Polyethylene Pipeline Systems - Avoiding The Pitfalls of Fusion Welding

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Abstract

Polyethylene (PE) has revolutionized low pressure pipe system design on a global basis and is testimony to PE's unique combination of properties, which have driven the replacement of traditional pipe engineering materials during the last 60 years. PE pipes and fittings are used extensively in operating gas and water distribution systems safely, reliably and economically, and enjoy an excellent performance track record[1].

PE offers the pipe industry an array of advanatges inclusive of[2];

- Economical, high volume manufacture – extrusion, injection moulding;
- Design flexibility – easily shaped;
- Integrated design – multifunction, ready assembled components – couplers and fittings;
- Low material cost;
- Light-weight design – ease of transport and handling;
- Flexibility – ease of transport and handling, use in conjunction with trenchless technologies and resistance to seismic activity;
- Relative ease of jointing (compared to metallic pipe systems);
- Squeeze-off for emergency gas flow stop;
- Corrosion and good chemical resistance;
- Biologically inert capabilities;
- Toughness, impact resistance, abrasion resistance and long term durability – technical lifetime of >50 years;
- Low temperature performance;
- Leak-free fusion jointing - low maintenance costs;
- Low friction bore - no scale build-up and efficient flow of transfer medium; and
- Environmental benefits - recyclable

The success of PE for pipeline applications has been achieved through a long legacy of historical development, catering for pipe industry requirements. Over the past 60 years, PE materials have evolved with advances in polymer science. Today's highly engineered bimodal PE100 now provides exceptional balance of strength, stiffness, toughness and durability consistent with demands of long-term gas and water pressure containment, ground loading and the service environment[2].

Key to the success of PE pipeline systems is the ability to quickly form reliable end load resistant fusion joints with a strength equivalent to the parent pipe materials with a minimum design life of 50 years. However, there is an ever increasing awareness that the technology and reliability is being undermined by operative workmanship in the field, posing a risk to the pipe network. This is a particular concern for gas distribution where premature failure can have catastrophic effects resulting in loss of life.

In order to reduce the risk to gas distribution pipelines there is a need for increased requirements for training and qualification of installers, including tooling requirements and servicing of tooling. The aim of this White Paper is to provide an overview of key parmeters which influcence butt fusion and electrofusion weld performance, typical failure modes seen in the field and preventative actions which can help mitigate the incidence of failure.

1.0 Introduction

PE pipe due to its chemical inertness, non-corrosive nature and long term durability offers outstanding service life, with conservative estimates standing at 100+ years. Today PE is the material of choice for pipeline transportation of water and gas where pressure containment and structural integrity is considered critical for the lifetime of the pipeline since system failure can result in flood, explosion, fire and loss of life resulting in costly litigation and damages. In addition, this can cause service interruption, safety concerns and loss of brand credibility.

Today, global operators of PE pipeline assets report that the major threat to PE pipeline integrity other than third party damage is poor fusion jointing. Joints are obviously a weak point in any engineering system. Axial or bending stresses caused by thermal expansion or contraction, or ground movement will increase the risk of failure of substandard joints.

At GL Noble Denton we have over 40 years experience of PE Pipeline Technology, and routinely conduct incident reports and independent forensic failure analysis of PE pipe systems. The purpose of this White Paper is dissemination of our failure knowledge in respect to butt and electrofusion so that lessons can be learnt from past mistakes in order to enhance the safety of their water and gas pipeline networks.

2.0 The fusion process

PE pipe is usually supplied either in 6m or 12m lengths (sticks), or coils of 50m to 150m in length. Consequently, it is necessary to create joints between pipe lengths and when transferring from one size of pipe to another, connecting branches or for connecting services to mains.

There are 3 main types of fusion joint geometry, which include;

1. Butt weld
2. Socket joint
    a. Electrofusion
    b. Hot iron socket
3. Saddle joint
    a. Electrofusion
    b. Hot iron socket

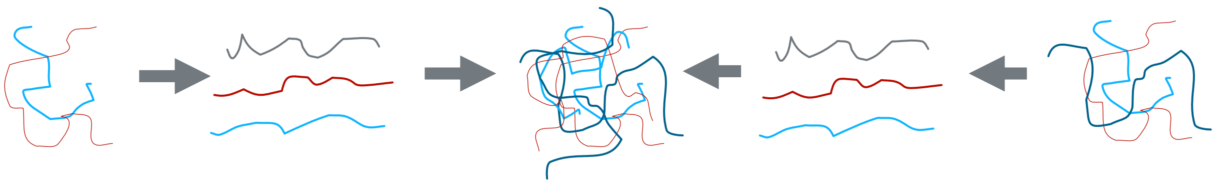
The butt fusion technique is a simple one whereby the two ends of the pipes to be joined are trimmed flat and square to each other and then heated using a flat heater plate under controlled temperature, time and fusion pressure.

Electrofusion involves the use of injection moulded PE fittings into which the pipes are inserted. Embedded within the fitting are a series of heating wires, located just below the surface of the internal bore of the fitting, with terminals on the outside of the fitting for electrical connection. These wires, when energised by a controlled electrical power source for a pre-defined duration, produce the necessary heat to melt the plastic and, once allowed to cool, form a welded joint.

The fusion process involves heating PE, until the material reaches its crystalline melt point at which it becomes a visco-elastic melt. In this melt state, under the action of pressure, the long chain like molecules of PE can uncoil, disentangle and slide over each other (shear flow) as shown in Figure 1.

Two separate melt phases i.e. pipe and joint interface, can then be brought together allowing molecules to mix together i.e. sliding over each other and entangling with each other resulting in molecular mixing. On cooling, chain mobility reduces, the chains re-coil, re-entangle and the crystalline zones are re-instated resulting in re-solidification. The resultant fusion weld can be as strong as original parent material[3].

Figure 1 Molecular Mixing of Molecules During Fusion



Successful jointing of PE pressure pipes using these methods requires strict control of the parameters and conditions. For a safe gas supply, joints must be totally reliable. In reality aerospace levels of reliability are required coupled with the ease of installation required by low cost labour working in muddy site conditions in all weathers.

