

Monitoring the quality of sewer renewal using polymeric systems in Sweden

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Abstract

Water and wastewater pipes require some of the highest levels of infrastructure investment; they also deteriorate faster than they can be repaired. The use of alternative rehabilitation technologies, which are quicker and less expensive than pipe replacement, has therefore increased significantly in recent years, worldwide. Field studies on relined wastewater pipes removed from buildings in different parts of Sweden revealed the existence of a variety of common defects, most of which could have been prevented by better installation. Increased quality-focused monitoring could help to ensure that relined pipes reach their expected service life, while comprehensive documentation could assist in providing sufficient information to facilitate progress in the field. This paper includes a brief overview of the technologies used in Sweden, current quality control practices, repeated observed defects related to installation, crucial steps that affect final quality, and recommendations to be considered in the contexts of detailed quality control and quality assurance procedures.

Key words: polymer, quality control, rehabilitation, relining, sewer, wastewater pipe

INTRODUCTION

Background

The original method used to rehabilitate sewer systems was to install a needle-felt tube impregnated with polyester resin inside the degraded pipeline (Wood 1977). At present, various materials and methods are used, and more than 100 different rehabilitation technologies are available (Matthews *et al.* 2014); however, the end result is similar in all techniques – creating a new pipe inside the old, deteriorated one, when renewal is complete (Matthews 2015).

Although water and wastewater pipeline rehabilitation using polymeric systems has seen some success and performed reasonably well in the past, in Sweden (Klintberg *et al.* 2012; Berglund *et al.* 2018) and elsewhere (Selvakumar *et al.* 2012; Alam *et al.* 2015), the technology could be improved by paying more attention to inspections and quality control/quality assurance (QC/QA) practices.

To evaluate existing rehabilitation methods, a study was conducted by KTH Royal Institute of Technology, Stockholm, Sweden, that included laboratory and field studies. The primary aim was to assess the performance of the materials used in wastewater rehabilitation in apartment buildings in Sweden. Analysis of the relined pipes removed showed that few problems were related to lining material deterioration; rather, they arose largely due to substandard installation. This suggests the existence of a gap between the ideal result and the quality achieved in operation, meaning that more attention needs to be paid during rehabilitation to enhance quality.

State of technology in Sweden

One of the conventional rehabilitation methods for small-diameter wastewater pipes in Sweden is the application of polymeric coatings to the inner surface of the old pipes. A modified epoxy, applied by

brushing on, and reinforced polyester, which is sprayed on, are two commonly applied coatings. They are applied in multiple layers with a recommended total, dry thickness of 2 or 3 mm, respectively (Jotun 2016). Another technique used regularly is the ‘flexible sleeve’: this method is similar to the cured-in-place pipe (CIPP), and is based on emplacing a flexible, resin-impregnated fiber tube in the old pipe. This is then cured *in situ* to form a new rigid pipe inside the old one. All these methods are referred to in the field as relining or pipe-lining.

A previous survey-cum-study based on interviews with the owners of 15,000 apartments in Sweden, showed that many relining users were satisfied with the results and that customers view the technology as an economical means of extending the piping system’s service life in their properties. The results showed that relining is worth considering as an alternative to total replacement, particularly if the apartment was recently renovated, and the floor drain and sealing layers in the bathroom are in good condition. According to the interviews, awareness of relining must be raised and the choice between different renewal methods needs to be based on a well-executed preliminary study (Lewald 2010).

A typical lining installation can include different steps. Some of the most common ones consist of inspection of the deteriorated pipe, usually by closed-circuit television (CCTV), cleaning – e.g., using a drag scraper – (Najafi 2010), and removing the solid contaminants and debris by high-pressure jetting or water-flushing followed by pressurized air to dry the surface, if needed, the application/installation of a liner, curing, and, finally, evaluating the result by CCTV inspection.

Current inspection and quality control practices

Several inspection and quality control practices are used currently in Sweden. The most common inspection technique, used both before and after relining, is CCTV. It is particularly well-established and has been used in Sweden for more than 40 years (STVF 2018).

One current Swedish quality control guide for CCTV inspection of pipelines (T25) is based on pictures for classifying and grading the situation, pipeline defects and the quality of the rehabilitation work (STVF 2013). It also includes recommendations on how to conduct, document and report the inspection.

