ACHIEVING ZERO LEAKAGE BY 2050: LAYING LEAK-FREE NEW NETWORKS

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UK Water Industry Research Limited provides a framework for a common research programme to undertake projects, which are considered to be fundamental to water operators on 'one voice' issues. Its contributors are the water and sewerage companies and the water supply companies of England and Wales, Scottish Water, Northern Ireland Water and Irish Water.

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Executive Summary

Objectives

This project is one of five UKWIR projects that form a strategic research programme to address the question "How can we achieve zero leakage by 2050?" The project aimed to identify what research and development will be required to facilitate the path to zero leakage.

The objective of this report is to identify the issues (design, materials and workmanship) that currently contribute to high leakage rates and to examine how changes to current installation practices or the need for new techniques are required to facilitate laying leak-free new networks.

Methodology

In order to achieve this objective, the following activities have been carried out:

- A review of research and development already carried out, and a broad indication of the results.
- Consultations with water companies, contractors, supply chain, consultants, academics and testing laboratories working in the area of water networks.
- Identification of research and development currently in progress.
- Assessment of the gaps, and therefore the additional research that is required to enable the eventual achievement of zero leakage.

Conclusions and Recommendations

The greatest potential for improvement in laying leak-free new networks lies in quality of workmanship and allowing for improvement in workmanship by incentivising it appropriately. Beyond the issue of workmanship: network design, jointing techniques, commercial contracts, self-lay, sensors and testing and commissioning were identified as areas which require additional research in order to allow installation of robust new networks with zero leakage.

Recommendations for projects that would move the industry towards zero leakage are made relating to:

- Understanding jointing techniques, causes of failure and the economic case for improved methods; and
- Training and contractual elements to drive improved workmanship.

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1 Introduction

UKWIR has recognised a need to undertake major strategic projects to help deliver a step change in innovation in the water industry. The first strategic area that UKWIR is addressing is leakage, and specifically seeks to explore 'How can we achieve zero leakage by 2050?'

There exists clear evidence that there is significant leakage in MDPE mains laid by the UK water industry. In 2010 UKWIR[1] reported electrofusion jointing as the predominant cause of joint failure on PE mains with a calculated failure rate of between 3 and 4 failures per 100km per year. Although there is a lack of more recent data there is a widely held view within the industry that failure rates on PE mains have not reduced in the past decade and there is still a significant problem.

Whilst minimising current leakage is a very topical problem, in order to reach 'Zero Leakage' by 2050, new networks must be fundamentally designed and laid in a way to mitigate against future leakage. This document reports on ideas, products and technologies which can contribute to that goal of laying networks which do not leak. Topics cover both historical and current trends as well investigating the technologies and ideas which are on the horizon.

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- Identification of research and development currently in progress.
- Assessment of the gaps, and therefore the additional research that is required to enable the eventual achievement of zero leakage.

The document is split into different network elements, covering topics from design through to workmanship. It is important to note that while the document is split up in this way, the topics interlink and all topics require consideration in order to be able to lay leak free networks in the future.

2 Network Design

One means of reducing leakage of future laid networks is to improve the way in which networks are designed so as to effectively design out the root cause(s) of leakage. This

[1] E. Ingham and M. Wheeler, Leakage From PE Pipe Systems, UKWIR Report Reference 10/WM/08/43, 2010

section explores techniques and practices for designing water networks from an early stage of planning to minimise the risk of leakage.

2.1 Joints

Joints are a weak point in the network and are often the source of leakage. Therefore it is reasonable to assume if the numbers of joints in a network are reduced the number of leaks will reduce and so there will be a reduction in overall leakage. On larger pipes, trunk mains and even District Metered Areas (DMAs) there is a limit to how many joints can be designed out of the network as the length of pipework required becomes physically restrictive. However, on smaller service and supply pipes (where a large percentage of leakage is thought to occur) there exists the potential to reduce the number of joints significantly.

It is recognised that some joints in water networks are necessary. Thus minimising the number of joints will only reduce leakage so far. The quality and robustness of necessary connections should also be addressed. This is investigated further in Sections 4, 5 and 7.

Longer pipe lengths – straight pipe

As both fusion joints (predominantly electrofusion) and mechanical fittings are common sources of leakage in PE water pipe networks, minimising the number of both fusion and mechanical joints within the system is a viable way of reducing leakage in new networks.

A very simple solution to reduce the number of joints in a system is to increase the lengths of individual pipe sections. Radius Plastics reported[2] that for a PE pipeline project where 450 mm and 500 mm pipes were installed it was possible to reduce the number of joints by 65% by using bespoke lengths of 12 m and 18 m pipe, rather than the conventional 6 m lengths. Although this approach is feasible in rural areas, where there are no issues with storing long sections of pipe, it is recognised that it will not always be suitable for urban areas and in these situations it may be more practicable to look at other options.

Removing joints from a system completely is not a currently available option, though an example of a technique that may become available by 2050 is on-site extrusion. This provides the opportunity to introduce a joint free section of the network. As with the use of longer lengths of pipe, this may only be suitable for rural applications where long lengths of straight pipe are required.

Longer pipe lengths - coiled pipe

Another possible option for minimising the number of joints would be to use longer lengths of coiled pipe. However, there are issues with the jointing of coiled pipes, which require specific techniques and equipment to produce satisfactory welds. The following section outlines the work that has been undertaken to produce longer lengths of coiled pipe. Jointing techniques when using coiled pipe is explored further in Section 4.

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[2] Radius Systems Provide Engineered Pipe Solution for the Haweswater Aqueduct to Ramsgreave Reservoir, Radius Systems News, 29 May 2014.

Innovative Coiling Processes to Increase Coil Length

A technique has been developed by Iplex Pipelines in Australia[3], in which the pipe is deflected to oval in cross profile. This results in an enhancement of the pipes properties allowing the pipe to be coiled more tightly. As the pipe becomes oval, it also occupies approximately 35% less space on the coiling drum, which allows longer lengths of pipe to be continuously coiled on to the drum. Iplex claims that by using this technique it is possible to coil pipes with a diameters of between 160 mm and 315 mm in 300 m lengths. When the pipe reaches the installation site it is re-rounded using specialist equipment which is attached to the coil trailer. It is noted that the only practical trials using this technique were carried out using 50 mm pipe. Although testing was carried out to determine that there was no effect on the long term performance of the pipe of the innovative coiling process, it would be necessary to conduct further research to confirm that this is also true for larger diameter pipes.

Pipe Coil Technology in the UK has developed a technique[4] to reduce the ovality of coiled pipe and coil the pipe at a reduced radius without the risk of buckling; allowing longer coil lengths. The company has developed specific trailers to maximise the size of coils that can be practicably transported and also have bespoke equipment to correct ovality as the pipe is dispensed on site. However, it does not appear that this equipment is able to straighten the pipe for jointing purposes.

Reduction of Coil Ovality during Manufacture

In response to the problems of electrofusion welding associated with the ovality of coiled pipes, manufacturers have invested in downstream equipment for pipe extrusion lines which significantly reduced the ovality of coiled pipe. The equipment uses a traverse layering caterpillar at the end of the extrusion line, which reshapes the pipe to reduce ovality. The caterpillar squeezes the pipe in one plane which has the effect of counteracting the ovality induced at 90˚ to the pipe axis as it is coiled.

Bonded Systems (CIPP and GFRP)

Currently used in the sewerage sector, cured in place pipe (CIPP) is a renovation technique for degraded sewer pipelines. This technique involves insertion and inflation of a composite liner which is pre-impregnated with resin. This is then cured using steam or ultraviolet (UV) light to produce a rigid pipe with minimal reduction in hydraulic capacity. This is a relatively cheap renovation technique that has proved successful in waste water applications. It is not currently used as a 'primary installation' technique. However, the small excavation required combined with tunnelling techniques could be combined to produce a useful 'new network' installation technique in the future, one which minimises the number of joints required.

Another example of a bonded system is the use of GRP (glass fibre reinforced plastic). The advantages of GRP is its strength to weight ratio and its chemical resistance, this makes it an

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[3] R. Connolly, Innovative Pipe Coiling Process Potentially Minimises Field Welding of >DN160 HDPE Gas Pipelines, International Plastic Pipes Conference (XVI), Barcelona, 2012.
[4] I. Wallace, Redefining Pipe Installations, International Plastic Pipes Conference (XVI), Barcelona, 2012.

ideal material for renovation techniques. There is great potential from the recent development of adhesives which make side connections made from GRP a real possibility. Connections made of GRP and glued on, may require cleaning the surface prior to fitting, but the light weight properties of these products reduce the risk to the contractors installing them. There is potential to bond GRP to PE either by achieving a mechanical bond by roughening the surface or by a chemical bond which requires the PE surface to be treated in order for the materials to bond successfully.

2.2 Meter Location

As explored in work carried out by WRc[5] in 2012 there are many issues relating to meter location. The choice whether to locate externally underground or above ground, or internally has a number of pros and cons. For the purposes of this project where the aim is Zero Leakage, the positioning of a meter will be considered from the leakage perspective.

Currently (if a meter is fitted externally) as a minimum there are three connections; the connection of the service pipe to the main, connection of the service pipe into a boundary box and connection of the supply pipe out of the boundary box. Even more joints may exist in multiple supply pipe configurations or where shorter lengths of pipe are used. These joints are all potential sources of leakage.

The most prevalent of meter locations, currently underground in a boundary box, is the most disadvantageous meter location for leakage. The reason for this is that the joints are underground, and therefore hidden from view. By locating the meter internally the number of joints is likely to be reduced (see benefits in Section 2.1). However with either internal or wall located meters, there is benefit as any leakage is far more easily viewed and as such any leakage which was to occur would be located more rapidly with easier accessibility for repairs than leakage from buried assets.

Locating meters externally on the wall or internally does restrict the ease of identifying leakage on the supply pipe, however if this was laid in one piece of pipe with no other joints, the risk of that leakage would be significantly reduced.

It is acknowledged that this is a simplistic view. Locating the meter internally takes up space (developers can be particularly adverse to this in the case of flats, where they may otherwise be able to sell the space used for meter cupboards). There are also problems with access to the meter once it is located internally. Locating the meter externally on the wall of the property is often seen as another aesthetically displeasing piece of street furniture and is often objected to by developers Wall-mounted installations and boundary boxes also don’t have a reputation for reliability due to their susceptibility to frost damage. This is not necessarily a fault of the technology but perhaps of the workmanship. It may be possible to address issues around workmanship (explored further in Section 7) and address issues of accessibility via AMR or similar technology. For the purposes of achieving zero leakage on new networks alone, it would possibly be advantageous to locate meters externally above ground or internally.

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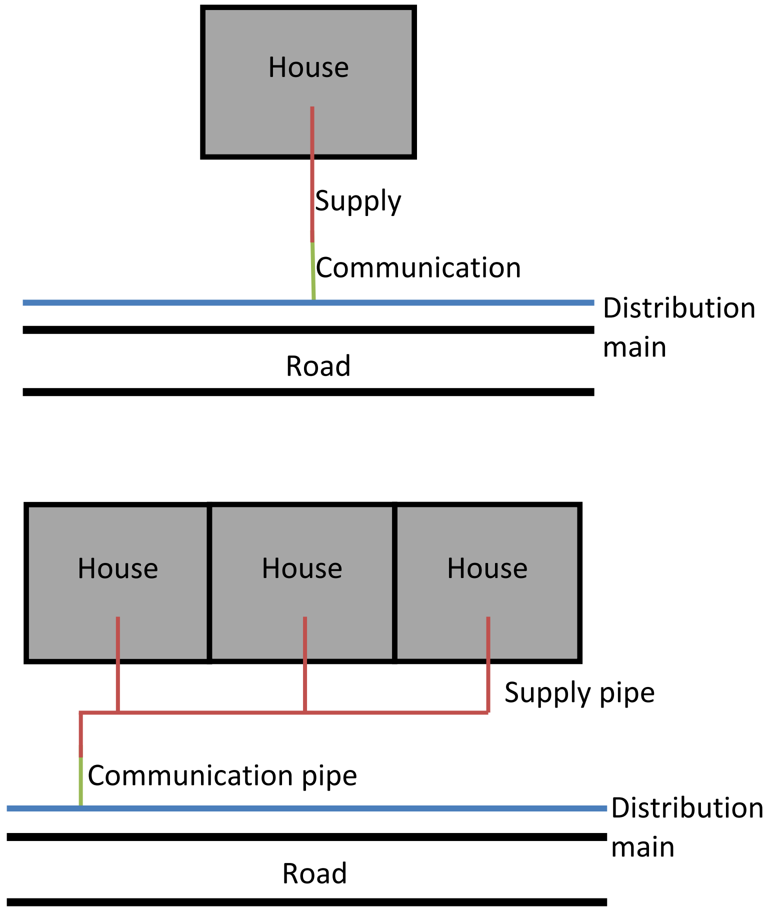
[5] WRc, Household Meter Location: Technical and Financial Assessment, P9046.02 (2012)

2.3 Supply Pipe Configurations

Supply pipes in the UK come in many different configurations.

Figure 1 shows typical examples found in the UK, though it is by no means an exhaustive list.

Figure 1 Examples of supply pipe configurations in the UK



The different supply pipe configurations have a variety of different costs and benefit implications. One of the key areas of note for reducing leakage in new networks is the number of joints as discussed previously. The configurations shown in Figure 1 will all have a different number of joints per connection although will also be dependent on the meter location as discussed in Section 2.2.

While the 'single property' supply type configuration is likely to have the least number of joints along the supply type, if that configuration were to be adopted for all dwellings the number of ferrule connections to the main would increase. This would raise the question of whether ferrule connections are more prone to leakage than joints along a supply pipe. A single supply per property would also increase installation costs as a result of the increased requirement for excavations and material. It is not possible to conclude whether increased installation costs may be offset in the longer term by reduced leakage costs and burst repair costs.

Due to the variation in dwelling types and arrangements across the UK, having a set or recommended supply pipe configuration is unlikely to be easily applied to every situation. It may instead be possible to attempt to design out as many joints as possible for any given supply pipe. In practice this would be closely linked with meter location. With a single supply per household arrangement and wall mounted / internal meter it would be possible to have no joints between the ferrule and meter connection. One of the main disadvantages of these meter locations are that they do not allow for identification of supply pipe leakage. However if the supply pipes are designed with no joints from the ferrule to the meter location and good practice used in the backfilling of the excavation the chance of leakage along the supply pipe should be minimised.

Increasing meter penetration – The Netherlands and Portugal

In a conversation with WRc (23/11/11), Dr Jan Vreeburg, a Principal researcher at the KWR Watercycle Research Institute, noted reasons for the very low leakage figures in the Netherlands. The Netherlands have had water meters on all connections for a number of years. Dr Vreeburg cites both the universal metering and the high skill level of technicians (and therefore a high quality of workmanship) as the main reasons behind low leakage levels. Workmanship is further explored in Section 7.