Another difficulty is that reliable inspection of polyethylene pipe joints using NDT has proven to be difficult, since radiography and ultrasound cannot reliably detect key issues that are known to affect PE joint quality such as fine particulate contamination, cold fusion in butt welds and misalignment and contamination in electrofusion joints. Furthermore, new developments such as ultrasonic phase array and microwave have not yet proved sufficiently reliable or cost effective for field implementation.

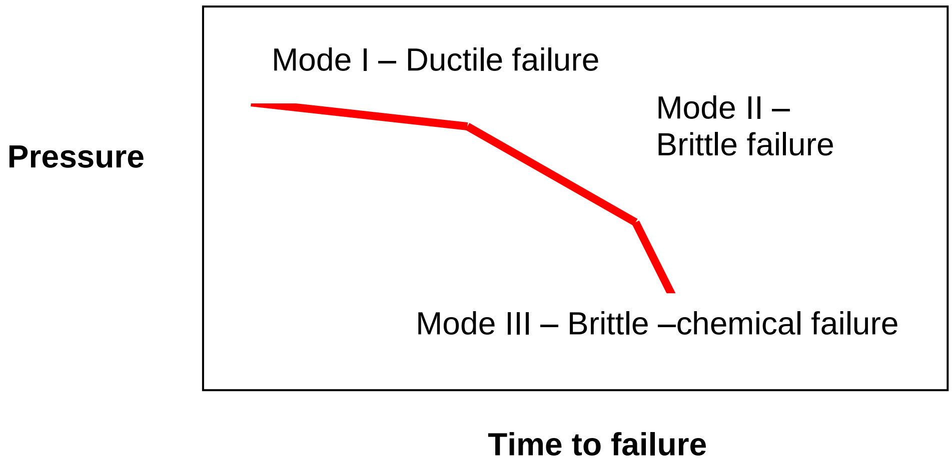
Consequently, in order to negate fusion joint failure it is considered a fundamental requirement that simple in field quality assurance and process control techniques are employed. Underpinning this approach must be a commitment to training to maintain competent levels of workmanship. Furthermore, there must be continual investment in equipment to ensure tooling is fit for purpose. Finally, the culture adopted by an organisation must drive behavioural change such that joint installers are self regulating and take ownership and responsibility for the quality of their workmanship.

3.0 Polyethylene failure modes

Stress Crack Growth (SCG) is a phenomenon in PE materials whereby slow growing cracks can occur due to the presence of stress in the material. It is widely recognised that the long term durability of PE pressure pipe is dependent upon its resistance to inhibit the initiation and slow growth of cracks. This failure mechanism can also occur in all types of fusion joints.

Early research of HDPE pipes established that SCG was one of three major failure modes for PE pipe, as shown in Figure 2[4].

Figure 2 Failure Modes of PE Pipe - Internal Hydrostatic Pressure Testing



Ductile failure mode I, results in yielding and reflects a material's propensity to undergo large-scale, irreversible 'plastic' deformation when under stress. The mechanism results in localized expansion of the wall section and final rupture of the deformed zone as shown in Figure 3.

Figure 3 Ductile Failure of PE Pipe Under Internal Hydrostatic Pressure

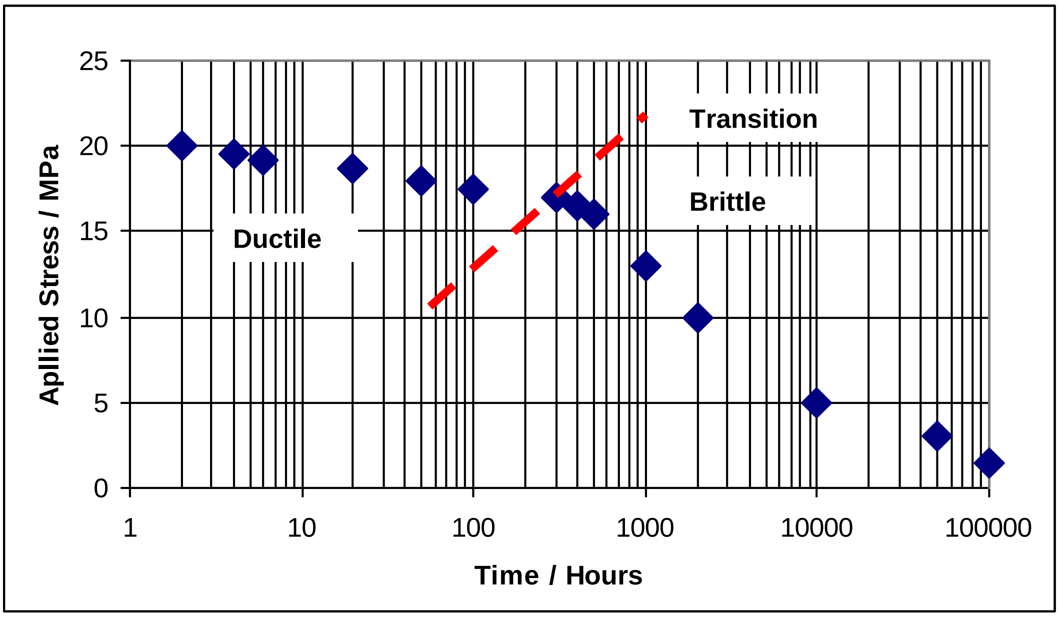
Failure Mode II is associated with Creep, Creep Rupture and SCG. Creep is time-dependant, non-reversible deformation, when exposed to a constant tensile stress. Creep rupture is the terminal event of creep and is a measure of the time that a material under a constant, applied tensile load takes to fail.

