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RE-ESTABLISHING CONFIDENCE IN PE ELECTRO-FUSION WELDING BY ENHANCED SURVEILLANCE

Johannes de Bruin
Kiwa Technology
Apeldoorn, the Netherlands
Johannes.de.bruin@kiwa.nl

René Hermkens
Kiwa Technology
Apeldoorn, the Netherlands

ABSTRACT

Gas distribution system operators (DSOs) are continuously debating the quality and safety of their assets and how these can be improved. Since the introduction of Polyethylene (PE) in the gas distribution sector (mainly in the form of pipes and couplers), the evolution from first to third generation PE materials has been marked by an improvement in the mechanical properties of these elements. The design of PE couplers has also evolved. In addition to the improvements in pipes and couplers, the PE welding procedures for making electro-fused connections have also improved. The welding procedure is now fully protocolised) and is no longer in the experimental stage.

There are currently more than 5,000 km of first generation PE pipes installed in the Netherlands. These pipes are mainly used to connect rural villages. To gain insight into the factors that influence the quality of PE piping systems, a so-called Exit Assessment programme was established by the Dutch DSOs in 2004. The Exit Assessment has demonstrated that the first generation PE pipes remain in good condition where they are not exposed to point loading[1]. It is also known that most problems occur at the joints[2]. In first generation PE piping systems, the connections were made using butt fusion or electro-fusion. As part of the Exit Assessment programme, Kiwa Technology has investigated the quality of first generation electro-fused joints by focusing not only on welding quality but also on whether they are full-end-load resistant. For safety reasons, full-end-load resistance is mandatory in the Netherlands for joints in PE piping systems operated at 1 bar(g) or higher. The study provides insight into the critical failure factors that may limit the technical life of these "old" assets. These first generation electro-fused joints may cause problems as they do not meet current standards and are not always full-end-load resistant. Problems with first generation PE electro-fused joints occur most frequently in the vicinity of excavation or digging sites.

When installing new PE piping systems, DSOs want to be certain that the quality of the joints is good. This has motivated quality control of the welded joint by means of both visual and destructive examination. About 2000 joints have been checked annually since 2005. Despite the improved quality of PE pipes, PE couplers and welding procedures, newly made electro-fused joints still regularly fail the peel decohesion test (ISO 13954)[3]. These failures have been attributed to insufficient scraping, incorrect alignment, incorrect cleaning or the presence of silicones in the welding zone[4]. This has been mentioned before in other publications [5,6,7,8,9]. As such, these failures have generally been attributed to incorrect execution of the welding procedure by PE welders. As a result, the DSOs have employed enhanced surveillance, especially with regard to correct execution of the welding procedure. This enhanced surveillance and guidance has made possible an increase in the quality of electro-fused joints. It may even lead to a 100% success rate in the peel decohesion test (ISO 13954), which would increase overall confidence in electro-fused joints.

INTRODUCTION

In the Netherlands, the distribution of natural gas takes place through a grid containing approximately 20,000 km of PE pipes. These make up over 15% of the Dutch distribution grid. First generation PE accounts for 5,200 km of this total. Most of the first generation PE pipes were installed between 1963 and 1974, when the natural gas field at Slochteren in the north of The Netherlands began production. First generation PE was mainly used to connect rural villages using pipelines operating at gas pressures of 3 or 4 bar(g). Second and third generation PE pipes were generally installed as service lines, and nowadays also as a replacement predominantly for asbestos cement and grey cast iron.

In order to gain insight into the quality of the first generation PE piping systems still in use today, a so-called Exit Assessment programme was established in 2004[10]. This programme is sponsored and supported by Netbeheer Nederland and all the Dutch DSOs. In this Exit Assessment, the quality of the existing Dutch PE grid is determined by taking samples from across the Netherlands and testing these at Kiwa Technology. Part of this programme involves investigating the quality of first generation electro-fused PE joints. It is commonly know that old joints in the first generation PE grid are the weakest parts of the PE piping system. This paper describes a programme of research aimed at obtaining insight into the quality of first generation electro-fused joints.

