COMPARISON OF LONG-TERM AND SHORT-TERM TESTS FOR ELECTROFUSION JOINTS IN PE PIPES

Mike Troughton, Chris Brown TWI Ltd
Joachim Hessel Hessel Ingenieurtechnik GmbH
Marco Piovano Italgas S.p.A.

ABSTRACT

As part of the Polytec Systems European-funded project, electrofusion (EF) joints in polyethylene (PE) pipe, containing different flaws, have been subjected to various standard and non-standard, long-term and short-term, coupon and whole pipe tests. The results were compared to determine which tests could discriminate between standard welds containing no deliberate flaws and welds containing different types and degrees of flaw (including particulate contamination, unscraped pipe surfaces and cold welds), and whether any short-term tests provided data that could give an indication of long-term performance.

INTRODUCTION

Even though the parent pipe itself may have adequate mechanical properties, the presence of joints can affect the overall structural integrity of the system. Therefore, there is a need for reliable standard test procedures to evaluate the mechanical properties of the welded joints. At present, there are a number of different mechanical test methods that can be used for assessing the integrity of EF joints in PE pipes. These tests are carried out either on coupons cut from the welded joint or on the complete weld, and can be either short-term or long-term. For quality control purposes, short-term coupon tests are preferred, since these are inexpensive and provide data quickly. However, since the weld is more likely to fail in the long-term in service, it is important that the results from these tests should correlate with those from long-term tests. To date, little work has been done to correlate results from one test with those from another, or to correlate results from short-term tests with those from long-term tests.

PRODUCTION OF WELDS

Welds were made using 125mm SDR11 blue PE100 pipe and black PE100 EF couplers. All couplers were supplied from the same manufacturer. Welding parameters were according to the manufacturers recommended values, and the pipe surfaces were prepared using a mechanical scraper, unless otherwise stated.

In addition to standard welds, made according to WIS 4-32-08 (1), welds were also made containing one of four different types of flaw: talc contamination, sand contamination, cold welds and unscraped pipe, in order to produce joints with different weld qualities.

The particulate contamination was applied to the scraped surface of the pipe to be welded using a rubber roller (see Fig.I). The talc (Westmin D100) had a median particle size of

22µm; and the sand (Fraction D natural uncrushed silica sand to BS 1881-131:1998 (2)), had a particle size of 150-300µm.

The cold welds were made by reducing the fusion time to 38% of the manufacturers recommended value.

Fig.I *Application of particulate contamination.*

MECHANICAL TESTS

The following standard mechanical tests were carried out:

- Peel decohesion test, according to ISO 13954 (3);
- Decohesion test, according to BS EN 12814-4 (4);
- Crush test, according to ISO 13955 (5);
- Specimen tensile creep test for socket joints, according to Annex C of BS EN 12814-3 (6);
- Hydrostatic pressure test at 80°C, as specified in BS EN 12201-3 (7).

The procedure used for preparing the specimens for the tensile creep test for socket joints is shown in Fig.II.

