Abstract

This paper describes the development and current status of an industry action plan for in-service welding of pipelines. The issues were identified during the first international conference on welding onto in-service petroleum gas and liquid pipelines, Wollongong, Australia, 2000. The action plan has developed to a stage that research proposals are being prepared for issues that need further research, other issues that do not require research will be developed into expert technology tools and available to industry.

Keywords

Pipeline, In-service Welding, Hot Tapping, Burnthrough, Hydrogen Cracking, Weldability.

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1. INTRODUCTION

Welding onto in-service pipelines and piping is a method frequently employed for repairs or modifications to existing systems. The alternatives to this technique would cost the pipeline and petrochemical industry millions of dollars, increase environmental problems with respect to venting large quantities of gas and decrease reliability of supply to customers.

For many years a large proportion of the world's in-service welding research effort has been devoted to low strength, thick walled pipelines. Recently however, it has become common practice for pipelines to be designed and constructed from high strength thin walled materials. Many of the new pipelines fall outside the current range of research outcomes regarding wall thickness and material strength.

The major concerns of welding onto in-service pipelines are burn-through and crack susceptibility. These problems intensify as the wall thickness decreases. Heat input levels are critical for thin walled pipes and control of heat input is complicated by the inherent process variability of the MMAW process.

A number of recent incidents have occurred within Australia, fortunately with no serious injury. The WTIA (Welding Technology Institute of Australia) SMART (Save Money And Reengineer with Technology) Pipelines Industry and Petro Chemical Groups decided however, that it was timely to conduct a conference on this important subject with indicators of potential problems surfacing. The first International conference on “Welding onto In-service Petroleum Gas and Liquid Pipelines” was held in March, 2000 at Wollongong Australia.

In contrast to most other welding activities there are no satisfactory code guidelines for in-service welding. There is very little practical guidance available on the subject to assist engineers and technical staff. There is almost a complete absence of information pertaining to thin walled, high strength pipelines.

Simulated testing that represents actual conditions for procedure qualification, is difficult and costly due to the need for pressure and flow conditions to be simultaneously represented.

Non-destructive examination on the completed in-service welds is typically limited to surface methods, which makes it difficult to detect crack susceptible microstructures in the HAZ subjected to rapid quench rate due to product flow effect. The same situation is believed to exist in most other countries as well as Australia.

The purpose of the conference was to bring leading experts from around the world to contribute to a highly structured discussion with a view to producing an action plan to:

1. Create an awareness of the potential problems;
2. Develop practical guidelines to assist engineers and technical staff;
3. Foster collaborative research between the leading researchers within this field

2. THE ESTABLISHMENT OF AN INDUSTRY ACTION PLAN

2.1 The Action Plan Objectives
During the In-Service Welding of Pipelines Conference, held in Wollongong at the beginning of March, one of the outcomes was the identification of the need to produce an Industry Action Plan that was based on the issues raised. This Action Plan must:-

Y Create an awareness of the problems, both real and potential, associated with In-Service Welding.
Y Develop practical Engineering solutions to these problems.
Y Provide practical guidelines for the approach to In-Service welding.
Y Foster collaborative research between interested parties on a worldwide basis.
Y Develop lasting relationships.

2.2 Key Issues to be Addressed

The key issue list was developed at the end of the Conference, with delegates noting the issues of concern to each of them. All of the issues were captured, and then an attempt was made to group them into common themes. These grouped themes are:

2.2.1 Hydrogen Assisted Cracking

Carbon Equivalent
- Formula;
- In-situ measurement.

Preheat
- How much?
- Practicability.

Heat Input
- Improved control;
- Arc efficiency.

Cooling Rate
- Standardise EWI;
- Heat Sink Capacity Test.

Hardness
- HV limit for modern steels.

Temper Bead
- Quantify role.

Multi-pass Welds
- Modelling capability.