To gain insight into the quality of newly made PE joints, several DSOs have established programmes to monitor the quality of electro-fused welded joints by means of both visual and destructive examination. One of the pioneers in this quality control process is Enexis, a Dutch DSO. In 2007, Enexis began verifying the quality of approximately 1200 electro-fused PE joints annually by sending these to independent companies for assessment in accordance with ISO 13954. ISO 13954 describes the peel decohesion test for PE electro-fusion assemblies with nominal outside diameters greater or equal to 90 mm. This test only indicates whether a proper assembly has been made; it gives no information about the cause of any faulty (brittle) assembly. This paper describes the results of the quality assessments carried out between 2007 and the final quarter of 2014.

QUALITY ASSESSMENT OF OLDER EXISTING JOINTS

In this assessment[11], first generation PE electro-fused joints were investigated. These joints, which were excavated at random from the gas network of the Dutch DSOs, were installed between 1967 and 1974. Two types of first generation PE electro-fusion couplers that were most frequently used during this period were investigated in this quality assessment. These are the electro-fusion couplers made by Mannesmann and Rollmaplast. The differences between these two PE couplers lie primarily in the design. The two sides of the Mannesmann couplers can be fused separately, while the Rollmaplast couplers are fused in one pass and have an distinctive groove on the outside (see Figure 1 and Figure 2). Other differences can be found in the fusion length (L_f): the Rollmaplast coupler has a shorter fusion length than the Mannesmann (see Figure 3 and Figure 4).

Figure 1 – Rollmaplast coupler with distinctive groove on the outside

Figure 2 – Mannesmann coupler

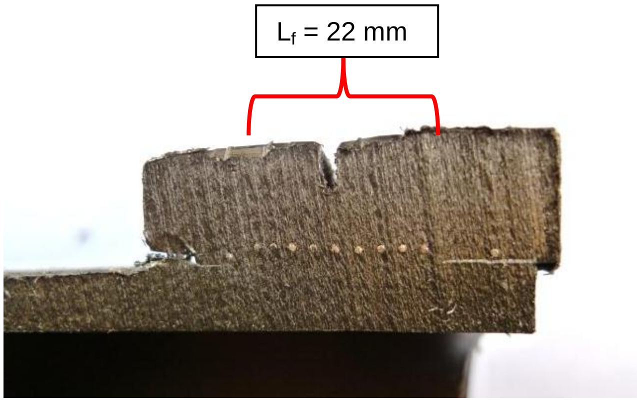

Figure 3 – Fusion length of the Rollmaplast coupler (Ø110, SDR11)

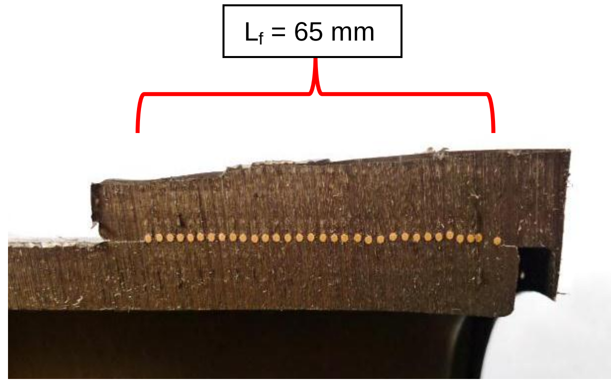

Figure 4 – Fusion length of the Mannesmann coupler (Ø110, SDR11)

As a first step towards gaining an insight into the quality of the first generation electro-fused PE joints, the assemblies were tested by means of the peel decohesion test in accordance with ISO 13954. Figure 5 and Figure 6 show representative examples of the welding zones of the Rollmaplast and the Mannesmann couplers respectively. In the case of the Rollmaplast couplers, cavities were found at the welding zone in most of the samples. As regards the Mannesmann couplers, it appears that there is almost no cohesion possible between the coupler and PE pipe due to the high density of wires at the welding zone.

Figure 5 – An example test sample after the Peel decohesion test on the Rollmaplast couplers. Cavities were found at the welding zones in many of the samples.

