Plastics Industry Pipe Association of Australia Limited ACN 086 511 686

Industry Guidelines

ASSESSMENT OF POLYETHYLENE WELDS

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Pipelines Integrity For a Cleaner Environment

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Assessment of Polyethylene Welds

1 INTRODUCTION

This guideline discusses the existing techniques for non-destructive (NDT) and destructive testing of electrofusion (EF) and butt welding options for jointing polyethylene (PE) pipe systems. It provides acceptance criteria for nominated weld features. A section has also been included related to the emerging alternative NDT technologies and aspects to consider when interpreting some destructive weld tests.

The two common methods of welding PE pipe are butt fusion and electrofusion (EF). Butt welding has been used successfully in Australia since the 1960's and EF since the early 1980's. These methods are used widely around the world with something in excess of 100,000,000 butt welds and around 20,000,000 EF joints completed annually. PE is the material of choice for gas distribution pipe systems around the world and is also widely used in the water industry, irrigation, mining and industrial applications. Based on this past success PE is now being used in highly critical pipe networks for applications such as nuclear power generation.

The weld procedures and practices used for jointing PE pipe systems are well understood and well documented. In Australia the major references are the PIPA POP001 and POP003 Industry Guideline documents detailing the procedures for EF and butt fusion respectively (both available from PIPA www.pipa.com.au). POP003 in turn references the International Standard ISO 21307 covering butt welding parameters. Other significant documents covering PE pipe welding include the German DVS Technical Codes on Plastics Joining Technologies and the UK Water Industry Standards.

The acceptance criteria suggested in this guideline are based on information contained in existing documentation. In particular the German DVS Technical Codes on Plastics Joining Technologies, AS/NZS 2033, AS/NZS 4129, UK Water Industry Standards, American Society for Testing and Materials F1055 and F2620 and other established industry practices such as those outlined in POP001 and the Iplex Poliplex Polyethylene Pipe Design Textbook

1.1 Background to weld assessment

The examination and testing of PE pipe welds has generally been based on visual and destructive testing options. These have proved very successful techniques for assessing welds along with a dedication to ensuring the correct surface preparation and weld procedures are employed. Visual examination of welds is a particularly useful NDT technique as it yields a great deal of information about the weld preparation, potential contamination, alignment and weld pressures. The value of visual examination of PE welds is often underestimated because many people have been conditioned to relying on radiography or ultrasonics in traditional metal welding.

Butt welding PE pipe differs significantly from metal welding and these differences make visual examination far more effective in PE than in metals. Butt welding PE pipe requires a machine that clamps, aligns, planes the surfaces to be welded so that they are both clean and square, applies heat using a calibrated plate, applies pressure to affect the weld and often also times and records the whole process. In the case of PE pipe welding there are no welding consumables (i.e. the actual pipe material forms the weld) and the entire surface to be welded is heated uniformly. After heating the pipe ends are forced together under pressure and some of the material that was on the original face of the pipe end is rolled out to form the bead. This contrasts enormously with metal welding where usually the weld is achieved by introducing a consumable welding material that differs from the pipe material and typically this consumable is introduced to the joint in a small localised molten pool often thousands of degrees hotter than the remaining weld surfaces and progressively moves around the circumference during the welding process. Hence the appearance, size and shape of the PE weld bead provide a great deal of information about the entire process – visual examination of metal pipe welds cannot provide this information and there is no equivalent in metal pipe welding.

1.2 Emerging Non-Destructive Testing Methods for PE

NDT Techniques other than visual assessment (for example ultrasonics and radiography) commonly used in the metals industry have limited application to PE weld examination.

Inspection of PE butt welds has been attempted using the NDT methods applied to steel welds. While these techniques are well suited for steel materials they do not reliably detect issues associated with poor PE joint performance such as incomplete fusion or “cold welds”. This is due to differences in the nature of the pipe materials that in turn lead to inconsistencies in the interpretation of the outputs from these methods.