Creep rupture can be accelerated by;

- Temperature
- Stress concentrations
- Fatigue
- Chemical environment

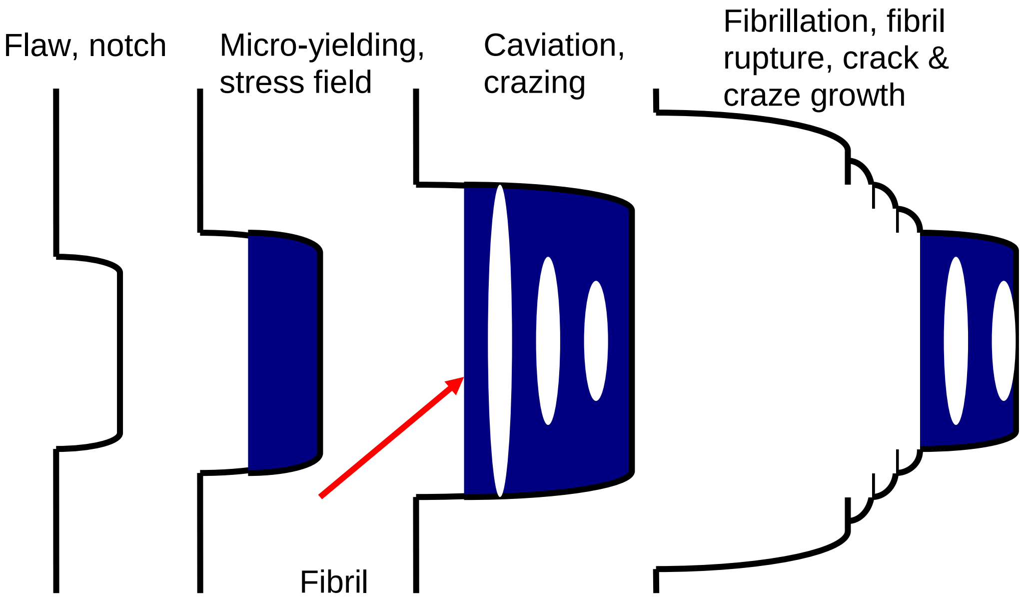
Figure 4 is representative of a creep rupture curve where the ductile-brittle transition signals the onset SCG.

Figure 4 Creep Rupture Curve



The events that lead to Creep Rupture are shown in Figure 5.0. After crack initiation voids develop ahead of the crack. These voids gradually merge into larger voids that are spanned by highly orientated load bearing fibrils. This process known as Crazing continues until a point is reached when the most highly stretched fibrils will rupture resulting in fracture.

Figure 5.0 Sequence leading to SCG



For PE, the tenacity of fibrils and their resistance to rupture will be highly dependent on molecular architecture, particularly molecular weight, molecular weight distribution, branching, crystallinity and tie molecules. The tie molecules are embedded in the crystallites and transverse amorphous regions, acting as mechanical links between the crystalline domains, and play a decisive role in the resistance to fibril failure and overall mechanical properties when subjected to stress. Mode III failure is related to degradation and embrittlement of the plastic due to thermo-oxidation with time[2,5,6].

Early research showed that it was necessary to take account of the long-term failure mode of PE to ensure the safe operation of gas distribution networks. Of paramount importance was a high degree of long-term strength in order to resist creep rupture for sustained low pressure loading of 50 years and more. Resistance to stress cracking was also critical in order to inhibit crack growth from notch type damage (scores, scratches and gouges) developed during transport and installation, and point loading due to rock and root impingement. Hence, an important design factor for PE pipes became commonly known as environmental stress cracking resistance (ESCR) which led to the development of medium density polyethylene or MDPE.

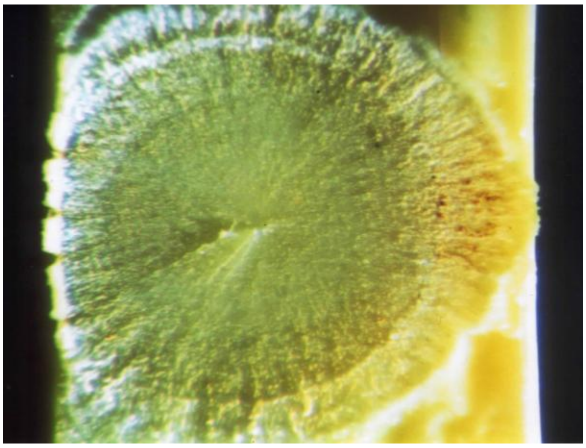
MDPE was less crystalline than the first generation HDPEs, giving improved resistance to SCG, stress cracking and rapid crack propagation (RCP). MDPE dominated PE pipe manufacture for 30 years but was limited in terms of pressure capability i.e. 8MPa for 50 years. Engineers pursued with their quest to extend the pressure capability and eventually Solvay made the break through in the mid 1980's by producing an HDPE rated at PE100 i.e. 10MPa for 50 years, with excellent resistance to both stress cracking and RCP, and was proclaimed the ‘third generation of PE’.

The general mode of field failure reported for PE pipe is brittle SCG through the pipe wall due to formation of stress concentration defects in the fusion zone. These cracks can initiate at microscopic stress-raising flaws, inherent in the basic pipe product or, more likely, from defects. These brittle mechanical failures are typically slit-type fractures that lie parallel to the pipe’s extrusion direction. Circumferential hoop stress in the pipe wall is the driving force for crack opening. Typical slit type fractures are shown in Figure 6.

Figure 6 Brittle Failure of PE Pipe - Slit Type Fractures

Circumferential cracks can also be initiated on either the outside or inside surface of pipes due to secondary stresses such as bending or impingement on the material. Visually, brittle cracks are typically smooth, featureless and devoid of any yielding and deformation process, as shown in Figure 7. They are initiated at stress concentrations within a materials structure, which may be inherent flaws, or defects such as residual stress, contaminant, inclusions or surface scratches. SCG due the presence of stress concentrations can also occur in all fusion joints.

Figure 7 Brittle Fracture Surface



4.0 PE joint contamination

A clean and uncontaminated surface is the single most important factor in achieving a good bond between two surfaces to be jointed. Contamination can compromise fusion integrity and particles can act as stress concentration sites, the precursors to SCG.