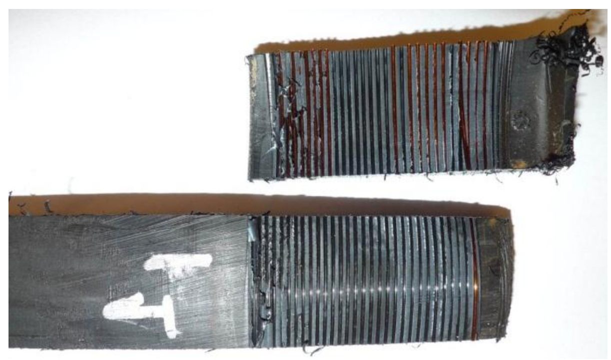

Figure 6 – An example test sample after the Peel decohesion test on the Mannesmann couplers. There is almost no connection possible between the coupler and PE pipe due to the high density of wires at the welding zone.

Figure 7 and Figure 8 show the results of all the examined first generation PE electro-fused joints for the Rollmaplast (11 in total) and the Mannesmann couplers (14 in total) respectively. In both figures the red wedges indicate brittle (poor quality) joints, while the green wedges indicate ductile (good quality) joints. Both figures show that the first generation couplers have high rejection rates in the peel decohesion test. Approximately 75% of the first generation electro-fused joints do not fulfil the current requirements for mechanical strength.

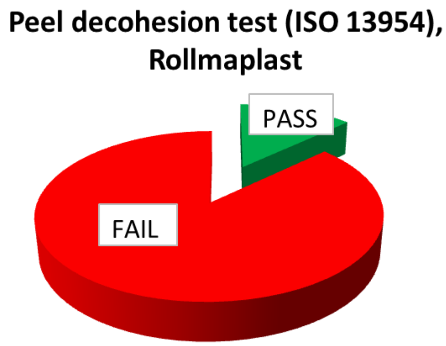

Figure 7 – Results of the Peel decohesion test on Rollmaplast couplers. Of the 11 investigated first generation PE electro-fused Rollmaplast joints, only 1 passed the peel decohesion test.

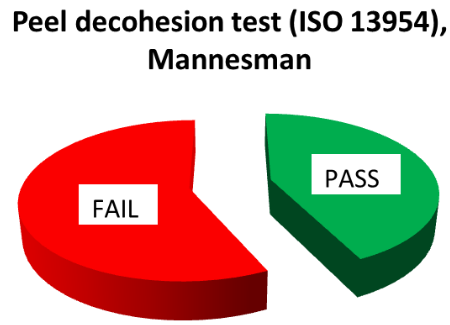

Figure 8 – Results of the Peel decohesion test on Mannesman couplers. Of the 14 investigated first generation PE electro-fused Mannesmann joints, only 6 passed the peel decohesion test.

The reasons for these failures have not been investigated extensively, but it appears that unsufficient scraping and contamination of the welding zone (mostly by sand) are the chief causes. This cannot always be blamed on the PE welder, as during the period in question (the 1970s) cleaning of the welding surface was not mandatory and scraping using a hand scraper was considered sufficient. Nowadays such practices would not be accepted. In addition, the design of the PE couplers may lead to failures in the peel decohesion test. In the case of the Mannesman couplers, for example, the high density of wires means that there is almost no PE material between the wires. This means that there is almost no cohesion between the coupler and PE pipe possible. As a result, the coupler can easily be peeled from the PE pipe at the welding zone (wire zone).

As a second step towards gaining insight into the quality of the first generation electro-fused PE joints, the assemblies were subjected to an axial tensile test on the complete joint in order to examine the full-end-load resistance of the joint. Figure 9 shows the test setup. The test pressure inside the PE piping system was maintained at a constant pressure of 30 mbar while the pull speed was kept constant at a crosshead speed of 5 mm/min (relates to the test speed mentioned in ISO 13953[12]).

Figure 9 – Test setup for testing the full-end-load resistance of the joint. The red arrow indicates the pull direction and the blue arrow the inlet for the air needed to keep the system at a constant gas pressure of 30 mbar.

