

Jointing of Polyethylene Pipe Systems

At the forefront of PE jointing technology is fusion welding, which can be used to join pipes directly or through fittings. Jointing methods for polyethylene pipe also include push-fit systems, mechanical couplings and many others.

Fusion Welding

There are three methods of fusion **butt fusion**, **electrofusion** and **hot iron**. Butt fusion is a technique which has been used for many years in joining polyethylene pipes above 50mm. Electrofusion has now largely superseded the hot iron technique – used for jointing pipes with socket-type fittings.

There are a number of unique benefits associated with fusion jointing. These can be summarized as follows:

- A fused joint is at least as strong as the pipe itself, and this in turn ensures that the corrosion immunity of the polyethylene pipe system is continuous and unimpaired. Moreover, a fused pipeline will be end-load bearing throughout its length.
- Fusion enhances the innate flexibility of polyethylene. With strong joints, flexible pipe strings can be fed easily into position from above ground, whatever installation technique is used.
- No bore impedance's need be introduced by fusion joints. Where devices such as pipe support liners are used, there is unavoidable interference to follow. The smooth internal finish of a de-beaded fused joint ensures there is no such impedance.

In this chapter we are concerned specifically with butt fusion and electrofusion.

Butt Fusion

In butt fusion the pipe ends to be joined are brought together in a dedicated butt fusion machine. The end faces are squared up by planing with a mechanical trimmer, then heated with thermostatically controlled non-stick heater plate. When molten, the faces are pushed together and allowed to cool.

The butt fusion process generates weld beads both inside and outside the pipe. These can be removed easily to produce a smooth bore or outer surface. Inspection of the beads also provides a useful quality check on the weld.

Codes of practice for mains-laying stipulate that this jointing method should be applied to pipes only, thus all fittings are delivered to site with half-metre 'pups' of pipe prefabricated to them.

Detailed instructions on butt fusion technique is given under 'A Guide to Good Welding' below.

Electrofusion

This method uses socket-type fittings with integral heating elements to construct a pipe system. Couplers are used to join mains pipes; saddle fittings are used to connect service pipes. Fittings such a flange adaptors are spigotted and can be used in conjunction with electrofusion couplers and reducers.

Within an electrofusion fitting there is a resistive heating wire connected to surface terminals. An electric current passed through the wire melts the polymer and fuses the fitting to the pipe wall.

The pipe to be welded is first prepared by scraping away the outer surface layer, then pipe and fitting are clamped together to restrain movement. An electrical current is applied across the terminals from a generator via a control box (generally 40V in the UK). After welding the assembly is allowed to cool thoroughly before under clamping.

Detailed instructions on electrofusion jointing technique is provided in 'A Guide to Good Welding' below.

A Guide to Good Welding

Though PE is relatively simple to weld, only by following the correct procedures can a sound butt fused or electrofusion weld be achieved every time.

Safe handling of molten material

During fusion welding of PE pipes and fittings, molten PE is formed. If allowed to come into contact with human skin, it will adhere strongly and burn severely. The thermal capacity of molten PE is high and it will remain hot for some time.

Gloves must be worn if there is any risk of skin contact. Small quantities of fumes may be given off during welding – more pronounced at higher temperatures. Great care should also be taken where there is a risk of PE residues adhering to heated surfaces such as heating plates used for welding. Some ventilation is important in ensuring safe working conditions.

Butt fusion welding

Only approved, well maintained machines should be used. There are two basic types of welding machine, manual and automatic, the difference being that the welding cycle is computer controlled in the automatic machine. Modern equipment is hydraulically operated, the old pneumatic machines need a compressor as well as a generator and should not be used.