Considering that the jointing of PE pipes is normally carried out under field conditions where contamination from the surroundings is continually a threat, great care is necessary in joint preparation. Under these circumstances, contamination is a major issue when assessing joint integrity. The types of contamination that will reduce PE joint integrity can be any one or a combination of the following;

1. Gross contamination such as mud, soil or tar deposits on the pipe surface
2. Slight contamination such as dust
3. Grease or 'oily' deposits from contaminated cloths or unclean hands touching the surfaces to be joined
4. Oxidation of the surfaces due to exposure to the air
5. Extended weathering of the surfaces due to prolonged exposure to ultraviolet light (e.g. greater than 12 months storage outside)
6. Surface water or moisture

Taking each one separately;

1 Gross contamination is obvious in that it can be readily observed and dealt with by cleaning either with water or a clean lint free cloth.

2. Slight contamination such as dust is less apparent but still an effective barrier to good fusion. In addition, during the drier spells of summer, it can be transferred as airborne particles on windy days where it can settle either or the pipe surface or the tooling used in pipe construction.

3. Grease or ‘oily’ deposits are generally attributed to on-site handling of the pipes and fittings. Contaminated gloves, cleaning cloths or ‘sweaty’, dirty hands will contaminate the jointing surfaces and cause premature joint failure.

4. Since exposure to the air is inevitable, oxidation of the pipe surface cannot be avoided. Consequently the pipe surface must be scraped to remove the oxidised layer prior to jointing. A range of proprietary tooling has been developed in order expose the clean unoxidised surface for jointing. The amount of material that requires removal is extremely thin (around 0.2mm).

5. Samples of pipe are purposely exposed to at least 12 months weathering in UK conditions as part of the GIS/PL2 test requirements. After this period, tests are undertaken to demonstrate that the effect of 12 months exposure has not adversely affected the ability of the material to be successfully fused. Pipe that has been exposed for greater than 12 months cannot be guaranteed as fit for use since its ability to be fused has not been determined.

6. Surface water or moisture can be a barrier to good fusion although in many cases, small amounts of water will disperse as steam when it comes into contact with the heat required for fusion. However, in some cases, if the water cannot escape as steam, bubbles are formed along the joint interface that can result in voids and possible premature failure of the joint.

For all fusion jointing techniques adequate preventative measures should be taken to protect the joint from contamination and the external environments prior to fusion. These measures should include the mandatory use of ground sheets and tents as shown in Figure 8. Furthermore end caps must be fitted to pipes in order to prevent ingress of water and reduce wind chill effects, which can cause a fluctuation in fusion temperature.

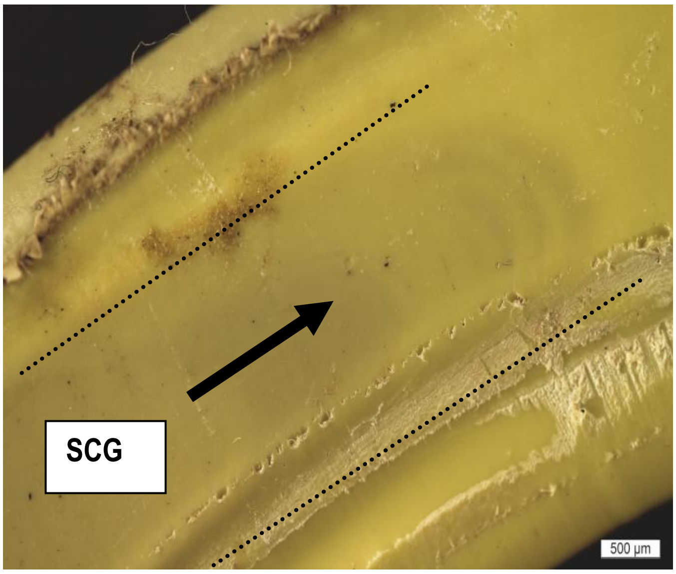
Figure 8 Protective Tents and Ground Sheets

5.0 Butt Fusion Failure modes

A common failure mode of butt fusion joints is the initiation of SCG at stress concentration defects at the fusion weld. Secondary bending stresses, typically misalignment, uneven support or pivot points drive crack propagation circumferentially round the joint until it becomes unstable, resulting in a transition to fast crack growth and catastrophic failure as shown in Figures 9 and 10. The rate of propagation is dependent on the applied stress and can vary from weeks to years leading to fracture of the complete joint. The amount of gas released in each case is dependant on the internal pressure and diameter of the pipe in question, and can be significant.

Figure 9 Catastrophic Failure of Butt Fusion Joint

Figure 10 SCG Preceding Catastrophic Fracture of the Complete Joint



There are many procedural factors that can affect weld quality. Taking each factor separately, it is possible to describe the potential fault.

a. Fusion Pressure

Fusion pressure is an important parameter in the butt fusion process since it produces the mixing of molten materials to form the joint. Too high a pressure and all of the molten material will be pushed into the weld bead leaving ‘cooler’ material at the joint interface at a temperature insufficient to achieve a good fusion joint. Too low a pressure can lead to insufficient mixing of the molten material at the pipe surfaces and the possibility of an incomplete joint with very poor strength.

In the early days, fusion pressures were set out in a table attached to each butt fusion machine and it was the responsibility of the operator to adhere to the correct pressure for the material and pipe diameter to be jointed. The pressure was applied using a hand operated hydraulic pump attached via hoses to the chassis of the butt fusion equipment. A pressure gauge within the hydraulic pump was used to observe the applied pressure.

Incorrect application of fusion pressure could be attributed to operator error and would be apparent in oversize or undersize external weld bead widths. Too low a pressure and the beads would be narrow and vice versa at too high a pressure.

b. Drag Pressure

Drag pressure is the pressure required to overcome both the weight of the pipe and the friction within the butt fusion machine. Before a joint is made, the pipes are set up in the machine and moved together using the hydraulic pump. Prior to the introduction of automatic machines, the operator was required to observe the pressure gauge and note the pressure required to move the pipes. This is the drag pressure and must be added to the fusion pressure as was shown on a label on the machine.

