International Symposium on Microalloyed Steels for the Oil and Gas Industry
Edited by W.J. Fazackerley, P. Bordignon, K. Hulka, and F. Siciliano
TMS (The Minerals, Metals & Materials Society), 2007

WELDABILITY PRE-QUALIFICATION OF STEELS FOR DEEPWATER SERVICE

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Abstract

The weldability of steels for deepwater applications must be determined long before welding procedures is qualified. The weldments of deepwater equipment such as steel catenary risers (SCRs) are subjected to currents which result in high cyclic stresses. It is imperative that steels selected for such service have high CTOD fracture toughness values after welding to ensure good defect tolerance. Through fracture mechanics analyses, these CTOD values are used to determine the defect acceptance criteria that is used for inspection of such weldments. The base metal and weld metal are more easily obtained, but because the weld joint design changes the position of the HAZs, the CTOD value for the HAZ is usually a combination of the base, weld consumable, and HAZ. The value obtained from such a test is suspect, and may give an optimistic value if the weld metal or base metal have high CTOD values. This paper discusses the various strategies for determining the true weldability long before construction commences, using API RP 2Z (1) Type tests for prequalification of base materials.

Introduction

Weldability may mean different things to different people and organizations. There are many different types of weldability tests but very few that have been standardized throughout a particular industry. For over a decade the offshore industry has relied on API RP 2Z as a standardized method to measure weldability of structural plate steels. The pipeline industry has used various types of tests to measure weldability for more specific characteristics such as susceptibility to hydrogen cracking and hardness for sour service conditions. The more recent usage of pipe steels for applications such as SCRs, tendons, and flowlines demands a more thorough evaluation of heat affected zone properties, especially fracture toughness when leak before break criteria are applied.

The API RP 2Z procedure was influenced by research conducted by Exxon in the early 1980's (4). In that research poor HAZ toughness was found to be associated with the presence of local brittle zones (LBZ). LBZs consist of martensite/austenite (M/A), second phase, which have been quantitatively correlated with CTOD toughness in research by Haze and Aihara (5). This work has shown that the CTOD values measured in simulated HAZs decline rapidly as the volume fraction of martensitic islands increased.

API 1104 Appendix A describes heat affected zone CTOD testing that is purely dictated by hardness, and does not necessarily locate the microstructure with the lowest, and therefore characteristic, toughness needed to correctly calculate the defect tolerance. The test protocol employed cannot guarantee the detection of the aforementioned M/A and consequent LBZs.

Pre-existing Weldability Codes, Standards, and Specifications

- API RP 2Z
- Euronorm EN 10225 (2)
- API 1104 Appendix A (3)
- Company Specific Requirements

Deepwater Equipment

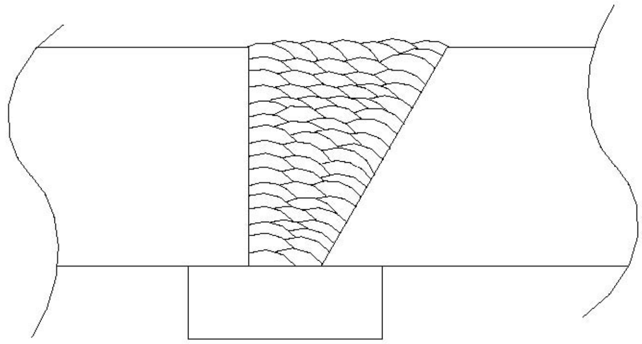
Twenty years ago projects in water depths of 300 meters were considered to be deepwater projects. Over the past twenty years the oil industry has expanded the term deepwater to mean depths up to and in some recent cases beyond 3,000 meters. At such water depths the fatigue considerations are paramount to the successful development of projects. Weldability characteristics are important for such deepwater applications as:

- Steel catenary risers (SCRs)
- Flowlines
- Top tension risers
- Pile castings
- TLP tendon pipe
- TLP tendon forgings
- Structural steel plate for hull and topsides
- Structural pipe for topsides
- Structural forgings

Experimental Methodology

API RP 2Z and Euronorm 10225 dictate certain operational constraints relative to the actual welding and configuration of the test coupons and procedural details. The size of the test plates is determined by the plate thickness and number of test coupons to be removed from the final weldment. API RP 2Z allows for the use of both T x T as well as T x 2T specimens but indicates a preference for the T x 2T. On thick plates this can result in massive test weldments when multiple CTOD coupons are required, especially at low heat inputs. This can be further increased when there can be, and usually are, multiple retests.

