Background of All-Weld Metal Tensile Test Protocol

Final Report 277-T-02

For Project

Weld Design, Testing, and Assessment Procedures for High Strength Pipelines

Prepared for the

Design, Materials, and Construction Technical Committee of
Pipeline Research Council International, Inc.
Project MATH-1 Catalog No. L5XXXX

and

U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration
Office of Pipeline Safety
DOT Project BAA DTHP56-07-0001

Prepared by
M.A. Quintana, The Lincoln Electric Company
J.A. Gianetto, CANMET Materials Technology Laboratory

September 2011

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<u>**FINAL REPORT STRUCTURE**</u>

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Report #	**Description**	**Lead Authors**
277-T-01	Background of Linepipe Specifications	CRES/CANMET
277-T-02	Background of All-Weld Metal Tensile Test Protocol	CANMET/Lincoln
277-T-03	Development of Procedure for Low-Constraint Toughness Testing Using a Single-Specimen Technique	CANMET/CRES
277-T-04	Summary of Publications: Single-Edge Notched Tension SE(T) Tests	CANMET
277-T-05	Small Scale Tensile, Charpy V-Notch, and Fracture Toughness Tests	CANMET/NIST
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277-S-01	Summary Report 277 Weld Design, Testing, and Assessment Procedures for High Strength Pipelines	CRES

Focus Area 2 - Development of Optimized Welding Solutions for X100 Linepipe Steel		
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278-T-01	State of The Art Review	Lincoln
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278-T-03	Microstructure and Hardness Characterization of Girth Welds	CANMET/Lincoln
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278-S-01	Summary Report 278 Development of Optimized Welding Solutions for X100 Line Pipe Steel	Lincoln

EXECUTIVE SUMMARY

Pipeline design must ensure that the pipeline is sufficient to accommodate the anticipated loads. Assessment of either stress or strain capacity is highly dependent on the reliability of mechanical property measurements for welds as well as base pipe. Accordingly, this work was undertaken for the purpose of improving the reliability of strength measurements for the specific case of narrow gap pipe girth welds. The investigation was part of a major consolidated program of research sponsored by DOT-PHMSA and PRCI to advance weld design, establish weld testing procedures and assessment methodologies, and develop optimized welding solutions for joining high strength steel pipe.

This report summarizes the development of an all-weld metal tensile test protocol for high strength steel pipe applications. The focus is on test method evolution as researchers sought improvements in measurement consistency. With these improvements came a broader understanding of the stress-strain behavior of high strength weld metal and some of the factors that influence tensile results. The results show that traditional methods of measurement can become inadequate as materials and methods of fabrication change. In this case, continuing to downsize tensile specimens for measurement of weld metal properties without establishing a context for those measurements can easily lead to errors in assessing the suitability of welding materials and welding procedures for the intended applications.

The proposed test protocol has proven effective in producing consistent weld metal tensile properties that are relevant and useful for pipeline designs. The test data demonstrate that the strength measured at 1.0% total strain provides reduced specimen-to-specimen variability by avoiding a region of stress-strain relation that has a large degree of variability. Using the strength measured at 1.0% strain allows for more effective differentiation of the effects of important welding parameters than the strength measured at 0.5% total strain or 0.2% offset strain. While the test method presented here lays a foundation for greater reliability in the measurement of all-weld tensile properties, it is clear that it is a “work in process” and that further improvements are needed. Recommendations for further consideration include the mechanical details of the test specimen and testing practice as well as consistent procedures for post test data processing.

TECHNICAL REPORT

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FROM

The Lincoln Electric Company

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CANMET-MTL

PREPARED FOR

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Final Report 277-T-02

Background of All-Weld Metal Tensile Test Protocol

ABSTRACT

This investigation is part of a major consolidated program of research sponsored by DOT-PHMSA and PRCI to advance weld design, establish weld testing procedures and assessment methodologies, and develop optimized welding solutions for joining high strength steel pipe. This topical report summarizes the development of an all-weld metal tensile test protocol for high strength steel pipe applications. The focus is on test method evolution as researchers sought improvements in measurement consistency. With these improvements came a broader understanding of the stress-strain behavior of high strength weld metal and some of the factors that influence tensile results.
The latest testing protocol, as it was refined during this program, was reviewed by engineers and technicians using it for the first time. Opportunities for further improvement are discussed.

KEYWORDS
narrow gap weld, high strength line pipe, weld metal, tensile test, tensile properties

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1 INTRODUCTION

This report provides an overview of work undertaken to develop tensile testing protocols that were used in the evaluation of girth welds produced for a major consolidated program of research with two primary areas of focus related to the welding of high strength steel pipelines. The first focus area aims to update weld design, testing, and assessment procedures [1]. The second focus area aims to optimize welding solutions for joining high strength steel X100 (Grade 690) pipe by examining the welding process and material variables that lead to variation in weld properties [2]. Reliable measurement of all-weld tensile properties is a key element in the overall effort to update weld testing and assessment procedures.

Any test method development nearly always occurs in the context of an industry need for measurements that are better suited to new or evolving applications. Recent history in the pipeline industry shows a clear move to higher strength materials. This shift in materials is occurring at the same time that design practices are evolving in response to increasing performance expectations and there is increasing use of automated fabrication methods in response to demands for higher productivity [3]. In view of these changes, this report focuses on the ability of standard tensile testing methods [4, 5] to satisfy current industry needs for high strength steel pipeline applications. Specifically, this report examines recent efforts to develop alternatives to such standard methods for measurement of weld metal tensile properties.

Modern pipeline design relies on the availability of materials that satisfy minimum standards for mechanical performance. For stress-based designs, which generally refer to pipeline designs where the maximum longitudinal stresses in practice will remain below the specified minimum yield stress (SMYS) of the materials employed, materials selection emphasizes conventional measures of tensile properties. For strain-based designs, where expected longitudinal strains greater than 0.5% (i.e., plastic deformation) are expected, the consideration of tensile properties must also account for strain hardening capacity and weld strength mismatch effects. Application of modern high strength line pipes in conjunction with more demanding pipeline designs, in particular strain-based design, has necessitated the critical re-evaluation of girth weld properties to ensure weld strength overmatching and adequate weld defect tolerance. In short, the objective is to prevent strain localization in the weld region at the total strain level anticipated by design.

In order to accomplish this, a comprehensive understanding of the weld metal tensile properties is required. This is somewhat challenging for the narrow gap pipe welds that are used extensively in automatic gas metal arc welding (GMAW) of pipelines because the geometry of the weld makes it difficult to remove all weld metal test specimens of reasonable size. For multiple pass arc welds industry standard practice is to use the largest standard test specimen possible without running the risk of incorporating HAZ or base material in the reduced section of what is intended to be an all weld metal test [4, 5, 6]. One such example is the specification for shielded metal arc welding electrodes [6] where the size of the round bar specimen changes with the volume of the weld joint employed. This practice ensures that the measurement of tensile properties is representative of the weld metal as a whole and not merely an incremental snapshot of a small region within the weld metal. Figure 1(a) illustrates how the reduced section of the round bar tensile specimen in a conventional groove weld samples a relatively large fraction of the weld metal. In the narrow groove weld, Figure 1(b), the largest round bar tensile specimen that can be used samples a small fraction of the total weld area. Depending on the specific placement of the small round specimen with respect to the weld pass sequence, the result measured is more likely to be determined by a single weld pass or reheat zone and is less likely to represent the performance of the weld as a whole.

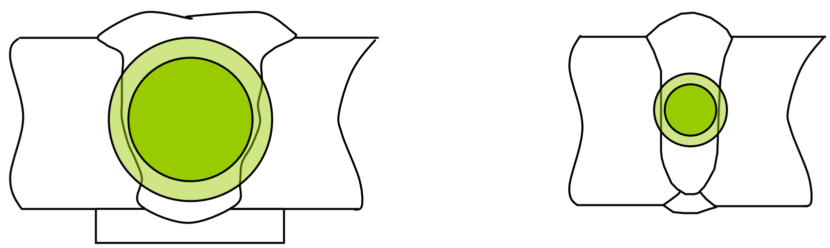


Figure 1. Schematic all-weld metal tensile specimen location, round bar
(Darker shaded area represents tensile specimen reduced section.)

Considering that there is always some normal variation in welding conditions and bead placement even with the best welding process control, it is easy to envision a relatively high degree of variability in tensile property measurements made with the small round bar test specimen. This situation is of particular concern for strain based design (SBD) pipeline applications where narrow groove weld joints are commonly used for automatic GMAW of girth welds and reliable tensile property measurements are essential in determining the strain capacity of the weld. Work published by CANMET [7, 8, 9, 10, 11, 12] clearly has shown significant variation in girth weld metal strength measurements both within a given weld and from weld to weld. In reviewing the literature, it is often difficult to clearly separate variation that is caused by deliberate changes in welding practice and chemical composition from the inherent level of imprecision in the measurement method.

It is important to recognize that narrow gap automatic GMAW has been used in the pipeline industry for many years. However, the traditional approach to welding procedure qualification is to require a transverse tensile test that must meet or exceed the specified minimum ultimate tensile strength of the base pipe, even if it fails in the weld. This approach provides no specific measurement of weld metal yield strength or tensile strength. It is the relatively recent use of higher strength steels in strain based design applications that is driving the need for full characterization of tensile properties in the weld region during procedure qualification.

2 OBJECTIVE

The primary purpose of this report is to review the progress made toward improving the reliability and consistency of all-weld tensile property measurements for narrow gap pipe welds. This review is intended to provide a foundation for the CANMET testing protocol that was further refined during this program.

3 HISTORICAL REVIEW

A review of the literature indicates that the interest in development of a better measurement system for weld metal tensile properties in narrow gap joints focused almost entirely on the test specimen itself - size, configuration, layout in the weld, and machining methods. The consistent motivation throughout the development process was the need to incorporate as much of the weld cross-section as possible, while excluding any possible contribution from the adjacent heat affected zone (HAZ). Any minor modifications in individual testing procedures were made only as needed to accommodate the modified test specimen geometries. Industry standard testing practices [4, 5] were followed with the exception of the test specimen.

3.1 TENSILE TEST SPECIMEN

The earliest change in test specimen geometry seems to have been made by the researchers at The Welding Engineering Research Centre (WERC) of Cranfield University, UK with the first comprehensive program on welding X100. For the GMAW girth welds, this program employed a number of narrow gap joint geometries. At a very early stage in the work, Hudson [13] abandoned the 4.0 mm round bar in favor of a strip tensile specimen, Figure 2. Hudson considered that this strip would incorporate a more representative section of the microstructures present in his multiple pass welds. The thickness and width of this specimen in the reduced section was selected specifically to maintain the same gage length/area cross-section ratio as the 4 mm round bar. The limited data available for welds tested with both specimen configurations indicates a less than perfect correlation, quite possibly for the reason indicated. The 4 mm round bar does not incorporate the full ranges of microstructures that a strip can. Therefore, in any given weld, the two test specimens can represent significantly different aspects of the same weld metal.