Hydrogen
- Hydrogen potential;
- Hydrogen transfer;
- Hydrogen control.
2.2.2 **Burn-through**

**Thickness**
- Validated burn-through limits.

**Heat Input**
- Improved control;
- Arc efficiency.

**Effect of Stress**
- Hoop stress;
- Longitudinal stress;
- Residual stress.

2.2.3 **Procedural Tools**

**User-friendly “Cooling Rate” models**

**Code-based Guidance**
- Essential variables.

**Qualification Test Protocol**
- Test pipe-cooling methods.

**Technology Transfer and Education**

**Welders**
- Guidance note for welding operators (in-service welding);
- Willingness to follow instructions;
- How often tested?

**Weld Monitoring and Inspection**

**O-Lets**
- Required reinforcement;
- Welding to achieve the required reinforcement.

Pre-qualification of Contractors for In-service Welding.

Training and Certification of Welding Inspectors for In-service Welding.

2.2.4 **Other Issues Identified Over the Three Days that Time did not Allow for Grouping**

**Buttering Runs.**

**Mechanised In-service Welding.**

**Real Meaning of Heat Input.**

**Pressure Issues.**

**Choice and Limitations of NDT.**

**Video on Risks of Things Going Wrong.**
3. WORK TO BE DONE ON THE ISSUES

The delegates felt that it was paramount to identify the organisations and individuals within those organisations who were currently involved with work on the groups of issues. The current status of the work needs to be identified, the percentage completed and the targeted outputs. The objective behind this was to then identify if any duplication was taking place, and also to highlight logical areas where individuals or organisations could work together to give more cost effective outputs. Some suggestions were:

- WTIA working with the Edison Welding Institute,
- CSIRO and/or the CRC-Welded Structures working with the Edison Welding Institute or the Battelle Institute.
- WTIA working with the Pipeline Research Council’s Welding Committee

4. FACILITATION AND CO-ORDINATION

The delegates also felt that in order to coordinate all of this work, a facilitator was required in each country where work was being carried out or where some collaboration was envisaged, with an overall co-ordinator of the project. The following people were suggested:

- Australia       Paul Grace   (Co-ordinator)
- Canada          David Dorling
- UK              Peter Boothby
- USA             Bill Bruce
- NZ              Valerie Linton

5. POSSIBLE OUTPUTS

The potential outputs stemming from the cooperation and collaboration between the partners were identified as:

- Technology transfer

- Collaborative research projects between the CRC for Welded Structures and the Edison Welding Institute.
The need for Expert Technology Tools to be developed and promoted within the industry.

An improvement in the Standards and Specifications applied to In-Service welding, including attention paid to the supply of fittings.

The Technology Transfer mechanisms would be improved. Examples are the extension to WTIA’s Technical Notes or possibly some Practical Guidelines for In-Service welding.

Some standardised, more focused procedures in order to improve efficiency and reliability.

Some changes within management, both in terms of culture and attitude, by inducing a real awareness of the problems.

6. CURRENT STATUS OF THE ACTION PLAN

The issues raised during the conference have been expanded into a list of questions, and grouped into four categories:

Category 1. - Expert Technology Tools.
The issues that form this category require little or no additional research to complete, but will require collaboration between local and overseas organisations to collate and complete.

Category 2. – Weldability Research.
A research proposal is required to deal with the issues in this category. The proposal will include funding requirements, timing, outcomes and perceived benefits. This research will include Gleeble machine work.

Category 3. – FEA Research.
A research proposal is required to deal with the issues in this category. The proposal will include funding requirements, timing, outcomes and perceived benefits. This research will utilise the outcomes from category 2 research to assist with FEA in-service welding modelling.

Category 4. – Test Loop
The issues that form this category require development work on a live test loop. The test loop would allow solutions to be provided for issues that are difficult and often impossible to simulate. The test loop will need to cater for various flow and pressure situations, also different pipe material grades and wall thicknesses.

6.1 Category 1 - Expert Technology Tools

1.1 - Carbon Equivalent
What is the optimum method for determining the chemical composition (carbon equivalent) of an in-service pipeline?
What carbon equivalent limit(s) should be imposed on manufacturers for different types of fittings (e.g., split sleeves, weld-o-lets, etc.)?

1.2 – Preheat
What other preheating methods can be used for in-service welding? What preheating levels are required for different in-service welding applications?

