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Condition monitoring of excavated CIPP-liners to ensure lifespan

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ABSTRACT
In Sweden there is a lack of knowledge on the expected service life of installed CIPP-liners and a general aim to request CIPP-liners with a 100-year lifespan. In cooperation with Swedish water utilities a national project has been launched for condition monitoring of used CIPP-liners. A large number of CIPP-liners installed in sewage pipes will be excavated and analyzed in order to evaluate material degradation and estimating remaining service life. The CIPP-liners are all between 5-35 years old.
The material performance of the CIPP-liners are either compared with the reference data provided from the installation, or in some case compared to pieces of corresponding CIPP-liners that have been kept in a storage. These pieces becomes especially valuable when looking at possible changes in mechanical properties that may have occurred during the time in use. The materials will be assessed by e.g. bending modulus to investigate material integrity and e.g. FT-IR for chemical stability in the environment of the sewage system. In total the results will give a valuable tool in assessing the expected lifetime of the installed CIPP-liners. The knowledge acquired will help Swedish water utilities to predict service life of installed CIPP-liners and to set sufficient quality demands on new installations for pipe renovation. At an initial stage two excavated CIPP-liners that have been in use for 12 and 16 years have been analyzed and compared with reference data from the time of installation.

INTRODUCTION
CIPP-liners has been a popular pipe rehabilitation method for non-pressurized sewage systems in Sweden for several decades. Many kilometers are installed annually and while the first installations have now been in used for a long period of time, there is a general desire from water utilities to perform a condition monitoring of the pipe material of installed CIPP-liners. From this desire a project have been launched that includes excavation and evaluation of CIPP-liners that has been installed and used for different times. The project started in 2018 and roughly 30 pieces of excavated CIPP-liners are expected to be analyzed before the project ends. Evaluation of excavated CIPP-liners have been performed to different extend in previous studies [Allouche et al, 2014][Alam et al, 2018][Bosseler et al, 2002][Alzraiee et al, 2014][Bakry et al, 2016]. Besides condition monitoring of excavated CIPP-liners the project also works with improving the level of knowledge about CIPP-liners for water utilities, to spread information about environmental impact of CIPP and to define and explain different material and technical properties to ease procurement for water utilities.

A common challenge in this kind of projects is to get access to excavated CIPP-liners. With narrow budgets an excavation solely for research and condition monitoring is seldom a prioritized task for the water utilities. In this project the excavation is financed by the municipalities, but mainly focusing on CIPP-liners that are excavated in connection to other pipe renovation or modifications. Meaning that CIPP-liners can be acquired at a limited cost for the water utilities. The drawback is that the project is limited to work with the CIPP-liners that possible to get hold of, making the acquisition time of interesting CIPP-liners long.

CIPP-lining in Sweden is mainly done by FRP, fiber-reinforced polymer, or Polyester needle felt. Several contractors are on the Swedish market.

METHODS

At this stage the project has acquired four different CIPP-liners with an age older than 5 years (Table 1). The pipes were cut out from in sections from 0.5 m – 2 m from a depth of 1.5-2.5 m. All pipe sections were cut out with the old concrete pipe included. They were all main pipes from domestic areas. Of these pipe sections only one has so far been more thoroughly investigated, the others have yet only been analyzed to a limited extent.

Table 1. Information about the excavated CIPP-liners

Sample #	**Kind of CIPP-liner**	**Year of installation**	**Diameter (mm)**	**Design thickness (mm)**	**Curing method**
1	FRP[a]	2003	225	4	Steam heating
2	FRP[a]	2007	150	4	Steam heating
3	FRP[a]	2010	225	4	no information
4	Polyester Needle felt	2006	150	4,5	no information

a. FRP – fiber reinforced plastics, sometimes also called GRP when glass fibers are used

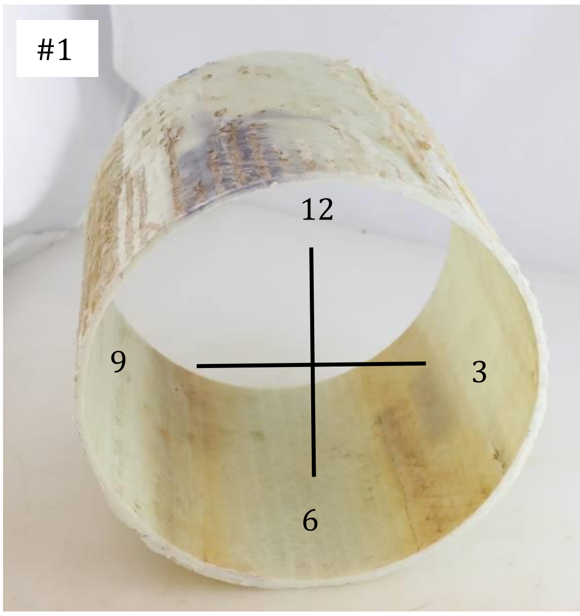

Figure 1. FRP CIPP-liner installed 2003, with upper point defined at 12 and bottom at 6.

