

Ballistics and Explosives Engineering

OHMS Research & Development Forum
NTSB Conference Center, Washington DC May 16-17, 2018

Introduction

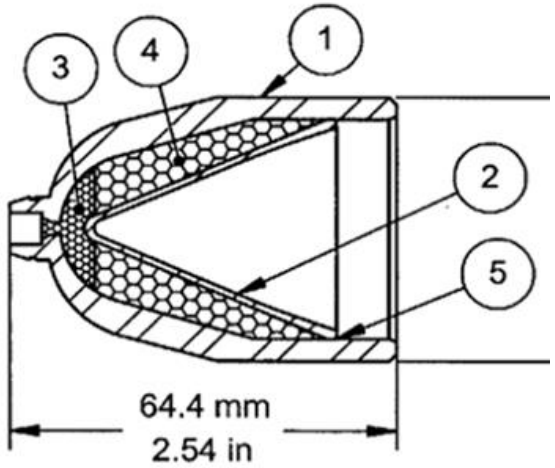
- Executing Agencies
  - DOT PHMSA (Funding Agency)
  - Southwest Research Institute (SwRI, Prime); Friedman Research Corporation (FRC, Subcontractor)
- Program Overview
  - Currently shaped charges are classified for transport either by UN Series 6 testing or through analogy based on previously characterized designs.
  - The existing classification by analogy criteria is simply based on the net explosive weight (NEW) of the device.
  - No scientific or engineering rational for this criteria has been documented.
  - SwRI and FRC are to conduct research leading to the development and validation of improved criteria for shipping hazard classification of shaped charges by analogy.
  - It is intended that guidelines will be backed with experimental data to confirm their suitability and limitations.

Project Overview

- Shaped charges are used extensively in the commercial oil and gas industry.
- New designs must be reviewed for shipping/storage hazards.
  - Changes to the explosive fill, case, liner, or packaging requires a new analysis.
  - Packing multiple articles into a single package effects the final hazard classification.
  - Testing is required, at cost to Industry. No shipping can occur until EX# application is approved by DOT.
- Can a suitable method for classification by default be developed to expedite this process?

What is a Shaped Charge?

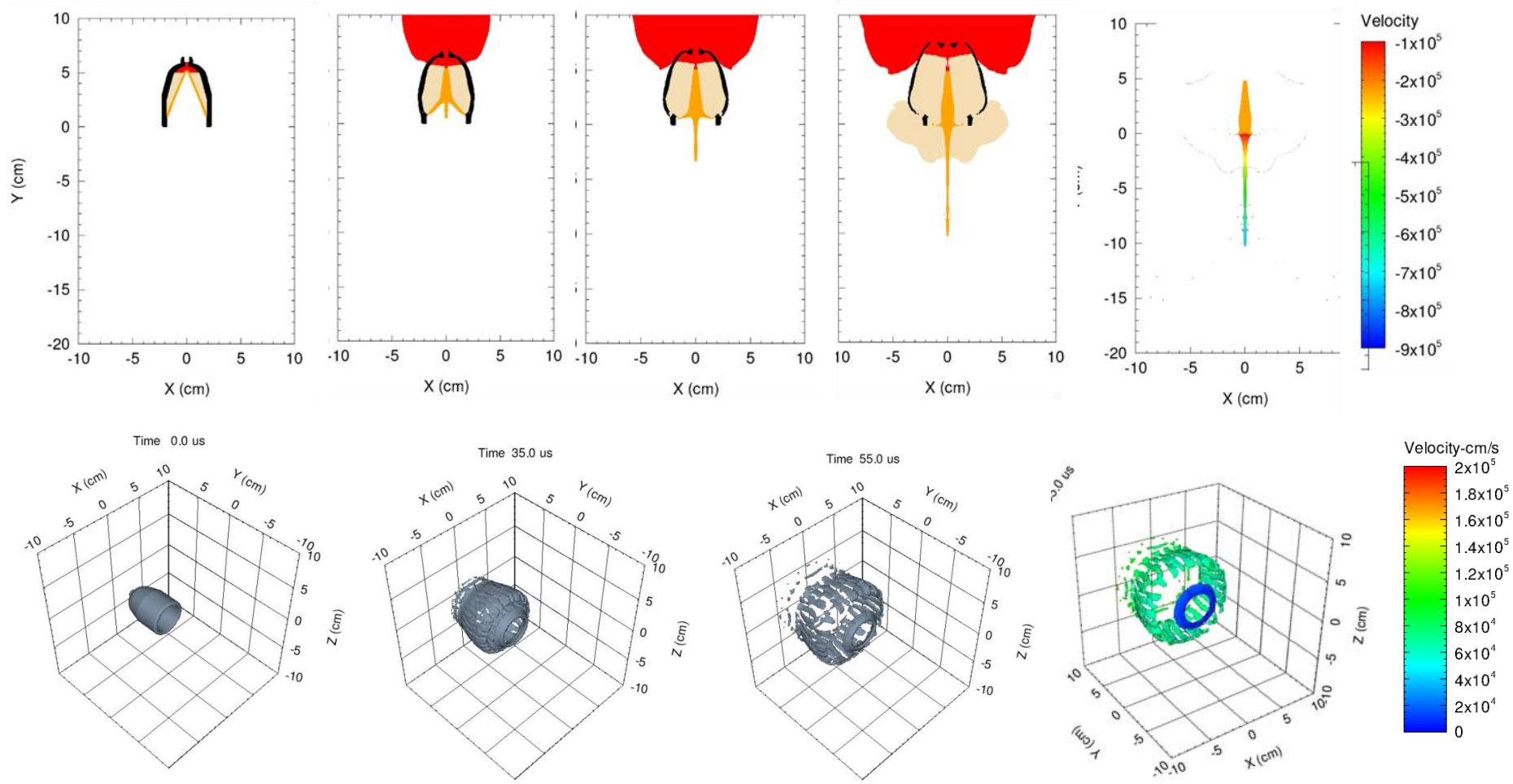
- Shaped Charge Basics
  - Explosive billet is used to collapse the liner, forming a high-velocity jet.
  - The jet is used to perforate geologic material in wells to increase output.
  - Case material generates radial fragmentation.



