

BUTT FUSION JOINTING OF POLYETHYLENE PRESSURE PIPES

Guidance Notes

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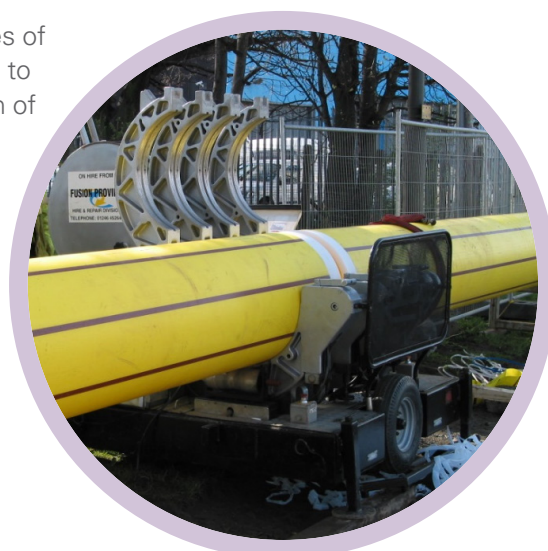
Introduction

Long lifetimes and trouble free operation are outcomes from using polyethylene pipes for pressure applications. To achieve this, there are simple proven techniques for joining pipes during the construction phase. Of these, butt fusion welding has been shown to consistently deliver quality pipe joints under a broad range of construction situations.

The purpose of this guide is to provide an explanation of the butt fusion technique and how it works. With the knowledge accrued over more than 50 years of combined experiences, high quality joints should be achieved as a matter of routine construction practice. In this guide then you will find important topics covered, which include:

- The selection of suitable pipes for pressure applications and the standards available in the United Kingdom that can be used for their specification.
- The reason for the absence of a universally accepted welding standard, leading to the purpose of this document to offer the preferred approaches.
- The availability of techniques to assess the quality of butt fusion welds that allow you to validate your machines, people and processes at the start and end of the construction period.
- How to adapt the process in response to conditions you find on a particular construction site that might be unique, such as new pipe sizes not used before, ambient temperature ranges, etc.

This document is therefore intended as a guide to the principles of butt fusion and identification of those things that are important to consider in the pursuit of high quality welds. In the preparation of this document every effort has been made to offer the most current and accurate information. However, to the broadest extent permitted in law, all information published or referenced in this document is provided without any representation or warranty of any kind expressed or implied. Changes and additions to any information contained herein may be made by BPF Pipes Group without prior notification.



A fully automatic butt fusion welding machine for 630mm diameter polyethylene pipe systems

Image courtesy of Radius Systems Ltd

The Butt Fusion Technique

The butt fusion technique refers to the method by which the square-cut ends of two pipes are first cleaned, then heated by pressing the pipes against a hot plate, after which the plate is removed and the molten pipe ends pressed together and allowed to cool. Throughout this guide, the assumption is that users are welding pipes of the same diameter, same wall thickness and same material type using this process. Other techniques are available which include infra-red (IR) non-contact heater plates, or bead and crevice free (BCF) butt welding forms but are not covered in this guide, nor is welding of dissimilar materials.

The technique is remarkably simple and the broad steps involved in making a satisfactory weld are detailed in the process map overleaf.

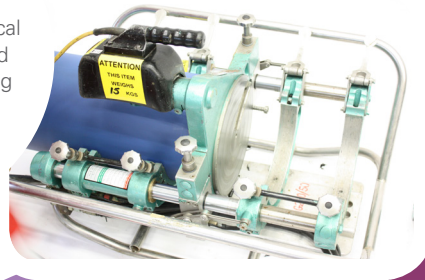
The process can have degrees of automation depending on the equipment used with three broad classifications:

- Manual butt fusion, using machines where each step requires a manual intervention by the welder. This was prevalent across all sizes in the 1970s and 1980s but is now less widespread.
- Semi-automatic butt fusion, using machines which automate some functions of the machine, such as setting of the hydraulic ram pressures to achieve the correct interface pressure between the pipe ends during welding.
- Fully automatic butt fusion, using machines which automate the welding process, specifically the heating of the pipe ends, ejection of the heating plate and subsequent welding and cooling of the molten pipe ends.