Figure 2. FRP CIPP-liner installed at 2007.

Figure 3. FRP CIPP-liner installed at 2010.

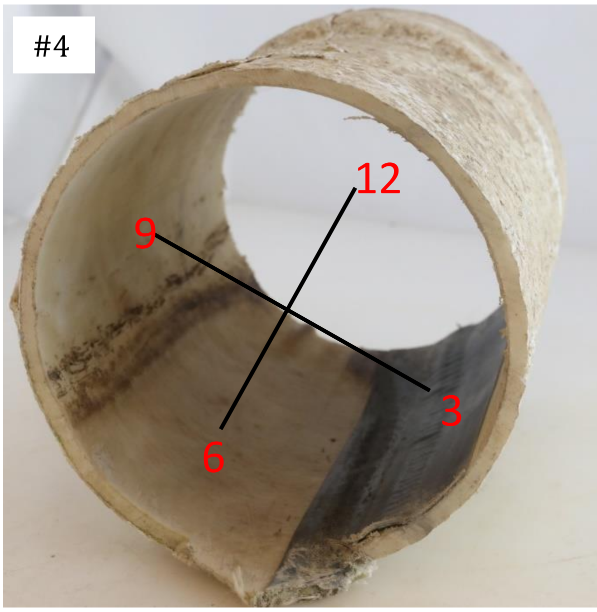

Figure 4. Needle felt CIPP-liner installed at 2006.

Experimental

Sample #1 was assessed by visual inspection, light optical microscopy (LOM) of cross section, differential scanning caliometry (DSC), 3-point bending and ring stiffness. Sample #2 and #4 was assessed by visual inspection, LOM and DSC, while #3 at this stage only was observed visually. DSC was performed on the outer part of the sample, but not on a piece of pure resin. For sample #3 measurements were performed. Ring stiffness was measured in constant deformation in accordance with EN 1228, and the thickness of the test piece was measured in accordance with EN ISO 3126:2005. Ring stiffness was performed on two test pieces over the whole circumvent on a test pieces with the length of circa 29.5 cm. Measurements were performed at 0°, 120° and 240°. The three-point bending was done on pieces with as uniform thickness possible and performed in accordance with EN ISO 11296-4 (Annex B) with a length/width ratio of 20:1 (ISO 14125). The test pieces for three-point bending was done with speckling of the surface in combination with Digital Image Correlation (DIC) in order to study strain fields during testing.

RESULTS AND DISCUSSION

From the visual inspection of the pipe wall cross section of Sample #1 the most noticeably was the great number of voids in the wall. The holes were distributed all around the circumvent and at different depth of the pipe wall. In Figure 5-9 the cross section of Sample #1 is shown, here it can be seen that the holes are distributed across the wall thickness. The width of the holes, with a main extension in the tangential direction, varied from a centimeter and more to a few millimeters. The depth of the holes varied but the extension in axial direction was noticeable which can be seen in Figure 6.

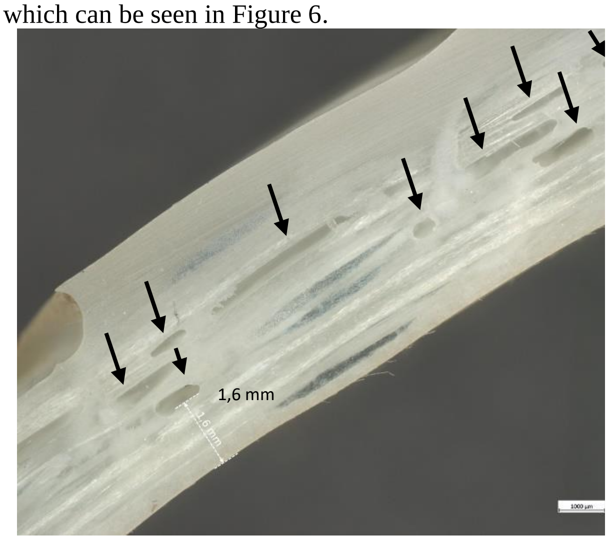

Figure 5. Light optical microscopy of a cross section of pipe wall from a CIPP-liner installed at 2003. The black arrows indicated holes in the pipe wall. The white scale bar is 1 mm.