1. Case
2. Liner
3. Explosive, booster
4. Explosive, main
5. Glue ring

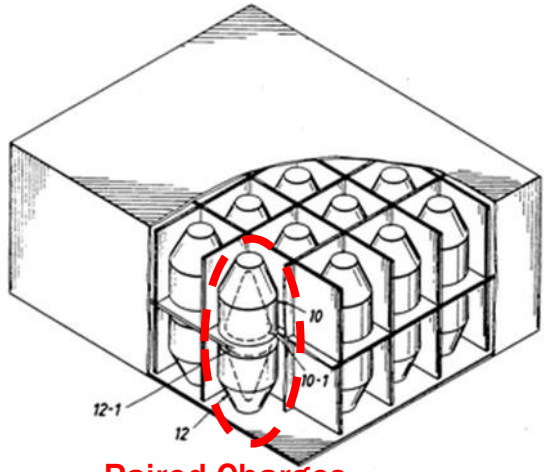
Jet Research Shaped Charge

Jet Formation and Radial Fragmentation



Typical Packaging

- ~10-50 articles per package
  - Intermediate packing and dividers; Paired charges in multiple rows
  - When multiple charges are packaged they must point inwards to minimize the jetting effect in the event of an unintentional initiation



Paired Charges

Hazard Classification Requirements

- Classification requirements as specified in
  - "Recommendation on the Transport of Dangerous Good, Model Regulations" Volumes 1 and 2
    - ST/SG/AC.10/1/Rev.19

- Testing as specified in
  - "Recommendation on the Transport of Dangerous Good, Manual of Tests and Criteria"
    - ST/SG/AC.10/11/Rev.5
  - Series 6 Tests
    - A-D