1.5 – Hardness
What is the optimum method of hardness measurement for in-service welds (e.g., format, load size, indent location, etc.)?

1.6 - Tempered Bead
What are the tolerances in terms of welding parameters for tempered bead welds (i.e., how big is the tolerance box)? How much additional welder skill/visual acuity is required for a welder to successfully execute a tempered bead weld?

1.8 – Hydrogen
What measures should be taken to assure that hydrogen levels for in-service welds made using low-hydrogen SMAW electrodes are minimized?

2.1 – Thickness
What precautions need to be taken to avoid burnthrough when welding onto in-service thin-wall pipelines?

2.3 - Effect of Stress
Is there a wall thickness above which the risk of burnthrough is independent of internal pressure?

3.2 - Code-based Guidance
Would the development/improvement of supplementary guidance for existing codes improve safety and reliability of in-service welding/welds?

3.3 - Qualification Test Protocol
Are existing methods for simulating in-service conditions (e.g., pipe section filled with water) adequate for procedure qualification tests?

3.4 - Technology Transfer and Education
What can be done to facilitate the transfer of technology to and the education of personnel involved with in-service welding? Would the development of a video pertaining to things that can go wrong facilitate technology transfer and education? Would a paper aimed at management facilitate technology transfer and education? Would a paper describing the environmental benefits of in-service welding facilitate technology transfer and education? Would better website coverage encourage technology transfer and education?

3.5 - Welders
What level of training/certification should be required of welders for in-service welding? What can be done to facilitate this training and certification?

3.6a - Weld Monitoring
What level of weld monitoring is necessary to assure adequate quality of in-service welds? What equipment/techniques is/are currently available for monitoring in-service welds (e.g., monitoring heat input levels)? Is/are there better equipment/techniques?

3.8 - Pre-qualification of Contractors for In-service Welding
Is there a testing protocol suitable for pre-qualification of contractors for in-service welding? What limitations should be imposed on pre-qualified contractors?

3.9 - Training and Certification of Welding Inspectors for In-service Welding
What level of training/certification should be required of welding inspectors for in-service welding?
What can be done to facilitate this training and certification?

6.2 Category 2 - Weldability Research (Including Gleeble Machine)

1.1 - Carbon Equivalent
What carbon equivalent formula should be used to assess the weldability of different line pipe steels (e.g., when should the IIW formula be used and when should the Pcm formula be used)?

1.2 - Heat Input
In terms of hydrogen cracking risk, is “heat input” produced by one welding process (e.g., MMAW) equivalent to the heat input produced by another process (e.g., GMAW)?

1.5 - Hardness
What hardness limits should be imposed for in-service welds?
Should hardness limits be a function of hydrogen level and material chemical composition?

1.6 - Temper Bead
How can the effect of tempering from subsequent passes be incorporated into hardness and cooling rate prediction methods for welds deposited using a temper bead sequence (i.e., temper bead welds)?

6.3 Category 3 - FEA Research

1.4 - Cooling Rate
Are there better ways of accurately predicting the cooling rate of in-service welds?
What limits should be imposed on weld cooling rates for in-service welds?

1.6 - Temper Bead
How can the effect of tempering from subsequent passes be incorporated into hardness and cooling rate prediction methods for welds deposited using a temper bead sequence (i.e., temper bead welds)?

1.7 - Multi-pass Welds
How should the effect of tempering in standard multi-pass welds be accounted for?

2.1 - Thickness
What is the minimum thickness for which in-service welding can be safely applied?

2.3 - Effect of Stress
What effect does the level of stress in the pipe wall (i.e., hoop stress caused by internal pressure) have on the risk of burnthrough?
For weld deposition repairs, does welding in the longitudinal direction represent a greater burnthrough risk than welding in the circumferential direction?

3.1 - User-friendly “Cooling Rate” Models
What can be done to further improve the existing models for predicting the cooling rates of welds made onto in-service pipelines?

Are there better ways of accurately predicting the cooling rate of in-service welds?

Are there better ways to use predicted cooling rates (i.e., better than using predicted cooling rates to predict hardness which is then used to predict cracking)?