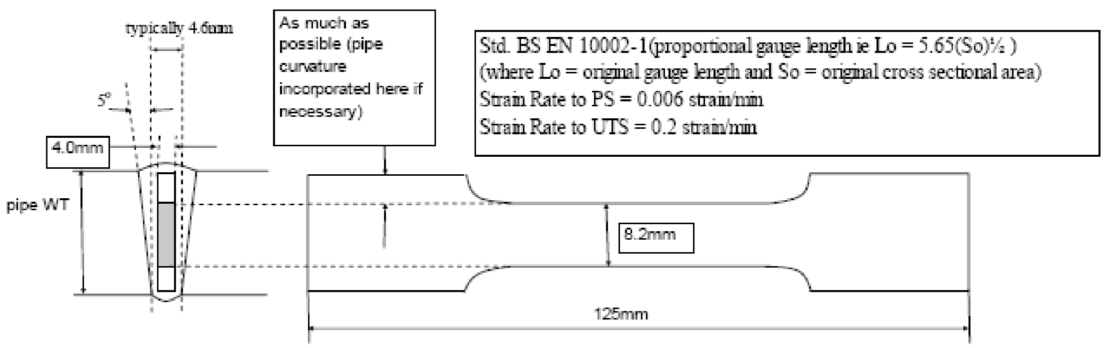


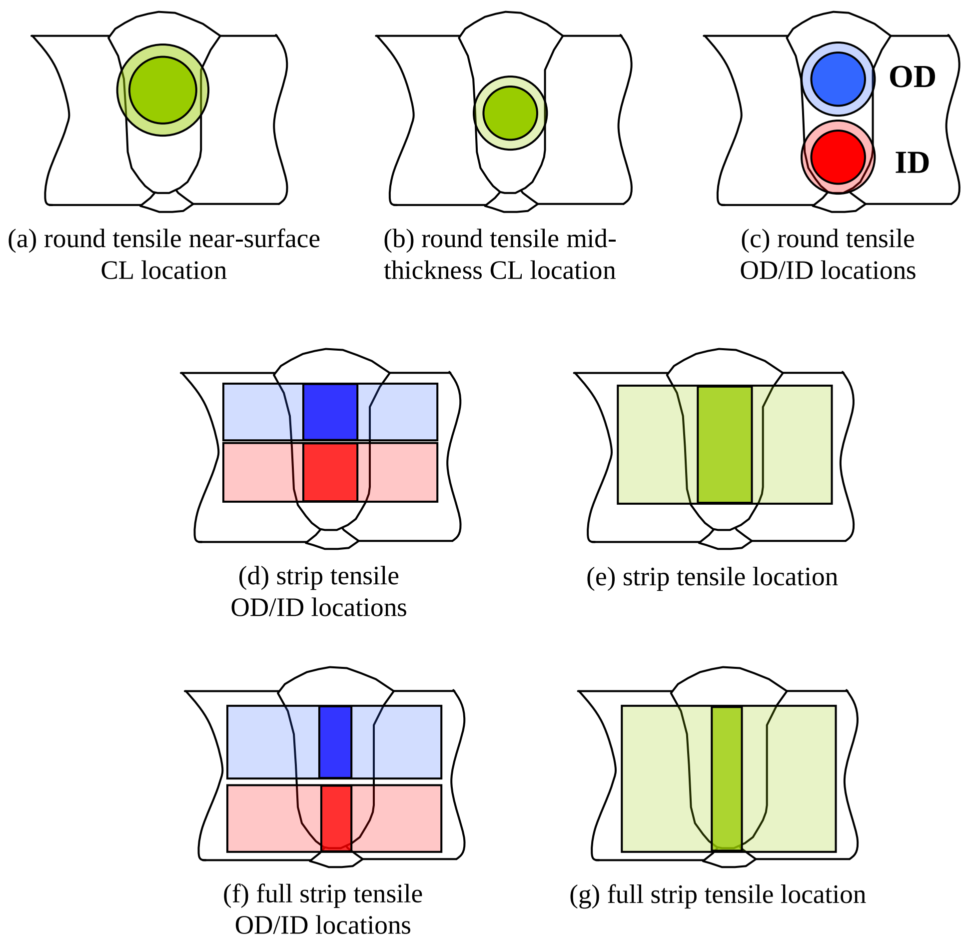
Figure 2. WERC strip tensile specimen
Reproduced from Figure 4-30 [13]

The major progress on test specimen development came through the efforts of CANMET-MTL. The work began during their investigations on X80 and X100 girth weld properties [7]. The initial approach was to extract the largest gage diameter standard round bar (nearly 5 mm gage diameter) from the weld, taking into consideration the specific joint geometry and weld width (or offset), Figure 3(a). The limitations imposed on the maximum size of the round bar by the weld joint configuration led to the development of alternatives and the strip configuration quickly evolved, Figure 3(e). The thickness of the specimen (dimension measured in the direction perpendicular to the pipe surface through the weld thickness) was dictated by the weld height above the hot pass. With the thickness determined, the width of the reduced section was determined individually by the actual width of the weld fusion zone. The objective was to maximize the amount of the weld fill passes included in the specimen cross section. Test specimen preparation thereby became much more of a precision business with additional care in layout and machining to ensure specimen extraction from the desired location.

As research continued in the ongoing effort to resolve the underlying causes of through thickness variation in weld properties [8], researchers supplemented the strip and near surface round bar tensile measurements with a split strip illustrated in Figure 3(d). This was accomplished using electric discharge machining (EDM) to section the strip into OD and ID pieces.

Over time, the near-surface round bar was replaced [9, 10] by the mid-thickness round bar, Figure 3(b). It is noted that a mid-thickness weld centerline location is used routinely for material certification testing and some procedure qualifications. Measurements made in this way could be cross-referenced against results produced for the same materials by other organizations. Gauge diameter could be as much as 5 mm depending on the width of the weld. Use of the strip specimen illustrated in Figure 3(e) continued. In this scheme, the round bar represented weld metal consistent with the ID bias in the strip specimen reduced section.

Subsequent research [11] made extensive use of the split strip, Figure 3(d), as well as the OD/ID round bars, Figure 3(c), in the ongoing effort to understand the sources of through thickness property variation in the high strength narrow gap welds. The work showed that the OD/ID round bar and split strip test specimens were nominally equivalent. Also, this research included consideration of a full thickness strip, Figure 3(g), and its equivalent of a split strip, Figure 3(f). Extending the specimen thickness to incorporate root/hot passes necessitates a smaller width in order to avoid inclusion of HAZ. Experiments included strips of different widths. The results reported for all strip specimens were in close agreement. Without any clear measurement advantage for an alternative strip, use of the "standard" Figure 3(e) continued [12].



(a) round tensile near-surface CL location

(b) round tensile mid-thickness CL location

(c) round tensile OD/ID locations

(d) strip tensile OD/ID locations

(e) strip tensile location

(f) full strip tensile OD/ID locations

(g) full strip tensile location

Figure 3. Schematic, mechanical property specimen locations
(Darker centers indicate tensile specimen reduced section and location of CVN notches.)

In the latest investigation involving evaluation of experimental X100 consumables [12], CANMET-MTL chose a narrow gap weld test protocol that included the strip and OD/ID round bar specimens to investigate the properties of the fill pass region. Consequently, the ID round bars were a bit smaller than indicated in the schematic to ensure that the ID specimen was located above the hot pass.

3.2 RESULTS

Much of this work to refine the tensile test specimen was conducted in conjunction with other studies examining the influence of welding practice and chemical composition on weld performance including toughness, hardness, and microstructure as well as tensile properties. Welding included single torch and dual torch procedures, 5G and 1G rolled welding positions, solid wire and metal cored electrodes, three grades of base pipe, and variations in joint geometry within the range expected for narrow gap welds. Because the test specimens and testing methods were evolving over the same time period, it was difficult to draw any firm conclusions about the strip vs. round bar. However, some general trends did emerge in considering the direct data pairs that did exist.

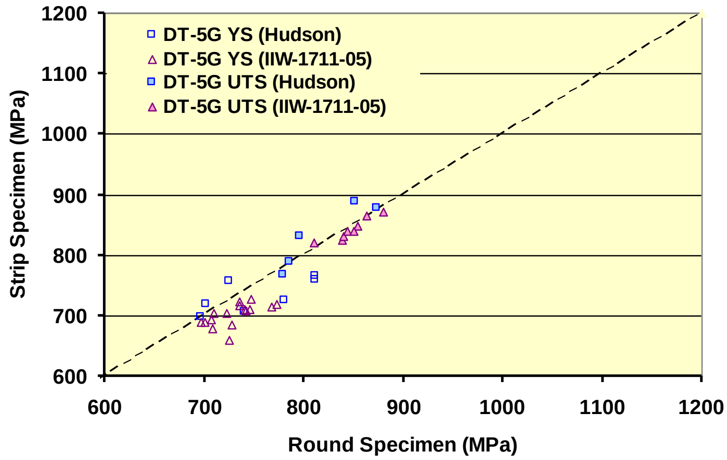
Comparison between dual and single torch welds is summarized in Figure 4(a) and 4(b), respectively. Data pairs were taken from the references indicated and represent yield strength by both 0.2% offset and 0.5% total strain as well as ultimate tensile strength. Since there seemed to be no significant difference among strip widths, they are all shown as strip. The round bar specimens are for near-surface or mid-thickness centerline specimens and do not include OD/ID. The diagonal line in both graphs represents 1 to 1 correlation. It is clear that most of the scatter is below this line. Where there is a significant difference in strength measurement between the strip and the round bar, it is the round bar that is higher. In some cases, the difference is over 100 MPa. Referring back to the source documents for the stress-strain curves, these significantly higher values tend to correspond to a change in yielding behavior from round house to discontinuous yielding.

The difference cannot be explained by specimen configuration. Similar paired data [10] are summarized in Table 1 for base pipe, and these clearly show no systematic difference between strip and round bar tensile measurements. It is important to remember that the pipe material is homogenous compared with the narrow weld, which is known to contain alternating regions of as-welded and reheated material. In this context, Table 1 confirms that the strip and round bar will deliver the same results if they are extracted from material that is consistent and relatively homogeneous.

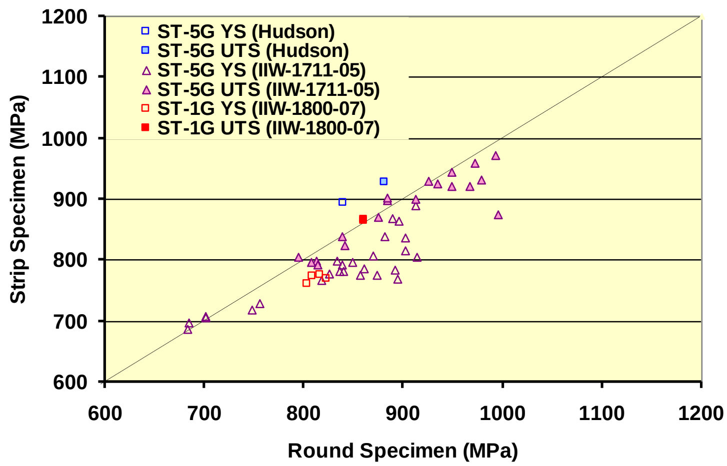
Table 1. Measurement comparison for base pipe - strip vs. round [10]

Material	Avg. Stress (MPa) @0.2% offset		Avg. Stress (MPa) @0.5% extension		Avg. Ultimate Tensile Strength (MPa)	
	Round	Strip	Round	Strip	Round	Strip
X70	580	592	580	593	649	652
X80	579	580	577	580	660	667
X100*	743	748	737	745	844	847

* X100 exhibited round house type yield behavior. All others exhibited discontinuous yield with sharp yield point.



(a) dual torch welds



(b) single torch welds

Figure 4. Comparison of strength measurement for narrow gap welds - strip vs. round.
ST=Single Torch; DT=Dual Torch

In the effort to examine through thickness variation in weld properties, the CANMET-MTL researchers observed systematic differences in strength measurement between the OD location and the ID or mid-thickness location. Figure 5 summarizes all data reported [7, 8, 9, 10, 11, 12] for OD/ID pairs - for both OD/ID round bar and split strip specimens - and clearly shows the reported tendency to higher yield strengths (0.2% offset method) at or below mid-thickness in the narrow gap welds. All of this data happens to be from single torch welds, most of which were produced in the 1G rolled position.