The results of the axial tensile tests are given in Figure 10. A total of 11 first generation PE assemblies were tested. The red wedge indicates the percentage of joints that were not full-end-load resistant, while the green wedge indicates the percentage of joints that were full-end-load resistant. The results show that approximately 33% of the first generation PE joints were not full-end-load resistant. Full-end-load resistant joints are mandatory due to the fact that most of the first generation PE joints are used in piping systems at gas pressures higher than 1 bar. Dutch standards specify that such joints need to be full-end-load resistant.

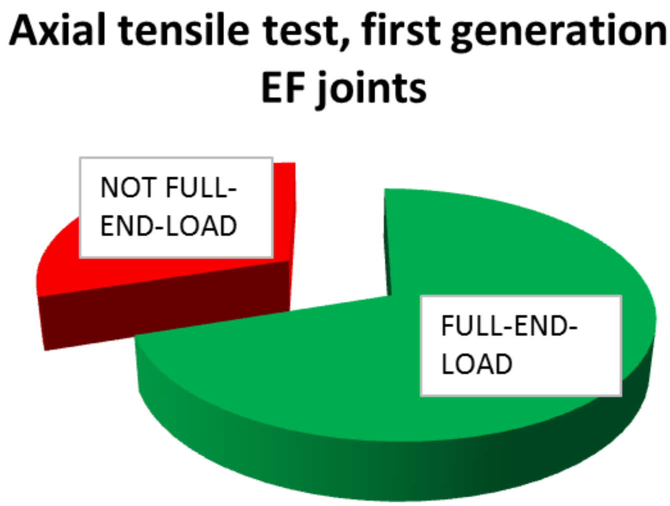

Figure 10 – Results of the axial tensile tests on the whole joint to test the full-end-load resistance of the joint. Of the 15 investigated Ø110, SDR 11 first generation PE electro-fused joints, 5 were not full-end-load resistant.

The mechanical stress, which is needed for yielding (of the thinnest PE pipe) of the full-end-load resistant joints, is the same as the tensile stress at yield values of PE materials. These values are approximately 23 MPa, depending on the quality of the PE material. The mechanical stresses at breaking point of the joints that were not full-end-load resistant measured during the axial tensile tests varied between 2 MPa and 16 MPa. This means that rupture of the joint can occur at very low stresses, which could lead to safety problems.

Although there is no one-to-one relationship between the peel decohesion test and the axial tensile test for first generation PE electro-fused joints, it seems legitimate to say that if the joint passes the peel decohesion test, then it is likely that it will also pass the axial tensile test. It can therefore be concluded that the quality control carried out by performing the peel decohesion test (ISO 13954) is conclusive. This is means that the test is useful for DSOs in ensuring the quality of PE electro-fused assemblies.

This quality assessment also shows that the quality of first generation PE electro-fused joints is far below the currently acceptable level (as determined for the peel decohesion test) and that they are also not always full-end-load resistant. This may cause severe problems if first generation PE joints are subjected to axial tensile forces. Such forces may occur in the vicinity of third party damage, excavations, soil sliding due to nearby excavation or subsidence and diastrophism. DSOs should demonstrate extra vigilance if these events occur in the vicinity of first generation PE joints.

QUALITY ASSESTMENT OF NEWLY MADE JOINTS

Almost ten years ago, as a result of several problems with PE electro-fused joints, DSOs began paying extra attention to correct execution of the welding procedure by means of visual inspection and destructive testing of the quality of newly installed joints. At present, approximately 2000 electro-fused joints are tested each year in accordance with the quality assessment procedures of the gas DSOs in the Netherlands. This is approximately 5% of the total number of electro-fused joints installed annually.

The first step in this quality assessment involves the visual inspection of the PE electro-fused joint. This visual inspection is primarily aimed at verifying if the welding procedure has been followed correctly. If this is not the case, then the joint is rejected. Factors that influence the visual inspection are: correct alignment and skinning, occurrence of fusion indicators, indicating cooling times on each coupler using a permanent marker and other DSO dependent parameters. Once the joint has passed visual inspection, the second step is carried out. In this step, the mechanical strength is checked by performing the peel decohesion test in accordance with ISO 13954. If this test is also passed, then the joint is accepted.

