

**HIGH QUALITY MANUAL BUTT FUSION JOINTS
USING LOW COST PIPE ALIGNMENT TECHNOLOGY**
by
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fulfilment of the requirements for the award of the degree of
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1 Introduction

Butt fusion techniques have been used for polyethylene pipe jointing in the UK since the 1970's. Today in the UK butt fusion operations are conducted using fully automatic butt fusion machines minimising potential human error. In Developing Countries such as Nepal and Timor Leste (formerly known as East Timor) manual butt fusion techniques have been developed and are used as a cost effective alternative to mechanical and electro fusion jointing. Despite their use in Developing Countries, no extensive testing has been undertaken to determine the strength of these manual butt fusion joints.

No testing of manual butt fusion joints is performed in Developing countries. The joint is made and the pipe is then filled and pressurised with water from the existing live system, and only if the joint leaks is the performance of joint known. Manual butt fusion techniques have a large potential for human error. This can include contamination, incorrect heating temperatures and pipe misalignment. A successful butt fusion joint should be as strong as the parent pipe (Wavin 2001).

This research project will examine manual butt fusion joints by constructing manual butt fusion jointed test pieces using the equipment and techniques used in Developing Countries, and testing the butt fusion joints to determine joint strength and performance under different testing conditions. As well as testing of manual butt fusion joints, testing of compression joints has been undertaken as part of this research project to enable direct comparison between the two different methods of pipe jointing.

After a detailed analysis of the testing results and comparison of jointing methods I shall end the report with my conclusions, describing how the testing went and how and why manual butt fusion jointing could be improved.

1.1 Aims and Objectives

The aim of this research project is as follows:

„To investigate the performance of manually welded butt fusion joints in comparison to compression joints on polyethylene pipes’

The objectives of the research project can be summarised as follows:

- To obtain a detailed knowledge of butt fusion technology including the joining procedure, its use in developing countries and its limitations.
- To obtain a detailed knowledge of compression joints, including the joining procedure, their use in developing countries and limitations.
- For the author to become competent and an expert in the manual butt fusion joining procedure producing manual butt fusion joints suitable for testing.
- To obtain a detailed knowledge of joint testing methods and undertake testing on manual butt fusion jointed and compression jointed test pieces.

1.2 Research Procedure

The following bullet points provide an outline of the research procedure that will be implemented to achieve the aims and objectives of the research project:

- A comprehensive literature review will be undertaken of butt fusion joining, compression joints and pipe testing methods. Literature will be obtained from journals, books, technical manuals, manufacturers and databases.
- Construction of manual butt fusion jointed and compression jointed test pieces following correct procedures, and preparation of testing rigs.
- Finally, laboratory testing of constructed manual butt fusion and compression jointed test pieces to enable the author to determine the performance of the joints under different test parameters.

1.3 Preface to Chapters

Chapter 2: Background and Literature Review. This chapter will provide detailed literature on manual butt fusion joints and compression joints, concentrating on the joining procedure and advantages and limitations of each joint in Developing Countries. The chapter will also provide literature on pipe testing, explaining hydrostatic pressure, tensile strength, bending strength and fatigue testing methods.

Chapter 3: Methodology. This chapter will provide details and justification of the testing parameters selected for the laboratory testing. It will also detail the test piece preparation including equipment required and the joining procedures for manual butt fusion and compression joints. Finally this section will provide details of each testing

rig for the different testing parameters and the testing procedures to be undertaken. Limitations of each testing procedure will be included where appropriate.

Chapter 4: Results. This chapter will present the results of the test piece preparation and testing results. The results of the test piece preparation will be presented in the form of a written account of the procedure including any difficulties experienced. The testing results will be presented in the form of graphs, tables and simple calculations. Observations, photographs and problems experienced will also be included in the results.

Chapter 5: Analysis and Discussion. This section will contain a full analysis and discussion of the results of the manual butt fusion jointed test piece preparation and testing of the manual butt fusion and compression jointed test pieces.

Chapter 6: Conclusion. Chapter 6 will draw definitive conclusions from the results and analysis of the manual butt fusion jointing. Recommendations will be made regarding how the manual butt fusion jointing procedure could be improved. The conclusion will also detail limitations of the research project and potential areas for further research.

2 Background and Literature Review

Polyethylene pipe was first used in the UK in the early 1960's as an alternative material to cast and ductile iron pipes in the low pressure (up to 75mbar) gas distribution system. By 1975 polyethylene pipe was commonly used throughout the gas industry in the UK for main and service laying purposes (National Grid 2007). Soon after this polyethylene pipes were introduced for water distribution. Today polyethylene is firmly established as pipeline material for water and gas operating up to 10bar for gas and 16bar for water pipes (Radius Systems 2008b, Wavin 2001).

Polyethylene pipe systems are cost effective and reliable. Polyethylene offers a number of advantages including corrosion resistance, chemical resistance, flexibility, light and easy to handle, low frictional resistance, good flow characteristics, strong and durable, and simple welding technologies for leak tight joints (WRc 1986). The flexibility of polyethylene pipe also allows it to absorb high levels of impact loads associated with the construction phase, and vibration and stress caused by soil or ground movement post installation (Radius Systems 2008b).

However, because polyethylene is a comparatively soft material it also has a number of limitations including sustaining wall damage from rocks, bricks and metal tools and can easily be scored. Polyethylene pipe can sustain score damage up to 10% pipe wall thickness and still perform adequately (National Grid 2007). Any part of a pipe with damage greater than 10% of wall thickness requires removal. Polyethylene is also at risk of UV degradation (WRc 1986) when exposed to prolonged sunlight and as such should be protected when stored for periods greater than a year or used above ground, where it should be placed in UV resistant sleeves (WRc 1986). Finally it is not possible to trace polyethylene pipe meaning either traceable marker tape or detailed as laid drawings are required.

Polyethylene pipe is available in two different strengths, PE80 (a material with minimum required strength 8MPa) and PE100 (a material with minimum required strength 10Mpa), and a wide range of pressure ratings (8bar to 16bar) and of sizes from 20mm to 630mm outside diameter (Wavin 2001). Coiled pipes of outside diameter up to 180mm are available in lengths of 50m and 100m (WRc 1986).

There is a range of possible jointing methods for polyethylene pipes. These include; butt fusion, electrofusion couplers, socket fusion, push-fit and compression joints. The following sections will examine in detail butt fusion and compression joints.

2.1 Manual butt fusion joints

Butt Fusion jointing in principle is simple (WRc 1986). Two prepared pipe ends are aligned and heated simultaneously against a Teflon coated heating plate. The heating plate is then removed and the pipe ends are brought together to form a homogenous weld (Wavin 2001). A small bead will form on the inside and outside of the polyethylene pipe upon completion of the joint (Figure 1). A butt fusion joint should be at least as strong as the parent pipe (Wavin 2001). Butt fusion jointing of polyethylene pipes is a technique that enables the joining of pipes on site that are the same strength (PE80 or PE100), and have the same outside diameter and Standard Dimension Ratio (SDR) [Specified outside diameter of pipe/Minimum specified wall thickness] (National Grid 2007).



Figure 1. An example of a butt fusion joint in polyethylene pipe

Butt fusion techniques have been used for polyethylene pipe jointing in the UK since the 1970's with fusion provided at the forefront of butt fusion machine design. Early butt fusion machines were manually operated and optimum results depended on the successful completion of an involved sequence of steps with considerable scope for error (Fusion Provida 1990). Advancements in butt fusion machine technology led to the introduction of the automatic butt fusion machine in 1987, which was essentially an old manual BF3 butt fusion machine converted. The automatic butt fusion machine was not designed to simply follow a fixed sequence, but was designed as a „intelligent' system (Fusion Provida 1990) able to adjust to changing conditions. Providing the user enters the correct information (Pipe type, diameter, SDR) into the control box of the automatic butt fusion machine, the only remaining human error can be misalignment of pipe and contamination of the joint (Fusion Provida 1990).

Modern automatic butt fusion machines (Figure 2) now additionally have a printer attached to enable joint records to be kept or a facility to allow joint information to be downloaded to a pc.



Figure 2. Automatic Butt Fusion Machine (Fusion Provida 2010)

Today in the UK and the USA automatic butt fusion machines are the only approved form of butt fusion machinery and are widely available, in a wide range of sizes from 63mm to 630mm (Fusion Provida 2010), and in some cases are constructed on self-propelled tracked machines, similar to units produced by Trackstar.

Butt fusion joint welding is also undertaken in Nepal (Scribd 2010) and Timor Leste (Reed 2010) but using much simpler technologies. In Nepal and Timor Leste sophisticated automatic butt fusion machines are not readily available. Instead butt fusion pipe jointing is completed using a hand held heating plate constructed from scrap metal, Teflon coated paper and a thermo chrome crayon (see Figure 3) (Reed 2010, Scribd 2010). The heating plate is heated by using charcoal or good quality firewood to a temperature of approximately 220°C (Junejo 2010, Jordan 1982). The

temperature of the heating plate is determined by marking the plate with the thermo chrome crayon. If the colour of the marking changes from white to brown within 5-10 seconds the plate is at operating temperature. If the marking changes colour in under 5 seconds then the plate is too hot, if the mark changes colour after 10 seconds then the plate is too cold and must be reheated. The Teflon coated paper is used to make a sleeve in which the heating plate is inserted so when pipe ends are pushed against plate molten material does not stick to the plate and contaminate the weld. The manual butt fusion process requires high levels of competency and skill as there are currently no pipe alignment tools used and the hot pipes ends are just 'held together by hand' to make the joint.

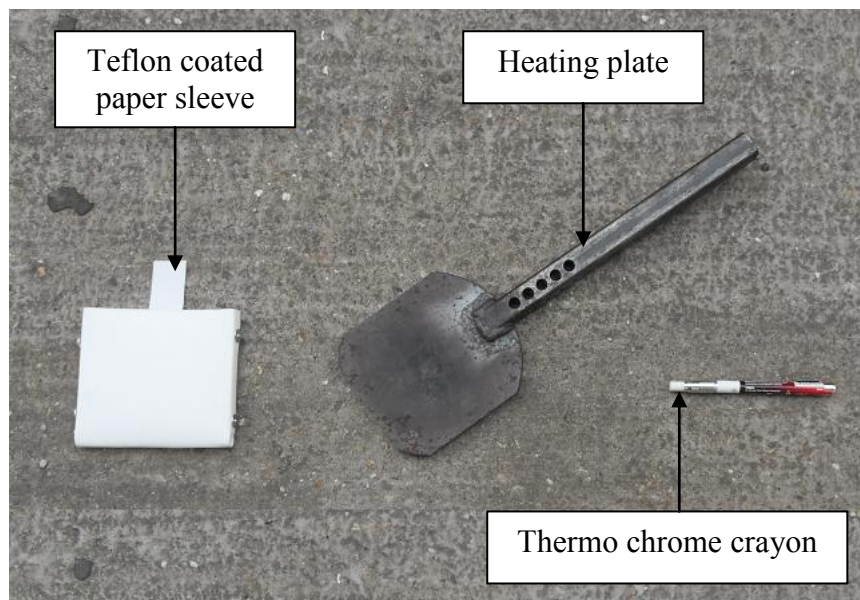


Figure 3. Equipment for manual butt fusion jointing

Manual butt fusion welding operations in Nepal and Timor Leste are only performed on pipes of 32mm and 63mm nominal outside diameters at present (Reed 2010). Additionally, municipalities in Nepal have also developed the manual butt fusion process to fabricate mitred bends and pipe cap ends from straight lengths of polyethylene pipe by cutting straight sections at strategic angles (Scrib 2010).

2.1.1 Butt fusion welding procedure

Despite the large variation in sophistication between the modern automatic butt fusion machinery in use in the UK and US, and the simple manual low cost equipment used

in Nepal and Timor Leste, the welding procedure follows the same basic procedure. The basic butt fusion welding procedure will now be described.

Stage 1

The first stage of the procedure is to ensure that the pipe ends are clean. If necessary the pipe ends should be cleaned with clean water and dried with a cotton rag (Plastic Pipes Institute 2009). All surfaces must be clean and the pipes must be cut squarely so that when pipe ends are pushed together there are no gaps between the pipe ends greater than 1 millimetre (Jordan 1982). The pipe ends should also be checked to ensure the pipe is round and not oval (usually a result of handling damage).

In a modern automatic butt fusion machine the lengths of pipe are secured and aligned in the butt fusion machine.

Stage 2

The ends of both pipes require trimming. This stage is completed to ensure that the pipe ends are smooth, parallel and clean mating surfaces (Plastic Pipes Institute 2009). Simple tools such as a file (Jordan 1982) are used to trim the pipe ends in Nepal and Timor Leste whereas a trimmer plate is used in the automatic butt fusion machine. Once the pipe ends are trimmed all pipe shavings, cuttings and debris should be removed and bagged for disposal. No contact should be made with the pipe ends, as this will contaminate the pipe end (Plastic Pipes Institute 2009). If pipe ends become contaminated then the cleaning and trimming procedures in stages 1 and 2 should be repeated. Finally, a second alignment check is carried out to ensure there are still no gaps between the pipe ends greater than 1 millimetre (Jordan 1982, National Grid 2007)

Jordan (1982) also recommends that the manual pipe jointing crew (Nepal and Timor Leste) make a practice attempt at the jointing procedure using the unheated heating plate, to be familiar with procedure as once pipe ends are joined together when heated they can not be separated and realigned.

Stage 3

Ensuring that the heating plate is clean, undamaged, and at the correct temperature, 220°C (Jordan 1982), the heating plate will be inserted in to a Teflon coated paper sleeve (heating plate in butt fusion machine has Teflon coating) and the two pipe ends are pressed firmly against the plate. When the pipe is heated a bead of molten material will form around the perimeter of the pipe (Jordan 1982). For pipe diameters of 32mm and 63mm the melt bead size required is approximately 2millimetres (Wavin 2001). When the correct sized melt bead has formed equally around both pipe ends the heating plate should be removed carefully so as not to damage the pipe ends and the pipe ends joined together. The time period between the heating plate removal and pipe ends joining must be as short as possible, ideally less than 10 seconds to prevent the fall in temperature of the pipe ends from being too large (Barber and Atkinson 1974). Once the pipe ends have been joined together, the pipe ends should still be pressed together until the joint has cooled down and can be touched by hand.

When using the automatic butt fusion machine, joining pressures, heater temperatures, bead size, fusion time, heat soak time and cool period are all controlled by the machines 'intelligent' system (Fusion Provida 1990). When operating an automatic butt fusion machine it is also common to complete dummy joints at the start of each day, or when changing pipe diameter to clean the heater plate (National Grid 2007). A dummy joint is a joint made following the same procedure as normal but aborted after the heating plate is removed so that the pipe ends are not brought together and joined.

Stage 4

Following cooling of the joint, a visual inspection can be carried out to check for potential jointing faults such as pipe misalignment, melt cooling and interface contamination as shown in Figure 4. The bead width can also be measured and checked that is consistent in width around the perimeter of the pipe (Radius Systems 2008b) and free of any contamination. In some cases the bead may be removed and will also be subject to a visual inspection. For short lengths of pipe the joint can also be flexed vigorously (Jordan 1982) to check the joints do not fail under simple manipulation.

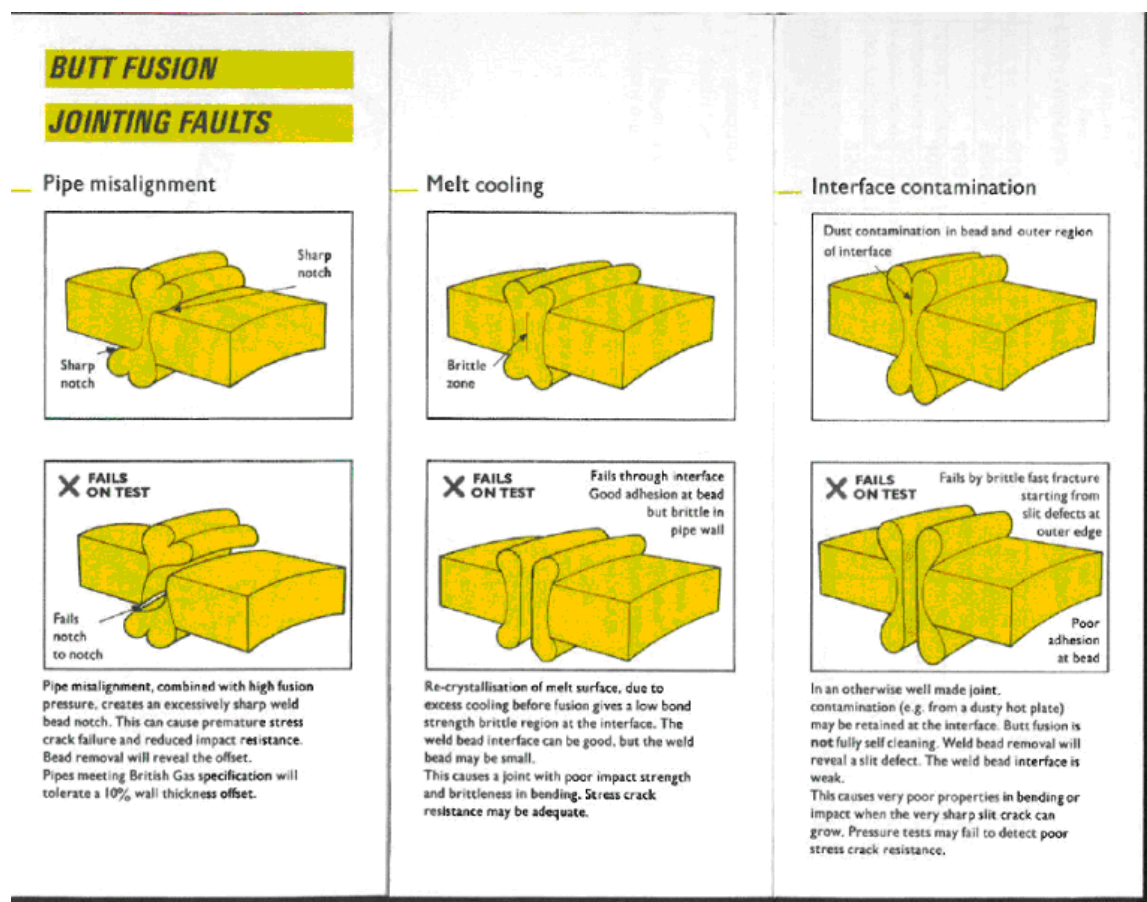


Figure 4. Butt fusion jointing faults (National Grid 2007)

2.1.2 Advantages of butt fusion joints in Developing Countries

Butt fusion jointing has many advantages over alternative pipe jointing methods. One of the main advantages is that it is a very efficient and cost effective method of pipe jointing as it does not require any expensive fittings. Table 1 compares the cost of fitting per joint for butt fusion, electro fusion and compression jointing methods. As can be seen as the nominal outside diameter of the pipe increases, the cost of electrofusion and compression couplers substantially increases whereas there is no cost of fitting per joint for butt fusion, as the two pipe ends are homogeneously welded together (Wavin 2001).

