THE SLOW PEEL TEST AS A TOOL FOR ASSESSING THE INTEGRITY OF ELECTRO FUSED JOINTS

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ABSTRACT

The long-term quality of electro fused joints in third, second and excavated first generation PE pipes was compared. Pipes from all three generations were joined using couplers produced from PE80 and PE100 resins. Six brands of PE pipes and three brands of electro fusion couplers were used and all 18 combinations were tested. Both a short-term test (the Peel Test according to ISO 13954:1997) and a long-term test (the Slow Peel Test - SPT) were used to assess joint integrity. The latter test typically takes 500 hours at 80 or 95 °C.
No failures at the joint plane occurred in either of the two tests, even for excavated first generation PE pipes. Whilst in the Peel Test failures often occur in the coupler, the Slow Peel Test exclusively produces slow brittle crack growth in the PE pipe wall. The time to failure in the Slow Peel Test on the joint is therefore governed by the resistance to slow crack growth of the pipe. These resistances vary widely between first, second and third generation pipes.
The scope of the Slow Peel Test programme was further widened by using it on the new type of “VRC” PE100 materials. These “Very Resistant to Cracks” pipe materials possess a much higher resistance to slow crack growth than traditional PE100 pipe materials. Improved results of Slow Peel Testing on joints made with a “VRC” material have been obtained.
Up to now, unwanted joint plane failures have never been found in Slow Peel Tests on electro fused PE pipes, including excavated first generation PE pipes. Such failures can only be produced by performing Slow Peel Tests on electro fused cross linked PE pipes. On such samples, the Slow Peel test can provide much clearer differences in electro fusion joint quality than the Peel Test at 23 °C.
A comparison was also made with another long-term test on electro fused joints, according to DVS 2203-4, Appendix 1. It appears that that test can only prove a long-term Fusion Factor (load ability of the joint divided by the load ability of un-fused pipe, assessed in a long-term test) of not higher than 44 %. Therefore this test is less critical for electro fused joints in PE pipes.

INTRODUCTION

A lot of experience has been gathered with electro fused connections in PE pipes. The quality is good, provided some basic precautions are taken. Still, only one ISO method exists to test the quality and this is the Peel Test according to ISO 13954. This is a short-term test, which can only assess the short-term quality of joints.

The Slow Peel Test (SPT) [1, 2] simulates the long-term behaviour of electro fused joints. The test is a combination of the traditional Peel Test at 23 °C and a constant load test according to the German standard DVS 2203-4 at 80 °C (or 95 °C). In each test bar from a joint in a 110 mm pipe, a joint area of about 1000 mm^2 is loaded to provoke a peeling action on the joint plane during typically 500 hours.

Two types of investigation were performed.
In the first investigation there were 3 goals. The first one was to assess the quality of electro fusion joints in first, second and third generation PE pipes. A second goal was to investigate whether first generation pipes could still be electro fused. Two types of test were used, the traditional Peel Test according to ISO 13954 and the Slow Peel Test (SPT). The third goal was to compare the information that can be obtained by using both test methods.

A second investigation was to assess whether the new "VRC PE100" resins [3, 4] can provide a better long-term joint quality. These "Very Resistant to Cracks" PE100 pipe materials possess a much higher resistance to slow crack growth than traditional PE100 pipe materials. When discussing the possible applications of VRC PE100 pipes it is often asked whether these materials can be butt fused and electro fused and whether such joints also possess an increased lifetime expectancy.
To answer these questions, experiments were performed on electro fused joints in "VRC PE100" pipes and on joints in pipes made of 2 other resin types, using the Slow Peel Test. Three types of resins were used in the fittings. All 9 pipe-coupler combinations were tested.
The goal of the work is to assess the influence of resin type in pipe and coupler.

EXPERIMENTAL METHODS

Materials

Three Generations of PE Pipes
In this investigation electrofusion joints in 6 types of PE pipes were compared. Two types of excavated first generation PE pipes were tested. These pipes, denoted P1 and P2, had been used for gas distribution for about 30 years.
The other 4 pipes were un-used. Three older PE80 pipes were tested, denoted P3, P4 and P5, produced in 1987 and stored since then. A PE100 pipe produced in 1999 and stored since then was also tested (P6).

