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SANDIA NATIONAL LABORATORIES
FCTO SAFETY, CODES AND STANDARDS

QUARTERLY PROGRESS REPORT FOR JANUARY 1, 2012–MARCH 31, 2012

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FY 2013 MILESTONES/DELIVERABLES

Task/Milestone Description	Planned	Status
Task 1: Behavior		
Subtask 1.1 Flame Light Up: Modeling and Experimental Validation of Sustained Flame Light-Up		
Document results through peer-reviewed journal publication or conference proceeding.	Q4	Ongoing
Subtask 1.2 Release Behavior: Shape factor effects from non-circular releases		
Document results periodically in quarterly and annual reports	Q4	Ongoing
Subtask 1.3 Flame Radiation: Update existing models with large scale flame radiation		
Document results through peer-reviewed journal publication or conference proceeding.	Q4	Complete
Subtask 1.4 Develop simplified overpressure model for transient release		
Document results through peer-reviewed journal publication or conference proceeding.	Q4	Ongoing
Task 2: Risk		
Subtask 2.1 Develop hydrogen specific QRA Tools		
Document results through peer-reviewed journal publication or conference proceeding.	Q4	Ongoing
Document results through peer-reviewed journal publication or conference proceeding.	Q3	Ongoing
Task 3: Materials		
Subtask 3.1 Test Method Development		
Document results through peer-reviewed journal publication or conference proceeding.	Q4	Ongoing
Subtask 3.2 Critical Data		
Document results through peer-reviewed journal publications or conference proceedings.	Q3	Ongoing
Subtask 3.3 Information Resources		
Document approach and development progress in quarterly and annual reports	Ongoing	Ongoing
Demonstrate functioning database prototype	Q4	Ongoing

Task/Milestone Description	Planned	Status
Subtask 3.4 Variable-temperature testing in H2 gas capability		
Document results periodically in quarterly and annual reports	Ongoing	Ongoing
Subtask 3.5 I²CNER Lead Principal Investigator for Hydrogen Structural Materials		
Document results periodically in quarterly and annual reports	Ongoing	Ongoing
Subtask 3.6 AIST-SNL collaboration on materials testing for standards development		
Document results through peer-reviewed journal publication or conference proceeding.	Q4	Reduced scope in revised AOP
Subtask 3.7 Hydrogen Materials Testing Equipment Workshop		
Document workshop output including gap analysis and proposed activity plan	Ongoing	Planned for Q3
Task 4: Materials		
Subtask 4.1 Composite and polymer materials and structures science and technology		
Document workshop output including gap analysis and proposed activity plan	Ongoing	Ongoing
Summary report of existing non-metal certification testing and related research activities in hydrogen environments	Q2	Added in Q1
Task 5: Safety, Codes and Standards Development Support		
Document results of document development and regulatory gaps periodically through, informal, quarterly and annual reports as needed.	Ongoing	Ongoing

PROJECT OVERVIEW

Sandia provides the technical basis for assessing the safety of hydrogen fuel cell systems and infrastructure with the accumulation of knowledge feeding into the modification of relevant codes and standards. The effort at Sandia consists of four core R&D components: 1) hydrogen behavior characterization, 2) scenario analysis and risk assessment, and 3) hydrogen-compatible materials, and 4) Composite overwrapped pressure vessel (COPV) safety. Sandia provides the technical guidance and management for these efforts, which are executed in concert through national and international collaborations with universities, national laboratories, other research institutions, and professional organizations.

The effort to characterize Hydrogen Behavior (Task 1) provides the foundation for the scenario analysis, risk assessment, and risk mitigation strategies. The experiments and analysis efforts of this task are structured to validate predictive engineering tools that describe hydrogen behavior. The validated predictive models enable understanding: release behavior, flame initiation, flame sustainment, radiation patterns and overpressures.

Scenario Analysis and Risk Assessment (Task 2) applies the understanding of hydrogen behavior to specific and relevant scenarios. This core activity develops quantitative risk assessment methodologies to identify the risk drivers in hydrogen refueling to support the development of risk-informed, performance-based codes and standards for the commercial use of hydrogen. By quantifying risk, we are able to develop requirements and implement mitigation technologies to enable deployment of fuel cell technologies at socially acceptable risk levels.

The Hydrogen Compatible Materials and Components Task (Task 3) develops the fundamental understanding of hydrogen effects on materials and applies that understanding to code requirements and standards for fuel cell technology components in hydrogen service. The results of this effort are optimized test methodologies and critical data that enable the rapid deployment vehicle, infrastructure, and stationary components.

Composite overwrapped pressure vessels safety (Task 4) develops fundamental understanding of the composite system used for stationary, transport and onboard storage of hydrogen. The results of this effort are optimized test methodologies and critical data which support use of COPVs.

The combination of these efforts results in a cohesive research, development and implementation effort that enables the development of traceable and defensible codes and standards and, thus, the rapid deployment of fuel cell technologies.