The most important feature of the API RP 2Z and Euronorm EN 10225 weldability tests is the straight-sided weld bevel and consequent HAZ microstructural sampling requirement. Considerable effort is expended in both specifications defining precisely how the straightness of the heat affected zone is obtained and verified. It is this aspect of the test that is most difficult to execute while staying within tight boundary conditions of welding heat input, etc.



Both specifications clearly delineate heat input ranges. API RP 2Z contains three heat input levels, low, medium, and high that are appropriate for high productivity structural fabrication. There are also requirements listed for preheat and interpass temperature whereby the low heat input coupon must be welded using the lowest preheat and interpass temperature. Conversely the high heat input weld coupon employs the highest preheat and interpass temperature. This is an attempt to cover the extremities of the range of operating variables during production fabrication.

API RP 2Z and EN 10225 are quite similar in their test requirements and sectioning methods. Both specifications require CTOD testing of the grain coarsened heat affected zone (CGHAZ) and subcritical heat affected zone (SCHAZ). The number of test coupons do differ between the two specifications. Some customer requirements specify the location for coupon extraction somewhat differently such as transformed heat affected zone (THAZ) and visible heat affected zone (VHAZ), but the actual specimen location is essentially identical.

API RP 2Z and EN 10225 both specify the use of BS 7448 Part 1(6) for CTOD testing. Due to this requirement and the strict metallurgical sampling, it is essential that a well-qualified laboratory with extensive experience in such testing, working in close cooperation with materials and welding engineers associated with the project, conduct the tests.

Each material supplier that attains prequalification using API RP 2Z or EN 10225 must produce material within very controlled processing and chemical composition parameters. Should material be produced outside these parameters the material is either rejected, downgraded, or subjected to the full testing program once again. In certain circumstances material has been ordered and supplied without the prequalification testing and documentation. When this occurs it is the responsibility of the purchaser to carry out API RP 2Z type prequalification testing under the guidelines of the test program defined by the end user.

