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QUALITY CONTROL OF JOINT INSTALLATION IN PRE-INSULATED PIPE SYSTEMS

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ABSTRACT

A three-step quality control method was developed and applied to more than 70 joints in pipes installed on behalf of a Dutch district heating supplier. Multiple joint types were visually examined, tested for leak tightness, and dismantled for further examination. Each type of joint (except for welded joints) comprised three water barriers to prevent groundwater and rain water from entering the interior of the joint.

Various installation errors were found. For example, tape had been incorrectly applied, the PE casing had not been sufficiently abraded, PUR foam had destroyed the PIB water barrier, water had become trapped inside the joint and insulation shells were cut off too short or were not straight.

The results show the importance of foolproof jointing systems in obtaining high-quality joints in the field. Moreover, it is recommended that the installer's staff training be improved.

INTRODUCTION

A district heating pipeline consists of different parts. Figure 1 shows a schematic of a typical district heating pipe. For pipes manufactured in accordance with EN 253 [1], it is important that the steel service pipe be protected from water to prevent corrosion. Water will also degrade the polyurethane (PUR) foam. If water enters the area around the hot service pipe it will heat up, accelerating the degradation and hydrolysis of the PUR foam.

The weak spots in plastic piping systems generally occur at the joints, since these are often made in situ [2]. This is also the case for pre-insulated pipe systems. Since the applications of pre-insulated pipe systems include district heating, district cooling and LNG transport, joints need to be made in a variety of (often harsh) environments.

In the Netherlands, this harsh environment is mostly a wet one, which arises as a result of high groundwater levels and weather conditions.

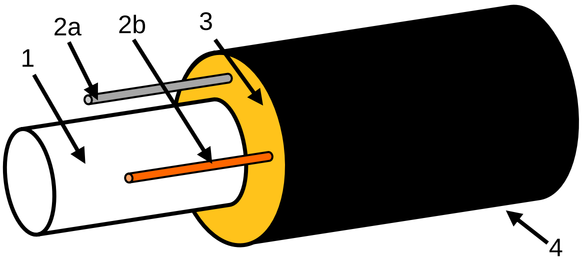

Figure 1. Schematic view of the end of a district heating pipe where a joint has to be made. (1) Service pipe (steel), (2) Leak detection ((2a) tinned copper, (2b) copper), (3) Insulation (PUR) and (4) Casing (PE).

Because joints may need to be made in wet conditions, they are a critical component in pre-insulated district heating systems. The edges of the joints are particularly susceptible to water ingress. Multiple water barriers are therefore used to prevent water entering the system.

If the water barriers fail and water enters the joint, heat losses in the district heating system will result in a less effective system. The leak detection system will warn the district heating supplier, so that the joint can be repaired. The service pipe can stay in place, meaning that the supply of hot water need not be interrupted.

However, if action is not taken quickly enough, the service pipe may corrode. If the service pipe fails, the escaping hot water may cause extensive damage to the surrounding area. Repairs will then include replacing part of the service pipe, resulting in an interruption to service, which will leave end users without a hot water supply. Aside from the inconvenience caused to end users, the repair costs will be high. This is especially so in the case of larger diameter pipes. District heat suppliers must therefore always remain alert. However, since prevention is better than cure, special care should be taken when making pipe joints.

Jointing systems that comply with EN 489 [3] are designed to withstand ground forces and remain leak tight throughout a technical life of at least 30 years. Joint installation on site must be done by specially trained personnel following the instructions given by the manufacturer in accordance with EN 13941 [4]. This means that the quality of the water barriers is largely dependent on the competence of the installer, but also the attention paid to the leak tightness of the joint during installation.

To ensure that the joints and their water barriers are properly made by the pipeline installer, a Dutch district heating supplier commissioned a quality control procedure for joints. This paper describes the results of this investigation. The goal of the operation was threefold:

1. To check the quality of the joints made by the pipeline installer. This also enables the district heating supplier to call the pipeline installer to account if mistakes are made, or even to withdraw the right to work for the district heating supplier.
2. To learn which mistakes are made when making joints, resulting in better on-site supervision by the district heating supplier.
3. To improve the work of the pipeline installer, simply by letting them know they are being checked. Not every joint is inspected, but the pipeline installer never knows which joints will be tested.