Clearly, there is variation in tensile properties from one part of the weld to another that can be characterized by tensile testing if the test specimens are small enough and carefully located. When a local view of material properties is not the objective, then a larger test specimen should be used. The strip specimen has been demonstrated to be a viable option for narrow gap welds.

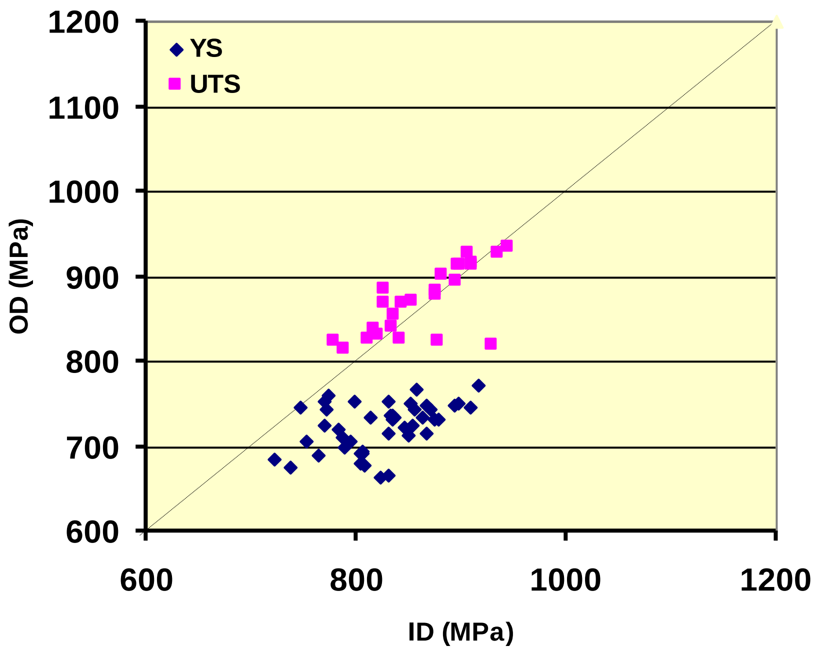


Figure 5. Measurement comparison for historical narrow gap welds - OD vs. ID

4 NEW RESEARCH

The first and second round pipe welds produced for this program [14] were tested using the CANMET-MTL strip tensile and OD/ID round bar specimens depicted in Figure 3(e) and Figure 3(c), respectively. The pipes were welded using a single electrode (ER90S-G) in both 1G-R and 5G welding positions and both single and dual torch configurations. The results from the 58 tensile tests conducted are presented in Appendix A. Yield strengths or flow stress were determined at 0.2% offset, 0.5% total strain and 1.0% total strain with the intention of evaluating which metric would provide the most consistent indication of weld metal yield strength for the X100 strength level. The elastic modulus, E, was determined from the slope of the linear portion of the stress-strain curve between about 150 MPa and about 600 MPa stress. This was necessary in order to minimize errors in reporting 0.2% offset yield strength, which was determined by the intersection of the stress-strain curve with a line of slope E was offset by 0.2% to the right of the linear portion of the stress-strain curve. Ultimate tensile strength was determined in the conventional manner [4].

The new research results confirmed the previously reported tendency for yield strength variation with specimen location, Figure 6. Further, similar discontinuous yield behavior was observed in ID specimens in narrow gap welds with similar joint configurations, Figure 7 and Figure 8. The new research further characterized the correlation of local variation in weld properties with micro-hardness measurements, which are plotted as topographical maps in Figure 8. Portions of a micro-hardness map [16] corresponding to the strip tensile, OD round bar, and ID round bar specimen locations in the weld cross-section are illustrated.

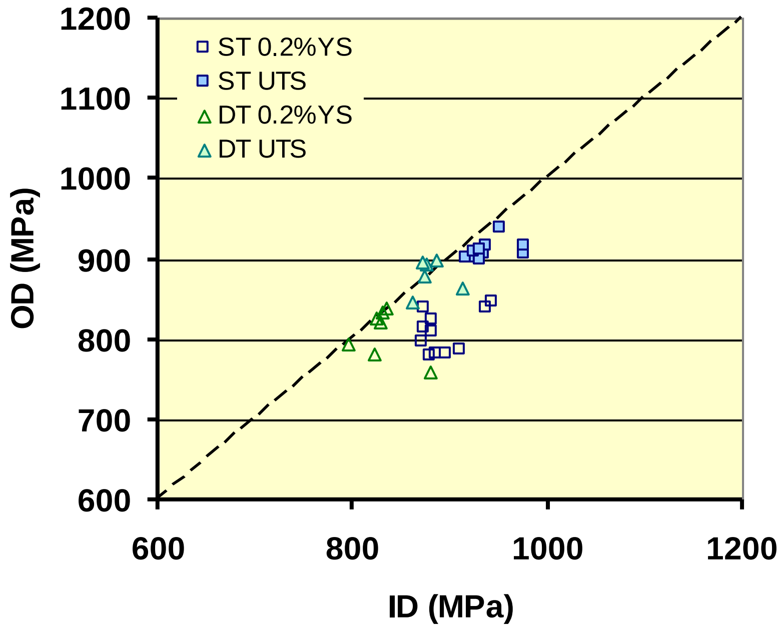


Figure 6. Measurement comparison for current narrow gap welds - OD vs. ID.
ST=Single Torch; DT=Dual Torch

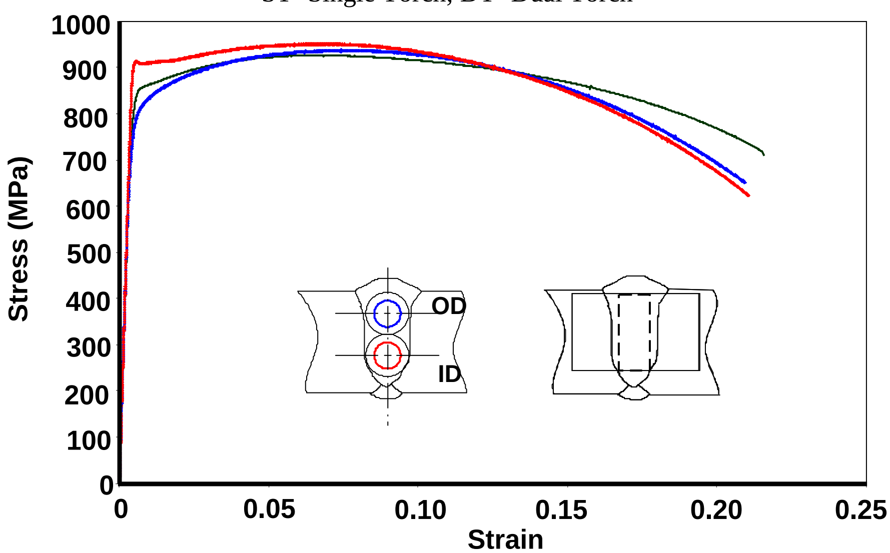


Figure 7. Narrow gap weld tensile properties (807F)
red - ID, blue - OD, black - strip

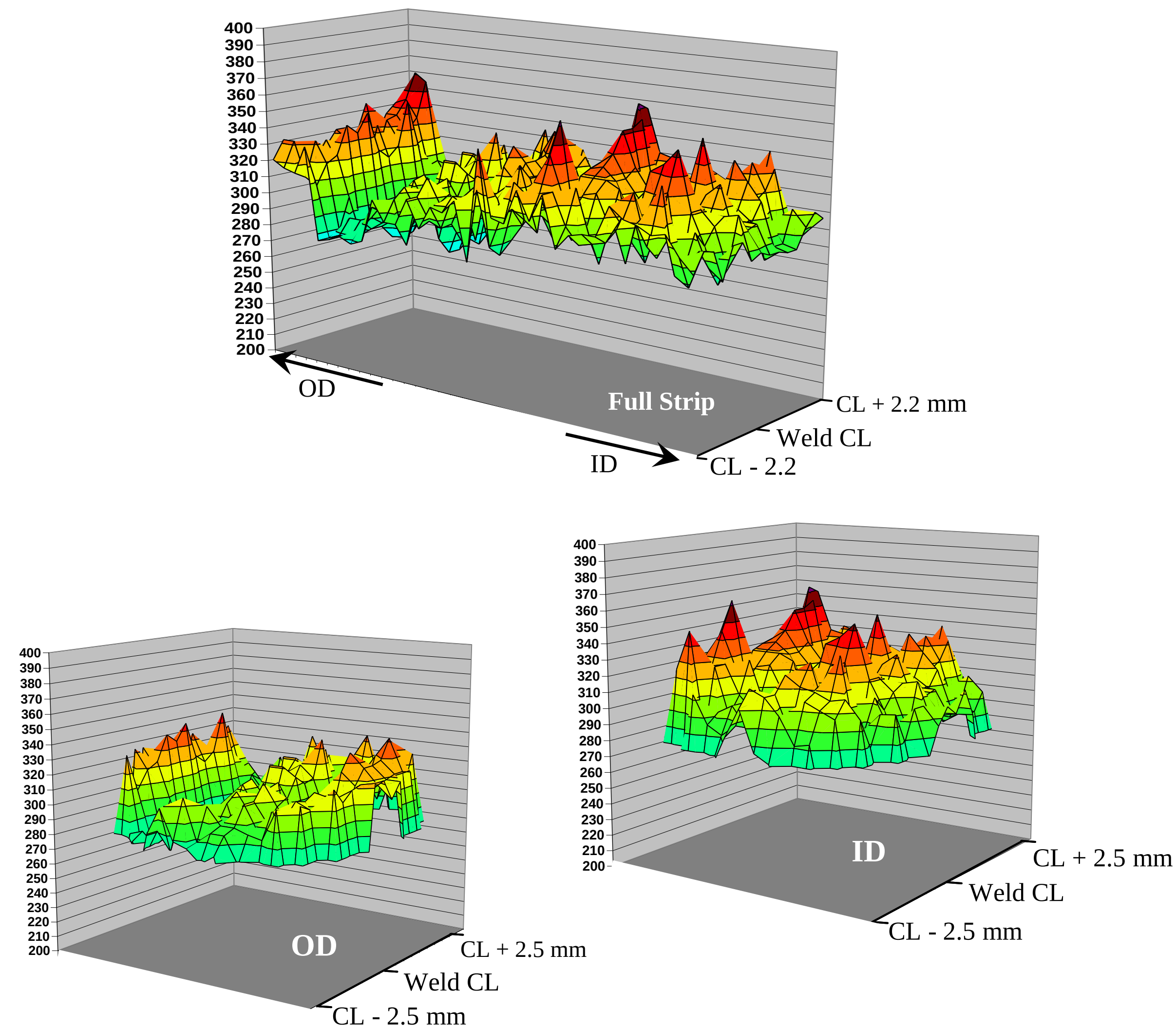


Figure 8. Microhardness (Hv-300g) corresponding to tensile specimen locations (807F)

The ID location is characterized by two bands of significantly higher peak hardness than is evident at the OD location. Clearly, there is a higher magnitude of variation over short distances at the ID location than at the OD location, where the hardness is more uniform. At the strip tensile location, bands of alternating high and low hardness evident in the topographical map seem to combine the features of both the OD and ID locations. The relative position of the stress-strain curves is consistent with the micro-hardness - the ID highest, the OD lowest, and the strip at an intermediate level. In general, the micro-hardness maps proved to be highly effective indicators of through thickness variation in the narrow gaps welds.