Contrast mechanisms used for examining metal welds are not readily applicable to PE. Simple pulse echo ultrasonics or radiography have severe limitations due to high signal attenuation for ultrasonics and significantly lower density for radiography that restricts the ability of these techniques to examine PE materials. Similarly techniques based on magnetic properties or requiring electrical conductivity are simply not options for PE materials which are neither magnetic nor conductive.

Recent developments using phased array time of flight diffraction ultrasonics and microwave technologies show promise that future NDT examination of PE welds may be possible in a similar manner to steel pipe welds. At the time of preparing this guideline none of these techniques had advanced to a stage where standards or acceptance criteria had been developed and no significant research outcomes had been reported.

An attempt has been made in Table 3 to identify butt weld defects that potentially could be detected by these emerging NDT technologies and provides guidance regarding the acceptance criteria if such technologies were suitable. No attempt has been made to identify potential defects in EF joints using alternative technologies given the uncertainties associated with the capability of these technologies.

Further information about emerging NDT techniques can be found in PIPA Technical Note TN016 “Non Destructive Examination of PE welds – Emerging Techniques”.

1.3 Welder qualifications

The key to the success of any welding process is based on the skills of the welder and the dedication to correct surface preparation and weld procedures. Before undertaking any inspection every effort should be made to confirm the experience and skills of the welder and the weld procedures adopted. This could be achieved by examining quality assurance records along with the qualifications and experience of the welder. All welding operators should be qualified and regularly recertified to PMBWELD302B (Electrofusion Welding of Polyethylene Pipelines) and/or PMBWELD 301 (Butt Welding Polyethylene Pipelines).

1.4 Long Term and Short Term Testing

This guideline focuses on so called short term testing of PE welds primarily aimed at field based or rapid turnaround test options typically used as QA/QC measures.

The purpose of long and short term testing is often misunderstood and hence the following outlines some of the long term type testing employed for welded PE pipe joints.

Plastics pipe systems undergo a range of long term type tests to prove their long term performance. These tests are laboratory based and often involve the exposure of the pipe to elevated temperatures during the test program for periods in excess of one year. These are not production tests but rather type tests to qualify materials and design to ensure service lives of 100 years or more will be achieved.

Welds for PE pipe have a range of long term tests that similarly prove the long term performance of jointing techniques. The long term tests for butt welds include the tensile specimen creep rupture test (EN 12814-3), the whole pipe tensile creep rupture test and the hydrostatic pressure test (ISO 1167).

The long term creep rupture tests involve preparing a tensile test specimen or using a full pipe section and in both cases an initial axial stress of 5.4-5.5MPa is generated in the pipe wall or at the weld interface. These tests are conducted in a hot water bath at 80℃ until failure – which typically occurs after several thousand hours.

The hydrostatic pressure test is also conducted in a hot water bath at 80℃ until failure – and again failure occurs usually after several thousand hours of testing.

Similarly for EF welds the long term test is the Slow Peel Test undertaken at elevated temperature between 50°C and 95°C and typically for testing times of around 500 hours. This test is currently being incorporated into the ISO suite of standards.

These long term tests are not production tests but rather used to establish the long term performance of welds and qualify weld parameters and procedures. These long term tests are not suitable for field assessment and are not addressed by this guideline.

2 TESTING OF BUTT WELDS

2.1 Visual Examination of Butt Welds

NDT examination should begin with a detailed examination of the weld and weld bead. As described above the nature of PE butt welding means that the bead itself provides a great deal of information about the weld.

The weld bead should be uniform and symmetrical around the full circumference as shown in Figure 1 below and should not contain any sharp notches. Table 1 below defines those features which can be quantitatively assessed. Table 2 provides a list of bead shapes that are undesirable. Measurement and comparison of bead sizes has deliberately been avoided as these will vary with differing weld parameters, PE materials and indeed simply due to gravity from the top to the bottom of the pipe.