MATERIALS

Over 70 joints made on pipes installed on behalf of a district heating supplier in the Netherlands were completely removed from the system immediately after installation by the pipeline installer. These joints were then tested in the laboratory of Kiwa Technology. Multiple types of joints of various diameters were investigated. These joint systems are produced by Logstor (Løgstør, Denmark), German Pipe (Nordhausen, Germany) and Isoplus (Rosenheim, Germany).

This paper discusses three types of joints: PEX shrink joints, PE shrink joints and welded joints. The shrink joints are installed with three water barriers.

A general schematic cross-section of a joint is given in Figure 2.

PEX shrink joint

After welding the steel service pipe (*1* at position *4* in Figure 2), two insulating PUR foam shells are placed around the service pipe. The shells are wrapped in a shrink film with mastic (*3* in Figure 2). Because the film is also attached to the polyethylene (PE) casing of the district heating pipe (*5* in Figure 2), it forms the first barrier against groundwater.

A cross-linked polyethylene (PEX) shrink sleeve (*7* in Figure 2) is placed over the shrink film to form the second water barrier.

A third barrier is created by applying two shrink collars (*6* in Figure 2) over the ends of the PEX shrink sleeve.

Because insulating shells are used, no subsequent foaming is needed. Therefore, no holes need to be made in the shrink sleeve and film to add foam, nor are water barriers needed to cover the plugs that would be required to seal such holes.

PE shrink joint

After welding the steel service pipe (*1* at location *4* in Figure 2) and coating the casing of the district heating pipe with a primer (*5* in Figure 2), a PE shrink sleeve (*7* in Figure 2) is used to connect the two pipes. No shrink film is used; instead, a polyisobutylene (PIB) tape is applied beneath the PE sleeve to act as the first water barrier.

The annular space between the service pipe and the PE sleeve is subsequently filled with PUR foam. To accomplish this, two holes are drilled in the sleeve: one for adding the foam, the other to allow the release of air during the foaming process. These holes are later closed with a plug (not drawn in Figure 2).

Butyl rubber is applied over the plugs and at the ends of the PE sleeve (*6* in Figure 2). This forms the second water barrier.

Densolen® tape N8 (*6* in Figure 2) is applied over the butyl rubber at the ends of the sleeve and at the plugs to form a third water barrier. The Densolen® tape N8 is mechanically protected by black Denso foil (*6* in Figure 2).

Welded joint

After welding the steel service pipe (*1* at position *4* in Figure 2), two insulating PUR foam shells are sometimes placed around the service pipe. A polyethylene (PE) sleeve (*7* in Figure 2) is welded to the casing (*5* in Figure 2) using copper wires (not drawn in Figure 2). Other types of welded joints don't use PUR foam shells but are instead filled with PUR foam after the welding process. In this case, two holes are drilled in the sleeve. These are subsequently closed with a plug.

A second water barrier is created by applying two shrink collars (*6* in Figure 2) over the ends of the weld sleeve. This type of joint does not have a third water barrier.

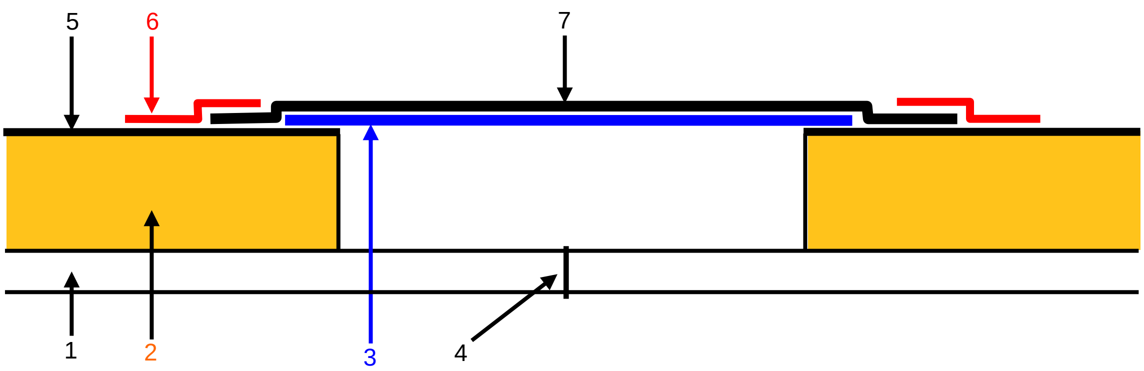

Figure 2. Cross-section of a joint (schematic). (1) Service pipe (steel), (2) Insulation (PUR), (3) Optional shrink film, (4) Weld in the steel pipe, (5) Casing (PE), (6) Shrink collar (PEX) or tapes (butyl rubber, Densolen N8 and black Denso foil) and (7) Shrink sleeve (PEX or PE) or welded sleeve (PE).