Additionally because butt fusion jointing does not require any specialist fittings the manual pipe joining crews will not have to potentially wait for the import of fittings or experience supply problems before completing repairs, which will in return reduce the leakage times.

Table 1. Comparison of costs of straight fittings of alternative pipe jointing methods
(Pipestock 2010a, Pipestock 2010b)

Nominal Outside Diameter of pipe	Cost of fitting per joint		
	Butt Fusion	Electrofusion coupler	Compression Coupler
32mm	£0.00	£2.39	£1.76
63mm	£0.00	£4.44	£5.41
90mm	£0.00	£6.53	£11.84
125mm	£0.00	£11.84	£63.41
250mm	£0.00	£51.84	Not Available

The low cost manual butt fusion procedure does not require any expensive machinery, tools or power supply. The heating plate is constructed from scrap metal and heated to the correct temperature using a natural fire source (Reed 2010).

2.1.3 Limitations of butt fusion joints in Developing Countries

One of major limitations of butt fusion jointing in Nepal and Timor Leste is that the manual butt fusion procedure is highly complex and requires skilled personnel. The quality of the final joint is highly dependant of the manual pipe joining crews experience and competency. As there are no pipe alignment tools used in the jointing operation, pipe misalignment is a potential problem that can cause premature joint failure. Additionally developing countries may experience difficulties in obtaining the Teflon coated paper and thermo chrome crayons.

Butt fusion jointing is commonly used in Nepal and Timor Leste for repairs, where sections of existing pipe are cut out (Junejo 2010). In this process two butt fusion joints will be required, one joint at each end of the section being replaced. This will require the second joint to be completed inside the excavation, which will increase the likelihood of joint contamination and pipe misalignment. Additionally the excavation required will have to be larger to increase the amount of movement in the existing pipeline and allow the new section of pipe to be “sprung in”.

Finally, successful butt fusion jointing requires the system being worked on to be fully isolated (i.e. no water flowing through repair section) and the pipe to be dry

inside. This will require effective flow stop equipment (squeeze offs). Compression joints may be carried out with small quantities of water still flowing through the isolated pipe section.

2.2 Compression joints

Compression joints provide a simple and efficient pipe joining method requiring simple tools and relatively low skilled labour. Compression joints may be constructed of metal or plastic material (Plastic Pipe 2010) and provide pressure integrity, leak tightness and resistance to end loads (Gas Industry Standard 2006). Compression joints allow the joining of pipes on site that are different polymer, have different wall thickness and different Standard Dimension Ratio (SDR) [Specified outside diameter of pipe/Minimum specified wall thickness] (National Grid 2007). Compression joints also enable the joining of pipes of different nominal outside diameter through the use of a reducer, and joining of pipes of different materials such as PVC, ABS and copper.

The main components of a polyethylene pipe plastic compression joint (see Figure 5) are the body, a threaded compression nut, a floating split ring, a thrust ring (a ring that holds the polyethylene pipe in position and prevents pull out from the fitting), a pipe stiffener (rigid internal tube stiffener that provides permanent support for polyethylene pipe to prevent creep in the pipe wall under radial compressive forces) and a gasket (George Fischer 2010a, Gas Industry Standard 2006). The design principle of the compression joint is that when the threaded compression nut is tightened onto the body of the fitting, the gasket and thrust ring become compressed between compression nut and body of fitting and grip the outside pipe creating a pressure tight seal (Plastic Pipe 2010, Wavin 2001). Additionally, as a result of the gasket and thrust ring gripping the outside of the pipe, pull out resistance exceeding the yield strength of the polyethylene pipe is also achieved. It is essential that the pipe stiffeners are inserted into the ends of the polyethylene pipes to be joined. If stiffeners are not inserted the pipe will creep under radial compressive forces, potentially resulting in a loss of pressure tight seal reducing pressure integrity and leak tightness, or grip which would reduce pipe pull out resistance (Plastic Pipe 2010).



Figure 5. Example of a compression joint

Compression joints have been in use in the Water Industry in the UK since the 1980's. Today compression joints are a common joining method for the repair of damaged polyethylene and lead pipes. Compression joints are also now used in the gas industry to repair damaged polyethylene of 16mm-63mm outside diameter (Gas Industry Standard 2006). George Fischer Italy piping systems have been exporting compression joints to developing countries since the late 1980's.

2.2.1 Compression fitting joining procedure

The compression fitting joining procedure for repairing a damaged pipe is described below. Note: if the damaged area of pipe is too large (shown as distance Z on Figure 6 below), then the damaged section of pipe will have to be replaced with new section joined to existing pipe with two compression fittings. When using compression fittings to join new lengths of pipe it is not necessary to completely dismantle the fitting, just insert pipe stiffeners into pipe ends and insert pipe end into fitting (George Fischer 2010a) avoiding the risk of incorrect assembly of the rings and seals.

Stages 1&2

The pipe is cut using pipe cutters or a hack saw at the point of damage leaving a distance of Z between the pipe ends (George Fischer 2010b). The pipe ends should be

cut square and all sharp edges removed (Polypipe 2010). Pipe stiffeners are fully inserted into the pipe ends up to the stop.

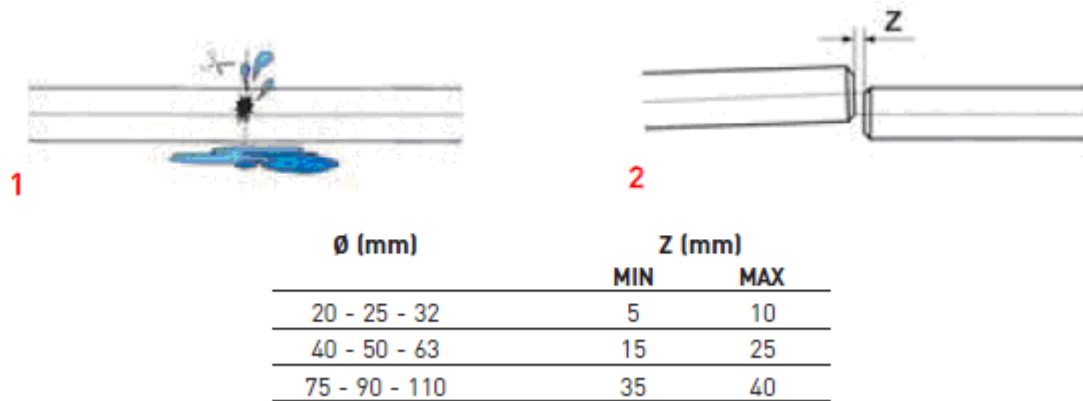


Figure 6. Stages 1&2 compression coupler joining procedure (George Fischer 2010b)

Stage 3&4

The compression nut, thrust ring and gasket (or O ring seal) should be fitted over both pipe ends in the correct order. Align pipe ends and mark on pipe position of the body of the fitting. This is to be used to aid alignment of fitting at stage 6.

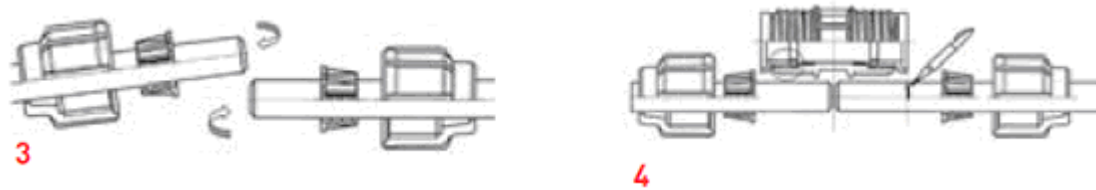


Figure 7. Stages 3&4 compression coupler joining procedure (George Fischer 2010b)

Stage 5&6

Insert the body over one side of the pipe, ensuring the pipe itself comes out of the body on the opposite side (George Fischer 2010b). Align the two pipe ends and slide the body over pipe ends until it aligns with the marks on the pipe applied at stage 4.



Figure 8. Stages 5&6 compression coupler joining procedure (George Fischer 2010b)

Stage 7&8

Without allowing the body to move along the pipe, slide the thrust rings and gasket until at the correct position on the body. Slide the compression nut up to the body and screw together ensuring the compression of the gasket (Figure 9). For pipe diameters 20mm-63mm tighten nut until a maximum of 1 thread on the body remains visible. For pipe diameters 75mm-90mm tighten nut until a maximum of 1.5 threads on the body remain visible (George Fischer 2010b). Fittings can be tightened manually by hand, using grips or a special wrench.



Figure 9. Stages 7&8 compression coupler joining procedure (George Fischer 2010b)

2.2.2 Advantages of compression joints in Developing Countries

The use of compression joints has many advantages in developing countries. Compression joints require no complex tools or equipment for the joining procedure. Compression joints can be tightened manually by hand or by the use of simple tools such as wrenches. Additionally there is no need for any electrical power supply unlike electrofusion coupler joining methods, or heat source requirement unlike for butt fusion joining.

Unlike butt fusion jointing methods, compression joints do not require highly skilled labour to complete the connections and, when installing compression joints in a new system, no dismantling of the fitting is required (George Fischer 2010a). Modern compression joints enable easy and fast installation, and can be installed in tight spaces, such as in an excavation, and are suitable for damp and wet conditions (George Fischer 2010a). Because there is no heat fusion required for compression joints, small pipe flows can still occur through pipe system when completing repairs. Additionally, as there are no heat fusion operations, the pipe and fitting do not become homogenous, and can therefore be taken apart easily and reused (George Fischer 2010a).

Compression joints are able to join polyethylene pipes together of different polymer, wall thickness, and SDR rating. With the use of an adaptor kit, compression joints can also be used to join polyethylene pipes of different diameters (using a reducer) and polyethylene pipe with PVC, ABS, PE-Xa, copper and metal pipes (George Fischer 2010a). This range of compatibility makes compression joints very useful in Developing Countries where pipe networks may consist of a range of different materials.

2.2.3 Limitations of compression joints in Developing Countries

The major limitation of compression joints in Developing Countries such as Nepal and Timor Leste is the high purchase cost of the fitting. As can be seen in table 1 each 63mm compression coupler costs £5.41. Despite the negligible cost of tools and equipment for compression joints the cost per fitting makes compression joints considerably more expensive than butt fusion joining methods.

Finally compression joints would have to be imported to developing countries, potentially creating supply problems and increasing leakage times when waiting for repair fittings.

2.3 *Pipe testing*

There are a number of different criteria by which a pipe can be tested. This section will examine the following testing methods: hydrostatic pressure, tensile strength, bending strength and fatigue.

Before carrying out complicated scientific tests on a section of pipe it is important to perform a visual check. This will examine all joints and connections and also confirm that the pipe wall has not been damaged which could lead to a failure of the pipe itself. During the visual check the pipe can also be flexed vigorously (Jordan 1982) to check the joints do not fail under simple manipulation.

2.3.1 Hydrostatic pressure

A hydrostatic pressure test demonstrates the mechanical integrity and tightness of a pipe system, and requires the system under test to be completely filled and pressurized with water. The application of the test will prove the integrity of the system and

enable any leakage within the system to be identified. Hydrostatic pressure is defined as the static pressure exerted due to the weight of a column of water, for example 100mbar water gauge pressure is one tenth of a bar therefore one bar pressure equates to a column of water 10metres high. A watch tested for water resistance at 5bar is subjected to the same pressure that would be exerted at the bottom of a water tank 50metres deep.

Unlike ductile iron and steel pipes, polyethylene pipes demonstrate a visco-elastic (creep) behaviour (WRc 1999). A polyethylene pipe sealed under test pressure will experience a non-linear reduction in pressure (pressure decay) due to the visco-elastic (effectively a stretching of the pipe) behaviour of the pipe (Wavin 2001) as shown in Figure 10. This will occur even in a leak free system and allowance must be made for this condition.

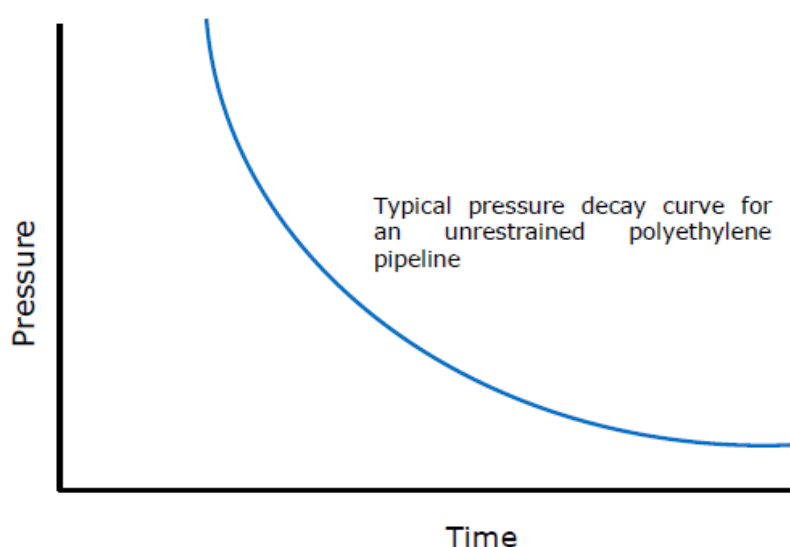


Figure 10. Graph showing visco-elastic behaviour of polyethylene pipe (Radius Systems 2008a)

When testing polyethylene pipes, tests should take place between blank flanges bolted to pipe ends or electro-fusion welded full end-load resistant end caps (Radius Systems 2008a, BS 1167-1: 2006). Testing against a closed valve is not recommended and should not be undertaken unless there is no alternative (WRc 1986).

The Water Research Council (WRc) recommend that testing should not be undertaken in temperatures in excess of 30°C because the creep behaviour of the polyethylene pipe may affect the results obtained. This can be overcome by either partially

backfilling or covering the pipe to maintain ambient temperatures throughout the test period (WRc 1986).

The pipe system will have a rated pressure marked on the side of the pipe, which is the maximum pressure that the pipe can operate throughout its design life (50 years). When applying a hydrostatic pressure test a system test pressure is used, this is a higher pressure than the rated pressure to enable the mechanical integrity and tightness of the system to be verified (WRc 1999). See table 2 for system test pressures for different pressure rated polyethylene pipes.

Table 2. Recommended System Test Pressure for PE pipe (WRc 1999, Radius Systems 2008a)

Rated pressure of PE pipe	Test pressure
Up to 10bar	1.5 x rated pressure
12bar to 16bar	1.5 x rated pressure (or 5 bar + working pressure, whichever is less)

Other considerations when conducting hydrostatic pressure tests include ensuring that air is removed from the pipe system when the system is being charged. This can be achieved by installing air valves at high points in the system (Wavin 2001). Due to compressibility of air, if any air remains in the systems this will distort the pressure test results (WRc 1986). When pumping water into the pipe system it is important to use a pump of adequate size (WRc 1999). It is recommended by the WRc that the pump should pressurise the system fully in 15 to 45 minutes as the loading time has an effect on the overall duration of the test. A long test duration is inconvenient and can increase the chances of temperature fluctuations.

There are two hydrostatic pressure tests recommended by the WRc and undertaken by manufacturers when testing a pipe system. These are the classified as Pressure Test Type 1 and Pressure Test Type 2. In this next section both pressure tests shall be explained and alternative test methods will also be briefly described.

2.3.1.1 Hydrostatic Pressure Test Type 1

The WRc Pressure Test Type 1 is a simple pass/fail test that can be used to test pipe systems of small diameter or of short length (Radius Systems 2008a). This test can only be used if there is no residual air in the pipe system.

The system test pressure is applied to the pipe system and maintained by additional pumping as required for a period of 30 minutes (WRc 1986). This sustains the creep in the polyethylene pipe. After maintaining the system test pressure for 30 minutes, the pressure in the system should be reduced rapidly to a nominal pressure (approximately 2bar) and the system should be isolated. A record of the pressure readings following the isolation of the system should be kept. The WRc (1986) recommend pressure readings every 2 minutes for the first 10 minute period, every 5 minutes for the following 20 minute period, and every 10 minutes for the following 60 minute period. The pressure in the system should rise following the isolation due to the visco-elastic behaviour of the polyethylene pipe as shown in Figure 11. If during the 90 minute period following the depressurising and isolation of the system the pressure drops, this would indicate a leak in the system.

