Shell Global Solutions

GS.07.53321
RESTRICTED

Failure investigation of GRVE caustic discharge line P-14049

Shell Nederland Chemie - Moerdijk

Shell Global Solutions

GS.07.53321
RESTRICTED

Failure investigation of GRVE caustic discharge line P-14049

Shell Nederland Chemie - Moerdijk

by

P.J.M. van Loon

RESTRICTED

Summary

At the request of Shell Nederland Chemie (SNC) Moerdijk, Shell Global Solutions has investigated glass-fibre reinforced vinyl ester (GRVE) pipe samples to determine the cause of failure (leakage), which has occurred in the 200 mm diameter, 100 m long, insulated and electrical heat-traced caustic discharge line.

The above ground, 500 m long, caustic discharge line runs from jetty-6 to storage tank T-0860, and consists of 400 m GRE pipe, line P-13072, and 100 m GRVE pipe, line P-14049. Pipe sections, about 1 m long, and a repair joint, were cut from the GRVE discharge line for further investigation. For comparison, microscopic inspection has also been performed on a GRVE reference pipe section, used in 2005 during an earlier investigation.

Leak failure of the GRVE caustic discharge line P-14049 is most probably caused by a combination of (i) impact damage, (ii) chemical attack of the liner, and (iii) significant corrosion attack of glass fibres in the damaged area of the laminate, resulting in micro-cracks, and subsequent leak path for the caustic fluid. Impact damage may have occurred during repair work performed in the vicinity of the damaged pipe section.

The earlier investigated GRE line P-13072 showed uniform chemical attack of the GRE wall but cracks in the GRE wall were not observed. Therefore the lifetime of the GRE P-13072 caustic discharge line could be predicted. For the GRVE line P-14049, uniform chemical attack of the GRVE wall was also expected, and therefore remaining life was initially predicted to be a minimum of 20 years. However, chemical attack of the GRVE wall was not uniform, and a combination of cracks and chemical attack has occurred. Therefore, long-term, leak free operation of the degraded GRVE caustic line P-14049 cannot be guaranteed.

It is recommended to replace the GRVE caustic line P-14049 at the earliest opportunity; probably within 1 to 2 years, preferably with a thermoplastic, UPVC lined GRVE pipe system.

Amsterdam, October 2007

Table of Contents

1. Introduction

At the request of Shell Nederland Chemie (SNC) Moerdijk, Shell Global Solutions has investigated glass-fibre reinforced vinyl ester (GRVE) pipe samples to determine the cause of failure (leakage), which has occurred in the 200 mm diameter, 100 m long insulated, and electrical heat-traced caustic discharge line.

The above ground, 500 m long, caustic discharge line runs from jetty-6 to storage tank T-0860, and consists of 400 m GRE pipe, line P-13072, and 100 m GRVE pipe, line P-14049. Pipe sections, about 1 m long, including a repair joint, were cut from the GRVE discharge line for further investigation. For comparison, microscopic inspection has also been performed on a GRVE reference pipe section, used in 2005 during an earlier investigation [1].

2. Service conditions

The service conditions specified for the SNC caustic discharge line are the following:

- Sodium hydroxide (NaOH), maximum concentration 50 %;
- Pressure: operating 4.9 barg, design 6.8 barg;
- Temperature: operating 30 ºC, design 60 ºC.

3. Pipe identification

3.1 Manufacturer

The manufacturer of the GRVE filament wound pipe is Sarplast, Iniziative Industriali, Italy.

3.2 Materials

Materials used for the GRVE pipe components, are:

- Resin: Vinyl ester, type Bisphenol A; Derakane 411 from Dow Chemicals;
- Fibre: E-glass roving; OCF R25H from Owens Corning;
- Liner: vinyl ester resin, reinforced with C-glass veil, 33 gr/m^2.

The manufacturers minimum specified glass transition temperature T_g for the GRVE pipe material is 110 ºC.

The manufacturers specified glass content (by weight) for the reinforced pipe wall is 65 % to 75 %.

3.3 Dimensions

The dimensions for the GRVE pipe, as specified by the manufacturer are:

- Internal diameter: 200 mm;
- Total wall thickness: 6.5 mm;
- Laminate thickness: 5.2 mm;
- Liner thickness: 1.3 mm.

4. Investigation

To investigate the cause of failure (leakage) for the caustic discharge line P-14049, visual and microscopic inspection has been performed on GRVE pipe samples, including a repair joint.

4.1 Pipe samples

For the investigation, the following GRVE pipe samples have been received from SNC:

- Pipe (half) section A, “6-o-clock” position, north of T860;
- Pipe (half) section B, “12-o-clock” (leak / blister) position, north of T860;
- Pipe section C, “12-o-clock” (pipe-clamp) position, north of T860;
- Pipe repair joint, location between tank T860 and road number 9 (after first 90º bend);
- GRVE reference pipe section, inspected in 2005 during an earlier investigation.

4.2 Visual and microscopic inspection

4.2.1 Pipe (half) section A

Figure 1 shows pipe section A, showing several light coloured areas, which can be easily wiped-off, and probably caused by spilled caustic. At Locations A1, A2, and A3, specimens have been taken for microscopic inspection. At Locations A1 and A2, areas of surface whitening are clearly visible. Position A3 was selected at a “clean” surface location.

Figure 2 shows a cross section of the GRVE pipe wall, at Location A1, showing de-lamination and radial cracks in the laminate, and significant degradation of the liner (radial cracks, and chemical attack of the glass-fibres).

Figure 3 shows the internal pipe surface at a location between A1 and A2, clearly showing a dark coloured “crazing type” pattern, corresponding to significant degraded areas in the liner, mainly caused by chemical attack of glass-fibres, see Figure 4 and Figure 5.

Figure 6 shows a cross section of the GRVE pipe wall, at Location A2, showing again de-lamination and radial cracks in the laminate, and degradation of the liner.

Figure 7 shows a cross section of the GRVE pipe wall, at Location A3 (i.e. “clean” surface area), showing again significant degradation of the liner. However, no significant damage, or chemical attack has been observed in the laminate, only minor radial cracks visible in the first inner layer (ply) of the laminate. Detail of a radial crack in the liner, which has extended into the first layer (ply) of the laminate, is shown in Figure 8.

It is concluded that significant degradation of pipe section A has occurred, mainly due to chemical attack of the glass-fibres in both the liner and laminate.

4.2.2 Pipe (half) section B

Figure 9 shows pipe section B. At Locations B1 to B6, specimens have been taken for microscopic inspection. At the Locations R1, R2, and R3 samples have been taken to determine the glass transition temperature (T_g) and the glass-fibre content (by mass), for the GRVE pipe material. At Location B1, where the leakage has occurred, a relative large “blister” (white area) is observed most probably caused by impact, see Figure 10.

Figure 11 shows a cross section of the GRVE pipe wall, at Location B1 (blister area), showing significant de-lamination damage, probably extended by chemical attack of the glass fibres, and degraded liner (radial cracks, and chemical attack of the glass-fibres).

Figure 12 shows the internal pipe surface at Location B1, showing a dark coloured “crazing type” pattern, corresponding to severely chemically attacked areas in the liner, shown in Figure 13.

Figures 14 to 17 show a cross section of the GRVE pipe wall, at Locations B2, B3, B5, and B6, respectively**.** All these locations, which are close to the blister (leak) area, show significant de-lamination, radial cracks, and chemical attack of the glass reinforcement fibres.

Figure 18 shows a cross section of the GRVE pipe wall, at Location B4, which is located relatively far outside the “blister” area. Compared to the Locations B1, B2, B3, B5 and B6, damage of the laminate (de-lamination, cracks) was not observed at Location B4. As for pipe section A, pipe section B also showed severe degradation of the liner.

It is concluded that the leak failure, which occurred in pipe section B, is most probably caused by a combination of (i) impact damage, (ii) liner degradation, and (iii) corrosion attack of glass fibres in the damaged area of the laminate, resulting in micro-cracks, forming a potential leak path for the caustic fluid. Impact damage may have occurred during repair work, performed in the vicinity of the damaged pipe section.

4.2.3 Pipe section C

Figure 19 shows pipe section C. At the Locations C1 and C2 (pipe clamp area) and C3 (outside clamp area), specimens have been taken for microscopic inspection. At the clamp area, some local surface colouring was observed (Figure 20), however, chemical attack was not observed.

Figures 21 to 23 show a cross section of the GRVE pipe wall, at Locations C1, C2, and C3, respectively**.** Damage of the laminate (de-lamination, cracks, chemical attack) was not observed. The liner showed significant degradation.

It is concluded that the laminate of pipe section C is still in good condition. However, the liner shows again significant degradation, mainly caused by chemical attack of the glass-fibres.

4.2.4 Pipe repair joint

Figure 24 shows a section of the laminated repair joint, showing detail of the external, and internal (liner) surface. At Locations E1, E2, and E3, specimens have been taken for microscopic inspection. The internal pipe surface (liner) shows a dark coloured “crazing type” pattern, similar as observed for the pipe section A and B.

Figures 25 to 27 show a cross section of the repair joint, at Locations E1, E2, and E3, respectively**.** At Location E1 (Figure 25), a significant amount of radial cracking in the laminate is observed, including severe degradation of the liner.

Locations E2 (Figure 26) and E3 (Figure 27) shows only minor cracks in the laminate, however, severe degradation of the liner is again observed. Cracks are not observed at the location of the laminate reinforcement, i.e. relatively thick wall section (Figure 26).

4.2.5 GRVE reference pipe section

For comparison, specimens have been taken from a GRVE pipe section, used during an investigation performed in 2005 [1]. Figure 28 shows a cross section of the GRVE reference pipe wall, showing an intact laminate, and reasonably intact liner, showing only a limited number of radial cracks.