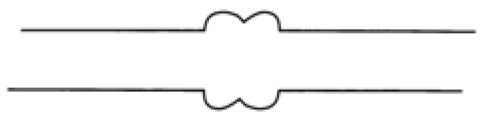


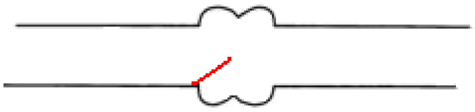
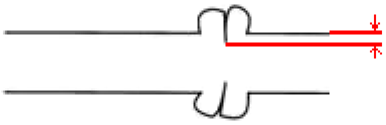
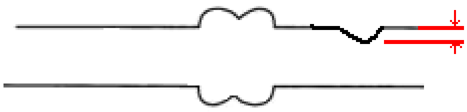
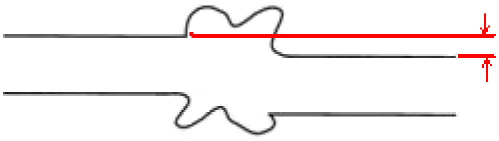
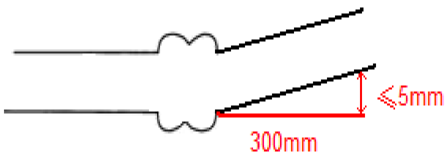
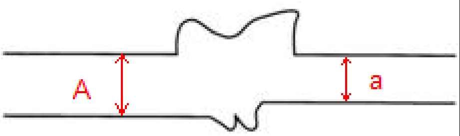
Figure 1

2.1.1 Bead Testing

Testing of the weld bead after removal from the pipe surface has been used as a simple field test to indicate weld acceptance. The test involves removing the weld bead (using a suitable bead removal tool) after the weld has fully cooled to ambient temperature. The removed bead should contain both sides of the flash joined along the centre line of the weld. The bead is then twisted or alternatively bent in the reverse curvature to the pipe surface. The bead should remain intact.

If the bead separates the parameters and welding process should be investigated.

TABLE 1 – QUANTIFIABLE CRITERIA FOR BUTT WELD VISUAL EXAMINATION

Weld Feature	Comments	Acceptance Criteria
1. Cracking 	Cracking of any kind anywhere in any direction or orientation	Not acceptable. *Based on the German DVS Code and also accepted industry practice internationally*
2. Notches at interface 	Sharp notch between weld beads that extends below the original pipe surface.	Not acceptable *Based on the German DVS Code and also accepted industry practice internationally*
3. Scoring or notching other than at the interface 	Notches or scoring in any direction	Acceptable where the depth of the notch or score does not exceed 10% of pipe wall thickness. *Based on the German DVS Code, AS/NZS2033 and also accepted industry practice internationally*
4. Displacement 	Where pipes ends are displaced relative to one another.	Acceptable where extent of displacement does not exceed 10% of pipe wall thickness.. *Based on the German DVS Code and also accepted industry practice internationally*
5. Angular misalignment 	Where pipe ends are not aligned squarely.	Acceptable where the extent of misalgnment measured at a point 300mm from the weld bead does not exceed 5mm. *Based on the German DVS Code and also accepted industry practice internationally*
6. Variation in pipe wall thickness 	Where pipe wall thickness 'A' varies compared to adjacent pipe wall thickness 'a'. In extreme cases the weld bead will be noticably uneven.	Acceptable where the difference in pipe wall thickness between 'a' and 'A' does not exceed 10% of the thicker pipe 'A'. . *Based on the German DVS Code and also accepted industry practice internationally*

Weld Feature	Comments	Acceptance Criteria
7. Blistering, bubbles or lumps on the weld bead	Where the surface of the weld bead contain blisters, bubbles or lumps indicating the weld surface may have been wet, too hot or possibly contaminated	Expert Investigation required. Typically the weld is not acceptable where there is foreign matter visible on the surface or large inclusions or lumps Conditions exist where the weld may be acceptable and these would typically occur where the surface imperfections were small and isolated. Under these circumstances further weld testing is recommended to confirm acceptance. *Based on accepted industry practice internationally*

TABLE 2: UNDESIRABLE BEAD PROFILES AND ASSOCIATED INVESTIGATIVE ACTIONS.

