HARMONISATION OF POLYETHYLENE PIPE BUTTFUSION PROCEDURES AND TEST METHODS

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ABSTRACT

Butt fusion welding and electrofusion welding with fittings are the principle joining techniques used for polyethylene pipeline systems. Several well established procedures are used for butt fusion welding. ISO 21307 has been developed to bring together the three principle procedures, ie Dual Pressure, European Single pressure and the USA High Pressure. However it is believed that these could be further rationalised to result in two or even one reference fusion procedure. In order to achieve this goal, this project has been established to evaluate fusion welding of large diameter thick walled pipe. The key to success of this project is to evaluate test methods to ensure that the short term and long term properties of the weld are fully understood. The project is being supported by members of the PE 100+ Association, with assistance from product manufacturers, fusion equipment suppliers, test laboratories, and end users.

INTRODUCTION

The advantage and ease of fusion welding of polyethylene was recognised during the early days of the introduction of PE pipeline systems. Fusion welding creates a fully end load resistant joint, resulting in a flexible pipeline system which will resist ground movement and even earthquakes, Nishimura et al (1). For a water supply pipeline, fusion welding also eliminates the risk of root penetration of the joint. The introduction of 'low sag' materials is allowing thicker walled pipe to be produced, and it is important that further information on the suitability of butt fusion procedures for such pipe is gained.

This paper outlines the status of butt fusion welding and the efforts being made by the PE100+ Association and the industry to further develop global standards for procedures, test methods and codes of practice suitable for thick walled pipe.

CURRENT SITUATION

There are several well established procedures and variations of these used for butt fusion welding within Europe and elsewhere. There are distinct differences between these procedures which can be a bit confusing for the contractor using butt fusion for the first time. Procedures have been developed mostly on a national basis, but it is recognised that the industry needs accepted international standards for the fusion procedure(s), test methods, site codes of practice, and certification of welders in order to be in a stronger position to promote large diameter PE systems.

The ISO 21307 Butt fusion procedures standard is being developed, which brings the European single cycle and UK WIS dual pressure procedures together with the USA high pressure method procedure into one document, (2). The document is currently in preparation for final vote. This is a major step forward, but it is believed that these procedures could be rationalised to result in two or even one reference fusion procedure. There is a significant difference between each of these procedures, but they each have a long successful track record, see Fig. 1. For the European Single Pressure procedure the pipes are brought together and held at a pressure of 0.15 MPa whilst cooling. The Dual Pressure procedure is performed at the same pressure, but the pressure is reduced to 0.025 MPa during cooling. The USA procedure is similar to the European procedure but a higher pressure of 0.517 MPa is used initially and during cooling.