It is concluded that the liner of the reference pipe shows significantly less degradation, when compared to the longer exposed pipe samples. This indicates on-going liner degradation occurred, mainly caused by chemical attack of the glass reinforcement fibres, which was expected.

4.3 Quality confirmation tests

To confirm if the GRVE pipe used for line P-14049 complies with the Manufacturers specifications, tests has been performed to determine (i) glass transition temperature (T_g), in accordance with ISO 11357-2 and glass-fibre content for the structural pipe wall, in accordance with ASTM D 2584.

At the Locations R1, R2, and R3 of pipe section B (Figure 9), samples have been taken to determine the glass transition temperature (T_g) and the glass-fibre content (by mass).

4.3.1 Degree of cure

The degree of cure (T_g) for the GRVE pipe material was determined by differential scanning calorimetry (DSC), according to ISO 11357-2. The T_g values measured are: 118 ºC, 119 ºC, and 118 ºC, for pipe section B, Locations R1, R2, and R3, respectively, i.e. well above the manufacturers minimum specified value of 110 ºC. The results of the DSC analyses are presented in Figure 29.

It is concluded that the degree of cure (T_g) for the GRVE pipe material complies with the manufacturers specification.

4.3.2 Glass content

The glass content (by weight) of the GRVE pipe wall was determined in accordance with ASTM D 2584, and the following values were measured: 66.9 %, 68.2 %, and 64.2 %, for Locations R1, R2, and R3, respectively, i.e. slightly higher than the minimum value, specified by the manufacturer. However, according to ISO 14692 [2], the glass content for filament wound GRP pipe should be in the range 70 % to 82 %.

It is concluded that glass-fibre content for the GRVE pipe used for discharge line P-14049 line, is rather low, and this may be explained by the use of relatively thick (i.e. high-tex value) rovings, typically resulting in increased ply thickness, reduced number of plies, and decreased glass fibre content.

The void content (% surface area) of the reinforced pipe wall (laminate) was measured in the range 2.6 % to 3.6 %, i.e. typical for filament wound pipe.

4.3.3 Dimensions

The following dimensions have been measured for the GRVE pipe:

A) Pipe section A, B, C:

- Total wall thickness: 5.5 mm to 6.3 mm;
- Liner thickness: 1.0 mm to 1.3 mm;
- Reinforced wall thickness: 4.5 mm to 5.0 mm;
- Number of layers (plies): 6;
- Average ply thickness: 0.8 mm.

The average ply thickness of 0.8 mm is considered excessive when compared to a thickness of 0.5 mm, which is typical for high quality filament wound pipe. An average ply thickness of 0.5 mm was measured for the earlier inspected GRE pipe used for line P-13072, i.e. better quality, compared to the GRVE pipe.

B) Pipe repair joint:

- Total wall thickness (pipe section): 4.1 mm;
- Liner thickness: 1.1 mm;
- Reinforced wall thickness: 3.0 mm
- Number of layers (plies): 4;
- Average ply thickness: 0.75 mm.

The minimum reinforced wall thickness of the repair joint is approximately 3 mm, i.e. only 60 % of the thickness measured for the GRVE pipe used for line P-14049. The number of plies in the reinforced wall of the repair joint is four, however, should be minimum six.

It is concluded that the pipe repair does not meet the minimum specified wall thickness requirement, i.e. poor quality repair.

5. Discussion

From the investigation it is concluded that leak failure of the GRVE caustic discharge line P-14049 is most probably caused by a combination of (i) impact damage, (ii) chemical attack of the liner, and (iii) significant chemical attack of glass fibres in the damaged area of the laminate, resulting in micro-cracks, and subsequent leak path for the caustic fluid. Impact damage may have occurred during repair work performed in the in the vicinity of the damaged pipe section.

The earlier investigated GRE line P-13072 showed uniform chemical attack of the GRE wall but cracks in the GRE wall were not observed. Therefore the lifetime of the GRE P-13072 caustic discharge line could be predicted. For the GRVE line P-14049, uniform chemical attack of the GRVE wall was also expected, and therefore remaining life was initially predicted to be a minimum of 20 years. However, chemical attack of the GRVE wall was not uniform, and a combination of cracks and chemical attack has occurred. Therefore, long-term, leak free operation of the degraded GRVE caustic line P-14049 cannot be guaranteed and it is recommended to replace the GRVE caustic line P-14049 at earliest opportunity; probably within 1 to 2 years, preferably by a thermoplastic, U-PVC lined GRVE pipe system.

6. Material upgrade options

The following materials upgrade options may be considered for the degraded GRVE caustic line P-14049:

- GRE or GRVE, including resin rich liner, reinforced with at-least two layers of synthetic veil (e.g. Nexus), and minimum liner thickness of 2.5 mm;
- UPVC lined GRVE (up-to 60 ºC).

Compared to conventional GRE, GRVE, thermoplastic lined GRP pipe is considered more reliable for transport of chemicals, e.g. caustic, for the following reasons:

- The thermoplastic liner will provide the required internal chemical resistance and the fibre reinforced plastic (GRP) wall will provide external chemical resistance, including the required mechanical strength (internal pressure, etc);
- In case damage at the GRP wall occurs, e.g. impact, the thermoplastic liner will prevent leakage of the fluid through a (damaged) GRP pipe wall.

7. Conclusions

(a) Leak failure of the GRVE caustic discharge line P-14049 is most probably caused by a combination of (i) impact damage, (ii) chemical attack of the liner, and (iii) chemical attack of glass fibres in the damaged area of the laminate, resulting in a leak path for the caustic fluid;

(b) Compared with an investigation performed in 2005, on-going degradation of the liner has occurred, mainly caused by chemical attack of the glass reinforcement fibres, as expected;

(c) Glass transition temperature (T_g), glass fibre content, and void content of the GRVE pipe wall are within acceptable limits, as specified by the pipe manufacturer;

(d) The non-uniform distribution of relative thick layers (plies) of the GRVE pipe wall indicates poor quality control during the filament winding process;

(e) The GRVE pipe repair joint does not meet the minimum specified wall thickness requirement, i.e. poor quality repair.

8. Recommendation

The degraded GRVE caustic line P-14049 should be replaced at the earliest opportunity; probably within 1 to 2 years, preferably by a thermoplastic, UPVC lined GRVE pipe system.

9. References

1. Loon van, P.J.M. “Investigation of GRP caustic discharge pipe Shell Nederland Chemie - Moerdijk”, GS.05.50579.
2. ISO 14692, “Petroleum and natural gas industries – glass reinforced plastics (GRP) piping, November 2003.