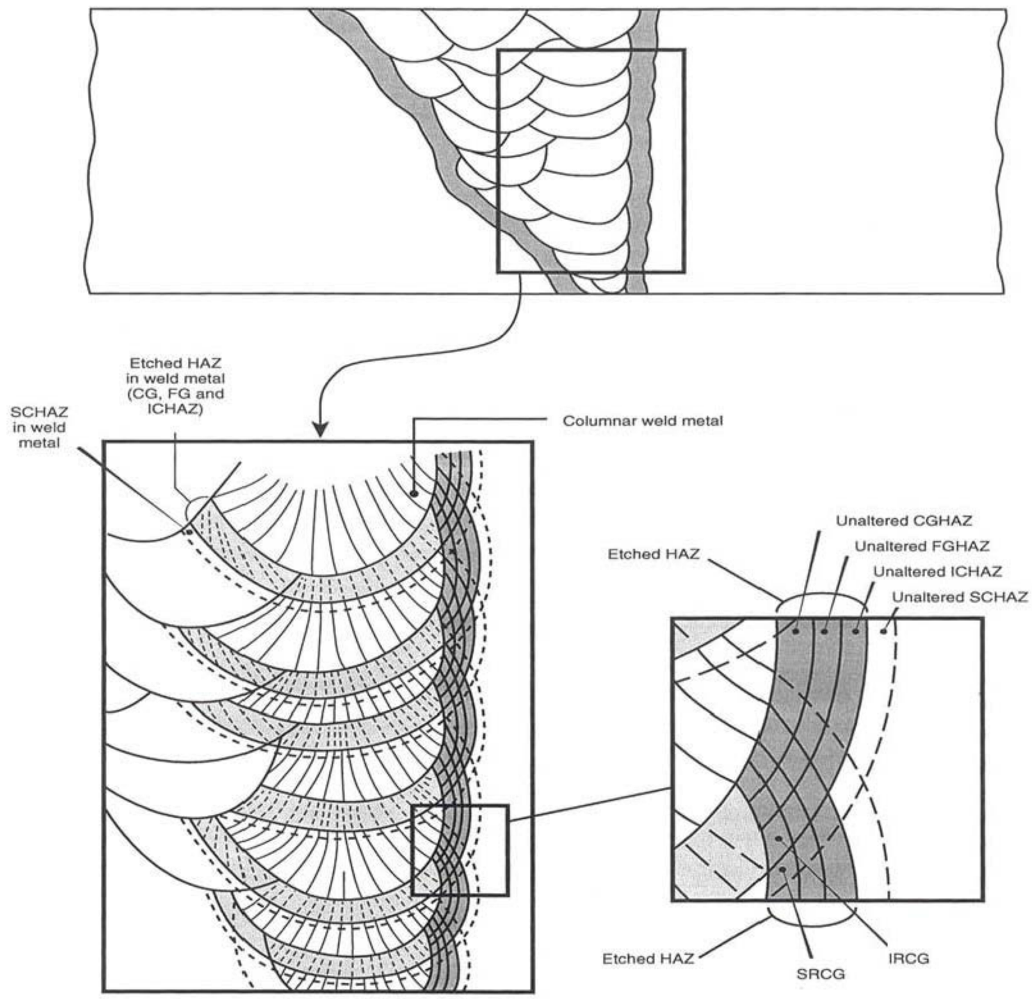


Figure 4a—HAZ Regions in a Multi-Pass Weld With One Plate Edge Unbeveled

In all codes and specifications there are additional requirements for other tests such as Charpy V-notch, hardness, and delayed cracking tests. We understand the need for these tests but will not include such tests in this presentation.

Discussion

One of the advantages of prequalification testing is that it may alleviate the need to perform HAZ CTOD testing during qualification of welding procedures by the fabricator. The importance of this is that many of the CTOD tests normally conducted by the fabricator do not truly represent the worst case CTOD scenario. The tests conducted in the HAZ may include large percentages of weld metal and or base metal depending upon the bevel design.

Limitations of API RP 2Z and Euronorm EN 10225

API RP 2Z and EN 10225 were intended primarily to cover the steel compositions and processing characteristic of structural plate steels. EN 10225 does address pipe and structural shapes, however, the emphasis is clearly placed on plate steels. The deepwater industry involves the use of other material forms that have chemical compositions and processing characteristics that would not easily fall into the required allowable ranges. Specifically, pipe steels, forgings, and castings are becoming widely used in highly fracture critical applications. These components often require the use of post weld heat treatment to gain the required properties, which is not fully quantified in either document.

Deepwater applications often require the use of low heat inputs due to out-of-position welding required during offshore pipe installation. Heat inputs as low as 0.4 kJ/mm are not uncommon in offshore pipe installation where the GMAW process is widely used. API RP 2Z has a lower bound heat input requirement of 1.5 kJ/mm and EN 10225 sets the lower boundary at 0.7 kJ/mm.

Both API RP 2Z and EN 10225 require a test temperature of –10 ^{o}C, this could have positive and negative effects. In deepwater Gulf of Mexico the lowest anticipated service temperature (LAST) is no lower than 0 °C, while the actual lowest temperature is 4°C. Conversely offshore North Sea applications may see LASTs as low as –40 °C. It is imperative that each individual project defines the LAST as soon as possible to make sure that the prequalification testing is carried out at the correct temperature by either the material supplier or the end user.

Projects are beginning to use a leak before break analysis more and more for many critical components such as SCRs, TTRs, and tendons. Such analyses have shown the need for CTOD values far in excess of those specified by API RP 2Z or EN 10225 (0.25 mm). CTOD values as high as 0.63 mm have been specified for deepwater SCR applications during the past few years.

Limitations of API 1104 Appendix A

While API 1104 Appendix A includes CTOD testing of the heat affected zone, the data that is gathered in most cases does not represent the true lower boundary fracture toughness. As can be seen in the following figure, the heat affected zone sample actually intersects more than 70 % base material. If the highest hardness location were to occur in the root area of this weld the heat affected zone CTOD sample could contain more than 70 % weld metal. The values attained can lead to complacency on the part of the fabricator and may lead to much higher levels of risk to the project due to the allowable defect sizes generated.