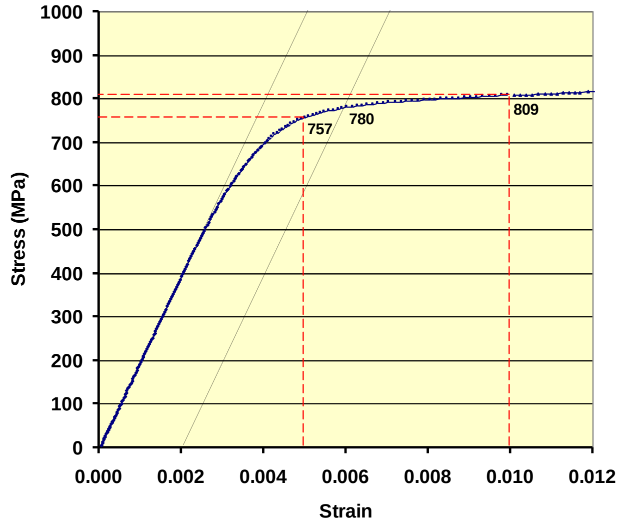
By the third round welding, tensile testing was conducted only with the CANMET-MTL strip specimen and micro-hardness maps replaced the OD/ID round bar tensile specimens for revealing the level of short range variation in weld properties.

Deviations from normal stress-strain response during initial stages of specimen loading as well as early departure from linearity as test specimens approach yield are common occurrences with the pipe weld samples reported herein, particularly for the strip specimens. Representative examples are illustrated in Figure 9. Consequently, it was not possible to uncritically accept the determination of yield strength from the automated software report from the tensile test instrumentation. Rather, each stress strain curve was evaluated individually by an experienced technician or engineer to determine yield strength and flow stress. The degree to which such issues create potential uncertainty in a measurement depends on the shape of the stress-strain curve at the point of interest (0.2% offset, 0.5% total strain or 1% total strain).

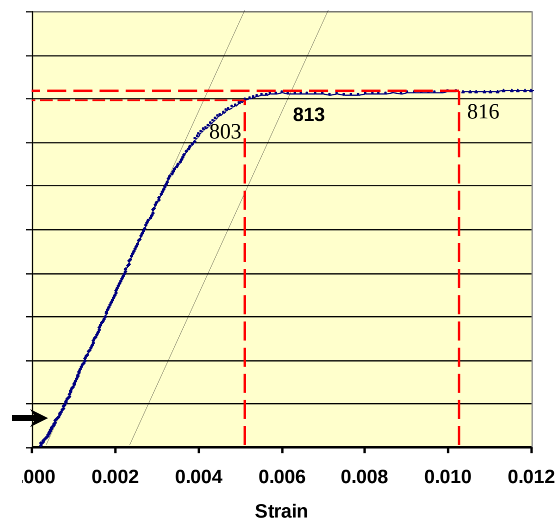
In all cases, a flow stress at 0.5% total strain under-represents the yield strength in these weld metals. Compared with the 0.2% offset and 1% total strain approaches, 0.5% total strain occurs at a location on the curve with the largest potential variation. The potential variability is more significant when the "round house" effect starts early, as illustrated in Figure 9(a) for 807J-R1-OD. Also in Figure 9(a), when the round house effect tapers off slowly, even the 0.2% offset method will indicate a stress that is still in the "knee" of the curve. The deviations from linear behavior at the beginning of the test, Figure 9(b-d), indicate a problem with strain measurement during initial loading. This may be due to misalignment of the test specimen in the loading fixture, a test specimen that is bent or distorted, or an extensometer that is not attached properly and is slipping. In the present case, distortion may be the major factor. For test specimens removed from pipe welds, the weld passes arc through what is intended to be a straight tensile test specimen. Therefore, the distribution of residual welding stresses, that tend to align with the welding pass sequence in the longitudinal direction, will not be axisymmetric with the test specimen and there should be a greater tendency to distortion than for test specimens removed from butt welds fabricated in flat plates. Regardless of the cause, the potential for significant scatter in strength measurements for the X100 weld metal tested is relatively high if care is not taken in determining the slope of the linear elastic portion of the stress-strain curve and in making appropriate adjustments to the offset.

Even with the care taken by researchers in this investigation, the variation in strength measurements for welds fabricated with a single wire electrode under a single set of welding and test conditions is higher than expected from the precision statistics published for the basic tensile test method [4]. The tensile tests reported here are for a single wire electrode at different locations in the weld cross-section, fabricated under different welding conditions, and representing both round and rectangular test specimen cross-sections. Because of the relatively large number of tests conducted at each condition, it was possible to assess the primary sources of variation in tensile properties using an analysis of variance (ANOVA) approach. The detailed analysis, conducted using Design-Expert®[1] Version 7.1.5, is presented in Appendix B.

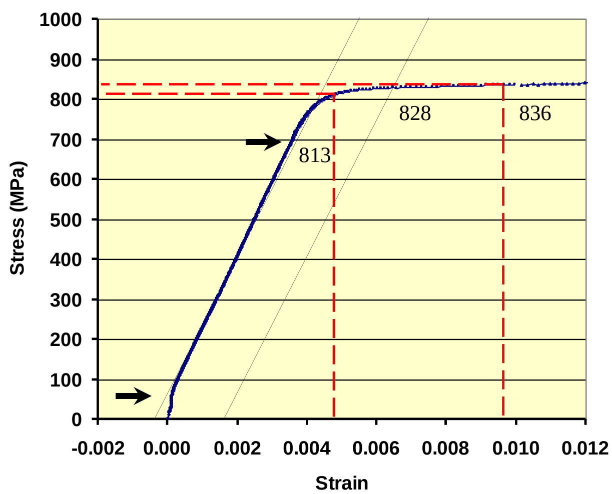
[1] Design-Expert is a registered trademark of Stat-Ease Inc., 2021 East Hennepin Avenue Suite 480, Minneapolis MN 55413



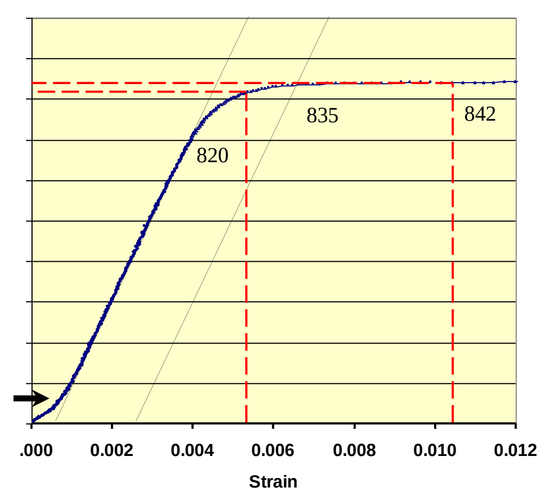
a) Weld 807J, specimen R1-OD



b) Weld 807H, specimen R2-OD



c) Weld 807H, specimen S3



d) Weld 883D, specimen S4

Figure 9. Examples of engineering stress-strain curves

The analysis indicates clearly that the apparent modulus of elasticity, E, is correlated with the type of tensile test specimen used as well as the welding practice. The only two factors indicated to be significant were the tensile specimen type (i.e. round or strip) and the torch configuration. The results summarized in Table 2 indicate that the round tensile specimens result in E close to the theoretical value of 207 GPa with variation expressed as standard deviation less than 10 GPa. E for the strip tensile specimens consistently is higher than for the round tensile specimens with the dual torch welds producing the highest levels. The higher apparent stiffness, even after corrections for strip specimen straightness, suggests that there are other unresolved issues (e.g. clip gage placement, fixture alignment, residual stresses remaining after specimen preparation, etc.). The effect of this variation in the modulus of elasticity is illustrated in Figure 10 for the strip tensile specimen 807J-S1 corresponding to E=236 GPa. In this case, E determined by the instrument software (E Instron), E calculated by linear regression between 100 and 600 MPa

(E Fit) and the theoretical modulus (E Theoretical) differ. The 0.2% offset yield strength determinations are 830, 831 and 849 MPa, respectively. A flow stress determination at 1.0% total strain of 849 MPa is not influenced in any way by the variation in E observed. This observation is common to all of the strip tensile stress-strain curves.

Table 2: ANOVA Results for Elastic Modulus, MPa
Values in parentheses represent one standard deviation

Torch Configuration	Round Tensile	Strip Tensile
Single Torch	204,400 (8811)	213,118 (23,806)
Dual Torch	199,553 (5125)	237,292 (20,639)

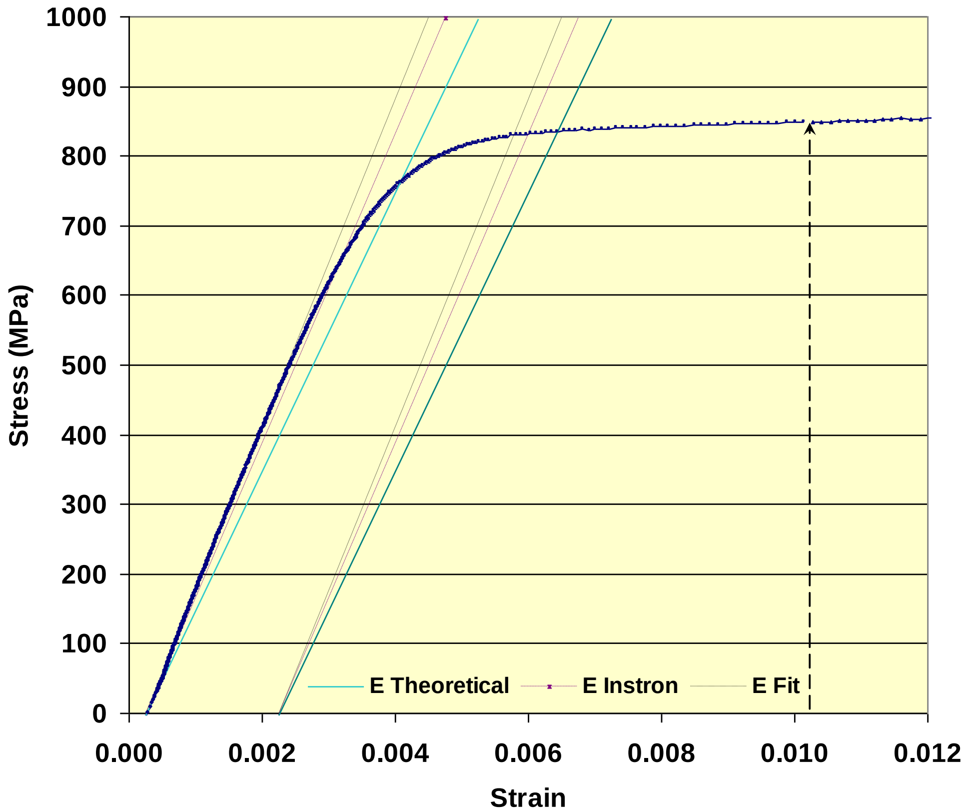


Figure 10. Stress-strain curve illustrating variation in elastic modulus for 1G-R single torch weld (807J-S1)

With regard to strength measurements, ANOVA indicates that the location of the test specimens in the weld cross-section (i.e. OD, ID, or near full thickness) and various aspects of the welding practice are significant. While the model predictions provide clear indication as to what variables are likely primary factors influencing strength measurements, there is significant lack of fit in all ANOVA models for strength. This suggests that there are other factors not accounted for in this study. Therefore, it is not possible to use the models to predict specific strength levels. However, it is possible to identify which of the factors investigated are more or less significant based on probability statistics (e.g. p values), sum of squares, and coefficient estimates. The assessments are summarized in Table 3 with factors of primary significance indicated as "primary", factors of potential secondary significance indicated as "secondary", and factors excluded from the models as insignificant indicated as "NA". Both 0.2% offset and 0.5% strength measurements are influenced primarily by the location of the tensile test specimen in the weld cross-section. Welding practice expressed as torch configuration is a potential secondary driver, but it is far less certain in the case of yield strength determined at 0.5% total strain. This is consistent with the inherent variation in 0.5% measurements described previously. It is not until 1.0% total strain has been reached that flow stress measurements show the potential for secondary effects of clock position and welding position. Both factors should influence yield strength measurements, but it is difficult to see the effects beyond the "noise". In this case, clock position and welding position actually are confounded because the two factors were not varied independently. All specimens from 1G-R welds were located at a clock position of 12:00. Only the 5G welds offered any opportunity to vary clock position.