Amsterdam, October 2007
wk

Figure 1 *Pipe Sample A, "6-o-clock" position, Location north of T860*

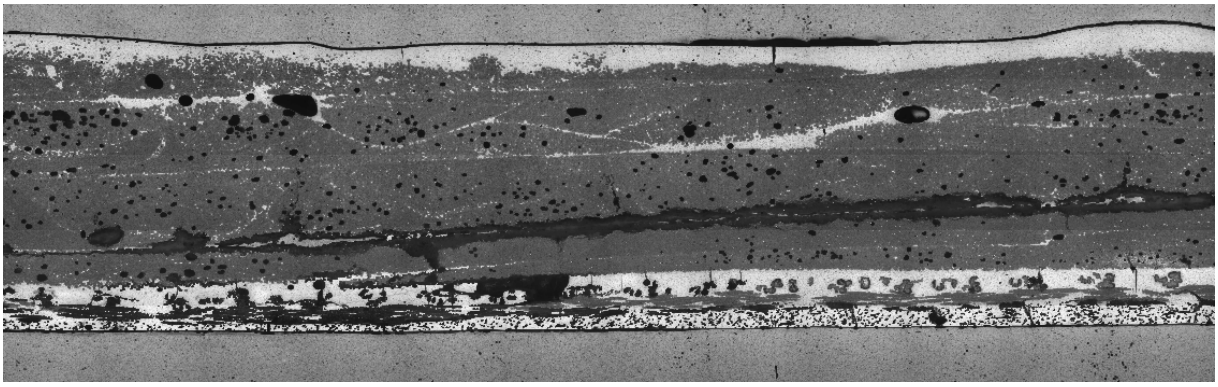


Figure 2 *Microstructure of GRVE wall of pipe Sample A, Location A1*

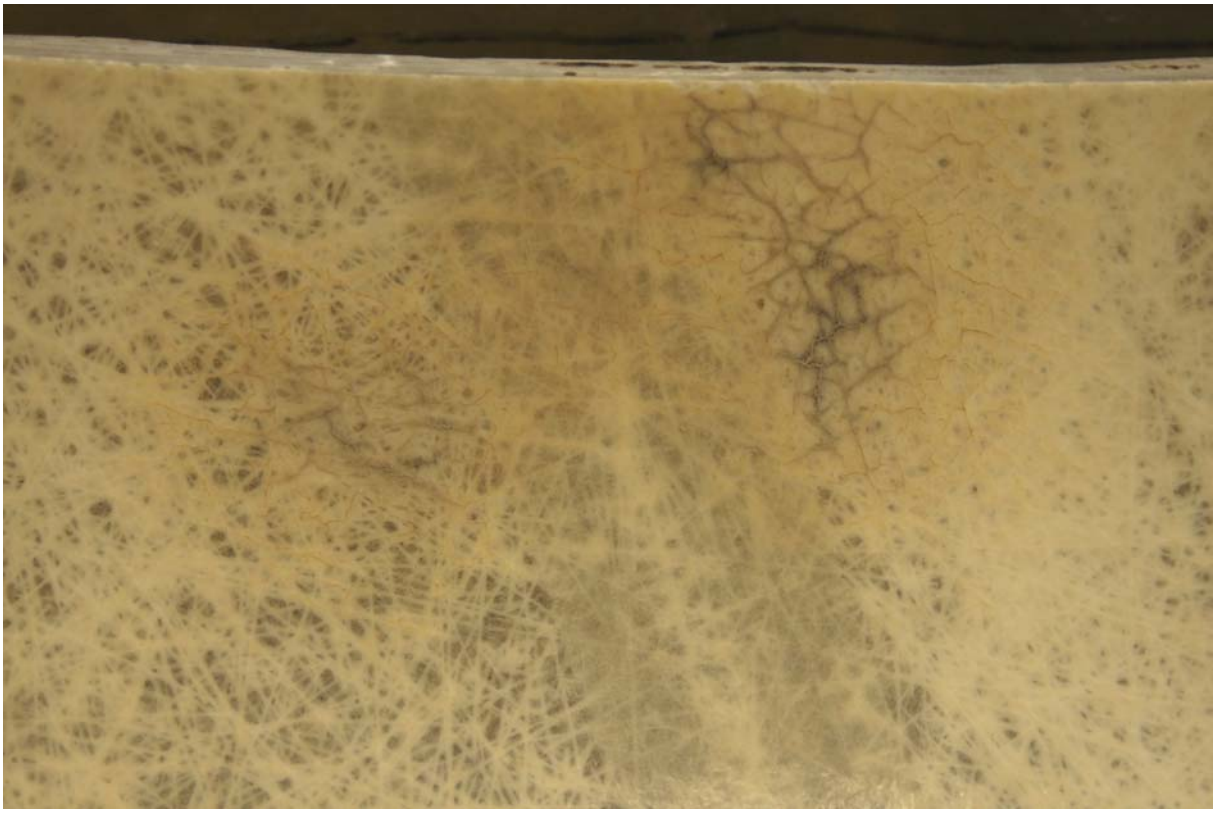


Figure 3 *Liner surface of pipe Sample A showing local "crazing type" pattern*

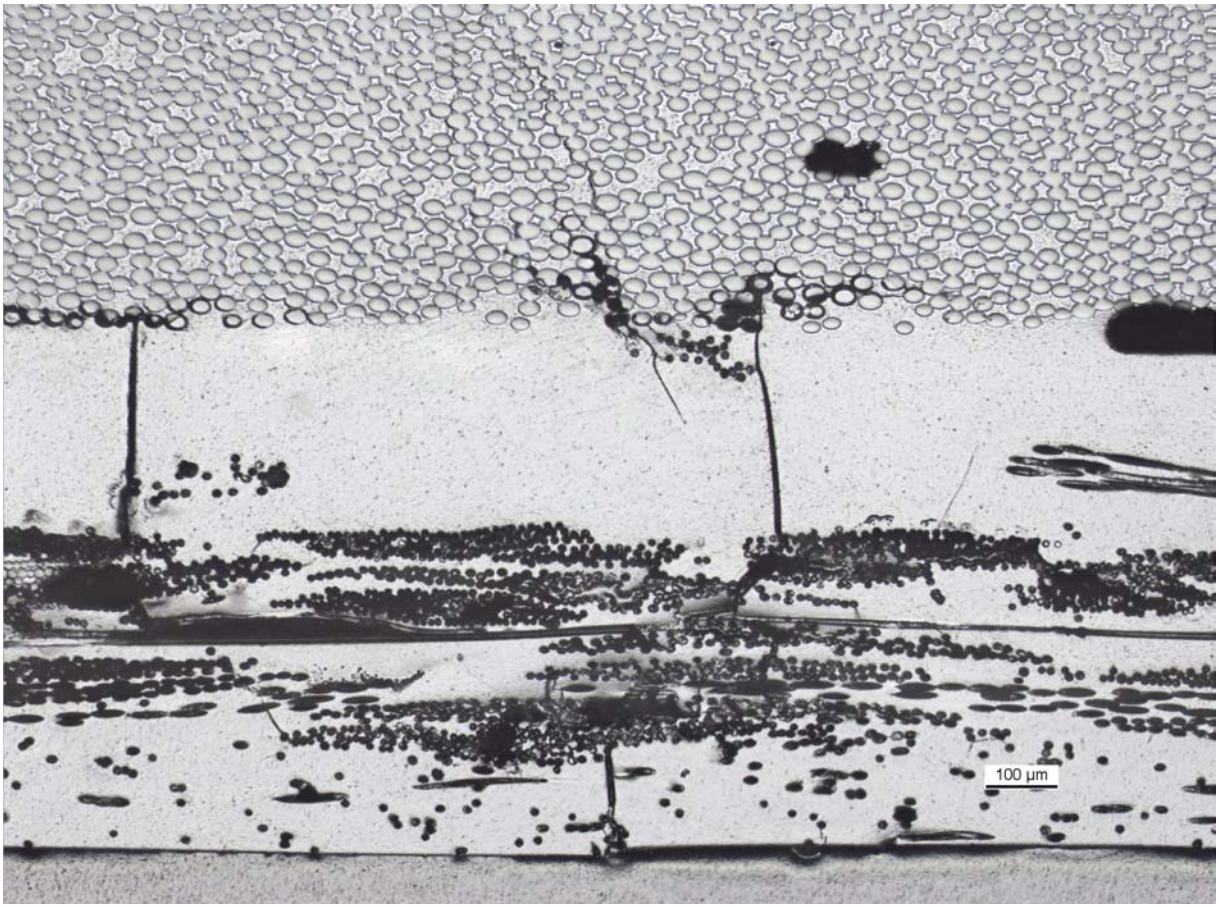


Figure 4
Microstructure of liner, pipe Sample A, showing radial and de-lamination cracks

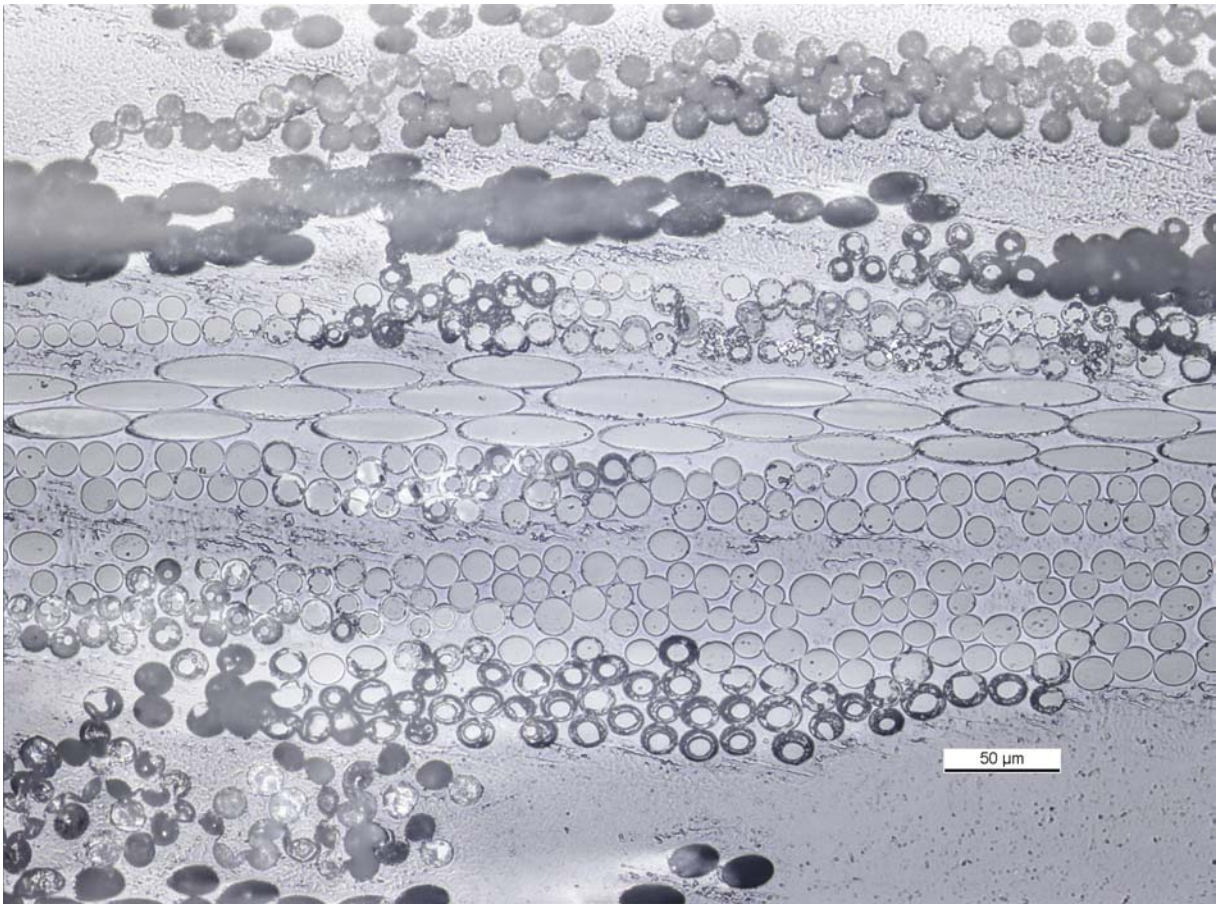


Figure 5
Detail of liner, pipe Sample A, showing cracks and chemically attacked glass fibres