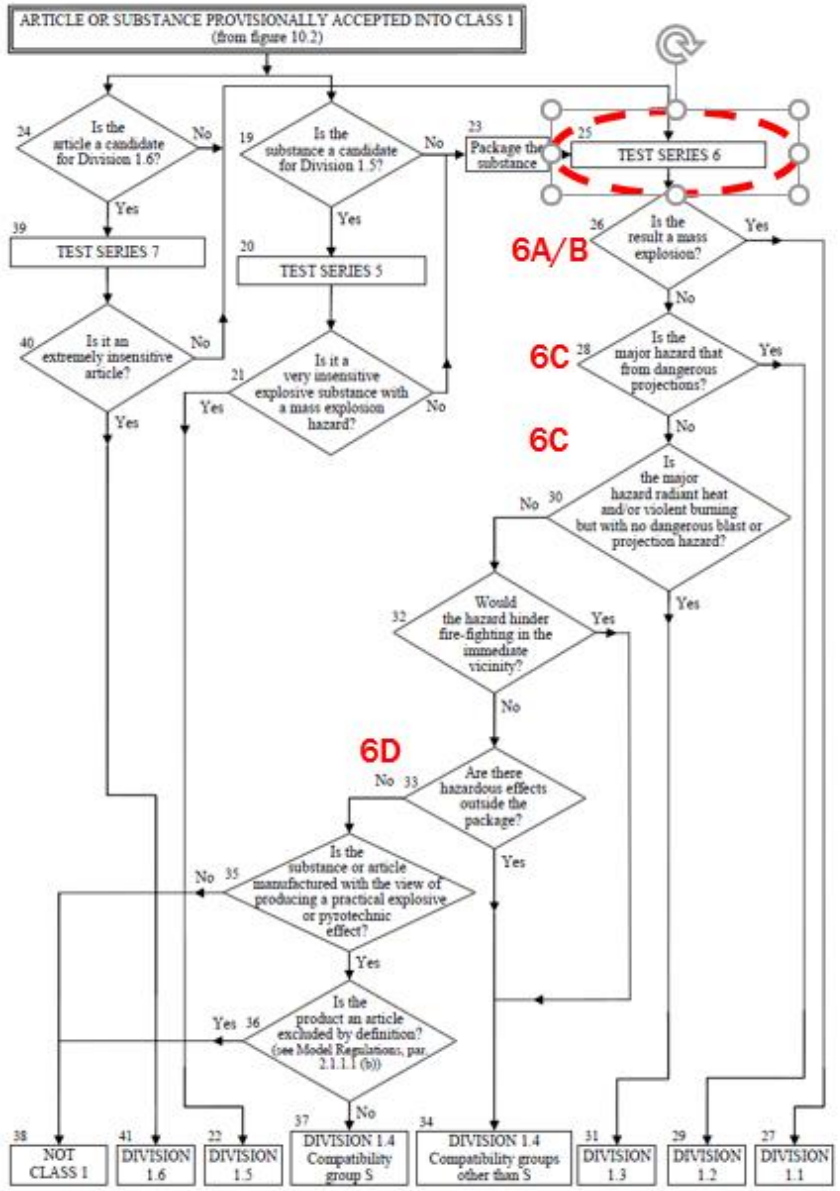
Explosive (Class 1) Divisions

- Division 1.1 ★
  - Substances and articles which have a mass explosion hazard
    - A mass explosion is one which affects almost the entire load virtually instantaneously
- Division 1.2
  - Substances and articles which have a projection hazard but not a mass explosion hazard.
- Division 1.3
  - Substances and articles which have a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard.
- Division 1.4 ★
  - Substances and articles which present no significant hazard
    - This division comprises substances and articles which represent only a small hazard in the event of ignition or initiation during transport. The effects are largely confined to the package and no projection of fragments of appreciable size or range is to be expected. An external fire shall not cause virtually instantaneous explosion of almost the entire contents of the package.

★ Shaped Charges typically fit into these categories

Classification Flowchart

- Normally conducted in alphabetical order.
  - Industry commonly skips straight to 6B.
  - 6D not common.
    - 1.4S no longer used for shaped charges.
  - Rudimentary instrumentation and data requirements.
- Testing must be witness by an approved Examiner.
  - EX application submitted to DOT for final hazard classification.



6A – Single Package Test

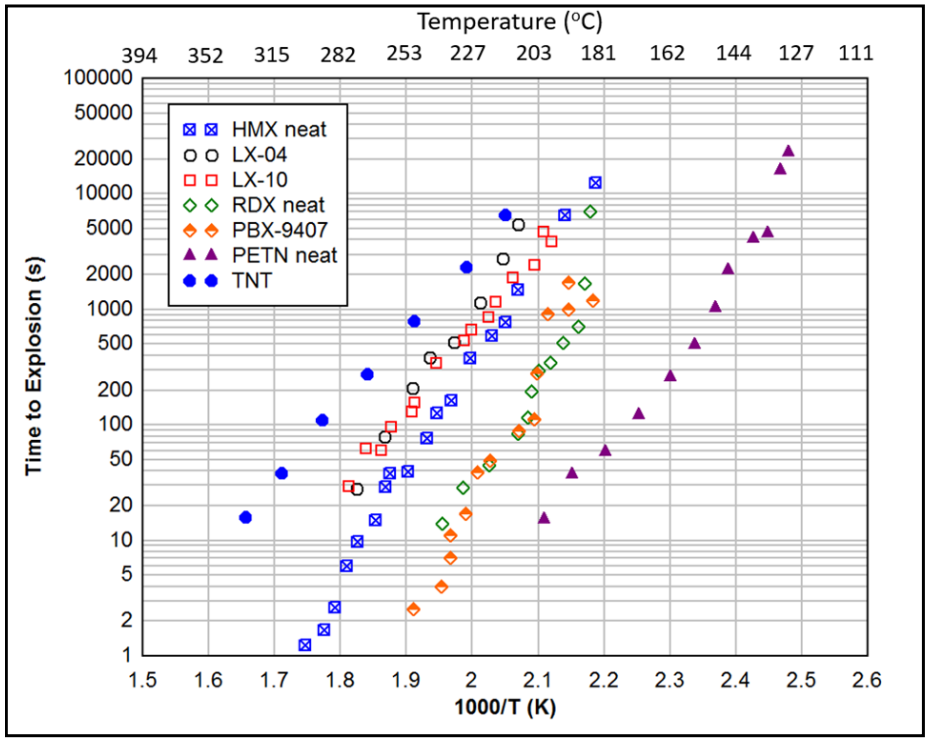
- Test Purpose
  - To determine if there is a mass explosion of the contents.
    - A charge is intentionally detonated in a package.
- Test Criteria
  - Evidence of a crater at the test site;
  - Damage to the witness plate beneath the package;
  - Measurement of blast;
  - Disruption and scattering of the confining material.
- Output
  - If mass explosion is detected, accept into Division 1.1, no further testing is needed.
  - Otherwise, proceed to test 6B

6B – Stack Test

- Test Purpose
  - To determine whether an explosion is propagated from one package to another.
    - A charge is intentionally detonated in group of packages.
- Test Criteria
  - A crater at the test site is appreciably larger than that given by a single package or unpackaged article;
  - Damage to the witness plate beneath the stack which is appreciably greater than that from a single package or unpackaged article;
  - Measurement of blast which significantly exceeds that from a single package or unpackaged article;
  - Violent disruption and scattering of most of the confining material.
- Output
  - If mass explosion of more than one (1) packaged is detected, accept into Division 1.1, no further testing is needed.
  - Otherwise, proceed to test 6C