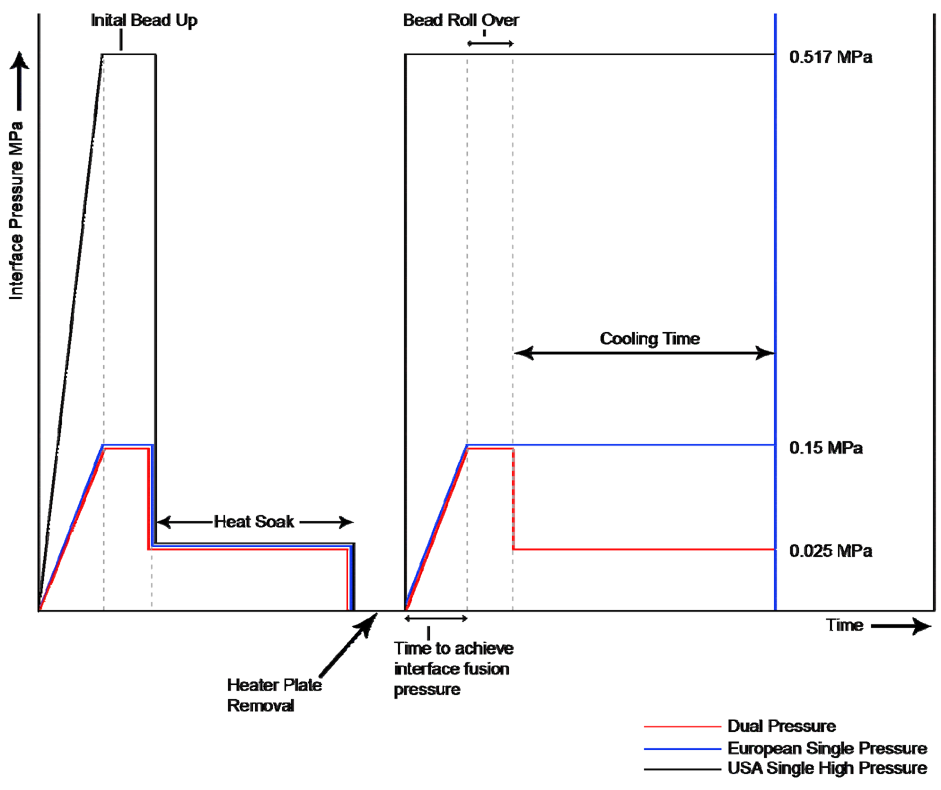

Fig. 1 European Single Pressure, Dual Pressure, and USA High Pressure buttfusion procedures.

Material and extrusion machinery development has enabled the possibility of an increasing size range of thicker walled pipe to be manufactured. Several manufacturers in Europe have the capability of producing pipe up to 2 metres in diameter. The introduction of ‘low sag’ PE 100 materials allows wall thickness well in excess of 100 mm to be produced with a minimal wall thickness variation around the circumference of the pipe. Some further assurance of the suitability of the welding procedure and site practice is required for such pipe. To achieve this goal not only reliable test methods suitable for thick walled pipe that prove the long term properties of the weld are required, but also both destructive and non destructive short term tests for site assessment are needed to give assurance to the end user

Test methods for butt fusion welds are perhaps more confusing and potentially misleading than the procedures used! Methods exist in ISO, European and many national standards. Short term destructive tests used include a variety of tensile tests on small specimens cut from the weld, impact tests, pressure tests and tensile tests on whole pipe assemblies. Long term tests include creep tests on full thickness specimens, CLT constant load tests and pressure tests.

Ultra-sonic non destructive testing (NDT) of plastics welds is not considered sufficiently developed at this time. NDT procedures may only be of value if the structure of the material in the heat affected zone could be assessed to indicate ductility. However visual examination of weld beads can reveal a lot of information. Removal of the beads and simply twisting them can be used to assess ductility. There may some value in carrying out thermal analysis of material from the beads to determine if any degradation is present and to assess other properties of the material.

SETTING UP THE PE 100+ PROJECT

After an initial discussion with Marcogas, the European gas suppliers organisation, the PE 100+ Association decided to initiate this project in order to consider harmonisation of test methods and procedures.

A steering group of experts has been set up with members from the PE 100+Association, Marcogas, Gaz de France DeTR, Kiwa GasTec, and test laboratories (Becetel, Bodycote PDL, and Hessel Ingenieurtechnik). In addition support is being received from Reinert Ritz (welding and test specimen preparation), Egeplast (supply of pipe), Widos (welding machine), and McElroy (welding to USA procedure). S.H.Beech has been appointed as Chairman of the group and the general organisation of the project.

PROJECT OBJECTIVES

The ultimate aim of the project is to harmonise butt fusion procedures confirming suitability for thick walled large diameter pipe, and to ensure these are documented in international standards along with test methods and codes of practice. The key to success is the evaluation of test methods to ensure that the short term and long term properties of the weld are fully understood. Some of the test methods currently used are misleading, and may not be applicable to the full range of wall thickness of pipe used nowadays. Also it is recognised that documented site practice and accepted site NDT procedures are essential for greater acceptance of large diameter PE systems.

PHASE I

The basis of the first phase of the project is the evaluation of test methods used for butt fusion welds and applicability for large diameter thick walled pipe, to be achieved by the following actions:-

- Review test methods used world wide
- Decide which short term and long term tests to evaluate
- Prepare pipe rings in 3 thicknesses from suitable pipe produced from a PE 100+ Association listed material
- Prepare welds using the three procedures detailed in ISO FDIS 21307
- Take samples from welds and carry out a programme of testing

Estimated timing for results, 2008/9

PHASE II

The second phase of the project will involve revision of test method standards and the ISO 21307 procedures as required. Some further test work may be required to refine procedures. It is also an aim to establish NDT procedures for butt fusion welds and to establish documented site practice, to be easily accessible in international standards.

- Revise or establish test methods in ISO and CEN standards as appropriate
- Re-assess butt fusion procedures and revise ISO 21307 as necessary
- Establish Codes of Practice and NDT procedures in ISO standards

Estimated timing, 2009-2010

EVALUATION OF TEST METHODS

A variety of test methods are used to assess PE pipe welds. In order to assess best practice the Steering Group discussed standardised methods including those from ISO, EN, ASTM, JIS and UK WIS standards. Also the experience of organisations worldwide was assessed including Marcogas, UK Water/Bodycote PDL, Germany – DVS, DVGW and Hessel Ingenieurtechnik, Belgium - Becetel, NL – Kiwa GasTec, Scandinavia - INSTA, USA – PPI and McElroy, Japan – Prime Polymers and Mitsui, and Australia - PIPA Australia.