Figure 6. Light optical microscopy of a cross section of pipe wall from a CIPP-liner installed at 2003. The white scale bar is 1 mm.

As can be seen in Figure 8 the thickness of the glass fiber reinforced part varies also between points close to each other, here going from 3.8 mm to 5.1 mm over a distance of 10 mm. At the thickest point (considering the fiber reinforced part) the wall was 7.1 mm, compared to the designed 4 mm. Outside the glass fibers a surplus of resin was also visible.

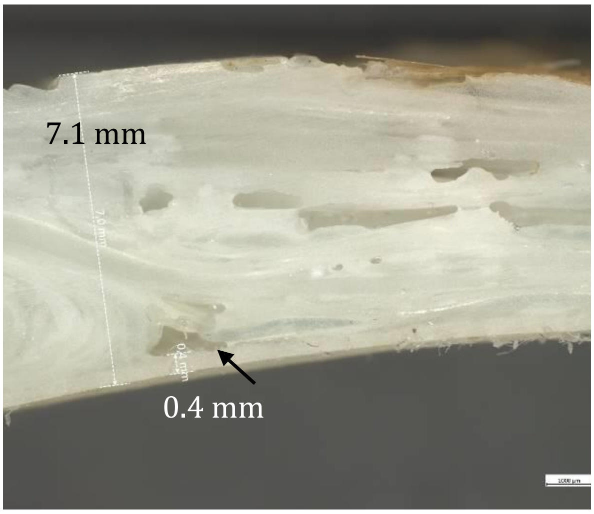

Figure 7. Light optical microscopy of a cross section of pipe wall with holes across the wall thickness. One hole was situated only 0.4 mm from the inside surface (black arrow). The white scale bar is 1 mm.

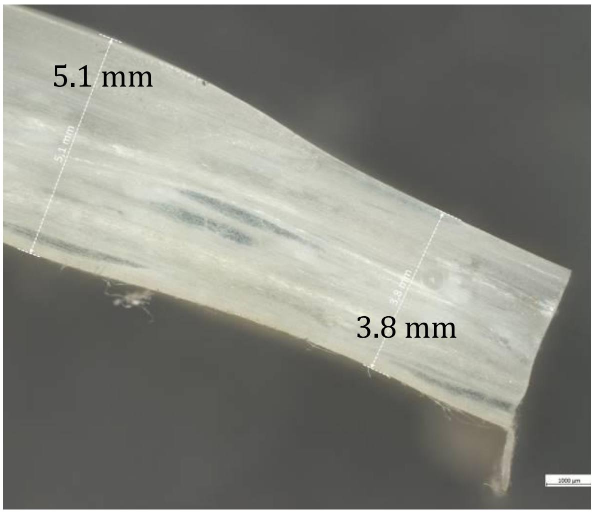

Figure 8. Light optical microscopy of a cross section of pipe wall shows how the thickness varies over short distances, also when only measuring the thickness of the glass fibers. The white scale bar is 1 mm.

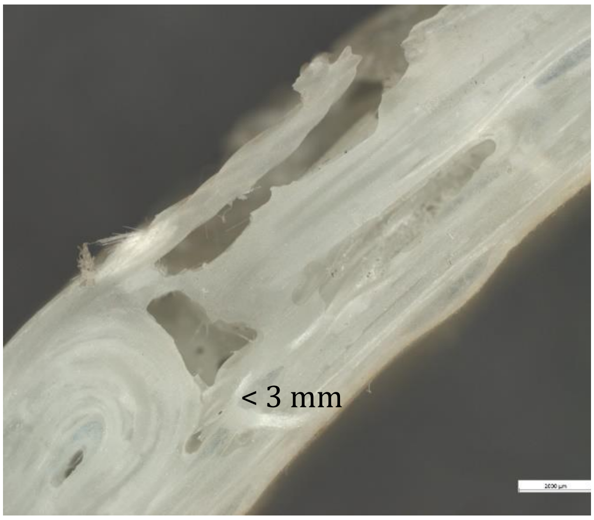

Figure 9. Light optical microscopy of a cross section of pipe wall shows that due to uneven distribution of resins the real thickness is lower than then designed value. The white scalebar is 2 mm.