In a similar way that universal metering is cited as a significant benefit in the control of leakage in The Netherlands, universal metering in Portugal may have helped identify a great number of leaks. According to Andrew Donnelly in a conversation with WRc (21/11/11), the Portuguese water utility Empresa Portuguesa das Águas Livres reduced leakage from around 23.5% to 13.5% in the period 2005 – 2011. The high penetration of meters allowed leaks to be located more quickly. In addition a targeted approach to interrogating each DMA, a high level of training among water company staff also helped.

Smaller DMAs

During a discussion with Stuart Trow (17/02/16), it was suggested that either designing new networks around smaller DMAs or 'designing in' points where it would be quick and easy to install a temporary meter, could be beneficial in tracing leaks when they do occur. However well a network is designed, at some point during the life of the network it is fair to assume a leak will occur. If DMAs were smaller or there were access points for temporary meters, leaks which do occur could be more quickly located and rectified.

Creating smaller areas in which to locate leaks was also cited by Frank van der Kleij (06/12/11) as one method used to tackle leakage more quickly when it does occur through the use of sub-DMAs in Bristol Water. DMAs of 1200-1300 properties are split into sub-DMAs of around 300 properties allowing any leaks that do occur to be located and fixed quickly.

2.4 Mains location

In other areas of the world water mains are not necessarily buried assets in the same way that they are in the UK. While above ground water mains may add some costs and complications (e.g. security, water quality, vandalism and illegal connections), it provides benefits in terms of visibility and accessibility of leaks.

Mains location and designs for ground conditions – The Netherlands

The Netherlands have very low leakage figures of below 6%[6]. During a conversation with Stuart Trow (17/02/16) he noted that in The Netherlands, water mains are laid in trunking in a 'service strip' type arrangement. The pipes are relatively near the surface resulting in a higher likelihood of leakage being spotted than in UK networks. With the high and increasing cost of land in the UK, housing developers are likely to object to service strip type arrangements in new housing developments unless, perhaps, a high rate of compensation is paid.

Rob De Bont noted, during a conversation with WRc on 15/12/2011, that in The Netherlands networks are designed specifically for the ground conditions where they are to be installed due to the great variation in soil types across the country. Around 40% of the soils are very sandy and the remainder are mostly a peat and clay mixture. The water utilities have a construction manual outlining design practice for the conditions they find and the manual is closely followed. Rob also noted the usefulness of the meters deployed by the utilities, not only at point of supply but also the meters in networks, in the help to identify and so repair leaks sooner. During the conversation Rob also noted how the economic level of leakage (ELL) was not as much of a concern in the Netherlands as perhaps it is in the UK. Reducing and repairing leakage is also about the carbon cost of the water lost. Even though the Netherlands is not water stressed, accepting wasted water via leakage seemed objectionable.

Mains location – Paris

The Parisian sewer system is famous for being designed and housed in large tunnels. The majority of the tunnels have walkways large enough for individuals to walk through and the systems largely mimics the road system above ground, where there exists a wide boulevard on the surface there will generally exist a wide channel underneath it flowing with sewage and surface water. The large underground network is also used in places for housing the piped network of other utilities, such as potable water. As with the mains location in Paris this makes any leakage visible and also has the advantage of being very accessible. This is advantageous not only for repairing leaks but the access of such systems provide far more desirable conditions for laying new mains than a trench based approach. Although costs are likely to be high, having such an accessible system is one way which Eau de Paris keeps leakage reasonably low at between 8 and 10 %[7,8].

2.5 Network Design Conclusions

- Reducing the number of joints is a key, and in many situations relatively easy way of designing the root cause of leakage out of new networks. This may be through a variety of techniques or tools, including using longer lengths of pipe where possible

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[6] Vewin, Dutch Water Sector (2014) [online]. Last accessed April 2016 at: http://www.vewin.nl/english/

[7] Pearce, F. The water industry is burying a leaking pipes scandal (2012). The Guardian [online]. Last accessed April 2016.

[8] Schiffler, M. Water, Politics and Money: A Reality Check on Privatization. Springer (2015).

or developing an appropriate policy on meter location and supply pipe configuration to help minimise leakage.

- Other more investment heavy options include looking at novel installation techniques for laying longer lengths of pipe without joints or laying networks in more easily accessible and visible locations.

3 Materials

This section briefly explores some alternative materials to those currently used in the UK but focuses on the development of more commonly used materials and those thought to remain the most prevalent in the future – plastics.

3.1 Alternative Materials

Ultra-High Strength Steels – experience from the aerospace industry

Although somewhat unlikely, within 35 years' time the cost of ultra-high strength steels may become affordable within the water industry. Steels such as Maraging steel are a good example of ultra-high strength steel and are currently used for missile casings, where strength and material thickness are paramount. These steels are inherently strong as they are able to resist crack propagation with it being 10 times slower than that observed in carbon steel.

The ultimate tensile strengths of Maraging steel in the range of 1,400–2,400 MPa, compared to ductile iron used in the water network which is 420 MPa. The Modulus of Elasticity in Maraging steel is 210 GPa whereas Ductile Iron is 170 GPa.

Super Nickel steel alloys are the main focus in the aircraft industry in respect to turbine blades which can now be made from one crystallographic cell. This reduces the number of slip plains which are often the cause of failure and greatly increases the strength and heat resistance of the turbine blades allowing turbine engines to increase their output. It may be possible to do the same with metallic pipes which would greatly improve their performance.

Water networks in earthquake zones

There may be some benefit in looking to see if there are any technologies or installation techniques associated with the installation of pipelines in severe environments, which could be applied to reduced leakage on pipe systems in the UK (i.e. in areas where movement of the pipeline is an issue due to soil conditions and associated ground movement).

In the United States, the American Lifelines Alliance (ALA) provides guidance on the installation of pipelines in areas which are prone to earthquakes, but this tends to be regarding risk assessment for pipelines and advice on metal pipes. There does not appear to be specific guidance or techniques for the installation of plastic pipes, which is possibly due to the fact that in a number of large earthquakes (e.g. Kobe and Christchurch), the plastic pipes (particularly PE) have generally survived very well.

The ALA guidance for metal pipelines does provide information on specific joints which have been developed to accommodate movement and prevent leakage where permanent displacement of the ground occurs, which could be of use.

It may be worth looking at the experiences of other countries that experience severe ground movement to see if there is any other information which may be applicable to or assistance in the UK.

Ceramics

Although ceramics are often considered brittle materials with poor mechanical properties, when used as composite materials or used in compression, ceramics have many beneficial mechanical and chemical properties. Therefore ceramics should not be ruled out as a potential engineering material for the water network in the future.

Graphene

In a conversation with Stuart Trow (17/02/16) he considered the use of Graphene as an outside possibility for use in the water industry. WRc followed up on this comment with some literature searching and it seems unlikely this will come to water industry pipelines in the next 50 years. This material is at an early stage of development and although potential applications are broad, the high costs and demand for Graphene in other more lucrative markets mean the industries currently being targeted do not include water.

3.2 Development of Plastic Materials for Water Pipes

Polyethylene (PE)

Plastics are continually improving; as more variations are developed, a greater variety of performance characteristics are available. The price of plastics is largely governed by the oil price, but is likely to be a comparatively cheap and available pipe material for many years to come.

The chemical resistance of plastics to aggressive conditions have improved over the years but it is still proving a problem. Some varieties of plastic domestic water meters may have been subject to chemical attack from potable water. This can result in an embrittling process which can result in catastrophic failure from transient pressures. These failures may also be a function of temperature effects as more failures occur during the summer months; this is due to the greater rates of reaction when the temperatures are higher. In addition there are many examples of hydrocarbon infiltration through the pipe wall causing water quality issues. The most common issue is leakage from domestic heating oil tanks. Barrier pipes do exist (see Section 6.1) however as these are expensive they would not typically be specified for many location such as where domestic heating oil tanks are located.

Within the UK, PE tends to be the dominant choice of plastic material due to its high resistance to slow crack growth (SCG) and rapid crack propagation (RCP). These characteristics along with its flexibility and the fact that it can be fusion welded to produce long lengths which have full end load resistance when the system is pressurised, make it difficult to better. The pipes can also be temporarily folded and re-rounded for certain types of rehabilitation, without any detrimental effect on the long term properties.

In recent years, developments of PE 100 RC materials have enhanced slow crack growth (SCG) resistance compared to conventional PE 100 materials. These materials are therefore much more resistant to the initiation of cracks from damage (e.g. scratches and scores) caused during installation and point loads from sharp stones within in the soil. PE 100 RC pipes are therefore very suitable for trenchless installation techniques such as pipe bursting and directional drilling.

Another advantage of using Polyethylene is that they have superior thermal insulation properties; this means that it is possible to lay a PE pipe in a shallow trench as is less likely to be affected by the effects of ground freezing. This has the potential to greatly impact laying costs on PE pipes.

Recycling Polyethylene (PE)

Polyethylene, although a thermoplastic, is deemed largely non-recyclable for structural applications in the water industry. The reason behind this is due to the shearing of the structural 'chains' within the material during re-processing. The shorter polymer chains in PE result in reduced strength and rigidity.

The water industry currently allows the use of regrind material (plastic that has been worked but has not left the factory) to be included in the manufacture of pipes. Due to the low quantities and known history of the material being reused there is no significant impact on the material properties of pipe.

PE has the potential to be recycled back into PE pipes with the addition of additives if required. Extensive testing would need to be carried out before recycled PE could be included as a 'percentage share' of the bulk product. One of the benefits of using high grade PE in pipes is that the recycled material is likely to meet the required property characteristics if re-processed properly. In-service PE is unlikely to be used as a recycled material for potable water pipe applications due to potential contamination issues. However the same restrictions would not apply for waste water and raw water applications.

PE can be collected and used as a fuel at the end of its life as it has a 30% higher calorific value than that of coal. This is often a more cost effective approach compared to recycling PE but when the whole life-cycle is taken into account this is obviously not a very efficient use of the material and one that may be prohibited in the future as companies strive to incorporate the circular economy mantra into their practices.

Polyvinyl chloride (PVC)

The problems of slow crack growth, which led to numerous failures of the very early PVC pipes, were addressed by close attention to processing and the introduction of demanding fracture toughness tests in product specifications. Despite these improvements, PVC is not a commonly used material in the UK and there are now no producers of PVC pressure pipe in the UK.

Modified PVC (PVC-A)

PVC-A is a PVC material which incorporates a small amount of rubber modifier that improves the impact toughness and also the resistance to initiation of cracks from defects caused during installation. The effect of the rubber modifier is to slightly reduce the yield stress of the material, which promotes a controlled ductile (rather than unstable brittle) mode of failure in the pressure regression tests which are used to determine the lifetime pressure rating of the pipe. The ultimate consequence of this change in failure mode is that the safety factor which is applied to the design stress calculation, used to determine the pressure rating of the pipe, is lower. The advantage being that PVC-A pipes have a thinner wall than PVCu pipes with the same pressure rating.

Research[9] was carried out in the 1990's that helped develop PVC-A materials which included much higher levels of impact modifier. These had comparable crack resistance to PE materials that were commercially available at the time. This work also examined the co-extrusion of different materials to produce high toughness composite PVC-A materials. Using the composite structure, it was possible to create pipes which would allow the construction of a fully end load resistant system.

These improved PVC-A materials were never adopted partly due to the cost of production and the emerging dominance of PE pipe systems which offered both high crack resistance and the ability to be fusion welded. As with PVC, PVC-A is no longer produced in the UK although it is available in Ireland.

Molecularly Orientated PVC (PVC-O)

PVC-O has been in the use in the UK since 1974. There are two processes by which PVC-O is manufactured. The first is a batch process in which a feedstock pipe is produced that has approximately twice the wall thickness and half the diameter of the finished pipe. This pipe is placed into a temperature controlled mould. The temperature of the mould is increased and then the pipe is blown up using internal pressure to fit the internal dimensions of the mould. Following cooling the orientated pipe is withdrawn from the mould.

The second method for producing PVC-O pipe is a continuous extrusion process. A standard PVCu pressure pipe is extruded, which is pulled over a mandrel that is in line with the extruder. As the pipe is pulled over the mandrel this results in orientation of the material in the hoop and axial directions, which is why it is sometimes referred to as biaxially orientated PVC.

The orientation process produces significant enhancement in the impact toughness, strength, pressure bearing capacity and fatigue resistance in comparison to PVCu pipes.

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[9] E.J. Ingham, The Development of Impact Toughness and Resistance to Slow Crack Growth in Modified Polyvinyl Chloride and Polyethylene Pipe Grade Polymers, PhD Thesis, Manchester Metropolitan University, 2003.

With the early PVC-O materials there were no fittings available, so it was necessary to use either PVC or ductile iron fittings. With current PVC-O material pipes, specific fittings are also available.

3.3 Self-Healing Plastic Pipes Materials

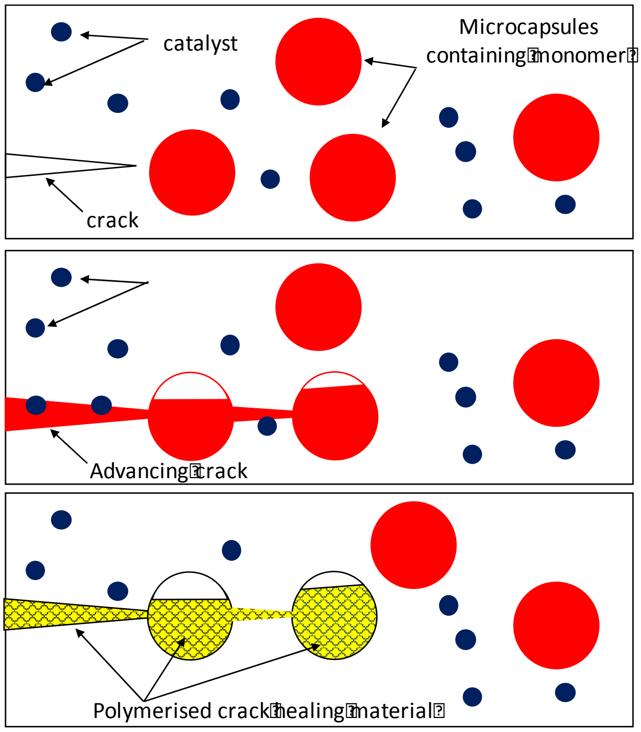
There is an on-going project in the United States which is being undertaken by the Northeast Gas Association and Nysearch[10] looking at the feasibility of developing polyethylene (PE) gas pipes, which are able to self-repair cracks in pipes caused by poor installation or which have initiated from defects in the pipe due to the imposition of point or bending stresses.