Table 3: ANOVA Results for Strength Measurements

Factor	0.2% Offset	0.5% Total Strain	1.0% Total Strain	Ultimate Tensile Strength
Clock Position	NA	NA	Secondary	Secondary
Tensile Type	NA	NA	NA	NA
Location	Primary	Primary	Primary	Secondary
Torch Configuration	Secondary	Secondary	Primary	Primary
Welding Position	NA	NA	Secondary	NA

5 PRACTICAL CONSIDERATIONS

CANMET-MTL conducted all of the tensile tests required for the round 1 and 2 girth welds. By round 3, the Mechanical Test Laboratory at The Lincoln Electric Company (LEC) had acquired the necessary equipment and instrumentation to begin testing using the CANMET-MTL strip tensile specimen. The detailed test procedure included in Appendix C incorporates some of the LEC experience with the CANMET-MTL history. Many of the issues faced by engineers and technicians implementing the method for the first time are still in process of being resolved. They are noted here for future consideration. These include:

- **Criticality of Center Line Determination** - Specimen blanks are cut oversized to account for adjustment of final specimen location based on center line determination. There is enough variation in weld cross-section arising from location conditions in the pipe (e.g. high/low misalignment) that specification of a larger blank may become necessary.
- **Surface Finish** - There are no surface finish requirements for the test specimen. This should be considered to ensure there is no interference with the extensometer knife edges.
- **Specimen Alignment** - Negative readings at the beginning of a test are not unusual, even after the load frame is checked for alignment. It is suspected that distortion of the specimen due to welding residual stresses is a contributing factor. Application of a 400-

500 lb. preload before attaching the extensometer provided a short term solution, but the root cause needs to be determined and resolved.

- **Grip Area is Limited** - The available grip area is limited due to pipe curvature. For pipe diameter smaller than 760 mm (30 in.) and pipe wall thickness larger than 19 mm (0.75 in.), the grip ends may need to be redesigned to ensure positive mounting of the specimen in the load frame. For the X100 girth welds tested, the grip arrangement used was adequate. The wedge grips used by both laboratories functioned without slipping. As application of the test method expands to higher strength material and higher levels of weld strength overmatch, it is expected that the grip arrangement and specimen configuration will require redesign to ensure that the grip ends are secure in the test fixture.
- **Grip Design** - The 25 mm (1 in.) gage length and the short overall length of the strip specimen do not leave much space for instrumentation between the grip heads. It is not yet certain if the anomalies occurring in the stress-strain curve are due to difficulties with the instrumentation in this confined space.
- **Post Test Data Analysis** - The stress-strain curves generated with the CANMET-MTL strip method for higher strength weld metals tend to exhibit two unique features that are not yet addressed by the test procedure.
    - The relatively long, flat plateau with little curvature at the top makes determination of the uniform elongation at ultimate tensile strength by conventional means somewhat subjective. Measurement precision could benefit from a curve fitting procedure applied during post test processing of the data [17].
    - The early departure from linearity for specimens that do not exhibit a distinct yield points affects the determination of yield stress using the conventional 0.2% offset method. Because laboratory personnel will come to expect deviations from linearity, some post processing of the data is prudent.
        - A check of the linear slope against theoretical elastic modulus is advised. Departures greater than ~10% at stresses up to UTS/3 are likely indicators, at least for the specimens with round cross-sections, of specimen misalignment, gages not placed securely, etc.
        - For the results reported herein, linear slope determination was an iterative process using a combination of engineering judgement and regression analysis. A more systematic approach that can be applied more consistently by many laboratories should be considered. One such method is the reduced strain or reduced displacement technique that has been applied to reduce measurement variation in the determination of fatigue crack growth rates [18] and fracture toughness [19].

6 SUMMARY AND RECOMMENDATIONS

Pipeline design must ensure that the pipeline is sufficient to accommodate all anticipated loads. Assessment of either stress or strain capacity is highly dependent on the reliability of mechanical property measurements for welds as well as base pipe. The work presented here shows that traditional methods of measurement can become inadequate as materials and methods of fabrication change. In this example, continuing to downsize tensile specimens for measurement of weld metal properties without establishing a context for those measurements could easily lead to errors in assessing the suitability of welding materials and welding procedures for the intended applications.

The proposed test protocol has proven effective in producing consistent weld metal tensile properties that are relevant and useful for pipeline designs. The test data demonstrate that the strength measured at 1.0% total strain provides reduced specimen-to-specimen variability by avoiding a region of stress-strain relation that has a large degree of variability. Using the strength measured at 1.0% strain allows for more effective differentiation of the effects of important welding parameters than the strength measured at 0.5% total strain or 0.2% offset strain.

While the test method presented here lays a foundation for greater reliability in the measurement of all-weld tensile properties, it is clear that it is a work in process and that further improvements are needed. Conventional methods of yield strength determination require reconsideration in the context of both stress based and strain based design assessment methods and requirements. For example, the yield strength to tensile strength ratio, Y/T, has become a proxy for a material's strain hardening capacity. This approach is meaningful only if the reported yield strength is a close approximation of actual material behavior, which may not be the case for reasons discussed in this report. Accordingly, both assessment methods and measurement methods need to evolve together to ensure that the test methods in use provide results that are meaningful for designs.

7 ACKNOWLEDGEMENTS

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9 APPENDIX A
Tensile Test Results

Weld	Tensile Type	Location	Clock Position	E (MPa)	0.2% offset YS (MPa)	0.5% YS (MPa)	1.0% YS (MPa)	UTS (MPa)
807F 1G-R Single Torch	Round	OD	12:00	213335	786	771	835	939
		ID	12:00	216553	911	909	910	952
	Strip	Full Section	12:00	210065	845	817	863	928
807G 1G-R Single Torch	Round	OD	12:00	202694	808	798	812	906
		ID	12:00	194860	882	872	884	934
	Strip	Full Section	12:00	198383	838	807	849	919
807H 1G-R Single Torch	Round	OD	12:00	204544	781	764	812	917
		ID	12:00	202508	895	895	894	936
		OD	12:00	208971	813	803	816	902
		ID	12:00	217066	874	876	872	920
		OD	12:00	191443	796	778	806	902
		ID	12:00	186074	871	861	871	917
	Strip	Full Section	12:00	187543	830	815	843	913
			12:00	192660	835	825	841	911
			12:00	181802	828	813	836	907
807I 1G-R Single Torch	Round	OD	12:00	214236	838	837	832	898
		ID	12:00	204337	874	863	873	930
	Strip	Full Section	12:00	198966	841	813	850	916
807J 1G-R Single Torch	Round	OD	12:00	197673	780	757	809	909
		ID	12:00	184964	879	851	882	924
	Strip	Full Section	12:00	235163	831	820	849	913
807K 1G-R Single Torch	Round	OD	12:00	202590	782	764	804	911
		ID	12:00	199825	885	878	886	931
	Strip	Full Section	12:00	244029	834	825	846	915
883G 5G Single Torch	Round	OD	12:00	205007	839	828	845	907
		ID	12:00	203026	936	912	940	975
		OD	9:00	213236	846	839	854	917
		ID	9:00	207145	943	926	945	976
		OD	6:00	201983	824	808	834	910
		ID	6:00	201883	882	870	887	931
	Strip	Full Section	12:00	227244	862	852	872	926
			9:00	250479	871	867	879	933
			6:00	225603	877	870	885	931
883D 1G-R Dual Torch	Round	OD	12:00	193196	822	826	830	880
		ID	12:00	200023	828	830	830	874
		OD	12:00	190240	840	839	843	893
		ID	12:00	203386	835	835	830	876
	Strip	Full Section	12:00	221785	821	817	822	878
			12:00	235987	831	830	830	881
			12:00	236221	828	826	834	892
			12:00	208207	835	820	842	901

Weld	Tensile Type	Location	Clock Position	E (MPa)	0.2% offset YS (MPa)	0.5% YS (MPa)	1.0% YS (MPa)	UTS (MPa)
883E 1G-R Dual Torch	Round	OD	12:00	201907	833	822	837	900
		ID	12:00	201522	830	827	833	866
	Strip	Full Section	12:00	257225	824	824	836	894
			12:00	266246	824	822	831	892
883F 1G-R Dual Torch	Round	OD	12:00	207930	826	822	832	896
		ID	12:00	200453	823	806	822	871
	Strip	Full Section	12:00	266188	829	829	831	883
			12:00	219602	826	820	830	888
883H 5G Dual Torch	Round	OD	12:00	199512	760	748	775	865
		ID	12:00	195862	879	880	884	912
		OD	9:00	198611	782	784	781	847
		ID	9:00	193015	822	818	816	860
		OD	6:00	207323	794	795	791	863
		ID	6:00	200760	795	795	798	852
	Strip	Full Section	12:00	216737	813	797	826	876
			9:00	228029	789	783	797	856
			6:00	253986	788	788	789	854

10 APPENDIX B
ANOVA Output From Design-Expert®

An analysis of variance (ANOVA) was conducted for all of the tensile results for round 1 and 2 pipe welds using the historical data option to determine the primary factors influencing the measurements. While the measurements were made for weld metal deposited with a single welding wire electrode, variations in test specimen configuration and location as well as welding process can influence results.

Factor	Description
A - Clock Position	This is the only numerical factor with “0” representing clock position 12:00, ”3” representing clock positions 3:00 and 9:00, “6” representing clock position 6:00
B - Tensile Type	This categorical factor at two levels refers to the physical shape of the test specimen cross section, “Round” and “Flat”
C - Location	This categorical factor at three levels refers to the location of the tensile specimen cross section in the weld joint - “OD” indicates bias toward the outer diameter, “ID” indicates bias toward the inside diameter, “F” indicates a specimen that samples nearly full weld thickness.
D - Torch Configuration	This categorical factor at two levels indicates welding with “Single” or “Dual” torch configuration
E - Welding Position	This categorical factor at two levels indicates welding in the “1G-R” or “5G” position

Elastic Modulus - ANOVA Table for Two Factor Interaction Response Surface

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.049E+010	3	3.495E+009	15.40	< 0.0001	significant
B-Tensile Type	*7.058E+009*	*1*	*7.058E+009*	*31.10*	*< 0.0001*	
D-TORCH	*1.221E+009*	*1*	*1.221E+009*	*5.38*	*0.0241*	
BD	*2.754E+009*	*1*	*2.754E+009*	*12.14*	*0.0010*	
Residual	1.225E+010	54	2.269E+008			
Lack of Fit	*3.536E+009*	*20*	*1.768E+008*	*0.69*	*0.8085*	*not significant*
Pure Error	*8.717E+009*	*34*	*2.564E+008*			
Cor Total	2.274E+010	57				

Std. Dev.	15063.49	R-Squared	0.4611
Mean	2.110E+005	Adj R-Squared	0.4312
C.V. %	7.14	Pred R-Squared	0.3540
PRESS	1.469E+010	Adeq Precision	9.540

The "Pred R-Squared" of 0.3540 is in reasonable agreement with the "Adj R-Squared" of 0.4312.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 9.540 indicates an adequate signal. This model can be used to navigate the design space.