Table 1. Pipe and fitting materials used in the work on electro fusion of 3 generations of PE pipes.

Pipe code	Resin type in pipe	Fitting code	Fitting resin type
P1	1st generation HDPE	F1	MDPE (PE80)
P2	1st generation HDPE	F2	PE100, company 1
P3	PE80 from 1987	F3	PE100, company 2
P4	PE80 from 1987		
P5	PE80 from 1987		
P6	PE100 from 1999		

Three types of fittings were used, one older type produced from PE80 (MDPE) resin and two produced from PE100 resins, denoted F1 and F2. All 18 fusion combinations were made and tested. Table 1 shows a list of these materials.

VRC PE100 Resin

In a second series 3 types of electro fusion fittings were tested, all produced by the same well-known fitting producer. Three different types of resins were used in them, denoted FA, FB and FC. All were different grades of PE resin, some especially modified for injection moulding.

The joints were made in 3 types of PE pipe materials, denoted D, E and a reference pipe F. E is a so-called “VRC” PE100 type, D is a traditional PE100 type (Table 2). All 9 combinations of pipes and couplers were tested in fourfold.

Table 2. Materials used for comparing VRC PE100 resin.

Fitting code	Resin type in the fitting	Pipe code	Resin type in the pipe	Grade name
FA	HE 3490-LS	D	Traditional PE100	HE 3490-LS
FB	HE 3470-LS	E	“VRC” PE100	HE 3490-LSH
FC	HE 3490-IM	F	Reference pipe	Undisclosed

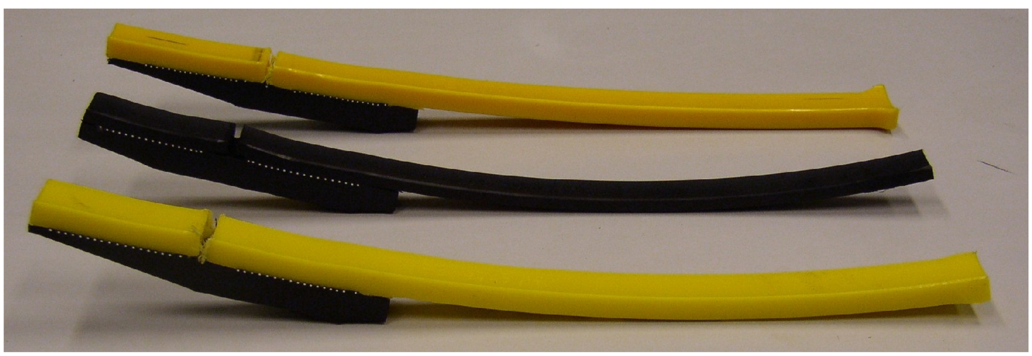

Figure 1. Strips (20 mm wide) for the Slow Peel Test.

Test Methods

Peel Tests at 23 °C

The tests were performed according to ISO 13954 with 2 test bars per condition.

Slow Peel Tests at 80 °C

Figure 1 shows typical test bars for the Slow Peel Tests.

The principle of this test is shown in Figure 2. It is intended to peel pipe segment and coupler segment apart, at a test temperature of 80 (or 95) °C. The peeling force is reduced to induce slow peeling, during typically 500 hours, although in some cases much shorter testing times are found. The force acting on each test bar is 4 Newton

per mm width of the test bar, which typically is 20 mm. The test bar length is kept constant for all test bars (300 mm).
The vertical displacement is measured using the displacement meter placed on the left side of the yoke (Figure 2, item 13), which measures the vertical displacement of the left side of the yoke. The displacement was corrected for the differences in length on the left and right hand side of the yoke.
In this way, the displacement of the test bar in vertical direction is found.