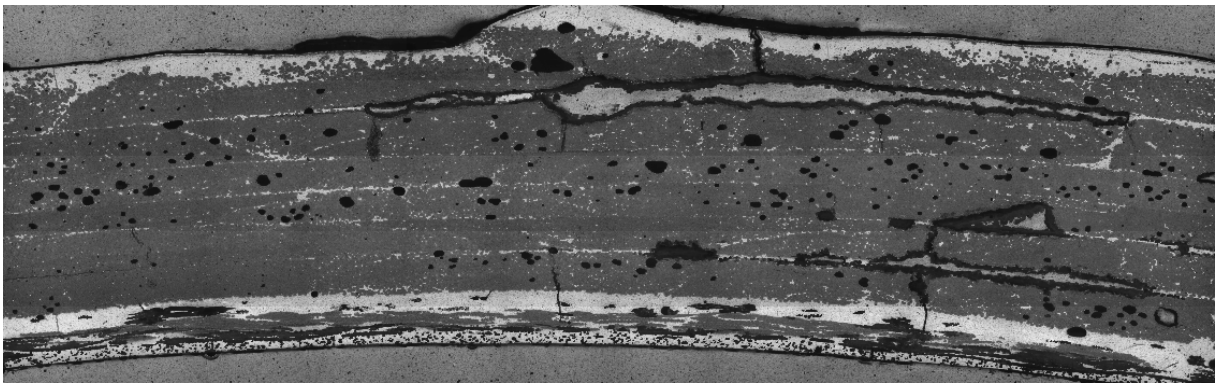


Figure 6 *Microstructure of GRVE wall of pipe Sample A, Location A2*

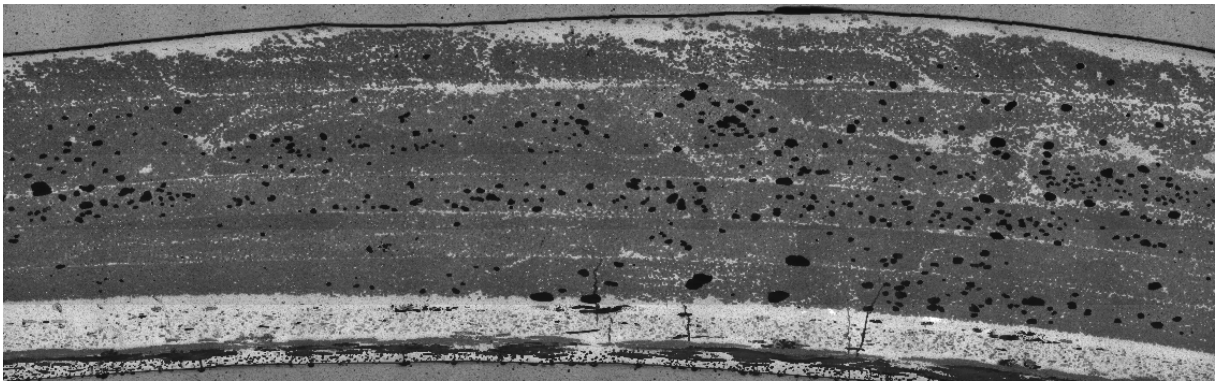


Figure 7 *Microstructure of GRVE wall of pipe Sample A, Location A3*

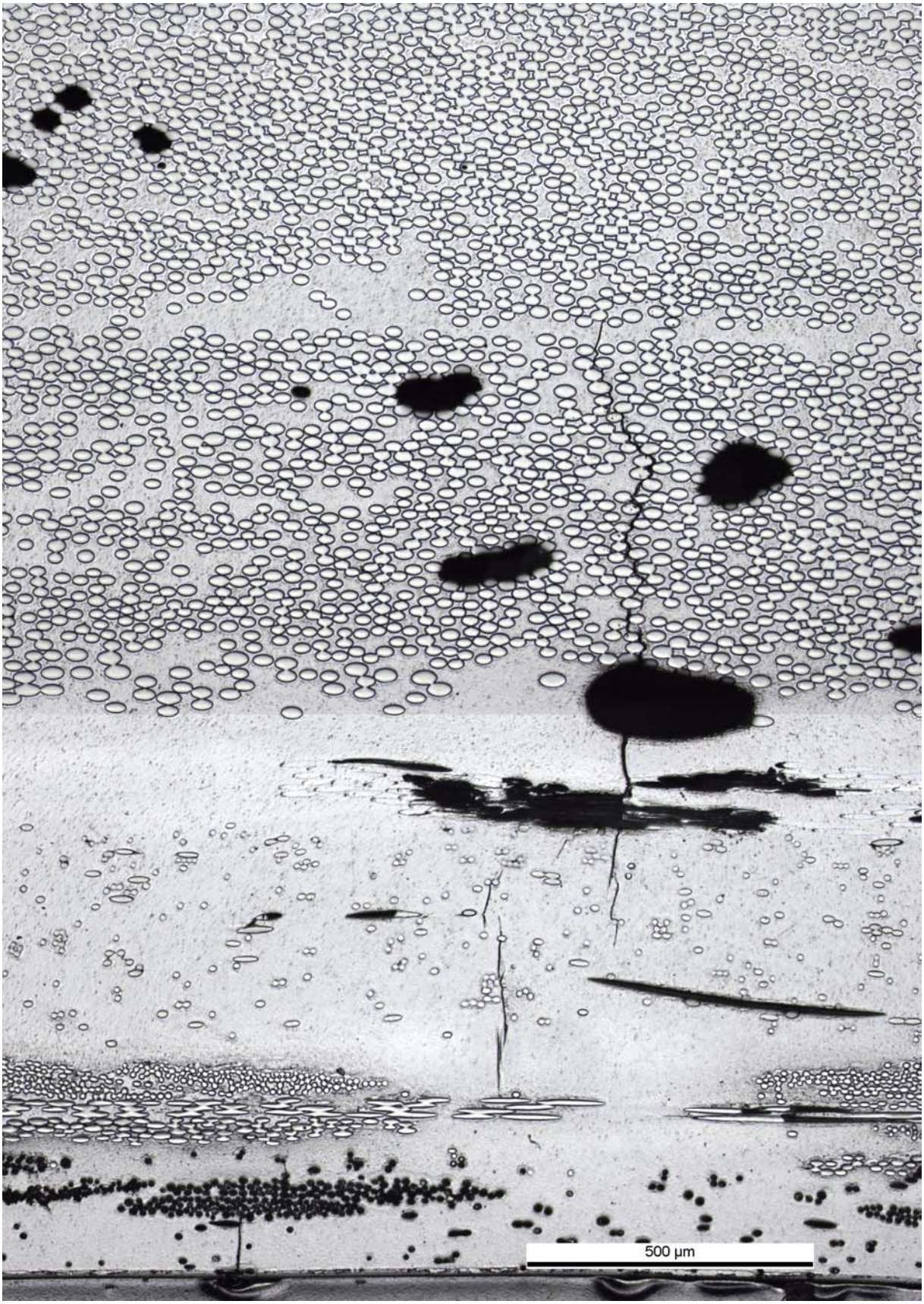


Figure 8 *Detail of liner, pipe Sample A, showing radial crack extending into the laminate*