SHORT TERM TESTS

Short term tests can be categorised as tensile tests on small specimens cut from the weld, bend tests, tensile tests on the whole pipe assembly, pressure tests on the pipe assembly, and impact tests. Tensile and pressure tests on pipe assemblies become impractical for larger diameters, and are considered only to show gross welding errors. Unless an additional tensile load is applied to a pressure test assembly, the stress is biaxial and non- isotropic. Impact tests are not particularly well developed. Potential variability of results because of a dependence on specimen geometry, tup weight, and strain rate may result in a change of behaviour and a misleading result. These types of test were discounted by the Steering Group.

There are several standards for tensile tests on small specimens, typically using square section parallel sided specimens or dumb bell specimens formed by drilling parallel holes. The problem with square parallel side specimens is that unless all sides are machined the specimen will be locally thicker at the weld. Both types of specimen may be subject to a greater plain strain effect in thicker sections and increased tendency to brittle behaviour.

ISO 13953 is the method commonly referred to in EN and ISO polyethylene product standards, (3). Parallel sided test specimens are specified for wall thickness < 25mm and $\geq$ 25 mm, a drilled dumbbell and a dumbbell with a 25 mm square waist section. EN 12814 specifies a drilled dumbbell, (4). The UK WIS 4-32-08 specifies drilled specimens but using a smaller diameter drill to increase the stress concentration, (5). These tests are dependent on a subjective assessment of fracture behaviour, but the WIS test often includes energy measurement to verify the assessment.

In Germany there has been a lot of experience with the DVS 2203-5 Bend test incorporated in EN 12814-1. Basically this is a three point bend test sometimes performed at a low temperature to induce brittle behaviour. Initiation of a crack from the weld bead should follow the edge of the heat affected zone and propagate into the pipe material in good welds. The test is performed on both the inner and outer weld beads.

The decision of the Steering Group was to include the WIS tensile test on drilled test specimens and the DVS bend test in the test programme. The WIS test will include energy measurement, an investigation of the aspect ratio width to thickness of test samples, and also the use of full thickness and half thickness samples. There has been limited experience using the bend test on thick walled pipe and the test geometry needs to be scaled up for wall thickness > 30 mm.

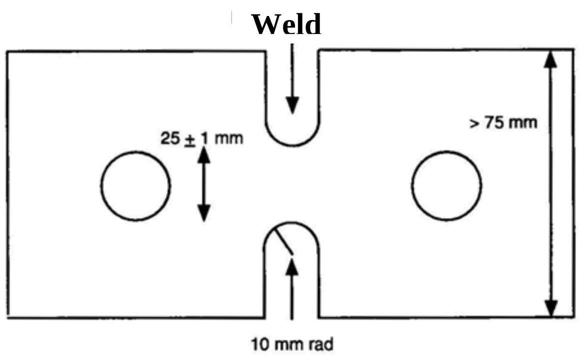

Fig. 2 UK WIS test specimen

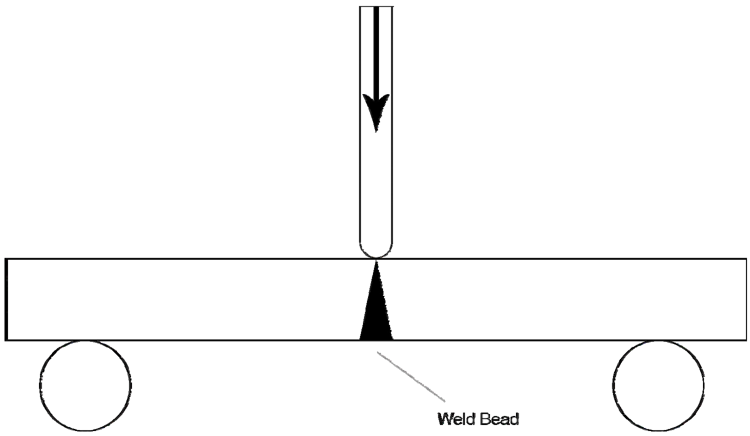

Fig. 3 EN 12814-1 Bend test

LONG TERM TESTS

Long term tests include creep tests on full thickness specimens, FNCT and pressure tests. The latter have been discounted as discussed. Ideally a test replicating failures seen in welds in pipe made from first generation HDPE materials with poor resistance to slow crack growth. The EN 12814-3 DVS Tensile creep test is such a test (6), used extensively in Germany and Scandinavia. The test specimen is subject to constant tensile load at 80 °C, using a detergent solution to accelerate failure. Both the time to failure and examination of the mode of crack propagation are used to assess the weld. Initiation occurs from the weld bead and in poor welds tends to propagate into the fusion zone, whereas in good welds it propagates into the pipe material, Hessel et al (7).