SP Technical Research Institute of Sweden, in collaboration with BRiF, the Relining Contractors’ Association, has developed new certification rules for two relining methods, spray-on coating and flexible-sleeve lining. The certificate – CR 072 – covers the use of these methods in rehabilitating wastewater systems in residential buildings. The procedure includes functional, as well as material and product requirements. Materials certified to CR 072 have a minimum service life of 50 years (SP 2016). Relining companies also have a quality control program – BRiF 3Q – whose use is mandatory for members (BRiF 2018).

Various standards and quality control guides have been developed internationally that can be used and applied in extended quality control procedures.

METHODS

Relined pipes which have been in working condition were removed from operation and evaluated in the laboratory (Table 1). Most had been relined using polymeric systems and minimal technical histories were available for them. The samples were cut to study the cross-section and liner-pipe interfaces, visually and microscopically – the latter using an optical microscope to collect images. For edge interface images, specimens were cut and ground before study under the microscope.

For thickness measurement, smaller circular pipe sections were cut, and five points on each edge of the relined sample were measured using a digital caliper. An average of three readings from the same point was calculated and recorded for each measurement.

Table 1 | List of relined pipe samples

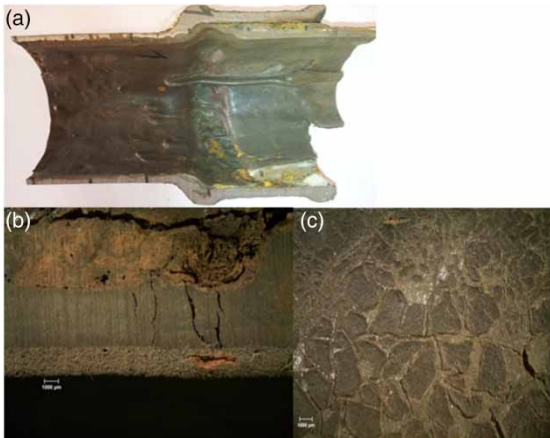
Relined sample	Relining Materials and methods	Operation Time (years)
1	Modified epoxy polymeric system applied by brush	6
2	Modified epoxy polymeric system applied by brush	6
3	Modified epoxy polymeric system applied by brush	10
4	Modified epoxy polymeric system applied by brush	<1
5	Reinforced polyester polymeric system applied by spray	<1
6	Reinforced polyester polymeric system applied by spray	3
7	Flexible sleeve impregnated with epoxy	2

RESULTS AND DISCUSSIONS

Issues observed during optical microscopy and visual inspection

Table 2 shows some of the defects observed in samples 1 to 7.

Table 2 | Issues observed during visual and microscopy inspection of samples

Sample images (all from optical microscopy)	Observed defects
	<p>Images 1 (a), (b) and (c) – sample 1 was relined using the modified epoxy polymeric system. Defects include thickness variation and runs (1(a)), cracks (1(b)) and surface cracks (1(c)). Corrosion between the liner and host surface was also observed in some places.</p>

Images 1 (a), (b) and (c): sample 1.

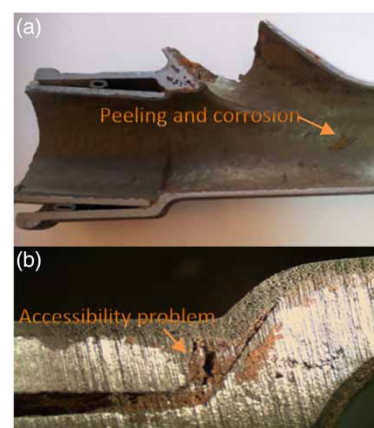


Image 2 (a) and (b): sample 2.

Images 2 (a) and (b). The pipe was relined using the modified epoxy polymeric system. Defects include liner peeling (2(a)), un-coated spots and areas without liner coverage, particularly where access was difficult (2(b)) and some corrosion.

(Continued.)

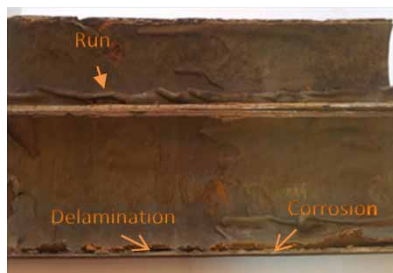
Table 2 | Continued**Sample images (all from optical microscopy)****Observed defects**

Image 3: sample 3.



Image 4: sample 4.



Image 5: sample 5.