The drag pressure differs for each pipe diameter and length of pipe being moved (6m, 12m or more), and it is important to measure this every time a joint is made. In some cases, the drag pressure can be significantly higher than the actual fusion pressure although with careful setting up and the use of pipe rollers, quite long lengths of pipe can be moved with an acceptable drag pressure. Incorrect measurement of drag pressure can only be attributed to operator error and problems present themselves in oversize or undersize weld beads.

c. Melt Temperature

To achieve a fusion joint in PE, the surfaces to be joined must be above the materials melting point of 140^{o}C. The fusion temperature currently used in butt fusion is 233^{o}C which is sufficient to melt the material but not sufficiently high to cause thermal degradation. Insufficient melt temperature will be result in higher viscosity melt, resistance to melt and molecular mixing and ultimately poor fusion.

d. Pipe Ovality

The fusion weld a butt fusion joint is restricted to the pipe end area, subsequently it is important that full use is made of the maximum available area. Pipe ovality is inevitable on PE pipe because of the way it is transported and stored. Circularity is important for all joint types and with butt fusion equipment, the pipe clamps used to grip the pipe also act as re-rounding clamps. By adjusting the clamping pressures on each pipe it is possible to minimise any pipe ovality before making a butt fusion joint. Pipe ovality is not generally considered a problem on butt fusion joints and is an unlikely source of premature failure unless the pipes are grossly mismatched.

e. Pipe End Preparation (Trimming) and Contamination

If trimming is incomplete, the pipe ends will be uneven, some areas will still be oxidised or contaminated with dirt and dust and when placed in contact with the heater plate, there will be gaps resulting in an uneven heat transfer across the pipe ends. It is the responsibility of the operator to ensure that the pipe ends are completely trimmed before making the joint. An example of SCG initiated by butt weld contamination is given in Figure 11.

Figure 11 SCG Growth Initiated by Butt Weld Contamination

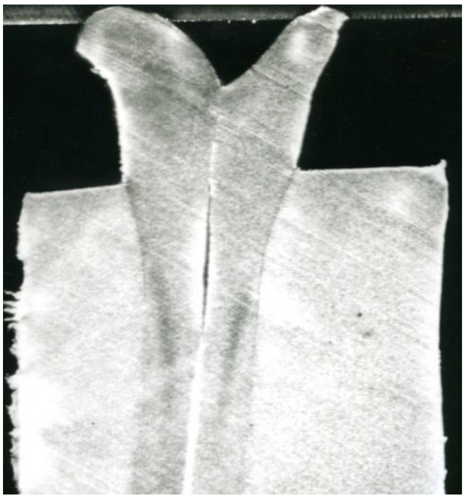
f. Pipe Alignment

Pipe alignment impacts on drag pressure and thermal contact between pipe and heater plate. In the first instance, in the case where long lengths of pipe are jointed and no rollers are used to assist its movement or align the pipes, a significant increase in the drag pressure results. Secondly, with no alignment, the actual weight of the pipes will bend the butt fusion machine chassis thus giving rise to the potential for a gap to occur between the pipe ends and the top of the heater plate. Each of these factors put at risk the joint integrity. A certain amount of misalignment is inevitable (maximum 1mm <180 mm diameter, 10% wall thickness >180mm) assuming beads widths are within acceptable limits.

g. Heat Soak Time

This is the time for which the pipe ends are in contact with the butt fusion heater plate. If the heat soak time is too short, the molten surfaces will not reach the required temperature and when the pipes are removed from the heater plate, the surfaces will cool quickly. The result would be an increase in melt viscosity, crystallisation prior to fusion and ultimately a ‘cold’ lap joint. A ‘cold’ lap joint (see Figure 12) may not exhibit any contamination, may be well aligned and perfectly trimmed. However, there will be no strength in the joint and if subjected to bending will separate completely.

Figure 12 Cold Lap Joint



h. Dwell Time

This is the time taken to remove the heater plate and bring the pipe ends together in a controlled manner to complete the joint. The faster the pipe ends can be brought together, the less likelihood that the molten surfaces will have time to cool down. The effect of a long dwell time in a butt fusion joint will be exactly the same as a short heat soak time in the joint will be 'cold' lap. The joint will have no strength and if subjected to bending, will separate completely.

5.0 Quality Assurance and In-Process Control

It is extremely important that at the point of installation, the construction of the PE pipeline is correctly undertaken. In this respect, great attention has been given to the training of operators and in-field quality control. In-field quality control is necessary because there are no non-destructive methods available to check joint quality on PE systems. Ultrasonic and radiographic techniques will only detect gross defects such as voids or contamination in PE joints. They will not detect small inclusions such as dust or a 'cold' joint where fusion is incomplete but no air gaps are present. As such, it is important to ensure that operators are given training in good jointing practices and where appropriate instructions on how to identify possible problem areas.

The 'achilles heel' of the PE system is at the point of installation. With the lack of non-destructive test techniques, the only other method of inspection is by observation. This approach should be supported technology by technology, which helps reduce procedural defects, whilst providing a means of auditing the fusion process. Some of the practices adopted include;

a. Automatic Butt Fusion

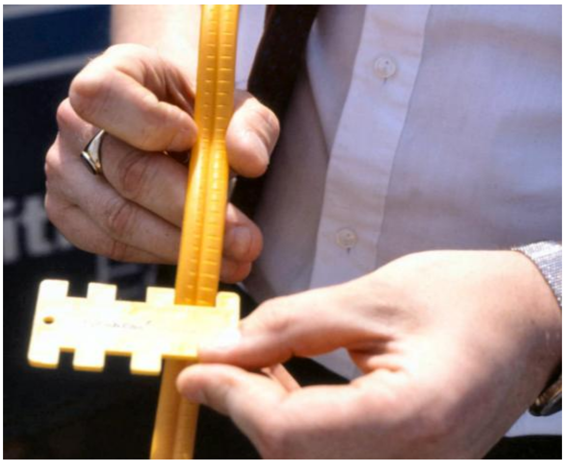
Automatic butt fusion equipment controls of a number of important fusion parameters and removes potential procedural problems associated with operator error. Subsequently, the use of automatic butt fusion is mandatory within the UK gas networks. Unfortunately, issues such as pipe alignment and adequate trimming cannot be automatically controlled and yet they are still extremely important to good fusion jointing. In this respect, the operation has not been completely de-skilled and the operator must concentrate on the setting up of the equipment and the preparation of the pipe prior to fusion taking place.