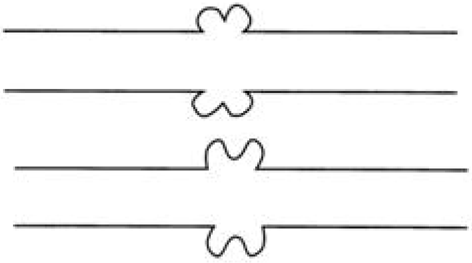
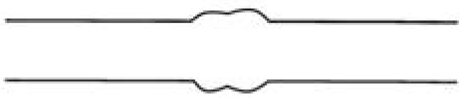
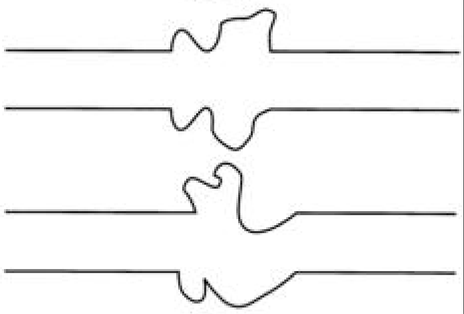
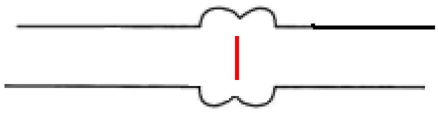
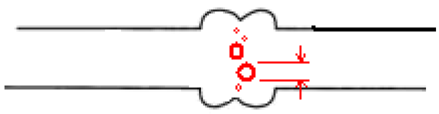
Weld Feature	Comments	Suggested Action
1. Weld bead too narrow or undersize 	The size and shape of weld beads varies due to the weld procedure. Any comparison must be done in relation to a known good weld using the nominated weld procedure and parameters. Possible causes for variations with known good welds could include incorrect pressures and/or temperatures	Comparisons need to be made to known acceptable welds. Investigate temperature and pressure aspects of welding machine and process. *Based on information in the Iplex Poliplex Textbook*
2. Weld bead appears flat 	See comments for 1 above. Possible cause could be insufficient weld pressure	Investigate weld pressures and capability of welding machine. *Based on information in the Iplex Poliplex Textbook*
3. Extremely uneven bead size 	Possible cause could include excessive temperature to one pipe end.	Investigate preheat times and process. *Based on information in the Iplex Poliplex Textbook*

TABLE 3: INTERNAL WELD DEFECTS AND ACCEPTANCE CRITERIA

Weld Feature	Comments	Acceptance Criteria
1. Lack of fusion 	Incomplete or no fusion of the pipe faces. Typically caused by contamination of the joint surfaces or incorrect weld parameters	Not acceptable. *Based on the German DVS Code and also accepted industry practice internationally*
2. Voids and foreign matter 	Isolated pores, shrinkage cavities or inclusions within the weld zone.	Permitted where the voids or inclusions are isolated (i.e. not in rows or grouped together) and where the size of individual pores or inclusions do not exceed 10% of the wall thickness *Based on the German DVS Code*

2.2 Destructive Testing of Butt Welds

2.2.1 Tensile testing of butt welds

There are a variety of standard test methods used for tensile testing PE butt welds - the WRc, those nominated in POP003 and ISO21307, BS EN 21814, ISO 13953, ASTM D 638 and F2634 for example. These tests are carried out on weld specimens cut from the weld and tested in a laboratory or in the field. Generally these tests require the test specimen to fail in a ductile manner and hence the failure mode must be interpreted from the specimen. The photographs below have been sourced from the WRc WIS 4-32-08 and Iplex Pipelines. They provide examples of ductile and mixed mode results.