FY2013, TASK 1: HYDROGEN BEHAVIOR

Point of Contact: Isaac Ekoto

BACKGROUND

Understanding hydrogen behavior during unintended release scenarios enables risk assessments of hydrogen storage, transport and delivery technology. This work explores fundamental convective transport, turbulent mixing, and ignition mechanisms responsible for the development of hazardous scenarios, along with the associated harm criteria resulting from these developed hazards. This improved understanding is then leveraged to enhance the predictive capabilities of release scenario engineering models and quantify the associated consequences. In addition to the experiments and numerical simulations, we will leverage our industrial and intergovernmental partnerships to determine next-generation R&D needs for emerging technology (e.g. cryo-compressed storage, materials-based systems).

OBJECTIVE

Complete validation of initial set of reduced order models to enable development of quantitative and hazard evaluation tools.

PUBLICATIONS/PRESENTATIONS

- Ekoto, I. W., “SNL R&D Needs for Reduced Order H2 Release/Ignition Behavior Models - The Sandia Perspective,” HySafe Research Priorities Workshop, October 16-17, 2012 Berlin.
- Ekoto, I. W., Ruggles, A. J., Li, X., Creitz, L., “Large-Scale Hydrogen Jet Flame Radiant Fraction Measurements and Modeling,” International Pipeline Conference, September 24 – 28, 2012, Calgary (also presented at IEA Task 31 Experts meeting, Bethesda, MD, Oct, 4-5, 2012).
- Ekoto, I. W., Houf, W. G., Evans, G. H., Merilo, E,. G., Groethe, M. A., “Experimental investigation of hydrogen release and ignition from fuel cell powered forklifts in enclosed spaces,” *Int. J. Hydrogen Energy*, Vol 37, No 22, pp. 17446-17456, Nov 2012.
- Ruggles, A. J, Ekoto, I. W. “Ignitability and mixing of underexpanded hydrogen jets,” *Int. J. Hydrogen Energy*, Vol 37, No 22, pp. 17549-17560, Nov 2012.
- Houf WG, Evans GH, Ekoto IW, Merilo EG, Groethe MA, “Hydrogen fuel-cell forklift vehicle releases in enclosed spaces,” *Int J Hydrogen Energy*, (in press).
- Ruggles, AJ, “Ignitability of Hydrogen Jets for Safety,” CRF Research Highlight Series, Livermore, CA, Feb 7, 2013.
- Ekoto IW, Ruggles AJ, Creitz LW, Li JX, “Updated Jet Flame Radiation Modeling with Corrections for Buoyancy and Wind,” ICHS 2013, (submitted).
- Ruggles AJ, Ekoto IW, “Experimental investigation of nozzle aspect ratio effects on underexpanded hydrogen jet release characteristics,” ICHS 2013, (submitted).
- Ruggles AJ, Ekoto IW, “Radial probability density function characterization for self-similar turbulent hydrogen jets,” J Fluid Mech, (submitted).

SUBTASK 1.1: FLAME LIGHT UP: MODELING AND EXPERIMENTAL VALIDATION OF SUSTAINED FLAME LIGHT-UP

For turbulent releases that are characteristic of most unintended hydrogen jet-flames, the mean concentration lower flammability limit (4%) conventionally is used as the light-up boundary given an ignition source. However, this point generally lies up to an order of magnitude downstream of experimentally determined light-up boundaries and thus represents an overly conservative metric for flame sustainment. The primary cause for the difference is due to convective strain and turbulence/chemistry interactions that lead to the extinction of an incipient ignition flame kernel. More accurate identification of the flame light-up boundary would significantly lessen current separation distances. This subtask is focused on acquiring relevant measurements on lab-scale flames that can then be used to identify dominant flow turbulence and mixing phenomena, that when coupled with combustion chemistry result in the transition from flame initiation to sustainment. These data will be compared against and augmented by complex large eddy simulations (LES). The eventual output will be a simplified flame light-up engineering model that can be used to evaluate flame sustainment probability for a range of accident scenarios through a risk assessment.

PROJECT STATUS

Complete – Measurements were completed in Q1. The model for ignition probability prediction is based on the flammability factor, *FF*, which is defined as the integration of the mole fraction probability density function, *PDF*, between the upper and lower flammability limits as defined in equation 1.

1) $$FF = \int_{LFEL}^{UFL} PDF\, d\chi_i$$

The inputs used to specify the PDF were shown to be readily obtained from self-similarity analysis, and the results were found to match well with measured ignition probabilities as shown in Figure 1. The improved ignition probability model improves the overall accuracy of the integrated QRA toolkit (subtask 2.1).

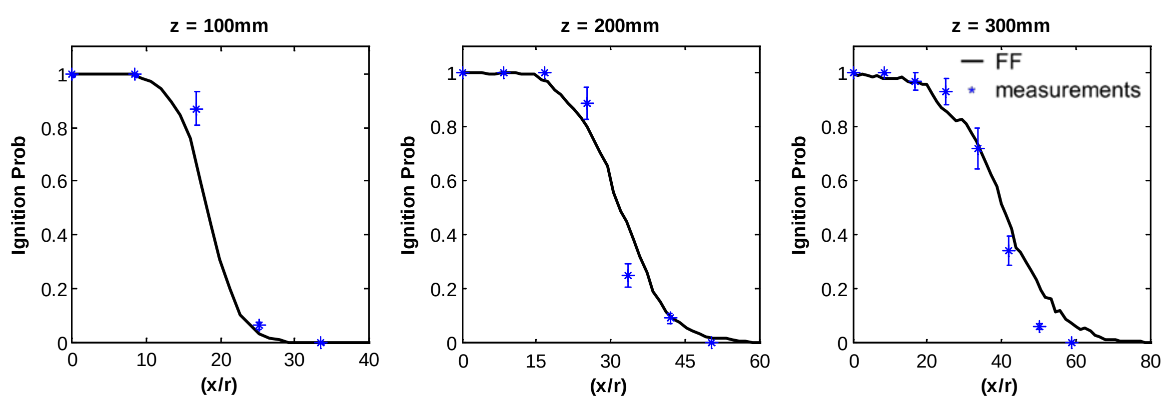


Figure 1 Comparison of Ignition Probability Prediction and Measurements taken as part of subtask 1.1