METHODS

The purpose of the laboratory testing method is to assess the quality of the joint. The water barriers in the joints were therefore carefully inspected. If any part of the water barrier in the joint is not applied as prescribed, the joint will be more susceptible to future leaks.

A practical testing method, consisting of three steps, was devised.

Non-destructive investigation

Firstly, the joints were inspected non-destructively by:

- Measuring the resistance of the leak detection wires (*2* in Figure 1). The leak detection wires of the pipe ends need to be properly connected across the joint. Without proper connections, any leaks cannot be detected. This renders the leak detection system useless.
- Checking whether the work instructions had been followed correctly. This involved a visual inspection of the outside of the joint in order to determine whether the pipe had been properly abraded before the joint was made, whether the primer was visible, whether the tapes had been correctly applied, whether the sleeves and collars were correctly centred, etc.

Leak tightness

Secondly, the leak tightness of the intact joint was verified. This leak tightness test was specially developed for this joint quality control inspection. Air pressure was applied between the outer casing and the PUR foam or shells. To obtain a good connection between the air supply and the outer casing, two short PE rods were welded onto the casing (Figure 3). A small hole was subsequently drilled through each PE rod and the casing into the PUR foam. One connection was for the air supply, of which the flow was measured, while the other was for measuring the pressure (Figure 4).

By pressurising the joints, the weakest point – or indeed any leaks – can be found. Initially, a relatively high pressure, sometimes as high as 0.5 bar(g), is needed to overcome the bond between the shrink sleeve or shrink film and the PUR foam or shells. This is necessary so that air can flow inside the joint towards the water barriers.

The measured air flow indicates whether or not a leak has occurred. If there is virtually no air flow, then there are no leaks. If a high air flow is measured, leak detection fluid (e.g. a soap solution) is used to find the leak. If no leaks are found, the pressure is increased and the air flow is monitored. For quality control purposes the pressure is not increased beyond 1.5 bar(g), since at higher pressures the procedure becomes a strength test.

Figure 3. Connections to a district heating pipe joint using two hollow PE rods to perform the leak tightness test.

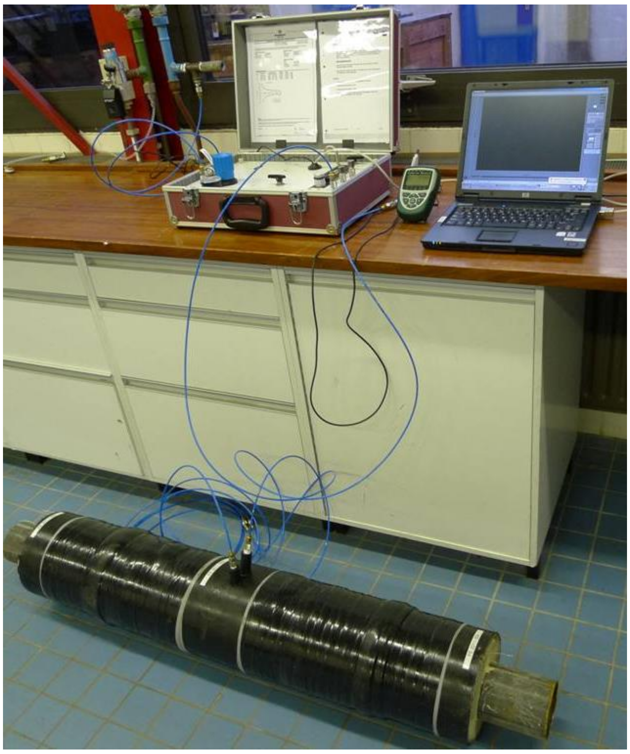

Figure 4. A district heating pipe joint is pressurised; the pressure and flow are measured.