6C – Bonfire Test

- Test Purpose
  - To determine if there is a mass explosion or a hazard from dangerous projections, radiant heat or violent burning or any other dangerous effect when involved in a fire.
- Test Criteria
  - Mass explosion;
  - Perforation of witness screens and fragment projection;
  - Fireball or jet of flame size;
  - Burn time.
- Output
  - Based on results, an assignment to Division 1.1, 1.2, 1.3, or 1.4



6D – Unconfined (Single) Package Test

- Test Purpose
  - To determine if there are hazardous effects outside the package.
- Test Criteria
  - Denting or perforation of the witness plate;
  - A flash or flame capable of igniting an adjacent material;
  - Disruption of the package causing projection of the explosives contents;
  - A projectile which passes completely through the packaging.
- Output
  - If there are hazardous effects outside the package, than the article is excluded from Compatibility Group S.

Development of Classification Criteria

- Purpose of criteria
  - To develop a science-based approach to classification by default
  - Expedite PHMSA's application review process
  - Decreased industry testing costs
- Goals
  - Easily determined from basic materials, geometry and packaging information
  - Consistent with historical Series 6 test results
  - Delineate between 1.1 and 1.4 Division assignments.

Criteria Development

- Analyze historical Series 6 results.
- Review of historical DOE/DOD information on common explosive formulations and their sensitivity.
- Examination insensitive munitions test results
  - Fast / slow cook-off and shock sensitivity
- Utilize analytical methods and simulations to estimate blast and fragment environment during Series 6 testing.
  - Assess the sensitivity of explosive articles to these stimuli.
  - Conduct highly instrumented testing to fill data gaps where necessary.
- Compare metrics with historical Series 6 test results to show applicability.
  - Iterate as needed.

Series 6 - Basic Responses

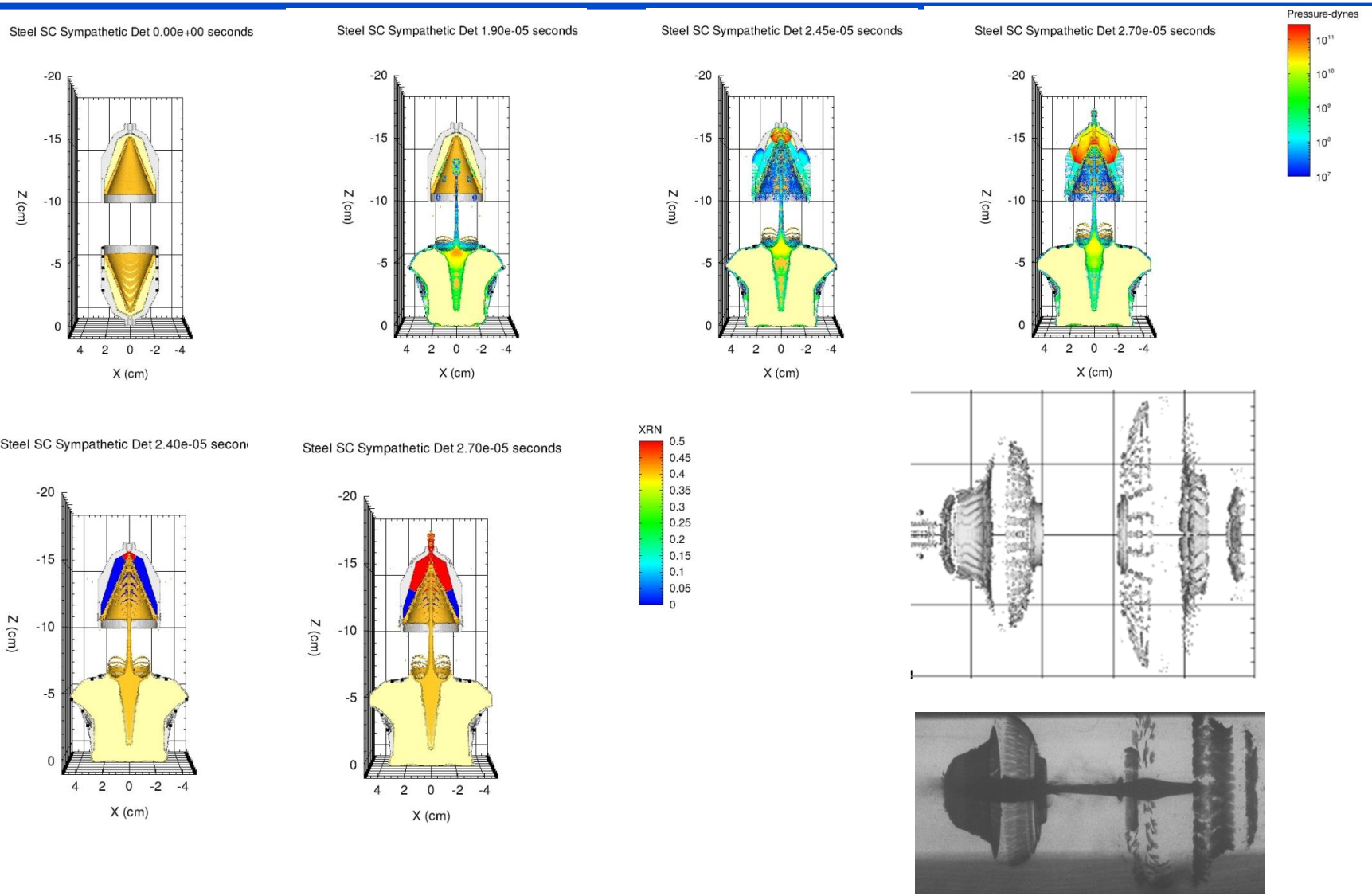
- Possible responses to Series 6 tests can be simplified into one of three categories that determine the final Division assignment.
  - Sympathetic Detonation
  - Cook-off (Fast or Slow)
  - No / Minimal Reaction