The work is based on previous studies on nanomaterials where a matrix material, in this case PE, is modified using nanoparticles. These nanoparticles, such as fillers can be used to improve the physical properties of the pipe such as tensile strength, modulus or resistance to slow crack growth (SCG). They can also be used to impart electrical or magnetic properties, which may have applications for locating pipe systems.

In this case the concept is to incorporate a microcapsule, which contains a polymer precursor (monomer) into the matrix material. The matrix material also contains a randomly distributed catalyst. Any cracks which are formed effectively release the monomer, which when it comes into contact with the catalyst is polymerised and seals the area which has been damaged by crack growth as shown in Figure 2.

[10] Technology Brief on Next Generation Advanced or Self-Healing Plastic Pipe for Natural Gas Applications, Northeast Gas Association and Nysearch, 2013.

Figure 2 Microencapsulated self-healing concept[11]



Experiments on materials containing cracks which have been repaired indicate that the repaired areas retain 75% of the tensile strength of the original PE material; however, it is unclear if this has been achieved with the PE in the form of pipe. A special facility was set up to develop the microcapsules that carry the monomer healing agent, as there appear to have been problems manufacturing capsules which would fracture to release the monomer when the crack penetrated them, but which are able to survive the conditions of high temperature and shear involved in pipe extrusion. This may also be an issue due to the high temperatures used when pipes are fusion welded. In April 2016 it was reported[12] that attempts are being made to move from feasibility testing to more advanced development, but no further information is available.

If the technology were to be used for water applications, there would need to be some consideration regarding the possible water quality issues with having monomer and catalyst components within the PE material.

However, based on the fact that the majority of leaks are the result of joint failure, the potential for self-healing PE materials specifically for pipes may well be relatively limited in the UK water industry. It is noted that researchers in this area see the benefit in terms of damage to pipe walls during installation but this has not been identified as a big issue in the

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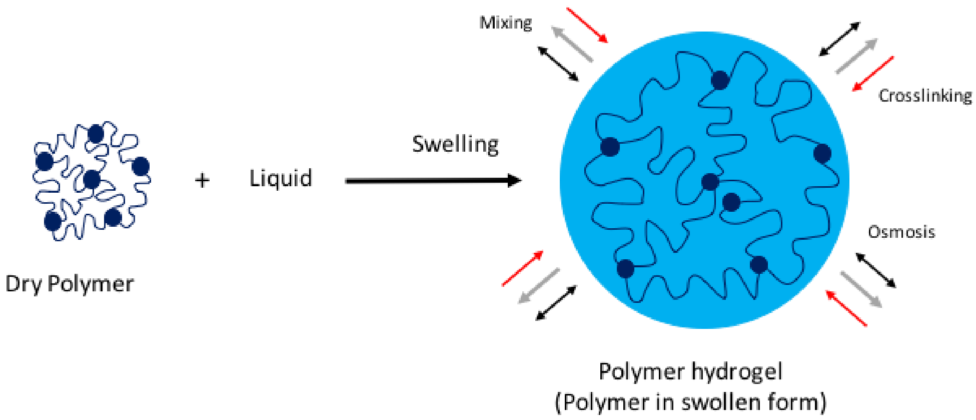
[11] S.R. White, N.R. Sottos, P.H. Geubelle, J.S. Moore, M.R. Kessler, S.R. Sriram, E.N. Brown and S. Viswanathan. Microencapsulated self-healing concept (from Autonomic healing of polymer composites. Nature 409 (2001), pp794-797). Jointing Techniques.

[12] Case No. 98-G-1304 - National Grid's Three Year Research, Development, and Demonstration Report, April 5th 2016.

UK. The use of self-healing materials within joints has potentially much greater opportunity to reduce leakage.

There has also been research[13] undertaken to investigate the potential of polymers which undergo swelling when in contact with water as shown in Figure 3. These materials which are referred to as hydrogels are lightly cross-linked hydrophilic polymers that can absorb and retain aqueous solutions hundreds of times their own weight as they swell. The three dimensional crosslinking of the polymer chains in the hydrogel, reduced the swelling to a defined value.

Figure 3 Swelling process of hydrophilic polymers[11]



In the design of sealing components, it is necessary to measure the sealing pressure that is developed by a polymer. This has been done by placing the polymer in a chamber in which the swelling volume is restricted. Water is then allowed to flow into the chamber through a semi permeable sieve and the pressure measured using a transducer.

The technology has been used in developing a self-repairing system for joints within sewerage pipes. The system comprises an elastomer made from ethylene propylene diene monomer (EPDM) as a sealing jacket, with a hydrophilic swelling polymer (polyacrylate derivative) as a core, as shown in Figure 4.

As in conventional socket and spigot joints, the elastomer seal prevents the escape of the fluid. When the pipe end or socket is displaced (e.g. due to ground movement), the seal is also displaced and fluid is able to escape from the joint. As the fluid escapes and comes into contact with the polymer at the core of the elastomer jacket, it swells causing the material to expand and re-establishes contact with the pipe and stops the leak as shown in Figure 5.

[13] 5H. Wack and J. Bertling, Water Swellable Materials. Applications in Self Sealing Systems. Proceedings of the First International Conference on Self Healing Materials 18-20 April 2007, Noordwijk aan Zee, The Netherlands.

Figure 4 Design of self-repairing sealing system[11]

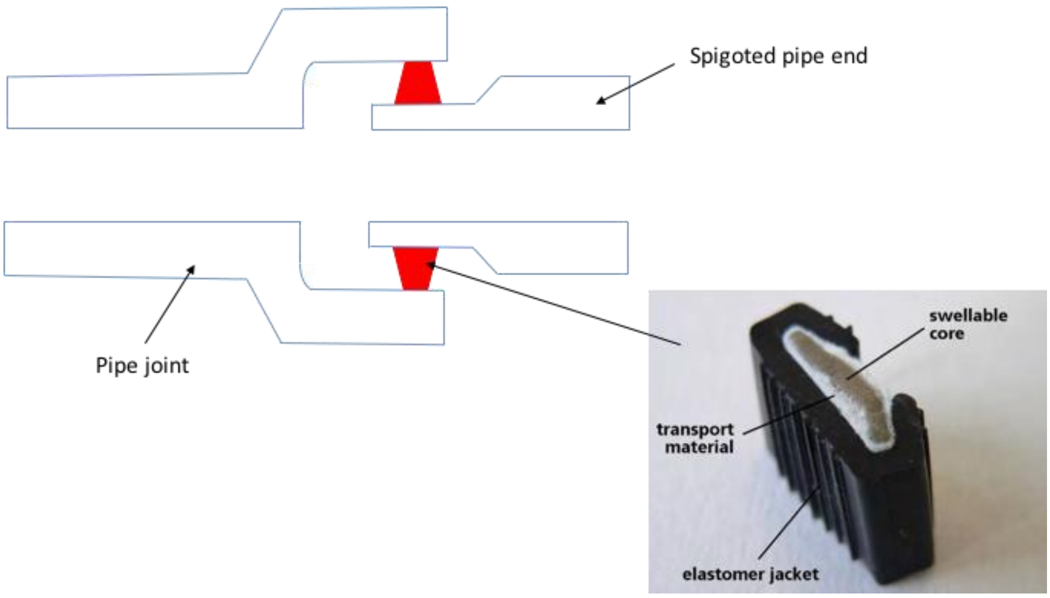
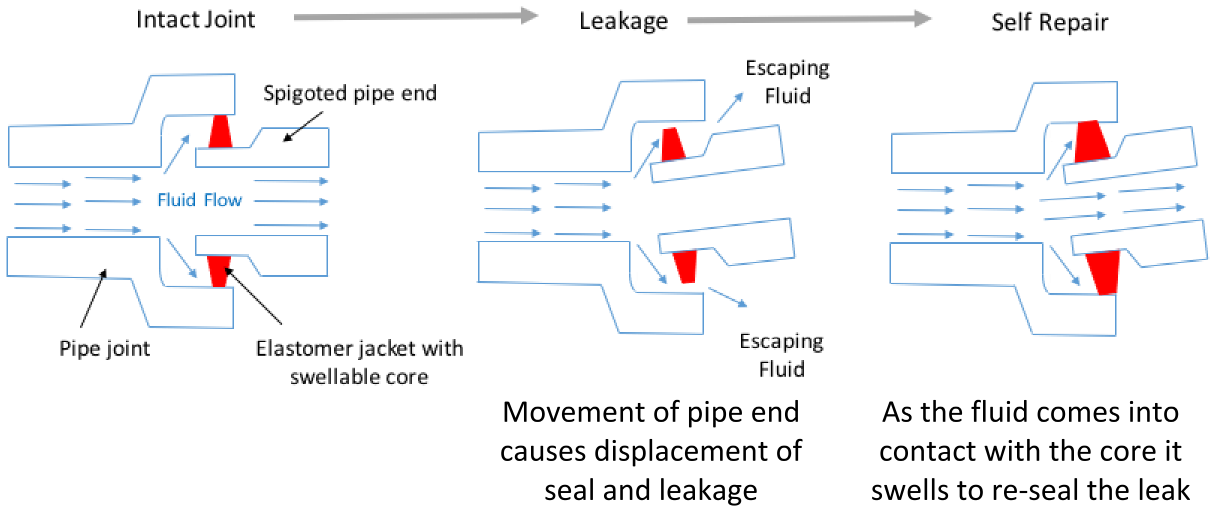


Figure 5 Principle of self-healing joint[12]



The sealing system has been tested on 150 mm and 400 mm pipes, but it is not stated as to whether the pipes were internally pressurised. In a pressurised system where water is escaping at high rate, it is possible that there may be some difficulty in creating an effective seal. It is considered that the system would probably work well for gravity fed or low pressure systems, but more research would be needed for pressurised systems. There is a possibility that this system could be used as a secondary backup sealing system (e.g. as a seal beyond the fusion zone in electrofusion fittings) which is activated if failure at the fusion interface occurs.

Self-healing polymers have also been developed by Stopaq Europe which is used for corrosion protection of steel pipelines. The specialist cold flowing polymer is applied to the pipe in the form of a tape wrapping. Another type of tape (e.g. PVC) is then wrapped over the top of the polymer. When both the external and polymer tapes become punctured, the polymer flows to fill the damaged area and gradually hardens (the time depending on the ambient temperature) to protect the exposed steel. The manufacturer states the tape is self-healing for small amounts of damage.

The technique could provide protection against external defects which are caused during installation, by repairing them before they have penetrated through the pipe wall. It is however unlikely that if a pressurised water pipe were cracked through the wall thickness, that an externally applied polymer would be effective at sealing a leak.

3.4 Materials Summary

- PE tends to be the dominant material as it can be fusion welded to produce long continuous lengths which have full end load resistance. This also makes the material very suitable for rehabilitation where pipes are drawn into existing pipelines.

- Some alternative materials may become available in the coming decades and should not be ruled out. However as PE pipes offer highly suitable characteristics it is likely to be of more benefit to improve laying techniques and practices of PE jointing rather than searching for a new material which is currently not economically viable or doesn't yet exist.

- In addition to PE, PVC-O pipes and fittings are also available which offer significantly better crack resistant properties than conventional PVC pipe materials used in the past.

- There are self-healing polymers available which could potentially be used to repair defects in pipes before leakage occurs.

- It is not certain how advanced studies are for self-healing polymers specifically for pressurised water pipes. Self-healing joints would offer greater benefit than self–healing pipes alone.

- There is a need to consider the effect of the self-healing materials on the water quality of the water.

- It is possible that the self-healing elastomer seals could be used as a secondary level of protection against leakage, should the primary sealing component fail.

4 Jointing Techniques

This section evaluates the jointing techniques available for use in the water industry. As with other sections closely related to choice of pipe material, the following focuses on jointing of plastic pipe from the perspective of joints being one of the more frequent sources of leakage.

4.1 Socket and Spigot Joints (Push Fit Joints)

Socket and spigot joints are used to connect plastic pipe materials such as PVC and PVC-O, where it is not possible to fusion weld the material. Socket and spigot joints do not offer full restraint against the end forces generated due to pressurisation and hence it is necessary to install concrete thrust blocks within the system.

This type of joint consists of a factory formed socket on one end of the pipe, which contains a rubber seal. The joint is produced by inserting another length of pipe, which has a chamfer on one end, past the rubber seal. In order to reduce the forces required to insert the chamfered end of pipe past the seal, a lubricant is also used.

There were issues with displacement of the early seals due to misalignment during assembly and pressurisation, but these were addressed in the early 1990's with the development of specialist stainless steel and nylon inserts which hold rubber seals securely in place.

With PVC-O pipes, specific tests were introduced into the Water Industry Specification (WIS 4-31-01)[14], which evaluate the resistance of seals to displacement when the joint is assembled with misalignment between the pipe and socket.

4.2 Fusion Welding of Polyethylene

Commissioning Procedures in the field

UKWIR in 2010[15] documents the best available data on joint failure rates and reviewed the tool and techniques available to improve electrofusion joining. The three main issues of electrofusion failures as specified in the 2010 report remain as:

- Misalignment (including problems associated with ovality)
- Contamination
- Poor pipe preparation i.e. scraping

A conversation with an ex-supervisor of a large mains replacement programme spoke with WRc to provide an understanding of these issues. Two types of jointing were used on the replacement programme - butt fusion and electrofusion.

Key points identified were:

- No knowledge of any butt fusion joint failures.

The whole process is automated with machines carrying out the jointing process pushing pipes together and heating under pressure. Unfortunately the size of the equipment

[14] 6.8. Water Industry Standard (WIS) 4-31-08. Orientated Polyvinylchloride (PVC-O) Pressure Pipes for Underground Use, Issue 2, 2001.

[15] E. Ingham and M. Wheeler, Leakage From PE Pipe Systems, UKWIR Report Reference 10/WM/08/43, 2010

required means the technology cannot be used within a trench. As a result many joints are made in trench using the electrofusion method.

- A large number of electrofusion joint failures despite the mandatory testing carried out on site.

In order to test the joints the water company designed a destructive sampling test regime. One of the problems with carrying out destructive testing was that one joint was removed for testing, which then required replacing by two joints. As joints are a major source of leakage this is undesirable. The testing involved cutting out a section of the joint and pulling it apart. The force required/time taken to pull apart the joint allowed the water company to classify the joint as a 'ductile' or 'brittle' joint. The outcome of the test was intended to highlight 'brittle' joints that the water company classified as not being able to withstand the pressures experienced in the network over time. One of the issues with this approach was that the destructive testing carried out was not representative of the in service conditions of the joint, and therefore unsure of the value of the results.

An improved on-site test representative of the in-service conditions would improve the situation. (Other methods are available such as ultrasonic scanning systems. These are explored further in Section 5).