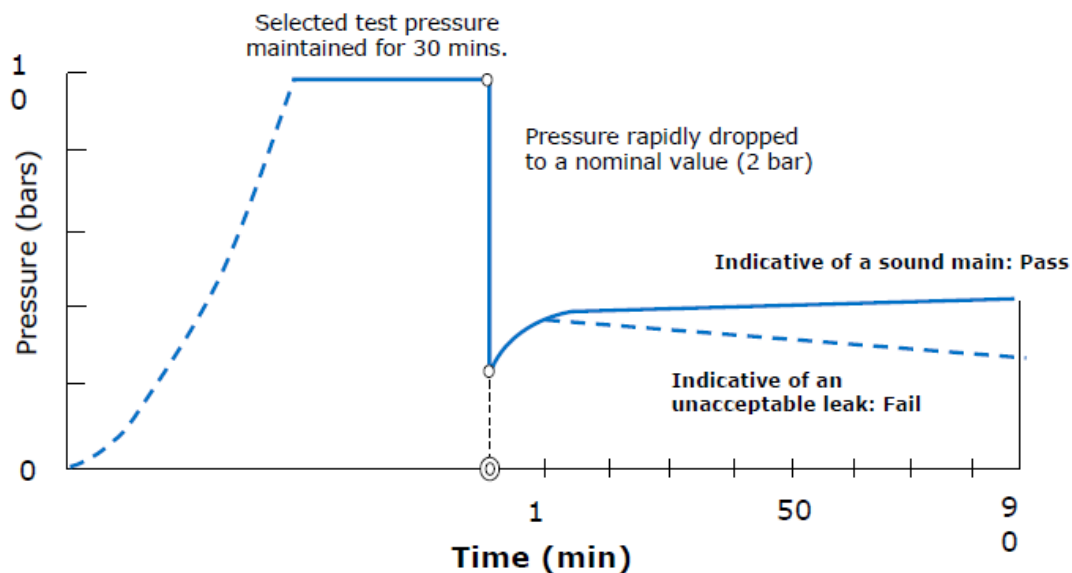


Figure 11. Hydrostatic Pressure Test Type 1 (Radius Systems 2008a)

2.3.1.2 Hydrostatic Pressure Test Type 2

The WRc Pressure Test Type 2 is a more sophisticated and traditional test method than WRc pressure test type 1 and is recommended by manufacturers including Wavin, Radius Systems and Polypipe. Again it is important that there is a minimal amount of air in the pipe system.

Application of pressure should be completed at a constant rate until system test pressure is achieved in the pipe system. The time taken to reach the system test pressure should be recorded. This time is known as t_l (WRc 1999). Once system test pressure has been achieved the system should be isolated and the pressure allowed to decay due to the characteristic stress relaxation of polyethylene pipe (WRc 1986). Pressure readings shall be taken from the time of isolation at pre-determined multiples of t_l to enable calculations to be made to assess the mechanical integrity and tightness of the system, see Figure 12 for sequence of pressure readings.

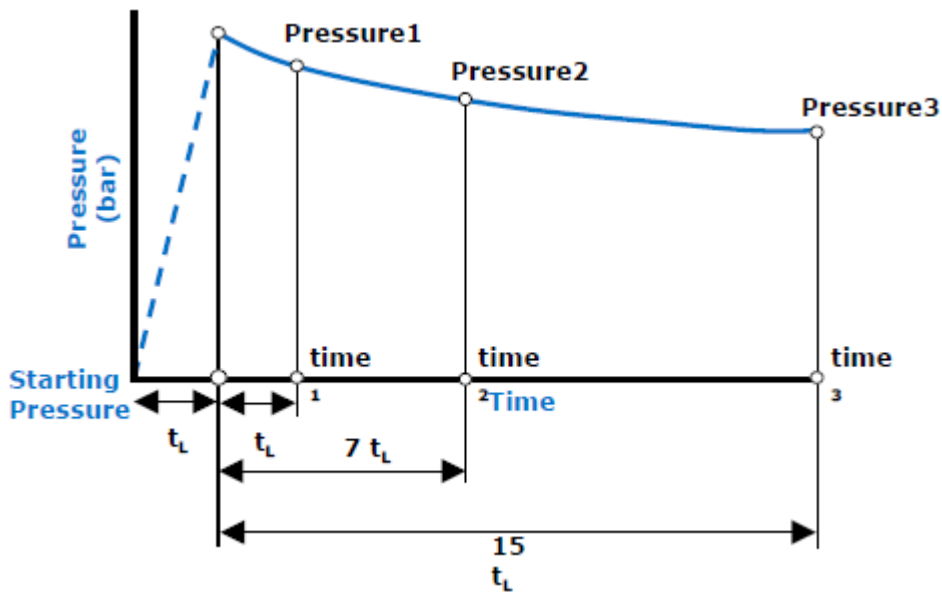


Figure 12. Hydrostatic Pressure Test Type 2 (Radius Systems 2008a)

- | | |
|---|-------------------------|
| First pressure reading (Pressure1) at time (time1), | $time1 = t_l$ |
| Second pressure reading (Pressure2) at time (time2), | $time2 = 7 \times t_l$ |
| Third pressure reading (Pressure3) at time (time3), | $time3 = 15 \times t_l$ |

To allow for creep behaviour in polyethylene pipes a correlation factor of $0.4t/l$ is applied to the times to enable ratios (N), the slope of the pressure decay curve to be calculated.

$$\text{Corrected time1, } \mathbf{time1c} = \text{time1} + 0.4t/l$$

$$\text{Corrected time2, } \mathbf{time2c} = \text{time2} + 0.4t/l$$

$$\text{Corrected time3, } \mathbf{time3c} = \text{time3} + 0.4t/l$$

$$N1 = \frac{\log \mathbf{Pressure1} - \log \mathbf{Pressure2}}{\log \mathbf{time2c} - \log \mathbf{time1c}}$$

$$N2 = \frac{\log \mathbf{Pressure2} - \log \mathbf{Pressure3}}{\log \mathbf{time3c} - \log \mathbf{time2c}}$$

For a sound pipe system with no leakage N1 and N2 should lie within the range 0.04 and 0.1. If N1 and N2 are lower than 0.04 this would indicate that there is air in the system. If N1 and N2 are greater than 0.1 this would indicate that there may be a leak in the system (WRc 1999).

To further improve the reliability of the test more than three pressure decay readings can be taken. Additionally, extending the time between reaching system test pressure and the final pressure reading, can increase the test sensitivity (Wavin 2001).

Simplification of the test procedure can be achieved with the use of data loggers to automatically record pressures (Radius Systems 2008a) as the logging facility will enable analysis of pressure data and can enable early leakage to be identified.

If a pipe system fails a test due to air in the system or an unacceptable leak then, following repair or venting, the system must be allowed sufficient time to recover. The WRc (1999) recommend a period at least five times the test period to enable the system to recover.

2.3.1.3 Alternative hydrostatic pressure test methods

Section A.27 of British Standard 805 (2000) has an alternative hydrostatic pressure test procedure for polyethylene pipes. Test pressure is initially applied to the pipe system and maintained by additional pumping for 30 minutes. The system is then isolated for a period of 1 hour during which time the pipe system may stretch due to the visco-elastic behaviour of polyethylene pipe. The test pressure is recorded at the end of the isolation period. If the pressure has reduced by more than 30% the test should be abandoned because there will be a potential leakage problem.

Following a successful preliminary stage, the remaining pressure in the system should be rapidly reduced to 10-15% of initial system test pressure, by bleeding water from the system, recording the volume of water removed. The allowable water loss will be calculated to ensure that the volume of water removed does not exceed allowable water loss. If water removed exceeds allowable water loss the test should be stopped.

The final stage of the test is to observe the pressure in the system for 30 minutes following the pressure reduction. The pressure should then slowly increase as a result of the contraction of the polyethylene pipe. The test is deemed successful if the pressure in the system is recorded to increase. If the pressure drops in the system in the final 30 minute period this would indicate a leak in the system.

British Standard 805 (2000) and WRc (1999) also describe alternative water loss, and pressure loss test procedures, however both of these tests are unsuitable for polyethylene pipes, as they are unable to accommodate the visco-elastic behaviour of the pipe material.

Finally the UK Water Industry has developed a hydrostatic pressure testing method for testing compression fittings (UK Water Industry 1998). This test method tests the compression fitting in a pipe system of minimum 300mm free length (length of pipe between fitting and end cap) each side of the fitting at a specified pressure and time (table 3). If the system does not fail within the specified time the pressure shall then be raised at a steady rate until failure occurs (UK Water Industry 1998).

Table 3. Example of specified test pressure and time for 63mm Compression fitting
(UK Water Industry 1998)

Duration (hours)	Minimum Test Pressure (bar)
5 000 to 10 000	20
100 to 1 000	22
1 to 10	25

The pipe system should fail by the pipe bursting in a ductile manner (Figure 13) prior to any leakage or failure of the fitting (UK Water Industry 1998). If failure occurs in a brittle manner (Figure 13) or within a distance less than 10% free length from the fitting the test should be disregard.

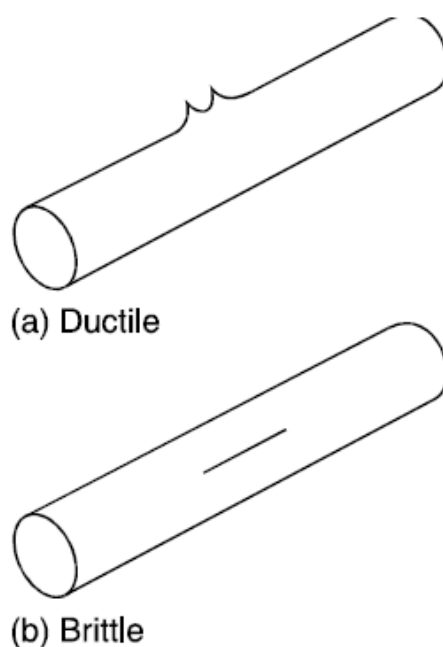


Figure 13. Types of pipe failure (UK Water Industry 1998)

2.3.2 Tensile strength

A tensile strength test determines the resistance of two lengths of pipe being pulled apart. The application of the test will prove the yield strength and elongation at break of the polyethylene pipe. Typical minimum results for tensile testing of straight lengths of polyethylene pipe give yield strength of 18N/mm² for PE80 strength pipe and elongation of over 600% (Wavin 2001, George Fischer 2010b). A tensile test can also determine the pull out resistance of a mechanical fitting. There are different tensile strength testing methods for straight lengths of polyethylene pipe, butt fusion

joints and compression joints. All testing should be undertaken at a test temperature of 23°C (BS 12201-5:2003). The testing methods for butt fusion joints and compression joints will now be briefly discussed.

2.3.2.1 Tensile strength testing methods for butt fusion joints

Tensile strength testing of butt fusion joints is carried out using the procedure from BS 13953:2001. A test piece is machined out along the longitudinal direction of the polyethylene pipe across the butt fused joint to give it a waisted section (Figure 14), and is subjected to a tensile stress at a constant speed of approximately 5mm/min ± 1mm/min. When loading the test piece in a tensile testing machine, the stress is concentrated through the jointed region and failure is in the vicinity of the joint (BS 13953:2001).

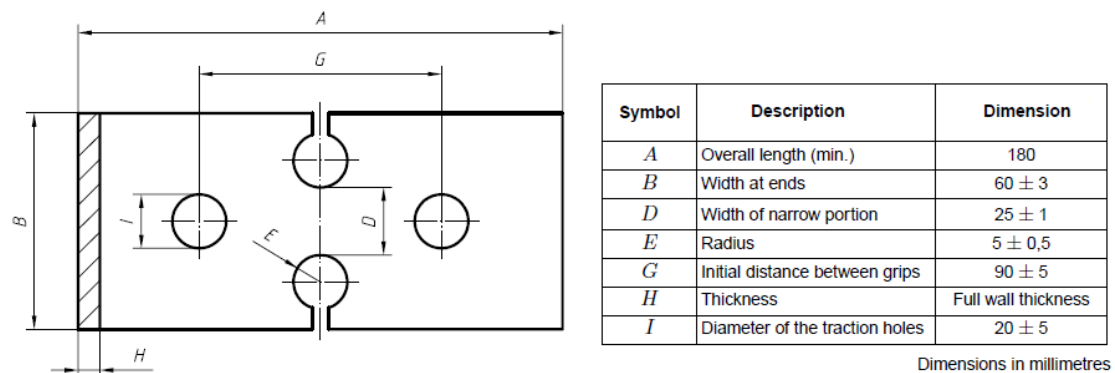


Figure 14. Machined tensile test piece for pipes with wall thickness less than 25mm (BS 13953:2001)

2.3.2.2 Tensile strength testing methods for compression joints

The UK Water Industry (1998) and British Standards (BS 712:1993) have similar testing methods for tensile strength testing of mechanical fittings. The main difference between the tests are the test duration and force applied to the test piece. The test piece shall consist of the compression joint fitting and one or more pieces of polyethylene pipe. Each piece of pipe should be at least 300mm in length (UK Water Industry 1998). In both tests apparatus is required capable of applying a constant force to the test piece, this may be in the form of a tensometer (BS 712:1993) or by means of applying weights (Figure 15).

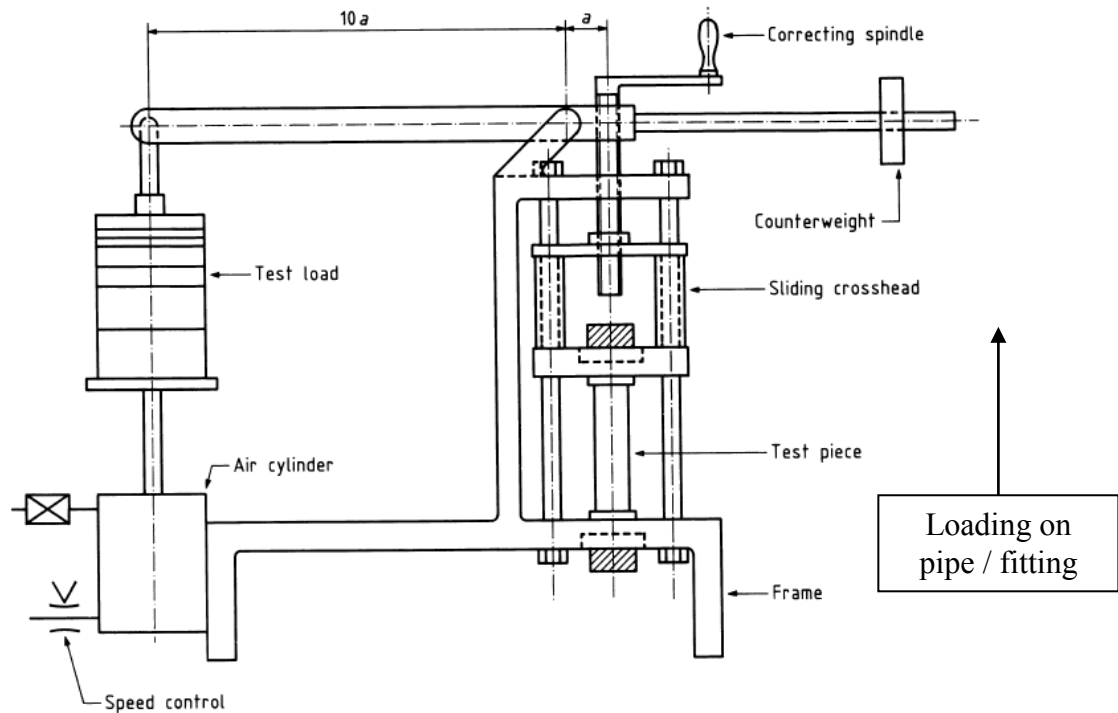


Figure 15. Diagram of apparatus for test for resistance to pull out of assembled joint (BS 712:1993)

The British Standard (BS 712:1993) procedure is to apply a force, F , to the test specimen gradually over 30seconds and then hold test piece in constant tension for a period of one hour. Force, F is calculated as;

$$F=1.5 \times \pi \times e_m \times \sigma_t \times (d_n - e_m)$$

Where

σ_t is the maximum permissible induced stress (Mpa)

d_n is the nominal outside diameter of the pipe(mm)

e_m is the pipe wall thickness (nominal outside diameter of pipe/SDR) (mm)

The UK Water Industry (1998) procedure is to apply test force gradually over a period of 15 to 30seconds. The test piece is then held in constant tension for a period of 5 minutes. The test force applied to the test piece is determined by the nominal outside diameter of the pipe (mm) (see table 4).

Table 4. Test forces for test under constant load (UK Water Industry 1998)

Nominal pipe size (mm)	20	25	32	50	63
Test force (kN)	1.9	2.5	4.1	9.8	15.6

On completion of the test, the test piece is removed and examined for pull out from the compression ring and/or fracture of the pipe (UK Water Industry 1998).

Finally, National Grid (Gas Industry 2006) has an alternative tensile strength test for compression joints in polyethylene pipes. A test piece is subjected to a tensile stress at a constant speed of $25\text{mm/min} \pm 10\text{mm/min}$ until the polyethylene pipe yields. The leak tightness of the test piece at 25mbar (air test) is verified before test and checked again after the pipe has yielded.

2.3.3 Bending strength

There is no requirement for manufacturers to test the bending strength of polyethylene pipes. However there is a recognised test for testing the internal pressure of a test piece consisting of a fitting and one length of pipe when subject to bending stresses (Figure 16) (UK Water Industry 1998).