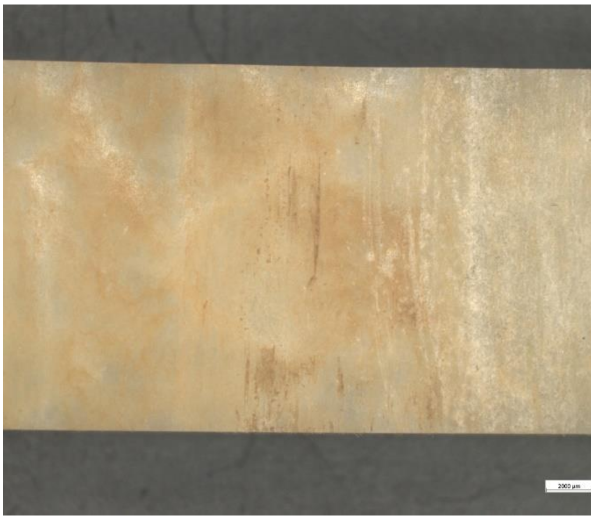

Figure 10. The inside surface of the sample showed good conditions with only surface cracks. The white scalebar is 2 mm.

In Figure 9 the disruption of glass fiber combined with an uneven distribution of resin leads the formation of large voids which reduces the actual thickness of the wall pipe. It is unclear how the holes are distributed in the depth, but based on the cross section of Figure 9 it is clear that installed product is not formed in the desired way upon installation. At the point in Figure 9 the efficient thickness is less 3 mm. The inside surface on the other hand shows good condition with only surface cracks visible (Figure 10).

When examine Sample #2 from 2007, produced by the same manufacture but a different liner, it shows to have the same problem with holes in the cross section. In Figure 11 a part of the pipe is seen, with a large hole in the middle of the wall. The hole is 1 cm wide, 3 mm thick and several cm deep. The hole in Figure 11 shows one of many holes that form defects in the pipe wall.

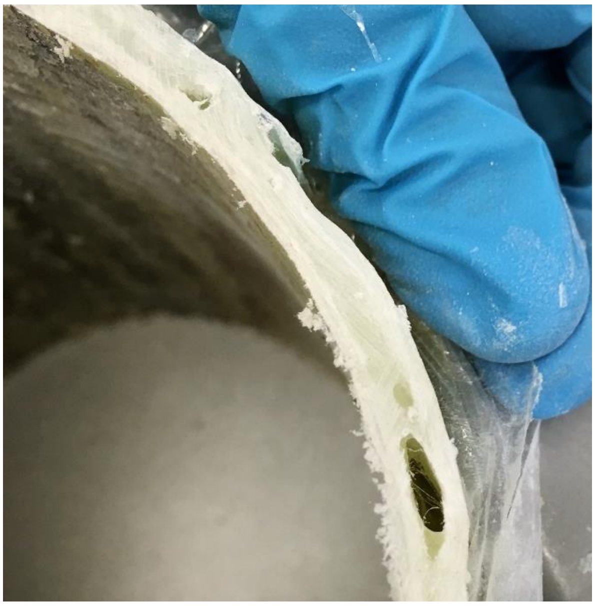

Figure 11. A defect seen in the pipe wall in between the reinforcing fibers for the CIPP-liner installed in 2007 (Sample #2).

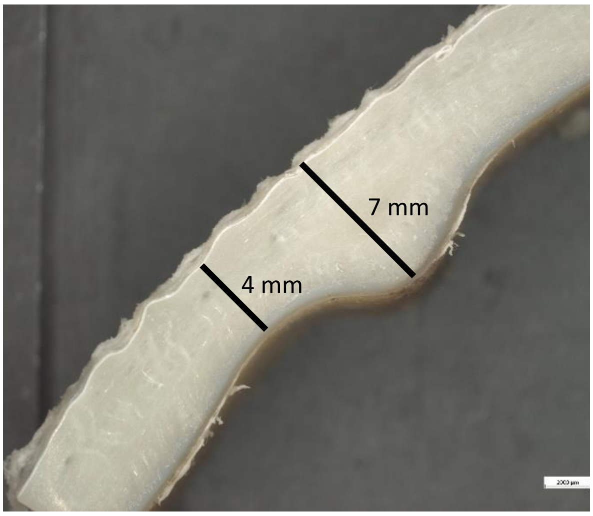

Figure 12. Light optical microscopy shows thickness variation in the needle-felt liner installed in 2006 (Sample #4). The white scale bar is 2 mm.