The results[13] of the quality control assessment of electro-fused joints performed for Enexis over the last eight years are given in Figure 11. This figure shows the annual percentage of acceptable joints (indicated with the green bracket for the year 2009). Since 2009, an additional distinction between visual and mechanical shortcomings has been made. The blue line indicates the percentage of acceptable joints that have passed both the visual and mechanical examination. The red line indicates the percentage of acceptable joints that have passed the mechanical examination. This means that the gap between the red and blue lines indicates the percentage of joints that show visual shortcomings. For the year 2009, this percentage is approximately 4% (indicated with the blue bracket). The red line above gives an indication of the percentage of mechanically rejected joints. For the year 2009, this is approximately 10% (indicated with the red bracket).

Despite a dip between 2011 and 2012, the percentage of approved joints has steadily risen. The main reason for this is considered to be enhanced surveillance. This has led to more awareness by both the contractor as well as by the DSO, which has eventually led to more widespread knowledge of the correct welding procedure. This has led to, for example, better equipment (including better skinning tools), compliance with cooling times, correct use of PE cleaners and the creation of "ideal" work areas.
There has also been a recent improvement in the percentage of assemblies that do not show any visual shortcomings (less than 1% in 2014). This also demonstrates that the welding procedure is being executed correctly more and more often.

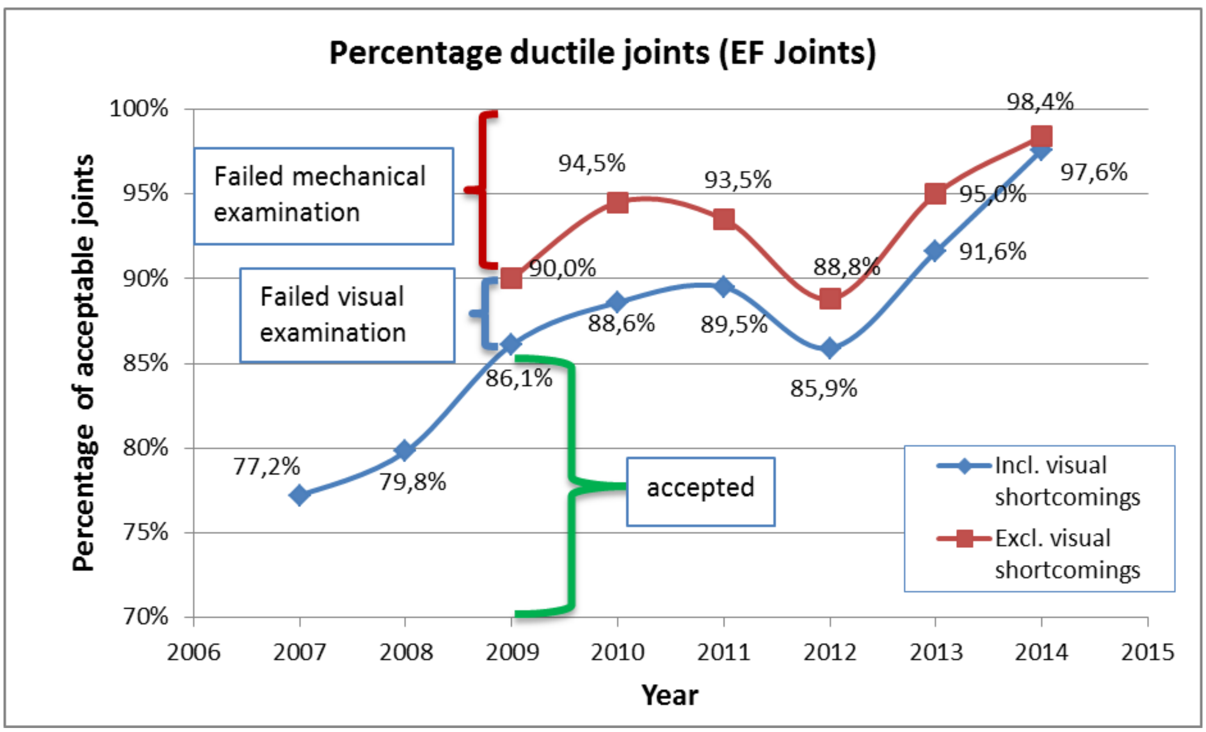

Figure 11 – Results of the quality control of electro-fused joints (including and excluding visual shortcomings)