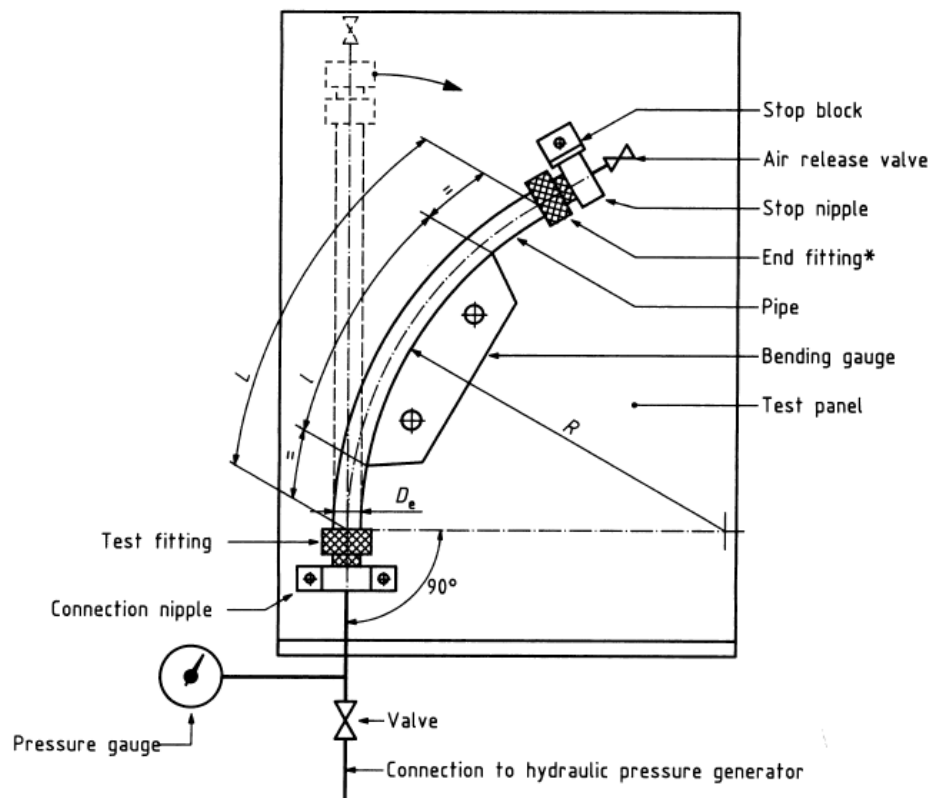


Figure 16. Diagram of apparatus for hydrostatic pressure test when subject to bending stresses (UK Water Industry 1998)

In this test, the test piece (25-63mm nominal outside diameter) is prepared with a maximum bend radius of 20 times nominal outside diameter and shall be subjected to a hydrostatic pressure test at 25bar test pressure (UK Water Industry 1998) for one hour. If the test piece does not fail the pressure shall be increased at a steady rate until failure occurs. The pipe should fail in a ductile manner (Figure 13) and before any leakage occurs on the fitting.

It is important to consider the safety consequences of failure of the test piece, therefore it is advisable for test pieces to be submerged in water or caged during testing.

2.3.4 Fatigue

Fatigue testing is undertaken to determine the working life of a polyethylene pipe system for quality control purposes (WRc 1986). Fatigue testing can be completed using hydrostatic pressure tests as described in section 2.3.1 at elevated temperatures (80°C) (Wavin 2001) for long test durations (5 000-1 0000 hours).

Notch sensitivity tests (Wavin 2001) may also be conducted to assess the fatigue of a polyethylene pipe. In a notch sensitivity test a test piece is notched to 20% of wall thickness at four points around circumference of pipe. The test piece is then subjected to a wall stress of 8bar (for PE80 polyethylene pipe) at 80°C for 170 hours. The purpose of this test is to record the stress crack resistance and ensure that crack growth does not occur within the required test life represented by the test duration (Wavin 2001).

2.4 Summary of Literature Review

This literature review should provide useful background information on polyethylene pipe systems, butt fusion and compression joints. It briefly examines the history, procedures, advantages and limitations of each pipe jointing method, and more relevantly jointing methods use in less economically developed countries.

This review also provides some background information on why pipes are tested and the different criteria by which a pipe can be tested. Finally, testing methods for each criteria are examined.

3 Methodology

To investigate the quality of manual butt fusion joints produced in polyethylene pipes. Manual butt fusion joints will be constructed and laboratory testing will be undertaken. From the information on pipe testing included in the literature review (section 2.3), the ability to withstand elevated hydrostatic pressures and testing the tensile strength of the manual butt fusion jointed test pieces have been chosen as the test parameters. For comparison purposes, the same tests will also be undertaken on test pieces joined using compression fittings.

Hydrostatic pressure testing was selected as a test parameter as it enables the mechanical integrity of the test piece to be checked and any leakage to be identified. Hydrostatic pressure testing is the most common test parameter used for water pipe systems during the manufacturing and installation stages. Because water is not readily compressible there is little stored energy in the pipework when pressurised and a failure of the pipe is not catastrophic, however if the test was pneumatic the air would be heavily compressed and therefore have greater stored energy and a greater potential risk of injury to any bystanders. Conducting hydrostatic pressure tests will determine the maximum pressures that the manual butt fusion joints in polyethylene pipes may withstand before failing. Tensile strength testing was selected as the second test parameter as it determines the resistance of two lengths of pipe being pulled apart and therefore assesses the strength of the joint. This test parameter is more appropriate than bending strength for polyethylene pipes to be used in Developing Countries, as manual butt fusion joints are commonly not located on long radius bends. This test parameter was also chosen because the equipment required to conduct the testing was readily available in the laboratory.

The author acknowledges the fact that fatigue testing would have enabled a better assessment of the working life performance of manual butt fusion joints, however, due to time constraints, he was unable to obtain the appropriate test pieces (weathered polyethylene pipe with manual butt fusion joints) to conduct standard hydrostatic pressure tests, and did not have the facilities to complete elevated temperature hydrostatic pressure tests for long time durations.

In total 12 test pieces will be required; 6 manual butt fusion jointed test pieces and 6 compression jointed test pieces. Hydrostatic pressure and tensile strength testing will be conducted on three of each type of jointed test piece picked randomly.

The remainder of this chapter will detail the preparation of test pieces for manual butt fusion jointed and compression jointed test pieces, the preparation of the testing equipment, and the hydrostatic pressure and tensile strength testing procedures. How the test results will be presented will also be explained.

3.1 Test piece preparation

The test pieces are to be constructed from 63mm nominal outside diameter, PE80 SDR11 gas pipe manufactured by Radius systems. The pipe has a rated pressure of 5.5bar. Gas pipe is to be used for the test pieces, as the author was able to obtain the pipe at no cost. Additionally, polyethylene pipes used in Developing Countries are predominately imported from Australia (Reed 2010), which produce different specifications of polyethylene water pipe to the UK, therefore reducing the ability to make direct comparison.

3.1.1 Manual butt fusion test piece

From the literature review it can be seen the equipment required for manual butt fusion in a developing country is minimal. In order to try and produce the most realistic jointing conditions, and before jointing could commence, the heating plate and Teflon coated sleeve had to be fabricated. An existing circular steel heating plate was obtained and cut down to a more suitable and compact design, see Figure 17. The Teflon coated paper sleeve had to be designed to fit sufficiently tightly over the heating plate while simultaneously being easy and quick to put on to minimise heat loss. The addition of a small holding tab on the top of the sleeve improved the ease of use of the Teflon coated paper sleeve (Figure 18). The Teflon coated paper sleeve was fabricated using aluminium pop rivets.

In Developing Countries the heat source for the heating plate would be a fire made with charcoal or good quality firewood (Jordan 1982). For the manual butt fusion procedure used here, the author has used a blowlamp for the heat source. The blowlamp was selected as the heat source as it was able to provide instantaneous heat

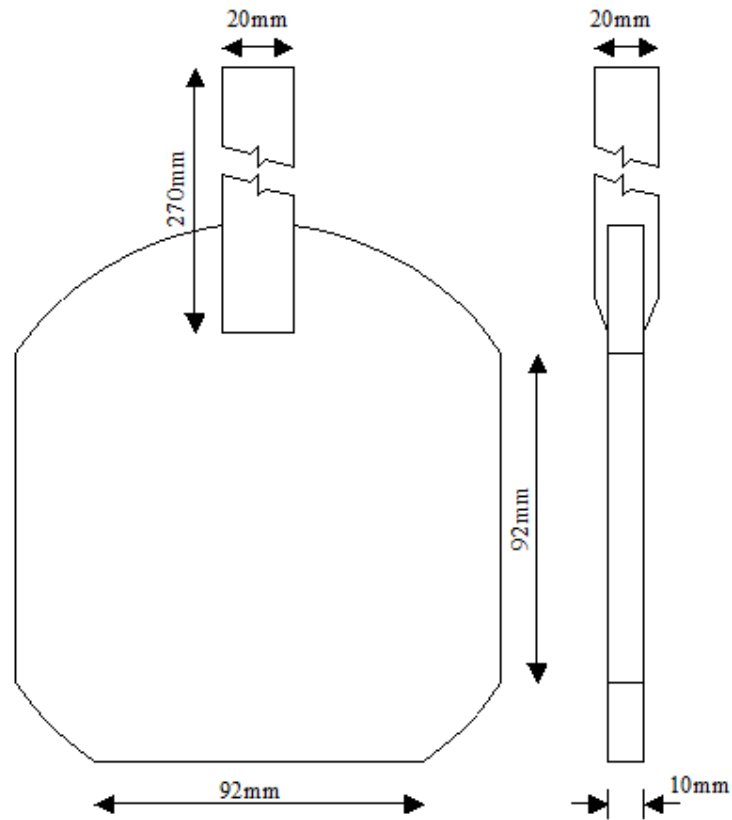


Figure 17. Design of heating plate

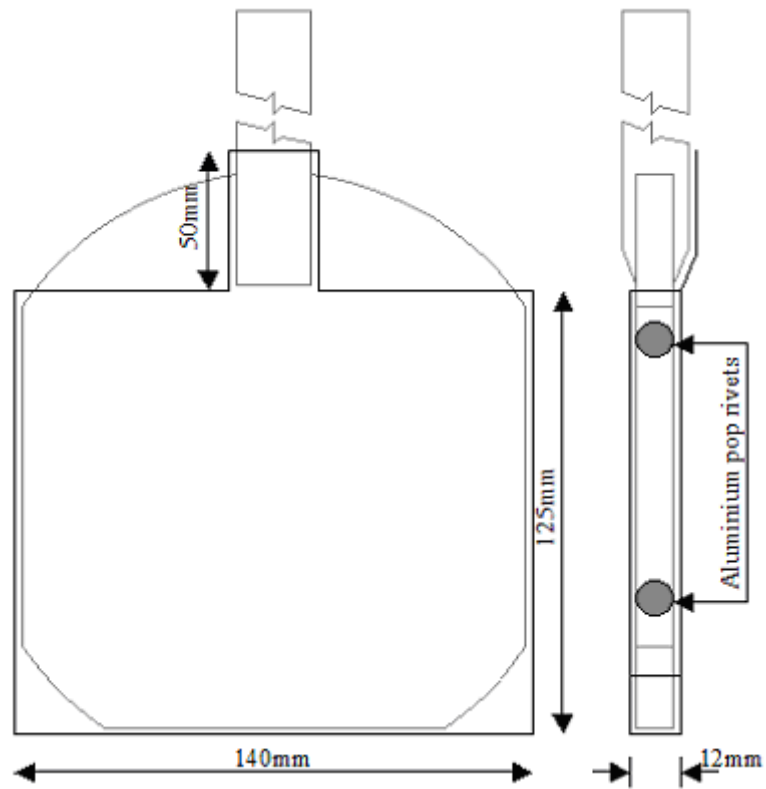


Figure 18. Design of Teflon coated paper sleeve

and enabled safer and instantaneous control of the heat source (on/off control). All operatives using the blowlamp were given training in its safe use by Michael Barker, Laboratory Technician, Loughborough University, and were issued heat resistant gloves as required by the risk assessment (Appendix A).

3.1.1.1 Manual butt fusion jointing equipment

The equipment required for the butt fusion jointing procedure is listed below and shown in Figure 19.

- | | | | |
|---|----------------------------|---|----------------------|
| A | Heat resistant gloves | F | Alignment clamp |
| B | Teflon coated paper sleeve | G | PE pipe cutter |
| C | Lighter | H | Thermo chrome crayon |
| D | Tape measure | I | Heating plate |
| E | Scraper and blades | J | Blow lamp |

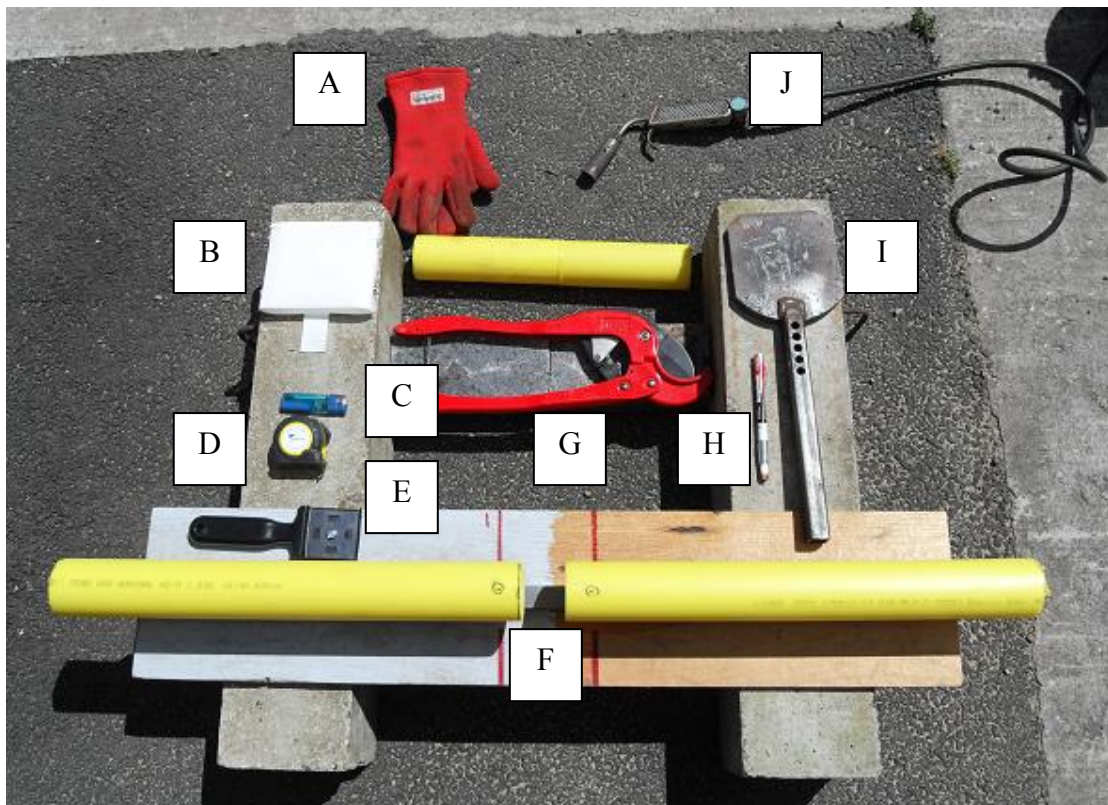


Figure 19. Equipment for manual butt fusion of polyethylene pipes

PE cutters (item G) were used to cut the polyethylene pipe instead of a hacksaw due to the fact that they gave a cleaner, straighter cut. An alignment clamp (item F) was utilised to minimise misalignment of pipe ends. In addition to the equipment shown

in Figure 19, all operatives wore suitable personal protective equipment (PPE) including safety boots and overalls.

3.1.1.2 Manual butt fusion test piece jointing procedure

The basic butt fusion procedure has already been detailed in the literature review (section 2.1.1). This basic procedure was used to complete the manual butt fusion joints. Additional notes regarding stages 1, 2 and 3 are included below.

Stage 1 and 2

The pipe ends were cut squarely using the PE cutters and trimmed using a hand scraper to ensure clean mating surfaces. Alignment of the pipe ends was checked using the alignment clamp. Once pipe ends were aligned, each pipe end was marked to aid alignment when joining the pipes during stage 3. Additionally the pipe was marked to ensure that the joint was made within the two red lines on the alignment clamp (Figure 20).



Figure 20. Alignment and marking of pipe ends

Stage 3

When using the blowlamp to heat the heating plate it is very important to heat all areas of the heating plate evenly otherwise there could be a localised cool spot. A thermo chrome crayon is used to ensure the heating plate is at the correct temperature

(220°C). The thermo chrome crayon used in the manual butt fusion procedure was manufactured by Tempil (Tempil 2010) and was rated at 246°C. When the heating plate is at the rated temperature the crayon mark will turn to a liquid smear. The higher rated temperature of the thermo chrome crayon allows for a drop in heating plate temperature between being heated by blowlamp, placed in the Teflon bag and being positioned between the two pipe ends. It is critical that when the blowlamp is not in use it is turned off and stored safely.

After the pipe ends have been pressed firmly and evenly against the heating plate and a molten bead of approximately 2mm has formed around the perimeter of the pipe (Figure 21), the applied pressure of pipe end against the heating plate should be reduced while maintaining contact. The following period is known as the heat soak time and ensures that the polyethylene pipe ends are not just heated at the ends but also heated through pipe. During the fabrication of the manual butt fusion test pieces, after examining the initial butt joints produced, the heat soak time was adjusted from 15 to 20 seconds.



Figure 21. Formation of molten plastic bead around perimeter of pipe

Following the heat soak time the heating plate should be carefully removed and the pipe ends pushed together. As stated in the literature review the time period between removal of heating plate and joining of pipe ends should be as short as possible (maximum 10 seconds) to prevent heat loss in the melted pipe ends. To limit possible

misalignment, when joining pipes one pipe end was secured in the alignment clamp with the other pipe end being brought towards and pressed firmly against the secured pipe end. Once pipe ends were joined the joint was allowed to cool in the alignment clamp until could be touched by hand.

Appendix B contains photographs showing each step of the manual butt fusion procedure.

Once the author was confident in performing the manual butt fusion joining procedure eight manual butt fusion joints were constructed with six chosen for testing. The first three had heat soak times of 15 seconds, and the remaining five had heat soak times of 20 seconds. The author selected six of the eight joints to be the manual butt fusion jointed test pieces, two with heat soak time of 15 seconds, and four with heat soak time 20 seconds.