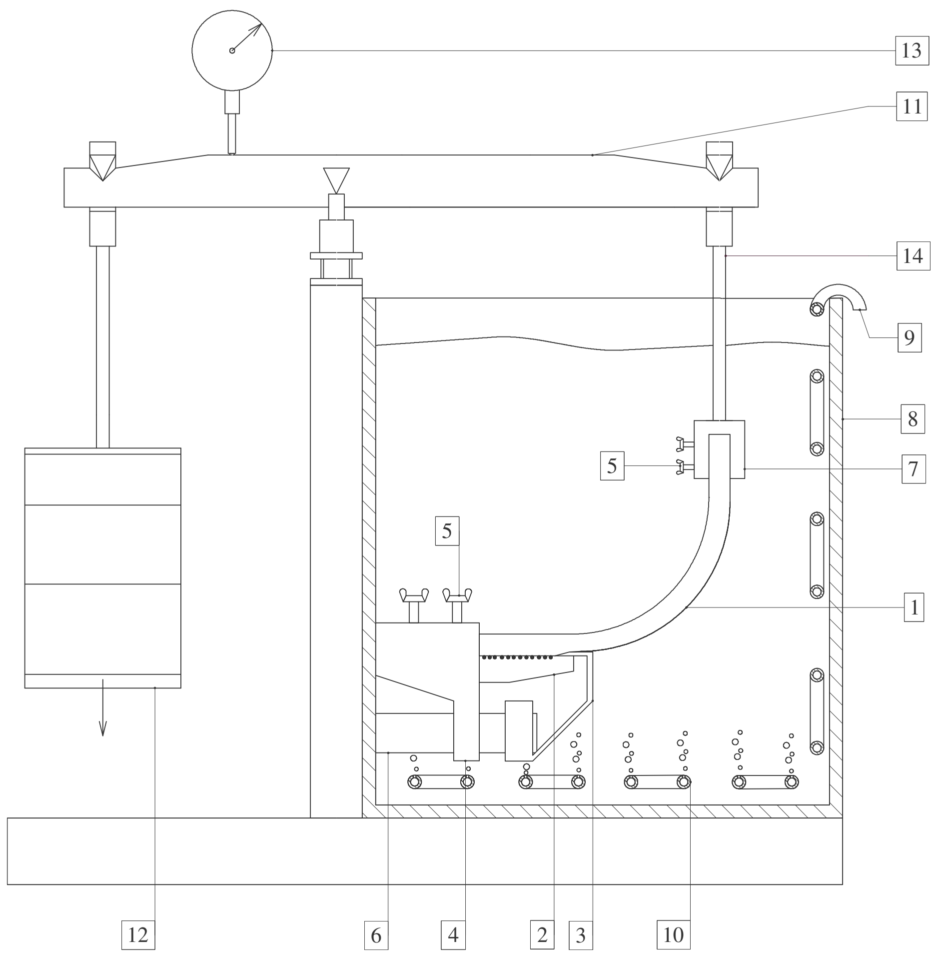

Figure 2. Principle of the Slow Peel Test.

1 Pipe segment
2 Coupler segment with wedge placed between coupler and pipe
3 Clamp to fix the wedge
4 Clamp to fix the coupler
5 Screws to fix part 1
6 Horizontal bar to fix the clamps (parts 3 and 4)
7 Clamp on the pipe segment
8 Container filled with 2% non-ionic detergent (Arkopal) in hot water*
9 Nitrogen supply by stainless steel tubes, which zigzag across the right and bottom wall of the container, so that the nitrogen is preheated.
10 Purging of the detergent solution by preheated nitrogen to prevent oxidation of the detergent
11 Yoke in horizontal position
12 Weight on the yoke
13 Displacement measuring device
14 Metal bar.

A continuous curve for each individual test bar is obtained of vertical elongation versus testing time. The time to failure can also be easily noted in the curves.
To accelerate the failure process, a 2% solution of Arkopal, nonylphenol ethoxylate, was used as testing medium.

RESULTS

Three Generations of PE Pipes

The Peel Test is designed to produce failures in all cases. Therefore, the important results are type and location of the failure. There are 3 different failure mechanisms:

1. Coupler and pipe peel apart partially or completely
2. The coupler fails
3. The pipe fails.

The results are given in Table 3.

Table 3. Peel Tests at 23 °C according to ISO 13954 on 3 fitting types. In this table all 6 pipe types were combined.

Resin type in the coupler	Failure in the fitting (%)	Maximum Stress on pipe segment (MPa)	Standard deviation (%)
PE80 (MDPE)	80	6.1	35
PE100-1	25	10.2	18
PE100-2	0	9.3	28

In none of the cases is failure of the actual joint plane noted. This means that all joints are acceptable.
During the test the maximum peeling force was also noted and divided by the width and thickness of the pipe segment in each individual test bar. In Table 3 the average maximum stress in the pipe wall is presented irrespectively of the failure location (pipe or coupler), to only show differences in load bearing capacity.