The main challenges of electrofusion jointing are highlighted as:

- Alignment of pipe. Clamps required to hold the pipe are cumbersome and not easy to use in a confined environment. In practice installers would perhaps use their foot to hold the pipe in place.

- Scraping top layer off plastic (to be carried out using a mechanical scraper). Many of the installers struggled using the mechanical scraper in a confined space. In practice installers might use a hand scraper where it was easier/more convenient. There was also a requirement following scraping to wipe with a 90-95% alcohol wipe to clean the jointing surface, however, it is difficult to get a guaranteed clean surface in site conditions.

- Ovality of pipe. This occurs with coiled pipe and is generated during pipe production when the pipes are not allowed to cool sufficiently before being coiled. Pipe re-rounders are available however site teams would not be aware of their effectiveness of different types. In some cases aluminium tubes were inserted into the joint section of pipe to ensure straightness and minimise ovality during the jointing process.

- Cleaning and decontamination of the pipework and fittings in a field situation.

- In live system repair scenarios, the upstream isolation valve also has to be secure and not passing or the water would dissipate the heat required for the joint to cure.

- Fitting type and quality. In the past there have been problems with the use of incorrect fittings but this has improved with improvements in the jointing technology. For example software on machines now reads barcodes on the pipes reducing the risk of this mismatch. There have also been problems with the quality of fittings, as water companies push for cheaper fittings the quality inevitably suffers, the cheaper fittings being less tolerant to other variables.

Wider consultation with the UK water companies and contractors raised the following additional points:

- EN 12201-3 sets minimum standards for EF fittings. Some fittings have better resistance to gaps and contamination, but there are no tests within the EN to differentiate between performance and purchase tends to be on the basis of price.

- The equipment to aid installation is available, but is not always used. There is some variation in the effectiveness of equipment e.g. Top loading clamps for tees tend to be more effective than those which use straps.

- The standard of training is extremely variable across the Industry and qualified personnel are not always conducting welding procedures.

- With rehabilitation in particulate teams are working against very tight time constraints and I believe this causes lapses in best practice.

As evidenced by the list of potential difficulties, electrofusion jointing in the field is susceptible to failure. The large number of variables which can affect the quality of the joint requires significant care from the installers. In the view of an ex-site supervisor, the poor reputation and experiences with electrofusion jointing is a combination of poor engineering practice, poor workmanship and the quality of materials and tools, added to the fact the joints are being made in difficult and dirty field situations.

Compression fittings are also available (including the Redman fitting by Radius Systems[16]) and site experience showed they worked well. However these were only used very occasionally. Unfortunately the fittings are 2 – 3 times more expensive than electrofusion jointing so the water companies are reluctant to authorise widespread use. However they were used by sub-contractors in circumstances where electrofusion was not possible e.g. the valve was letting water by, and hence cooling the pipe preventing cure of an electrofusion joint. The fittings come in a variety of sizes and use a dedicated hydraulic pump to compress the fitting. The supplier states they can be used in all weather conditions require little pipe preparation and provides an end load bearing joint once fitted. Similar products may be available from alternative suppliers.

Socket Fusion

Socket fusion welding was used in the UK Gas Industry with the early Aldyl A PE pipes, but was gradually phased out in favour of butt fusion and electrofusion welding. The technique was also used to a limited extent in the UK Water Industry.

[16] Radius Systems Ltd. Redman Fittings by Radius Systems (2016) [online]. Last accessed May 2016 at: www.radius-systems.com

The technique uses pipes and an injection moulded fitting. A metal socket mounted on a hot plate heats the exterior of the pipe, while a metal spigot on the opposite side of the heater plate is inserted to heat the inside surface of the fitting. The pipe and injection moulded fitting are heated for a specific period of time, after which the heating tool is removed and the pipe is pushed into the fitting. The pipe and fitting are then allowed to cool for a specific period of time.

However, the early PE materials had a substantially lower resistance to slow crack growth than current PE materials leading to failures at the stress concentration created by the weld bead formed between the pipe and fitting. These stress concentrations can act as a point for the initiation of crack growth if the pipe is exposed to bending.

It may be worth revisiting and possibly developing this technique as an alternative to electrofusion as it is essentially much simpler. However, the heating tooling required for socket fusion could make it a less attractive option for in-trench welding and repairs.

Butt Fusion

In this technique the pipe ends or fitting spigot ends are heated so that the temperature of the plastic is raised above the melting point, after which they are then brought together so that mixing of the polymer melt at the interface occurs for fusion to take place. The pipe ends are held together for sufficient time to allow cooling and solidification to occur without disturbance.

Within the UK this is an established technique and extensive research was carried out in ensuring that the welding parameters, which are detailed in WIS 4-32-08[17], produce high quality welds which have integrity against failure in service.

Historically there have been very few failures of butt fusion welds, although in the last few years, there have been a number of failures of large diameter thicker walled PE pipes which have been attributed to issues with the welding procedure or installation. Consequently there has been significant work to look at the welding parameters for larger diameter thicker walled pipes and also consider the different welding parameters used in the Gas and Water Industry in other parts of the world. The UK has also been active via the British Standards Institute (BSI) in ensuring that the welding conditions used in the UK are correctly reflected in the ISO specification (ISO 21307[18]), which is currently under revision.

It should be noted that there are welding parameters in use in other parts of the world, which allow much faster fusion/cooling times and hence significantly shorter welding cycle times. Although these parameters are attractive in terms of productivity, there is some doubt that the welds will have the same integrity in service as welds produced in accordance with the requirements in the UK.

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[17] Water Industry Standard (WIS) 4-32-08 (under revision). Specification for the Fusion Jointing of Polyethylene Pressure Pipe Systems Using PE 80 and PE 100, Issue 3, 2002.

[18] ISO 21307:2011 Plastics Pipes and Fittings. Butt Fusion Jointing Procedures for Polyethylene (PE) Pipes and Fittings Used in the Construction of Gas and Water Distribution Systems.

The development of a WIS standard for the training of butt fusion and electrofusion welding personnel and which could eventually be referred to in water utility procurement documents has been started.

Electrofusion

An electrofusion coupler or tee is a fitting where the means of heating to achieve polymer melting is via a coiled electrical wire laid into the bore (electrofusion sockets) or the base (saddle tees) of the fitting. In the case of electrofusion, the pipe ends are prepared by removing the outer surface of the pipe end which is then inserted into the socket. The complete assembly is restrained in clamps. With tees, the contact area of the pipe is prepared and the tee held in place using a loading clamp. When a current is passed through the coil, there is heating of the surrounding polymer and heat transfer to the pipe wall. As with butt fusion, melt mixing takes place and constrained by the cold zones at either end of the heating coil a high melt pressure is maintained. This ensures adequate melt mixing between the pipe and fitting. The applied current is discontinued after a prescribed period of time and the pipe and fitting held in place to cure.

In comparison to butt fusion welding there are a significant number of failures of electrofusion fittings, which are usually attributed to the following issues with the welding procedure:

- Contamination from dirt and dust on the fusion interfaces
- Poor surface preparation
- Gaps between the pipe and fitting arising from misalignment due to poor clamping
- Gaps caused by failure to re-round the pipe

With electrofusion fittings the contamination and pressure resistance is determined by the length of the fusion zone. As the European specification for electrofusion fittings (BS EN 12201-3)[19] specifies minimum fusion lengths and the cost of the fitting is dictated by the length of the fusion zone (amount of heating wire used), then manufacturers generally manufacture to the minimum value.

A study was carried out by the University of Sheffield that investigated the fatigue performance of contaminated Electro-fusion Tapping Tees[20]. Using a servo-hydraulic fatigue testing machine, talc was the chosen particulate used for the contamination as it is known to have a detrimental impact on the fracture toughness. The fatigue cycles were performed in a trapezoidal loading pattern with a fixed mean pressure. The results concluded that electro-fusion joints made to best practice proved not to fail under the test regime. The fatigue failure dramatically reduced as the pressure range decreased. Further testing was carried out using the crushing decohesion test which showed similar debonding patterns. The

[19] BS EN 12201-3:2003 Plastic piping systems for water supply. Polyethylene (PE). Fittings.

[20] P.Tayefi, The Influence of Contamination on the Fatigue Performance of Electrofusion Joints. University of Sheffield 2014.

results of the testing suggested a strong correlation between failures and the amount of contamination on the surface.

The following table summarises the associated costs with electrofusion joint failures:

Table 1 Associated cost of electrofusion joint failures

Cost to Repair	Cost to Water Company	Cost to Society
Leak detection	Loss of a valuable resource	Environmental damage
Excavation of pavement	Non-billed water	Failure to supply water
Removal, repair, replacement	Cut of water service	Claims and compensation
Cleaning and disinfection	Flushing water for cleaning and disinfection	Public and private property damage
Landfill debris disposal		Damage to companies image

Improvements in Electrofusion Fittings

In the UK a test to determine the resistance of electrofusion fittings to contamination was introduced in to WIS 4-32-08, which brought a step change in performance. Although most UK manufactures carry out the test, UK Water Utilities are unable to legally specify this test in procurement documents.

It is however noted that certain manufactures are supplying fittings with longer fusion zones and also longer penetration depths which compensate for misalignment, bending stresses and also to ensure even build-up of melt pressure.

There is not a great deal of academic research into the design of electrofusion fittings as the majority of development is conducted by the fitting manufacturer and each has specific design features.

The introduction of a specific standard for the training of welding personnel will prevent some of the failures that occur due to poor installation in service. However, this may not significantly assist the problems with larger diameter fittings where producing high quality welds is more difficult. It may therefore be necessary to consider an alternative method.

In Scandinavia the Water Utilities (Sweden, Denmark, Norway and Finland) have taken a different approach thorough their 4S group. They have experienced significant problems with electrofusion fittings and decided that the current performance is inadequate. Through the 4S group, they have engaged with manufacturers and initiated competitions to design fittings with improved performance and provided some finance for prototype designs. The group are also involved in reviewing NDT techniques for fusion welds and also improving the training of welding personnel.

Development of Coil Straightening Equipment

The development of suitable equipment for the straightening of PE pipe prior to fusion welding has been carried out in the UK by Steve Kent of Exova (formerly Pipeline Developments).

The first version of the equipment for straightening of coiled pipe prior to installation was developed in 1991. The equipment was mounted on the coil trailer and was operated by a hydraulic pusher. Trials conducted on 90 mm, 125 mm and 180 mm PE 80 determined that the straightening process caused some reduction in pipe diameter and the forces exerted in pushing or pulling the pipe through the equipment were excessively high. The use of a hydraulic pushing unit made the equipment both large and expensive. Only one water utility ever stipulated the use of a coil straightener and the equipment was only used very rarely.

In 2008 the equipment was re-developed as a stand-alone unit which could be located directly in the trench into which pipe was being installed. For safety, at the start of the straightening process, the pipe is manually fed into the straightening equipment while it is attached to the coil straightener. When trials were conducted on PE 100 the reduction in pipe diameter and towing forces were significantly greater than for the original trials on PE 80. There were also difficulties in achieving a balance between increasing the radius of curvature of the pipe and preventing a significant reduction in diameter, while taking into account variations in ambient temperature. The equipment also tended to damage the PE pipes even though they had a protective polypropylene (PP) skin.

The equipment was modified so that it had a split frame, which included a die plate with a large orifice, which allows working of the very outer diameter of the pipe to achieve the required radius of curvature and ovality, but with a smaller reduction in diameter. Using the equipment, it is possible to produce pipes with a radius of curvature >10 m and an ovality in the region of 2%. Although there is some decrease in the radius of curvature of the pipe after the straightening process, as the pipe recovers, measurements have shown that the pipe is in a satisfactory condition for jointing for approximately 1 week. The revised configuration of the equipment also prevents damage to pipes with a protective polypropylene skin.

With the latest design of equipment, it has been possible to produce joints (using optimum conditions and contamination) which have been satisfactory in terms of performance when destructively tested in accordance with WIS 4-32-08.

Although there has been extensive development of this coil straightening equipment, it is not commercially available. There is commercially available coil straightening equipment which is provided by McElroy which is referred to as the 'Line Tamer'. It is not believed that this equipment is widely used in the UK.

It should be noted that although there is equipment potentially available to allow coiled pipe to be processed to produce curvature and ovality which are within the tolerances for effective fusion welding, it is essential that best practice welding techniques and robust clamping equipment is used to produce joints of consistent quality.

Difficulties and potential solutions of service pipe joints

Joints connecting service pipes are thought to be a source of considerable water loss, although it is uncertain if any formal study has been conducted to determine if the leakage is predominantly from electrofusion fittings or other types of mechanical fitting.

Lead pipe is often not a standard size. When connecting to existing lead pipes, it is often necessary to reduce the diameter to allow the use of a transition fitting. It is difficult to reduce the diameter in a uniform manner, which may compromise the integrity of the joint.

Radius Systems have developed a PE electrofusion tapping tee (Anaconda[21]) for gas applications, which has a flexible corrugated pipe pre-welded to the outlet of the tee, so either an on-site electrofusion weld or mechanical fitting is not required. The flexible corrugated pipe is also capable of accommodating horizontal and vertical changes between the main and service pipe connection.

4.3 Alternative Welding Techniques for PE Pipes

Linear Vibrational Welding

A study was carried out by The Welding Institute (TWI)[22] into the feasibility of using linear vibrational welding (LVW) of 125 mm SDR 11 PE 80 and 180 mm SDR 17 PE 100 pipes. The mechanism for generating heat during vibrational welding is by the interaction of two rubbing surfaces. This is produced by linear motion of one of the pipes relative to the other, while a force is applied. Once sufficient molten material is generated, the vibration is stopped and the pipes are aligned. The applied force is maintained until the weld is sufficiently cool.

The welding technique provides significant time savings over butt fusion welding and when destructively tested the welds exhibited an exclusively ductile mode of failure. One practical issue with the technique is that in this study the pipes are held vertically in the welding equipment and development of the equipment would be required to allow on site welding.

In the trials conducted to date, the pipes have been relatively thin walled and more extensive trials would be required to determine the performance of thicker walled and larger diameter pipes before this technique would be accepted.

Infrared Welding

Infrared welding[23] is also a technique which can be used for the jointing of PE pipes. In the welding process the pipe ends are brought into very close proximity with an electrically heated plate, but not directly in contact with the plate as in butt fusion welding. After a

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[21] http://www.radius-systems.com/products/gas-systems/fittings/anaconda/

[22] M.J. Troughton, Linear Vibration Welding of Polyethylene Pipes, International Plastic Pipes Conference (IX), Edinburgh 1995, p424-432.