Sympathetic Detonation

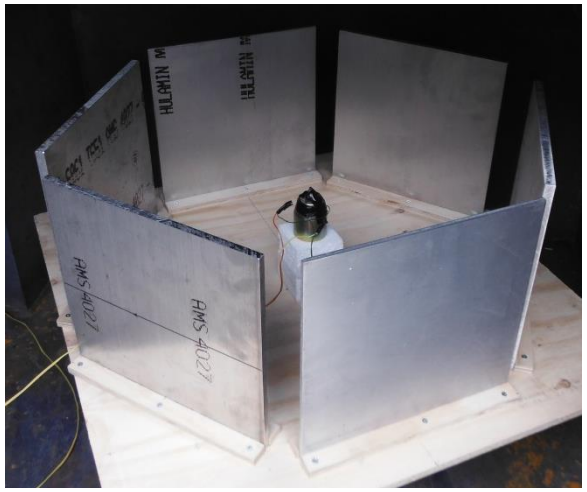
- Definition:
  - Initiation of an explosive article results in propagation of detonation into adjacent articles or packages.

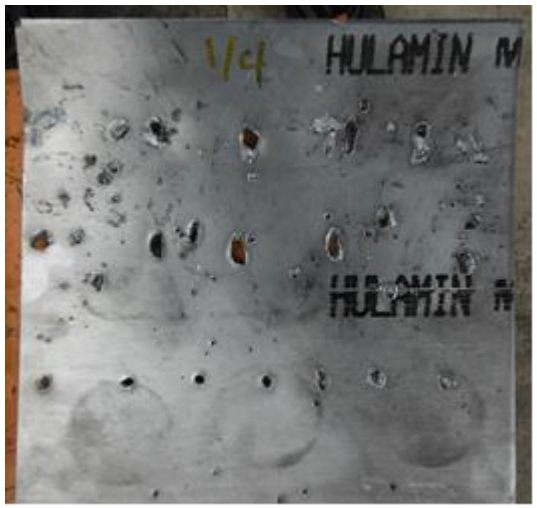
- Modes of propagation include:
  - Shaped charge jet impact
  - Case fragment impact
  - Blast over-pressure

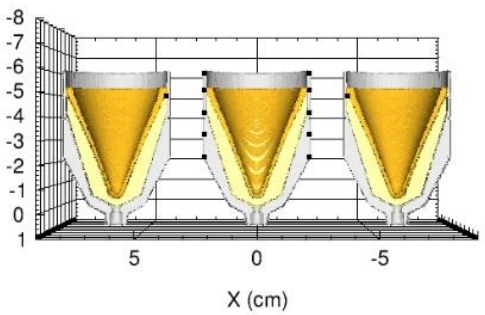
Sympathetic Detonation – Jet Impact

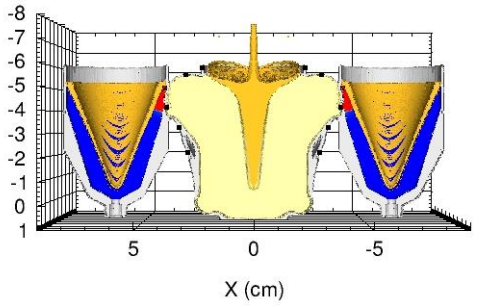


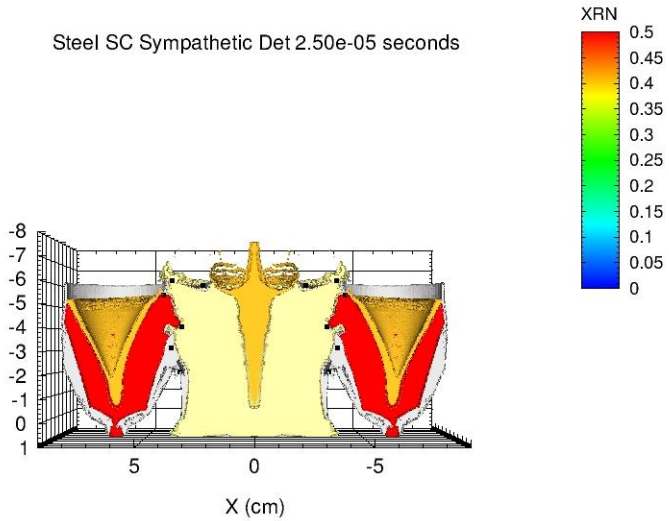
Sympathetic Detonation – Radial Fragments