PLANS FOR NEXT QUARTER AND KEY ISSUES

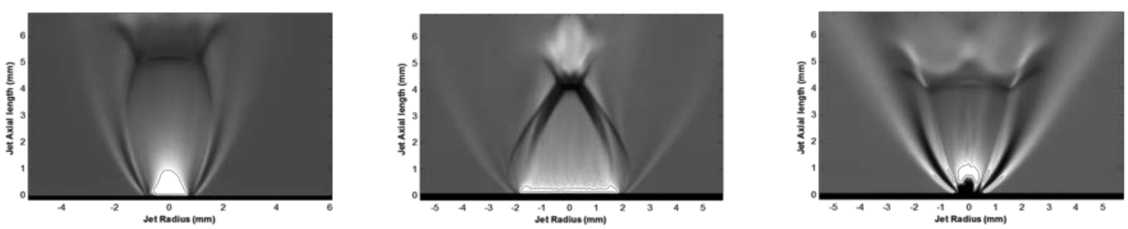
Use results of subtask 1.2 to extend ignition probability predictions to non-circular releases.

SUBTASK 1.2: RELEASE BEHAVIOR: SHAPE FACTOR EFFECTS FROM NON-CIRCULAR RELEASES

To date, nearly all release and dispersion models have an assumed circular source orifice due to the modeling simplicity from symmetry, the broad amount of data currently available for these release types, and the fact that such a release was thought to result in the largest flammable extent and thus represented the worst case scenario. More recently, it has been acknowledged that certain hazardous phenomena may be enhanced by a non-circular source orifice. For example, the radiative flame emission from an ignited pipeline rupture that emanates from the axial section of pipe is several times greater than the emission from a circular orifice jet fire with an equivalent exit area and flow rate. Moreover, from a system component standpoint, the most common leak is expected from a leaky fitting, which is highly non-circular and thus will greatly impact dispersion characteristics. This subtask evaluates hydrogen behavior characteristics from ‘real world’ leaks from both non-choked and choked conditions. The expected output is a notional nozzle model that accounts for shape factor in overall release and ignition characteristics.

PROJECT STATUS

On Target – Measurements of downstream scalar (and hence flammability) behavior are ongoing. Early Schlieren images of shock structures (Figure 2) indicate that slot release geometries greatly impact the downstream flow characteristics.



(a) (b) (c)

Figure 2 Schlieren images of shock structures for (a) circular opening - aspect ratio 1 (b) slotted opening major axis - aspect ratio 8 (c) slotted opening minor axis. All releases at pressure ratio of 10:1

PLANS FOR NEXT QUARTER AND KEY ISSUES

Expecting to complete initial release experiments in Q3. We will analysis results and publish in Q4.

SUBTASK 1.3: FLAME RADIATION: UPDATE EXISTING MODELS WITH LARGE SCALE FLAME RADIATION

Although current hydrogen jet-flame models are suitable for predicting radiative heat fluxes in the far-field (i.e., at distances from the centerline greater than half the flame length), near-field radiation prediction where the hazards are greatest is still poor. Furthermore, current flame radiation models have only been validated for moderate sized hydrogen flames (i.e., < 10 m), and it is unclear if empirical correlations developed from the smaller-scale flame data apply to larger flames that are more representative of catastrophic accident scenarios. This task will utilize large-scale hydrogen jet flame heat flux data provided by Air Products and Chemicals Inc. to validate and refine current flame radiation modeling methods for these larger flame types.

PROJECT STATUS

On Target – The original model used to estimate radiative heat flux boundaries was based on a single-point source method with a non-dimensional radiant power correction for different observer axial and radial locations relative to the flame centerline. The model was updated with a weighted multi-source formulation and validated against heat flux measurements from a small scale (~1 m) hydrogen jet flame. When the model was compared to radiative heat flux data from 2 large-scale hydrogen jet flames (17.4 and 48.5 m respectively), the model agreement was much improved with the data. In particular, it was observed that surface reflection from steel surfaces could be a major contributor to radiant loads — these results were confirmed by more controlled lab-scale flame experiments. Results and analysis were published in the Proceedings of the International Pipeline Conference.

PLANS FOR NEXT QUARTER AND KEY ISSUES

Further activity related to this task is deferred to future fiscal years. Follow on activity would incorporate an integral model into the current model framework to better account for flame trajectory due to buoyancy and wind.