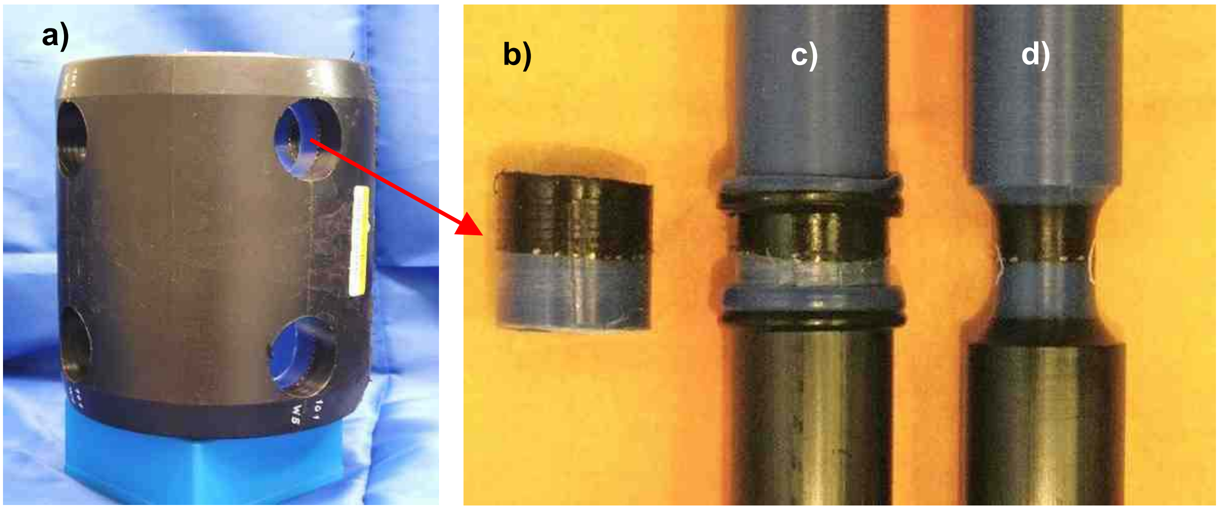


Fig.II *Preparing specimens for the tensile creep test: a) welded EF joint showing positions from where "cork" specimens were cut, b) "cork" specimen, c) extension bars hot plate welded to cork specimen, d) final specimen waisted at the electrofusion weld interface.*

In addition, two non-standard tests were performed. The first was a short-term hydrostatic pressure test, to simulate the post-installation pressure test carried out on site. This consisted of pressurising a 900mm (35 inch) long welded sample at ambient temperature to an initial pressure of 10 bar, recording the pressure for a period of 1 hour, and comparing the pressure drop with that from a control sample, consisting of a single 900mm (35 inch) length of pipe with an EF coupler welded in the middle.

The second non-standard test was the whole pipe tensile creep rupture test (see Fig.III). This test subjected welded whole pipe samples to a constant axial tensile stress of 5.5MPa (800 psi), based on the cross-sectional area of the pipe, in water at 80°C (176ºF). The tensile load was applied to the pipe sample via a stainless steel push rod, which passed down the inside of the pipe. The top of the push rod was in contact with the ram of a hydraulic jack and the bottom end was attached to the bottom end plate, which had a hole in it to allow the inside of the pipe sample to fill with water when it was inserted into the water bath.

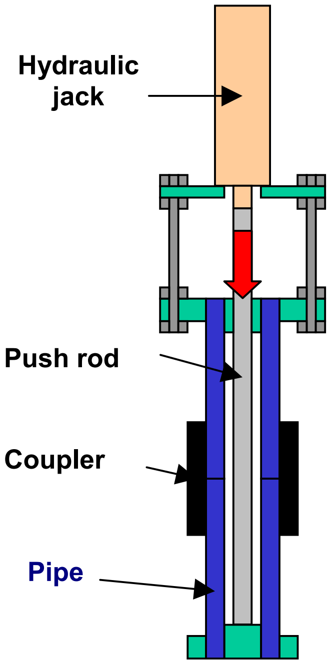


Fig.III *Diagram of whole pipe creep rupture test loading arrangement.*

RESULTS

ISO Peel Decohesion Test

The results of the ISO peel decohesion tests are given in Table I.

Table I *Results of ISO peel decohesion tests.*

Type of weld flaw	No. of tests	Average percentage brittle failure decohesion
No deliberate flaws	7	0
Talc contamination	5	80
Sand contamination	5	0
Cold weld	5	0
Unscraped pipe	5	0

The above results show that this test could only differentiate welds containing talc contamination, all of which failed in a mainly brittle manner through the weld interface (see Fig.IV). All other specimens either failed in a fully ductile manner through the plane of the heating wires (Fig.V) or through the pipe (Fig.VI).