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	2.136E+005	1	2082.55	2.094E+005	2.178E+005	
B-Tensile Type	11614.38	1	2082.55	7439.11	15789.64	1.02
D-TORCH	4831.76	1	2082.55	656.49	9007.02	1.09
BD	7255.24	1	2082.55	3079.98	11430.50	1.08

The analysis indicates that the model is significant. There is only a 0.01% chance that an F-value value this large could occur due to noise. The relative significance of factors is indicated by p value. Values less than 0.05 indicate the associated factors are significant. Values greater than 0.10 indicate the associated factors are not significant. This model has been reduced to include only significant factors. Lack of fit is not significant and signal to noise ratio is adequate.

The ANOVA suggest that the tensile test specimen type has a greater influence on elastic modulus than torch configuration.

Yield Strength, 0.2% Offset - ANOVA Table for Linear Model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	46156.05	3	15385.35	23.00	< 0.0001	significant
C-LOCATION	*33422.51*	*2*	*16711.26*	*24.98*	*< 0.0001*	
D-TORCH	*12259.72*	*1*	*12259.72*	*18.32*	*< 0.0001*	
Residual	36129.33	54	669.06			
Lack of Fit	*31300.70*	*20*	*1565.04*	*11.02*	*< 0.0001*	*significant*
Pure Error	*4828.63*	*34*	*142.02*			
Cor Total	82285.38	57				

Std. Dev.	25.87	R-Squared	0.5609
Mean	836.10	Adj R-Squared	0.5365
C.V. %	3.09	Pred R-Squared	0.4899
PRESS	41973.99	Adeq Precision	13.295

The "Pred R-Squared" of 0.4899 is in reasonable agreement with the "Adj R-Squared" of 0.5365.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 13.295 indicates an adequate signal. This model can be used to navigate the design space.

Term	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	834.23	1	3.45	827.32	841.15	
C[1]	-29.18	1	4.91	-39.02	-19.34	
C[2]	31.60	1	4.91	21.76	41.44	
D-TORCH	-14.77	1	3.45	-21.68	-7.85	1.01

The analysis indicates that the model is significant. There is only a 0.01% chance that an F-value value this large could occur due to noise. The relative significance of factors is indicated by p value. Values less than 0.05 indicate the associated factors are significant. Values greater than 0.10 indicate the associated factors are not significant. This model has been reduced to include only significant factors.

In this case, lack of fit is significant, yet the signal to noise ratio is considered adequate. The sum of squares for model is higher than the sum of squares for lack of fit. Accordingly, the model is not useful for discrete prediction, but does indicate trends that are consistent with practical experience.

The ANOVA suggest that the tensile test specimen location is the primary factor influencing 0.2% offset yield strength.

Yield Strength, 0.5% Total Strain - ANOVA Table for Linear Model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	41792.54	3	13930.85	17.75	< 0.0001	significant
C-LOCATION	*35927.76*	*2*	*17963.88*	*22.89*	*< 0.0001*	
D-TORCH	*5445.85*	*1*	*5445.85*	*6.94*	*0.0110*	
Residual	42376.98	54	784.76			
Lack of Fit	*33684.48*	*20*	*1684.22*	*6.59*	*< 0.0001*	*significant*
Pure Error	*8692.50*	*34*	*255.66*			
Cor Total	84169.52	57				

Std. Dev.	28.01	R-Squared	0.4965
Mean	826.79	Adj R-Squared	0.4686
C.V. %	3.39	Pred R-Squared	0.4154
PRESS	49205.04	Adeq Precision	11.209

The "Pred R-Squared" of 0.4154 is in reasonable agreement with the "Adj R-Squared" of 0.4686.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 11.209 indicates an adequate signal. This model can be used to navigate the design space.

Term	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	825.70	1	3.74	818.21	833.19	
C[1]	-29.45	1	5.32	-40.10	-18.79	
C[2]	33.33	1	5.32	22.67	43.99	
D-TORCH	-9.84	1	3.74	-17.33	-2.35	1.01

The analysis indicates that the model is significant. There is only a 0.01% chance that an F-value value this large could occur due to noise. The relative significance of factors is indicated by p value. Values less than 0.05 indicate the associated factors are significant. Values greater than 0.10 indicate the associated factors are not significant. This model has been reduced to include only significant factors.

In this case, lack of fit is significant, yet the signal to noise ratio is considered adequate. The sum of squares for model is higher than the sum of squares for lack of fit. The sum of squares for the torch configuration is actually lower than that for pure error. Accordingly, the model is not useful for discrete prediction, but does indicate trends that are consistent with practical experience. The coefficient estimates suggest that the tensile test specimen location is the primary factor influencing 0.5% total strain yield strength.

Flow Stress, 1.0% Total Strain - ANOVA Table for Linear Model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	45196.34	5	9039.27	16.25	< 0.0001	significant
A-CLOCK	*2352.00*	*1*	*2352.00*	*4.23*	*0.0448*	
C-LOCATION	*24388.09*	*2*	*12194.05*	*21.92*	*< 0.0001*	
D-TORCH	*18151.26*	*1*	*18151.26*	*32.63*	*< 0.0001*	
E-POSITION	*2410.04*	*1*	*2410.04*	*4.33*	*0.0423*	
Residual	28929.94	52	556.34			
Lack of Fit	*25521.31*	*18*	*1417.85*	*14.14*	*< 0.0001*	*significant*
Pure Error	*3408.63*	*34*	*100.25*			
Cor Total	74126.28	57				

Std. Dev.	23.59	R-Squared	0.6097
Mean	842.17	Adj R-Squared	0.5722
C.V. %	2.80	Pred R-Squared	0.4949
PRESS	37438.34	Adeq Precision	15.314

The "Pred R-Squared" of 0.4949 is in reasonable agreement with the "Adj R-Squared" of 0.5722.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 15.314 indicates an adequate signal. This model can be used to navigate the design space.

Term	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	819.81	1	10.76	798.22	841.39	
A-CLOCK	-28.00	1	13.62	-55.33	-0.67	2.03
C[1]	-26.05	1	4.48	-35.04	-17.06	
C[2]	26.01	1	4.48	17.02	34.99	
D-TORCH	-18.06	1	3.16	-24.41	-11.72	1.02
E-POSITION	9.97	1	4.79	0.36	19.59	2.05

The analysis indicates that the model is significant. There is only a 0.01% chance that an F-value value this large could occur due to noise. The relative significance of factors is indicated by p value. Values less than 0.05 indicate the associated factors are significant. Values greater than 0.10 indicate the associated factors are not significant. This model has been reduced to include only significant factors.

In this case, lack of fit is significant, yet the signal to noise ratio is considered adequate. The sum of squares for model is higher than the sum of squares for lack of fit. The sum of squares for both clock position and welding position are actually lower than that for pure error. Accordingly, the model is not useful for discrete prediction, but does indicate trends that are consistent with practical experience. The ANOVA suggest that the tensile test specimen location and torch configuration the primary factors influencing 1.0% total strain flow stress.

Ultimate Tensile Strength - ANOVA Table for Linear Model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	30972.45	4	7743.11	28.45	< 0.0001	significant
A-CLOCK	*870.12*	*1*	*870.12*	*3.20*	*0.0795*	
C-LOCATION	*2440.13*	*2*	*1220.06*	*4.48*	*0.0159*	
D-TORCH	*26394.64*	*1*	*26394.64*	*96.98*	*< 0.0001*	
Residual	14424.93	53	272.17			
Lack of Fit	*11374.05*	*19*	*598.63*	*6.67*	*< 0.0001*	*significant*
Pure Error	*3050.88*	*34*	*89.73*			
Cor Total	45397.38	57				

Std. Dev.	16.50	R-Squared	0.6823
Mean	903.90	Adj R-Squared	0.6583
C.V. %	1.83	Pred R-Squared	0.6147
PRESS	17493.02	Adeq Precision	14.827

The "Pred R-Squared" of 0.6147 is in reasonable agreement with the "Adj R-Squared" of 0.6583.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 14.827 indicates an adequate signal. This model can be used to navigate the design space.

Term	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	890.84	1	6.04	878.71	902.96	
A-CLOCK	-11.98	1	6.70	-25.43	1.46	1.01
C[1]	-7.76	1	3.13	-14.04	-1.48	
C[2]	8.63	1	3.13	2.35	14.91	
D-TORCH	-21.72	1	2.21	-26.15	-17.30	1.02

The analysis indicates that the model is significant. There is only a 0.01% chance that an F-value value this large could occur due to noise. The relative significance of factors is indicated by p value. Values less than 0.05 indicate the associated factors are significant. Values greater than 0.10 indicate the associated factors are not significant. This model has been reduced to include only significant factors.

In this case, lack of fit is significant, yet the signal to noise ratio is considered adequate. The sum of squares for model is higher than the sum of squares for lack of fit. The sum of squares for both clock position and specimen location are actually lower than that for pure error. Accordingly, the model is not useful for discrete prediction, but does indicate trends that are consistent with practical experience. The ANOVA suggest that the torch configuration is the primary factors influencing ultimate tensile stress.

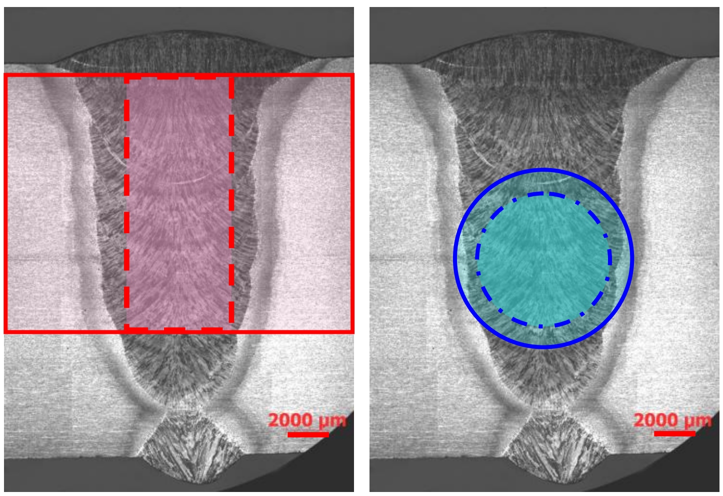
11 APPENDIX C
Recommended Practice for All-Weld Metal Tensile Testing Of Narrow Gap Pipeline Girth Welds

1 Scope

This recommended practice describes a method to measure the all-weld metal (AWM) tensile properties in narrow gap welds. While the methodology can be used for narrow gap welds in plate, this practice addresses the specific case of narrow gap girth welds in large diameter line pipe. It differs from other weld metal testing methods in that the specimen configuration has been modified to sample as much of the weld fusion zone as possible. In this way, results will be representative of the weld metal as a whole and not dominated by the local conditions in a single weld bead or reheat region.

2 Purpose and Intended Use

The tensile test protocol described herein is intended for assessment of narrow gap pipeline girth welds with emphasis on strain based design (SBD) pipeline applications where weld strength overmatching in relation to actual pipe properties is a design requirement. In the narrow groove geometry, the AWM strip test specimen and corresponding test procedures provide better quantification of weld metal strength than is possible with the traditional round bar tensile test specimen. Using the AWM strip, it is possible to significantly increase the cross-sectional area of the specimen in the weld and sample a greater percentage of the fill passes, as shown in Figure 2-1. Also, to support SBD applications it is intended that the full stress-strain curve be determined for each tensile test.