SUBTASK 1.4: DEVELOP SIMPLIFIED OVERPRESSURE MODEL FOR TRANSIENT RELEASE

Deflagration overpressure is the primary hazard associated with the ignition of unintended hydrogen releases within enclosures. As hydrogen powered fuel cells and indoor refueling becomes more common within the material handling sector, there will be an ever greater risk for a catastrophic incident resulting from the uncontrolled release and ignition of hydrogen indoors unless critical safety standards and protocols are in place. In order to develop these standards and practices to lessen the ultimate risk, a simplified, predictive deflagration overpressure model that is flexible enough to work in a variety of enclosure configurations (e.g., size, shape, ceiling height, release rate, ventilation). This critical subtask directly supports the development of risk assessment tools described in Task 2.

PROJECT STATUS

Complete – the initial simplified overpressure model has been integrated to the current version of the toolkit. This effort integrated the jet dispersion model (FY08 result) with the layer model developed in FY12. Overpressure is a result of ignition of the resulting accumulated gas cloud. The current model is only valid for steady state conditions – results from FY11 experiments could validate the development of unsteady condition models.

PLANS FOR NEXT QUARTER AND KEY ISSUES

Continue to support the QRA toolkit, requiring periodic support as a part of subtask 1.4 through the end of FY13.

The accuracy of the QRA toolkit is adversely affected by the absence of a model which accommodates unsteady conditions. Validation data exists to support the development of the unsteady conditions and thus improve the QRA toolkit accuracy.

FY2013, Task 2: Scenario Analysis, Risk Assessment

Point of Contact: Katrina Groth

Background

Safety scenario analysis develops a scientific basis for evaluating credible safety scenarios, providing technical data for codes and standards decisions. Sandia develops benchmark experiments and a defensible analysis strategy for risk assessment of hydrogen fuel cell systems and infrastructure. Quantitative risk assessment will be used to identify risk drivers and the associated consequences in step-out hydrogen technologies.

Objective

Develop QRA tools. Form a volunteer review group of peers and early users by hosting a workshop.

Publications/Presentations

- Lachance, J. "Risk Informed Development of Hydrogen Codes and Standards" IEA Task 31 Experts meeting, Bethesda, MD, Oct, 4-5, 2012).
- Groth, K., Lachance, J., Harris, A. "Early-Stage Quantitative Risk Assessment to Support Development of Codes and Standard Requirements for Indoor Fueling of Hydrogen Vehicles" Sandia National Laboratories Report, SAND2012-10150.
- K. Groth presentation to JPEC/RISE on "Developing a QRA approach for hydrogen infrastructure" (Jan 29th in Livermore).
- J. LaChance presentation at same meeting.

Subtask 2.1: Develop Hydrogen Specific QRA Tools

Quantitative Risk Assessments for use in development of codes and standards has been critical to the development and changes to model codes such as NFPA 2. This work has also found international influence. Barriers now exist for specific hydrogen installations when interpreting the model codes, specifically the requirements based on QRA. This task will scope and develop version 1.0 of a hydrogen specific QRA tool. A workshop will be held to present current approach to creation of version 1.0, solicit feedback from the QRA practitioner community, and introduce the QRA process to possible users.

Project Status

On Target – The model development effort continued in Q2. A sensitivity analysis was conducted and reported by teleconference in Feb 2013. As a result of that effort, the input parameters were modified to accept a range of input values (where previous versions contained discrete values). This change will facilitate future sensitivity evaluations as the small analysis proved very valuable to identification of key risk drivers for the indoor fueling scenario. The integral model from subtask 1.4 was coupled to the QRA code. Further work is required to ensure the integral model is correctly coupled and fully functional within the integrated QRA architecture. Next steps will require the same process for adding the layer model and the overpressure model into the code.

Began preparations for stakeholder workshop to be conducted at DOE in June – goals established, invitations complete, invitee list pending.

Hosted JPEC/RISE for a one day meeting to discuss potential application of QRA for Japanese retail hydrogen stations. This was an exploratory meeting for the JPEC/RISE representatives regarding potential research efforts in advance of the Japanese fiscal year, beginning in April 2013.

PLANS FOR NEXT QUARTER AND KEY ISSUES

The next quarter will focus on the version of the model (not yet version 1.0) to be presented at the workshop. In addition, the approach and example results will be presented at a workshop in June. The workshop hopes to acquire feedback from potential users of the QRA toolkit. Using this feedback, and completing undone tasks will be actions for Q4 with hopes to complete version 1.0 by the end of FY13.

FY2013, TASK 3: HYDROGEN COMPATIBLE MATERIALS AND COMPONENTS

Point of Contact: Brian Somerday

BACKGROUND

The Hydrogen Compatible Materials and Components subtask has several objectives: 1) optimize the reliability and efficiency of test methods for structural materials and components in hydrogen gas, 2) generate critical hydrogen compatibility data for structural materials to enable technology deployment, and 3) create and maintain information resources such as the "Technical Reference for Hydrogen Compatibility of Materials". Each of these objectives supports the development, optimization, or implementation of hydrogen containment codes and standards, such as ASME Article KD-10 for stationary and transport vessels, ASME B31.12 for piping and pipelines, CSA HPIT1 for industrial truck fuel systems, SAE J2579 for compressed hydrogen storage systems on vehicles, and CSA CHMC1 for hydrogen containment material qualification.