In addition to the manual butt fusion jointing of the 63mm nominal outside diameter, PE80 SDR11 gas pipe for the test pieces, trial manual butt fusion joints on 32mm nominal outside diameter, PE80 SDR11 water pipe were also completed. Trial joints on 32mm pipe were completed to enable the author to experience the difficulties of attempting to join smaller diameter curved lengths of pipe. Photographs of the trial joints are included in Appendix B

The results of the manual butt fusion jointing will be presented in the form of a written account of the experiences of the procedure. Photographs of completed joints and bead examination will also be included.

3.1.2 Compression joint test piece

Compression joint test pieces were constructed to enable direct comparisons to be made between the manual butt fusion test pieces. The compression joints were procured from Pipestock.com and were 63mm MDPE couplings. The couplings have a rated pressure of 16bar.

3.1.2.1 Compression fitting jointing equipment

From the literature review (section 2.2.1) it can be seen that the only equipment required to joint the compression fittings are grips or a special wrench. The author investigated obtaining a universal strap wrench (special wrench) to tighten the compression nuts but decided to use large pairs of adjustable pipe wrenches, or Stilsons (24 and 36 inch), as they were readily available in the laboratory and more likely to be used in Developing Countries as they are a universally popular tool.

3.1.2.2 Compression joint test piece jointing procedure

The compression joint test piece jointing procedure was identical to the jointing procedure described in the literature review (section 2.2.1). The components were assembled in the correct sequence and the compression nut was tightened firstly by hand and then using the pairs of Stilsons (Figure 22). The jointing procedure states that the compression nut should be tightened until a maximum of one thread remains visible on the body. This was the standard first adopted by the author however the test pieces were found to be leaking at this tightness. To resolve the leakage problem the compression nuts were then retightened until no thread remained visible on the body.



Figure 22. Tightening of compression nut using pairs of Stilsons

During the construction of the compression joints the author was surprised at the difficulty he had tightening the compression nuts on to the body of the fitting. This difficulty would have been further amplified if jointing was carried out within an excavation, in a confined space in muddy conditions.

3.2 Testing procedure

All testing was conducted in the Civil Engineering Laboratory at Loughborough University. The tests took place at ambient temperature (23°C). The testing equipment used for both the hydrostatic pressure and tensile strength test was predominately equipment already in the laboratory. The lengths of test piece for hydrostatic pressure and tensile strength testing were 1000mm and 600/800mm respectively.

3.2.1 Hydrostatic pressure testing

3.2.1.1 Testing rig

The hydrostatic pressure testing rig had to be designed and constructed by the author before testing could commence. The design of the test rig had to include how the test piece would be pressurized, what end load resistant caps to use, how pressure was going to be recorded, and how to isolate the test piece from pump.

The most complex aspect of the design was the end load resistant caps. This is because the end load resistant caps were required to include an inlet at one end of the test piece for pressurizing water in test piece, and a valve in the opposite end of the test piece for filling the test piece with water and releasing the pressure after testing. Initial design proposals had electro fusion end caps permanently fused at each end of the test pieces. This would have required drilling and threading end caps and would have been a complex procedure as each test piece would have required its own individual end caps, increasing costs and test complexity. Additionally, electro fusion equipment would have to be sourced which would have increased the cost of testing. A simpler design solution was selected which used MDPE flange adaptors at each end of the test piece.

A systematic drawing and photograph of the hydrostatic pressure testing rig are shown in Figures 23 and 24. Each part of the testing rig is detailed after the photograph.

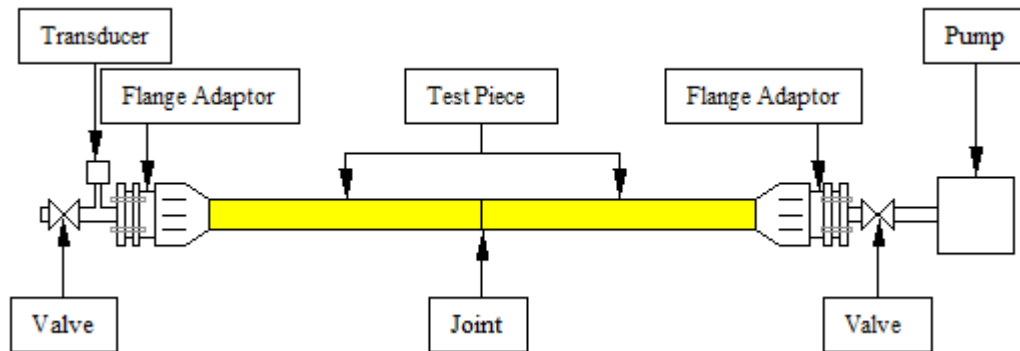


Figure 23. Systematic drawing of hydrostatic pressure testing rig



Figure 24. Hydrostatic pressure testing rig

Pump

Two different types of pump were used in the hydrostatic pressure tests to pressurize the water in the test piece. For the low pressure tests (up to 12bar) a simple pressure vessel was used to provide air to pressurize the water in the test pieces. A compressed air line was used to pressurize the water in the test piece. For the high pressure tests (18-25bar), an accumulator pump was used to provide air to pressurize the water in the test pieces. Again compressed air was used for the pressurization. The author was given training in the safe use of each pump by Michael Barker, Laboratory Technician, Loughborough University

Valve

Isolation valves were installed at each end of the test piece to enable the test piece to be isolated for the pressure decay test. The isolation valve could also be used to fill the test piece with water and ensure all air had been vented from the test piece prior to testing. The isolation valves were manufactured from aluminium and were supplied from the laboratory equipment store.

Flange Adaptor

MDPE flange adaptors were chosen for the end pieces of the test piece. The flange adaptors selected were 63mm x 2" MDPE flange adaptors procured from Pipestock. The flange adaptors have a rated pressure of 16bar. MDPE flange adaptors were selected because they could easily and quickly be connected to the different test pieces and, after testing, they can be removed and re-used. Blank flanges for the ends of the MDPE flange adaptors were constructed in the Laboratory by Michael Barker and bolted to the MDPE flange adaptor. To enable the testing equipment to be connected the blanks were drilled and tapped with $\frac{3}{4}$ " British Standard Pipe (BSP) threads. The prepared blanks were bolted to the flange adaptors using nitrile rubber gaskets to make the seal.

Transducer

A tee section was inserted into the testing rig between the isolation valves to enable a transducer to be installed. A transducer is a sensor that is able to detect pressure and convert it to an electrical current at a remote gauge. The transducer used for the testing was limited to 10bar pressure and therefore was only used for the pressure decay test. For the high pressure tests the transducer was removed to avoid damaging it and the tapping point was plugged.

The transducer was connected to a data logger capable of recording pressures 6 times a second (6Hz). For these tests the data logger was configured to record pressures every 10 seconds (0.1Hz). This frequency was deemed sufficient for the testing being undertaken.

The data logger computer programme enabled the results to be saved directly to a Microsoft excel spreadsheet. The programme also included a facility to display a

graph showing real time pressure recordings. Figure 25 shows a screen shot of the data logger computer programme

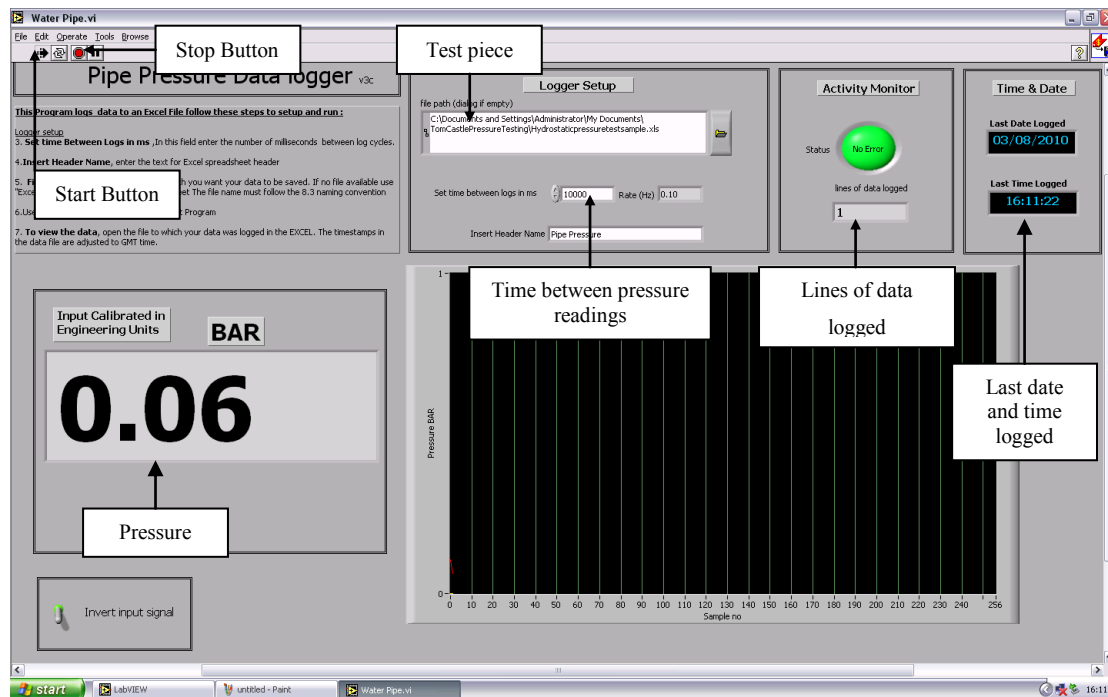


Figure 25. Data logger computer programme

3.2.1.2 Testing procedure

Each test piece underwent three individual hydrostatic pressure tests, a pressure decay test, a long duration constant pressure test, and a high pressure test (Manual butt fusion jointed test pieces only). The minimum time between the different tests on each test piece was five hours, this allowed time for the test piece to recover. The common practice was for pressure decay tests to be completed in the afternoon, and then the long duration constant pressure test would be completed the following morning for each test piece. After each test piece was filled with water and checked to ensure no air remained in the system, the test piece would be left for an hour to stabilize before commencing testing. The testing procedures were as follows:

Pressure decay test

The pressure decay test, also known as hydrostatic pressure test type 2 (WRC 1986) was undertaken as it is perhaps the simplest test to show the mechanical integrity of the test piece. The test pieces were constructed from gas pipe pressure rated at 5.5bar. Table 2 (see literature review) states that the recommended system test pressure for

polyethylene pipe with rated pressure up to 10bar, is 1.5 times the rated pressure. Therefore system test pressure for the test pieces was 8.25bar (5.5x1.5).

The application of pressure was completed at a constant rate until system test pressure, 8.25 ± 0.05 bar was achieved in pipe system. The test piece was then isolated and the pressure was allowed to decay in the test piece. The procedure in 2.3.1.2 in the literature review was then followed; taking pressure readings at predetermined multiples of t_l . The author undertook rough calculations during each test enabling him to predict any problems. Accurate values of N1 and N2 were determined using the information from the data logger computer programme following testing.

The results of the pressure decay test will be presented in the form of graphs and simple calculations. Observations and any problems experienced will also be included in the results. Full pressure reading results for each test piece will be included in Appendix C.

The main limitation of the pressure decay test is that any leakage on the mechanical fittings of the testing rig (MDPE flange adaptors) will affect the results obtained. Throughout testing all mechanical fittings were regularly inspected for leaks.

Long duration constant pressure test

The long duration constant pressure test consisted of maintaining a pressure of 2 times the rated pressure of the polyethylene pipe for 5 hours. Therefore, the test pressure for the long duration constant pressure test was 11bar (5.5x2). The test procedure adopted is similar to the hydrostatic pressure testing method for testing compression fittings (UK Water Industry 1998), but at lower pressures.

The application of pressure was completed at a constant rate until 11bar test pressure was reached. The pressurization was completed in 15-30 seconds for each test piece. The test piece remained connected to the pump throughout the test enabling the test pressure to be maintained. Throughout testing the pressure gauge was constantly monitored and all mechanical fittings were inspected for leaks.

The long duration constant pressure test is a pass/fail test. The results of the long duration pressure test will be descriptive stating if the test piece passed or failed the test. If the test piece failed the time and type of failure (joint failure/ductile failure of pipe/brittle failure of pipe) was recorded.

High pressure test

The high pressure test was designed to investigate the ultimate strength of the manual butt fusion joints. The test pieces had been constructed of gas pipe with a rated pressure of 5.5bar. Most water pipe systems are constructed of water pipe with a rated pressure of 10 or 12.5bar. Despite the first two hydrostatic pressure tests being completed at the correct system test pressures, the maximum pressure the joints had been exposed had not exceeded 11bar, approximately the same pressure as the rated pressures for water pipes. The high pressure test was designed to test the joints at a minimum of 1.5 times the rated pressure of 12.5bar water pipe (18bar) increasing to 25bar.

The application of pressure was completed at a constant rate until pressure in the test piece reached 18bar. The pressurisation was completed in 15-30 seconds for each test piece. Once 18bar test pressure had been reached the pressure was then increased at a slower rate to a maximum pressure of 25bar. The test piece was then subjected to a 45minute test at a constant pressure of 25bar.

The results of the high pressure test will be in the form of observation and comments. If the test piece failed the pressure, time and type of failure (joint failure/ductile failure of pipe/brittle failure of pipe) was recorded. Photographs of the point of failure on the test piece will also be included.

When completing all hydrostatic pressure tests the test pieces were covered in plastic sheeting (Figure 26). This was to protect the author and all observers from any failure of the test piece. Because of the short length of test piece and low volume of pressurized water this safety precaution was adequate and there was no need for the testing to be conducted within a cage. During testing the author and all observers were additionally required to wear safety glasses.



Figure 26. Plastic sheeting protection from testing rig

3.2.2 Tensile strength testing procedure

3.2.2.1 Testing rig

Tensile strength testing was carried out using the Instron tensile rig (Figure 27), located in the materials testing department of the Civil Engineering Laboratory, Loughborough University. The Instron tensile rig is capable of applying a load of 100KN on a test piece, and measuring elongation of test piece. The author was under constant supervision when using the Instron tensile rig by Michael Smeeton, Laboratory Technician, Loughborough University. The test piece end restraints had to be designed to withstand the pull out forces of the loading. Michael Smeeton fabricated two sets of wide clamps manufactured from aluminium, and two solid aluminium insert stiffeners.

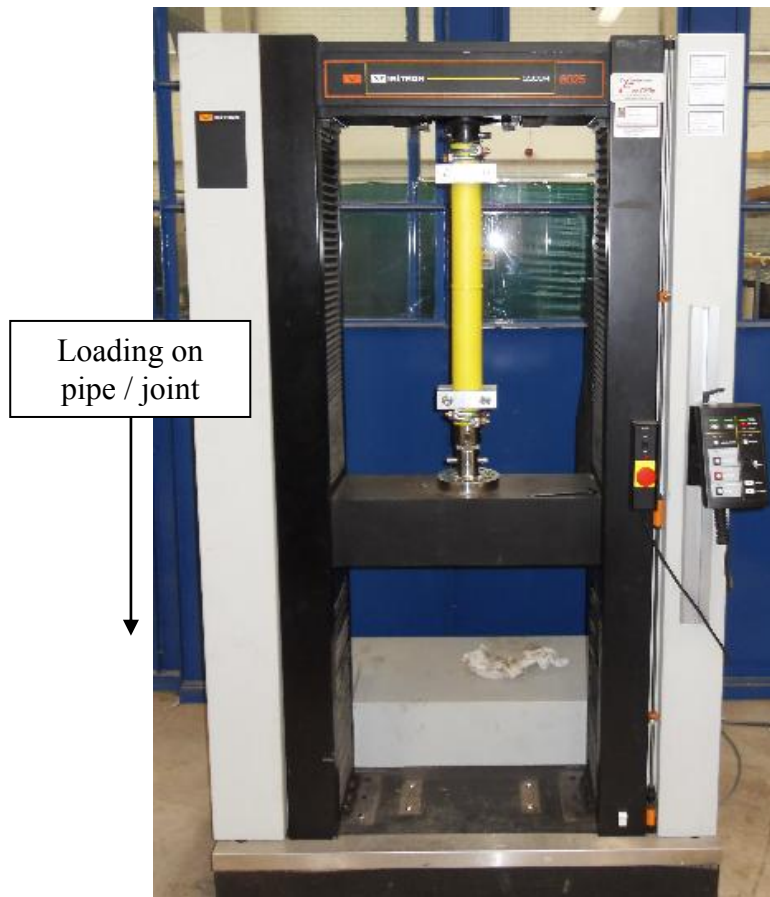


Figure 27. Instron tensile rig

When conducting trial tests, the wide clamps were unable to provide sufficient grip to the pipe and aluminium insert stiffener, resulting in the test piece being pulled out of the end restraint at 15KN (below the test force of 15.6KN). The aluminium insert stiffeners were then machined to have three deep grooves on the body enabling the stiffener body to grip into the pipe wall and the test was repeated however this did not resolve the problem. An alternative end restraint was designed using a secured MDPE flange adaptor at the base of the test piece, and both wide clamps at the top of the test piece and secured perpendicular to each other. This design was also unsuccessful.

The end restraint design solution was to procure 4no. 63mm exhaust pipe clamps from a local Ford Dealers and fit two pipe clamps at top and bottom of test piece. The clamps were fitted in opposite directions to provide a uniform grip. The wide clamps were then re-fitted at the top and bottom of the test piece (Figure 28). Finally, extra grooves were machined around the stiffener along the full length of the body to

provide additional purchase. This new end restraint design solution when tested was able to withstand forces up to 21KN.



Figure 28. End restraint design (two pipe clamps and wide clamp)

3.2.2.2 Testing procedure

Each test piece was to undergo the UK Water Industry (1998) tensile strength testing method for compression joints. This test was selected to enable a direct comparison to be made between the manual butt fusion and compression jointed test pieces. The free length of polyethylene pipe each side of the joint was 300mm. Because of the difference in size of joint (between butt – approx 5mm, and compression joint – approx 200mm), this made the total length of test pieces 600mm for manual butt fusion jointed test pieces and 800mm for compression jointed test pieces.