Destructive examination

Finally, the joints were dismantled for further examination. Four strips were cut from the joint, including the collars, for all joint types. The collars were manually peeled away from the casing and the sleeve while the strength of the bonding was continuously assessed. The sleeve was manually peeled away from the casing. The bonding of each part was then examined visually. The PUR foam or shells and PIB tape (if relevant) were also inspected. Finally, the primer was analysed using Fourier transform infrared spectroscopy (FTIR) in order to check whether any differences in bonding of the tape might be due to the use of a different (i.e. other than prescribed) primer.

RESULTS

Non-destructive investigation

In one of the 58 joints inspected, one of the leak detection wires (*2* in Figure 1) was not correctly connected across the joint. Although only one broken connection was found, this is a major fault, as explained earlier.

A situation in which the tinned copper wires were connected to the copper wires was observed more often. The wires were thus not connected to the same type of wire (tinned copper to tinned copper and copper to copper), but to the other type of wire. Although this is not in itself incorrect, it makes the leak detection surveillance diagram more complex.

The PE casing was not properly abraded in more than 50 % of the joints. In some cases the casing had only been lightly abraded, while in others this had not been done at all. Sometimes the casing had been abraded in the axial direction, resulting in potential leak paths under the sleeve.

Furthermore, folds or wrinkles in the sleeve or collar of several PEX shrink joints were found (Figure 5 and Figure 6).

Signs of insufficient heating, such as the absence of mastic next to the collars, were observed in about 10 % of the joints.

Tape had been wrongly applied to more than 50 % of the PE shrink joints. Tapes require special attention when applied, as they must be wrapped tightly over the joint.

The (small) mistakes were therefore mainly due to sloppiness: folds, air inclusions and tape endings halfway were observed (Figure 7). Tape was also found to have been applied separately over the sleeve ends and the plugs, while it should have been applied in one piece (Figure 8). Although these are not major mistakes, they do introduce unnecessary weak points in the water barrier of the system. The resulting reduction in the leak tightness of the joint is out of proportion to the extra effort required from the pipeline installer in order to apply the tape correctly.

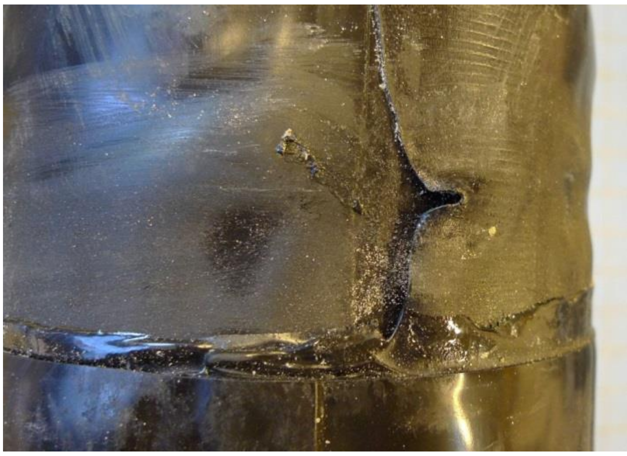

Figure 5. Fold in PEX shrink sleeve.

Figure 6. Wrinkles in the collar of a PEX shrink sleeve.

Figure 7. A tape ending halfway across the taped area. This causes a weak spot in the system.

Figure 8. The left side has two separate tape sections. This leads to unnecessary extra possible entry points for water and points at which the tape may detach. Tape applied correctly in one piece can be seen on the right-hand side.

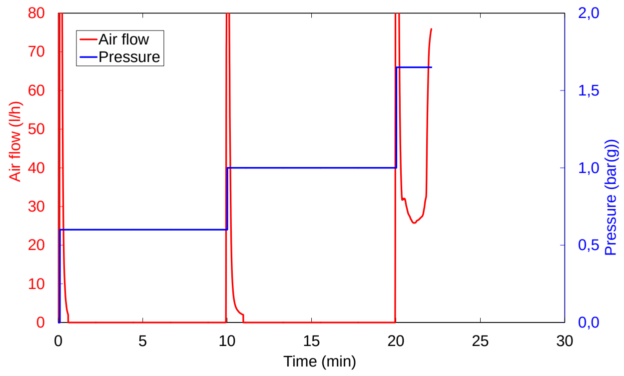

Figure 9. Air flow (lower trace, red) and pressure (upper trace with steps, blue) during a pressure test with air until failure of the PE shrink joint. Below 1 bar(g) the air flow is 0 l/h after an initial peak as the pressure increases. At 1.5 bar(g) the air flow increases considerably, indicating a leak.