The objective of optimizing testing procedures for materials in high-pressure hydrogen gas was derived based on initial efforts to exercise existing standards and measure benchmark properties of materials. During these efforts, it was found that existing materials testing protocols in high-pressure hydrogen gas required more development. In particular, protocols were needed to ensure that material property measurements were suitable for structural design, i.e., the properties represented reliable and conservative measurements, and that test durations were not impractical. Variables that must be explored for fatigue crack initiation and growth measurements are cyclic stress frequency and cyclic stress waveform. The effects of these variables on fatigue crack initiation and growth must be established for the different structural materials tested in hydrogen gas. These activities are directed toward optimizing the materials testing methods currently specified in standards such as ASME Article KD-10, ASME B31.12, SAE J2579, and CSA CHMC1.

The objective of generating critical data has been prompted by the effort to gather data for the Technical Reference, where this exercise has demonstrated that significant deficiencies exist in the hydrogen compatibility database. Few data exist to enable quantitative life prediction of structures in high-pressure hydrogen gas. Data are lacking for both particular materials (e.g., welds) as well as specific properties (e.g., fatigue crack initiation and growth). These data are essential for qualifying hydrogen containment components according to new codes and standards, e.g., ASME Article KD-10, ASME B31.12, and SAE J2579. SNL/CA is uniquely positioned to generate data for structural materials exposed to hydrogen gas pressures exceeding 70 MPa. The pressure capacity of these materials testing systems makes them unique among research institutions in the U.S.

In addition to the test method development and critical data activities, we guide future research directions and develop capabilities based on stakeholder input including industry, government, and research organizations. This objective is designed to maintain a dynamic and proactive program in hydrogen compatible materials and components that will provide national and international coordination of research and development. The product of this effort is an analysis of the current state-of-the-art in materials research and experimental capabilities with a roadmap for emerging needs and gaps.

OBJECTIVE
Facilitate generation and dissemination of critical hydrogen materials data for the purpose of improving safe design and enabling cost reduction innovations. Exercise leadership role in defining research directions and implementing research results in codes and standards.

PUBLICATIONS/PRESENTATIONS
- K. Nibur, B. Somerday, C. San Marchi, J. Foulk, M. Dadfarnia, and P. Sofronis, "The Relationship Between Crack-Tip Strain and Subcritical Cracking Thresholds for Steels in High-Pressure Hydrogen Gas", *Metallurgical and Materials Transactions A*, vol. 44A, 2013, pp. 248-269.
- T. Michler, C. San Marchi, J. Naumann, S. Weber, M. Martin: "Hydrogen environment embrittlement of stable austenitic steels". *Intern J Hydrogen Energy*, vol. 37, 2012, pp.16231-16246.
- C. San Marchi, B.P. Somerday. "Technical Reference for Hydrogen Compatibility of Materials", Sandia National Laboratories Report SAND2012-7321, 2012.
- (invited presentation) C. San Marchi, "Overview of Gaseous Hydrogen Embrittlement Testing at Sandia", Korean Society of Mechanical Engineering, Annual Fall Meeting, Special International Session on Hydrogen Effects in Materials, Chagwon, Korea, Nov. 2012.
- (invited presentation) C. San Marchi, A. Harris, D. Dedrick, "Investigation of the Hydrogen Release Incident at the AC Transit Emeryville Facility", Korea Research Institute of Standards and Science (KRISS), Daejeon, Korea, Nov. 2012.
- (invited presentation) C. San Marchi, "Standards for Qualifying Materials for Hydrogen Service", Korea Research Institute of Standards and Science (KRISS), Daejeon, Korea, Nov. 2012.
- (invited presentation) C. San Marchi, "Evaluation of gaseous hydrogen embrittlement in metals for hydrogen service", National Institute of Advanced Industrial Science and Technology, Tsukuba Japan, March 2013.
- (invited presentation) C. San Marchi, "Full-scale evaluation of fatigue and fracture of steel pressure vessels with gaseous hydrogen", Kyushu University, Hydrogenius, Fukuoka, Japan, Marchi 2013.
- C. San Marchi, B.P. Somerday, K.A. Nibur, "Development of standards for evaluating materials compatibility with high-pressure gaseous hydrogen" ICHS 2013, (submitted).
- L.A. Hughes, B.P. Somerday, D.K. Balch, C. San Marchi, "Hydrogen compatibility of austenitic stainless steel tubing and orbital tube weld" ICHS 2013, (submitted).
- B.P. Somerday, K.A. Nibur, and C. San Marchi, "Measurement of Fatigue Crack Growth Rates for SA-372 Gr. J Steel in 100 MPa Hydrogen Gas Following Article KD-10", ASME PVP2013, Paper No. 97455, 2013, submitted.
- B. An, H. Itouga, T. Iijima, C. San Marchi, and B. Somerday, "Hydrogen-assisted twin boundary fracture of type 304 austenitic stainless steel at low temperature investigated by scanning probe microscopy", ASME PVP2013, Paper No. 97355, 2013, submitted.
- C. San Marchi, L.A. Hughes, B.P. Somerday, and X. Tang, "Hydrogen-assisted fracture of type 316L tubing and orbital welds", ASME PVP2013, paper no. 97538), 2013 submitted.

SUBTASK 3.1: TEST METHOD DEVELOPMENT

Test method development for material, components and systems is a critical component of the DOE FCT SC&S sub-program element. Test methods that are conducive to standardization and balance data reliability with test efficiency are essential for technology deployment. International harmonization of materials, components, and systems is a core tenant of the test and qualification method development process.