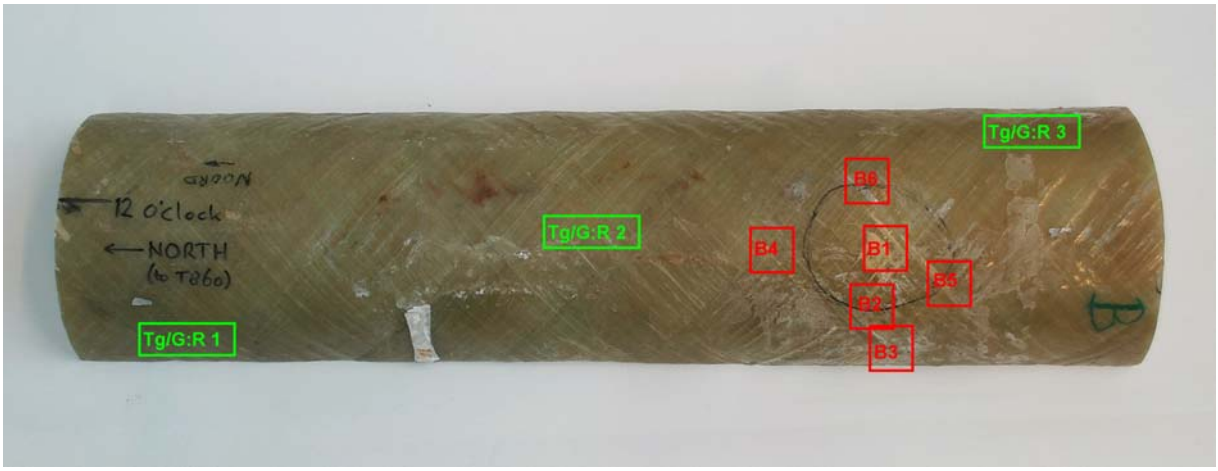


Figure 9 *Pipe sample B, "12-o-clock" (leak / blister) position, north of T860*

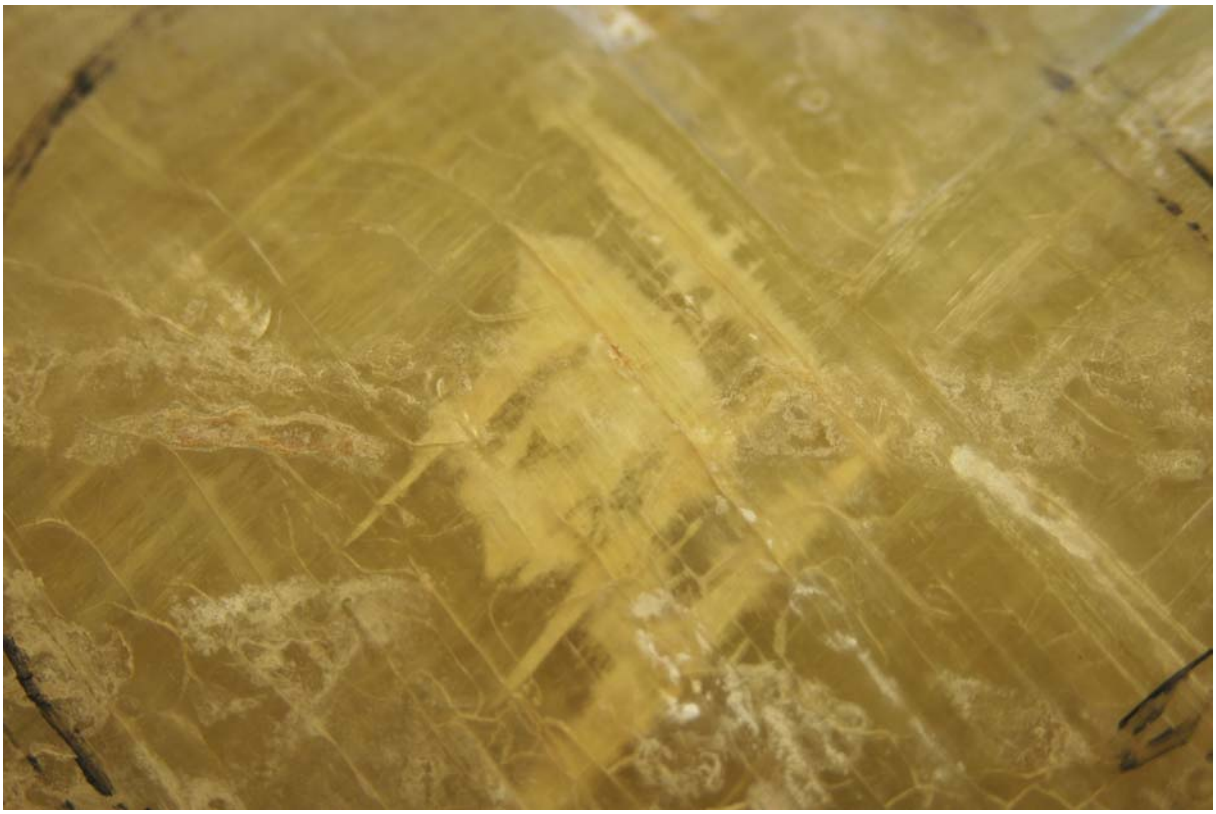


Figure 10 *Detail showing the blister area (leakage) at Location B1of pipe Sample B*

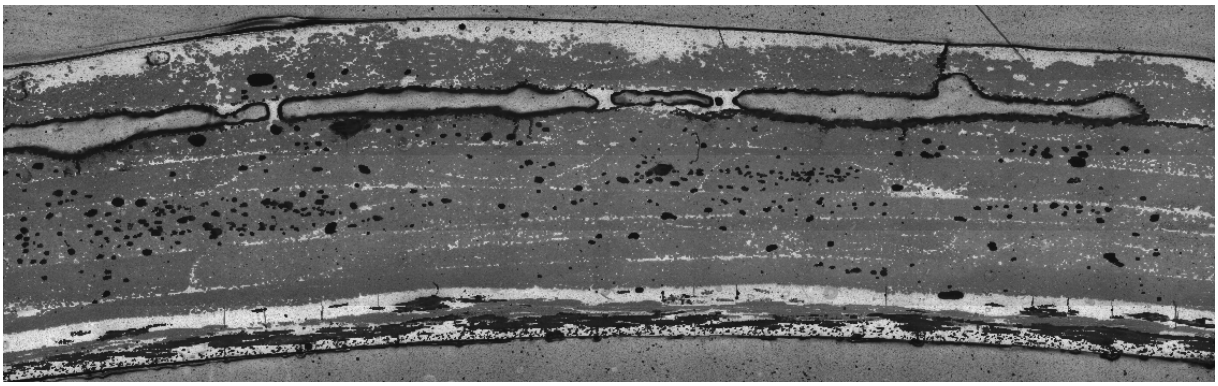


Figure 11 *Microstructure of GRVE wall of pipe Sample B, Location B1*

Figure 12 *Liner surface of pipe Sample B showing local "crazing type" pattern*

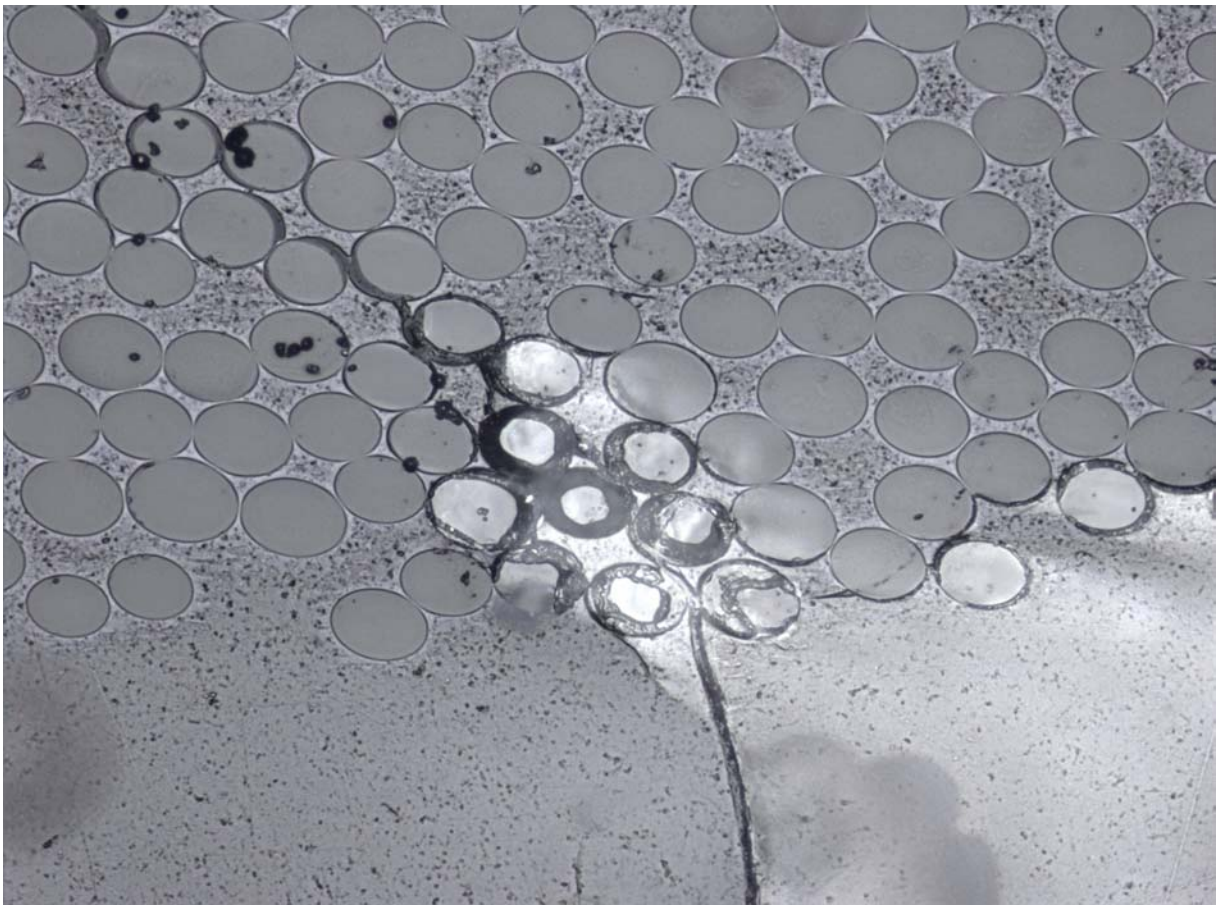


Figure 13
Detail of liner, pipe Sample B (location B1) showing cracks and chemically attacked glass fibres