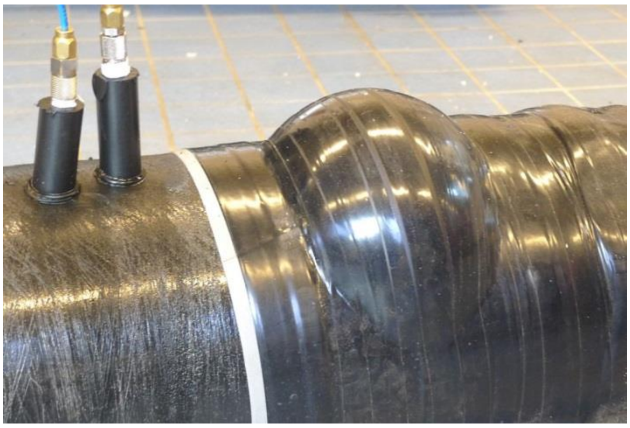

Figure 10. Failed joint after being pressurised up to 1.5 bar(g).

Leak tightness

Five of the 20 PE shrink joints failed during the leak tightness test (Figure 9 and Figure 10). None of the other joint types failed.

The five defective PE shrink joints all failed at the plugs. In one of the five cases, the butyl rubber and Densolen tape were strong enough to withstand the pressure; the tape thus blew up like a balloon. In the other four cases the tape did not have enough adhesive strength; this created a leak path. The poor adhesion was confirmed during destructive inspection.

Destructive examination

Destructive examination was carried out in order to visually examine the performance of the water barriers.

In more than 50 % of the PE shrink joints, one or more tape strips could be peeled away from the casing and/or PE shrink sleeve (compare Figure 11 with Figure 12). It was often found that the pipe ends and PE sleeve were not properly abraded. Improper abrading can therefore result in a low bonding strength of the tape, which decreases the quality of this water barrier and thus increases the possibility of water entering the joint.

Figure 11. A poorly abraded joint, resulting in a low tape bonding strength. The tapes were easily peeled away from the PE casing and shrink sleeve manually. The quality of this water barrier is therefore low.

Figure 12. These tapes were strongly bonded to the PE casing. The edge on the right side shows unsuccessful attempts to detach the tape.

Only about 15 % of the collars in the PEX shrink joints could be peeled away from the casing and/or PEX shrink sleeve manually (Figure 13). In slightly more cases (about 20 %) the PEX shrink sleeve could be peeled away from the casing manually (compare Figure 14 with Figure 16). Insufficient heating, insufficient abrasion and/or contamination, e.g. by sand, of the joined surface are expected to be the principle causes of the poor adhesion. In the other cases the PEX sleeve and shrink film all had strong bonds with the PE casing. In each of these cases considerable force was needed to separate the various components at room temperature.

Surprisingly, over 60 % of the welded joints could also be manually peeled away from the PE casing (compare Figure 15 with Figure 17). In a welded joint, the PE of the casing and sleeve are melted together to form a very strong bond.

Being able to manually peel the sleeve away from the casing is a clear indication that the casing and sleeve have not fused together properly. Welded joints are used in the most severe conditions and for the most important district heating systems. Since this type of joint only has two water barriers (in some cases, even the collars are omitted), a good weld is essential in order to guarantee the quality of the entire joint.

In two PE shrink joints, water was found trapped beneath the PE shrink sleeve (see Figure 18). This could have been caused either by condensation or by rainfall. Regardless of the cause, the pipe and other components had not been properly dried before joining, despite this being specified in the installation instructions. Since water had already passed the water barriers, the risk of joint degradation was increased.