Table 4. Results of Slow Peel Tests on 1st, 2nd and 3rd generation PE pipes electro fused with 3 coupler types.

Pipe code	Average time to failure (h)	Standard deviation (h)	Standard deviation (%)	Failed test bars
P1	16.1	2.0	12.6	6/6
P2	71.4	6.3	8.8	6/6
P3	67.9	6.9	10.2	6/6
P4	429.3	25.6	6.0	6/6
P5	> 553.5	-	-	1/6
P6	> 543.5	-	-	0/6

Table 4 shows the results of the Slow Peel Tests on the same joints. In this Table all joints were ordered per pipe group, irrespective of coupler type.

Curves on these materials have been published earlier [2].
In none of the test bars was failure type 1 found. Only complete or partial pipe failures were noted. Coupler failures (type 2), for instance at the location of the heating wires, did not occur either. In all cases the (partial) failures were brittle.
Because all failures were in the pipe, averages and standard deviations could be calculated.

VRC PE100 Resin
Figure 3 only shows a selection of all results. Three groups are shown, denoted by the 3 different resins in the pipes (D, E and F).

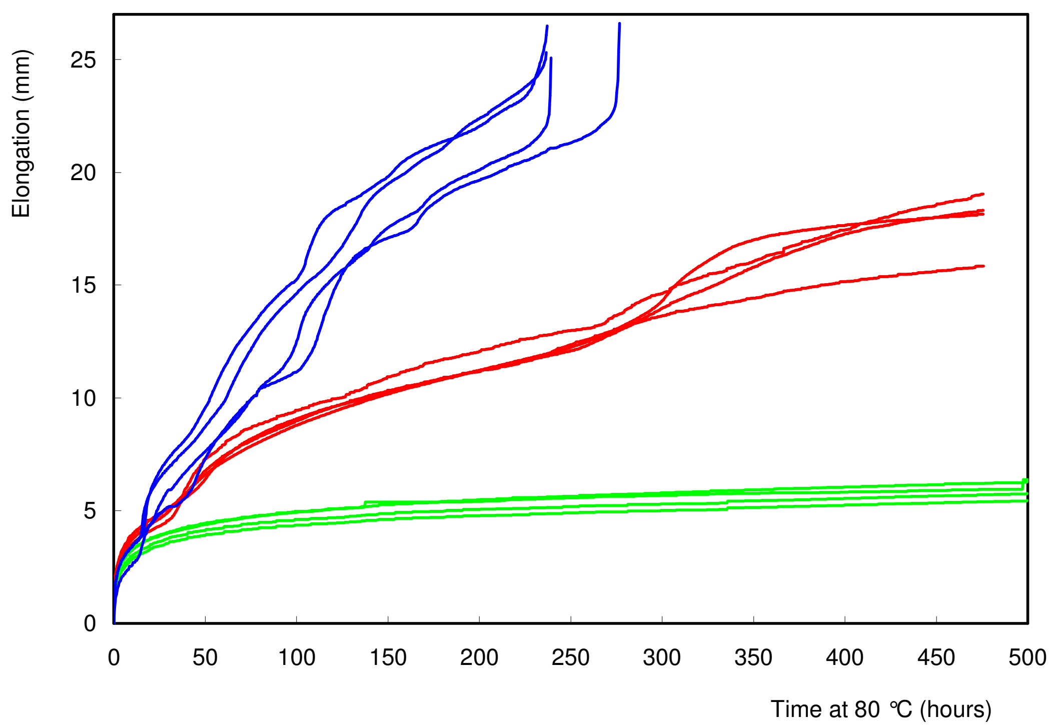

Figure 3. Slow Peel Tests on joints made in pipes made of resin D (red), resin E (green) and resin F (blue). Each group shows the curves of 4 out of 12 test bars.