(a) modified strip tensile test specimen

(b) round bar tensile test specimen

Figure 2-1. Tensile specimen location in narrow gap weld cross-section

(Darker shaded area in the middle of each test specimen indicated the reduced section of the gage length.)

The instructions provided for test specimen preparation are specific to narrow gap welds made in two sizes of pipe - 19 mm (0.75 in) nominal wall thickness, 914 mm (36 in) diameter and 14.3 mm (0.563 in) nominal wall thickness, 1067 mm (42 in) diameter. They describe test specimen configuration, layout, and preparation in detail. The general approach may be applied to other girth welds produced in pipe of different diameters and/or wall thicknesses by modifying the length, width, and thickness dimensions. However, application to nominal pipe diameter below 762 mm (30 in) is not considered feasible because the pipe curvature will limit specimen length and/or thickness to the point that there will be little, if any, advantage over a conventional round bar test specimen.

Testing of the specimens is to be conducted in accordance with ASTM E8. Additional information relevant to the AWM strip test specimen configuration is provided when applicable.

3 Referenced Documents

ASTM E8/E8M-09, Standard Test Methods for Tension Testing of Metallic Materials, ASTM International, West Conshohocken PA US

AWS B4.0: 2007, Standard Methods for Mechanical Testing of Welds, 7th Edition, American Welding Society, Miami FL, US

4 Terminology

ASTM E8/E8M-09 standard terminology applies.

5 Test Specimen

The AWM strip tensile specimen is a rectangular tension test specimen, modified from ASTM E8. The requirements and recommendations of ASTM E8/E8M apply, except as modified herein.

As illustrated in Figure 2-1(a), the AWM strip tensile specimen is shifted toward the weld cap, or OD, to ensure that a majority of weld fill passes are sampled. The height and width of the reduced section of each modified strip tensile specimen are governed by the actual width of the weld fusion zone in each case. This is influenced by the pipe diameter, pipe wall thickness, weld joint details, any high/low misalignment at the root, etc. Therefore, layout of the specimen in the weld and correct positioning of the gauge section at the middle of the specimen is essential to ensure that the test measure all-weld metal tensile properties.

5.1 Test Specimen Blank(s) Preparation

One blank, 82 mm (3-1/4 in.) minimum along the circumference by 70 mm (2-3/4 in.) minimum transverse to the weld is needed for each AWM strip tensile specimen. The 70 mm (2-3/4 in.) dimension must be roughly centered on the weld.

It is recommended that saw cutting, or other mechanical mean, be used to remove the blank(s) from the pipe girth weld. If flame cutting is used to rough cut the blank(s), a distance of at least 203 mm (8 in.) must be maintained from the girth weld centerline to ensure that the weld region is not overheated. If further flame cutting is used to cross the girth weld (e.g. to produce smaller rings or curved sections of pipe weld), add at least 25.4 mm (1 in.) to the rough blank length since the grip ends of the AWM strip tensile specimens are relatively short and any overheating of the gage section must be avoided.

5.1.1 Locate and mark the nominal position(s) where rectangular blank(s) are to be cut from the girth weld. This is generally indicated by clock position for pipe welds. However, any means of uniquely identifying the location of each test block with regard to circumference on the pipe is acceptable. This information must be reported with the test result.

5.1.2 Cut the blank(s) from the pipe girth weld, Figure 5-1. Initial cuts can be made normal to the pipe wall so that further machining will produce rectangular blank(s) that are tangent to the pipe outer and inner walls at mid-length. The excess pipe material on either side of the weld should be cut parallel to the weld longitudinal axis to obtain blank(s) that are centered on the weld.

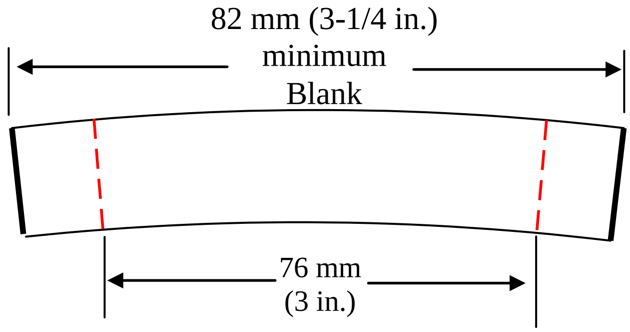


Figure 5-1. Schematic diagram of AWM strip tensile blank
(Broken lines indicate approximate location of AWM strip tensile in the blank.)

5.1.3 Machine and grind both ends parallel, Figure 5-2(a). Etch the ground ends to locate the weld centerline. Then, machine the two curved sides, Figure 5-2(b), parallel to the weld centerline and square with the ends.

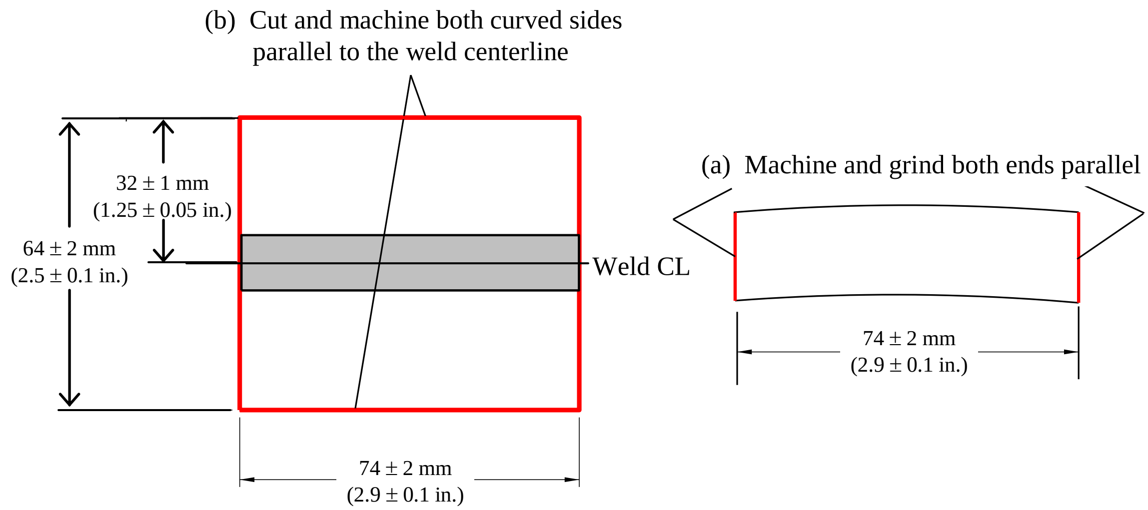
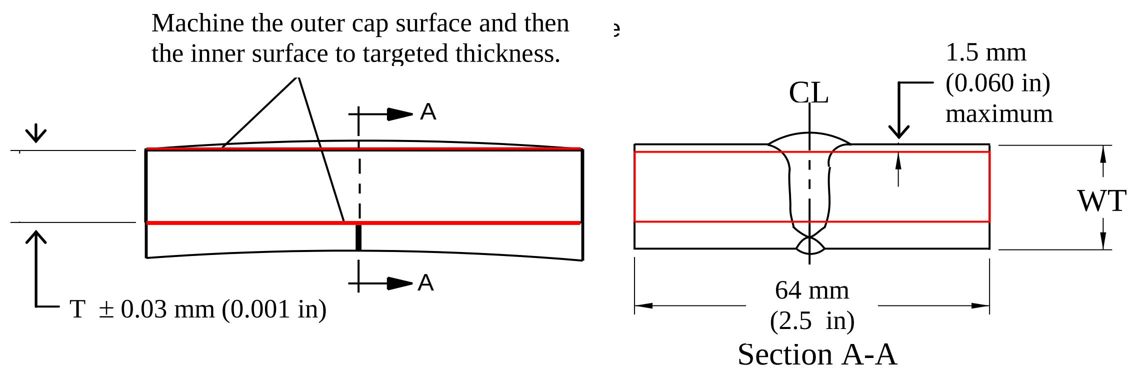


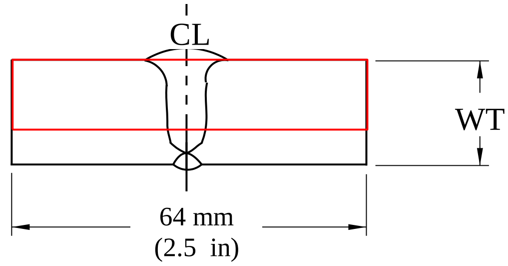
Figure 5-2. AWM strip tensile blank, (a) elevation view and (b) plan view showing weld cap on OD



(a) Elevation parallel to weld centerline

(b) Cross section at mid-length

Pipe		Blank target thickness, T mm (in)
nominal wall thickness, WT mm (in)	Diameter, D mm (in)	
19 (0.75)	914 (36)	12.70 (0.500)
14 (0.55)	1067 (42)	7.90 (0.312)

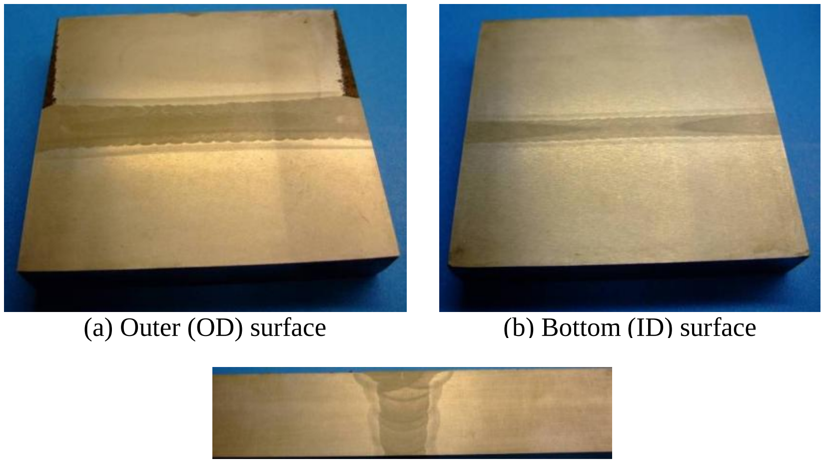


(c) End view

Figure 5-3. Preparation of AWM strip tensile blank

5.1.4 Machine the outer (OD) surface flat by removing no more than 1.5 mm (0.060 in) at the mid-length, Figure 5-3. Machine the inner (ID) surface flat to achieve target thickness, T, as indicated.

5.1.5 Etch top and bottom surfaces to make weld fusion zone clearly visible on four surfaces, Figure 5-4. Note that the ends should have been etched at 5.1.3. Re-etch ends, as needed, to ensure weld fusion zone is visible on four sides as illustrated in Figure 5-4. Relocate and re-scribe weld centerline on both ends as needed for visibility.



(a) Outer (OD) surface (b) Bottom (ID) surface

(c) End surface

Figure 5-4. Photographs of blanks etched with 3-5% Nital
(a) reveals cap pass(es), (b) reveals hot/root pass, (c) reveals through-thickness profile

5.1.6 Scribe weld centerline on bottom (ID) surface in line with the scribe lines on both ends. At mid-length on the bottom (ID) surface, check to ensure that the scribe line is actually centered in the weld. Measure the weld width at this location and subtract 0.50 mm (0.020 in.) to determine finished width of the AWM strip tensile specimen reduced section, w in Figure 5-5, to the nearest 0.1 mm (0.005 in.). This reduction is needed to ensure only weld metal is in the gauge section.