Equipment

- Generator to power the machine's heater, trimmer and hydraulic pump.
- Welding machine of suitable size, including clamp frame, clamp shells, trimmer, controller (for automatic machines) and hydraulic pump – an electrically operated pump is best, since it enables one person to carry out welds on pipe up to 250mm.
- Pipe Support Rollers
- Pipe end covers
- Welding tent
- Clean, dry, lint free cloth or paper towel.
- External/internal debanding tool.
- Bead gauge
- Calibrated digital thermometer and probe.
- Timer

Pre-welding checks

Before commencing a welding operation, check that:

- The site is suitable for welding and a tent is used.
- You know the correct welding parameters for the machine and pipe being welded. These are normally on the machine's data plate. If in doubt, refer to our Technical Services Department.
- The machine is complete and undamaged.
- The generator has enough fuel for the work to be done.
- The heater plate is clean – if not, wash it while cold with lots of clean water and dry with a clean, lint free cloth or paper towel.
- The trimming tool is clean and sharp.
- The clamp shells are of correct size and clean, with no embedded grit which could lead to pipe misalignment.
- The heater plate is at the correct temperature.
- The pipes to be welded are of the same material and SDR (wall thickness).

Dummy welds

Before a welding session, a dummy weld should be carried out to clean the heater plate. The welding process (see instructions below for manual and automatic) should be followed up to the heat-soak stage, at which point the weld may be aborted. Any dirt will be transferred from the heater plate to the pipe end which, when cold can be retrimmed for welding.

Pipes larger than 180mm should be dummy welded twice before proceeding.

Manual welding procedure

Pipe end preparation:

1. Place the welding machine on a clean, dry surface such as a board, enclosed within a tent.
2. Open fully the machine carriage.
3. Place pipes to be joined on rollers to ensure free movement during welding.
4. Ensure pipes are correctly aligned and adjust rollers as necessary.
5. Clean pipe ends, taking care to remove embedded grit.
6. Fit pipe trimmer and place pipes on the welding clamp with pipe ends touching trimmer.
7. Cover pipe ends to eliminate draughts.
8. Tighten pipe clamps.
9. Start trimmer and close machine carriage.
10. Trim pipe ends until a running swarf strip of full pipe wall thickness is produced.
11. While trimming continues, reduce carriage closing pressure to zero.
12. Open the carriage fully.
13. Stop machine and remove trimmer.
14. Remove swarf. Do not touch planed surfaces.
15. Check visually that both pipe ends are completely trimmed.
16. Bring pipe ends together, check for alignment and gaps.
17. If necessary adjust rollers, re-trim and check again.
18. Determine drag pressure for the weld by noting pump pressure required to activate the machine.

Note that when welding pipes larger than 315mm OD, always align the 'TOP' stamping mark on the pipes.

Making the weld:

1. Place heater plate in machine and close carriage.
2. Apply the correct bead-up pressure (including drag pressure).
3. When initial bead has reached required size around each pipe end, reduce gauge pressure to specified heat-soak pressure (or zero if none is needed).
4. Heat-soak period begins as soon as bead-up pressure is released. Set trimmer to the right soak time for the pipe.
5. Open carriage and carefully remove heater plate.
6. Within maximum plate removal time, close carriage, bringing molten pipe ends together.
7. Apply correct fusion pressure (including drag pressure).
8. Check and maintain fusion pressure during in-machine cooling time.
9. Carefully remove welded pipe string from clamps and allow to cool before stressing the joint excessively or de-beading.

Post-welding checks:

1. Use bead gauge to check that bead width meets specification.
2. Check repeatability of weld beads along pipe string.
3. Externally debeat the weld and inspect for slit defects.
4. Check for surface dirt on removed bead.

Automatic welding procedure:

Note that some manufacturers' machines provide fully automatic pipe end cleaning, alignment and welding cycle, others offer automatic welding cycle only.

Pipe end preparation:

1. Switch on controller and select pipe size and SDR rating.
2. If preparation is not automated, proceed as for manual welding.
3. Load trimmer into machine.
4. Place pipes to be joined on rollers to reduce drag.
5. Cover pipe ends to prevent draughts.
6. Load and clamp pipe ends.
7. Press "AUTO-TRIM" button on controller. Trimming will continue up to its programmed stop, but as soon as a running swarf strip of full pipe thickness is visible, trimming may be stopped by pressing the auto-trim button again.
8. When trimming cycle is complete and carriage has opened, remove trimmer and swarf. Be careful not to touch pipe ends.
9. Close carriage and check pipe alignment; re-trim if necessary.
10. Visually check pipe ends for completeness of trimming.

