Proposed HDPE Butt Fusion and Electrofusion Bonder, and In-Process Qualification Test Methodology

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INTRODUCTION

This document provides a methodology, in-line with standards from multiple jurisdictions, for how to assess the quality of HDPE fusion welds, both Electrofusion (EF) and Butt Fusion (BF). It establishes three levels of risk classification acceptance as shown in Table 1. Level I has the highest risk and, as a consequence, most demanding quality requirements and Level III having the lowest risk and least stringent requirements.

A Level I classification might be applied for critical HDD bores, for pipelines in densely populated areas, or for firewater lines that could be considered mission critical. Level II classification might be applied to sweet low pressure natural gas service, less densely populated areas, environmentally sensitive areas, or water / sewer lines in critical areas. Level III might be applied in the least stringent service requirements. The risk level would be determined by the pipeline owner / operator and reviewed / approved by the applicable regulatory agency.

As is typically the case, the procedure qualification is the most rigorous and includes non-destructive visual inspection, NDE by Microwave Interferometry, destructive visual inspection of weld cross-sections, and waisted ISO tensile tests of the parent pipe material(s) and the weld. The tensile energy to break derived from of welded coupons is then compared to that of the parent material(s). Ultimately, these values should be agreed upon by the owner / operator in conjunction with the regulator.

For the fusion bonder qualification, the test requirements are the same as for the procedure qualification except that the waisted tensile test is dropped. However, in the case where the results of the fusion bonder qualification are still inconclusive, the waisted tensile test can be reintroduced with the prior agreement of the pipeline owner / operator. In the case of conflicting results, the tensile test results will outweigh the preceding tests. By making the two levels of qualification testing similar, economies are introduced. As is frequently the case, procedure and bonder qualifications are submitted simultaneously. A successful procedure qualification will also approve the fusion bonder who performed it. This also precludes the anomalies observed with the current standard testing methodology where the procedure can pass but the fusion bonder is failed (or potentially vice versa).

For the in-process tests every weld should undergo non-destructive visual inspection to requirements of Table 2, and the non-destructive testing (Microwave Interferometry) percentage to the risk classification acceptance level specified by the owner /operator, or applicable regional standards, whichever is greater. If a weld is questionable based on the threshold levels but not strictly rejectable, an NDE inspection can be requested by the site QA / QC representative. Otherwise, the site QA / QC representative shall enforce NDE inspection based on a pre-approved / previously agreed sampling plan that will have been specified by the owner / operator and reviewed / approved by the applicable regulator. One approach to statistical sampling plan frequencies might be to use the frequencies required for steel pipelines in the applicable regional codes (i.e. generally 100% for critical service applications and 15% for others).

The preceding provides for some flexibility on the part of the site QA / QC inspector and avoids, as much as practicable, the cutting out of welds which reduces productivity. In general, 100% of tie-ins (Golden Welds) should be inspected with NDE methodologies.

Table 2 summarizes some of the possible visually available defects, their potential causes, and their acceptance thresholds based on the risk classification acceptance level specified.

A list of applicable codes and standards used in the creation of or specifically referenced in this document appears on the last page.

Procedure Qualification

Butt Fusion (BF)

Conduct a Microwave and/or TOFD UT scan of the weld, record any indications and measure the crystallinity constant (microwave).

Section pipe at 0°, 120°, and 240° degrees per the ISO13953, or areas of concern chosen using Microwave Interferometric NDE testing (Figure 1). Cut cross-sections of welds at these locations, grind /polish, and thermally etch to reveal weld macrostructure. Measure and record an image of these cross-sections.

Cut and machine tensile test coupons from these locations in accordance with ISO13953:2001.

Cut and machine the three tensile coupons (and any from areas of concern) from the pipe parent material(s) in accordance with ISO13953:2001. Operator / Construction company must provide evidence that both sections of pipe to be joined are from the same manufacturer and batch or run in order to avoid a double test of the parent materials.

Tensile test all coupons in accordance with ISO, record the stress – strain curve, calculate the TEB in accordance with EN 12814-7, calculate the weld factor (W_f), record the ultimate tensile stress, ultimate elongation, failure mode (photomacrographs), and ensure the test report is in accordance with EN 12814-7.

If the sample passes the ISO testing in accordance with the standard and accepted owner / operator criteria, the sample is considered a "nominal fusion" and can be used as a calibration standard for on-site production NDE (Microwave and/or TOFD).