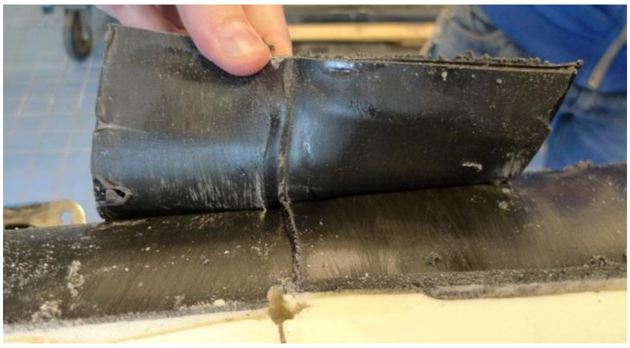

Figure 13. The collar of this PEX shrink joint could easily be detached manually from the casing and the PEX shrink sleeve.

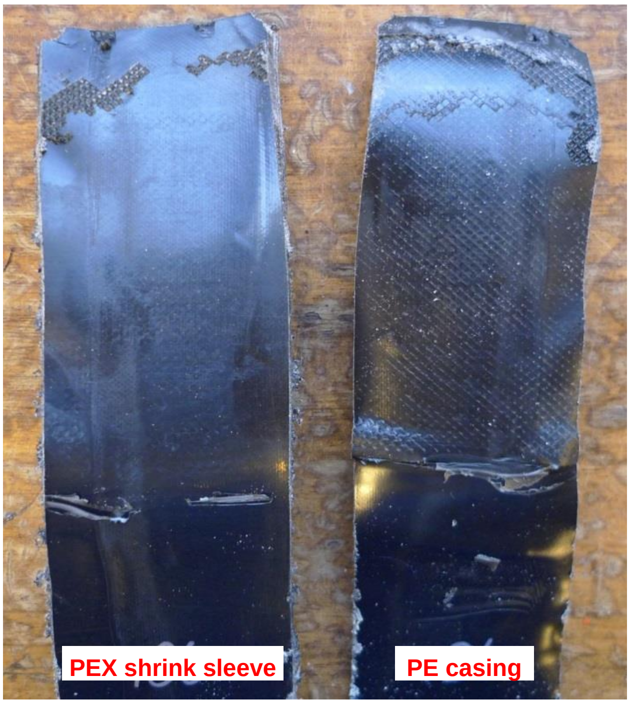

Figure 14. There is no bonding strength between the PEX shrink sleeve and PE casing, probably due to insufficient heating.

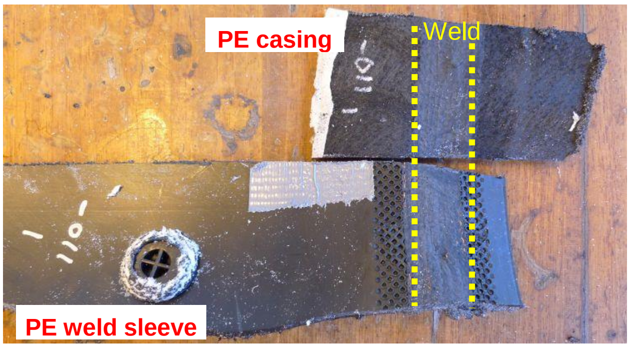

Figure 15. The PE weld sleeve and the PE casing are not properly fused. The PE weld sleeve could therefore easily be manually peeled away from the PE casing.

Figure 16. The bonding between the PEX shrink sleeve and the PE casing is strong enough to withstand manual peeling.

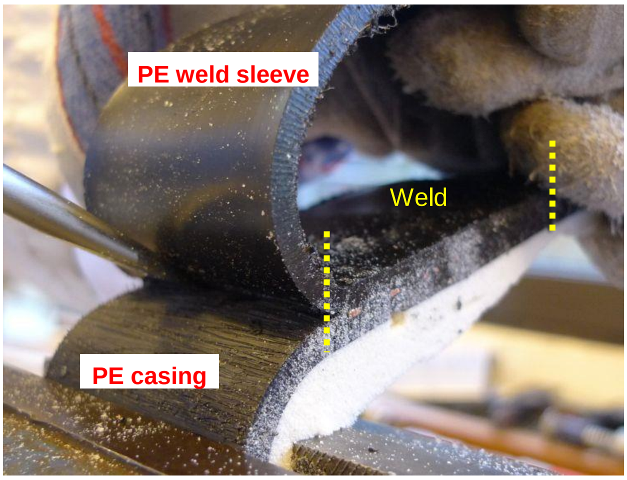

Figure 17. The weld is strong enough to withstand manual peeling.