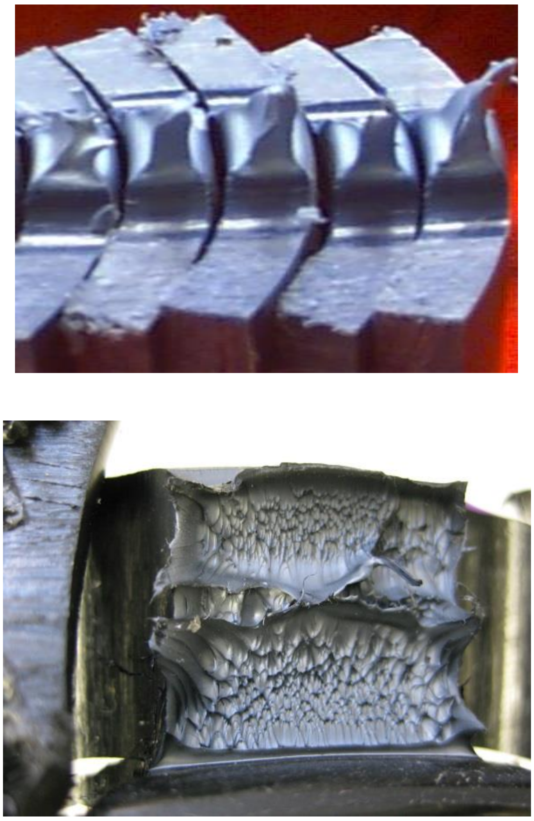


Figure 2: showing fully ductile failure mode of tensile weld specimens.

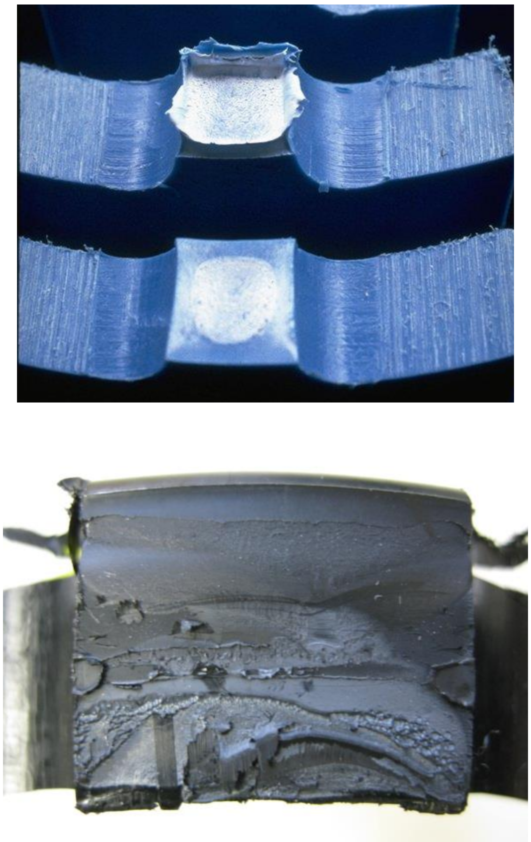


Figure 3: showing “mixed” and brittle failure modes of tensile specimens.

In addition there have been several field based tensile testing procedures adopted around the world. These tests are also destructive requiring coupons to be cut from the weld being examined. As an example the UK adopted a simple field test performed on site using a small tensile testing machine mounted in a van where the result was acceptable if the failure was ductile – similar to the laboratory based tests. Agru have used a simple field tensile test in Australia for many years and ISCO industries have recently offered another field tensile test option that requires little interpretation using a standard test coupon that simultaneously compares the tensile strength of the weld to the parent material where the acceptance criteria is simply that the parent material fails first– there is no interpretation of failure mode required.

The interpretation of the fracture surface is subjective and often open to interpretation. Interpretation requires the assessment of ductile and brittle fracture surfaces based on appearance. This is often a difficult aspect to assess and further complicated by the presence of “artefacts” on the fracture surfaces. When interpreting these fracture surfaces it is firstly important to confirm that the test specimen has actually yielded during the test.