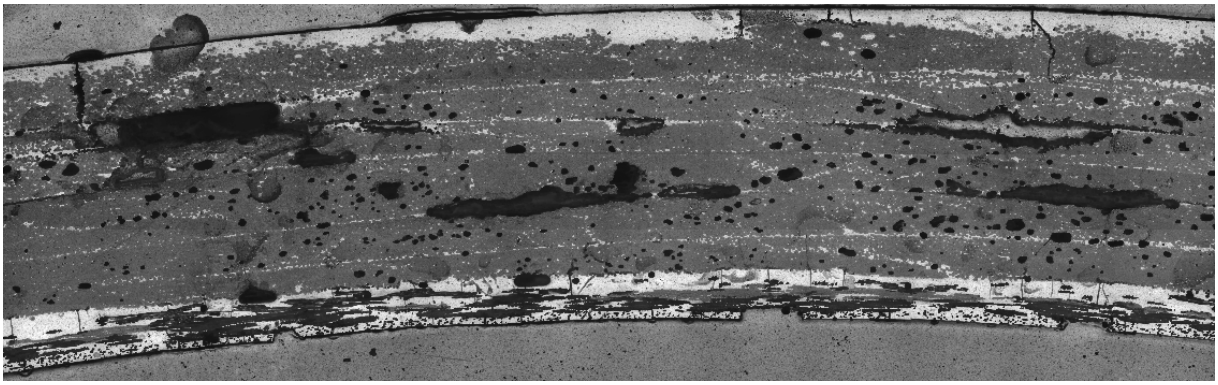


Figure 14 *Microstructure of GRVE wall of pipe Sample B, Location B2*

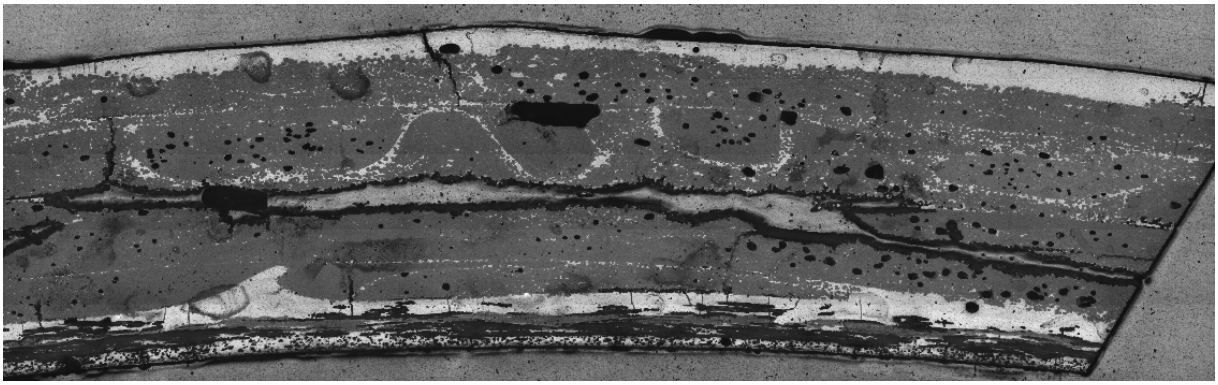


Figure 15 *Microstructure of GRVE wall of pipe Sample B, Location B3*

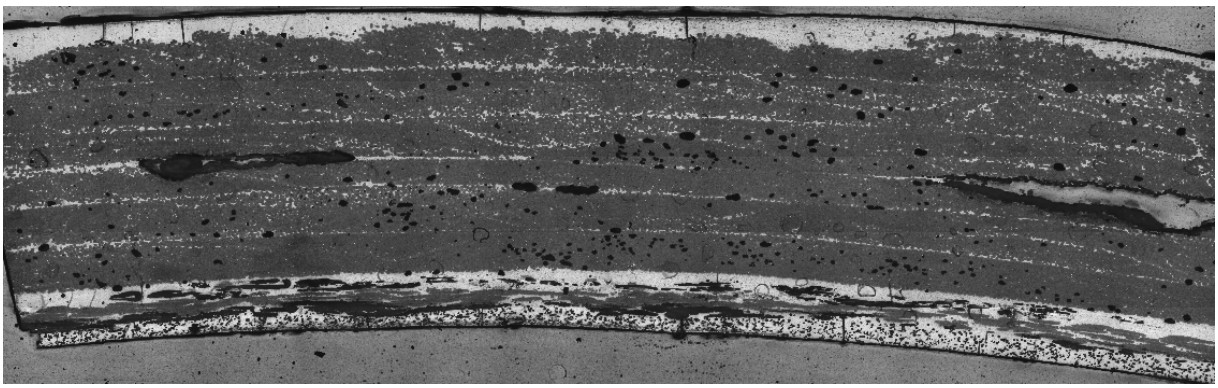


Figure 16 *Microstructure of GRVE wall of pipe Sample B, Location B5*

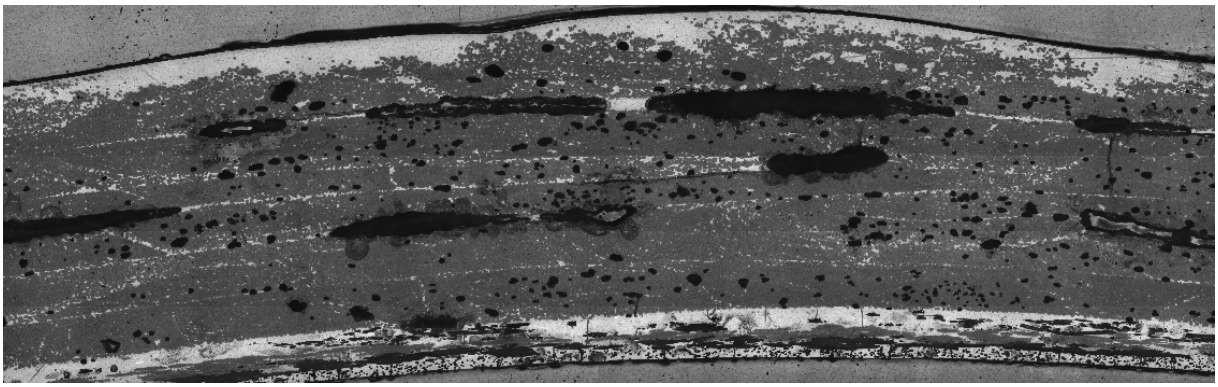


Figure 17 *Microstructure of GRVE wall of pipe Sample B, Location B6*

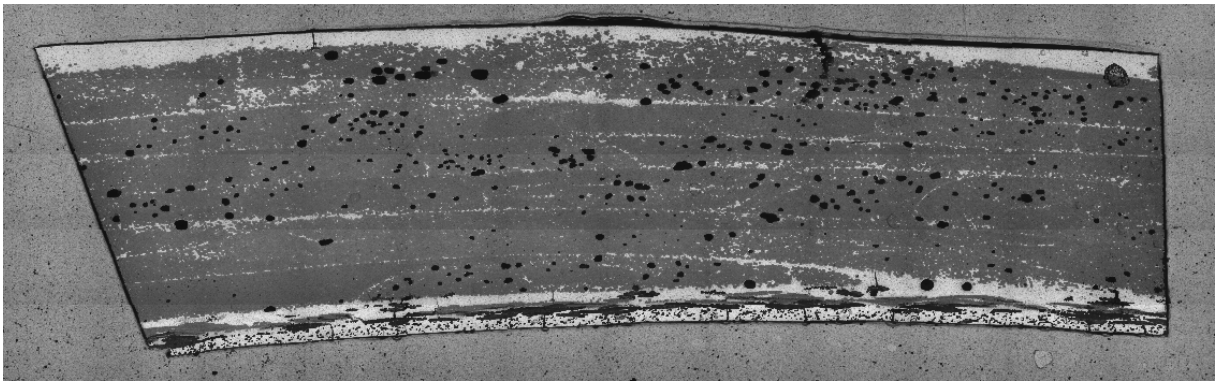


Figure 18 *Microstructure of GRVE wall of pipe Sample B, Location B4*

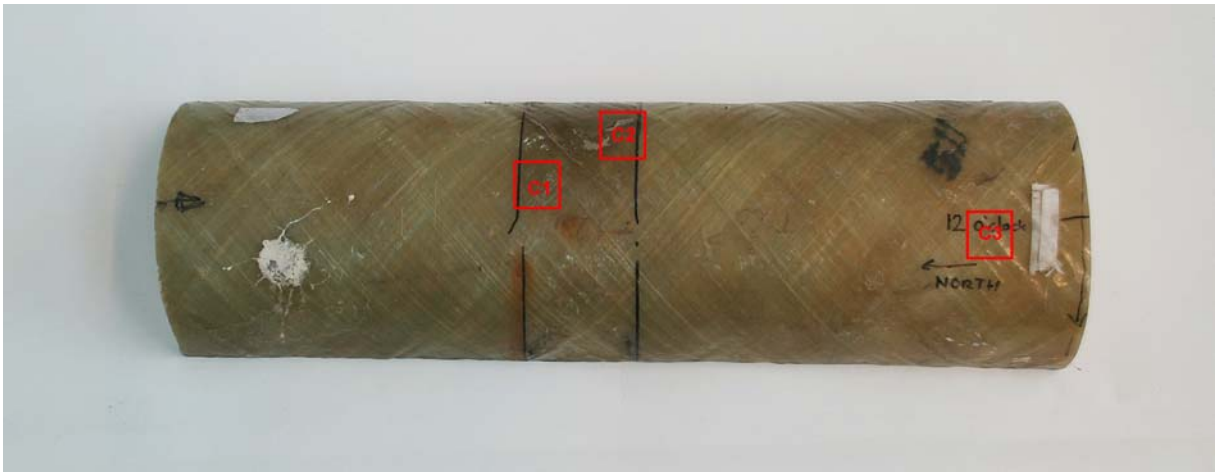


Figure 19 *Pipe section C, "12-o-clock" (pipe-clamp) position, north of T860*

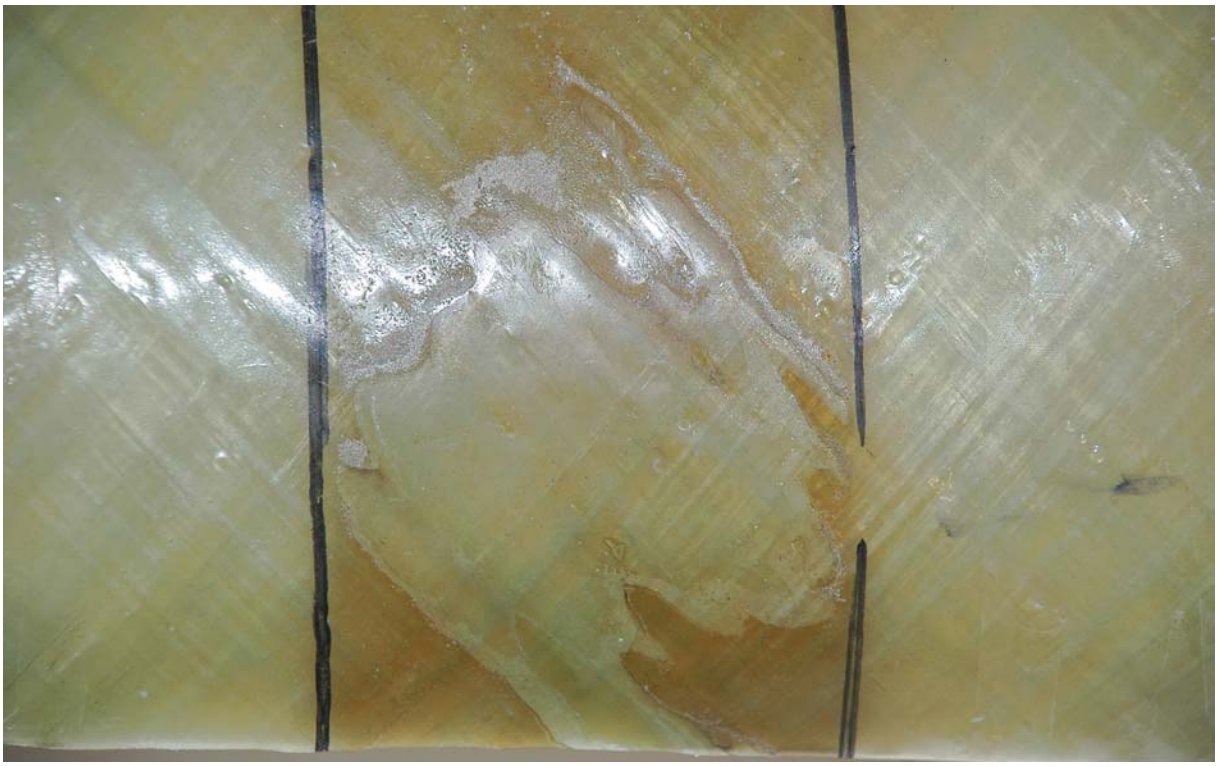