PROJECT STATUS

On Target – Test matrix for fatigue crack growth measurements on 34CrMo4 and SA372 Grade J pressure vessel steel in high-pressure hydrogen gas complete. Completion of these measurements represents a milestone in that full scale vessels of similar steels were previously tested. Therefore this coupon scale data may be compared with the full scale system. It is rare that both full scale and coupon level tests so closely align. The analysis of these measurements in juxtaposition with full scale measurements may offer important insight into areas of improvement for optimizing safe designs and improved test methods.

Steel	S_u (MPa)	H_2 pressure (MPa)	Test frequency (Hz)	Load ratio	Status
SA372 Gr. J	890	10	10	0.1	Complete FY12-13
		10	variable	0.1	Complete FY12-13
		45	10	0.1	Complete FY11-12
		45	variable	0.1	Complete FY11-12
		100	10	0.1	In progress
		100	variable	0.1	Complete FY12-13
34CrMo4	1045	10	10	0.1	Complete FY12-13
		10	variable	0.1	Complete FY12-13
		45	10	0.1	Complete FY11-12
		45	variable	0.1	Complete FY12-13
		100	10	0.1	Complete FY12-13
		100	variable	0.1	Withdrawn

PLANS FOR NEXT QUARTER AND KEY ISSUES

Report results of tests and receive feedback from peers.

SUBTASK 3.2: CRITICAL DATA

Critical data are needed to qualify hydrogen containment components according to new codes and standards, e.g., ASME Article KD-10, ASME B31.12, and SAE J2579. SNL/CA is uniquely positioned to generate data for structural materials exposed to hydrogen gas pressures exceeding 70 MPa. Enabling deployment of selected hydrogen containment components promotes market transformation for hydrogen energy technologies. Critical data focus areas include: welded materials and structures, high strength structural materials, lower-cost materials, high pressure hydrogen testing and non-metals. The non-metal portion of this subtask will leverage work at the Hydrogen Industrial Use and Storage (HYDROGENIUS) project at Kyushu University.

PROJECT STATUS

On Target – Two sets of welded tubing testing completed. Results have undergone initial analysis with final results expected in Q3.

Initial results are currently inconclusive as the variation experienced for 'weld B' in Figure 3 is under investigation. Increased sample sizes are necessary to refine the results supporting a conclusion.

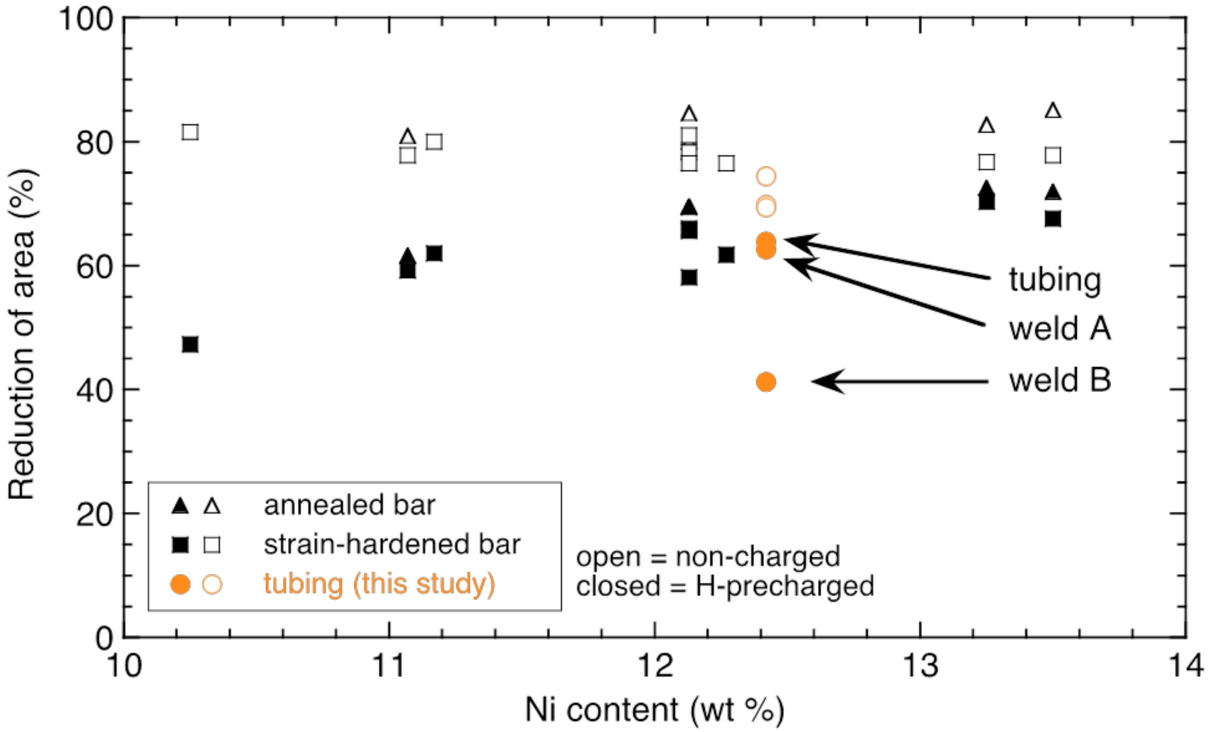


Figure 3. Comparison of tensile ductility tests for annealed bar, strain-hardened bar and tubing of type 316 and 316L - results are plotted as a function of nickel content

PLANS FOR NEXT QUARTER AND KEY ISSUES

A summary of the testing lessons learned, test results and analysis are expected to be presented at the Annual Merit Review.