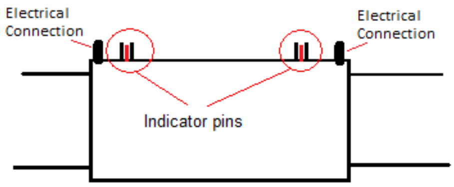
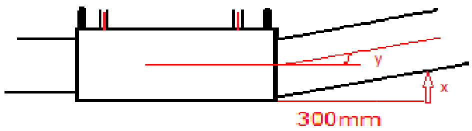
Bend testing of butt welds

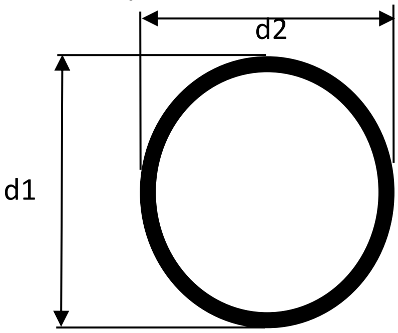
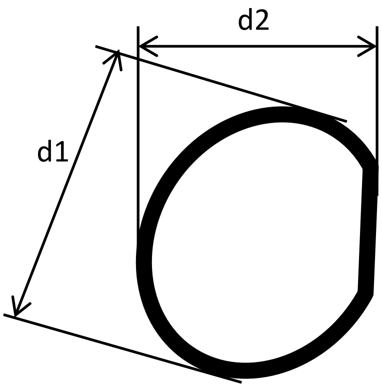
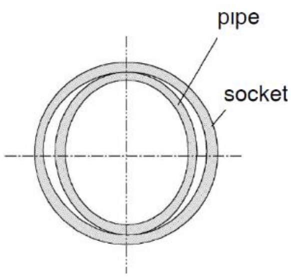
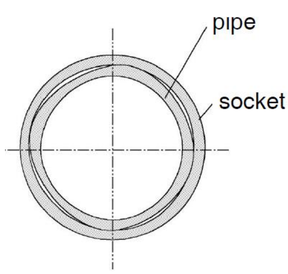
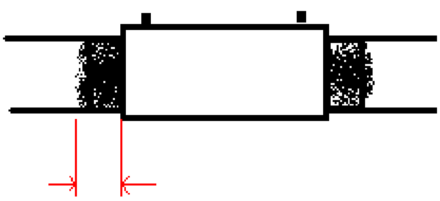
As for tensile testing there are several standard bend tests in operation in Europe, Australia and the US - some with relatively well defined acceptance criteria others with more qualitative assessment. One such test is described in ASTM F2620 where a longitudinal strip of pipe including the weld is cut, held in clamping device and bent back on itself. This is a simple test that can be used in the field where the acceptance criteria was simply that the specimen did not crack or fracture at the weld. This test however has some physical limitations as the wall thickness exceeds 20-25mm the stored energy in the bent specimen presents potential OH and S risks for those performing the test.

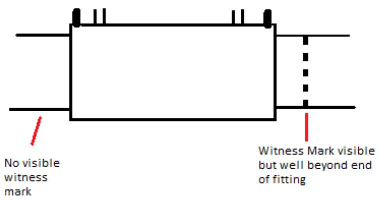
3 TESTING OF ELECTROFUSION JOINTS

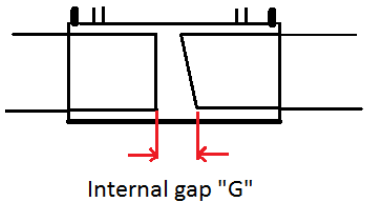
3.1 Visual Examination of Electrofusion Joints