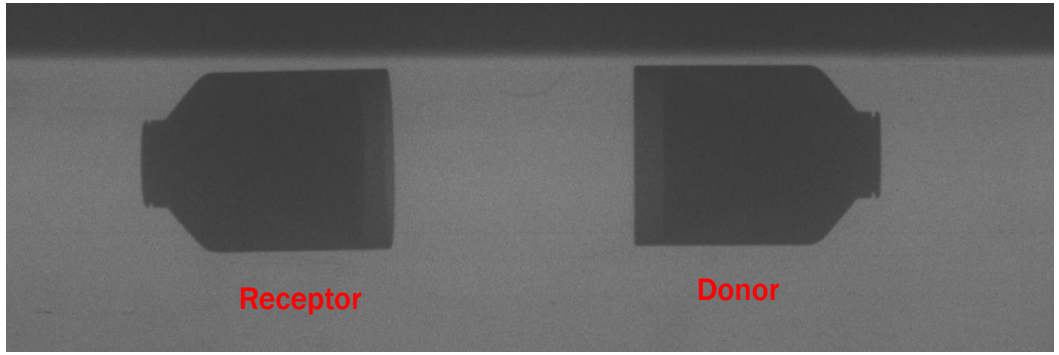
Cook-off – Series 6C

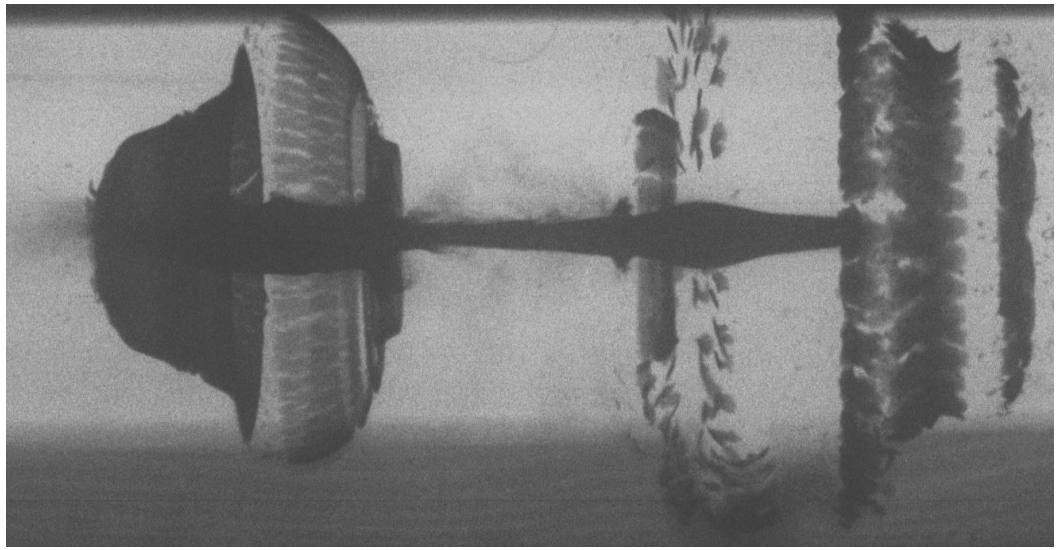
- External heat (bonfire) causes fast or slow cook-off of an explosive article.
  - Fast cook-off can appear like a detonation.
  - Slow cook-off can cause projection of high speed/mass fragments due to internal pressurization of the shaped charge case.
- Response is a function of
  - Temperature and duration, rate of heat transfer, presence of venting in the explosive article, etc.

Series 6C Bonfire Pre-Test

Post-Test

Questions ?





Points of Contact

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PHMSA R&D Forum

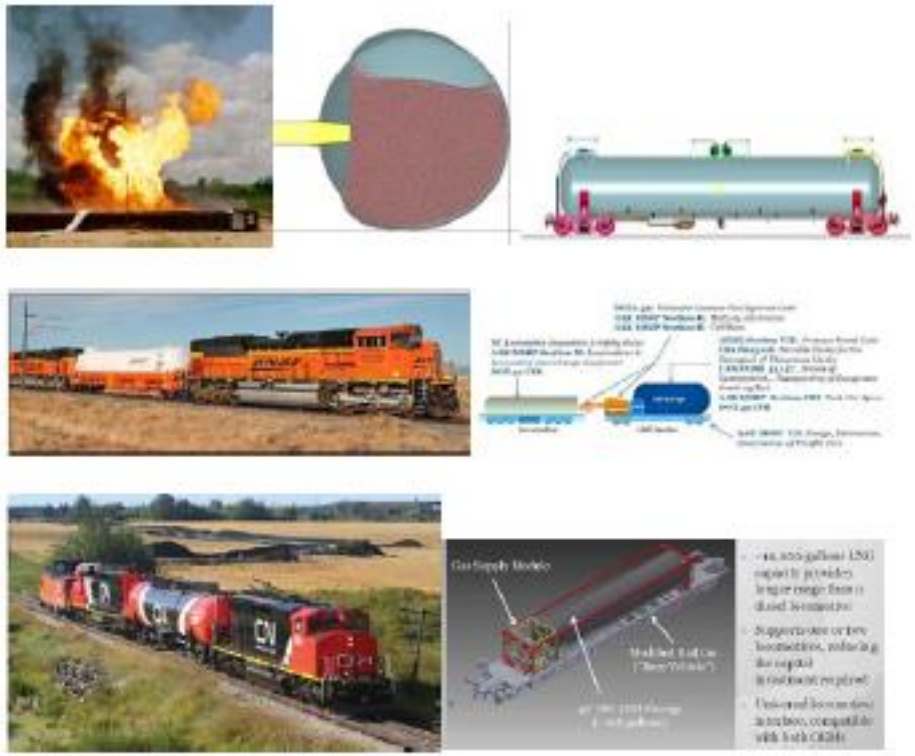
OFFICE OF RESEARCH DEVELOPMENT & TECHNOLOGY
FRA OFFICE OF RAILROAD POLICY & DEVELOPMENT