Good quality welds are produced by attention to the core principles, particularly control of cleanliness, heat energy and pressure in the welding process. A competent welder attending to these principles can make good welds with any level of automation and the choice of machines will depend to a large extent on their availability at the time of construction. The core principles are set out in the next section.

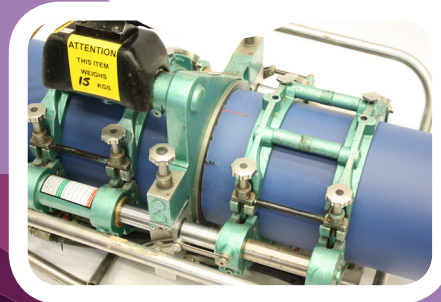
1. Cleaning

The pipe ends are cleaned to remove physical contamination deposited during transport, handling and storage and then presented to the welding station.



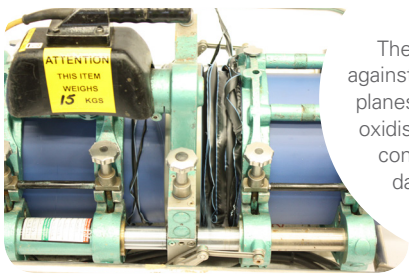
2. Clamping

The pipes are clamped into the machine. One side is fixed and one side can move. The pipes are clamped and checks made that their ends align.



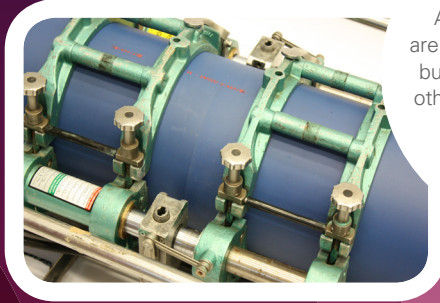
3. Trimming

The pipes are pressed against a trimmer tool which planes the ends to remove oxidised material, physical contaminants and any damaged sections.



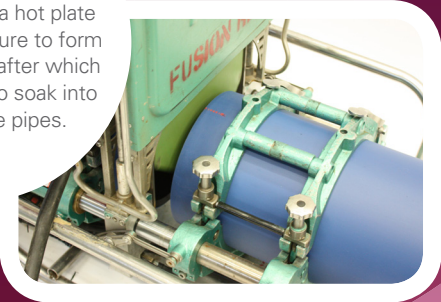
4. Aligning

After trimming, checks are made that the pipe ends butt squarely against each other without any gaps and any offsets are within agreed acceptance limits.



5. Melting

The pipe ends are pressed against a hot plate at a set temperature to form intimate contact after which heat is allowed to soak into the end of the pipes.



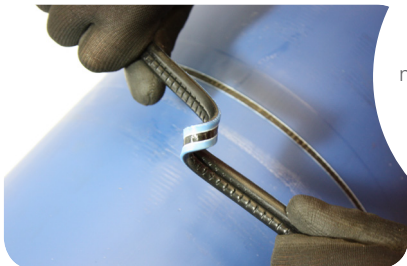
6. Cooling

The joint is immobilised in the clamps whilst the material cools and reforms its crystalline structure, only then is it removed from the machine.



7. Checking

On completion, the weld beads can be removed and non-destructive tests applied to provide feedback on the quality of each weld as the construction progresses.



Core Principles for Butt Fusion Welding

The technique of butt fusion welding polyethylene pipes is extremely forgiving and tolerant. That said, the usual reasons for not achieving good quality often come down to basic workplace organisation for the welding operation. The core principles have a direct impact on weld quality that you should keep in mind when making choices in connection with welding procedures:

- **Cleanliness.** In the field of welding, no matter what the material, cleanliness matters and should be emphasised throughout the process. Machines should be clean. Pipe should be clean. Welding area should be protected on the construction site. All these things are designed to prevent contaminants getting into the weld which might reduce the lifetime of the asset being installed.
- **Heat energy.** To make a satisfactory weld the pipe must be heated such that all the material at the end of the pipes to be joined has achieved the target temperature for the operation, and holds this temperature whilst the heater plate is removed and the pipe ends pressed together.
- **Pressure.** The pressure, sometimes referred to as the interfacial pressure experienced by the pipe ends when they are butted against each other, matters. Pressure is used to ensure the molten pipe ends are fully squeezed together to form an intimate connection so the minimum level matters.
- **Time.** This is the final element, each of the cycle times has a design intent behind it, whether this is ensuring adequate time for heat to soak into the pipe ends; ensuring they don't cool down too quickly when heater plates are removed; or allowing the joint to cool properly in clamps after the weld has been made so that the material can reform its crystalline structure and be handled without damage.

The practical steps to meet these core principles are set out in the next section.

Practical Steps for Butt Fusion Welding

Practical steps that can be taken, or which should be taken, to create the conditions for successful welding operations are provided below. These have been loosely grouped into four steps covering condition of the butt fusion machine; selection of the welding parameters; control of the site conditions likely to affect quality and commissioning of the process on the construction site.

Stage 1 – Condition of the butt fusion equipment

The condition of the butt fusion machine itself matters. If the machine is defective, then there is a good chance the welds will be defective. A simple checklist can be used to assess a machine each time it is set up for operation and the checks also act as good practice for ensuring a safe working environment for the machine operators:

- **Chassis** - the machine has a basic chassis onto which the pipe clamps (one of which is fixed and one of which is designed to be a moving half) and hydraulic pistons are fixed. The chassis should not be bent (check with straight edge tools).
 - **Hydraulic rams** - the moving half of the machine should be cycled without a pipe in the clamps to prove that minimal ram pressure is needed to slide the clamps through full cycle (proves low friction, rams or chassis not bent).
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- **Hydraulic hoses and connections** - should be checked for leaking fluid or damage that might cause a burst hose leading to injury or contamination and connected in the right sequence so that the moving half of the machine moves to open or close correctly when directed from the control panel. Pressure gauges should be calibrated and working.
- **Electrical cabling, connectors and environmental seals for motors and sensors** - should be checked for damage either physical or from water ingress leading to risk of electrocution of the welder. To commission the heater plate will require a surface contact thermocouple with calibrated temperature display available on the work site.
- **Safety measures** - all guards and emergency controls should be checked for function.

The U.K. has legislation about the commissioning of machines in construction environments, for example PUWER and LOLER inspection. Butt welding machines normally have moving parts, electrical and hydraulic components that should be considered in this context.

Stage 2 – Selection of butt welding parameters

The parameters used for butt welding can be obtained by reference to international, national or private standards where they are available and the project fits within their scope. Equally, the pipe supplier can and will provide butt fusion parameters for its products and is the recommended source for advice. You can find advice on standards later in this guide. There are a few basic points to keep in mind if you do venture into adapting welding parameters to suit a particular site situation:

- The temperature around the heater plate where it touches the pipe is important. If it is too low then insufficient heat will be taken up by the pipe, if it is too high then potential degradation of the pipe material might occur, so a range is specified – usually 225°C to 240°C, with the setpoint typically 230°C.
- When the pipes are first pressed against the heater plate they start to melt and a small bead is formed (this is termed ‘bead up’). The bead step compensates for some ‘out of true’ in the machining stage, provides some of the compensation for pipe material temperature and so on.
- After the bead is formed, heat is allowed to soak into the pipe ends. Enough heat must soak in so that it compensates for the ambient temperature of the pipe material (adjusts for extremes of hot and cold) and maintains at least a minimum temperature when the heater plate is removed and pipes butted.
- As well as temperature, the pressure applied to the pipe ends also matters. Too little pressure may be insufficient to move melt to cause defusion bonding and achievement of full strength, too much may simply squeeze all the melt out of the joint causing voids and cold lap weld conditions.
- And finally, the pipe needs to be left in the machine when the weld is completed to allow the strength to develop – typically by allowing the bulk temperature or maximum temperature within the pipe to drop below around 80°C to 90°C so that the material is crystallised. This provides the long term reliability of the pipe.