[23] T. Sixsmith, J. Wermelinger and C. Williamson, Advantages of Infra-Red Welding of Polyethylene Pipes for Industrial Applications, International Plastic Pipes Conference (IX), Edinburgh 1995, p424-432.

sufficient heating time the pipe ends become molten and are brought together to form the weld. Infrared welding is up to 50% faster than hot plate welding. As heating is achieved without the pipes being physically in contact with the heater plate the chance of contamination the weld surface is minimised. The welding technique is also based on displacement of the pipe ends, rather than an applied pressure to form the weld. In the study referenced, there was no assessment of the quality of the welds by destructive mechanical testing.

The equipment required to produce welds is similar to that required for butt fusion welding and as a result it is unlikely the technique would provide an alternative method to in-trench electrofusion welding. It is also unlikely that it would replace an established technique such as butt fusion.

Mechanical Jointing

There are an extremely wide range of mechanical fittings available for plastic pipe systems and hence it is difficult to give a concise overview of the relative benefits of the different types. As fittings often incorporate a number of components, such as grip rings, inserts and seals, leakage can occur due to issues with assembly of the fitting on the pipe. Where fittings (e.g. stub flanges) rely on the compression of gaskets using bolts, leakage can occur due to stress relaxation over a period of time or due to incorrect or insufficient tightening of the bolts.

4.4 Jointing Techniques Conclusions

- Butt fusion welding for PE pipes is an established method and the incidence of failures is rare.

- Electrofusion welding is a much more difficult technique to execute on site (particularly with larger diameter pipes) and there is a significantly higher incidence of leakage and failures than for butt fusion.

- The components of the systems such as the fittings, coupling and the tools used in electrofusion jointing are in principle fit for purpose and should not be the reason for leakage. There is however evidence to support the fact that water companies and contractors procurer inferior fittings to cut costs and this has an impact of failure and resulting leakage.

- Poor workmanship is considered the biggest cause of poor jointing and the resulting leakage. The implementation of a specific standard for the training of electrofusion welders (under development) would be expected to reduce the incidence of failures in smaller diameter electrofusion fittings.

- It is thought that it may be necessary to consider a new alternative method of welding for larger diameters.

- Alternative welding techniques such as linear vibrational welding and infra-red are unlikely to replace the established butt fusion and electrofusion methods.

- The use of longer lengths of coiled pipe will require further availability of specialist equipment to produce pipe with satisfactory curvature and ovality characteristics to allow the production of high quality fusion joints.
- It is necessary to ensure that effective ancillary equipment such as re-rounding/ restraining clamps are available and the personnel making the welds have sufficient training to make use of them.

5 Testing and Commissioning

5.1 Destructive Testing of Butt Fusion Welds

In terms of quality control testing of plastic pipelines during construction and prior to pressure testing, destructive testing is limited to PE butt fusion and electrofusion welds.

Tensile Testing of Butt Fusion Welds

The tensile testing of butt fusion welds is an established method of assessment, as detailed in WIS 4-32-08. Assessment of weld quality is based on a visual assessment of the fracture surfaces. There are companies that offer both laboratory and onsite testing. The benefit of onsite testing is that any issues with welding procedure may be addressed immediately.

5.2 Destructive Testing of Electrofusion Welding

Electrofusion Couplers

A double cantilever bending test is used to cause separation of the weld interface. This test is also outlined in WIS 4-32-08. Assessment of the weld quality is based on a visual assessment of the fracture surfaces and also the calculation of a fracture toughness, which provides a measure of the resistance of the fusion interface to crack growth. Smaller diameter fittings are assessed by crushing the end of the pipe to cause separation of the pipe from the fitting and evaluating the mode of failure at the interface.

Top Tees

Top tees may also be assessed by causing separation of the weld interface by crushing of the pipe. There is also a test in which attempts to remove the tee from the pipe, by clamping the pipe and applying a tensile force to the tee. These tests are detailed in WIS 4-32-08 and rely on a visual assessment of the weld interface.

Frequency of Testing

At present WIS 4-32-08 and other testing specifications do not state the frequency with which welds should be tested. In addition, the specifications do not state the importance of (where possible) sampling and testing production welds from the installed system. For electrofusion welding, it has been demonstrated that quality of welds produced on the surface under supervision are significantly better than those produced in trench[24].

Summary of Destructive Tests for Butt Fusion and Electrofusion Welds

- There are destructive tests available for both butt fusion and electrofusion welds to identify issues with procedures/equipment and to ensure consistent weld quality. These tests can be carried out on site to allow immediate correction of any issues.

- The test specifications do not currently provide guidance on the frequency with which welds should be tested or emphasise the importance of sampling welds installed in the system to ensure the best measurement of the quality.

5.3 Non Destructive Testing of Butt Fusion Welds

Bead Twist Test (Manual Test)

With butt fusion welding it is good practice to remove the weld beads using a bespoke bead removal tool, to allow visual inspection for uniformity and evidence of defects or discontinuities. In addition to the visual inspection, the bead can also be physically tested by welding personnel. This is done by both bending and twisting the bead to apply a stress to the welded interface and examining for signs of splitting, defects or signs of contamination. If any issues are observed with the bead, then the weld is removed and another weld produced. In the case that issues are noted with the next weld, then further production welding is suspended until the problems have been rectified through equipment checks and producing further trial welds.

Automated Bead Twist Test

It is often the case that the bead twist test is not carried out or the testing of the complete bead is only partially completed. In addition, for larger diameter thicker walled pipes where the beads are bigger, it is often difficult to apply sufficient force to the bead manually to ensure it has been tested effectively.

For this reason, Control Point developed a bead diagnostic instrument (BDI)[25], which applies a combination of bending, shear and tensile stress along the length of the bead, as it is drawn through the mechanism of the instrument. As the bead passes through the instrument and optical sensor monitors the bead for any signs of splitting and provides a visual indication to the installer regarding the integrity of the bead. The data for the assessment of the bead can be linked to the welding data from the butt fusion equipment and uploaded to a dedicated website for audit processes. In the case where the BDI identifies a defective weld bead, use of the welding equipment can be prevented until corrective action has been implemented.

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[24] E. Ingham and M. Wheeler, Leakage From PE Pipe Systems, UKWIR Report Reference 10/WM/08/43, 2010.

[25] E. Bridgestock and D. Carey, Bead Diagnostic Instrument. A Reliable and Simple Non-Destructive Test for Polyethylene Butt Fusion Joints, Control Point Technical Paper, December 2015.

Figure 6 Bead Diagnostic Instrument (BDI)

Control point report that in the development of the BDI, 450 butt fusion welds were produced (including welds produced in optimum conditions and welds with contamination applied to the welding interface). A 100% correlation between the results for the BDI and mode of failure in destructive tensile tests which were subsequently conducted on the weld were achieved.

5.4 Auditing of Butt Fusion and Electrofusion Welding

On Site Auditing

A number of companies provide on-site auditing of the welding personnel and on site testing of welds to identify any issues. They also provide training to correct any problems with the welding procedure.

Technology for Auditing of Electrofusion Welding

Real time joint inspection is a tool which is being currently used so that trained joint technicians can assess live joint connections made, to determine if they are fit to be incorporated into the network. Following identification of a poor joint, the technician can notify supervisors before backfilling takes place to reduce the likelihood of that joint failing in the future. This system provides an audit trail to assess any future failures and inform the person responsible, helping the whole team improve on a continual basis and apply re-training where necessary. This process can be carried out for both butt fusion and electro-fusion joints.

5.5 Non Destructive Testing (NDT) of Butt Fusion and Electrofusion Welds

There are a number of testing techniques which are available for the non-destructive testing of butt fusion and electrofusion welds. The type of defects which can be detected such as cold fusion, lack of fusion, contamination and voids is dependent on the type of technique. At present the techniques can be used to identify problems with the welding procedure, so that corrective action can be taken, but there are no acceptance criteria available for either the size or concentration of any defects which are detected. In addition, there are also issues with relating the presence of defects to the long term performance of welds. It would appear that there is a great deal of work being carried out in this area, which will be presented in a specific NDT workshop at the next International Plastic Pipes Conference which will be held in Berlin in September 2016.

At present it is not possible to state the lifetime of a fitting on the basis of the analysis carried out- they tend to act as a means of identifying issues and putting corrective measures in place. There will be a big focus on NDT at the forthcoming Plastics Pipe Conference in Berlin in September 2016 which will yield more information.

A summary of some of the NDT techniques which are available and under development are provided in the following section of the report.

Phased Array Ultrasound (PA-UT)

In terms of NDT techniques, phased array ultrasound has been shown to have the most potential for the inspection of plastic materials. Significant research has been conducted on polyethylene welds and progress made regarding the identification of defects[26]. In comparison to the pulse-echo method which uses a single probe (element) in a wedge, a phased array probe contains multiple elements arranged in an array in the same wedge. The advantage with a phased array probe is that the elements can be adjusted to change the beam angle used to inspect a specific part. It is possible to electronically control the time at which the elements fire, it is possible to focus and alter the shape of the beam, so that inspection can be tuned to the geometry of the part which is being inspected. The method is effective in detecting physical boundaries such as voids and cracks which will result in a change in the time of flight of the returning signal to the probe. The PA-UT method is suitable for use with PE and other plastic materials.

This is probably one of the most mature NDT techniques for the evaluation of PE welds. There has been a large amount of work using the technique by TWI and it has proved to be successful in detecting defects in both electrofusion and butt fusion welds, which have been verified in subsequent destructive testing. The technique is however reliant on an experienced operator.

A number of companies offer on site assessment of welds using phased array ultrasound and there is a standard (ISO DTR 16943)[27] available, which utilities could reference in procurement documents if the technique were to be considered.

Single shot 'A scan'

One example of this technique is the system currently offered as a service by Impact Solutions Ltd. The systems uses single shot a scan ultrasonic technology to assess the quality of an electrofusion joint in a non-destructive manner. The system picks up brittle structures and voids in the weld that pose a risk to the joint life. For example if the weld contained dirt but this had not affected the weld integrity this would not be picked up. If a section of the pipe had not welded as a result of misalignment for example, the system would show this as a risk, as shown in Figure 7 below.

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[26] F. Hagglund. Phased Array Ultrasonic Inspection of Electrofusion and Butt Welded Joints in Plastic Pipes. 18th World Conference on Non Destructive Testing. Durban 2012.

[27] ISO DTR 16943 Thermoplastic pipes for the conveyance of fluids. Inspection of polyethylene electrofusion socket joints using the phased array ultrasonic testing method).

Figure 7 Non-destructive testing result example

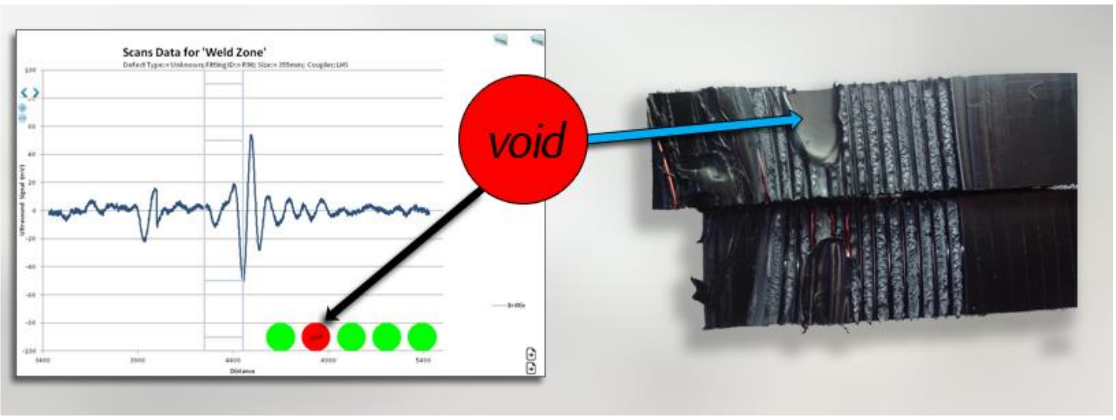


Image courtesy of Impact Solutions Ltd.

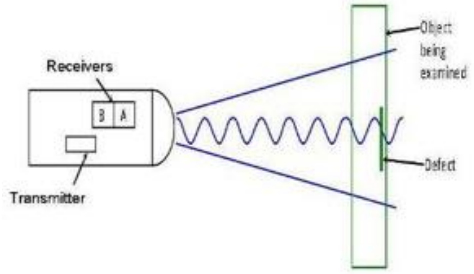
In a conversation (16/05/16) David Smith, Commercial Manager at Impact Solutions told WRc that the ultimate objective is to get the technology to a stage where they could offer a ‘black box’ to those wishing to assess the quality of electrofusion joints and with some training, weld-quality inspectors would be able to use the system with the software carrying out the majority of the work. Impact Solutions believe they will have the technology ready for this type of arrangement by the end of 2016. At this stage the operator will require several days training in order to be able to effectively use the system. As the product continues to be developed they hope to reduce the amount of operator input (and therefore) training required and put more of an onus on the software within the testing ‘black box’. The system has been used in the UK in several situations to-date.

Impact Solutions provided a case study in which the Impact NDT system was used to test electrofusion joints on a relayed fire main. The original fire main had experienced a number of early life joint failures. Destructive tests were performed on the burst joints which lead to the contractor choosing to relay the main and conduct NDT assessment on all new electrofusion welds. Impact NDT was used on forty two electrofusion joints on the new main, two of which were highlighted as being a potential risk which the contractor chose to redo. David noted that one of the challenges was to get the system recognised at all levels of the chain i.e. water company, tier 1 contractor and any subsequent sub-contractors. Other similar non-destructive testing systems are available from other suppliers such as TWI and Exova.

Microwave NDT

A microwave NDT probe consists of a transmitter and two receivers. A non-conducting material is inspected by sending low power (millivolt) microwave energy of a constant frequency (≈ 25GHz) from the transmitter to the part. Energy is reflected from any electrical boundaries within the material which may constitute many types of defects. The reflected energy is picked up by the two receiving channels, A & B, and creates a resulting signal measured in volts. These are collected across the sample to create an image. One advantage of the technique is that it is a volumetric method of inspection resulting in no thickness limitations.

Figure 8 General configuration of microwave probes



The technique has been successfully used to identify defects in butt fusion welds, which have been subsequently verified by destructive testing[28]. Microwave imaging has also shown significant potential in the assessment of electrofusion jointing, although the interpretation of the images is more difficult than for butt fusion joints. As with most NDT techniques the acquisition and interpretation of the images is highly dependent on the skill and experience of the operator.

An automated version of the microwave technique is available for the scanning of butt fusion welds and a draft standard[29] for the assessment of PE fusion joints is being developed.