Figure 12 shows the cross section of the needle felt liner. From the LOM-evaluation it showed homogeneity with only smaller porous visible. The thickness on the other hand varied a lot between different positions, shown clearly in Figure 12 where the thickness varies between 4 and 7 mm within 1 cm of the circumvent. The uneven thickness may create folds that can reduce flow capacity and enhance deposit of solid material.

Sample #3 was of the same liner model as Sample #2 but installed 2010, but it showed no sign of holes (Figure 3). If it relates to an improved control of the product, the probability of assessing a defect region or a better installation is difficult to say.

Thermal analysis by DSC showed for Sample #1 a difference in degree of curing for the bottom part (at 6 o'clock) compared to the upper part (at 12 o'clock). Figure 13 shows the DSC curves for the first heating of a samples taken at 6 (red) and 12 (black). The red curves show an exoterm peak during heating that is related to curing of non cross-linked resin. Such reaction cannot be seen for samples taken at 12 or during the second heating at any of the positions. The difference in degree of curing might be related to the effect of steam curing during installation, where condense water form in the bottom of the liner and cools down the curing. In this case the degree of curing was calculated to 92%, taking a glass content of 53 % in account (determined by burning of the resin). The same behavior was seen for Sample #2, with a curing during the first heating for the samples taken at 6 o'clock. This was not experienced for samples taken at position 12 o'clock.

For the needle felt liner (Sample #4) no differences were seen for different positions nor between first and second cycle.

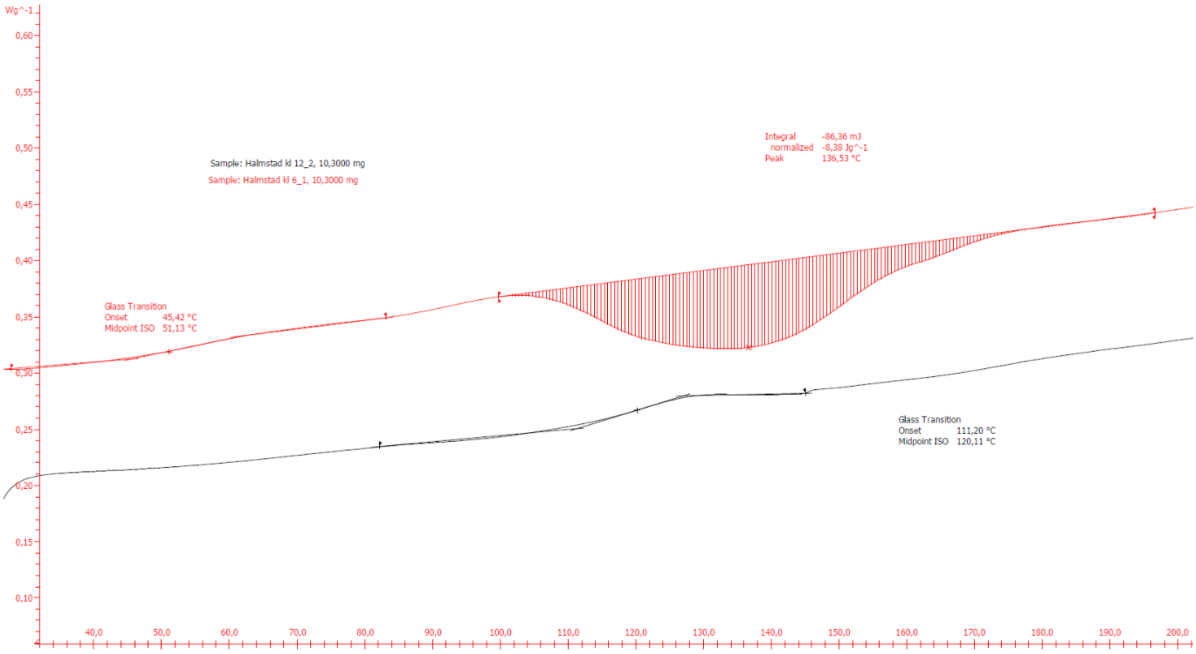

Figure 13. DSC of Sample #1, with pieces taken from 6 o'clock (red) and 12 o'clock (black), shows an exoterm peak for the bottom part of the liner. Indicating that there exists non-reacted resin to an extend it does not in the upper part of the liner.