Although in each pipe group 12 bars were tested (3 coupler types in fourfold), for reasons of clarity, only 4 are shown in each group. This is because all 12 curves within each pipe group are very similar (see also Table 5 and Table 6).
In group D, all test bars failed partially in a brittle manner, but never completely. In group E, not even crack initiation occurred, no matter which fitting type was used. In group F all test bars failed completely in a brittle manner. These differences are also reflected in the curves, as D is intermediate between E and F.

Table 5 shows the statistical evaluation of the crack length after Slow Peel Tests on joints made with pipes of resin D.
In series F all elongations are larger than those in series D en E. All test bars failed completely between 200 and 340 hours. Statistical evaluation is given in Table 6.

Table 5. Slow Peel Tests on joints with all pipes made of resin D. Length of the crack in the pipes measured on the left and right edges is given as well as the average.

Fitting resin	Left (mm)	Right (mm)	Average (mm)
FA	4.59	4.92	4.76
FA	4.47	4.59	4.53
FA	5.65	7.07	6.36
FA	4.59	5.00	4.80
FB	4.44	4.63	4.54
FB	3.08	4.96	4.02
FB	5.13	4.02	4.58
FB	6.49	6.06	6.28
FC	5.04	6.14	5.59
FC	3.46	6.73	5.10
FC	4.91	6.50	5.71
FC	5.10	5.66	5.38
Arithmetic mean			5.13
Standard deviation			0.73
Standard deviation (%)			14.3

Table 6. Statistical evaluation of the times to failure after Slow Peel Tests on joints in which all pipes were made of resin F.

Fitting resin	Time to failure (h)	Fitting resin	Time to failure (h)
FA	318.3	FC	334.3
FA	247.2	FC	266.3
FA	205.2	FC	237.7
FA	206.2	FC	229.7
FB	276.7	Geometric mean (h)	250.3
FB	239.2	Arithmetic mean (h)	253.0
FB	237.6	Standard deviation (h)	40.0
FB	237.1	Standard deviation (%)	15.8

DISCUSSION

3 Generations of PE Pipes

Table 7 shows an overview of the times to failure in several tests, a joint test (SPT, Table 4) and 2 pipe tests (Full Notch Creep test [7] and PENT test [8]). For the first generation pipes P1 and P2, the testing stress in the PENT test was decreased to 1.5 MPa, to prevent immediate failure at the prescribed value of 2.4 MPa.

In the SPT on these joints, only failures in the pipe wall were noted. Consequently, the time to failure in the SPT is governed by resistance to Slow Crack Growth of the pipe the joint was made with.

This explains why there is a correlation between the time to failure in the Slow Peel Test on electro fused joints and the time to failure in the pipe tests on the same pipe which was used in the electro fused joints.

Table 7. Average time to failure in the Slow Peel Test (SPT) compared to the Full Notch Creep test and the PENT test at 80 °C, both at 2 stress levels.

Pipe code	SPT (h)	Failures in SPT (%)	FNC test at 4 MPa (h)	FNC test at 3.5 MPa (h)	Stress level (MPa) PENT test	Time to failure (h) PENT test
P1	16.1	100	-	-	1.5	2.4
P2	71.4	100	-	-	1.5	64.2
P5	67.9	100	17.8	22.2	2.4	8.0
P3	429.3	100	80.2	139.5	2.4	> 1151
P5	> 553.5	17	93.0	152.0	2.4	> 1202
P6	> 543.4	0	178.6	316.1	2.4	371

VRC PE100 Resin

There is only a measurable crack length after the tests in series D. In series E there is no crack formation whilst in series F there is complete failure of all test bars. These results are reproducible.
The crack lengths in the pipes show a standard deviation of 14.3%. This is favourable and confirms that the Slow Peel Test provides reproducible results.

All failures - when they occur – are located in the pipes. Joint failures and coupler failures do not occur, as was noted before [1, 2]. With all non-cross linked PE pipe materials, any failures in electro fused joints tested with the Slow Peel Test always occur in the pipe at the place where the first heating wire in the coupler is located [1].

Only in series F complete test bar failures occurred. Therefore, times to failures are known and statistical analysis is possible. While in the tests on the three PE generations the standard deviation in the time to failure was 8 – 12 %, in this case it is slightly higher (15.8%).