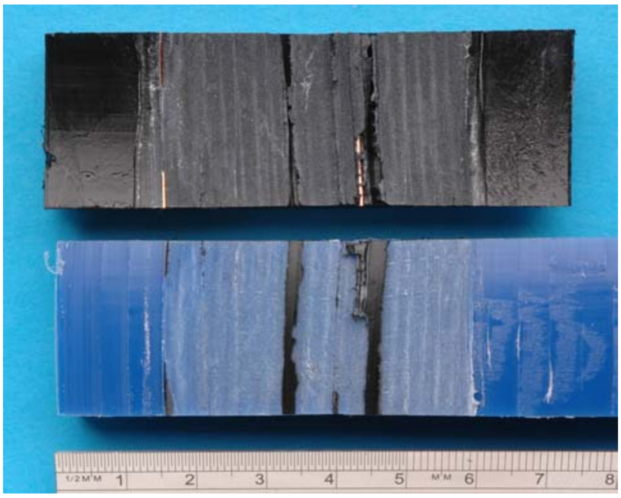


__Fig.IV__ Fracture surface of ISO peel decohesion test specimen containing talc contamination.

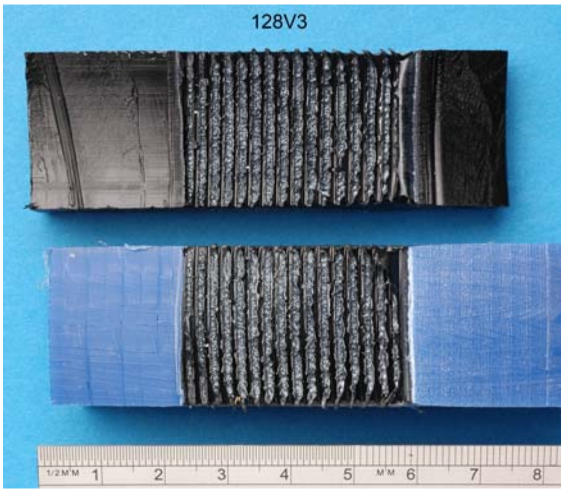


__Fig.V__ Fracture surface of ISO peel decohesion test specimen showing fully ductile failure through the plane of the heating wires.

__Fig.VI__ ISO peel decohesion test specimen showing fracture through the pipe wall.

EN Decohesion Test

The results of the EN decohesion tests are given in Table II.

Table II *Results of EN decohesion tests.*

Type of weld flaw	No. of tests	Average percentage brittle failure decohesion
No deliberate flaws	7	0
Talc contamination	5	62.8
Sand contamination	5	<2
Cold weld	5	<1
Unscraped pipe	5	2

The above results show that, similar to the ISO peel decohesion test, this test could only differentiate welds containing talc contamination, all of which failed in a mainly brittle manner through the weld interface. As with the ISO peel decohesion test, all other specimens either failed in a ductile manner through the plane of the heating wires or through the pipe wall.

Crush Test

The results of the crush tests are given in Table III, which shows that this test could only distinguish between welds containing talc contamination and welds containing no deliberate flaws. A photograph of a crush tested joint containing talc contamination is given in Fig.VII.

Table III *Results of crush tests*

Type of weld flaw	No. of tests	Average percentage brittle failure decohesion
No deliberate flaws	8	0
Talc contamination	4	100
Sand contamination	4	0
Cold weld	8	0
Unscraped pipe	8	0