SUBTASK 3.3: INFORMATION RESOURCES

The proceedings from the Materials Compatibility workshop (LVOC, November 3rd, 2010) indicate a need for a materials database that is structured to coordinate test methods and consolidate testing results to harmonize requirements and standards development. In FY13, we will formulate a Hydrogen Materials Collaboration Database, as a resource for the broader hydrogen community. It will include discussion forums, archives of open-source content and reports from conferences or meetings, and new results on hydrogen compatibility testing that have not yet gone through peer review for incorporation into the Technical Reference. The Hydrogen Materials Collaboration Database will enable global harmonization of test methods, facilitate research coordination, and lead to accelerated deployment of hydrogen systems.

Project Status

- Database file architecture developed for sharing data; Excel spreadsheet dissemination of information. Files have been posted on OpenEi website.
- Commercial database software has been explored and found to be a robust solution to long-term archiving and dissemination of data; data can be shared via Internet interface. Investment (financial) for software limits implementation; Sandia corporate has committed to lifetime investment to purchase software licenses to support NW activities, which will be leveraged resources for this program.

Plans for Next Quarter and Key Issues

Continue developing spreadsheets and identify critical path milestones for go/no-go decision with commercial software option.

Subtask 3.4: Variable-temperature testing in H_2 gas capability

Sandia has designed and maintained a unique laboratory capability for conducting tests on materials under dynamic loading in high-pressure hydrogen gas. This system is essential for executing the materials testing tasks related to fatigue crack initiation and growth in hydrogen gas. The current capability only operates at room temperature, but it has been recognized that fatigue testing must be conducted at sub-ambient temperature for certain materials classes such as stainless steels. In this task, a new system will be developed that allows materials testing under dynamic loading in high-pressure hydrogen gas but with the ability to vary temperature. This activity involves both capital investments as well as labor costs. It is expected that the capability will be developed by leveraging resources from the EERE/Fuel Cell Technologies Office and NNSA.

Project Status

On Target – Ongoing work to install automated gas supply and distribution manifold. This quarter saw further progress in installation of piping systems and manifold components. This work is leveraged with support from the various programs that it supports and is occurring at a controlled pace consistent with available resources.

Plans for Next Quarter and Key Issues

Continue completion of gas manifold, emphasizing electrical systems and software interface. Completion of gas manifold is expected by end of FY13. Collaboration with student design teams at Boise State University expected to provide two design concepts for pressure vessel with variable-temperature feature; these designs will be available in May. Submitted capital equipment request to NNSA for funds to procure pressure vessel with variable-temperature feature. The pressure vessel is the final sub-system needed to complete the fully functioning capability.

SUBTASK 3.5: I²CNER LEAD PRINCIPAL INVESTIGATOR FOR HYDROGEN STRUCTURAL MATERIALS

Sandia provides leadership for the Hydrogen Structural Materials Division within the International Institute for Carbon-Neutral Energy Research (I^2CNER). This research division in I2CNER is focused on understanding fundamental mechanisms of hydrogen embrittlement and developing new materials for hydrogen service – two areas that are critical to the Safety, Codes and Standards Program. Support of this task will enable Dr. Somerday (Division Lead Principal Investigator) to interface the research performed in I^2CNER with the DOE FCT program, providing a conduit for research information between this international institute and the Fuel Cell Technologies Program.

PROJECT STATUS

Brian Somerday attended the I^2CNER Annual Symposium at Kyushu University in January, presenting an overview of research progress in the Hydrogen Structural Materials Division. In addition, he served as a session chair at the HYDROGENIUS & I^2CNER Research Symposium on Structural Materials, which featured presenters from 8 different countries. Brian Somerday also met with collaborators in I^2CNER, exchanging views and providing guidance on basic research that complements the applied research in the Materials Compatibility activity.

PLANS FOR NEXT QUARTER AND KEY ISSUES

In June, Brian Somerday will travel to Kyushu University for the MEXT Site Visit, essentially an annual review of the Institute. As Lead Principal Investigator, he will represent the Hydrogen Structural Materials Division in the review.

SUBTASK 3.6: AIST-SNL COLLABORATION ON MATERIALS TESTING FOR STANDARDS DEVELOPMENT

The DOE and METI have coordinated R&D efforts in the area of hydrogen safety, codes and standards. One of these coordinated activities is collaboration between AIST-Tsukuba and Sandia to develop standardized test methods for fracture threshold and fatigue crack growth measurements of steels in high-pressure hydrogen gas and to define the mechanisms of hydrogen-assisted fracture in stainless steels. An evolving project plan initiated in FY12 outlines the details of coordinated research between AIST-Tsukuba and Sandia in these two topic areas. The collaboration is expected to involve reciprocal visits to the U.S. and Japan.