Making the weld:

1. Load heater into welding machine and secure.
2. Press 'JOIN' button on controller (this check heater temperature).
3. Place heater in operating position, push home until fully locked.
4. Press 'JOIN' again. Fusion cycle will be carried out automatically.
5. When controller display show 'JOINT COMPLETE', press reset button.
6. Remove heater plate, unclamp pipe and remove carefully.
7. Allow pipe to cool properly before installation.

The rules for butt fusion

NEVER

- Attempt to weld together pipes of different SDR (wall thickness).
- Touch trimmed pipe ends.
- Leave trimming swarf inside pipe or on welding machine.
- Allow equipment to get wet or dusty.
- Use non-approved machinery.
- Remove a weld from the machine before cooling time has elapsed.
- Allow untrained personnel to use welding equipment.
- Cut corners in any part of the welding procedure.
- Weld pipes of different material.

ALWAYS

- Support pipes on rollers.
- Check pipe and welding clamps are clean.
- Check for thoroughness of pipe trimming.
- Check for alignment of pipe ends.
- Measure the drag pressure for each weld.
- Cover pipe ends to prevent draughts.
- Use a welding tent.
- Check that pipe wall thickness match before butt welding.
- Stand well clear of automatic machines during operation.
- Carry out a dummy weld at the start of a welding session.

Electrofusion welding

There are a number of electrofusion jointing techniques, some manual and some automatic, though procedures for preparation and assembly of welds is common to both. There are two types of fittings; socket welds and saddle welds. Most fittings need a 40V (2kW) supply, but couplers larger than 250mm need 80V (4kW).

Equipment

- 110V output generator of sufficient power to supply control box (generally 3-3.5kVA for 40V fittings and 6-7kVA for 80V)
Electrofusion control box providing 2kW power at 39-40V RMS for 40V fittings or 4kW power at 78-80V RMS. The unit should be approved for this application where relevant specifications exist. Manual control boxes are suitable for nearly all electrofusion fitting types. Some automatic boxes require dedicated fittings and vice versa.
- A combination generator and control box unit meeting the specifications stated above can also be used.
- Clamping equipment, including pipe and restraining clamps for all couplings and tapping tee clamps to suit the type to be welded. If in doubt, consult our Technical Services Department.
- Pipe scraping equipment capable of scraping pipe ends or tapping tee surfaces so that 0.05-0.2mm of pipe surface is removed, extending beyond the area to be covered by the fitting.
- Ancillary equipment; welding tent, solvent based marker and clean, dry lint-free cloth or paper towel.

Electrofusion socket fitting procedure

Pipe end preparation:

1. Check that pipe ends are less than 2% of pipe OD out of square to centre line.
2. Wipe loose dirt from pipe ends with clean, dry, lint free cloth or paper towel.
3. Scrape one pipe end completely for more than half the fitting length.
4. Wipe off loose swarf with clean, dry, lint free cloth or paper towel.
Do not touch the scraped pipe surface or allow surface to get damp prior to continuing.
5. Place prepared pipe end in restraining clamp.
6. Open fitting bag, check the fitting is clean and place over pipe end.
7. Mark penetration depth on pipe, leaving the bag over the fitting for temporary protection.
Do not touch the bore of the fitting. All electrofusion fittings should be kept clean in their bags until welding. Loose dust can be removed with a clean, dry cloth or paper towel – if cleaning fails, reject the fittings.
8. Prepare second pipe as described above.
9. Remove bag and push second pipe home. Mark its penetration depth and tighten restraining clamps.
10. Check fitting penetration – you should not be able to move it along the pipe.

Making the weld:

1. Check generator has enough fuel.
2. Connect control box input to generator output and start generator.
3. Connect control box output leads to the electrofusion fittings.
4. Switch on control box.
5. Check weld time marked on fitting; enter this figure into control box.
6. Press 'START' and hold down until display begins countdown. When weld is complete, display will show a letter C.
7. Allow weld to cool for time stated on fitting before removing clamps and moving assembly.
Do not touch fusion indicators during steps 6 and 7.

Quality checks:

1. Check that fusion indicators have risen.
2. Check that no melted material or wire has exuded from the fitting.
3. Check that pipes have not pulled out during welding.

If the weld fails any of these checks, cut it out and use another fitting.