Melissa Shurland
Francisco González, III
May 2018

FRA Hazardous Materials and Tank Car Research

- Mission:
  - Reduce incidents of hazardous materials releasing from railroad tank cars and containers
- Goal:
  - Provide support to the Office of Railroad Safety through development of regulations, standards and best practices

Fire test with an ISO tank on a Flat car



Objectives

- Conduct a full scale fire test of a UN-T75 ISO tank used to transport LNG by rail.
- Provide a realistic fire exposure to the tank and the flatcar
- Obtain experimental data with internal and external instrumentation
- Assess the ability of a cryogenic portable tank to withstand exposure to a pool fire.

Test data

- Test date: 11th May 2017, 1:15 PM at Southwest Research Institute (SwRI) facility
- UN-T75 ISO Portable tank: 10,000 gallon nominal capacity; 40 ft long and 9 ft diameter located in the middle of a flat rail car (89 ft length)
- Tank was constructed by INOX/CVA with guidance from FRA and SwRI
- Tank was filled with liquid nitrogen
- Propane pool fire: 40 ft x 10 ft pool with pipe matrix to release propane liquid under 6” of water.
  - Propane: 7,000 gallons pumped from a storage tank about 800 ft from the test site.

Test Article – UN-T75 ISOTank

Figure 1. ISO Test Tank Photographs.

Tank Interior

Test Setup

Fire

Test

Post test

Time Progression of Test Events

Time (h:min:s)	Observations
0:00:00	Start DAQ/Cameras
0:11:13	Lit torch
0:12:05	Liquid Propane Flow Initiated
0:12:16	Burner Ignited
0:14:58	Vacuum pressure increasing
0:21:00	Tank Pressure and Vacuum pressure increasing, Flame pushed to west side by wind
~0:24:00	Valve cover melting
0:33:45	Vacuum pressure signal lost
0:37:45	Vacuum pressure signal has returned, but may not be reliable
0:49:19	Some Type T TCs seem to be losing connection
0:56:23	All Type T TCs are unresponsive

Time Progression of Test Events

Time (h:min:s)	Observations
1:00:00	Internal Pressure is increasing
1:05:58	Internal pressure reached 114 psig
1:06:00	First PRV opened; and later resealed
1:10:00	First PRV reopened (~116.5 psig internal pressure)
1:15:00	PRV pressure increasing, but tank pressure also still increasing
1:20:00	Noticed flat car is bowing downward
1:28:00	Visual PRV venting, but pressure still increasing
1:30:00	No change
1:33:38	2nd PRV opened (~155 psig internal pressure)
2:45:00	Liquid Propane Flow Shut-off
2:46:58	Burner fire self-extinguished
2:51:00	Stopped DAQs (restarted High-Speed DAQ to record cool-down)

Post test Observations

- The tank successfully vented its contents, and did not rupture.
- The tank kept venting overnight and was at atmospheric pressure the next morning.
- When the flatcar started to buckle, it sank into the burner and impacted the piping, which contributed to burner performance.
- It was confirmed visibly that the fire damaged the vacuum pressure cable.
- The Type T thermocouple connections did not appear to sustain a lot of damage even though these channels stopped responding during the test.
  - It may be possible that there was internal shorting out of these pass-through connectors, as opposed to the thermocouples.

Test summary

- A UN-T75 ISO tank filled with LN2 was exposed to a liquid propane fire for 2 h, 35 min.
- There was no rupture or BLEVE of either the inner or outer tank.
- The fire temperature exceeded the yield temperature of steel in the flatcar. The flatcar buckled until it made contact with the fire pan.
- The pressure inside the inner tank increased monotonically during the fire exposure and stabilized at approximately 180 psig.
- The PRV system worked as designed. The lower pressure (116.5 psig) relief valve opened and reseated twice and then opened fully. The higher pressure valve opened at about 155 psig. The pressure continued to rise until 180 psi and the venting stabilized.
- There was additional venting after the fire was extinguished and venting continued for more than 3 h, 40 min