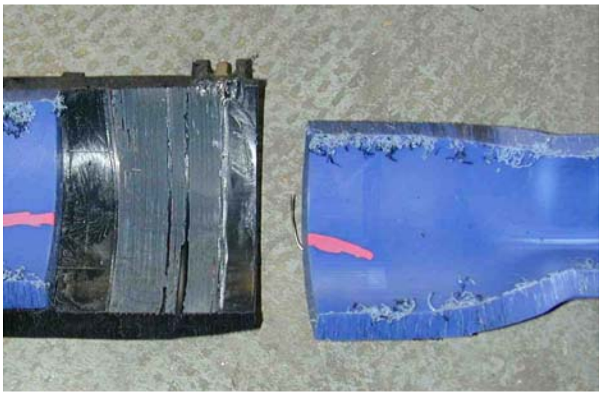


Fig.VII *Photograph of talc contaminated joint after crush testing.*

Specimen Tensile Creep Test

A problem was encountered when carrying out this test, due to the occurrence of circumferential voids in the plane of the heating wires (see Fig.VIII) in over 90% of the specimens. These voids, although only a small percentage of the overall weld area, were a large percentage of the area of the test specimen. This resulted in an increase in the effective stress at the weld and in consistent failure in the plane of the heating wires, irrespective of the included flaws (see Fig. IX). For this reason an additional series of welds were made using couplers from a different manufacturer, which did not generate voids in the welded joint. The results of these tests are given in Table IV.

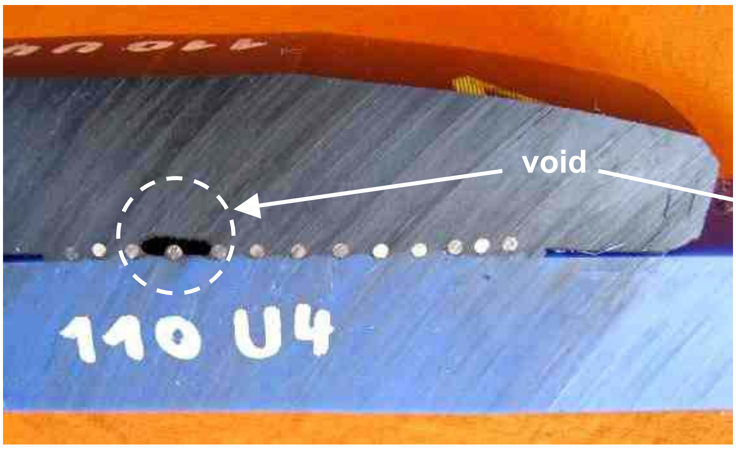


Fig.VIII *Cross-section of EF joint showing voiding between heating wires.*

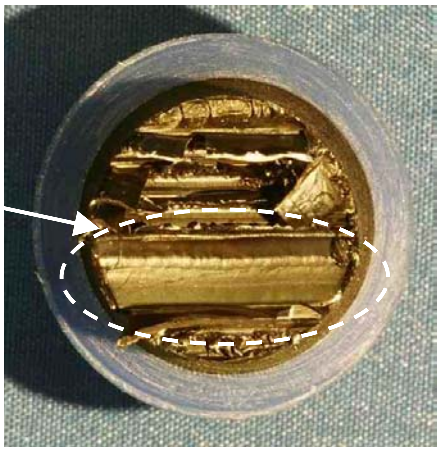


Fig.IX *Fracture surface of tensile creep test specimen containing a void.*

Table IV *Results of specimen tensile creep tests*

Type of weld flaw	No. of tests	Time to rupture, hours	Failure position		
			Weld interface	Mixed	Plane of heating wires
No deliberate flaws	8	160 ± 34	0	0	8
Talc contamination	6	99 ± 33	2	1	3
Sand contamination	6	137 ± 19	0	0	6
Cold weld	6	154 ± 50	0	2	4
Unscraped pipe	6	221 ± 85	0	0	6

As can be seen in the above table, the welds containing no flaws, sand contamination and unscraped pipes all failed through the plane of the heating wires (see Fig.X). Even though the average times-to-rupture for these specimens are different, this cannot be due to the flaws because the failures were not through the weld interface. Two out of the six specimens containing talc contamination failed through the weld interface (Fig.XI), with one specimen failing partly through the weld interface and partly through the plane of the heating wires (Fig.XII). Also, the average time-to-rupture for these specimens was lower than for the welds with no deliberate flaws.

Fig.X *Fracture surface of tensile creep test specimen through the plane of the heating wires.*

Fig.XI *Fracture surface of tensile creep test specimen through the weld interface.*

Fig.XII *Fracture surface of tensile creep test specimen showing a mixed failure mode.*

Two of the specimens containing cold welds also failed partly through the weld interface and partly through the plane of the heating wires, with the remainder failing fully through the plane of the heating wires. The average time-to-rupture for the cold weld specimens was very similar to average value for the welds containing no deliberate flaws.