Digital Radiography

Digital radiography is a form of X-ray imaging, where digital X-ray sensors are used instead of traditional photographic film. Radiography relies on changes in bulk density to detect features or anomalies within a specimen. Radiography has been used to supplement the visual inspection of larger diameter polyethylene pipe. Although this technique is relatively new in terms of inspection of electrofusion joints, it can readily determine tolerance or assembly issues such as misalignment, insertion distance (lack of fusion) or highlight issues with the heating wires.

Summary of NDT Techniques for Butt Fusion and Electrofusion Welds

- There are a number of techniques for the NDT of butt fusion welds, which vary in their maturity.
- A number of companies are already providing phased array ultrasound and microwave NDT as on-site techniques to assess the quality of butt fusion and electrofusion welds.
- At present as there are no formal acceptance criteria for the size and concentration of defects which are detected. The techniques therefore tend to be used for the identification of issues with the welding process and then applying corrective action.

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[28] K.A. Murphy and D. Lowe, Evaluation of a novel microwave based NDT inspection method for polyethylene joints. ASME PVP 2011, Baltimore, July 2011.

[29] ISO/TC138/SC5/WG17 N132 (Inspection of polyethylene fusion joints using microwave imaging non-destructive evaluation).

- The techniques are reliant on the skill and experience of the operator for interpretation of data obtained.

5.6 Pressure Testing of Plastic Pipelines

The pressure testing of plastic (PE, PVC and GRP) is outlined in the UK Water Industry information and guidance note WIS 4-01-03[30], which takes account of the European specification EN 805[31]. The standard has been developed and modified over 20 years and is considered to be very robust in identifying leaks.

Pressure Testing of New Mains

Pressure decay (Type 2) testing is used for the testing of new plastic water mains. The test is very simple to carry out and involves using a pump to increase the pressure of the main. On achieving the required test pressure, the pump is switched off and a valve closed and the pressure decay is monitored as a function of time, either using a pressure gauge or transducers. The accuracy of the test improves the longer the decay in pressure is monitored, but leaks can be detected in relatively short timescales.

Pressure Test for Rehabilitation (10 Minute Test)

Where rehabilitation of existing mains is conducted, there are often strict time restrictions to ensure that any disruption to the water supply is minimised. As the Type 2 test takes a minimum of an hour to complete, it may not be suitable. For this reason, a 10 minute pressure test was developed in which the system can be pressurised against a closed valve or sections of pipe which has been isolated. The test differs from the Type 2 test in that it is a constant pressure rather than a constant volume test. In the 10 minute test, the System Test Pressure (STP) should be 1.5 * PN of the lowest rated component in the length under test, up to a maximum of 15 bar. This pressure is then maintained constant while a visual inspection is conducted on the test section for any sign of leakage.

The 10 minute test does not offer the same level of robustness as the Type 2 test in terms of interpretation and hence detection of small leaks. These tests are defined in WIS 4-01-03.

If trenches or reception pits are open when the test is conducted, visual checks for leaks can be used to complement the analysis of pressure data.

Test for Tapping Tees and Service Connections

WIS 4-01-03 includes a test which can be used to test tapping tees and service connections. With tapping tees the integrity of the weld (electrofusion tapping tees) or attachment (mechanical tees) is determined by pressurising the tee through the outlet, before tapping through the main to make the connection.

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[30] Water Industry Information and Guidance Note (IGN 4-01-03) Pressure Testing of Pressure Pipes and Fittings for Use by Public Water Suppliers, Issue 2 October 2015.

[31] BS EN 805:2000. Water supply. Requirements for systems and components outside buildings.

The other joints in the service connection up to the stop tap can also be tested in a similar manner by pressurisation through the tee, prior to tapping into the main.

This test is a visual test which is carried out over a period of only 2 minutes.

This testing of tapping tees and service connections is routinely undertaken by the water industry but further development in a simple field test to rapidly cycle the pressure within a fitting to induce a potential fatigue failure to identify poorly made connections should be considered.

Recording of Pressure Test Data

In the UK there are a number of companies, which offer independent pressure testing and analysis of data. In some cases, the data loggers supplied have GPS which allows the exact location of the pressure test to be recorded for audit purposes.

5.7 Testing and Commissioning Conclusions

- The UK pressure testing specification contains a robust series of tests for detecting leaks in plastic water pipe systems.
- In addition to tests for new mains, the standard contains alternative tests for pipes which have been rehabilitated, tapping tees and service connections which accommodate the time constraints which are often in place for restoring customer supply.

6 Protection Systems

6.1 Barrier Systems

Currently there are polymeric and transition epoxy coatings available for providing protection to the pipe when in contact with aggressive conditions. These cater for the different soil types and aggressive environments to which the pipes may be subjected to. They are also required to be chemically inert and have good abrasion resistance.

6.2 Pipe Lining Materials

Cement and epoxy liners are currently used in metallic pipes, these help to resist abrasion from the coarse particles in sewage. These lining materials therefore help to prolong the onset of invert corrosion and soffit corrosion, as they also provide good chemical resistance.

6.3 Additive Layer Manufacture/ 3D Printing

If these techniques become commercially available and affordable on a large scale they may be explored as a means applying a barrier system or preventing the onset of further degradation of a live main. This may allow the removal of the damaged material and replacement with new material. There may also be applications to maintain or renew coatings.

6.4 Sacrificial Anode Cathodic Protection Systems (Metal Pipes)

Sacrificial anodes are a system which degrade preferentially to the pipeline materials and consequently protect the pipeline from electrochemical corrosion. This system is not without flaws as it is likely to rely on manned staff checking the condition of the sacrificial anodes on a regular basis. This has the potential to be automated if smart infrastructure is applied, especially if smart infrastructure becomes more cost effective.

6.5 Impressed Current Cathodic Protection Systems (Metal Pipes)

Cathodic protection systems provide a sacrificial anode connected to an external DC power source. This is used when the galvanic cathodic protection is not adequate due to the size of the pipeline structure or there is high soil resistivity. The DC output is adjusted to the optimum level for the protection system. The limited use of cathodic protection is currently cost driven and may change in the future. Cathodic protection can also help prevent stress corrosion cracking in some cases.

7 Workmanship

In a conversation with WRc (24/03/16), an ex-site supervisor for mains replacement noted that there were a variety of reasons for plastic pipe failure. Questionable workmanship practices were cited including anecdotal evidence of installers using feet instead of clamps. In an article published by WWT in 2015, Bob Warren of GPS PE Pipe Systems noted the competency required for installers are higher elsewhere in Europe[32]. Many European countries require certification of installers by third parties, and while it is noted there are some training standards available, they have either not been adopted by the UK Water industry (BS EN 13067: 2012 – Plastics welding personnel: Qualification testing of welders and thermoplastic welded assemblies) or are non-mandatory advisory standards, (WIS 4-32-08 'Fusion Jointing of Polyethylene Pressure Pipeline Systems'). Improving the level of training and qualification of the installers joining plastic pipes would be likely to increase the standard of the joints made. That is not to say that the installers are not currently competent but perhaps don't fully realise the importance of following the correct procedures (i.e. the need for using clamps to align the pumps instead of feet). Systems are available which monitor and allow for remote 'real-time' inspection and approval of procedures by experts. An example of this is the RedBox telemetry system developed by ControlPoint[33]. In instances where it has been used the system has been highly successful in improving the quality of workmanship.

7.1 Laying of Mains and Services

There is a Network Construction Operations scheme for the installation of water mains and services, which has been developed by the Energy, Utility and Skills Register (EUSR) in

[32] Warren, Getting to Grips With... Electrofusion Jointing (2015), WWT [online]. http://wwtonline.co.uk/

[33] Institute of Water, Severn Trent Water and RedBox Technology: Proving Polyethylene Works (2012). IoW [online]. https://www.instituteofwater.org.uk/

conjunction with the water industry. It is not certain if all Water Utilities and their contract staff follow this particular scheme and further investigation would be required.

EUSR also holds and stores training records that can be accessed by employers to check that personnel are appropriately qualified. The training is aimed at a number of levels (assistant, trainee, service layer, mains layer and supervisors), with the term of qualification ranging from 15 months (for an assistant) to 5 years for the other roles. Most of the individual elements of the various qualifications are based on the modules taken for the New Roads and Street Works Act (NRSWA) training courses. The Certification and Assessment Board for the Water Industry (CABWI) and City and Guilds certificates which are required for each level of qualification are also outlined.

In terms of installation of mains, the qualifications are divided into categories which are dependent on pipe diameter (up to 180mm, up to 315mm and 315mm and above). In each of these categories personnel must demonstrate a number of competencies regarding excavation of trenches and jointing of the pipe using fusion and mechanical jointing techniques.

Further enquiries would be required to determine exactly which schemes each of the individual Water Utilities uses for personnel, contractors and self-lay organisations. Potential gaps in training need to be identified and addressed.

7.2 Training for Butt Fusion and Electrofusion Welding Personnel

There are currently a number of issues relating to the training of butt fusion and electrofusion welding personnel as noted below:

- Some training courses based on UK WIS 4-32-08.
- Lack of a National Standard causes inconsistencies in training and consequently the competence of installers.
- Training is classroom based rather than under true site conditions.
- All practical assessments use relatively small diameter pipes.
- Practical assessments are on straight pipe and not coils.
- No time limit before re-training/refresher training is required.
- No system to address poor workmanship/or ensure corrective training is taken.

In order to address these issues a group comprising of the Water Utilities, pipe and fitting manufacturers, training providers and contractors has begun preparing a WIS standard for training of fusion welders.

A draft of the standard is at an advanced stage and the following section provides a summary of the proposed structure of the document:

The pipe size ranges for each level of qualification and the areas which will be assessed are shown in Table 1. The drafting group has decided that there should be three qualifications for electrofusion and two for butt fusion. The qualifications for both butt fusion and electrofusion will be awarded on a modular basis (i.e. to gain EF 2, the candidate must first hold a current EF 1 qualification).

Table 2 Structure of the specification

Training Area	Electrofusion 1 (20mm-180mm)	Electrofusion 2 (200mm-315mm)	Electrofusion 3 (≥355mm to 710mm)	Butt Fusion 1 (63mm-355mm)	Butt Fusion 2 (≥355mm to 900mm)
Electrofusion	✓	✓	✓	-	-
Butt Fusion	-	-	-	✓	✓
Service Pipes	✓	-	-	-	-
Distribution Pipes	✓	✓	✓	✓	✓
Straight Pipes	✓	✓	✓	✓	✓
Coiled Pipe	✓	-	-	✓	-
Pipes with Peelable Layer	✓	-	-	✓	-
Barrier Pipes	✓	-	-	✓	✓
Coextruded Pipes	✓	-	-	✓	-
Branch Saddles	✓	✓	-	-	-

As the purpose of the standard is to provide an appropriate level of training to allow welding personnel to be self-supervising, it is not necessary to have a separate standard for supervisors. Individuals will be able to demonstrate their suitability to supervise welders through a continuous record of competency. It has been suggested that this could be demonstrated by them carrying out a full day of fusion operations on site at a minimum of six monthly intervals. Other aspects of supervisory skills will be covered by the NVQ level 3.

Further work has provisionally outlined the areas which are covered in the theoretical exam and also the structure of the practical test, such as the diameters of pipe which need to be welded and also a definition of the conditions under which the welds are made. The aim is to have the welders produce assemblies under conditions which simulate those that they are likely to encounter on site.

There are on-going discussions to assemble a group of experts from water utilities to assist with the administration of qualifications for welding personnel. The proposal is to operate the scheme along the same lines as for spray lining, where one organisation holds the qualifications of personnel, which are audited by an independent body that holds UKAS Accreditation.

Case Study – Training in Spain

A study has been carried out in Chicago, USA, following the training programme that Spanish utilities carried out in order to improve the electro-fusion workmanship. This course was carried out by recognised training centres in the country. The training carried out in Spain provided a general knowledge of the plastic materials, hydraulics, standardisation and certification of products. There were also guidelines over best practice associated with transport and handling, trench types, pipe laying, jointing and anchoring in addition to backfilling, compacting and field testing.

Due to the range of topics covered and practical demonstrations, the course was carried out over 5 days, concluding with a practical and theory test. On completion and passing the course they would receive an installer's card to demonstrate that they have undergone training. This card is valid for 5 years, after which renewal is required. Currently 140 courses have been conducted and 1,400 professionals hold the 'AseTub' installers card.

7.3 Mechanical Fittings

There do not appear to be any specific training schemes for the installation of mechanical fittings, which is probably due to the very extensive range of fittings that are available in the UK. The component parts and methods of assembly also differ between fittings. In the EUSR qualifications for personnel installing mains and services, there is a requirement to demonstrate the joining of sections of pipe using mechanical fittings. The UK suppliers all offer their own specific technical training for the assembly and installation of their mechanical fittings.

When there are changes in the type of fittings used it is important that specific technical training for the assembly/ installation of the new fitting type be provided.

There is an EN standard (EN 1591-4)[34] which outlines the competency requirements for personnel making flanged connections to pipework.

7.4 Leakage And Excavations Innovation Action Group (LEIAG) Initiative

The LEIAG group was formed by WRc four years ago to drive actions on the zero leakage and zero excavations agenda. The group sought to engage with the right stakeholders, approach the right funders and build the business case for delivering action. LEIAG membership comprised a number of volunteers who expressed interest in being an active member driving forward the identified actions. Membership was drawn from WRc, water companies, suppliers, contractors, consultants and a trade association.

34 BS EN 1591-4:2013 Flanges and their joints. Qualification of personnel competency in the assembly of the bolted connections of critical service pressurized system.

An initial action the group took forward was with regard to plastic pipe joints. There was a need to identify why the industry has an issue with plastic pipe joints, was this a real issue and if so how could it be resolved. Much of the information regarding workmanship practices is anecdotal. The group identified a need to take this research further in identifying the real problems as a means to being able to address them. No individual stakeholder was appropriate to drive this work.

The working group explored the issues from various industry stakeholder perspectives and identified what activities are currently being undertaken to improve the situation. Priority actions were identified for the group to address. The need to quantify the problem (number of poor joints) was seen as an essential first step. This work has now been superseded by the work of UKWIR with the 2050 Zero Leakage project.

7.5 Workmanship Conclusions

- The standard of workmanship is thought to be one of the main reasons for failure of newly laid pipe networks. As a result this area offers some opportunities for further research and improvements.

- There are schemes (e.g. EUSR), for the training of personnel installing mains and services, but as this is an extensive area and further work would be required to establish which schemes individual utilities follow, the suitability of the training and any gaps which exist.

- At present there is no specific standard for the training of personnel carrying out butt fusion and electrofusion welding, which leads to inconsistent practice. A draft training standard is well advanced in its development, but there needs to be an initiative to complete the standard and ensure it is widely adopted as soon as possible as it will produce a step change in the quality of workmanship.