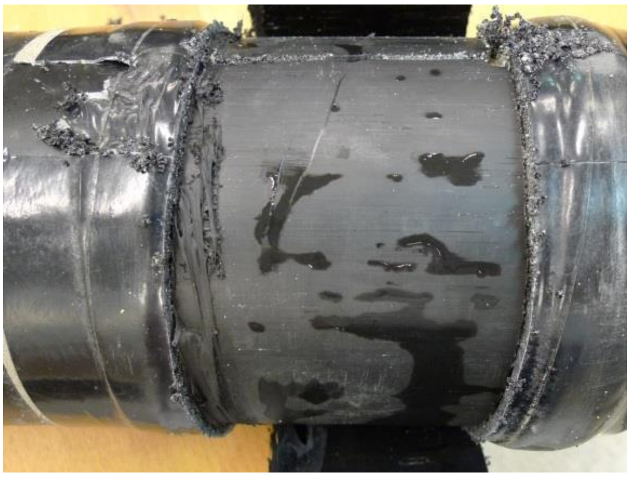

Figure 18. PE shrink sleeve removed to show water trapped in the joint.

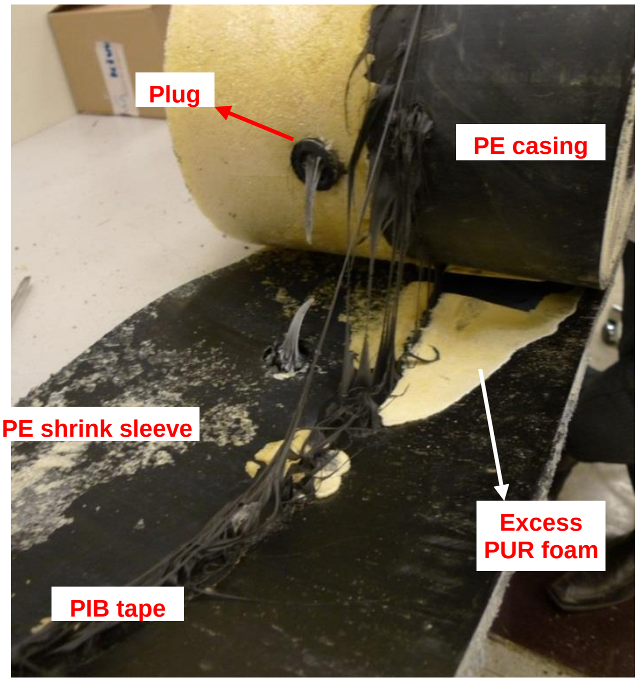

Figure 19. PUR foam has flowed beyond the PIB tape barrier, creating a failure in the first water barrier.

Inspection of the PIB tape in PE shrink joints revealed that in various cases, PUR foam had flowed beyond the PIB tape barrier (Figure 19). After joining the steel pipes, the annular space between the service pipe and the PE sleeve is filled with foam. It appeared that the foam had been able to flow beyond the PIB tape. The PIB tape, which is the first water barrier, was in the process destroyed. This is therefore a very undesirable situation.

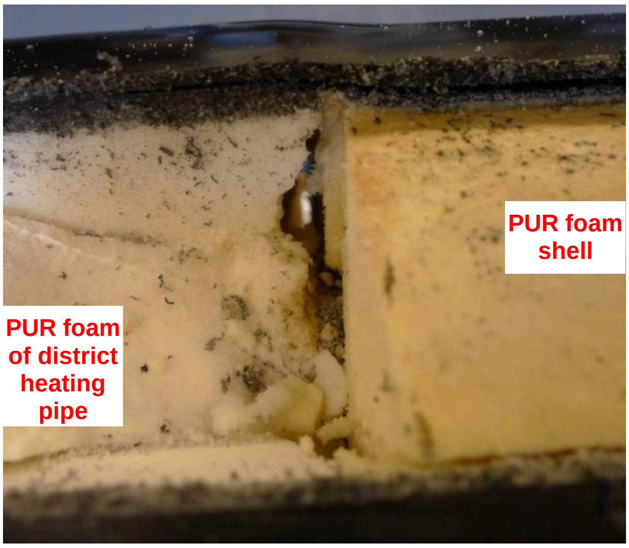

Figure 20. PUR foam is cut very irregularly, so that the PUR foam shell does not fit tightly, which leads to large gaps.