80° Hydrostatic Pressure Test

The results of the 80°C hydrostatic pressure tests are given in Table V.

Table V *Results of 80°C hydrostatic pressure tests*

Type of weld flaw	No. of tests	Time to rupture, hours	Comments
No deliberate flaws	3	255, 294, 890	Failure initiation from the internal cold zone notch, with propagation through the coupler
Talc contamination	2	385, 391	
Sand contamination	2	268, 623	
Cold weld	2	536, 889	
Unscraped pipe	2	405, 507	

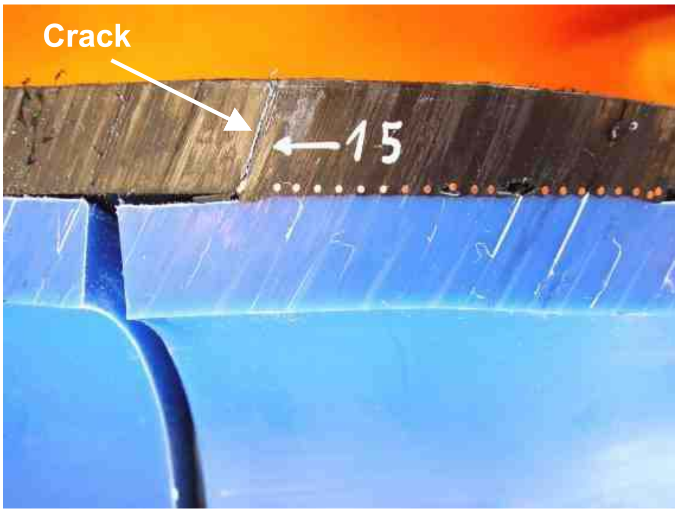


Fig.XIII *Section through failed joint subjected to 80°C hydrostatic pressure test.*

These results suggest that this test cannot distinguish between welds containing no deliberate flaws and welds containing any of the four flaws examined. In fact, crack initiation and propagation was identical for all of the welds tested and was due to the stress concentration at the internal cold zone notch and also the resistance to slow crack growth of the coupler material. An example of a failed joint is shown in Fig.XIII.

Short-Term Hydrostatic Pressure Test

The results of the short-term hydrostatic pressure tests are given in Table VI.

Table VI *Results of short-term hydrostatic pressure tests*

Type of weld flaw	No. of tests	Percentage pressure drop after 1 hour	Comments
Control sample	1	34.2	No leaks, pressure drop caused by expansion of test sample
Talc contamination	2	34.6, 36.4	
Sand contamination	2	31.7, 36.2	
Cold weld	2	35.5, 36.9	
Unscraped pipe	2	35.1, 36.0	

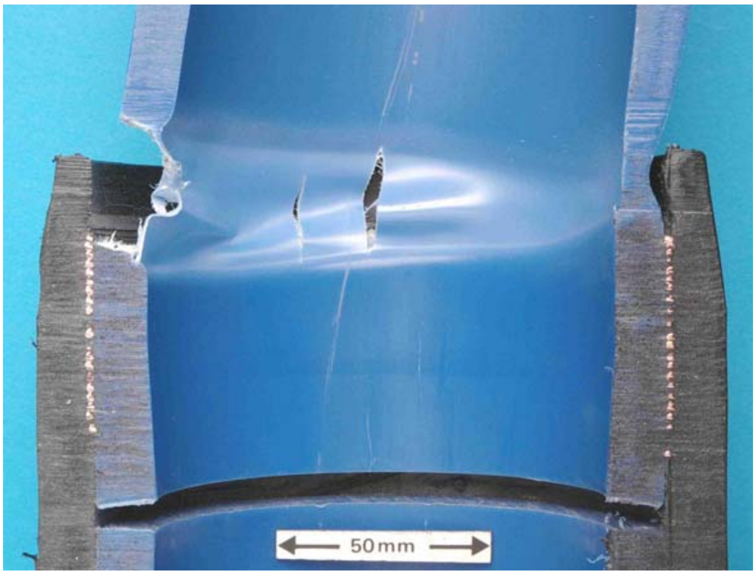
None of the welded joints leaked during the short-term hydrostatic pressure test and the percentage pressure drops recorded for all samples were very similar, suggesting that this test cannot distinguish between welds containing the flaws examined in this study and unflawed welds.