Pipeline repairs with electrofusion couplers

In repair work electrofusion couplers are used without centre stops. The section of damaged pipe should be cut from the main, as squarely as possible, and the pipe ends cleaned and dried. The replacement section should be cut no more than 5mm shorter than the gap it is to fill, then each end should be cleaned thoroughly to beyond the depth of penetration.

Welding is carried out as described above under 'Electrofusion Socket Fitting Procedure' except that, when setting up, the full depth of penetration of the repair coupler should be marked on one of each pair of pipe ends to be welded. This ensures that the coupler is positioned centrally over the pipe ends.

Electrofusion saddle fitting procedure

Pipe end preparation:

1. Expose pipe on to which saddle is to be welded.
2. Check for excessive ovality and that vertical or horizontal curvature does not exceed a radius of 25 times the pipe diameter.
3. Remove loose dirt with a clean, dry lint free cloth.
4. Still in its protective bag, place fitting over required position on the pipe.
5. Mark pipe surface 10mm clear all round contact area.
6. Scrape uniformly entire surface within marked area, removing between 0.05 and 0.2mm of material.
7. Wipe away any loose swarf with a clean, dry cloth or paper towel.
8. Remove fitting from bag and attach to pipe with suitable clamping equipment.
9. Do not touch the electrofusion surface of the saddle.

Making the weld:

1. Follow steps 1 – 7 'Making the Weld', set out under socket fittings procedure.
2. Allow an additional 15 minutes cooling time before tapping pressurized main with integral cutter or other approved device.

Do not touch the fusion indicators.

Quality checks:

1. Check that fusion indicator has risen.
2. Check that no melted material or wire has exuded from the fitting.

If the weld fails either of these checks, do not tap the main. Carry out a repeat weld with a new fitting at least 200mm from the failed joint.

Automatic recognition electrofusion fittings

In automatic recognition systems, control box software identifies the fittings being fused and its welding parameters. A number of electrofusion systems use bespoke fittings and control boxes.

Pre-weld assembly procedure is as described above. Additionally with these fitting types you should always ensure that fittings and control box are compatible – if in doubt consult our Technical Department – and always check that the weld time shown on the control box matches that on the fitting.

The rules for electrofusion

NEVER

- Touch prepared pipe surfaces, fitting bore or saddle.
- Allow assemblies to get damp.
- Leave fittings lying around out of their protective bags.
- Leave assemblies for any length of time before welding.
- Touch fusion indicators during welding.
- Use dirty fittings – reject them.

ALWAYS

- Use approved equipment only.
- Cut pipe ends square.
- Scrape pipe surfaces thoroughly.
- Use alignment clamps or stack loading clamps for tapping tees.
- Allow the weld to cool properly.
- Use a shelter in wet or in dry, dusty weather.

Joining PE to PE by Fusion

PE pipes of different SDR

NEVER BUTT WELD pipes of differing SDR for any pressure application, including gravity pipelines.

Electrofusion fittings are designed to weld differing wall thickness' (SDRs) using the same welding conditions, thus pipe and fittings of differing wall thickness' can be joined successfully. Electrofusion fittings are available in a choice of 10 bar or 16 bar rating; be careful to ensure that the pressure rating of the fittings is equal to or greater than that of the pipe.

Joining different types of PE

MDPE can be joined to MDPE either by butt welding or electrofusion. Different pipe producers may have alternative suppliers of preferred MDPE grades; these are all intended to be joined by identical techniques. Similarly it is intended that different grades of Excel can be joined together. Butt welding different pipe materials – for example, MDPE to Excel – is not recommended on site. Ask our Technical Services Department for advice in such instances.

Electrofusion fittings are designed to overcome this problem and will join different grades of polyethylene using the same welding conditions; thus pipe and fittings of different polyethylene grades can be joined successfully. Electrofusion fittings are available in a choice of 10 bar or 16 bar rating. Be careful to ensure that the pressure rating of the fitting is equal to or greater than that of the pipe.

Joining blue to black PE

The first step when intending to join blue to black pipe is to check it is allowed under local by-laws and codes of practice (ascertain, for example, whether black pipe is permitted for underground use and for potable water applications).

Before attempting to join pipe and/or fittings of different colour, discuss the feasibility of your proposed system with the pipe manufacturers' technical department.