API STANDARD 1104

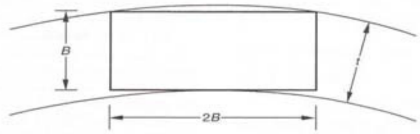


Figure A-2—Machining Objective for CTOD Test Specimen With Respect to Pipe Wall

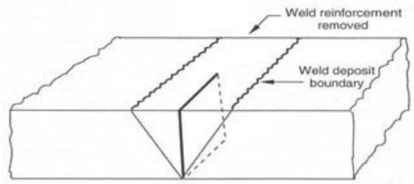


Figure A-3—Location of Notch for Weld-Metal Specimen

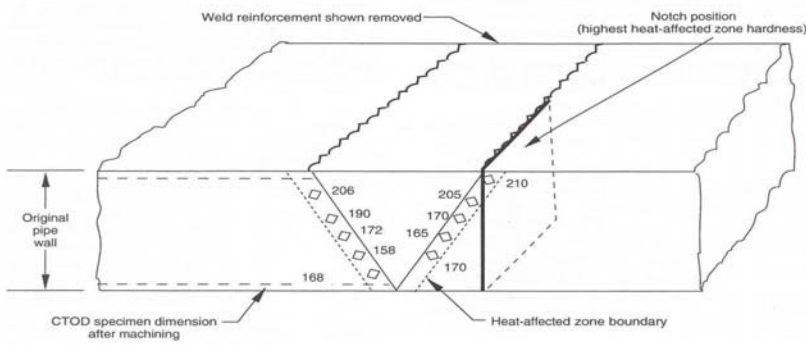
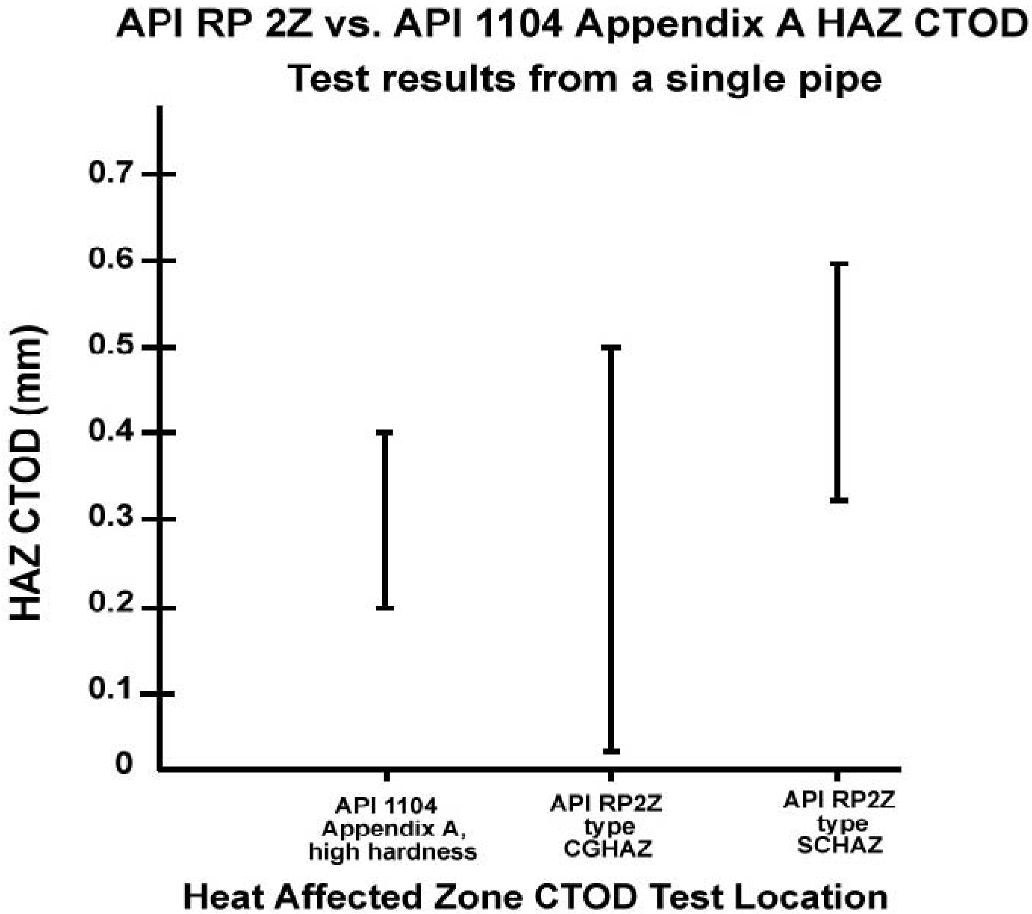


Figure A-4—Location of Notch for Heat-Affected Zone Specimen

With regard to chemical composition and processing parameters API 1104 Appendix A simply states the following as an essential variable: "a change in the grade or manufacturer of the pipe material or a basic change in the chemical composition or processing by a single manufacturer". We believe this to be a very vague statement that is open to many different interpretations. An example of this being a single DSAW pipe mill producing pipe from numerous different plate suppliers, may or may not be considered to be an essential variable depending upon the interpretation of the term basic change. We believe that API 1104 Appendix A is based around weld qualification and weld metal properties, it does not fully characterize the base material properties. An example of this can be seen below which demonstrates the different HAZ properties gained from a single piece of API 5L pipe. It is very interesting to note that the lower bound HAZ CTOD value from a straight-sided API RP 2Z type test program was 0.025 mm. The exact same pipe yielded 0.20 mm as the lower bound value in a standard API 1104 Appendix A qualification test. Based on ECA / Fracture Mechanics Analyses this discrepancy could have catastrophic consequences if the allowable defect size is generated using the API 1104 Appendix A data.