Stage 3 – Control of site conditions likely to influence quality

A few simple precautions on site can deal with common problems in welding processes and mostly this is thinking about the site conditions.

- When ordering equipment for site works, as well as the butt fusion machine itself, a tent and some temporary pipe endcaps are strongly recommended by the BPF Pipes Group as essential items that can help provide the controlled conditions needed for successful welding.

- The machine is normally used inside a protective shelter, not in an excavation. It should be located on firm level ground where it can be anchored and the pipe is free to move in and out of the machine without large drag forces as the butt weld is made. Roller supports are used for the pipe either side of the machine to minimise drag forces during the welding process and to allow the pipe string to be advanced out of the machine once a weld is completed.
- Power generation equipment should be located outside of the shelter to ensure fumes from exhaust systems are rapidly dispersed to avoid risks to the health of the welder and their team.
- In preparing the work area it is recommended that a groundsheet is laid underneath the butt welding machine and a tent or shelter is used to enclose it. This stops biological matter being drawn from the ground into the machine and airborne matter (e.g. dust) being blown into molten pipe ends/welds.
- As well as a strong focus on cleanliness, tents also assist in preventing wind chill effects drawing heat away from the pipe ends. Using temporary stoppers in the ends of the pipes being welded (ends furthest from the weld) stops significant cooling effects for wind chill caused by chimney effects.
- It is worth thinking about ambient temperature and temperature of the pipes to be welded and in extremes of hot or cold conditions adapting the process. It is reasonable to increase or decrease the heat soak times for example for temperature extremes.

Stage 4 – Commissioning the process on site

Commissioning a machine on site is a prelude to being confident that when multiple welds are made, which may involve considerable time and effort, you are achieving good welds every time. There are many things that you can do, which include:

- First, it helps to have competent and experienced operators. There are many national schemes for training, experience and competency certification that can be used, and this is highly recommended.
- When using the machine for the first time, there are two main considerations - that the heater plate is thoroughly cleaned and that it achieves its working temperature across the area expected to be in contact with the pipe ends during welding. A good practice recommendation for this comes in the form of a three -step process:
 - Whilst it is cold, remove the heater plate from its protective sleeve and clean. Disposable single use lint free cloths are recommended for cleaning, together with isopropanol fluid if grease or oil contamination needs to be removed. Allow the plate to go back into and out of the protective sleeve a few times to make sure this process does not contaminate the plate;
 - Allow the heater plate to warm up to its working temperature which is usually in the range 225°C to 240°C. Once stable, take manual measurements of its surface temperature from both sides of the plate and around the full circumference expected to be in contact with the pipe ends to confirm that the plate temperature is correct;
 - Make a dummy weld to remove any fine particles of dust or contamination which may be trapped in the hollows of the textured surface of the plate. A normal weld procedure is followed but the cycle is aborted once the initial bead up phase is completed – at this point the molten pipe end is allowed to cool so that it can be trimmed off ready to make a full weld. For some larger pipes it is often specified to make two dummy welds.

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- When you start work, the key is to ensure that the machine, the operator, and your chosen parameters can produce a good weld. It is recommended that a weld is destructively tested to validate the process before making lots of welds (recommended practice). This can be quick and simple if the test facilities are pre-booked or available on site.
 - After cleaning the heater plate and at the start of commissioning a machine and completing dummy welds so that you are satisfied there is no contamination, make welds using your chosen parameters, either picked from a standard that you have selected and/ or any adaptation made for your site conditions.
 - Cut the first weld out, take samples around the full circumference of the weld and destructively test to check the weld is fully ductile (see 'Methods of Assessing Weld Quality').
 - It is normal to perform further testing through the production process at site where desired by the client to demonstrate consistent quality is being achieved.

Installation Procedure

Many companies and industry sectors have preferred procedures to be followed when making butt fusion welds. Some of these are very prescriptive, with detailed step by step procedures to be followed. Appendix 1 of this guide lists relevant standards where these are known.

These should be consulted in the first instance, together with instructions provided by the manufacturer of the butt welding machine which is to be used.