Data acquisition is also employed so that details of the welding operation of each joint can be retained for quality assurance purposes.

b. Bead Inspection

Significant information can be gleaned from inspection of the external weld bead generated during the butt fusion process as shown in Figure 13. The technique is discussed in detail in BS EN 12007[7].

Figure 13 Bead Gauge Measurement



The size and shape of the bead can indicate error with procedural factors and raise alarm about the quality of the joint.

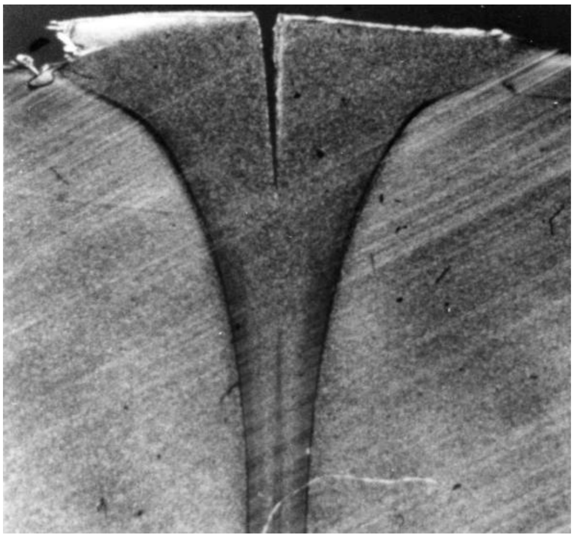
In the UK each generic PE pipe diameter and SDR has a defined bead range determined experimentally for joints at extremes of ambient temperatures expected to be encountered in the UK Butt fused joints with beads within the acceptable range are considered satisfactory and those outside the range considered suspect.

The effectiveness of the procedure was proven by a study, which revealed that over 95% of the butt fusion failures recorded up to 1985 should have been rejected during installation by examination of the external weld bead.

c. Bend Back Test

In 1986, a previously unknown butt fusion joint defect was discovered. The new defect was identified as being caused by fine dust particles transferred to the joint interface either by wind or heater plates. Whilst the butt fusion process experiences little melt movement during the making of the joint, it does push the dust particles towards the external and internal beads leaving a clean and relatively strong joint at the centre of the pipe wall. The resultant bead will be within the acceptable width range and there will be no visible indication of contamination. The dust particles trapped within the joint act as a barrier to fusion and produce a fine ‘slit’ defect (See Figure 14) that is almost impossible to detect by eye.

Figure 14 Slit Defect in Butt Fusion Weld



In tension, the joint is almost as strong as a well made joint, however, if the joint is subjected to bending, the slit defect will act as a fracture initiation point and the joint can snap in a brittle manner. Further investigation revealed that if the bead is removed with a de-beading tool, and bent back on itself, any slit defects will open and be visible. The defect within the bead was mirrored in the butt joint itself and therefore in 1987, it became mandatory for UK gas networks to remove the external weld bead from all butt fusion joints to enable the additional bend back inspection to be undertaken as shown in Figure 15. Additionally, a ‘dummy joint’ was introduced at the start of the day, change of pipe diameter / SDR in order to clean the hotplate of finite dust contamination

Figure 15 Bead Quality Control (Bend Back Test)

The bend back test can also be used to detect poor fusion, which will result in bead separation. Examination of the underside of the bead over its complete length also allows detection of general contamination.

d. Destructive Testing

At the discretion of the responsible Engineer a randomly selected butt joint (or a number of joints) can be destructively tested in order to assess joint quality and give confidence in the quality of the pipeline being laid. Cut samples taken from the weld are subjected to tensile tests in accordance with BS ISO 13953[8] (see Figure 17). Failure must be ductile, not brittle (see Figures 18 and 19) and must meet the following pass criteria;

- PE80 tensile strength ≥15 MPa
- PE100 tensile strength ≥ 20 MPa

Some gas network operators adopt very stringent destructive test regimes for pipe laying projects and may wish to test up to 10% of the total joints laid. This may be reduced during the project if experience and joint quality give sufficient confidence. This approach is very effective in deterring careless, negligent workmanship, however, may not be cost effective.

Figure 17 Tensile Testing of Butt Fusion Weld Specimen

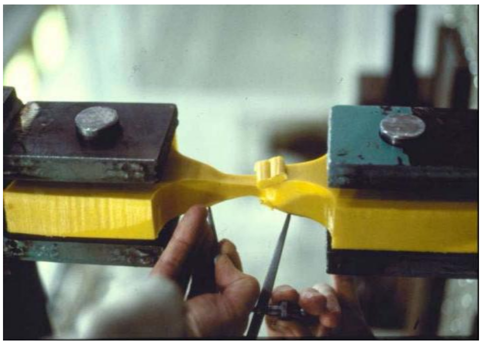
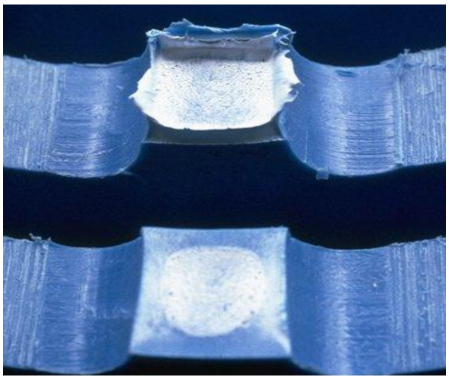


Figure 18 Ductile Failure

Figure 19 Mixed Mode Failure (Top) and Brittle Failure (Bottom)



e. Equipment Maintenance

In a similar way to servicing a motor vehicle, the equipment used for PE construction requires periodic maintenance and it is the responsibility of the end user to ensure compliance with this schedule. The manufacturer should state a maintenance schedule for the equipment when purchased. Disregard of this advice could result in PE joints being incorrectly constructed or operational delays due to equipment breakdown.