It now appears that the “VRC PE100” pipe resin E provides the best results in the Slow Peel Test. There is no crack initiation in the pipe and any deformation is due to creep of the test bars.
Pipe resin D is second best in this test series. In all pipes made from this resin, partial failure occurred at the location of the first heating wire in the coupler. No complete failure occurred after 500 hours of testing.
Pipe resin F shows the poorest results. All test bars fail completely between 200 and 340 hours, at the location in the pipe as described above.

Consequently, the most obvious difference between the three pipe materials is linked to the type of resin in the pipes the joints were made with. Resin type in the pipes is the predominant influential factor. Multi-variate statistics was used to test whether there is any secondary effect of the resin in the fittings using Sigmastat 3.5 from Systat software [5]. It appeared that in no case there was a statistically significant effect of the resin in the couplers.

General discussion on SPT
Up to now, only pipe failures have been found in the Slow Peel Tests on electro fused PE pipes. Unwanted joint plane failures have never been found. However, such failures can be produced by using the Slow Peel Test on electro fused cross-linked PE pipes. Clear and reproducible differences between different PEX pipes were noted earlier [1], which had not been detected using the Peel Test according to ISO 13954. This proves that the Slow Peel Test is more sensitive to fusion quality differences of critical joints.

Comparison to DVS 22034-Annex 1
There is one other long-term test of electro fused joints, which is only used in Germany [6]. This test was applied by the authors to other electro fusion joints in modern PE100 types. The recommended testing stress at 95 °C in this standard is 2 MPa, but it proved necessary to reduce this value to 1.8 MPa, to prevent premature failure of electro fused joints and ductile failures. The latter would render the test useless, because the failure surface needs to be brittle for more than 30 % [6].
The reduced testing stress is necessary because the location of the heating wires is the weakest spot in the fitting when tested according to this method. At this location, there is no PE material which could otherwise take up part of the load. Due to this, there is a reduced cross-sectional area and hence a reduced load-bearing capacity of the coupler, but not necessarily of the joint plane.

The 8 test bars from the electro fused fittings mentioned above showed a geometrical mean of the time to failure of 60 hours. This is compared to non-fused PE100 materials. If test bars taken from non-fused PE100 pipe are tested in axial direction, according to DVS 2203-4 at 95 °C, the geometrical mean of 6 failure times at a stress level of 4.05 MPa is 802 hours [9].

If – for the sake of argument - these differences in time to failure between non-fused and electro fused PE100 pipes are ignored, the ratio of the stress levels in both tests (the Long-term Fusion Factor) is 1.8 MPa / 4.05 MPa, which is only 44 %. Consequently, when testing electro fused joints at 1.8 MPa, a Long-term Fusion Factor of electro fused joints higher than 44% can not be proven with this test.

CONCLUSIONS

- None of the electro fused joints in 6 first, second and third generation PE pipes, made using PE80 and PE100 couplers, failed in the Peel Test at 23 °C at the fusion plane between pipe and coupler. With all investigated pipe and coupler type combinations, satisfactory joint qualities can be produced, provided the prescribed pipe scraping and jointing procedures are followed.
- The maximum peeling force in the Peel Test at 23 °C and the failure location is governed by the strength of the weakest part in the joint, either the pipe or the location of the heating wires in the coupler. Both failure types are acceptable.
- Joints with couplers made from PE100 resin are best in the Peel Test at 23 °C in all cases, except with the poorest first generation pipe P1, for which PE100 couplers do not provide an improvement. In all other cases PE100 couplers provide the highest load-ability of joints, which is favourable in case of third party damage.

- The Slow Peel Test provides reliable test data during typically 500 hours at 80 °C in Arkopal detergent and simulates long-term behaviour. Repeated tests on the same joints lead to reproducible times to failure. In those cases where this could be determined, the standard deviation in the time to failure is 10 - 16%.
- In the Slow Peel Test the time to failure of the electro fused joints is governed by the resistance to slow crack growth and notch sensitivity of the pipe. In this test, failure always takes place in the pipe wall next to the first heating wire of the coupler.
- Pipes made of "VRC" PE100 resin show a largely improved resistance to failure in the Slow Peel Test. Whilst other pipe resins show (partial) brittle failure in the pipe wall, there is no crack initiation in the "VRC" pipes. Therefore, the quality of electro fused joints in such pipe materials is also very much improved.

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