The test force, 15.6KN (see table 4) was applied to the test piece gradually over 30 seconds and then the test piece was held in tension for 5 minutes. The elongation of the test piece was recorded when the test force was reached and then every 30 seconds during the test.

The results of the tensile strength tests will be presented in the form of graphs, tables and simple calculations. Measurements of pull out from compression joints and pipe condition will also be stated. Observations, photographs and problems will also be included in the results where appropriate.

4 Results

Manual butt fusion jointed test piece construction, hydrostatic pressure testing and tensile strength testing was conducted between the 14th July and 4th August 2010.

4.1 *Manual butt fusion jointing results*

Manual butt fusion jointing commenced on 14th July 2010. All of the manual butt fusion jointing equipment was checked to be in good working condition and the jointing team received training in the use of the blowlamp before trial jointing of the 63mm nominal outside diameter, SDR11 PE80 gas pipe began.

Following a number of initial trial joints the jointing team developing a working relationship that enabled successful joints to be constructed. The jointing team consisted of the author and his brother, Alex Castle, Postgraduate student, Loughborough University. The pipe ends were cut square and loose material removed using a hand scraper. While one team member was heating the heating plate using the blowlamp, the second team member would be aligning and marking the pipe ends. When the heating plate was at the correct temperature (checked using the thermo chrome crayon) and the pipe ends were aligned and marked, the blowlamp was shut down and the heating plate was inserted into the Teflon coated paper sleeve and positioned vertically and perpendicular to the pipe ends in the centre of the alignment clamp. The first team member would hold the heating plate in the centre of the alignment clamp and the second team member pressed one pipe end firmly against the heating plate. The second team member then simultaneously held the heating plate while pressing one pipe end firmly against heating plate, as the first team member pressed the other pipe end firmly against the heating plate. When equal force was being exerted on both sides of the heating plate, it was left free standing while a uniform bead of molten plastic around the pipe perimeter and the heating plate formed. If the jointing team had consisted of three members then one member would have been solely responsibly for handling the heating plate.

The jointing team initially experienced difficulty in applying an equal grip around the pipe perimeter to provide an equal force on the heating plate. This would lead to a non-uniform bead forming around the pipe perimeter, with a very small bead forming

on the underside of the pipe. This problem was overcome by applying pressure on the pipe from the opposite open end of the pipe, while maintaining a downward force to keep the pipe in position in the alignment clamp.

After the formation of a bead approximately 2mm width around the whole perimeter of the pipe and following the heat soak time (15-20seconds) the pipe ends were pulled cleanly away from the heating plate and the heating plate was removed. During the trial stage both pipe ends were then pushed together to form the joint however this caused misalignment in most cases. For the production of the test pieces one pipe end was held securely and the team member who removed the heating plate then joined their pipe end to the secured pipe end (Figure 29). This reduced the possibility of human error and misalignment.

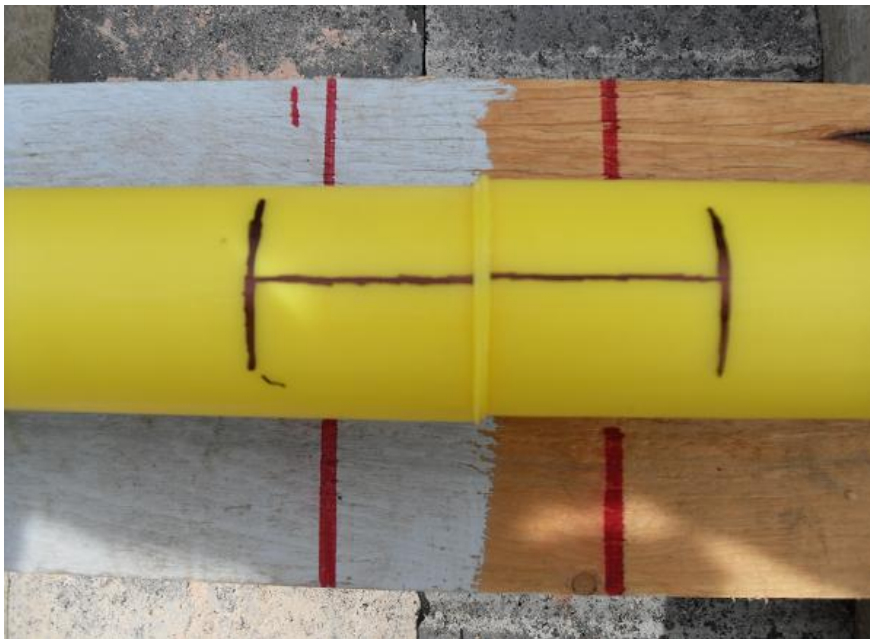


Figure 29. Completed manual butt fusion joint (hydrostatic pressure test piece 3)

The manual butt fusion test pieces were constructed on the 15th July 2010. The joints were visually inspected for any contamination, distortion in the bead, and bead size was measured around the perimeter of the pipe to check for uniformity (an indicator that pressures had been applied evenly). Before any joint was used for testing it was flexed vigorously by hand to ensure it did not fail under simple manipulation. No manual butt fusion joints constructed failed under simple manipulation.

The manual butt fusion joint of hydrostatic pressure test piece 1 was additionally examined by removing the outer bead from the pipe and carrying out a visual inspection on the bead for defects and any contamination at the joint face. A visual inspection of the bead can highlight any contamination, lack of fusion or slit defects of the joint, all indicators of poor fusion. The check is completed by bending the bead backwards on itself. No faults were found on the bead.

When conducting trial manual butt fusion jointing on 32mm nominal outside diameter SDR11 PE80 water pipe, not a formal part of this research, the jointing team encountered difficulties due to the curvature of the pipe. The jointing team attempted to straighten the pipes by flexing the pipe to ensure pipe ends were as straight as possible before joining. This enabled the alignment clamp to be used for the jointing procedure. The jointing team followed the same procedure as used for the larger diameter test pieces. The completed trial joints were slightly misaligned and the beads were not uniform compared to the large diameter test pieces. Photographs of the completed trial joints are included in Appendix B.

If the jointing team had been jointing two 50m coils of 32mm nominal outside diameter SDR11 PE80 water pipe together, then the jointing team would have initially connected a short straight length of pipe to the ends of the two coils to improve alignment and manageability.

4.2 Hydrostatic pressure testing

4.2.1 Pressure decay test

The results of the pressure decay test will be presented in the form of graphs and calculations to determine values of N1 and N2. For a sound pipe system with no leakage N1 and N2 should lie within the range 0.04 and 0.1. For full pressure reading results see Appendix C.

Test piece 1 – Manual butt fusion joint heat soak time 15 seconds

Test start 10:31:24 20/07/2010. System test pressure 8.25bar.

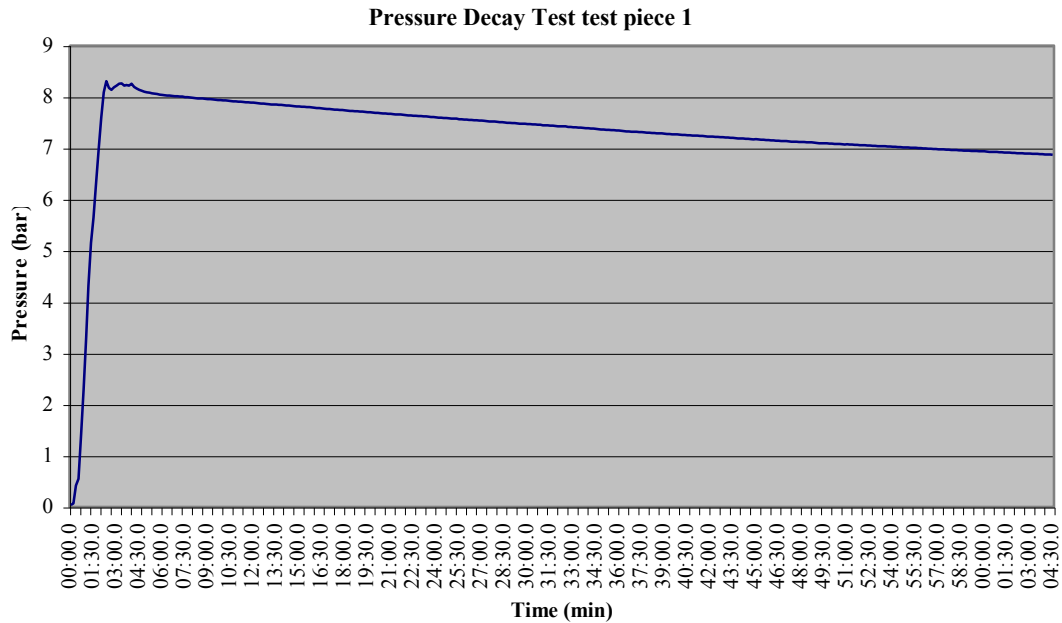


Figure 30. Graph showing pressure decay test – test piece 1

Table 5. Pressure and time readings for test piece 1

Time (min) ($t_l = 4\text{min}$)		Corrected Time (min) ($\text{Time} + 0.4t_l$)		Pressure (bar)	
time1 (t_l)	4	time1c	5.6	Pressure1	7.98
time2 ($7xt_l$)	28	time2c	29.6	Pressure2	7.43
time3 ($15xt_l$)	60	time3c	61.6	Pressure3	6.88

$$N1 = \frac{\log \text{Pressure1} - \log \text{Pressure2}}{\log \text{time2c} - \log \text{time1c}} = \frac{\log 7.98 - \log 7.43}{\log 29.6 - \log 5.6} = 0.0431$$

$$N2 = \frac{\log \text{Pressure2} - \log \text{Pressure3}}{\log \text{time3c} - \log \text{time2c}} = \frac{\log 7.43 - \log 6.88}{\log 61.6 - \log 29.6} = 0.1052$$

The value of N1 is ok and is within the allowable range. The value of N2 is just outside the allowable range and would suggest the system is leaking. Upon inspection

Results

of the test piece and mechanical fittings, a leak was discovered on one of the blank flanges (Figure 31). The testing equipment was removed and then refitted applying polytetrafluoroethylene (PTFE) tape around the thread to ensure a seal, and testing was continued.

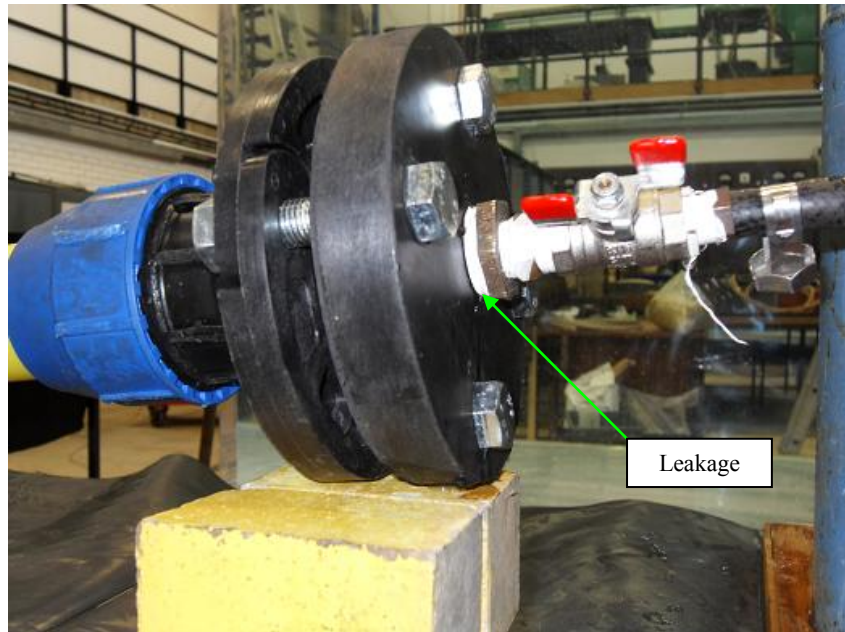


Figure 31. Leaking mechanical fitting

Test piece 2 – Manual butt fusion joint heat soak time 20 seconds

Test start 10:40:04 24/07/2010. System test pressure 8.29bar.

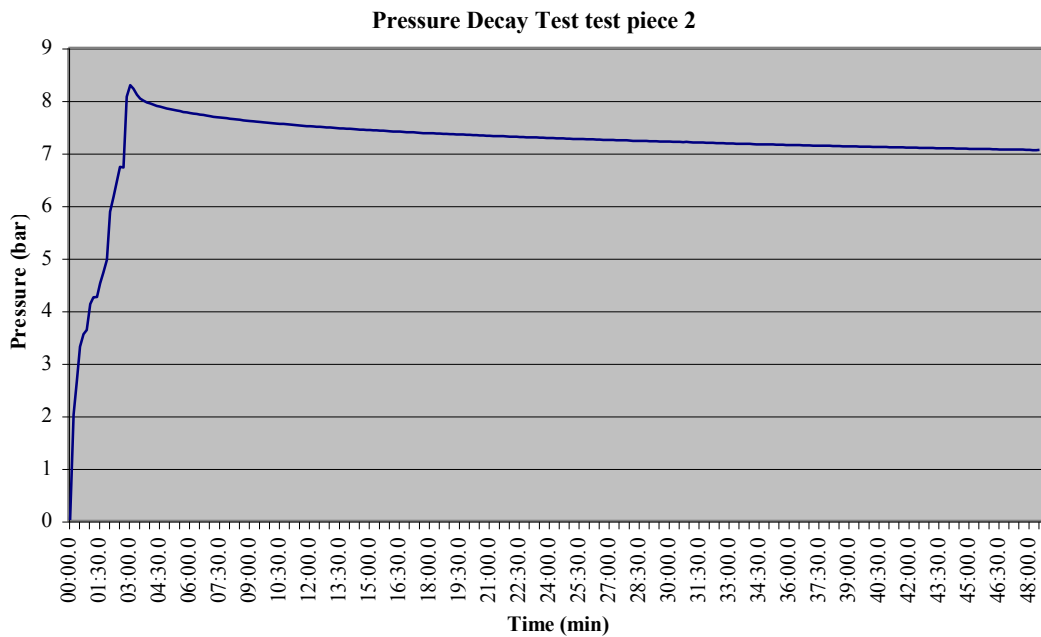


Figure 32. Graph showing pressure decay test – test piece 2

Table 6. Pressure and time readings for test piece 2

Time (min) ($t_l = 3\text{min}$)		Corrected Time (min) ($\text{Time} + 0.4t_l$)		Pressure (bar)	
time1 (t_l)	3	time1c	4.2	Pressure1	7.76
time2 ($7xt_l$)	21	time2c	22.2	Pressure2	7.29
time3 ($15xt_l$)	45	time3c	46.2	Pressure3	7.06

$$N1 = \frac{\log \text{Pressure1} - \log \text{Pressure2}}{\log \text{time2c} - \log \text{time1c}} = \frac{\log 7.76 - \log 7.29}{\log 22.2 - \log 4.2} = 0.0381$$

$$N2 = \frac{\log \text{Pressure2} - \log \text{Pressure3}}{\log \text{time3c} - \log \text{time2c}} = \frac{\log 7.29 - \log 7.06}{\log 46.2 - \log 22.2} = 0.0425$$

The value of N1 is outside the allowable range and would suggest that there is probably air in the system. The value of N2 is ok and within the allowable range.

Test piece 3 – Manual butt fusion joint heat soak time 20 seconds

Test start 14:41:05 22/07/2010. System test pressure 8.28bar.

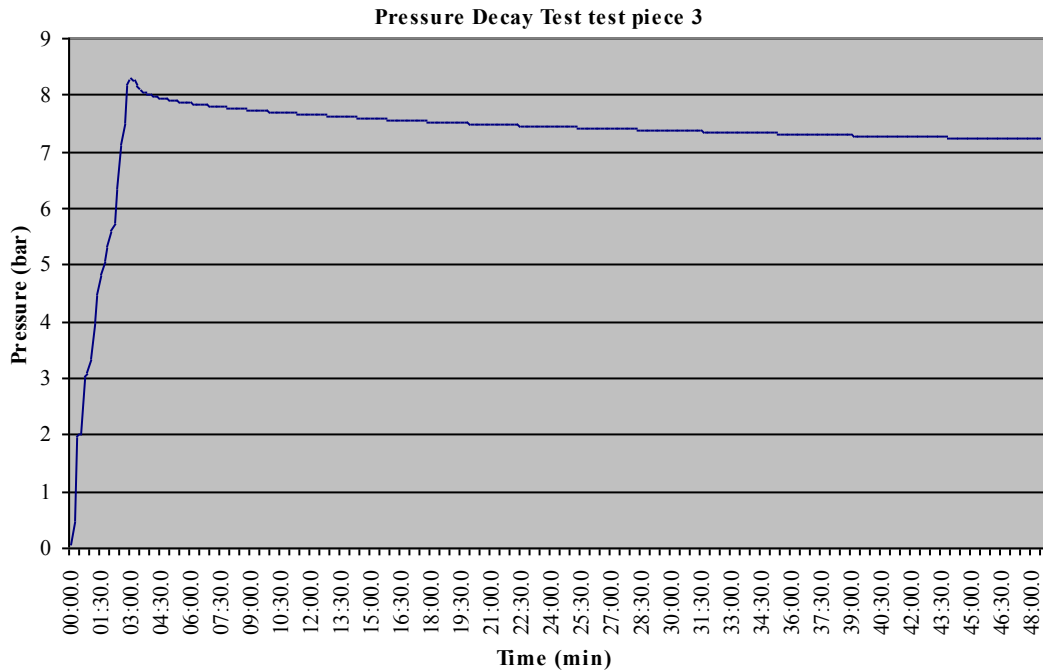


Figure 33. Graph showing pressure decay test – test piece 3

Table 7. Pressure and time readings for test piece 3

Time (min) (t/ =3min)		Corrected Time (min) (Time + 0.4t/)		Pressure (bar)	
time1 (t/)	3	time1c	4.2	Pressure1	7.86
time2 (7xt/)	21	time2c	22.2	Pressure2	7.44
time3 (15xt/)	45	time3c	46.2	Pressure3	7.22

$$N1 = \frac{\log \text{Pressure1} - \log \text{Pressure2}}{\log \text{time2c} - \log \text{time1c}} = \frac{\log 7.86 - \log 7.44}{\log 22.2 - \log 4.2} = 0.0328$$

$$N2 = \frac{\log \text{Pressure2} - \log \text{Pressure3}}{\log \text{time3c} - \log \text{time2c}} = \frac{\log 7.44 - \log 7.22}{\log 46.2 - \log 22.2} = 0.0408$$

The value of N1 is outside the allowable range and would suggest that there is probably air in the system. The value of N2 is ok as it is just within the allowable range (0.04).