- Personnel installing mains and services must show some competency in the jointing of pipelines using mechanical fittings. There is no specific training for mechanical fittings due to the wide range which are available, but manufacturers provide their own specific technical training.

8 Commercial Incentives of Sub-Contractors

There is an often held belief that with today's technology, materials and material processes it is more than possible to lay leak free networks. Poorly made electro-fusion joints are known to be the most common cause of failure in PE mains. This causes leakage, bursts and interruptions to supply. The defects are most commonly caused by poor workmanship in the preparation of the joint prior to welding. The challenge is therefore not a technical one; the issue is around the incentive and behaviour of site workers and those that manage them.

Traditional contracts are either awarded on a lump sum, item rated or a combination of the two. The measure when laying pipes is the length that can be laid and profits increase with increased laying rates with quality and workmanship a secondary concern. There have been measures put in place to try and control quality through testing and "sign offs" on pipe laying jobs though these at best only result in minimum standards. There are also contracts around sharing pain and gain e.g. target cost, these are designed to drive efficiencies and still incentivises driving down cost rather than increasing quality.

One way to change the behaviour of site operatives is to change the incentive mechanism and this can be done through the contract. There are novel business models that can be used to create a much more collaborative style of working with quality and whole life cost as a consideration rather than simply project cost.

Build-Operate-Transfer is a style of contract that ensures that whoever builds something is then tasked with running it for a number of years. This means that longer term costs are taken in to consideration with the on-going maintenance costs, balanced against the upfront building cost. It also ensures that quality is a greater incentive as poor quality will lead to higher maintenance costs. The asset is still transferred after a number of years to the purchaser who can then decide on how to proceed with operation of assets.

This style of contract has proven to work in house building, road and other large civil projects. Its application to laying leak free networks may need some more novel thought. It could be that the new area network is metered and that the contractor takes responsibility for any increase in leakage over the operation window of say 20 years. If the leakage increases then the contractor is fined or penalised for not delivering their commitments.

'Joint Venture' initiatives have an element of integration and are one way in which to share risk and reward as part of a project. This enables those involved to work much more closely and in an aligned fashion in theory driving up the quality of work and sharing the on-going costs. Joint Ventures between water companies and suppliers should lead to win-win scenarios where both parties "win" if the project does well. There are concerns around the lack of competition in these situations and this will need to be balanced against the value of long term working relationships.

Thames Water has now entered a new Joint Venture with several companies. They have two designs and build joint ventures under the commercial umbrella of Eight2O. This is a new initiative and the true benefit of this style of working is yet to be seen though the rhetoric is more aligned around long term value to all involved and ultimately value for money for Thames Water customers.

However it is reported[35] that in 2012, twenty per cent of construction Joint Ventures ended in dispute. This indicates that it is the mentality and the ethos of companies which is key to the working relationship of supply chains with water companies rather than the specific contract type.

When choosing contracts and contractors, selecting those on the basis of price rather than demonstrated value and open working style will drive the need for speed of laying networks. This will ultimately come at the cost of workmanship and quality of the laid network. There needs to be much more consideration of the required mentality of contractors and the best

[35] Withers, I. One in five joint ventures end in dispute (2013). www.building.co.uk. Last accessed May 2016 at: www.building.co.uk

way to influence this is to approach contracts in the right way and to select likeminded suppliers to work with.

This seems to lead to the old adage of ‘an honest day’s pay for an honest day’s work’. If the pay schedule is such to allow for good workmanship and quality of final product then this will attract honest workers who can deliver honest work. This almost leads back to the idea of ‘time and material’ contracts where contractors are paid for the time they work plus the cost of material used. This could be combined with maximum price ceilings for work or tracked through client auditors or ‘clerk of (the) works’.

It should be remembered that there is also the added complication of tiered contract work. Tier 1 contractors may have a positive style of working relationship though this may not have been passed on to Tier 2 or Tier 3 contractors. It only takes one broken link in the supply chain to deliver poor workmanship. New approaches need to incentivise the whole supply chain to deliver every job 'right first time'.

There is also the involvement of procurement teams in water companies that are tasked with ensuring value for the company who often only take in to account the cost of works. Without understanding the technical value of the work or the effect of squeezing margins, cost is often driven down to the detriment of value. The incentives/drivers of the procurement team need to be aligned to those of the water company.

There is no clear contract type that can deliver the improvements in workmanship required to lay leak free network. However contracts should incentivise an improvement in the standards of workmanship by ensuring that all stages of the supply chain are incentivised to deliver 'right first time'. There should also be consideration of the likely effect of contract terms on standards of workmanship by those drawing up both incentive and management arrangements for operatives.

9 Sensing Technology

The use of sensors in the water network can be broadly divided into three areas:

i. Reactive sensing - detecting leaks or bursts quickly and accurately after they occur, enabling rapid and targeted response.

ii. Proactive sensing (measurement and control) – frequent measurements within the network used to control flow and pressure to manage the system to meet demand while minimising the impact of leakage and busts.

iii. Proactive sensing (asset condition) – measuring asset condition and thereby providing a warning of potential future asset failure, enabling corrective action to be taken such as refurbishment or replacement.

In practice the distinction between approaches is not clear cut. It is however important in the context of this report and a future with zero leakage to make such a classification. A reactive approach will minimises leakage, whereas a proactive approach, at least in theory, has the potential to prevent leakage. As a result, in ‘zero leakage world’ it can be assumed that there will be a need for reactive but also a much greater emphasis on proactive sensing.

The future use of sensors in new networks can be further sub divided into two areas:

i. The concept of embedded sensors located within the pipe fittings.

ii. The use of more conventional separate sensors installed at the same time as the pipe.

These are considered separately in the following sections.

9.1 Embedded Sensors

The concept of embedded is not a new one and a range of sensors are already in use for monitoring critical assets and large structure. The idea of transferring this technology to water networks is logical; however, there remain significant challenges such as:

- Cost - using current sensing technology would add a significant premium to the production cost of pipes.

- Communication systems - currently represent the weak point in sensing below ground assets.

- Robustness and reliability – the industry needs confidence as these sensors will be buried and may well not have easy access to perform maintenance.

- Power - extended life power supplies are a big issue enabling sensors to operate for 10, 20, 50 years. This technology is currently not available. Current power harvesting technologies are expensive.

- Data - methods for the capture, analysis and response to data from such sensors.

Embedded sensors to detect leakage and asset failure are most likely to offer the greatest potential in terms of cost benefit. Sensors which measure asset condition such as pipe wall properties are thought to offer less potential, primarily because point measurements are of limited value and the deployment of sensors would needs to be very high.

An interim step to embedded sensors is the use of fibre optic cables run inside or alongside the pipelines. This technology is currently prohibitively expensive for all but highly critical pipelines. This approach is covered in greater detail in Lot 2; Leak Detection.

9.2 Separate Sensors

There is a large array of 'supervisory sensors' and systems available for water networks. These are detailed within Lot 2; Leak Detection. Though not a new concept, ensuring some supervisory systems were incorporated into new networks would enable any leaks which did occur in the future to be detected and fixed. These products could be installed as standard on new networks to help alert water companies to leaks much more rapidly.

During a discussion with Stuart Trow he noted that when laying new mains it would not be difficult to always install tracer tape. This would enable quicker, more accurate location of the main when a leak in the area has occurred, reducing the time taken for leak repair and as such reducing leakage. Some tracer tape has ability to detect soil moisture content which may be able to give an early indication of leaks.

9.3 Sensor Conclusions

- In a world where new pipeline assets still fail as they age and over time interact with the environment; to achieve zero leakage requires proactive monitoring of the network to identify areas of risk and potential asset failure.

- The use of sensors to detect leaks and bursts quickly and accurately after they occur, enabling rapid and targeted response, is a key element to the use of sensors within the network.

- The use of embedded sensors represents a longer term solution. The barriers of cost, available technology and communication are significant and need to be overcome. The concept needs to be demonstrated to deliver reliability, robustness and benefits; most probably this will be achieved through transfer of this technology from other sectors rather than the water industry being the technology leader. An overall shift to a longer term cost benefit approach to justify an increased cost at installation will also be needed.

- There exists a very wide range of 'supervisory sensors' already used in the water network. The greater use, i.e. the greater penetration of sensors within new networks, is a logical first step the reducing leakage. Increasing the number of sensors at the design stage will have similar benefits to designing in smaller DMAs. It will be easier to build up a true picture of usage and quicker to pick up on leakage and locate it.

10 Suitability of Standards

10.1 Stop Cock Location

There is some disagreement within the industry for the need for a boundary stopcock where a wall mounted meter box is installed. As noted by the Water Regulations Advisory Scheme (WRAS) "Where a […] meter box is mounted on the wall of a property thereby supplanting the need for a boundary stopcock, one legal interpretation based upon sections 46(6), 158(4) and 163(2) of the Water Industry Act 1991 is that a boundary stopcock is still required. However, this interpretation is not shared by Ofwat and some water suppliers". Seeking clarification on this point, and perhaps seeking clarification in the working of the Water Industry Act 1991, would alleviate current issues around the ambiguity. Clarification may allow if desired, to have a ferrule joint to the main, and a joint entering the above ground wall-box on a property thereby reducing the number of underground buried joints, and so effectively designing leakage out of the network[36].

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[36] https://www.wras.co.uk/consumers/resources/interpretations_and_advice/installation/i01/

10.2 Pipe Materials

In the UK the standards for plastic materials are generally well developed, but there are a few gaps and improvements that could be made.

Polyethylene (PE)

In the UK, standards for PE pipes for pressurised water and sewer pipes are covered by parts 1 to 5 and part 7 of EN 12201[37,38,39,40,41,42] . Part 1 (General) covers the approval (type tests) tests for pipe materials and fittings. Part 2 covers pipes, Part 3 covers fittings, Part 4 covers valves, Part 5 covers fitness for purpose of the system and Part 7 covers assessment of conformity.

The standard was originally published in 2002 and is well developed. Any developments or improvements which are made to European gas standard (EN 1555) and ISO water standard are usually adopted when EN 12201 is reviewed every 5 years. The next review is due in 2017.

The EN standard does not cover installation or welding as this practice varies between different countries and is generally dealt with by national standards. Certain elements of the original WIS standards for pipe have been retained within the National Foreword, but there are the following omissions:

- No tolerances for ovality of coiled pipes.
- Fusion lengths specified for electrofusion are a minimum.
- No contamination test for electrofusion fittings (WIS 4-32-08).
- Fittings >630 mm (e.g. stub flanges not covered).
- Important tests (e.g. AREL) are not covered in standards for mechanical fittings.

[37] BS EN 12201-1:2011 Plastics piping systems for water supply, and for drainage and sewerage under pressure. Polyethylene (PE). General.

[38] BS EN 12201-2:2011+A1:2013 Plastics piping systems for water supply, and for drainage and sewerage under pressure. Polyethylene (PE). Pipes.

[39] BS EN 12201-3:2011+A1:2012 Plastics piping systems for water supply, and for drainage and sewerage under pressure. Polyethylene (PE). Fittings.

[40] BS EN 12201-4:2012 Plastics piping systems for water supply, and for drainage and sewerage under pressure. Polyethylene (PE). Valves.

[41] BS EN 12201-5:2003 Plastic piping systems for water supply. Polyethylene (PE). Fitness for purpose of the system.

[42] PD CEN/TS 12201-7:2014Plastics piping systems for water supply, and for drainage and sewerage under pressure. Polyethylene (PE). Guidance for the assessment of conformity.

An advice document has been published by the British Plastics Federation (BPF) [43] advising Water Utilities on the appropriate EN specifications to apply and also which WIS standards are current and those which have been withdrawn.

Molecularly Orientated PVC (PVC-O)

In the UK, the requirements for PVC-O pipes are specified in WIS 4-31-08. There is also an applicable ISO standard (ISO 16422)[44]. There is a proposal to develop a European standard for PVC-O which will be based on ISO 16422. It is likely that certain important tests contained in WIS 4-32-08 (such as the test to test seal integrity if joints are misaligned during assembly) will not be included in to the European standard.

Mechanical Fittings

There are a number of specifications for mechanical fittings and as with specifications for PE pipe; it has been suggested that the BPF provide a guidance note on appropriate documents and their application. Certain EN and ISO standards have lower performance requirements, particularly in terms of pressure testing, where specified pressures are often below those used in commissioning in the UK. In one instance the UK has had to produce a stand-alone national specification (BS 8561)[45].

When selecting mechanical fittings it is important to select those which offer type 1 end load resistance, where the end load resistance is greater than the longitudinal strength of the pipe. It is also important that the fittings have undergone suitable stress relaxation tests at elevated temperature (such as the AREL test outlined in WIS 4-24-01)[46] to provide confidence that leakage will not occur as bolt torque is reduced with time due to creep of plastic materials and relaxation of gasket materials.

Pipe Selection Manuals

In the UK there was a pipe selection manual[47], which covered selection procedures, and structural design for asbestos cement, copper, PE, PVC, glass reinforced plastics, ductile iron, steel and concrete materials. A polyethylene manual was published as an online guide, but is no longer available.

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[43] Specifications for polyethylene pipe and fittings for water supply, drainage and sewerage under pressure, BPF Advice Document, 2015.

[44] ISO 16422:2014 Pipes and joints made of oriented unplasticized poly(vinyl chloride) (PVC-O) for the conveyance of water under pressure. Specifications.

[45] BS 8561:2013 Specification for mechanical fittings for use in the repair, connection and renovation of pressurized water supply pipelines. Requirements and test methods.

[46] Water Industry Standard (WIS) 4-24-01. Specification for mechanical fittings and joints for polyethylene pipes of nominal sizes 90 to 1000, Issue 2, July 1998.

[47] Pipe Materials Selection Manual: Water Supply 1995 Trew, Tarbet and De Rosa.

10.3 Installation

Structural Design of Pipelines

The structural design of both plastic and metal pipelines is covered by EN 1295:1997[48]. However, it was felt in the UK, which even for experienced Engineers EN 1295 was not the easiest of standards. EN 1295 includes descriptions such as 'wide' and 'narrow' trenches, without giving any guidance as to what actually constitutes a wide or narrow trench. The document also introduces new equations, which many engineers simply have to take on trust. Although using EN 1295, it is possible to design pipelines in accordance with the National Annex and meet the required criteria; engineers may not fully understand the principles behind the design. This is dangerous because the implications of any changes made to the design, may not be understood and could lead to costly failures.

In 2010 a British standard (BS 9295)[49] was produced as a guide to EN 1295, which provides simple explanations as to the equations and concepts for rigid, semi rigid and flexible pipelines within a National Annex. It includes clear diagrams to amplify concepts and also reproduces the equations, making it a comprehensive and standalone structural design guide.

The document was publicised by the Pipeline Industries Guild (PIG) at the time of issue, but it is not known if all water utilities actively use the standard.