Table 4: Weld features and acceptance criteria for EF joints

Weld Feature	Comments	Acceptance Criteria
1. Melt Indicator pins  	Many EF fittings have melt indicator pins. These should rise during the welding process. They indicate sufficient pressure has been achieved during the weld process, however, failure of pins to rise does not necessarily indicate a failed weld.	Pins failing to rise should be a trigger to investigate the joint further. *Acceptance criteria and suggested actions are provided in POP001.*
2. Melt run out  	Molten PE extrudes from the fitting socket. There are multiple reasons why this could occur including: Excessive welding time, uneven gap between pipe and fitting, incorrect welding process and misalignment.	Not acceptable. *Based on the German DVS Code and also accepted industry practice internationally*
3. Misalignment  	Pipe has been welded at an angle on one or both sides of a fitting. Misalignment can create gaps and damage the wire filament that may result in an internal defect. Misalignment can result from poor joint assembly, failure to use alignment clamps	Acceptable if the angle 'y' does not exceed 1.2 degrees or alternatively measure displacement at a point 300mm from the end of the coupler - the displacement 'x' does not exceed 6mm. *Based on the German DVS Code and also accepted*

Weld Feature	Comments	Acceptance Criteria
	correctly or during the welding process due to stress on the joint. Misalignment can also be created by incorrectly assembled alignment clamps. See Note 1 in relation to coiled pipe	*industry practice internationally*
4. Ovality and "flat areas"   **d1 = maximum OD of pipe** **d2 = minimum OD of pipe**	This deformation may cause an excessive gap between the pipe and the EF fitting. This gap can be tolerated up to a certain limit.  	Pipe ovality at fusion zone area prior to welding. **Gap Tolerance** **Pipe DN < 315** **d1 – d2 < 1.5% DN or 3 mm** (whichever is the smallest value.) **Pipe DN ≥ 315** **d1 – d2 < 1% DN or 5 mm** (whichever is the smallest value.) Guidance on minimum average pipe diameter after peeling is provided in POP001 Note: Where pipe cannot be rerounded, within the acceptance criteria other methods may be applied such as butt welding pipe tails to allow compliance with the acceptance criteria.
5. Extent of surface peeling 	Surface peeling of the pipe should extend beyond the end of the EF fitting with the pipe fully inserted.	This feature alone should not be a justification for rejection but should trigger an investigation of the weld under consideration. Acceptance would rely on all other aspects of the weld being acceptable.
6. Incorrect insertion	Pipe ends not inserted correctly into fitting socket	Ensure the witness mark is just visible and aligns

<table>
<tr><th>Weld Feature</th><th>Comments</th><th>Acceptance Criteria</th></tr>
<tr><td>




</td><td>exposing the fusion zone inside the fitting. Typically caused by incorrect insertion of one or both pipe ends, failure to cut the pipe end square, or as a result of pull out during welding in an incorrectly restrained joint.</td><td>with the end of the fitting socket. The weld is unacceptable if the witness mark is well outside the end of the fitting socket. Where no witness mark is visible the joint requires further investigation as it is not possible to determine if the correct insertion has been achieved, without use of an endoscope pipe insertion camera. Unless otherwise specified by the fitting manufacturer, for pipe sizes <400mm diameter the internal gap "G" between any point on the pipe ends shall be ≤5% of the pipe diameter. For sizes ≥ 400mm diameter the gap shall not exceed 20mm.

Based on the German DVS Code and also accepted industry practice internationally</td></tr>
</table>

Note 1: Misalignment can occur with coiled pipe where alignment clamps alone are unable to address the problem. There are several other measures that can be employed to correct misalignment with coiled pipe including:

- Butt Welding short lengths of straight pipe to the end of the coiled pipe
- Use proprietary pipe warmers specifically designed for addressing curvature in coiled pipe.
- On warmer days layout the coil and restrain at several points along the pipe to aid in controlling pipe curvature.
- Use coil straightening equipment as the coil is unrolled.
- Use two alignment clamps, both mounted eccentrically to the joint. Both clamps reinforce each other acting as quadruple clamp, forming a stress free joint

3.2 Destructive Testing Electrofusion Welds

3.2.1 Peel Decohesion Testing

This test involves cutting a longitudinal piece of welded fitting and pipe and then mechanically peeling them apart. The acceptance criteria is defined in AS/NZS 4129 with subsequent references to ISO 13954 and ISO 13955. The peel decohesion requirement of AS/NZS 4129, specifies the percentage of brittle failure decohesion < 33.3% of the joint fusion length, or more specially > 66.7% of the joint fusion length must display a ductile mode of separation. The photographs below are from the WIS 4-32-08 specification showing ductile and mixed mode results.