Figure 20 *Detail of surface colouring in the clamp area, pipe section C*

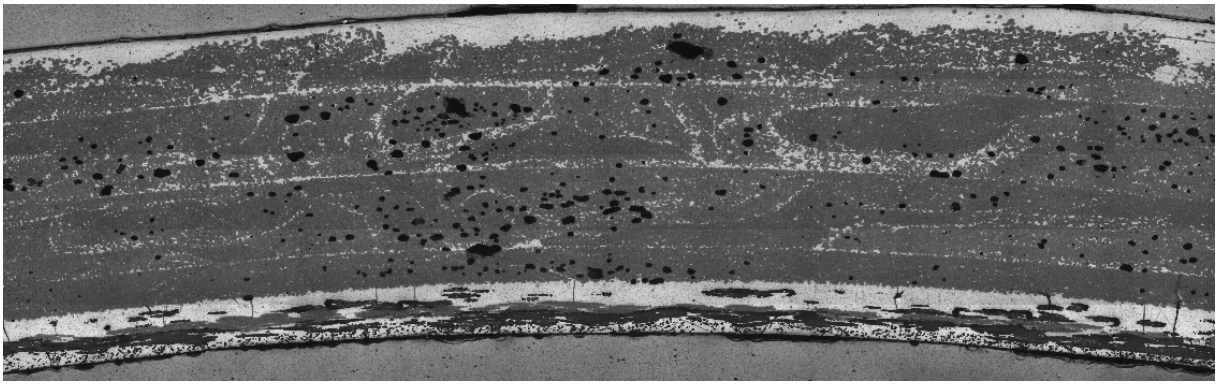


Figure 21 *Microstructure of GRVE wall of pipe Sample C, Location C1*

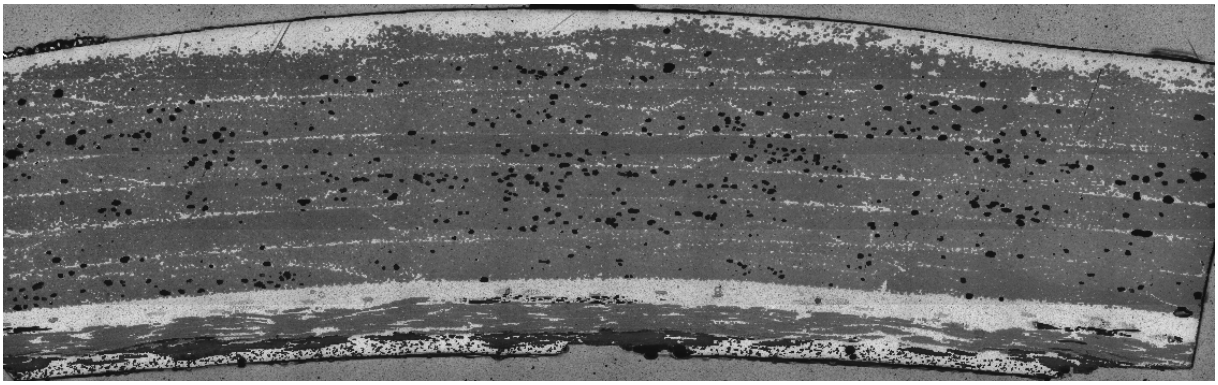


Figure 22 *Microstructure of GRVE wall of pipe Sample C, Location C2*

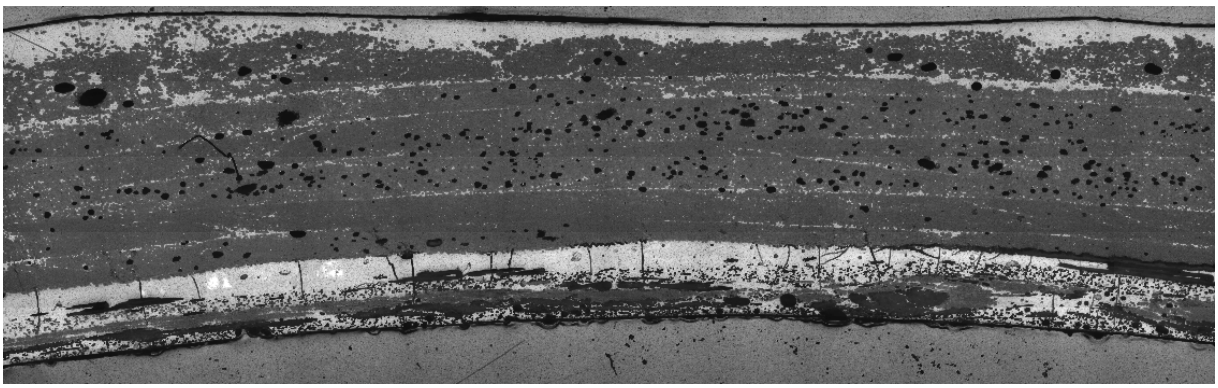
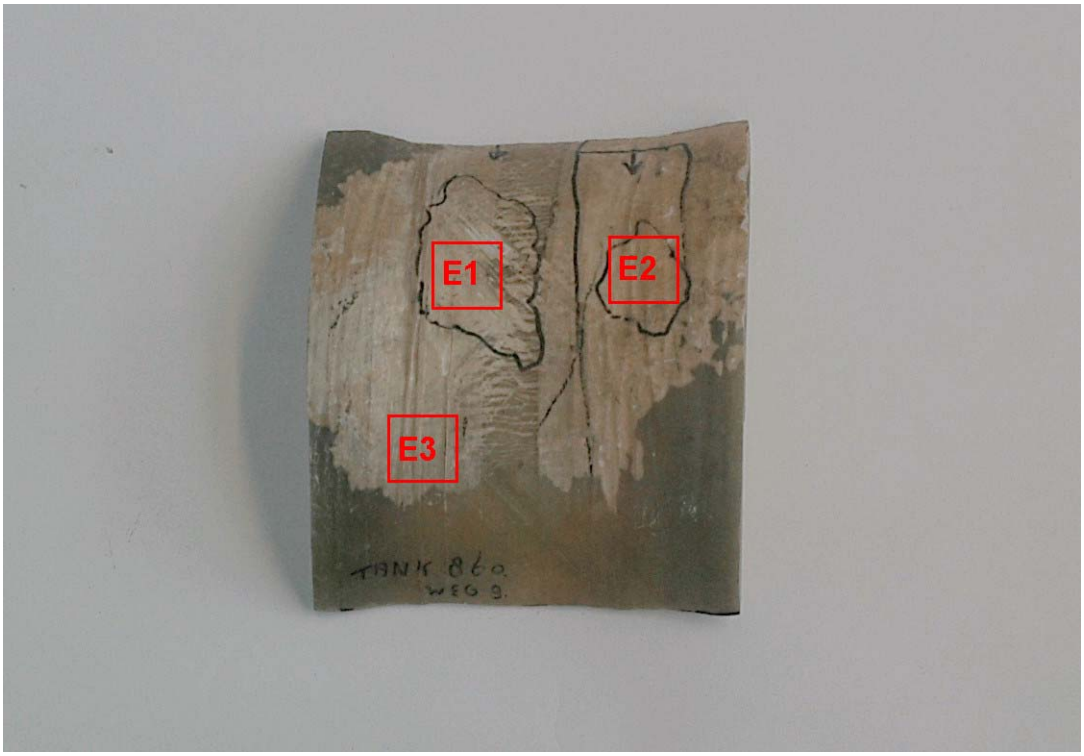


Figure 23 *Microstructure of GRVE wall of pipe Sample C, Location C3*



(a) *External surface of repair joint; showing locations of samples taken*

(b) *Internal surface of repair joint, showing local "crazing type" pattern*

Figure 24 *Pipe repair joint, location between tank T860 and road number 9 (after first 90º bend)*