Whole Pipe Tensile Creep Rupture Test

The results of the whole pipe tensile creep rupture tests are given in Table VII.

Table VII *Results of whole pipe tensile creep rupture tests*

Type of weld flaw	No. of tests	Time to rupture, hours	Comments
No deliberate flaws	2	1427, 2074	Failure initiation from the external cold zone notch, with propagation through the pipe
Talc contamination	2	1802, 1658	
Sand contamination	2	2180, 2463	
Cold weld	1	1806	
Unscraped pipe	2	1898, 1839	



Again, these results suggest that the whole pipe tensile creep rupture test cannot distinguish between welds containing the above flaws and welds containing no deliberate flaws. In this test, crack initiation was from the external cold zone notch and propagation was through the pipe wall, for all joints tested. An example of a failed joint is shown in Fig.XIV.

Fig.XIV *Cross-section through failed whole pipe tensile creep rupture test.*

DISCUSSION

The above results suggest that most of the types and degrees of flaw examined in this work have no effect on either the short-term or long-term performance of EF joints. Only talc contamination had any effect on the short-term properties and none of the flaws had an effect on the results of the whole pipe tests.

There is good correlation between the short-term specimen tests in that they all generated a brittle weld interface failure with talc contamination but failure either through the plane of the heating wires or through the pipe wall for the other types of flaw and for joints containing no deliberate flaws. However, they do not agree with the long-term whole pipe tests, which consistently failed through the wall of the pipe or coupler, irrespective of the “quality” of the weld. The specimen tensile creep test could sometimes, but not always, differentiate welds containing talc contamination and cold welds.

The probable reason for the difference in failure mode between the specimen and whole pipe tests is the different stress distribution in these tests. The specimen tests all generate large stresses, and indeed large strains in the case of the peel and crush tests, perpendicular to the weld interface. If the inherent weld interface strength is weaker than that of the coupler material, taking into account the reduced cross-sectional area due to the heating wires, then these specimens will fail through the interface. However, the whole pipe tests generate greater shear and hoop stresses at the weld interface and, even if the inherent weld interface strength is weaker than the pipe/coupler material, the stresses in the pipe/coupler wall will be greater and the sample does not fail through the interface.

Since, under normal service conditions, the joints will be under stresses more akin to those in the whole pipe tests, this suggests that weld interface flaws will have less of an effect on the weld integrity than that indicated from specimen tests.

It should be stressed that this study does not vindicate that correct welding procedures, in terms of pipe scraping and cleanliness, are not necessary. The welds produced in this work were made in a laboratory under ideal, consistent, conditions. The pipes used had not been exposed to direct sunlight and were welded within five months of production. Therefore, the effect of not scraping the pipe surface may not have been as significant.

In order to explain the difference in failure between the whole pipe tensile creep rupture test and the hydrostatic pressure test, some finite element (FE) modelling was undertaken. Fig.XV compares the stress fields in the two tests and shows that the region of maximum stress in the whole pipe tensile creep rupture test is in the pipe at the external cold zone notch, which explains why the samples consistently fail through the pipe at this location. For the hydrostatic pressure test, the FE model shows that the region of maximum stress is in the coupler at the internal cold zone notch, which again agrees with the experimental observations.