Cut bend samples (if the sample is large enough, use preference to field-tensile samples) from the remaining weld material and perform the bend test to CSA-Z662-13 and datalogged field-tensile testing to the "McElroy Field Tensile Testing General Procedure, Based on Modified 80% Test Block."

Electrofusion (EF)

Electrofusion couplings can be tested to the ISO 21751 Strip Bend test, the ISO 13955 Crush Decohesion test, or the ISO 13954 Peel Decohesion test. The ISO 21751 and 13955 can be performed on-site given the availability of equipment based on the DN of the pipe. The 13954 provides the most in-depth quantification of a procedure but can only be performed in a laboratory setting.

Saddle fusions can be tested to the ISO 21751 or ISO 13956 Tear Decohesion standards with a preference to the 13956 due to the ability to view the entire fracture surface of the saddle and measure directly the decohesion levels.

All couplings and saddles to be tested should be examined non-destructively using Microwave Interferometry and/or Phased Array UT before destructive testing.

Fusion Bonder Qualification

Repeat as above. Tensile/lab based testing is optional at the discretion of the QA / QC authority. Field level testing (bends/tensile) should be performed to establish a baseline for field level inspection of that fusers production welds.

In-Field Tests

Field level destructive testing should be carried out daily as per the CSA-Z662-13. The use of a morning (first fusion of the day) dummy weld has been shown through significant field use not only to easily locate issues with the procedure and/or welding equipment, but also used as a daily nominal standard with which to inspect production fusions using Visual and NDE methods.

The fusion must be cut out of pipe that is intended to be used in production (i.e. the same material, size and batch) but may be constructed from “test pups” rather than cut out of a production line. On reception, the bead is measured around the circumference, stripped and twisted as per the WIS-4-32, and the results documented. The fusion is then inspected using an NDE technique(s) and the results recorded. The macro is cut out, and measured and photographed.

Follow the procedures outlined in the document “McElroy Field Tensile Testing General Procedure, Based on Modified 80% Test Block.” Evaluate the data in accordance with the applicable acceptance level (Table 1) and visually according to the outline in Table 2. If agreed upon by the owner / operator, the fusion is also bend tested in accordance with the CSA-Z662-13, which can be used to meet regional regulations or as a further method of establishing fusion quality.

In general, for DN over 90mm, all electrofusion saddles and couplings should be inspected visually (in accordance with the manufacturers procedures, which can differ between commercial brands), and the installation process should be monitored / checked for appropriate scraping, insertion depths, alignments and cleanliness of installation.

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Field level destructive testing of EF fittings is not practicable due to cost and time; the ISO 21751 and 13955 can be performed on-site in the circumstances of a suspected issue such as malfunctioning equipment or defect from factory of fittings.

As traditionally BF welds comprise the main quantity of fusions on a normal pipeline, it is recommended that 100% of EF couplings and saddles are inspected using Microwave Interferometry and/or PAUT to determine the fusion quality. In particular, all tie-ins (Golden Welds) should be inspected using NDE.

Table 1

Risk Classification Acceptance Levels

Acceptance Level	Requirement Level	Inspection Level
I	High requirements concerning safety, reliability, and load-bearing capability e.g. sour natural gas service, densely populated area, water in mission critical service	100% Visual 100% NDE 100% Weld Monitoring Test weld Daily
II	Medium requirements concerning safety, reliability, and load-bearing capability e.g. sweet natural gas service, unpopulated area or environmentally sensitive area, or water / sewer in critical areas	100% Visual 15% NDE/Random Random Weld Monitoring Test weld Daily
III	Low requirements concerning safety, reliability, and load-bearing capability e.g. water / sewer elsewhere	100% Visual NDE as required Test weld Daily