Methods of Assessing Weld Quality

One of the great things about butt fusion welding of a polyethylene pipe is that there are a range of techniques that can be used to assess the quality of welds. This includes simple on-site tests that the welder can perform, non-destructive examination (NDE) and destructive testing in laboratories under reference conditions.

During the formation of a butt fusion joint, an internal and an external weld bead is formed at the location of the joint. The bead formed on the outside of the pipe can be removed easily with simple mechanical tools and provides a quick and easy means of checking for common problems in welding.

- Before removing it from the pipe, the external weld bead can be visually checked. It should be uniform both in terms of its width and of each side of the bead when viewed around the circumference of the weld. If not, then it would indicate that there most likely is a problem with the heater plate (distorted, or heater elements broken).
 - The width of the bead can be measured to check it falls between a minimum and maximum width. A bead too small might indicate insufficient heat in the weld, a bead too large may be too much heat or too much pressure during the welding process.
 - Once removed, the bead can be subjected to bending and twisting along its length. If the bead splits in a brittle fashion then it is likely that the pipe joint also has brittle areas (the bead is representative of the weld quality in the pipe wall). If the bead has brittle like defects then the pipe joint should be remade.
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Non-destructive examination (NDE) of butt fusion welds can be performed and tools are usually very good at detecting voids, or contamination, which may exist in the weld and need to be addressed. NDE techniques are not routinely used as the industry has very good experience of combining the assessment of weld beads together with sampling of joints by destructive testing, as the means by which it demonstrates the suitability of the technique. However, for high risk installations it may be desirable to specify NDE, for example phased array ultrasound testing (PAUT) of butt fusion joints.

Definitive tests on weld quality can be made by conducting destructive testing. Such tests can be made on construction sites in a simplified form but in case of reference, are conducted in a laboratory. The purpose of such testing is to check that the butt fusion machine is working properly and that the welds it makes are of the expected quality, so often it is the first weld made on the site that is tested as a minimum. These tests are typically tensile specimens cut from the weld and pulled to force failure which can be assessed both quantitatively and qualitatively.

Case Studies

Butt fusion techniques using polyethylene pipe have been used in the United Kingdom, indeed throughout Europe since the 1960s and good experience has been gained. The technique in practice is normally found on pipes 63mm in diameter or larger, and most recently has been used to join pipes of up to 2500mm. The size is not a limitation of the technique, only it is the largest pipe produced so far.

Case 1

Welding in different conditions, a tolerant technique

If the simple rules are followed, then it is possible to make good quality butt fusion welds under a variety of site conditions. Temperature extremes from a warm day at the beach to a cold day in the middle of winter can be tolerated by the method of butt fusion jointing.

This example has been provided by Georg Fischer Piping Systems

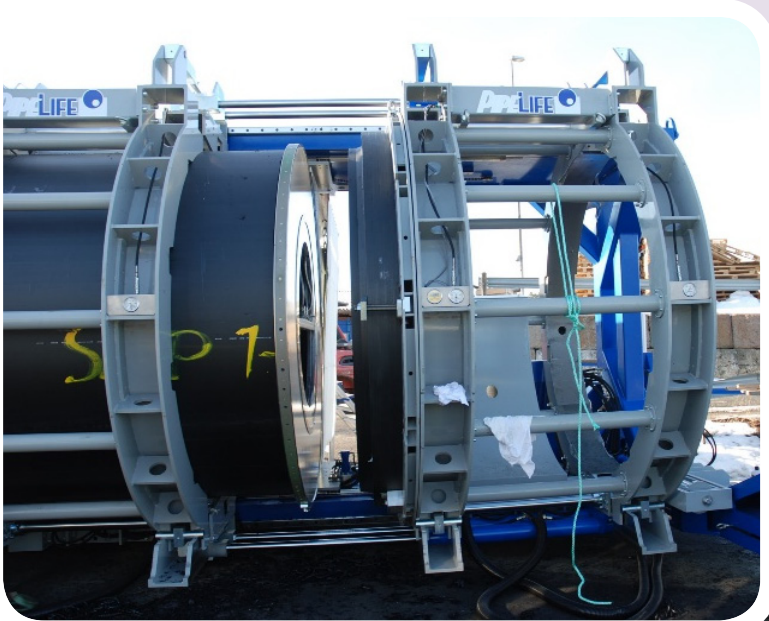




Case 2

An example of very large pipe being welded

Butt fusion techniques work across all pipe sizes to form reliable high quality welds. This example is of a 2500mm pipe (2.5m diameter) for a power station project in Algeria. Here the pipe has been supplied in a continuous string and a stub flange is now being butt welded directly to the end of the pipe to enable a mechanical connection to be made.