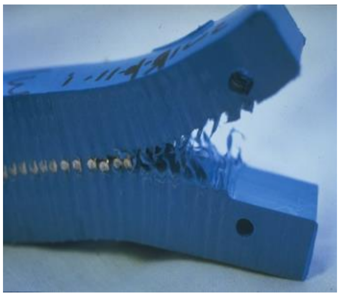


Figure 4: ductile behaviour

Figure 5: mixed mode behaviour.

Interpretation requires the assessment of ductile and brittle fracture surfaces based on appearance. The interpretation of the fracture surface is subjective and often open to interpretation.

In some EF weld tests the assessment involves comparing weld features as a proportion of the fusion zone length. The length of the fusion zone varies considerably between fittings from different manufacturers and is an individual design element for each fitting. The design fusion length is a feature that should be nominated by the fitting manufacturer. Simply measuring the length covered by the heating wires is not a suitable method of determining the design fusion length. In these types of EF weld tests determination of the design fusion zone is a critical aspect of the process and it is strongly recommended that the advice of the fitting manufacturer be obtained in this regard.

3.2.2 Strip Bend Testing

ISO 21751 describes a simple decohesion test for assessing EF joint integrity called the ”Strip Bend Test”. A longitudinal specimen is cut axially through the joint and undergoes a side bend test as shown in Figures 6 and 7.

Figure 6: ISO 21751 strip bend specimen prior to bending

Figure 7: ISO 21751 strip bend test showing acceptable EF weld after bend testing.

4 REFERENCES:

POP001 Electrofusion Jointing of PE Pipe And Fittings For Pressure Applications

POP003 Butt Fusion Jointing of PE Pipes And Fittings - Recommended Parameters

PIPA TN016 Non Destructive Examination of PE welds – Emerging Techniques

Iplex Poliplex Polyethylene Pipe Design Textbook

DVS Technical Codes on Plastics Joining Technologies (German Welding Association)

AS/NZS 2033 Installation of Polyethylene Pipe Systems

AS/NZS 4129 Fittings for polyethylene (PE) pipes for pressure applications

WIS 4-32-08 Specification for the Fusion Jointing of Polyethylene Pressure Pipeline Systems Using PE 80 and PE 100 Materials

ASTM F1055 Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene and Crosslinked Polyethylene (PEX) Pipe and Tubing

ASTM F2620 Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings

ISCO Industries Field Weld Tensile Test

ISO 13954 Plastics pipes and fittings -- Peel decohesion test for polyethylene (PE) electrofusion assemblies of nominal outside diameter greater than or equal to 90 mm (note the size restriction)

ISO 11413 Plastics pipes and fittings -- Preparation of test piece assemblies between a polyethylene (PE) pipe and an electrofusion fitting

ISO 11414 Plastics pipes and fittings -- Preparation of polyethylene (PE) pipe/pipe or pipe/fitting test piece assemblies by butt fusion

ISO 13953 Polyethylene (PE) pipes and fittings -- Determination of the tensile strength and failure mode of test pieces from a butt-fused joint

ISO 13957 Plastics pipes and fittings -- Polyethylene (PE) tapping tees -- Test method for impact resistance

ISO 13955 Plastics pipes and fittings -- Crushing decohesion test for polyethylene (PE) electrofusion assemblies

ISO 13956 Plastics pipes and fittings -- Decohesion test of polyethylene (PE) saddle fusion joints -- Evaluation of ductility of fusion joint interface by tear test

ISO 21307 Plastics pipes and fittings -- Butt fusion jointing procedures for polyethylene (PE) pipes and fittings used in the construction of gas and water distribution systems

ISO 21751 Plastics pipes and fittings -- Decohesion test of electrofusion assemblies -- Strip-bend test