Problems Observed

A number of fabricators as well as suppliers have attempted to produce acceptable prequalification test coupons with very limited success. The degree of control of all welding variables and the specific techniques required to obtain a straight heat affected zone exceed the normal and customary procedures employed by most organizations. A far better success rate has been obtained by specialized welding organizations such as Acute Technological Services, Inc. (ATS) and Edison Welding Institute (EWI) who are dedicated to producing these types of weldability tests with skilled welding technicians.

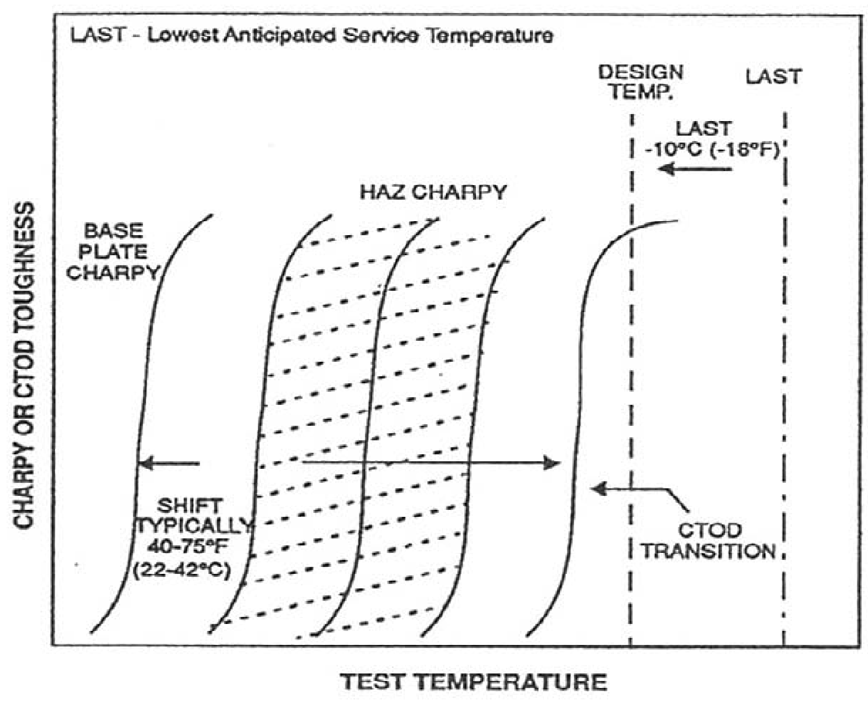
As deepwater applications require higher strength materials (X-80 and above) it becomes increasingly more difficult to obtain weld metals with overmatching strength and fracture toughness in the event that the CGHAZ specimens contain limited amounts of weld metal. This could result in artificially low HAZ results or invalid crack propagation paths.

Alternate Prequalification Methods

Where project specific requirements or materials that do not easily fit in the essential variable categories listed in API RP 2Z and EN 10225 occur, modifications to the standard API and EN test methods have been successfully employed. In these instances the projects are usually in a position to understand the end use of the component and can therefore tailor the prequalification test program to suit the specific project requirements. Areas of modification could include the following:

- Heat input ranges
- Preheat / Interpass temperatures
- Chemical composition ranges (forgings, castings, etc.)
- Number of specimens
- Test temperature
- Specimen location
- Inclusion or exclusion of supplementary tests such as Charpy V-notch, hardness, etc.

It has been established by extensive testing on plate steels that there is a direct correlation between base metal Charpy transition temperature (50% FATT) and the ability to pass the API RP 2Z prequalification program (7). The data has shown that the 50% Fracture Appearance Transition Temperature (FATT) must be below –60 °C, if the material is to have a chance at achieving the API RP 2Z requirements. Below is a schematic of the transition temperature change for base material and heat affected zones related to Charpy and CTOD testing (8). Although this temperature shift has been established for plate steels it has not yet been successfully established for any other components such as pipe, forgings, casting etc.



Conclusions

• Current codes and standards for weldability testing may be insufficient for the demanding requirements of today's deepwater developments.
• API RP 2Z and EN 10225 do not address steel compositions and processing parameters used in the production of castings and forgings.
• API 1104 Appendix A does not adequately characterize HAZ fracture toughness for critical projects.
• Past experience has shown that specialized welding techniques are required to reliably attain the correct specimen geometry and representative fracture toughness.
• Project specific prequalification plans may well develop more meaningful data and also prove more economical and schedule compliant.

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