Test piece 4 – Compression joint

Test start 16:00:53 23/07/2010. System test pressure 8.29bar.

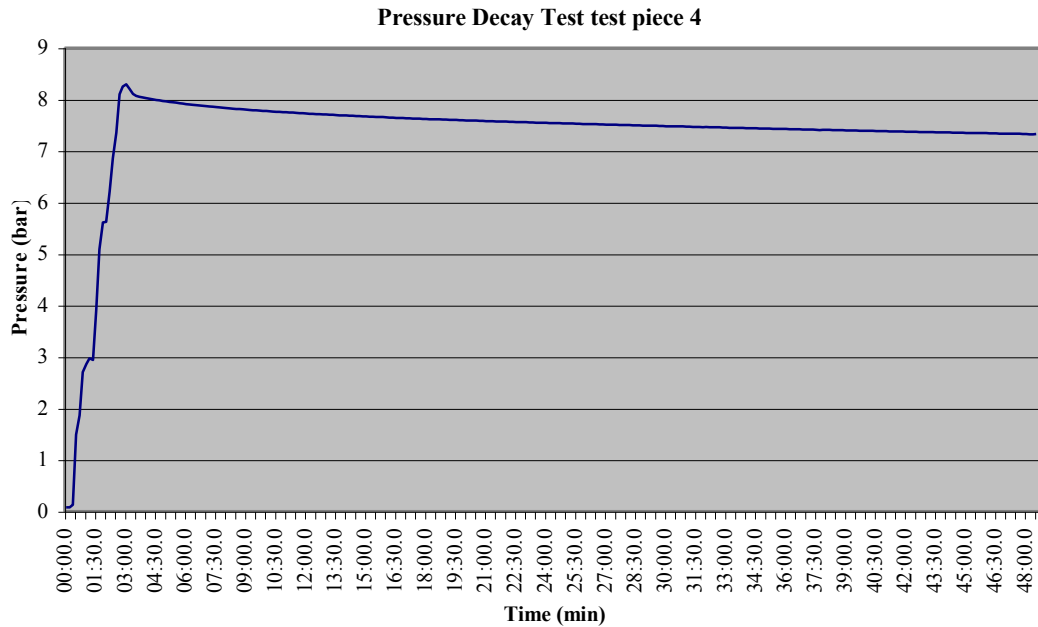


Figure 34. Graph showing pressure decay test – test piece 4

Table 8. Pressure and time readings for test piece 4

Time (min) ($t_l=3\text{min}$)		Corrected Time (min) ($\text{Time} + 0.4t_l$)		Pressure (bar)	
time1 (t_l)	3	time1c	4.2	Pressure1	7.91
time2 ($7xt_l$)	21	time2c	22.2	Pressure2	7.54
time3 ($15xt_l$)	45	time3c	46.2	Pressure3	7.33

$$N1 = \frac{\log \text{Pressure1} - \log \text{Pressure2}}{\log \text{time2c} - \log \text{time1c}} = \frac{\log 7.91 - \log 7.54}{\log 22.2 - \log 4.2} = 0.0283$$

$$N2 = \frac{\log \text{Pressure2} - \log \text{Pressure3}}{\log \text{time3c} - \log \text{time2c}} = \frac{\log 7.54 - \log 7.33}{\log 46.2 - \log 22.2} = 0.0400$$

The value of N1 is outside the allowable range and would suggest that there is probably air in the system. The value of N2 is ok as it is limit of the allowable range.

Test piece 5 – Compression joint

Test start 14:34:22 27/07/2010. System test pressure 8.29bar.

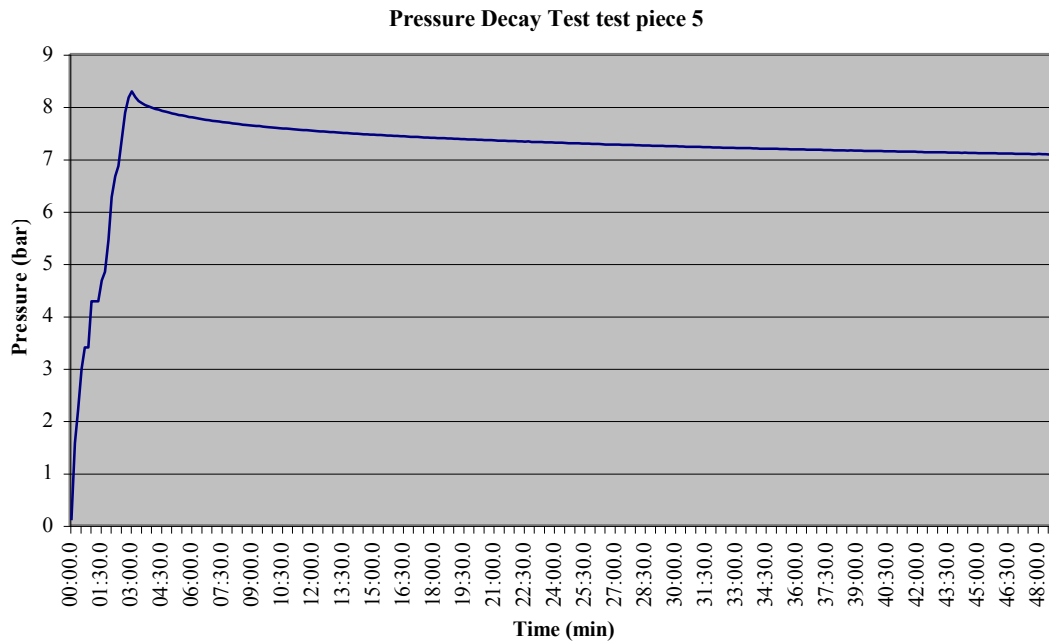


Figure 35. Graph showing pressure decay test – test piece 5

Table 9. Pressure and time readings for test piece 5

Time (min) ($tl=3min$)		Corrected Time (min) ($Time + 0.4tl$)		Pressure (bar)	
time1 (tl)	3	time1c	4.2	Pressure1	7.79
time2 ($7xtl$)	21	time2c	22.2	Pressure2	7.31
time3 ($15xtl$)	45	time3c	46.2	Pressure3	7.09

$$N1 = \frac{\log \text{Pressure1} - \log \text{Pressure2}}{\log \text{time2c} - \log \text{time1c}} = \frac{\log 7.79 - \log 7.31}{\log 22.2 - \log 4.2} = 0.0383$$

$$N2 = \frac{\log \text{Pressure2} - \log \text{Pressure3}}{\log \text{time3c} - \log \text{time2c}} = \frac{\log 7.31 - \log 7.09}{\log 46.2 - \log 22.2} = 0.0409$$

The value of N1 is outside the allowable range and would suggest that there is probably air in the system. The value of N2 is ok as it is just within the allowable range (0.04).

Test piece 6 – Compression joint

Test start 12:22:40 28/07/2010. System test pressure 8.28bar.

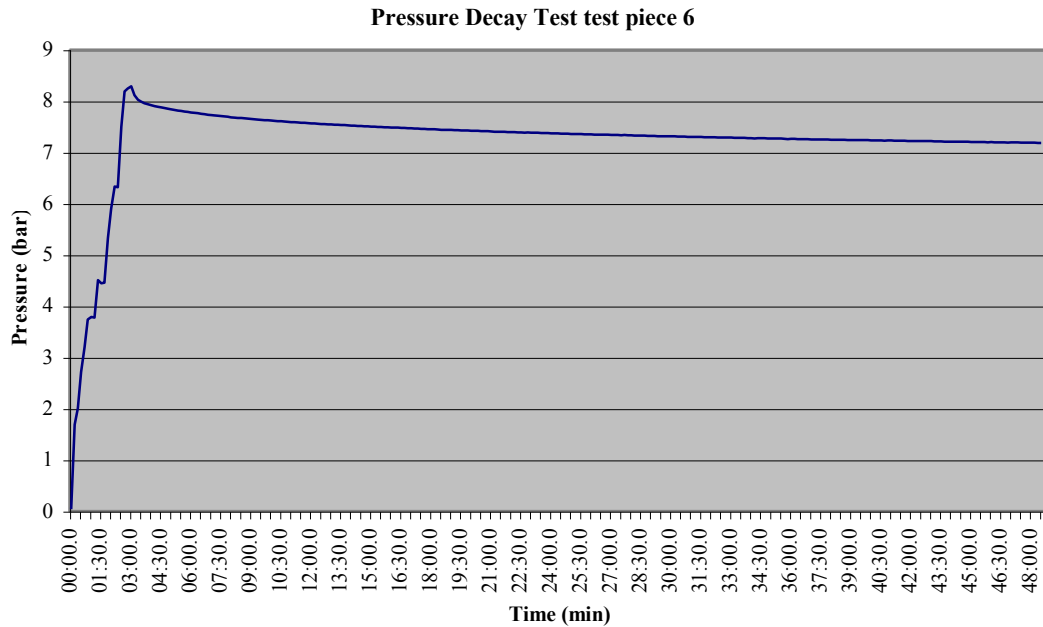


Figure 36. Graph showing pressure decay test – test piece 6

Table 10. Pressure and time readings for test piece 6

Time (min) ($t_l=3\text{min}$)		Corrected Time (min) ($\text{Time} + 0.4t_l$)		Pressure (bar)	
time1 (t_l)	3	time1c	4.2	Pressure1	7.78
time2 ($7xt_l$)	21	time2c	22.2	Pressure2	7.37
time3 ($15xt_l$)	45	time3c	46.2	Pressure3	7.19

$$N1 = \frac{\log \text{Pressure1} - \log \text{Pressure2}}{\log \text{time2c} - \log \text{time1c}} = \frac{\log 7.78 - \log 7.37}{\log 22.2 - \log 4.2} = 0.0321$$

$$N2 = \frac{\log \text{Pressure2} - \log \text{Pressure3}}{\log \text{time3c} - \log \text{time2c}} = \frac{\log 7.37 - \log 7.19}{\log 46.2 - \log 22.2} = 0.0346$$

The values of N1 and N2 are both significantly lower than the lower limit of the allowable range (0.04). This would suggest that there was air remaining in the system.

Summary

From the pressure decay test results it can be seen that in most test pieces there may have been a small volume of air in the system affecting the results leading to low values of N1 and N2 (<0.04). A second factor impacting these results was that the loading profile was not uniform and constant for each test. Due to the speed of the pump and the manual adjustments on pressure it can be seen that there are steps in pressure level in each graph. The only time the results indicated a leak was in test 1, where a leak in the mechanical fitting was subsequently found and repaired.

4.2.2 Long duration constant pressure test

All of the manual butt fusion jointed test pieces and compression jointed test pieces passed the long duration constant pressure test. No failures occurred at anytime in the testing. The test pieces were connected to the pump at all times allowing a constant pressure to be maintained.

4.2.3 High pressure test

Only the manual butt fusion jointed test pieces were subjected to the high pressure test. Despite the use of manual butt fusion in developing countries, the ultimate strength of manual butt fusion joints is unknown. The hydrostatic pressure test was completed with the aim of obtaining the ultimate strength of the manual butt fusion joint. 25bar was selected as the maximum test pressure as it was the upper limit on the incubator pump, and significantly higher than the 18 bar test pressure for water pipes.

High pressure testing was undertaken on the 29th and 30th July 2010. All three manual butt fusion jointed test pieces successfully passed the high pressure test sustaining a constant pressure of 25bar for 45minutes, a pressure 4.5 times greater than the rated pressure of the 63mm nominal outside diameter SDR11 PE80 gas pipe, and 2.5 times the rated pressure of 63mm nominal outside diameter SDR11 PE80 water pipe (10bar). Unfortunately hydrostatic pressure testing could not continue above 25bar due to the limitations of incubator pump and as such the ultimate strength of the manual butt fusion joints could not be obtained.

4.3 Tensile strength testing

Tensile strength testing was successfully undertaken on the 4th August 2010. The elongation of each test piece was recorded manually every 30 seconds during the 5 minute test. Tables 11 and 12 show the elongation of each test piece and the pull out of pipe from compression joint (test pieces 4-6). The elongation results of all test pieces are also presented a graph in Figure 37.

Table 11. Elongation results of tensile strength testing

Time (min)	Elongation (mm)					
	Test piece 1 Manual Butt	Test piece 2 Manual Butt	Test piece 3 Manual Butt	Test piece 4 Compression	Test piece 5 Compression	Test piece 6 Compression
0.00	21.43	22.36	24.83	58.97	32.37	34.77
0.30	29.54	28.85	31.13	62.2	41.48	43.83
1.00	32.48	33.15	34.07	64.58	44.91	46.24
1.30	34.73	35.5	36.15	66.02	48.56	50.04
2.00	36.15	37.47	37.57	68.98	50.3	52.65
2.30	37.89	38.91	39.33	71.27	53.01	55.24
3.00	39.03	40.73	40.48	74.04	55.02	56.6
3.30	40.09	41.92	41.87	75.44	56.88	57.99
4.00	41.15	43.34	43.07	77.16	58.99	60.18
4.30	42.38	44.41	44.3	78.67	62.1	62.7
5.00	43.23	45.47	45.69	80.27	62.57	65.62

Table 12. Pull out of pipe from compression joint

	Test piece 4 Compression	Test piece 5 Compression	Test piece 6 Compression
Pull-out at top of compression joint (mm)	18	6	7
Pull-out at bottom of compression joint (mm)	18	5	6

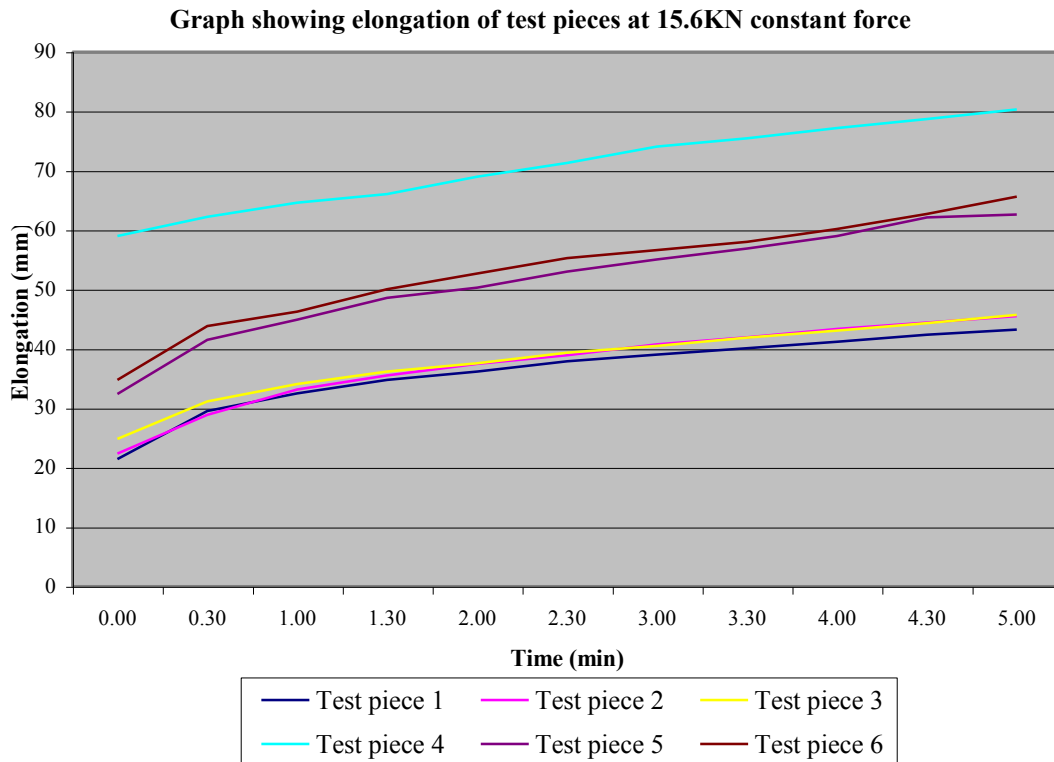


Figure 37. Graph showing elongation of test pieces at 15.6kN constant force

From Figure 37 it can clearly be seen that the manual butt fusion jointed test pieces (1-3) performed in a uniform manner during the tensile strength tests. The range of variation in elongation after 5 minutes between the manual butt fusion jointed test pieces is only 2.46mm. During the tensile tests it was possible for the author to see the manual butt fusion jointed test pieces necking around the joints. From Figure 37 it can also be seen that the compression jointed test pieces (4-6) also had similar performance. The major difference between the elongation of the compression jointed test pieces was the amount of pipe pull out from the compression joint. The results suggest that test piece 4 may not have been sufficiently tightened.

5 Analysis and Discussion

This chapter will analyse and discuss the results of the preparation and testing of the manual butt fusion and compression jointed test pieces. A detailed comparison of manual butt fusion and compression jointing methods will also be completed addressing all relevant SHTEFIE (Socio-cultural, Health/Hygiene, Technical, Economical, Financial, Institutional, and Environmental) aspects.

5.1 Analysis of test piece preparation

The construction of the manual butt fusion and compression jointed test pieces was successfully completed over a period of three days. After one day of familiarisation with the manual butt fusion jointing equipment and procedure the jointing team, who had no previous experience of jointing pipes in this way, felt competent in the manual butt fusion process. The procedure followed was based on the existing procedures in place for automatic butt fusion machines in the UK adapted by the author for manual butt fusion.