6.0 Electrofusion

The electrofusion fitting is designed with special ‘cold zones’ located in the centre of the fitting and at each mouth where the pipe enters. When the fitting is energised, the molten plastic is contained within the joint by the cold zones and due to thermal expansion a melt pressure is built up. This promotes mixing of pipe and socket material and when cooled, makes a strong fusion joint.

In cases where the pipe is not pushed fully home into the socket bore (Figure 20), or where there is severe misalignment of the pipe and socket (Figure 21), the wires become exposed and molten material flows away from the joint interface (Figure 23). This in turn allows the wires to move within the molten material and can lead to the wires touching or bunching together causing short-circuiting or localised overheating. The result can be thermal degradation, void creation along the fusion interface, or a drop in energy input resulting in partial fusion. In order to negate these possible failure modes the pipe must be aligned and restrained during the fusion cycle.

Electrofusion sockets are designed with a clearance to allow pre-assembly, whilst at the same time maintaining an even gap between the socket bore and the pipe outer diameter so melt pressure is not lost. Pipe ovality can pose a significant threat to the fusion gap and consequently re-rounding clamps must be used to reduce pipe ovality.

Field experience has shown that without the use of clamps the probability of defective joints will be high. Consequently, their use must be considered mandatory.

Defects within the fusion zone arising from poor installation practice will act as stress raisers and initiation sites for SCG. When a joint is subjected to internal pressure, severe misalignment and bending, SCG will propagate through the joint interface leading to premature failure and a leakage of gas analogous to that of a leaking cast iron joint. Premature joint failure due to these installation errors is common place.

Figure 20 Incorrect Pipe End Penetration

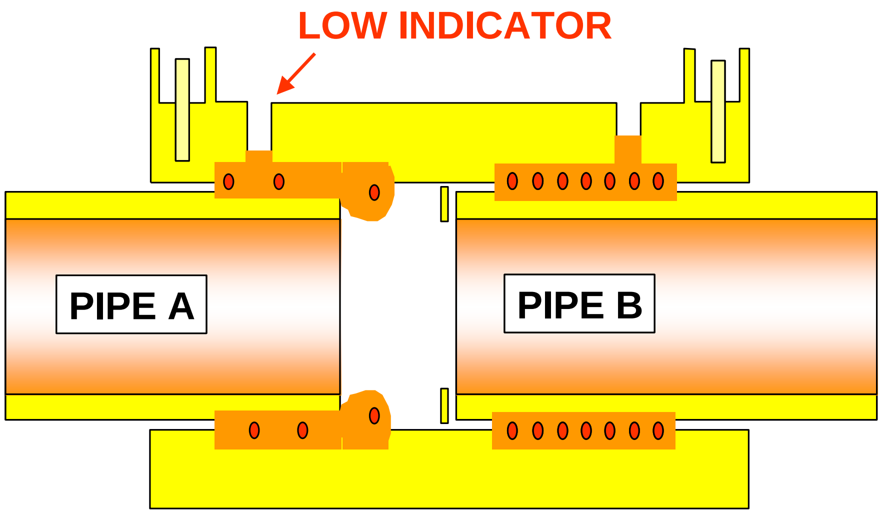


Figure 21 Pipe Misalignment

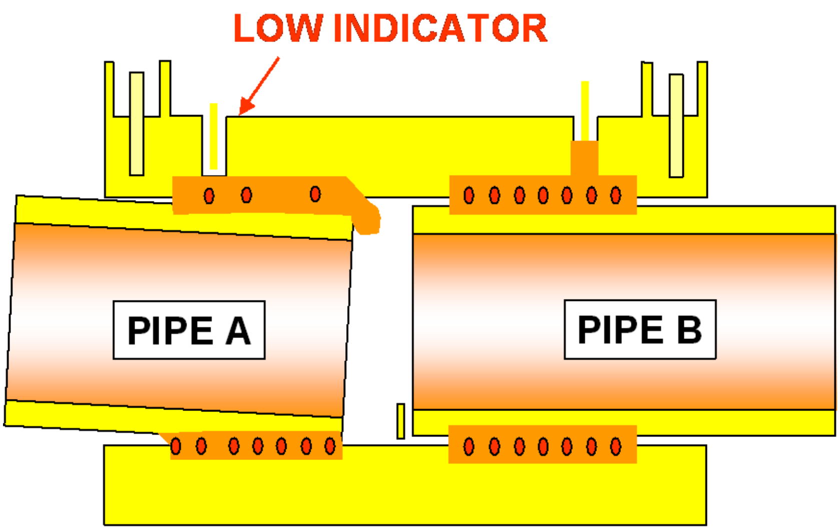
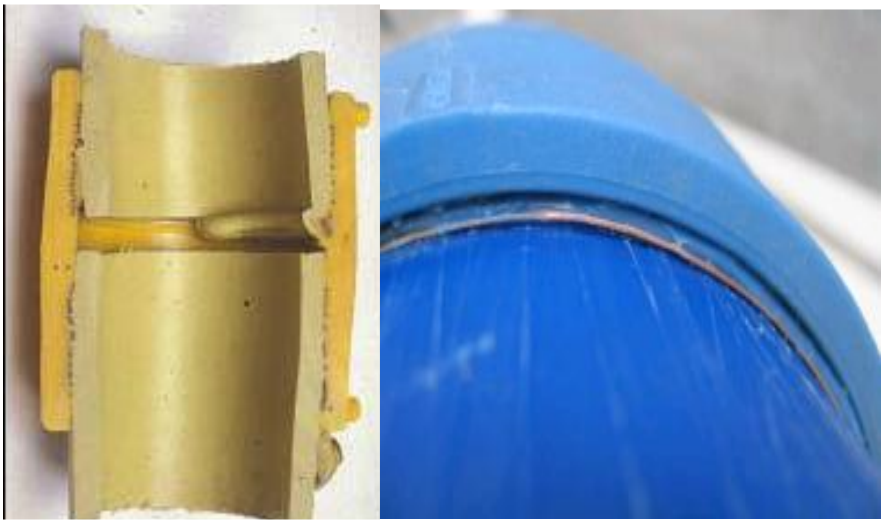


Figure 22 Consequences of Incorrect assembly



Contamination is also a major issue that can lead to premature failure of electrofusion joints. It is generally associated with the surface of PE pipe because of the way it is transported, stored, handled etc. However, two surfaces are required to make a joint and sometimes the condition of the fitting surface is forgotten.