Assessment of Butt Fusion Welding Capability

Visual Inspection

All welds should be examined visually to check that the bead is the correct shape and size and that excessive misalignment of pipes has not occurred. It should be remembered however that it is possible to produce welds which appear perfectly satisfactory, but which will fracture easily in a brittle fashion.

If the external bead formed by the welding process is removed when cold, by means of suitable equipment which does not damage the pipe it can be used to give an indication of the quality of the weld. On examination following repeated bending of the weld bead, there should be no sign of any circumferential slit defect between the two halves of the weld bead and it should not be possible to separate the two halves. If any defect is observed, the weld should be cut out and retained for further investigation.

Tensile Testing

Dumbbell-shaped tensile test specimens are cut along the length of the pipe, across the weld, so that the welded region is in the middle of the specimen. In the UK the “gauge length” is foreshortened from that of the specimen design used for tensile testing of pipes, in order to “force” failure at the weld rather than in the pipe itself. The specimens can then be “pulled” to failure in a suitable tensile testing machine. For a weld to be considered satisfactory, tensile specimens should show a large percentage elongation to failure (high degree of ductility).

Microstructure Examination

Thin sections cut across the butt fusion weld, can be assessed by examination of their microstructure under an optical microscope and using polarised light.

In 1967 Menges and Zohren identified four zones in butt fusion welds but at the time offered no comment on the nature of the zones, other than to suggest that they were the result of temperature effects. Later, Barber at Leeds University etched his welds in chromic acid and using a scanning microscope, identified five zones. Further work by DeCourcy at Leeds showed that the zones represent areas of molecular orientation the welds. Molecular orientation is caused by the shear forces resulting from the flow of material during welding and it was observed that in the region of zone three the presence of internal stresses which result from the materials desire to return to its normal un-orientated state and these stresses will have a significant effect on the observed ductility of the weld.

For the purposes of simple analysis, the width of the heat affected zone, will give a good indication as to the integrity of the butt weld. If the heat affected zone is thin, this implies that there has been excessive melt movement and that the bulk of the molten material has been “pushed” out from the joint interface which results in a high degree of molecular orientation at the interface, resulting in poor ductility of the weld. The most likely cause for this is excessive pressure at the pipe ends during fusion. Conversely a wide heat affected zone would indicate lower than the desired pipe interface pressure during fusion and in the worst case could give rise to void formation as cooling takes place.

Non Destructive Testing

The use of radiography may possibly detect large defects such as porosity, shrinkage cavities, cracks and inclusions but will not detect defects such as result from cold fusion and incorrect fusion pressures.

Ultrasonic testing is known to be more sensitive in detecting the latter forms of defects but up until fairly recently, results with this technique have not been encouraging. However development work is ongoing and equipment is available which suggests much better success rates may be achieved.

PE 100

PE 100 a higher performance high density polyethylene. The unique chemical structure results in a product with superior physical properties. Impact toughness, tensile strength, and particularly resistance to rapid crack propagation being much improved on those of other PE pipe polymers.

Sine its successful introduction to the water industry in 1990, PE 100 has seen considerable growth in its use, particularly in larger diameters. This has focused attention on the welding characteristics of thick walled, larger diameter PE pipes.

Some properties of this new pipe polymer are quite different from both MDPE and conventional HDPE. Standard welding conditions developed for MDPE do not give optimum joints for thick walled pipe. Reduced ductility is sometimes observed during tensile testing of welds made from pipe having walls of 25mm thickness or grater. This promoted a thorough investigation into the appropriateness of standard welding parameters for thick walled HPPE pipes and recommendations for revision have now been evolved.

Butt Welding

Butt welding is a simple thermal technique used to join a variety of materials and has been successfully adapted to join PE pipes. This tried and tested process involves imparting heat to prepare pipe ends so that melting takes place, enabling the pipe ends to be pushed together to form a welded joint. The applied pressure during fusion forces a portion of the molten material to be squeezed out giving a weld bead on the inside and outside of the pipe – indeed the weld bead itself may be used as a crude indicator of weld quality. The actual microstructure and performance of the joint will depend upon the welding parameters employed. The choice of these is also influenced by environmental factors, pipe geometry and the characteristics of the pipe material.