5.2 Test Specimen Preparation

Prepare a single AWM tensile test specimen from each blank. Figure 5-4 illustrates three views of etched blanks. Note the rough edges still remaining on the outer (OD) surface, Figure 5-4(a), to one side of the weld (towards top of photograph). This condition is caused by variation in pipe alignment (*e.g*. high/low condition) that can exist around the circumference of a pipe girth weld. If these regions are sufficiently narrow that the grip area of the finished specimen will be adequate to conduct the tensile test, proceed with test specimen preparation. Otherwise, reduce the target thickness and repeat 5.1.4 for the outer (OD) surface. Figure 5-4(b) illustrates the bottom (ID) surface revealing the hot/root pass. It is this surface that is used to determine the final width of the finished AWM strip tensile specimen at the reduced section. The end view in Figure 5-4(c) is used to establish weld centerline, as described previously

5.2.1 **Reduced Section Width -** Determine the test specimen width from the width of the weld fusion zone on the bottom (ID) surface, as illustrated in Figure 5-5. At the mid-length, measure the weld width. Subtract 0.50 mm (0.020 in) to determine finished width of the AWM strip tensile specimen reduced section, w. This reduction is needed to ensure that the gage section is all weld metal and does not include any heat affected zone. The 0.50 mm (0.020 in) is sufficient to accommodate the irregularity typical in the fusion boundary of a narrow gap GMAW pipe weld.

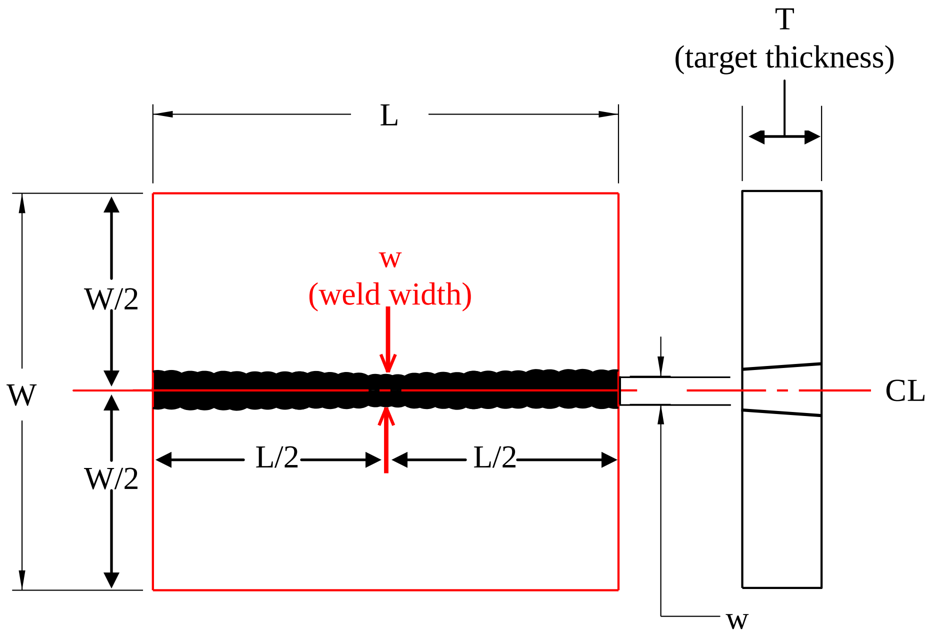
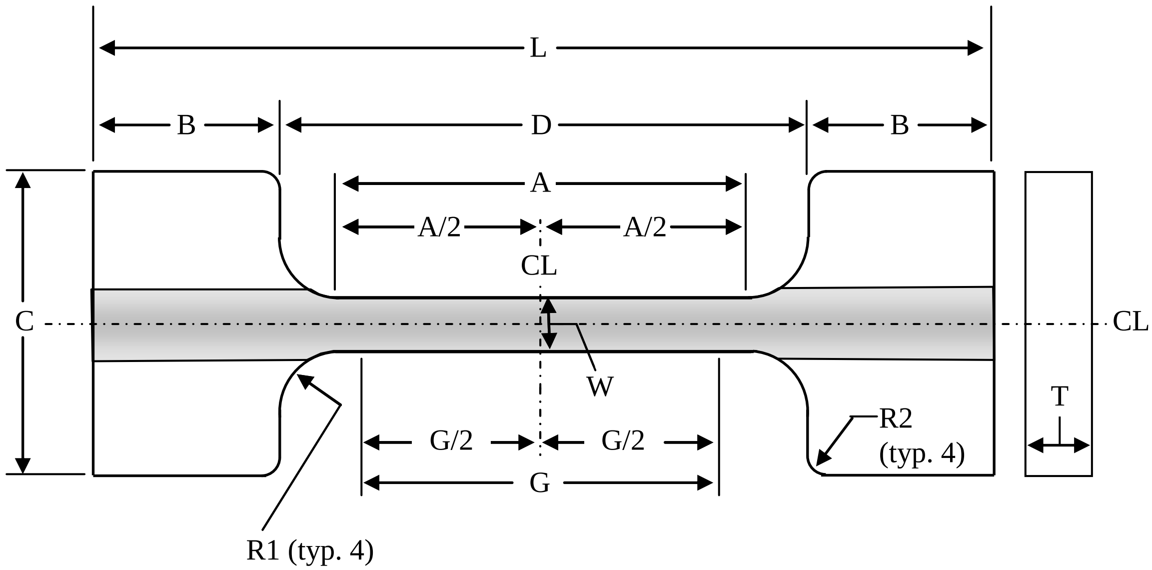


Figure 5-5. Measurement of weld width for determination of specimen width

5.2.2 **Final Specimen Preparation -** Using the scribed centerlines for reference, CL in Figure 5-6, machine the AWM strip tensile specimen from the prepared blank to the dimensional requirements of Figure 5-6. Figure 5-7 illustrates a typical AWM strip tensile specimen in finished condition prior to test.



	Dimension, mm (in.)	Tolerance, mm (in.)
G - gage length	25.0 (1.000)	± 0.1 (0.003)
W - width of reduced section	See 5.1.6	±0.001
T - specimen thickness	See Fig. 5-3	See Fig. 5-3
R1 - radius of fillet	5.1 (0.20)	minimum
L - overall length	74 (2.9) See Fig. 5-2	± 2 (0.1) See Fig. 5-2
A - length of reduced section	32 (1.25)	minimum
B - length of grip section	66 (0.6)	approximate
C - width of grip section	25 (1.0)	minimum

Figure 5-6. AWM strip tensile specimen dimensional requirements

Figure 5-7. AWM strip tensile specimen prior to test,
(a) bottom (ID) surface visible with hot/root pass, (b) end view

6 Testing

The AWM strip tensile specimen must be tested using either hydraulic or mechanical wedge grips by clamping the wide machined surfaces as illustrated in Figure 6-1. Careful alignment of the specimen is necessary. It is important the specimen is held tight and that it does not slip or bend during test. Attachment of the extensometer requires care because of the potential for residual stresses in weld specimens. The surface used for attachment of the strain gage is important, since an error in initial strain measurement can occur when the gage is placed on the through-thickness face.

The test shall be conducted in accordance with ASTM E8/E8M. Because the intent is to document the complete stress-strain behavior for the specimen, the extensometer must remain in place for the entire test and the loading rate must not be increased after yield.

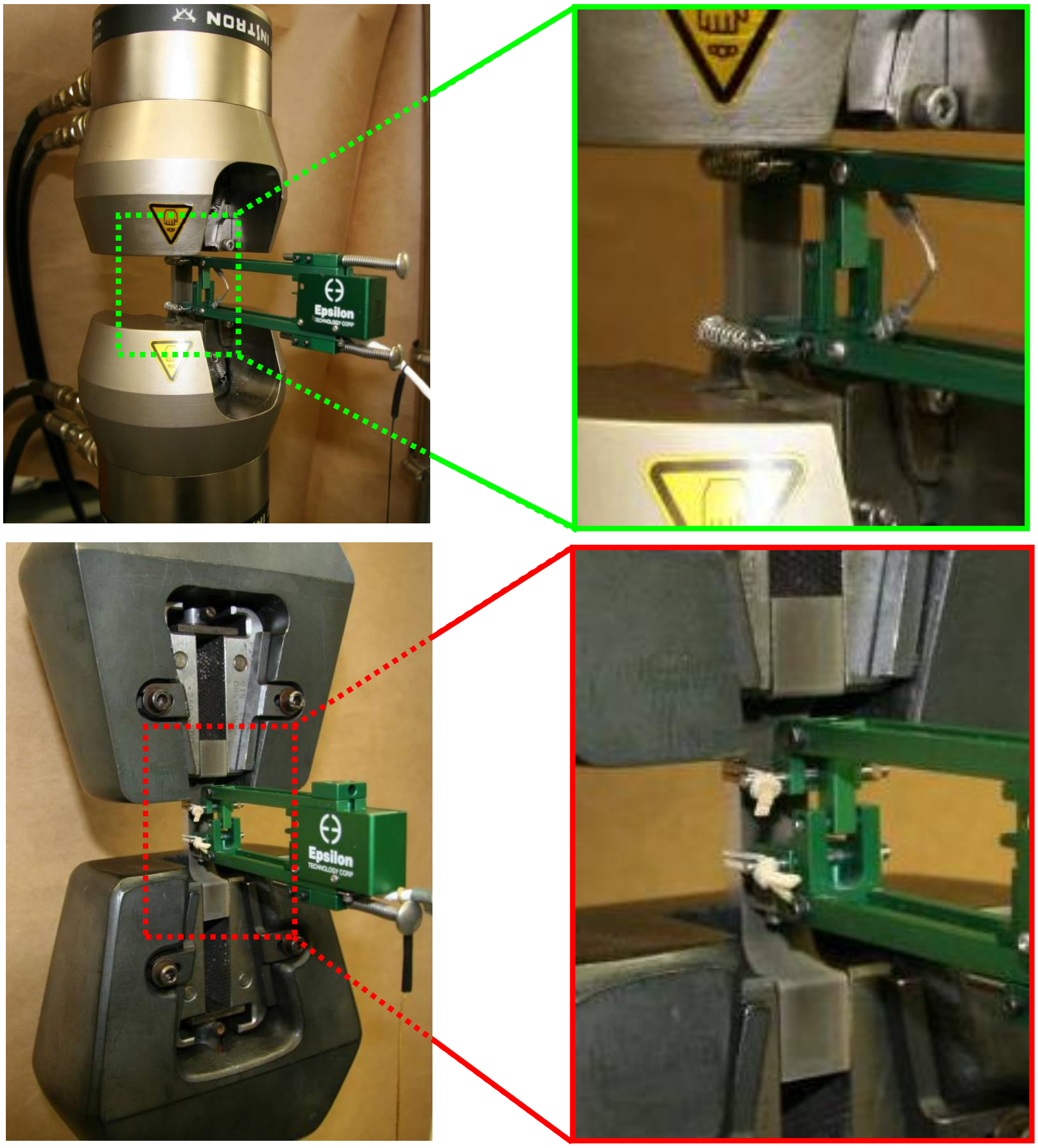


Figure 6-1. AWM strip tensile test
(Note placement of extensometer on OD / ID surfaces.)

7 Post Test Analysis and Reporting

The tensile property data from AWM strip tensile specimens can be processed and evaluated in several ways. As a minimum, the following information is to be reported for each test unless otherwise specified:

- Weld identification
- AWM strip tensile identification
- AWM strip tensile dimensions, T and W
- AWM strip tensile location (e.g. clock position, quadrant, etc.)
- Yield strength, 0.2% offset method
- Yield strength, 0.5% total strain method
- Flow stress at 1.0% total strain
- Ultimate tensile strength
- Uniform strain
- Percent total elongation
- Percent reduction of area
- Strain hardening coefficient
- Elastic modulus
- Full engineering stress-strain curve