The noted defect is not a result of the pressure test, since the cured PUR foam is a very rigid material and should not therefore be able to flow beyond the PIB tape.

In addition to examining the water barriers, the destructive inspection also examined the quality of the PUR foam shell installation.

In about 10 % of the joints the PUR foam shells were not placed tightly enough against the PUR foam of the district heating pipe (*3* in Figure 1), resulting in large gaps (Figure 20). Such gaps are undesirable as they lead to:

1. Extra heat losses.
2. Heat build-up in the mastic used in the PEX shrink joints, leading to possible movement of the collars and shrink sleeves.
3. Migration of any water that may have entered the joint towards the steel service pipe. The water will heat up and become very hostile to the PUR foam. Hot water can quickly degrade and hydrolyse the PUR foam, thus decreasing the thermal insulation. This will cause the water to heat up still further, etc. If the new joint is subsequently foamed, then this process will occur much less quickly, since the water cannot easily reach the hot service pipe. This in turn means that it will take longer to heat up and attack the PUR foam.

FTIR measurements showed no differences in the primers used. District heating suppliers are nevertheless aware that other primers are used in the field. This therefore remains a potential issue.

DISCUSSION

The three-step quality control method described in this paper was specifically developed in order to ensure that district heating joints and their water barriers are properly made by the pipeline installer. An outer visual inspection gives some indication if errors have been made. These include insufficient or incorrect abrasion, folds and wrinkles in the sleeve and/or collar or insufficient heating of the collar and/or sleeve. However, (manually) peeling these parts away from the PE casing gives a much better indication of the bonding strength, and thus leak tightness, of the water barriers. Although the pressures and loads applied in the leak tightness test and the destructive examination are not comparable with loads in practice, they nevertheless give a good indication of where the weak spots in the system are.

Performing the destructive inspection revealed that about 20 % of the PEX shrink joints were poorly bonded. This was mainly due to insufficient heating. The installation of PE shrink joints is a more laborious process; this resulted in 50 % of the tapes having poor bonding. In this case sufficient abrasion in the tangential direction is an important step in obtaining a good bond. Surprisingly, about 60 % of the welded joints could be separated manually. The reason for this is unclear. Specific research is needed in order to determine which crucial steps failed, thus causing the poor bonding. It is interesting to note the differences in design between welds made in gas and water pipes and in district heating pipes.

Furthermore, it was found that the plugs in the holes used for foaming after installation of the sleeves of PE shrink joints can form weak spots, especially if the tapes have a low bonding strength on the PE casing. The district heating system is designed for a technical life of 30 years. Therefore, weak spots of this nature in a wet environment such as the Netherlands are highly undesirable.

In view of the errors made, it is clear that there is still much room for improvement. The three-step quality control method is not only intended to check the quality of the joints but also so that it is possible to learn from mistakes. On-site supervision could easily prevent errors such as insufficient or incorrect abrasion, folds and wrinkles in the sleeve and/or collar and gaps between the PUR foam of the pipe and the PUR foam shells of the joint. In particular, communicating these mistakes to the various contractors and stressing the importance of high-quality work has already improved the latter. This research therefore assists on-site supervision and indicates at which installation steps the installer's staff need to improve quality, for example by proper heating of the joint, to obtain high-quality joints with a technical life of at least 30 years.

CONCLUSIONS

A three-step quality control method of three types of joints in district heating pipes revealed various installation errors. Most of these errors were found in PE shrink joints with a PE shrink sleeve and tapes.

Various installation errors were found. For example, tape had been incorrectly applied, the polyethylene casing had not been sufficiently abraded, polyurethane foam had destroyed the polyisobutylene water barrier, water had become trapped inside the joint and insulation shells were cut off too short or were not straight, leading to gaps.

The results show the importance of foolproof jointing systems in obtaining high-quality joints in the field. Moreover, it is recommended that the installer's staff training be improved.

OUTLOOK

Completely extracting the joint from the field, including the steel service pipe, is costly. This is especially so in the case of larger diameter pipes. Therefore, preliminary tests can be performed to examine joints in the field. Although visual inspection is slightly more difficult in the field than in the lab, the three steps (non-destructive, leak tightness and destructive testing) can also be performed in the field.

ACKNOWLEDGEMENTS

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