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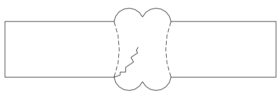
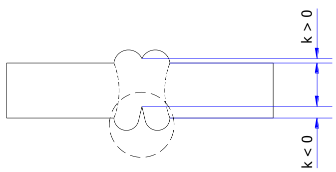
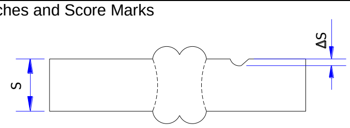
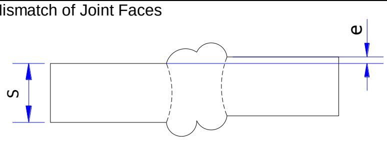
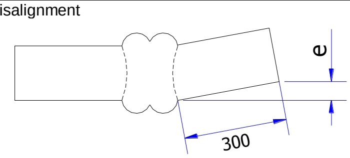
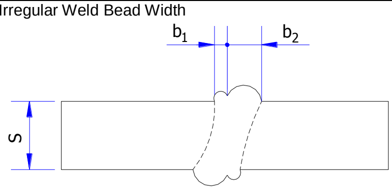
Table 2
Description of Acceptance Levels for HDPE Butt Fusion Welds

Item No.	Feature	Description	Acceptance Level		
			I	II	III
External Condition of Weld by Non-Destructive Visual Inspection					
1	Cracks 	Cracks oriented lengthwise to or across the weld These may be located: 1. In weld 2. In the parent material 3. In the zone exposed to heating	Not permitted	Not permitted	Not permitted
2	Welding Flash Notches 	Welding flash notches with k<0, e.g. due to 1. Insufficient joint pressure 2. Heating time too short 3. Cooling time too short 4. Surfaces not parallel 5. Change of clamped workpiece position during welding 6. Mismatch	Not permitted, k<0	Not permitted, k<0	Not permitted, k<0
3	Notches and Score Marks 	Notches in the edge of the parent material, lengthwise or cross-wise to weld, e.g. due to 1. Clamping tools 2. Incorrect Transportation 3. Edge preparation faults	Locally permissible if ends get gradually shallower and the bottom of the notch or groove is not acute $\Delta s \leq 0.1s$ but not greater than 0.5 mm	Locally permissible if ends get gradually shallower and the bottom of the notch or groove is not acute $\Delta s \leq 0.1s$ but not greater than 1.0 mm	Locally permissible if ends get gradually shallower and the bottom of the notch or groove is not acute $\Delta s \leq 0.15s$ but not greater than 2.0 mm
4	Mismatch of Joint Faces 	The joint faces are not aligned or the thicknesses have not been matched correctly, 1. Depending on the material and the thickness, this may impair the joint quality 2. Circumferential misalignment: due to residual stress in coiled pipe 3. Rotational misalignment: most pronounced in thicker pipes where pipes tend to shown a pronounced extrusion crown	Permissible if $e \leq 0.10s$	Permissible if $e \leq 0.15s$	Permissible if $e \leq 0.20s$
5	Axial Misalignment 	For example, due to: 1. Machine tool fault 2. Tool set-up fault 3. Non-permissible pressure applied during cooling 4. Deformation 5. Pipe removed from clamp too soon	Permissible for pipes (straight lengths) if $e \leq 1$ mm	Permissible for pipes (straight lengths) if $e \leq 2$ mm	Permissible for pipes (straight lengths) if $e \leq 4$ mm
6	Weld Flash Shape	Due to the large variety of materials, material grades and the resulting different flash formations that may evolve, it is not possible to define a standardized evaluation scheme here. **It is not possible to predict the long-term behaviour of the welded joint by inspecting the shape of the flash.**	The fabrication and testing of sample welds as a reference is recommended.	The fabrication and testing of sample welds as a reference is recommended.	The fabrication and testing of sample welds as a reference is recommended.
7a	Upset Volume is Noticeably too small or too large	Due to incorrect welding parameter values 1. Make a comparison weld to verify welding parameter settings	Not permitted	Not permitted	Not permitted
7b	Irregular Weld Bead Width 	Weld beads of different width, either along a part or the entire joint length or circumference 2. Heated tool at an angle 3. Joint face not orthogonal to axis 4. Melt flow rates (MFR) of the materials joined differ (flashes are of different size all along the joint	Permissible if $b_1 \geq 0.7\ b_2$	Permissible if b_1 .6 b_2	Permissible if $b_1 \geq 0.5\ b_2$