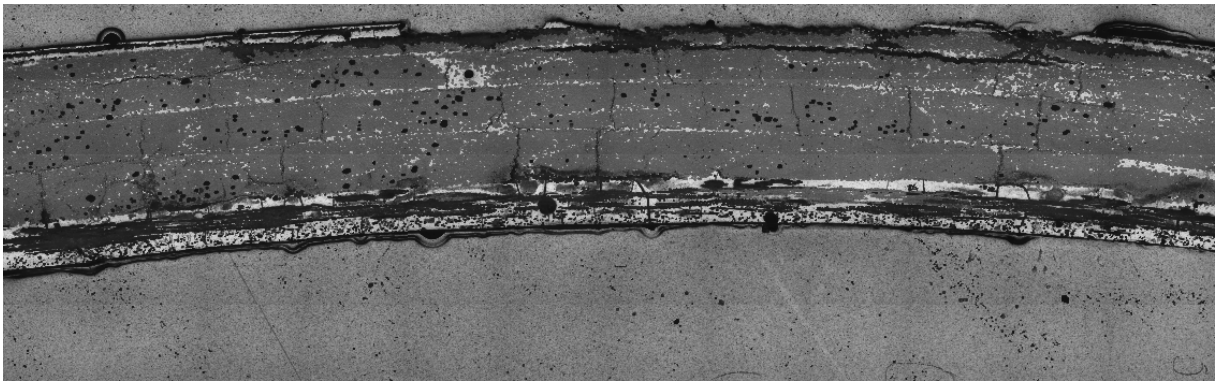


Figure 25 *Microstructure of GRVE wall of pipe repair joint, Location E1*

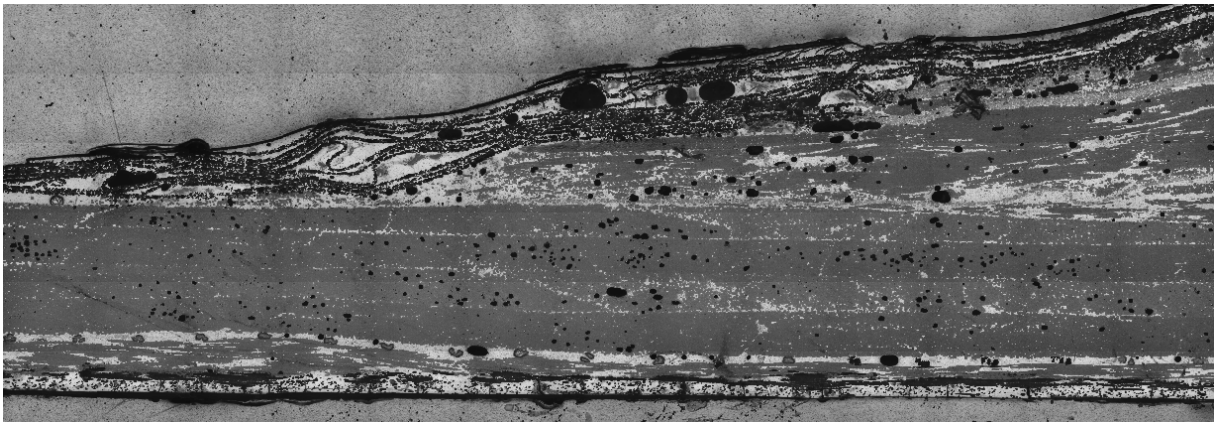


Figure 26 *Microstructure of GRVE wall of pipe repair joint, Location E2*

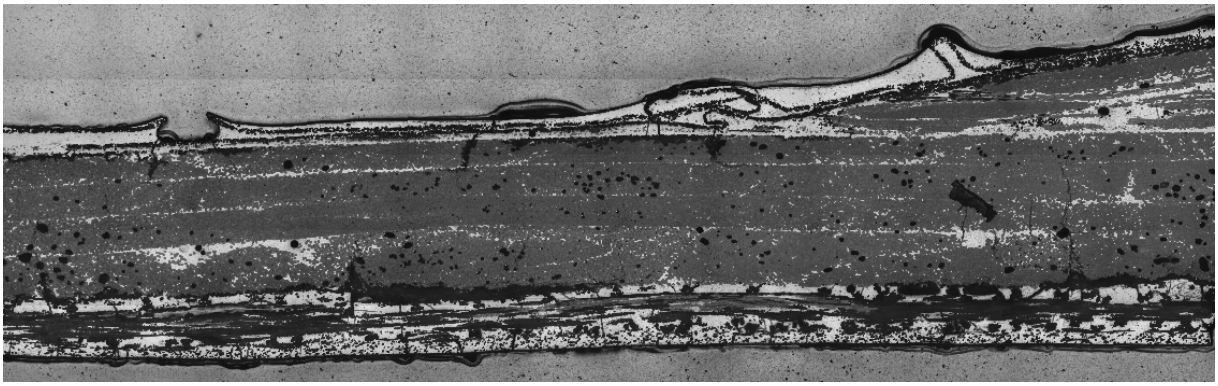


Figure 27 *Microstructure of GRVE wall of pipe repair joint, Location E3*

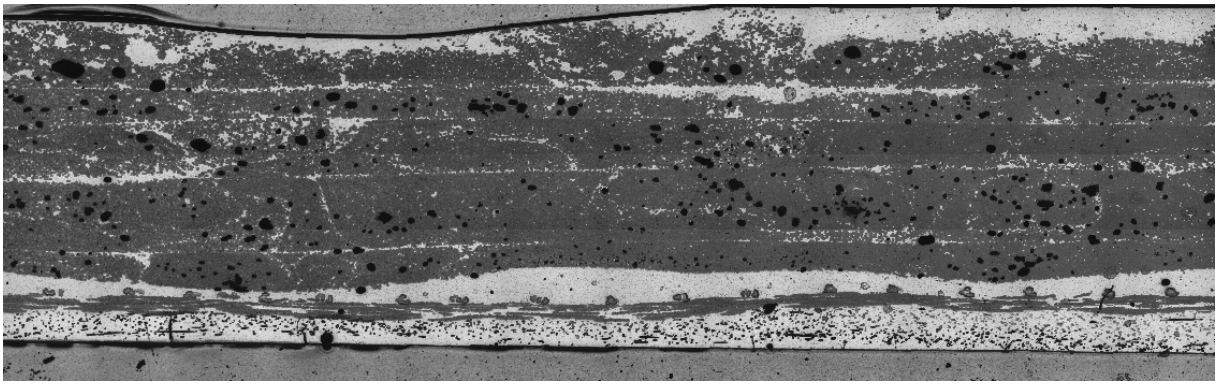


Figure 28 *GRVE reference pipe section, inspected in 2005 during an earlier investigation*

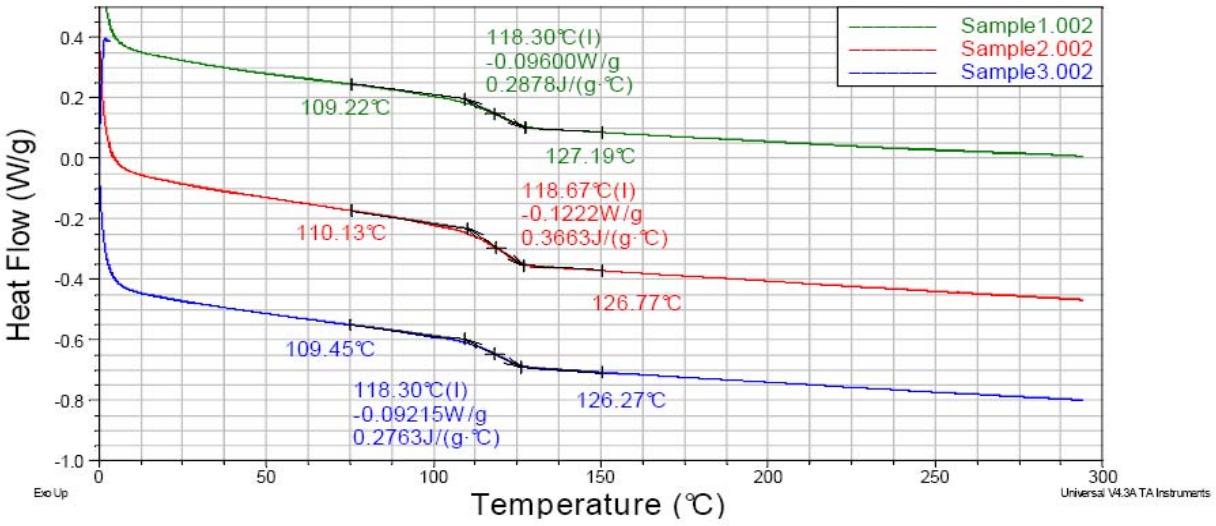


Figure 29 *DSC results for GRVE material, pipe Sample B, Locations R1, R2, and R3*

Bibliographic Information

This report has been classified as Restricted and is not subject to US Export Control regulations.

Report Number	:	GS.07.53321	
Title	:	Failure investigation of GRVE caustic discharge line P-14049	
Subtitle	:	Shell Nederland Chemie - Moerdijk	
Author(s)	:	P.J.M. van Loon	GSEI/1
Reviewed by	:	M.A.S. Sargent	GSEI/1
Approved by	:	M.A.S. Sargent	GSEI/1
Content Owner	:	M.A.S. Sargent	GSEI/1
Issue Date	:	October 2007	
Activity Code	:	54012020	
Project Number	:	54012020	
Sponsor	:	Shell Nederland Chemie B.V.	
Keywords	:	GRVE, caustic, discharge line, SNC, failure, investigation, chemical attack	
Electronic file	:	GS.07.53321.pdf	
Issuing Company	:	Shell Global Solutions International BV, Amsterdam P.O. Box 38000, 1030 BN Amsterdam, The Netherlands. Tel: +31 20 630 9111 Established at The Hague, Amsterdam Office, Badhuisweg 3, 1031 CM Amsterdam Commercial Register, Amsterdam 33276928	

Customer Info

Name	:	Shell Nederland Chemie B.V.
Address	:	Chemieweg 25 4782 SJ Moerdijk

Report distribution

Outside Shell Global Solutions

Company name and address	E or P	No. of paper copies
Shell Nederland Chemie B.V., Moerdijk		
F.J.M. Busch (CEI/2)	E & P	1
K.T. Torberson (MEOD)	E	
M. van der Horst (CEI/131)	E	
V. van der Keemel (CEI/166)	E	
R. Habes (MEOD/3)	E	
D. Lammens (CMS/3)	E & P	1
D.P.L.M. Doggen (CFD/3)	E	
A. Woerden (CEI/213)	E	

Within Shell Global Solutions

Name	Ref. Ind.	Location	E or P	No. of paper copies
Shell Research and Technology Centre	GSNL-GSXI	(Reports Library) Amsterdam	E & P	1
P.J.M. van Loon	GSNL-GSEI/1	Amsterdam	E & P	1
M.A.S. Sargent	GSNL-GSEI/1	Amsterdam	E	
K.M. Orzessek	GSNL-GSEI/2	Amsterdam	E & P	1

This report can be freely shared with all Shell Global Solutions employees.