Mechanical analysis of Sample #1 gave an average ring stiffness of 10.67 kN/m^2 (kN/m^2 corresponding to SN) for the two test pieces and an apparent modulus of 9512 MPa (N/mm^2). The average thickness was determined to 5.35 mm. The bending modulus as measured from three-point bending was measured to 9880 MPa. Corrected for the curvature of the test pieces the bending modulus was calculated to 12831 MPa. The test report for the installation determine the short-term E-modulus to 12000 MPa (N/mm^2). The short-term E-modulus is within in the same values as determined in the laboratory, but at this stage the author do not for sure know how the E-modulus was determined after installation and at this stage no further conclusion can be drawn. A rather large scatter was seen for the stress-strain curves of the three-point bending. It is possible that this could be influenced by the defects in the pipe wall. For the time of testing no considerations was taken to possible defects in the pipe wall.

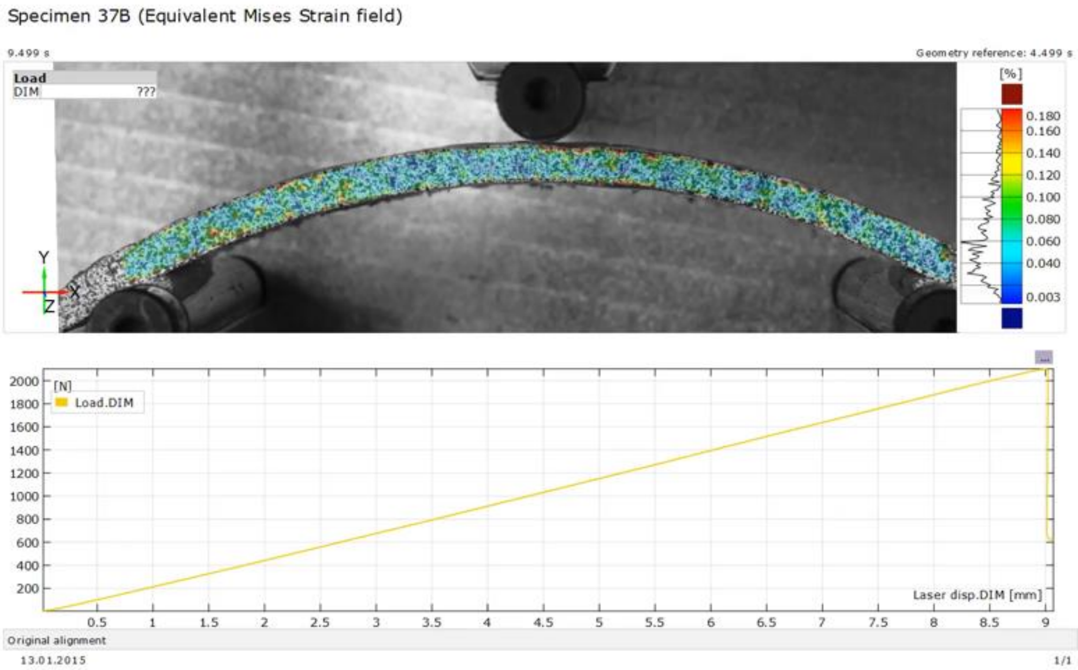

Figure 14. Three point bending in combination with Digital Image Correlation of Sample #1. The colorized bar at the right gives the values of the strain field and the plot beneath gives the load (N) as a function of displacement (mm).

Even though the project has not reach state where solid conclusion or recommendation to water utilities regarding CIPP-liner conditions can be given, some interesting observations can be noticed. It is obvious from the samples that have been assessed so far that it is common for 10-15 years old CIPP-liners to deviate from the designed thickness. As long as the thickness is thicker than designed it may mainly have an influence on the flow capacity, assuming the interior provides a flat and even surface with no folds. A greater concern is the existence of CIPP-liners with voids within the wall. This could be an effect of an insufficient impregnation process during fabrication and may in the end cause leaking pinholes and deteriorate mechanical properties, which is suggested by Alam et al. (2018). The voids give a bad impression at the position investigated, but one should consider how it might look at other positions in the installed liner. It could likely be worse than what experienced in the excavated pipe. Thanks to the mild chemical conditions in the domestic sewage system even a defect liner, such as the one investigated can perform well. That is, despite the observation of defects, a good remark for the technique.

Another interesting observation is the difference in degree of curing at different positions for steam generated curing. A lower degree of curing will in the end deteriorate the mechanical properties and chemical stability of the material. In this initially study the influence of a lower curing at the bottom part was not seen, but on the other hand no designated measurements were performed to detect it.

With time when the project acquires more excavated CIPP-liners and perform complete material assessments a greater knowledge about the service condition of installed liners in Swedish utilities will be reached. There is more is to come.

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