FNCT tests have been used to assess the material in the fusion zone of the weld and comparing with the pipe material. A variation of this test has been used by Gaz de France DeTR using a novel cylindrical test specimen, Bertier et al (8). This has the advantage of more accurate formation of the notch and removal of any stress concentration that may occur in the corners of a square sided specimen.

The Steering Group decided to evaluate the DVS Creep test and the GdF FNCT test to include in the test programme.

Fig. 4 DVS Creep test showing crack propagation from the weld bead into the pipe material.

TEST PROGRAMME

An important aspect of this project is to evaluate welds in large diameter thick walled pipe with a range of wall thicknesses. Using several pipes means that different extrusion lines, extrusion conditions and batches of material are used. Therefore it was decided to use the same pipe but to machine the inner lip of bore of the pipe to give three thicknesses.

A 1200 mm SDR 17 70.6 mm nominal wall thickness pipe produced from a PE 100+ listed material was kindly supplied by Egeplast DE. The expertise of Reinert Ritz DE, a leading producer of fabricated fittings, was offered to prepare the machined rings of the pipe, and also to carry out the onerous task of cutting the welds into multiple test specimens.

Rings of full 70.6 mm, 50 mm and 30 mm wall thickness were produced. Welding was carried out using a Widos welding machine using the European Single Pressure and the UK Dual Pressure procedures. The UK base of the US welding machine producer, McElroy, offered to produce welds using the USA High Pressure procedure. In addition a ‘poor weld’ was produced using lower temperature and heat soak time for comparison.

Pipe Thickness	**Length including weld**	**Dual Cycle**	**Single Cycle**	**USA Cycle**	**‘Poor’ Weld**
70.6 mm (Full)	**750 mm**	**X**	**X**	**X**	
50 mm	**550 mm**	**X**	**X**	**X**	**X**
30 mm	**500 mm**	**X**	**X**	**X**	

Fig.5 Welding of pipe rings.

PREPARATION OF TEST SPECIMENS

The logistics of cutting such large diameter pipe welds into multiple specimens cannot be under estimated. Any residual stress remaining in the pipe rings can make cutting a hazardous operation. The expertise of Reinert Ritz to develop a method of cutting the welds was essential to progress the project.

Fig. 6 Full thickness weld cut into required test specimens.

PROGRESS

At the time of writing this paper, the preparation of test specimens from welds made with the European and Dual Pressure procedures was completed enabling the test programme to commence. Preparation of the welds using the USA procedure was in progress.

NDT OF PE BUTT WELDS

The question of availability of NDT testing of PE welds is often raised by contractors and end users. Establishment of accepted procedures will be a major benefit to the promotion of large diameter PE systems.

For many years manufacturers of ultrasonic NDT equipment have tried to develop systems for plastics welds. Whilst it might be possible to detect voids in PE butt welds, not normally an issue, it is the structure and behaviour of the material in the heat affected zone of the weld that is important, Scholten (9). Examination and analysis of weld beads may offer potential NDT methods for PE butt welds. The size and uniformity of the weld beads can reveal any misalignment of the pipe. The size of the weld beads may reveal the use of incorrect temperatures and pressures. Bubbles or protrusions in the weld beads can indicate the presence of moisture or contamination. Twisting of removed weld beads can indicate ductility but separation indicates a need for further investigation. Thermal analysis techniques may be useful to assess the material properties of the weld bead and any presence of degradation. These topics are being discussed by the Steering Group.

CONCLUSION

There have been many years of excellent experience with butt fusion of PE pipeline systems, but procedures, testing and codes of practice are mostly developed as national or industry standards. This situation is recognised by members of ISO/TC 138 who initiated the development of the ISO 21307 Butt fusion procedures standard. However the PE 100+ Association has realised that further effort is required to develop test methods, further harmonise procedures, and to develop codes of practice and NDT for butt fusion welding. This project has been set up by the Association with help from the industry to address these issues.

ACKNOWLEDGEMENT

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