PROJECT STATUS

On Target with reduced scope – This activity was reduced due to budget constraints. The reduction eliminated experiments on pressure vessel steels at Sandia that complement companion experiments at AIST. The reduction preserves hosting the researchers from AIST-Tsukuba for project meetings and discussion. Brian Somerday met twice with his project-lead counterpart at AIST, once at AIST and another time at Sandia, to discuss progress on testing pressure vessel steels in hydrogen gas at AIST. Chris San Marchi visited to AIST/Tsukuba for two weeks in March (expenses paid by AIST); presenting seminars at AIST and at Kyushu University (Hydrogenius). Nippon Steel and Sumitomo Metals was also visited to share experience with testing in gaseous hydrogen and explore opportunity for collaboration with a steel manufacturer.

PLANS FOR NEXT QUARTER AND KEY ISSUES

- AIST-Tsukuba will continue to conduct experiments on pressure vessel steels in hydrogen gas which will form the basis for discussions in project meetings hosted at SNL-CA throughout FY13. Sandia is providing test specimens from a U.S. pressure vessel steel specification for inclusion in the AIST test matrix.
- Dr. Bai An from AIST is planning a visit to Sandia in May to continue our collaboration.

SUBTASK 3.7: HYDROGEN MATERIALS TESTING EQUIPMENT WORKSHOP

The proceedings from the Materials Compatibility workshop (LVOC November 3rd, 2010) and publication of the CSA CHMC1 standard motivate the need to develop a network of materials testing capabilities. Based on the limited number of existing materials testing laboratories around the world, several different approach methods and new techniques have been developed. This workshop will collect experiences in materials testing in an effort to establish best practices to benefit the development of new capabilities in the stakeholder community.

PROJECT STATUS

Workshop will occur on April 9-10 with an expected 20 participants from 6 countries.

PLANS FOR NEXT QUARTER AND KEY ISSUES

A summary of the workshop outcomes is planned for Q3.

FY2013, Task 4: Composite Overwrapped Pressure Vessel (COPV) Safety

Point of Contact: Chris Moen

Background

This task provides the foundation for improved understanding of composite and polymer materials systems behavior at FCEV-relevant conditions. Polymeric materials are used in high-pressure hydrogen fuel system and dispensing applications as Type IV tank liners, dispensing hoses, seals and O-rings. There is little technical information on polymer material performance at the high pressures and low temperatures found in these applications. Hydrogen system designers would like to characterize polymer materials at extreme conditions as they strive to reduce cost, improve reliability, improve safety, and develop physically-motivated performance-based product standards.

Objective

Leverage successful materials characterization activity in task 3 for non-metal materials

Publications/Presentations

- Contributed to Proceedings from Informational Meeting held Oct 17-18, 2013 at DOE Headquarters, Washington, DC.
- “Polymer and composite materials used in hydrogen service”, Polymer and Composite Materials Information Exchange Meeting Proceedings, SAND2012-10860P, Sandia National Laboratories, 2012.

Subtask 4.1: Composite and polymer materials and structures science and technology

Test method development for material, components and systems is a critical component of the DOE FCT SC&S sub-program element. Test methods that are conducive to standardization and balance data reliability with test efficiency are essential for technology deployment. International harmonization of materials, components, and systems is a core tenant of the test and qualification method development process and is a focus area in the Sandia FY13 International Programs AOP.

Project Status

On Target – Hosted information exchange meeting at DOE Headquarters in early FY13Q1. Proceedings of that meeting were published in FY13Q2. Towards the end of FYQ2 this subtask expanded to include a literature review of existing information with regard to non-metal behavior in hydrogen environments. This review will complete in Q3.

Plans for Next Quarter and Key Issues

Continue to support the FCTO with presentations and leadership of non-metals material behavior in hydrogen environments. Publish literature review and work to establish strategic goals for identification, investigation and innovation relevant to non-metal materials performance in high-pressure hydrogen environments.

FY2013, Task 5: Safety, Codes and Standards Development Support

Point of Contact: Aaron Harris

Background

The subtasks listed are summarized as targeted code and standards development activities where significant barriers exist to the market penetration of hydrogen powered fuel cell systems. Leadership in this area is crucial to ensure that the investments placed in scientific evaluation, research and innovation from the tasks above are communicated to industry lead codes and standards development activities.

Objective

Eliminate barriers to deployment of hydrogen fuel cell technologies through scientific support in codes and standards development efforts

Publications/Presentations

- Harris, A. “Public-Private Cooperation” presented to IEA Experts meeting in Bethesda, MD. Oct 4-5
- Harris, A. “Status of NFPA 2 Fueling Working Group” presented to NFPA 2 committee, NREL, Golden, CO. Nov 14
- Harris, A. “Discussion of lessons learned from a hydrogen release” ICHS 2013, (submitted).
- Harris, A. “What is an acceptable hydrogen leak?” ICHS 2013, (submitted).

Project Status

Due to budget Sandia has substantially reduced participation in codes and standards participation including support of several standards activities, including the role of chairperson for CSA HPIT1, CSA HGV 4.9 and NFPA 2 Fueling Working Group.

Plans for Next Quarter and Key Issues

Continue to provide support to FCTO subprogram with regard to key standards activities. Stand prepared to expand activities and re-engage with standards committees in the event that funding is restored. Prepare plans for FY14 that include appropriate level of effort in codes and standards support within conservative budget estimates.