Recent finds have identified the potential for optimization of the weld parameters for jointing of thick walled HPPE pipe. A dual pressure butt welding, technique which introduces a second, low pressure fusion stage to the butt weld sequence has been the subject of most extensive investigations.

Testing of Welds

Assessment of the weld quality under current specifications is a purely subjective judgment of the appearance of test specimens following rupture. As a crude indicator or ductility developed in the weld this method is of some value – but is of limited use as a tool for optimization of weld parameters. In addition, the changing cross-sectional geometry of tensile specimens taken from pipes of differing wall thickness has a significant influence upon failure mode (this is currently being addressed). Of the various alternative test methods proposed the most valuable would appear to be the Charpy impact test. This method gives a route for developing numerical data directly related to material properties developed within the weld zone, and is not affected by tensile test piece geometry. Furthermore, fracture toughness related data is arguably of greater value in assessing the probable long term performance of real pipes.

Tensile Testing

Tensile testing using the foreshortened gauge length test piece specifically designed for the testing of butt welds, is a requirement of Water Industry standard 4-32-03.

Tensile tests have been carried out on a range of welds using a variety of Excel pipe diameters and wall thickness'. Visible inspection of failure modes together with absorbed energy data, measured via extensometry during the tensile test, were used to assess and compare both standard and dual pressure welds of increasingly thick walled pipes.

Findings showed that in all cases, the ductility of any particular weld was improved by using dual pressure weld conditions. Indeed with very thick wall pipe sections, where conventional weld parameters may result in an apparently brittle failure mode (at full wall thickness), dual pressure welding gives a satisfactory ductile weld appearance.

Impact Testing

Further testing of the HPPE material characteristics and the effect of varying weld parameters was carried out using the Charpy impact test. This test involves machining a standard series of notched specimens cut from the weld (the notch being placed at the joint interface) and subjecting the specimens to specified impact loading.

From dimensional aspects of the test pieces and measured impact data, a strain energy release rate (Go value) may be calculated. This value can be used as a measure of the impact toughness of any particular weld at its interface, and for evaluating the effects of varying weld parameters with greater sensitivity.

Calculation of Strain Energy Release Rate (Gc)

$$G_c = \frac{U}{B \times D} \times \frac{1}{C} \times \frac{d}{(a/D)} = \frac{U}{B \times D \times C \times d(a/D)}$$

U = Absorbed Energy

D – Depth

B – Width

a = Notch depth

C – Sample compliance

Test data show that plate temperature and particularly jointing pressure are the weld parameters which have the most profound influence upon the impact toughness and ductility of any weld. Slightly higher hot plate temperatures and reduced jointing pressures give superior weld performance. The dual pressure technique combined with a hot plate temperature of 230°C gives a good balance between superior weld performance and maintenance of polymer thermal stability.

Interpretation of Findings

In order to understand why dual pressure welding should improve weld properties, consideration was given to the relationship between weld parameters, structural response and subsequent joint property.

Numerous investigations have been undertaken to optimize butt weld parameters notably the works of Potente and Menges. The results show that high integrity joints between MDPE pipes can be produced for a relatively wide range of welding conditions.

Low pressure / low temperature conditions produce insufficient bonding or void formation due to non compensation of cooling contractions. Conversely, high pressure and excessive melt flow produces pronounced molecular orientation, and since it is this shear zone area which often contains the fracture in joint failures, this is undesirable.

The understanding of such melt behaviour and structural re-organisation within a weld region is well established since Atkinson et al postulated the micro-structural '5-zone' theory. 'The theory states that a weld may contain up to five separate areas of structural variation depending upon weld conditions.

HPPE behaves similarly to MDPE during welding but because of its molecular conformation and larger spherulitic microstructure, it is more sensitive to shearing effects.

Dual pressure butt welding consists of a short duration standard pressure jointing stage (to allow full bonding at the interface), immediately followed by a secondary lower pressure jointing stage which minimizes shearing of the melt during cooling. This produces broader welds with maximum separation of opposing shear zones. Additionally the higher hot plate temperature of 230°C adopted for dual pressure welding aids molecular mixing and resulting in properties close to the parent pipe material.