Laying of Mains and Services

With the exception of the outdated pipe selection manuals there do not appear any specific standards or guides for water mains or services. The Self Lay guide (Section 10.4) may be relevant.

Rehabilitation

The standards for rehabilitation using plastic pipe systems are well advanced, with much of this work being undertaken by ISO TC 138 SC8 which has a number of working groups dealing with different materials and types of installation. The different techniques and outline of the clause structure of the standards are shown in Figure 9. Each standard covers the pipe materials which are used, the installation techniques, jointing of pipes and inspection/testing of the installed pipeline. It is likely that as ISO TC 138 SC8 develops new standards these will eventually be adopted as European standards under the Vienna agreement. ISO TC 138 SC8 has a UK convener and a number of active UK technical experts to ensure that specific UK requirements are reflected in these documents.

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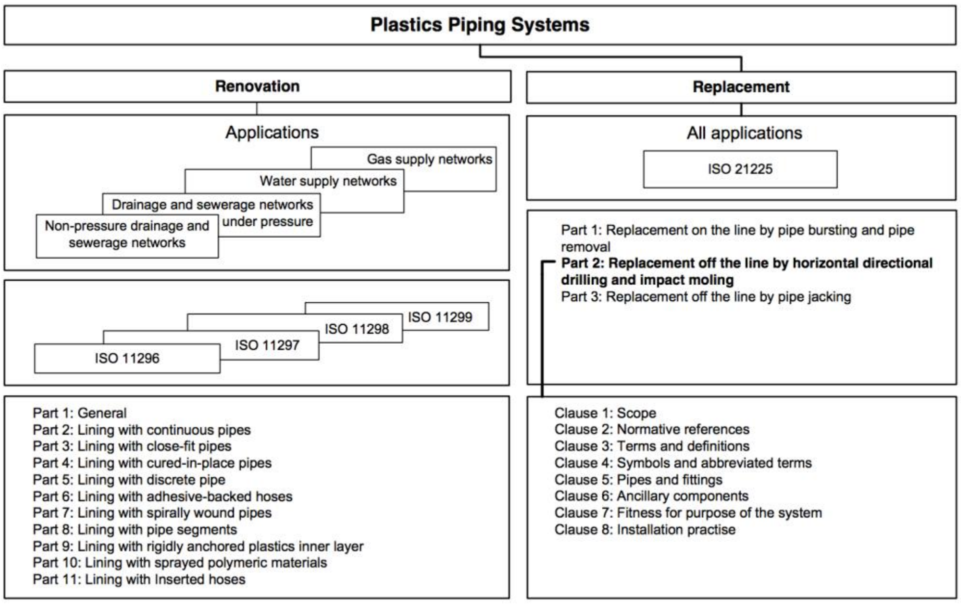
[48] BS EN 1295-1:1997. Structural design of buried pipelines under various conditions of loading. General requirements.

[49] BS 9295:2010 Guide to the structural design of buried pipelines.

Figure 9 Rehabilitation techniques and clause families



Fusion Welding

The principles of butt fusion and electrofusion and advice on appropriate equipment and testing of welds is provided in WIS 4-32-08. The specification does not provide any advice on training and this is being dealt with by the development of a stand-alone WIS document further detailed in Section 7.

Mechanical Fittings

There are no specific UK standards for the installation of mechanical fittings although manufacturers provide detailed technical/installation guides. There is an ISO specification for hand tools for tightening fastenings on mechanical fittings (ISO 6789)[50].

The European Pressure Pipes and Fittings Association (TEPPFA) have produced a good practice guide for jointing of flange adaptors for PE pipes[51].

10.4 Self-lay

Many elements of newly laid networks are no longer installed by water companies or their sub-contractors, but instead are adopted by the water companies following a self-lay installation. A self-lay code of practice[52] is available for those involved in such work to follow. If more and more new network is becoming 'self-lay' it may be necessary to revisit

[50] ISO 6789:2003 Assembly tools for screws and nuts. Hand torque tools. Requirements and test methods for design conformance testing, quality conformance testing and recalibration procedure.

[51] A Good Practice Guide for Flange Jointing of Polyethylene Pressure Pipes, TEPPFA Technical Guidance Document - AGU/2014/02.

[52] The Code of Practice for Self- Laying of Water Mains and Services - England and Wales, WRc

the codes of practice and investigate the quality control checks and contractual issues surrounding the adoption of self-lay mains. Unless some of the good practices and requirements discussed in this document are in place for self-lay as well as network installed by contractors it will be very difficult to achieve the zero leakage target.

Information from one water company suggests the proportion of new development mains and services installed by Self-Lay Organisations (SLO's) has gradually increase to a level of now around 90%. Although it is believed this particular water company has a particularly high proportion of 'self-laid' mains, this further reinforces the importance of having an adequate specification and inspection policies for adopting these networks.

From discussions with the water company it seems the option exists to veto certain types of pipes and fittings, although reasons for this must be robust. As an example, the SLO wished to lay 315 mm PE pipe, a size not stocked by the water company. The veto was supported as the cost of stocking pipe and fittings to maintain 315 mm would be disproportionally expensive for the water company involved.

The water company who discussed SLO for the purposes of this research shared their desire to develop a more stringent materials requirement to ensure the pipe and fittings are of the highest standard and able to be maintained without any significant increase of costs over and above what would be normal.

The adoption process currently includes:

- Inspection of the SLO installation by a water company technician, who also ensures the operatives hold the appropriate certifications.
- The SLO undertakes disinfection and pressure testing and unless self-certified, the water company technician ensures compliance.
- The water company take water samples for analysis, lay any off-site mains and make the final connection.
- Most developer/SLO's request the water company to undertake the design. If the developer/SLO submits a design it is reviewed by the water company at no charge.
- If requested, the water company will sell the necessary pipe and fittings to the SLO.

The water company noted that they do not have much experience of leakage due to poor workmanship. The only recent major issue is of a system connected with fusion collars which developed several leaks from the collars soon after installation. The SLO was required to relay the pipework.

10.5 French Decree n°2012-97

A French Decree published in 2012 put in place a target of 'efficiency' for water suppliers in France. The 'network efficiency rate' of 85% can be interpreted as a leakage target of 15% since network efficiency was calculated by dividing the volume produced and purchased by measured consumption and the volume sold as a percentage. The penalties for not reaching the target efficiency by 2015 were a high increase in income tax for the companies not complying. A review published in 2014 showed that for the water companies who were complying with the Decree at the time of writing there had been an increase in retail price of water. This may have a variety of explanations but highlights the cost implications of improving asset understanding and management. Water suppliers complying with the regulation at the time of writing also had higher rates of network renewal and asset records[53].

The Decree could be seen as an equivalent to the leakage targets set by OFWAT though by a different mechanism. Would writing leakage targets into law be more effective than targets set by the market regulator? There are similar efficiency laws relating to the use of water such as the German DVGW W392 Standard which sets out the control of water loss as a goal for hygienic, safety, economic and ecological reasons[54,55]. It is beyond the remit of this project to fully understand their effectiveness in comparison with the targets for leakage set in the UK.

10.6 Suitability of Standards Conclusions

- Some areas of existing standards may require clarification and inclusion of topics previously covered but which have now become unavailable.
- It is unclear to what level some industry standards are being actively used in the water industry.
- The UK has good representation on several standards currently in development, this should be continued to ensure UK requirements continue to be included in their development.

11 Alternative Water Delivery

The conventional model for water treatment and supply is treatment of water to potable water standards at large-scale, centralised plants and delivery the treated water to consumers through extensive distribution networks. The capacity of the treatment plants must allow for any leakage from the distribution system. In terms of overall energy consumption, the majority is related to distribution pumping. However, all of the water delivered to the consumers, and lost to leakage, is treated to potable water standards, thus carrying the full cost of treatment, whereas only a small proportion of the water supplied is actually used for potable purposes.

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[53] Salvetti, M. The network efficiency rate: a key performance indicator for water services asset management? (2014). Chaire Economie des Partenariats Public-Privé Institut'Administration des Entreprises. EPPP DP No. 2014-01.

[54] European Commission. EU Reference document Good Practices on Leakage Management (Main report) (2015). CIRCBC. Last accessed May 2016 at: https://circabc.europa.eu

[55] European Commission. EU Reference document Good Practices on Leakage Management (Case studies) (2015). CIRCBC. Last accessed May 2016 at: https://circabc.europa.eu

Various alternatives to the conventional model might be considered involving degrees of localisation. Various treatment technologies (e.g. package media filters, hypochlorite dosing systems, membranes, UV) are available enabling treatment to potable water standards at a scale as small as a single point-of-use. Localisation may allow for a separation between potable and non-potable supplies, with the former receiving more extensive treatment than the latter. But in simplistic terms unless measures are taken which either reduce the volume of water supplied or the distance through which it is transported, the level of leakage is unlikely to be significantly affected. Localised recycling of grey water or rain water collection are possible ways of reducing supply volumes. Reduction of pumping distances will require the availability of a local primary raw water source.

12 Gap Analysis

As discussed above, there are a great variety of variables and stakeholders in relation to the laying of new networks. There is a great variety of techniques available for leak detection and much research being conducted into new techniques. Based on the information gathered and conversations which have taken place, it is felt that the 'hardware' required (i.e. materials and technologies) to enable laying of leak free networks exist and are currently commercially available. In many cases the cost of these technologies and techniques add to the cost to laying networks which are not currently warranted by those laying the networks. The following section summarises some of the issues discussed throughout the document that require additional research in order to improve the robustness of new networks and ultimately to install networks with zero leakage.

Network design

- Investigation of how supply pipe configuration and meter location can reduce the number of joints and ultimately lead to zero leakage on supply pipes. This could lead to different policies on meter location and configuration from those which are currently used in order to drive down leakage.

- Investigate feasibility of using novel designs where possible in order to minimize leakage (use of conduits, service strip or above ground pipes). This is likely to be more practicable on larger scale developments where space is not at a premium.

Jointing techniques

- Investigate cause of failures on joints to enable the causes to be designed out, either through processes, contractual incentives or by another means.

- Carry out research to assign a value to the cost of a failed joint. This will allow for the development of economic evidence to justify a higher cost for 'doing it right' the first time. The higher cost of doing right first time may come from a number of different elements. The cost-effectiveness of these elements could also be investigated as part of this research.

Workmanship

- Review requirements for training and competencies for those installing the networks. Improve these requirements and procedures to increase skill level of those laying the networks.

- From investigatory work on failed joints, review techniques to mitigate against failed joints and other areas of leakage in order to put in place the most cost-effective mitigating methods.

Commercial Contracts

- Carry out research into the contractual aspects of new network laying, investigating the incentives given to contractors at all levels. The aim of this research would be to highlight what actions, practices and current incentives are driving performance and ultimately adjust contracts to drive long term asset robustness.

Self-Lay

- Investigate and quantify leakage rates and causes of failures on adopted networks to ascertain if self-lay is a significant issue. Review the Code of Practice for Self-Lay and the robustness of quality checks and assurances which are done during the process of adoption.

Sensors

- Review the cost effectiveness of sensor installation as part of laying new networks in order to include in the design the optimum number and type of sensors at the time of laying the new main.

Testing and Commissioning

- Review the robustness of testing and commissioning procedures when laying new mains.

- Carry out an independent review of new non-destructive testing methods for joints in PE pipe in order to increase the number of joints inspected.

There are several other factors highlighted as potential solutions in the report which are not highlighted in this gap analysis. The items identified here are thought to be the most significant issues currently preventing the laying of leak free networks. From the research and conversations undertaken, the greatest potential for improvement lies in quality of workmanship and allowing for improvement in workmanship by incentivising it appropriately.

13 Recommendations for Future Research

We have considered all of the recommendations for further research identified within the gap analysis (Section 12) and identified two that would offer the greatest potential to advance the UK water industry from current methods in the medium term. Each of these ideas has been expanded upon in the following sections, with an idea on how a research project on the topic could be designed.

13.1 Understanding Jointing Techniques, Causes of Failure and the Economic Case for Improved Methods.

Impact

Joints are a week point in the network and a major cause of leakage. Efforts focused on understanding the cause of failure and the financial impact would enable appropriate solutions to be implemented and justified.

Background

The cost of a failed joint is not known by the UK water industry, without such data the economics evidence to justify a higher cost for ‘doing it right’ the first time cannot be presented. In order to do this first the cause of joint failure needs to be better understood.

Objectives

It is envisaged the project could comprise 2 parts:

Part 1 – Establish the cause of failures on joints to enable the causes to be designed out, either through processes, contractual incentives or by another means.

Part 2 – Assign a value to the cost of a failed joint.

Outcomes to be achieved

Part One – This work needs to gather evidence from the UK water industry to establish based on real data, the cause of failures on joints. It is recommended that this information collection is planned to consider the likely variables which may impact on joint failure such as for example geographical variations, installers/contractors, age, time of year installed etc. Consideration will need to be made to ensure the information is collected in such a way that blame doesn’t does not prevent the true reasons being established.

Part Two – This work would analyse existing operations, costs and impacts to establish economic evidence to justify a higher cost for ‘doing it right’ the first time. The higher cost of doing right first time may come from a number of different elements. The cost-effectiveness of these elements could also be investigated as part of this research.

13.2 Training and Contractual Elements to Drive Improved Workmanship

Impact

The standard of workmanship is thought to be one of the main reasons for failure of newly laid pipe networks. As a result this area offers some opportunities for further research and improvements.

Background

There is an often held belief that with today's technology, materials and material processes it is more than possible to lay leak free networks. Poorly made electro-fusion joints are known to be the most common cause of failure in PE mains. This causes leakage, bursts and interruptions to supply. The defects are most commonly caused by poor workmanship in the preparation of the joint prior to welding. The challenge is therefore not a technical one; the issue is around the incentive and behaviour of site workers and those that manage them.

Objectives

It is envisaged the project could comprise 3 parts:

Part 1 - Review requirements for training and competencies for those installing the networks. Set in place measures to improve these requirements and procedures to increase the skill level of those laying the networks.

Part 2 - From investigatory work on failed joints, review techniques to mitigate against failed joints and other areas of leakage in order to put in place the most cost-effective mitigating methods.

Part 3 - Carry out research into the contractual aspects of new network laying, investigating the incentives given to contractors at all levels. The aim of this research would be to highlight what actions, practices and current incentives are driving performance and ultimately adjust contracts to drive long term asset robustness.

Outcomes to be achieved

This work would, for the first time, assess both the practical skills and competencies of those people laying new networks but also, importantly how the contracts they work under impacts on the quality of work, the quality of equipment and fittings used and ultimately the failure rate and level of leakage. This project would provide data which demonstrates the link between contract conditions, workmanship and leakage rates in a way which presents the financial case for action to change current approaches.