This example has been provided by Pipelife



Case 3

An example of a thick walled pipe being welded

Butt fusion techniques are able to reliably join both large diameter and big wall thickness pipes, that includes pipes with wall thicknesses up to 100mm or more. In this example a mid range pipe size is being welded, a pipe of 800mm in diameter.

To appreciate the time taken to weld pipes an 800 SDR 11 pipe, having a wall thickness of around 73mm, would normally take close to 2 hours to make a high quality weld, that covers both welding and cooling of the material ready for handling within the construction site. In the picture below, an example of an 800 SDR 17 pipe, having a wall thickness of close to 50mm is shown. That takes around 1 to 1.5 hours to weld and cool, and then it can be handled. In this example the pipe is being welded and then advanced from the machine into a nearby river ready for the next weld to be made.





Case 4

An example of welding in a trench

Butt fusion is not exclusively used above ground. If you take care to control the environment around the machine then it is perfectly practicable to make butt fusion welds within a trench environment.

Two examples are shown here. In the image above left, a 900 SDR 17 pipe is being welded in a trench. In the image above right, a 630mm butt fusion machine has been shelled to permit welding of 355mm diameter pipe and is being used to join a butt fusion pipe elbow to a length of pipe directly within the excavation.



Case 5

An example of welding a thin walled pipe for lining works

Butt fusion joints are reliably formed on large diameter thin wall polyethylene pipes. In this example 1050 SDR 51 pipe is being welded within a shelter. On site quality assurance is used to prove that good joints are formed. With good joints, the whole pipeline is then ready for temporary deformation as part of a lining system where it is installed within an ageing metallic pipeline to rehabilitate it. This example is for a worksite in the North West of England



This example has been provided by Radius Systems



Case 6

An example of welding a thin walled pipe for lining works

Butt fusion joints have been used in urban as well as rural areas as part of planned replacement works for old iron pipes. In this example an 800mm diameter pipe, the largest polyethylene pipe laid to date as part of the UK gas distribution system, is being welded to form a continuous pipe string. That pipe is being inserted into an old iron main once joints are fully cooled and crystallised allowing the pipe to be moved.

Appendix 1: Standards and Procedures

UK Applications

Pipe Standards

Standards for drinking water pipes

BS EN 12201-2: Plastic piping systems for water supply and sewerage under pressure – Polyethylene (PE). Part 2: Pipes

Standards for gas distribution pipes

GIS/PL2-2 Specification for polyethylene pipes and fittings for natural gas and suitable manufactured gas — Part 2: Pipes for use at pressures up to 5.5 bar.

GIS/PL2-8 Specification for polyethylene pipes and fittings for natural gas and suitable manufactured gas - Part 8: Pipes for use at pressures up to 7 bar.

BS EN 1555-2: Plastics piping systems for the supply of gaseous fuels - Polyethylene (PE). Part 2: Pipes

Standards and guidelines for butt fusion welding of PE pressure pipe

Drinking water pipes

WIS 4-32-08: Specification for the fusion jointing of polyethylene pressure pipelines systems using PE80 and PE100 materials. <https://standards-board.water.org.uk/wis-ign/>

This is a procedure for welding of pipelines intended for use by water and sewerage companies. It is in the public domain and can also be used for non-drinking water applications.

Gas networks

GIS/PL2-3: Specification for polyethylene pipes and fittings for natural gas and suitable manufactured gas — Part 3: Butt fusion machines and ancillary equipment.

This is a procedure for welding of pipelines intended for use in fuel gas distribution networks. It is not in the public domain. Limited advice is available in IGEM/TD/3 'Steel and PE pipelines for gas distribution' and it is recommended that guidance be sought from the pipe manufacturers.