An in-depth focus on the results for the year 2014 makes clear that several of the contractors have achieved a 100% acceptance level (see Figure 12). It can therefore be concluded that it is possible, including under field conditions, to make perfect electro-fused joints. This will nevertheless require enhanced surveillance by all stakeholders and in particular by DSOs.

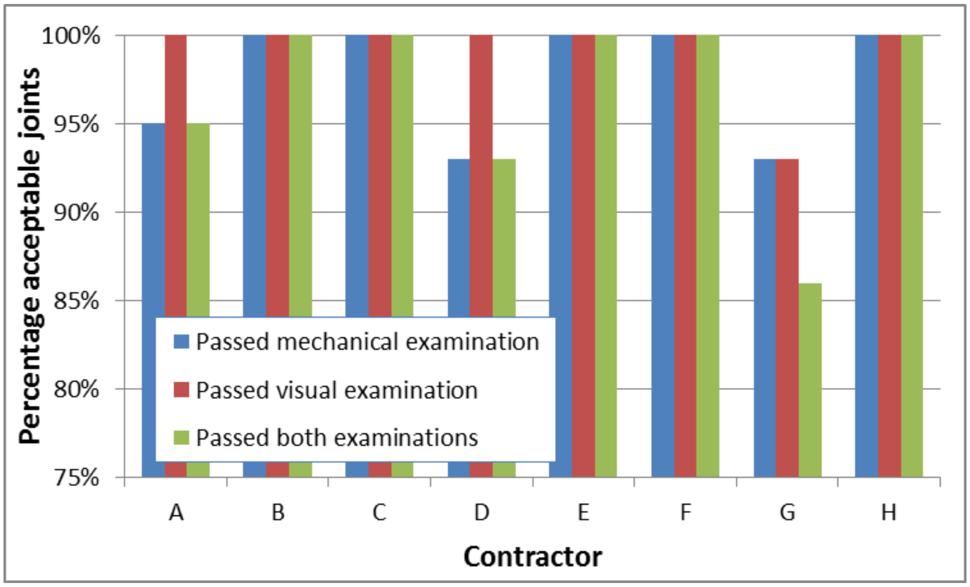

Figure 12 – Results of quality control assessment by contractor

In summary, it can be said that increased surveillance by the DSOs can lead to an immense improvement in the quality of the entire PE piping system. This is especially the case in those parts that are often seen as a weak point in the PE system, namely the electro-fused joints.

CONCLUSIONS

Although there is no one-to-one relationship between the peel decohesion test and the axial tensile test for first generation PE electro-fused joints, it seems legitimate to say that if the joint passes the peel decohesion test, then it is likely that it will also pass the axial tensile test. It can therefore be concluded that the quality control carried out by performing the peel decohesion test is conclusive. This means that the test is useful for DSOs in ensuring the quality of PE electro-fused assemblies.

Research into first generation PE electro-fused joints also shows that the quality is far below the currently acceptable level (as determined for the peel decohesion test) and that they are also not always full-end-load resistant. This may cause severe problems if first generation PE joints are subjected to axial tensile forces. Such forces may occur in the vicinity of third party damage, excavations, soil sliding due to nearby excavation or subsidence and diastrophism. DSOs should demonstrate extra vigilance if these events occur in the vicinity of first generation PE joints.

The investigation into third generation PE electro-fused joints also shows that, under field conditions, it is possible to achieve a 100% acceptance level in accordance with ISO 13954. This has been accomplished thanks to enhanced surveillance by all stakeholders and in particular by the DSOs. Increased surveillance by the DSOs can lead to an immense improvement in the quality of the entire PE piping system. This is especially the case in those parts that are often seen as a weak point in the PE system, namely the electro-fused joints.

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