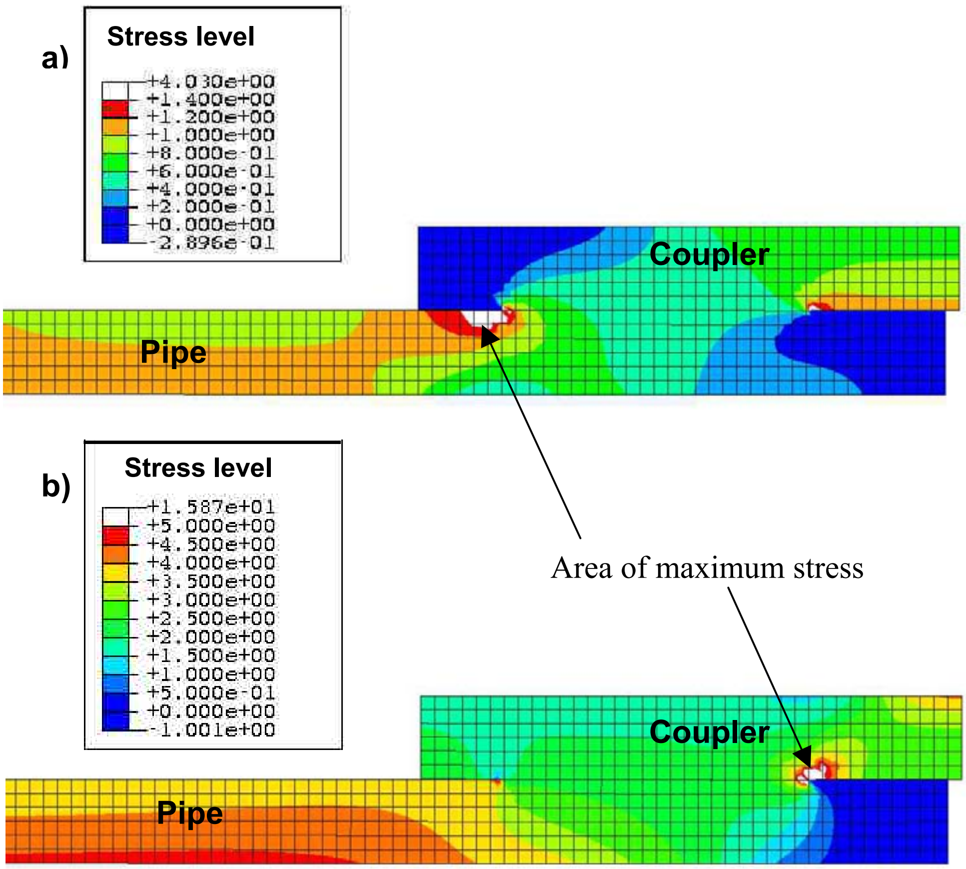


Fig.XV *FE models of stress distribution in: a) whole pipe tensile creep rupture test, b) hydrostatic pressure test.*

CONCLUSIONS

Based on the relatively small number of specimens/samples tested by each method, the conclusions of this work are:

- Electrofusion joints in PE pipes are fairly tolerant to flaws at the weld interface.
- Talc contamination can be identified from tests on specimens cut from the welded joint but not from tests on whole pipes.
- FE modelling can be used to predict the initiation position and direction of crack propagation in the whole pipe tensile creep rupture, and hydrostatic pressure, tests.

ACKNOWLEDGEMENTS

Polytec Systems is a collaboration between the following organisations: TWI Ltd, Egeplast Werner Strumann GmbH, Simplast S.p.A., NDT Consultants Ltd., Horton Levi Ltd., Vermon S.A., Isotest Engineering S.r.l., Italgas S.p.A., Northumbrian Water Ltd., South West Water Ltd., Consorzio Catania Ricerche and Hessel Ingenieurtechnik GmbH. The project is co-ordinated and managed by TWI Ltd and is partly funded by the EC under the CRAFT programme ref: COOP-CT-2003-507376.

All welds were made at Egeplast Werner Strumann GmbH and Simplast S.p.A. The crush tests were carried out by Italgas S.p.A.; the EN decohesion test, specimen tensile creep tests for socket joints, and hydrostatic pressure tests were carried out by Hessel Ingenieurtechnik GmbH; and the ISO peel decohesion tests and whole pipe creep rupture tests were carried out by TWI Ltd.

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