2018-2019 Planned Research Activities

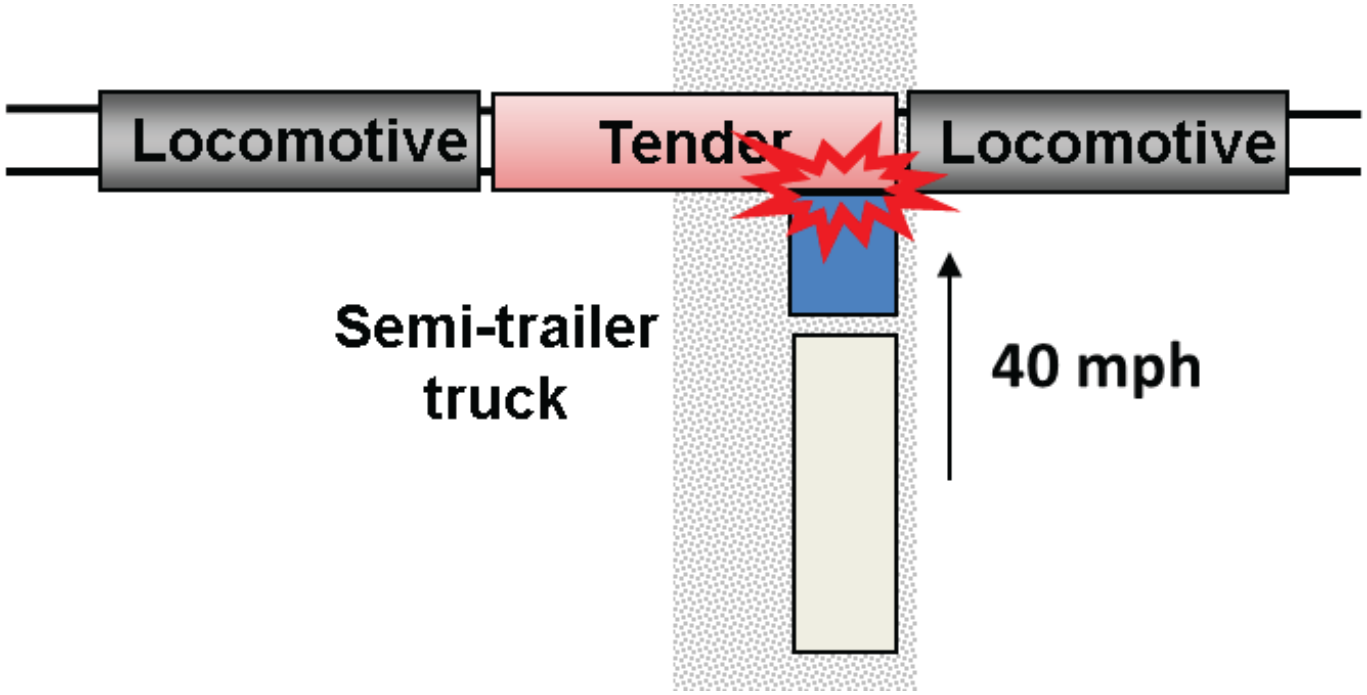
2018

- Similar fire test of UN-T75 ISO Tank
- Use LNG in the tank
- Improvement in instrumentation and data recording
  - Better Capture temperature of contents inside the tank
- Improvement in external data collection - video recording

2019

- Dynamic Impact test of LNG tender
- Follow AAR M-1004 Specification of Liquefied Natural Gas Fuel Tender

Highway Grade-crossing Collision Load Case on LNG Tender Car



Test Objective

- Evaluate the survivability of valves and pipings enclosed in the side protective housing of a LNG tender car under impact of a 80,000 lb highway vehicle at 40 mph
- Side protective housing contains pipes and valves used to fuel and off-load LNG from tender.
- FRA is concerned that the valves may not operate as intended and shut close fully if the cabinet is impacted in a grade-crossing accident.

AAR M-1004 Crashworthiness Requirements

AAR M-1004 Chapter 11 Crashworthiness Requirements

- Five dynamic load cases to access crashworthiness of tender: Head-on Collision; Highway Grade Crossing Collision, Tender Rollover, Blunt – Head Impact and Blunt-Shell Impact.
  - **High-grade crossing impact collision**
    - **11.4.3.1 Initial Conditions**

      11.4.3.1.1 The tender shall be stationary on the grade crossing coupled between two locomotives.
    - The tender shall be impacted by a tractor-semitrailer combination weighing 80,000lb, at an area between body bolsters having a side protective housing.
    - **11.4.3.1.2** The speed of the tractor-semitrailer at moment of impact shall be 40 mph. The track in the grade crossing shall be assumed tangent and level. The highway leading into the grade crossing shall be level, at 90° to the track and at the height of the top rail.

Test Data

- LNG tender will be built to AAR M-1004 specifications
  - Will not include heat exchangers and internal cryogenic pump components
  - INOX/CVA will build the tender
  - Testing will be executed at Transportation Technology Center by Transportation Technology Center Inc.
  - Finite Element Modeling will be done by The Volpe National Transportation Center
- Impact vehicle will be a 80,000 lb dump truck at 40 mph
  - AAR M-1004 specifies semi-tractor trailer. We will try to use a truck with similar chassis as the semi-tractor trailer used in AAR modeling
  - TTCI expressed concerns over controlling the trailer during the test and so relief from this requirement was sought and received from AAR
- LN2 will be filled in the tender

Questions?

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