3.7 - Weld-O-Lets
Are procedures qualified for branch connections using a branch made of pipe suitable for in-service welds to attach weld-o-lets? If not, what procedure qualification tests are appropriate for small diameter weld-o-lets (e.g., < 50mm diameter)?

6.4 Category 4 - Trials Conducted on Gas Test Loop

1.2 - Preheat
What applicability does the new induction preheating equipment have for in-service welding?
What effect, if any, does condensation on the pipe from flame preheating have on weld hydrogen levels?

1.3 - Heat Input
What effect does the variability in heat input experienced during manual welding have on the integrity of in-service welds?
In terms of hydrogen cracking risk, is “heat input” produced by one welding process (e.g., MMAW) equivalent to the heat input produced by another process (e.g., GMAW)?
Under what conditions is mechanized welding required to alleviate problems resulting from variability in heat input experienced during manual welding?

1.4 - Cooling Rate
Should weld cooling rate limits be a function of hydrogen level and material chemical composition?

1.6- Temper Bead
How can the effect of tempering from subsequent passes be incorporated into hardness and cooling rate prediction methods for welds deposited using a temper bead sequence (i.e., temper bead welds)?
What are the tolerances in terms of welding parameters for temper bead welds (i.e., how big is the tolerance box)?

1.7 - Multi-pass Welds
Are hardness and cooling rate prediction methods for single pass welds appropriate for standard (non-temper bead) multi-pass welds?
How should the effect of tempering in standard multi-pass welds be accounted for?

1.8 – Hydrogen
What other low hydrogen welding processes are suitable for in-service welding?

2.1 - Thickness
What is the minimum thickness for which in-service welding can be safely applied?

2.2 - Heat Input
In terms of burnthrough risk, is “heat input” produced by one welding process (e.g., MMAW) equivalent to the heat input produced by another process (e.g., GMAW)?
2.3 - Effect of Stress
Are there ways of accurately predicting a safe pressure for welding onto in-service thin-wall pipelines?

3.2 - Code-based Guidance
What improvements can be made to the current codes for in-service welding?

3.3 - Qualification Test Protocol
Under what conditions is it necessary to separately qualify a procedure with regard to both hydrogen cracking (i.e., high rate of heat removal to simulate worst case) and burnthrough (i.e., low rate of heat removal to simulate worst case)?
Is there a cost-effective method for simultaneously qualifying a procedure with regard to hydrogen cracking and burnthrough?

3.5 - Welders
What level of training/certification should be required of welders for in-service welding? What can be done to facilitate this training and certification?

3.6b - Inspection
What non-destructive testing methods are appropriate for various in-service weld geometries (e.g., branch, sleeve, etc.)? What level on NDT should be required for in-service welds?

3.8 - Pre-qualification of Contractors for In-service Welding
Is there a testing protocol suitable for pre-qualification of contractors for in-service welding? What limitations should be imposed on pre-qualified contractors?

3.9 - Training and Certification of Welding Inspectors for In-service Welding
What level of training/certification should be required of welding inspectors for in-service welding?
What can be done to facilitate this training and certification?

7. CONCLUSIONS
The objectives of the Wollongong conference were achieved, including an extensive list of issues being developed. Many of the issues raised were related to the unique situation of Australian pipelines being thin wall and high strength, however many other issues were raised that affect in-service welding technology worldwide. The action plan has progressed to a stage whereby funding will be required to progress and provide the solutions required for industry. Sources of potential funding have been investigated and work is in progress to secure such funding. Priority setting is underway, thus we intend to concentrate on the issues of most significance to industry and not to reinvent the wheel in the cases where work has already been completed or underway.
The conference demonstrated that issues that affect an industry sector on a local and global basis can be identified and actioned in a much more effective way when we collaborate as a group. The true test of providing solutions for industry will be securing the funding for collaborative research and development with respect to in-service welding that is much needed. All suggestions/recommendations for improving the action plan or priority setting are most welcome and should be directed to the WTIA.

8. ACKNOWLEDGMENTS
Edison Welding Institute, particularly Bill Bruce in his capacity as Technical Director for the conference and also for his ongoing efforts in progressing the action plan, are thanked for their contribution.

9. REFERENCES