Electrofusion fittings (both socket and saddle) are packed in polyethylene bags at their place of manufacture and then supplied in boxes. In addition, electrofusion saddles also have a cardboard insert attached to the saddle base to prevent damage to the embedded wire heating element. This affords total protection from contamination and transportation damage. Unfortunately, fittings are frequently removed from their boxes (and the polyethylene bags) and stored in operator vehicles. This is an extremely risky practice since most of the vehicles are dirty due to the muddy equipment stored within them. Therefore, the risk of contamination of the fittings is high not only from the vehicle environment but subsequent handling by the operator. In the UK fittings must be kept in their protective bags until such time that they are used. Fittings that are removed from their bags and handled with dirty or greasy hands will inevitably be contaminated and any resulting joint will be at risk of failure.

Since electrofusion jointing is not a self-cleaning process, pipe preparation is essential and the removal of surface contamination and oxidised layers requires a scraping device. An un-scraped surface will not fuse successfully and all electrofusion joints assembled without adequate scraping are highly likely to fail.

Typically, the type of scraper used is a simple proprietary hand held scraper and it is down to the operators' skill as to how well the PE pipe surface is prepared. The amount of material that needs to be removed is quite small (around 0.2mm) and the scraper is quite capable of achieving this. However, for larger pipe diameters i.e. ≥355mm scraping can be tiring and time consuming and this can lead to incomplete removal of oxidised layers and thus potential leak paths can remain along the joint interface. The development of mechanical scraping devices has not been too successful in that the tooling is cumbersome, difficult to use and expensive to purchase. As a result, the industry has not embraced their use and hand scraping is still very much the norm. At the other end of the size scale, over-zealous scraping of service pipes has also been identified as a problem. Small diameter pipes such as 16mm, 20mm 25mm and 32mm pipes are at risk if subjected to intensive scraping resulting in a large gap along the interface between the pipe surface and the bore of the electrofusion socket. The gap can be such that the fusion pressure generated during the jointing cycle is reduced leading to an incomplete fusion.

The maintenance and cleanliness of the scraper is clearly of paramount importance. Yet, is it not uncommon in the field to observe jointers using blunt, rusty and heavily contaminated scrapers (see Figure 23). Such acts are just one of many factors demonstrating poor understanding and non-compliance in the field, which is ultimately undermining electrofusion technology and posing a threat to polyethylene pipeline asset integrity.

Figure 23 Peelable PE Pipe

The difficulties presented by scraping have driven the development of peelable PE pipe. This consists of a core PE pipe and a sacrificial polypropylene (PP) skin with the outside diameter and wall thickness of the core PE pipe meeting the requirements of relevant PE gas pipe standards (see Figure 24). The pipe is manufactured from a non-pigmented PE 100 resin that matches traditional pigmented PE100 pipe in all aspects of dimensions and hydrostatic strength and includes all the usual additives packages that protect the resin (anti oxidants etc.). The PP skin is additional sacrificial material, which can be removed by peeling from the core PE pipe. The design and processing of the pipe is such that the skin can be peeled from the core PE pipe in a controlled manner. Removing the skin exposes the core PE pipe for the first time after solidification. PE core pipe can be joined using EF technology without the need to scrape the core PE pipe. The no scrape aspect of 'peelable' pipe is a key attribute for utility companies that wish to increase jointing integrity and at the same time reduce installation costs.

Benefits include;

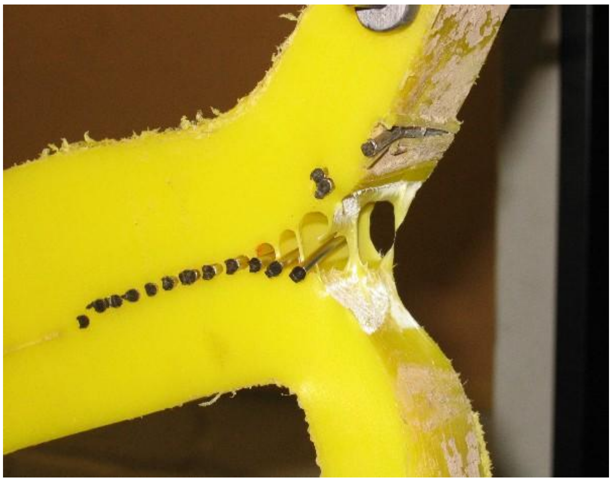
- Reduced pipe surface damage during transportation, handling and installation.
- The ability to quickly identify, and then assess, pipe surface damage.
- Improved efficiency of pipeline installation, particularly with respect to EF joining, where the installation time is typically halved.

Figure 24 Peelable PE Pipe

In the absence of NDT techniques, engineers can only resort to in process control destructive testing of joints in order to assess joint quality and give confidence in the quality of the pipeline being laid. Cut samples taken from the weld are subjected to tensile tests in accordance with BS ISO 13954[9] (see Figure 25). The pass criteria is ductile interface tearing along the fusion length over a minimum length of 66 % of the apparent fusion length

New developments to help field conditions and promote good practice include the use of remote cameras such as Fusions Cyclops Redbox, which can remotely monitor and record the quality of joint workmanship in the field. The very fact that the operator knows that joint quality is being inspected provides an impetus to comply with good practice.

Figure 25 Tensile Testing of Electrofusion Weld Specimen



7.0 Conclusion

The greatest threat to the integrity of polyethylene pipelines other than third party damage is fusion joint quality.

It is considered that the factors contributing to premature joint failure are a combination of poor training and awareness, non-compliance with industry good practice, lack of robust in-field quality assurance and spot check auditing methodology.

It is considered that front end investment to combat these issues would be a cost benefit in terms of reducing the risk to public health. The commercial benefits would be greater assurance in the longevity of pipeline lifetime for 100+ years.

8.0 References

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