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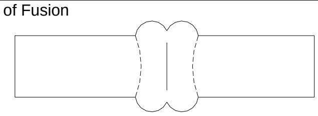
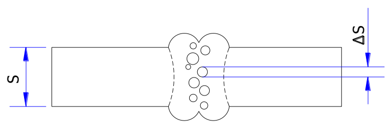
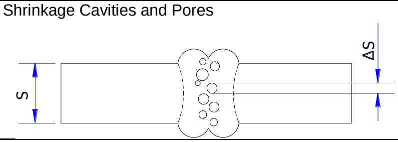
8	Flash Containing Bubbles or Lumps	Thermal damage: 1. Heated tool too hot 2. Mating and / or heating-up time too long 3. Damp or wet surfaces	Not permitted	Not permitted	Not permitted
Internal Condition of Weld by Destructive Visual Inspection and / or NDE Method					
9	Lack of Fusion 	No fusion at all or incomplete fusion of the joint faces, either of sections or distributed throughout the cross-section of the weld, with or without bubbles or lumps, e.g. due to: 1. Damp or wet surfaces 2. Contaminated joint faces 3. Oxidized joint faces 4. Changeover time too long 5. Wrong heated tool temperature 6. Joint compression force too low	Not permitted	Not permitted	Not permitted
10	Pores and Foreign Matter Inclusions 	Numerous isolated pores and / or inclusions distributed throughout the weld or occurring in local concentrations, e.g. due to: 1. Evaporation during welding (water, solvents, residual hydrocarbons, cleaning agents) 2. Dirty heated tool faces	Small isolated pores are permitted if Δs ≤ 0.05s	Small isolated pores are permitted if Δs ≤ 0.10s	Small isolated pores are permitted if Δs ≤ 0.15s
11	Shrinkage Cavities and Pores 	Cavities in the joint plane, e.g. due to: 1. Joint compression force too low 2. Cooling time too short	Small isolated pores are permitted if Δs ≤ 0.05s	Small isolated pores are permitted if Δs ≤ 0.10s	Small isolated pores are permitted if Δs ≤ 0.15s
Mechanical Test					
12	Waisted Tensile, According to BS ISO 13593 Compare property of parent material(s) to weld property using weld factor (W_f). In case of dissimilar materials being joined compare to lower strength material. Start by comparing W_f based on TEB. If, unclear compare UTS, UE, and fracture mode.	Quality Criteria in order of preference: 1. Tensile Energy to Break (TEB) 2. Ultimate Tensile Strength (UTS) 3. Ultimate Elongation (UE) 4. Fracture Mode	W_f ≥95	W_f ≥0.90	W_f ≥0.85

Applicable Codes and Standards

1. CSA Z662-11/, 'Oil and Gas Pipeline Systems', Canadian Standards Association

2. BS ISO 13953:2001, 'Polyethylene (PE) Pipes and Fittings – Determination of the Tensile Strength and Failure Mode of Test Pieces from a Butt – fused Joint', International Standard

3. EN 12814-7:2002, 'Testing of Welded Joints of Thermoplastics Semi-Finished Products – Part 7: Tensile Test with Waisted Test Specimens

4. DVS 2202-1:2006, 'Imperfections in Thermoplastic Welded Joints: Features, Description, Evaluation', German Technical Code

5. WIS43208 "Specification for the Fusion Jointing of Polyethylene Pressure Piping Systems Using PE80 and PE100 Materials"

6. BS ISO 13954:2001, 'Peel decohesion test for polyethylene (PE) electrofusion assemblies of nominal outside diameter greater than or equal to 90 mm'

7. BS ISO 13955:1997 'Crushing decohesion test for polyethylene (PE) electrofusion assemblies'

8. BS ISO 13956:2010, 'Determination of cohesive strength — Evaluation of ductility of fusion joint interface by tear test'

9. BS ISO 21751:2011, 'Decohesion test of electrofusion assemblies -- Strip-bend test'

In Writing Stage Codes and Standards

1. Recommended Practice SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing – Microwave Inspection will appear in the next release

2. ANSI-CP105 Training Outlines for Qualification of Nondestructive Personnel – Microwave Inspection will appear in the next release

3. ASTM WK40655 - New Practice for Microwave Examination of High Density Electrofusion Joints and Couplings Used in Piping Applications (to be balloted this quarter) http://www.astm.org/DATABASE.CART/WORKITEMS/WK40655.htm

4. ASTM WK51094 - New Practice for Standard Practice/Guide for Microwave Examination of High Density Polyethylene Butt Fusion Joints (to be balloted this quarter) http://www.astm.org/DATABASE.CART/WORKITEMS/WK51094.htm

5. ASME BPVC, Section III Appendices, Appendix XXVI

6. ISO TC138 - "Inspection of Polyethylene Fusion Joints using Microwave Imaging"