Because of the short lengths of polyethylene pipe being joined together (500mm) and the more rigid characteristics of the larger (63mm) nominal outside diameter pipe, the alignment clamp could be used to assist the joining process. Smaller nominal outside diameter pipe, such as the 32mm nominal outside diameter, SDR11 PE80 water pipe which was also trial jointed, is delivered in 50m coils and can be more difficult to straighten which is necessary when using the existing alignment clamp.

From the manual butt fusion jointing experience the author believes that the most important factors for a successful joint are; cleanliness of the process, ensuring that the pipe ends are cut squarely, and applying a uniform grip around pipe to ensure uniform pressure around perimeter of pipe end against heating plate. When the pipes were cut squarely alignment problems were significantly reduced. Preparation of the pipe ends was the most time consuming element of the manual butt fusion procedure but necessary to ensure a good quality joint.

The alignment clamp being used for the manual butt fusion procedure was a simple steel angle section (from a proprietary racking system) attached to a plank of wood to

provide stability. The design principle of the steel angle is that the alignment clamp can be used for wide ranges of pipe diameters (20-63mm). The jointing team had difficulties applying an equal grip around the perimeter of the pipe when pressing the pipe ends against heating plate. This problem could be overcome with a slight re-design if 150mm sections of angle were cut out of each side of alignment clamp. For larger lengths of pipe being joined this would not be a problem as jointing team would be able to get strong grip around perimeter of pipe outside of alignment clamp.

When joining larger lengths of polyethylene pipe, potentially 50/100m coils, a larger jointing team will be required. Following discussions with Bob Reed, Lecturer, Loughborough University, extra manpower is not an issue in developing countries as communities are willing to help improve/repair water supply systems. When using a larger jointing team communication will be essential to avoid human error and pipe misalignment. The author would recommend that the team member handling the heating plate be in charge of the joining operation. The alignment clamp should also be adapted to enable the polyethylene pipe to be secured in the clamp, possibly by the use of straps.

The author is aware that the test pieces were manually butt fused together above ground in a clean working environment. In developing countries this may not be possible and care should be taken to ensure the pipe ends remain uncontaminated during the joining procedure. If manual butt fusion jointing is to be completed to repair existing polyethylene water pipes sufficient excavation will be required to enable movement of the existing pipes. When new polyethylene water pipes are laid in a trench, they are snaked along the trench to provide flexibility and movement in pipe if repairs are required. The author is unaware of the flow stop procedures and equipment used in developing countries which would have to be considered for the use of manual butt fusion jointing pipe ends must be dry with no flow permitted while the repairs are taking place.

By the time the last manual butt fusion jointed test piece was completed, the jointing team were able to complete the jointing procedure in under 10 minutes, not including the cooling period. The jointing team visually inspected the completed manual butt fusion jointed test pieces and no obvious contamination or faults could be seen.

The compression jointed test pieces were constructed in one day. The compression nuts were tightened using two pairs of adjustable pipe wrenches (Stilsons). Whilst not ideal, Stilsons were selected over a special strap wrench as they are a universally popular tool and more likely to be used and available in developing countries. The compression nut on the compression fitting is manufactured from plastic. When using the Stilsons the exterior of the compression nut was damaged. The author has already expressed his surprise at the difficulty he had tightening the compression nut to the body of the fitting, the jointing procedure may have been easier using the special strap wrench, as is designed specifically for tightening plastic fittings.

The use of compression joints on longer lengths of pipe requires no additional operatives. A two man jointing team would be adequate. The compression jointed test pieces were constructed above ground in a clean working environment. If the jointing procedure is to take place within an excavation then sufficient space would be required around the joint to enable tightening of the compression nut.

5.2 Analysis of hydrostatic pressure testing

All of the test pieces successfully passed the hydrostatic pressure tests. From the pressure decay test results it can be seen that in all cases there appears to have been a small amount of air in the system affecting the results. Because air is compressible it will act to maintain pressure with time distorting pressure readings. In pressure decay test 1 the value of N2 was greater than 0.1 suggesting the system was probably leaking. A leak was found and repaired on one of the flange adaptors (Figure 31). At no time during the pressure decay tests were any of the manual butt fusion joints and compression joints found leaking.

The pressure should be applied at a constant rate during the pressure decay test. Some difficulty was experienced by the author in applying the pressure at a constant rate due to the small length/volume of test piece and poor sensitivity of pressure valve. The pressure decay test is commonly used to test larger diameter, longer length polyethylene water mains in the UK.

Following testing the author believes that the testing rig could have been improved by installing filling points and an air bleed at a higher level than the test piece. Figure 38

shows a systematic drawing of a revised testing rig. By having the filling point and air bleed valve above the test piece, when the system is filled, and water is coming out of air bleed valve, the water should displace all air from the test piece. Connection of high level filling point and air bleed valve would be best achieved using electro fusion top tees heat fused to the test piece. The mechanical fittings could also be adapted by inserting a t-section to at each end, setting the pipe in a vertical position and filling the pipe from the bottom before laying down for testing.

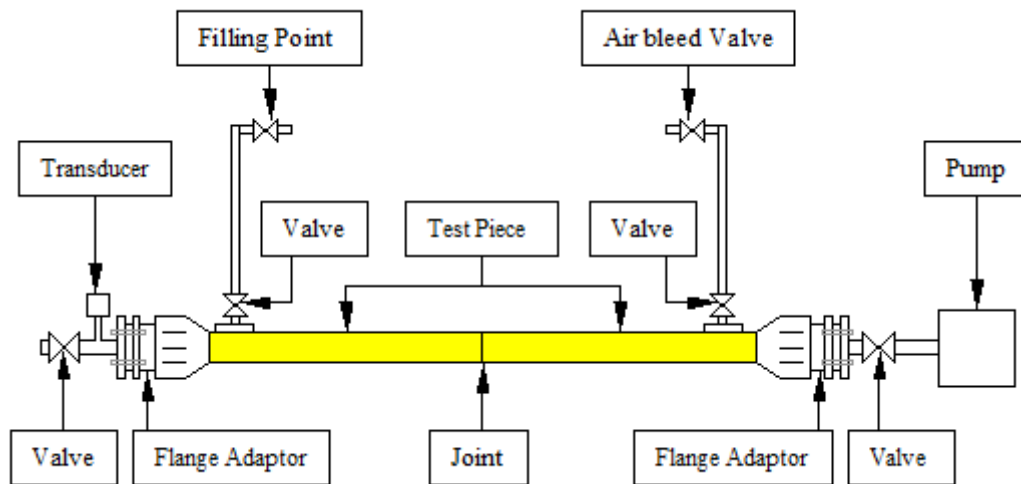


Figure 38. Revised systematic drawing of hydrostatic pressure testing rig

The second hydrostatic pressure test conducted was the long duration constant pressure test, each test piece was subjected to a constant pressure of 11bar for 5 hours. From the results it can be seen that all test pieces successfully passed this test. When reviewing this test it can be seen that despite pressurizing the test piece to double the rated pressure of the polyethylene pipe (5.5bar) the pipe and test joint was easily able to withstand the pressure. Additionally, because the pipe tested was gas pipe, the test pressure for the long duration constant pressure test was within the rated operating pressures of the equivalent SDR11 PE80 water pipe (10bar/12.5bar). As a result of this finding an additional high pressure test was designed and implemented for the manual butt fusion jointed test pieces.

The high pressure test tested the manual butt fusion jointed test pieces at pressures over 18bar. The high pressure test was only conducted on the manual butt fusion jointed test pieces as the ultimate strength of the manual butt fusion joints was

currently unknown and the manual butt fusion joints are the focus of the research project. The manual butt fusion jointed test pieces all successfully passed the high pressure test, sustaining a maximum of 25bar for 45 minutes. The ultimate strength of the manual butt fusion joint i.e. the failure pressure could not be established due to the constraints of the testing equipment (delivering a maximum pressure from incubator pump of 25bar).

Having obtained the results of the long duration constant pressure test and high pressure test, the author would have liked to merge the two tests enabling all test pieces (manual butt fusion and compression jointed) to have been subjected to the higher pressure for a longer duration (5-10 hours). This was not possible due to time constraints.

Test pieces had to be prepared for pressure testing by attaching the flange adaptors, consisting of a compression fitting similar to the compression joints to connect the polyethylene pipe. The jointing procedure for joining the flange adaptors to the test piece was the same as the procedure described in section 2.2.1. However, because the compression nuts on the flange adaptors were being repeatedly tightened and loosened, the exterior of the compression nuts became badly damaged causing considerable difficulty in gripping the nut when tightening. Replacement flange adaptors had to be obtained for the high pressure tests as the flange adaptors initially used had become damaged beyond safe use.

It was noted that when the high pressure tests were carried out the flange adaptors would begin to leak once the test pressure in the system was above 21bar. The flange adaptors had a rated pressure of 16bar.

5.3 Analysis of tensile strength testing

All of the test pieces successfully passed the tensile strength test, sustaining a constant force of 15.6KN for 5 minutes. From Figure 37 (elongation graph) it can be seen that the manual butt fusion jointed test pieces performed more favourably during the tensile strength test recording lower elongation results. During the testing the manual butt fusion jointed test pieces could be seen necking (Figure 39), stretching / narrowing at the joint, due to the visco-elastic behaviour of the polyethylene pipe.

The manual butt fusion joint performed in a homogenous manner. At no stage during the tensile strength test were the manual butt fusion joints affected by the force applied. When the force was removed from the test piece, the test piece returned to its original length.



Figure 39. Manual butt fusion jointed test piece necking during tensile strength test

From the elongation results and visual observation of the testing (Figure 40) of the compression jointed test pieces it would appear that the compression joint was not sufficiently tightened on test piece 4. The pull out recorded above and below compression fitting for test piece 4 is considerably higher than the pull out recorded for the other compression jointed test pieces. The affects of this additional pull out can clearly be seen in Figure 37. When the force was removed from the test pieces there were some misalignment when the free polyethylene pipe was pushed back inside the compression joint fitting.

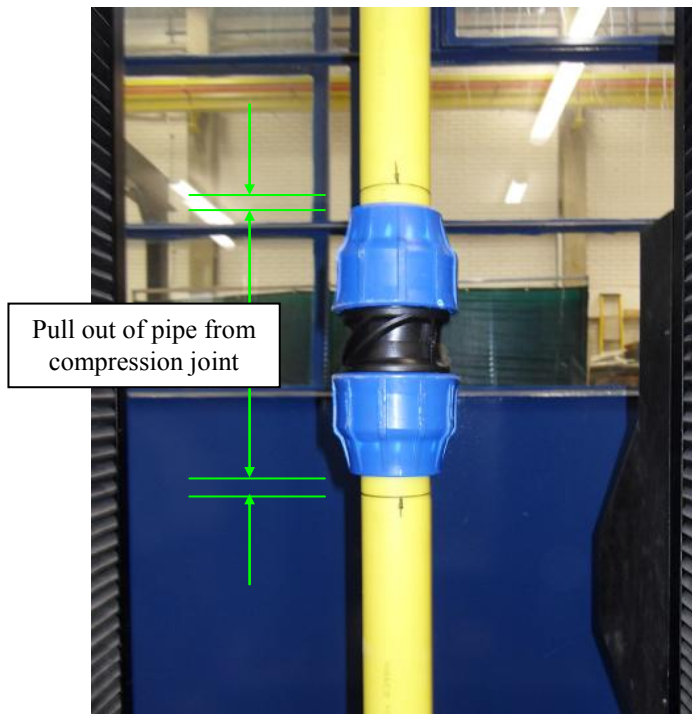


Figure 40. Pull out from compression joint Test piece 4

The author is aware that the elongation results of the tensile strength tests are contributed to by the elongation of the free lengths of polyethylene pipe each side of the test joint. If the end restraints had been able to withstand forces greater than 25KN the author would have tested each test piece till yield to determine if the joint had a higher yield strength than the parent polyethylene pipe.

5.4 Discussion of manual butt fusion and compression jointing methods.

From the testing undertaken as part of this research project it can be seen that both jointing methods are able to successfully pass the hydrostatic pressure and tensile strength tests. No testing of manual butt fusion joints constructed in this method had been completed before this report.

Each of the jointing methods could be taught to operatives from a water utility company or volunteers on a community project in a developing country within a day using simple language and hands on training. The use of compression joints should ensure each joint is constructed to the same quality as long as the joint is assembled correctly. The manual butt fusion procedure has a large potential for human error. This can include poor cleanliness, heating the plate to the wrong temperature, not

applying the correct force on pipe end against heating plate, pipe misalignment, and insufficient cooling periods.

The manual butt fusion jointing equipment includes a heating plate which can be constructed from scrap metal, and a thermo chrome crayon and Teflon coated paper sleeve that would have to be purchased. The alignment plate can be manufactured from scrap materials. Thermo chrome crayons and Teflon coated paper can be purchased for approximately £8 (Tempil 2010) and £8.50/m² (Reed 2010) respectively. The equipment required for compression jointing is either two pairs of Stilsons or a special universal strap wrench. For the joining of the compression jointed test pieces the author used Stilsons as they are a universally popular tool. However good quality Stilsons are expensive (24” Stilsons approximately £70, 36” Stilsons approximately £153.50). A special universal strap wrench costs £28.50. As can be seen the cost of equipment for the compression jointing procedure is considerably higher than the manual butt fusion jointing equipment. Additionally because Stilsons are a universally popular tool with many different applications there is a greater risk of theft or the tool being unavailable. A thermo chrome crayon and Teflon coated paper sleeve would have limited use apart from manual butt fusion pipe jointing.

In addition to the higher equipment cost, as already shown in Table 1 in the literature review, compression couplers are expensive (£5.41 per 63mm coupler). Manual butt fusion jointing requires no expensive fittings, making them more economically viable. If part of the compression coupler is lost, e.g gasket seal, the compression coupler cannot be used. Compression joints would have to be shipped to Developing Countries, which may take considerable time, increasing potential levels of non-revenue water.

There is also a risk to the health of members of the jointing team during the manual butt fusion procedure. The use of charcoal or good quality firewood to heat the heating plate means there is a risk of burns. Care should be taken when handling and storing the plate, and heat resistant gloves, if available, should be used.

6 Conclusions

The focus of this research project was to examine the performance of joints in polyethylene pipe produced using manual butt fusion techniques in field conditions and compare these with compression joints. Before this report there had been no extensive testing of manual butt fusion joints.

The research project has successfully achieved the objectives set out in section 1.1. – Aims and objectives, which was „to investigate the performance of manually welded butt fusion joints in comparison to compression joints on polyethylene pipes’. The research project contains a detailed literature review on manual butt fusion and compression jointing, and the results of hydrostatic pressure and tensile testing of manually welded butt fusion and compression joints, which have been analysed and discussed.

The manual butt fusion joints tested were constructed at Loughborough University using similar equipment and procedures to those used in Developing Countries by a jointing team who had no previous experience in manual butt fusion jointing prior to this project. After one day of training and trialling the jointing team were able to produce robust, good quality joints that withstood all the testing procedures. There was no failure of any joints during testing. The ultimate (failure) strength of manual butt fusion joints was unable to be determined due to the constraints of the testing rigs.

Throughout the research and testing there was no advantage in the compression joint over the manually butt fused joint, in some cases the butt joints performed more favourably.

6.1 Recommendations

Where there is a relatively skilled local workforce, manual butt fusion jointing should be considered as a serious alternative to mechanical and electro fusion jointing in all Developing Countries. Simple picture guidance sheets which could be laminated would serve as training guides and also show faulty and poor joints caused by poor joint preparation, incorrect fusion temperature and misalignment.

This report has highlighted the strength and performance of manual butt fusion joints and the low production costs involved.

Improvements in the design of the alignment clamp should improve joint quality and with modifications may enable mitred joints to be constructed from straight pipe and the use of straps to secure pipe to the clamp. It may be possible for one side to be on a sliding clamp to allow pipes ends to slide together although this adds to cost and complexity to the equipment which, ideally, would be made locally.

To ensure standards are maintained simple pass / fail gauges could be produced to check for misalignment and minimum bead size and a simple and cheap bead removing tool could be used to remove joint beads and allow quality checks for contamination and slit defects. Any quality assurance, however basic, is worthwhile in maintaining standards.

6.2 *Limitations of research project*

Testing equipment used for this project was developed and constructed from materials available in the civil engineering testing laboratory. During hydrostatic pressure testing, because the incubator pump could not produce pressures in excess of 25bar, it was not possible to test joints to failure. Also test durations, which had to be supervised, could not exceed the access periods allowed in the laboratory.

It was not possible to source pipes used in Developing Countries which are manufactured with different specifications and properties to UK sourced polyethylene pipes but this was not a major factor as the tests were undertaken to UK water industry standards.

After commencement of testing, the author was informed that 63mm nominal outside diameter polyethylene pipe is not commonly used in developing countries, more often 50mm and 32mm nominal outside diameter polyethylene pipe is used. The author had already sourced materials and commenced testing when told of this and it would not have been feasible to re-source materials, construct new joints and reconfigure testing apparatus. However, this setback did not affect the nature or purpose of the research to examine the performance of manual butt fusion joints. The resulting joints

were successfully tested at much higher pressures than the specified design ratings to conform with UK water industry testing standards.

6.3 Areas for further research

This research project has provided the author the opportunity to study manual butt fusion jointing practises and experience laboratory testing, including comparisons with compression joints.

The author would like to highlight the following topics that came to his attention during the research project and could provide areas for further research:

1. Design of a low cost simple technology pipe alignment clamp to assist in the manual butt fusion procedure with a mitre jointing facility.
2. Investigation of the amount of allowable misalignment of pipe (poor jointing) that will still provide sufficient strength for normal operating conditions.
3. Fatigue testing to develop whole life data on manual butt fusion joints.
4. Further investigation to obtain the ultimate hydrostatic pressure strength of manual butt fusion joints.

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