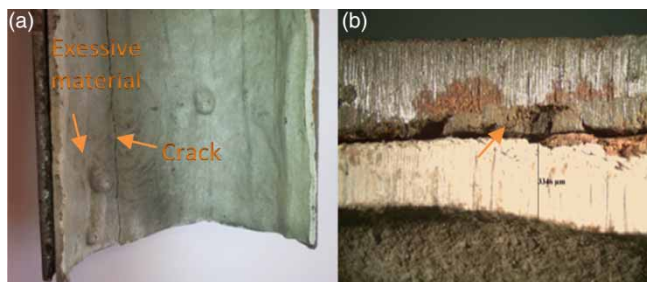


Image 6 (a) and (b): sample 6.



Image 7: sample 7.

Image 3. The pipe was relined using the modified epoxy polymeric system. Defects include runs, loose adhesion of epoxy lining to the host, liner delamination from the pipe, corrosion, and uneven liner film application.

Image 4. The pipe was relined using the modified epoxy polymeric system. The relined pipe was removed after only 2 weeks because the application failed, leaving a non-uniform, inadequate lining film. Many parts had no liner coverage.

Image 5. The pipe was relined using the reinforced polyester polymeric system. Defects include delamination and the lining thickness not being uniform. When the piece of pipe was cut, the lining layer came off, revealing corrosion underneath.

Images 6(a) and (b). The pipe was relined with reinforced polyester and had been in use for only seven days before being removed due to application failure and defects. The excessive film application, thickness variations and cracks can be seen in 6(a), with corrosion between the liner and host pipe (6(b)). Other defects were also observed.

Image 7. The pipe was relined using the flexible sleeve method and the sample removed shortly after installation due to the poor quality of the renovation. Impregnation of the material into the textile was very poor, as can be seen. The technical history available for the rehabilitation was insufficient to enable analysis of the cause of the issue.

One of the repeated issues was uneven lining thickness – i.e., too much or too little material being applied. Excessive material application, contrary to the manufacturer's recommendations, can lead to a range of defects, including runs, which can be seen in Image 1(a) and Images 3 and 6(a).

If the dry film is too thick, this limits liner flexibility and can cause stress failure cracks – Images 1 (b) and 6 (a). The surface cracks seen in Image 1(c) – the so-called alligator defect – may also be due to excessive application. When the film is too thick, the top layer can cure faster than the rest, causing surface cracks after all the layers are cured. Small areas of excess material – see Image 6(a) – can be due to faults in the spray machine used for application.

In samples 2, 4 and 7, however, material application was inadequate in places, such that the surface cover was insufficient. Applying a uniform layer of liner can be difficult for pipe segments such as sample 2, due to its specific design and structure. The coating application was so poor in sample 4 that many areas were left without coverage – Image 4. The impregnation of material was very poor in sample 7.

The other defects observed are most probably related to poor preparation and inadequate cleaning of the surface before liner application.

A critical issue that arises from surface contamination and poor preparation is weak liner adhesion to the pipe, or segregation of liner and pipe. Liner-pipe adhesion is particularly important when using a coating rehabilitation method; because the coating's functionality as a corrosion barrier, as well as its long-term performance and longevity/stability, are related to its adhesion to the host pipe substrate.

Poor surface preparation can cause peeling – Image 2(a) – probably due to contamination reducing the strength and bonding inside the material, which can be pulled or flake away from between coating layers (Image 2(a)), or between the coating and the pipe – e.g., along the edges of sample 3 (Image 3). Delamination or segregation – sample 5 – probably occurs due to inadequate surface preparation.

In all cases, the analysis of defect sources would have been more accurate if a more complete technical history of the rehabilitation work and cleaning process had been available.

Issues observed during thickness measurement

The nominal dry film thickness for liners based on modified epoxy is 2 mm, if applied in two layers, so that each layer is between 900 and 1,100 μm in thickness. For reinforced polyester coatings, the total thickness of the three layers is recommended to be 3 mm (Jotun 2016). However, thickness measurements at different places in the samples used revealed significant variation (Kharazmi 2019).

As Table 3, and Figures 1 and 2 show, the liners applied in samples 1, 3 and 6 exhibited large thickness variations.

Table 3 | Liner thickness measurements (mm) based on measuring 10 points (five points from each edge of each sample) for samples 1 to 4 (relined with epoxy liner), and 5 and 6 (with polyester liner)

Sample	Average (mm)	Max (mm)	Min (mm)	STDV (mm)
1	3.03	6.93	1.77	1.80
2	1.64	2.64	0.9	0.58
3	2.58	8.5	0.6	3.05
4	0.73	1.29	0.38	0.34
5	3.48	4.76	2.4	0.82
6	3.92	6.68	2.45	1.51

Issues observed in documentation

None of the relined samples available came with a detailed technical history, and significant proportions of the most important information were missing. The lack of technical history such as

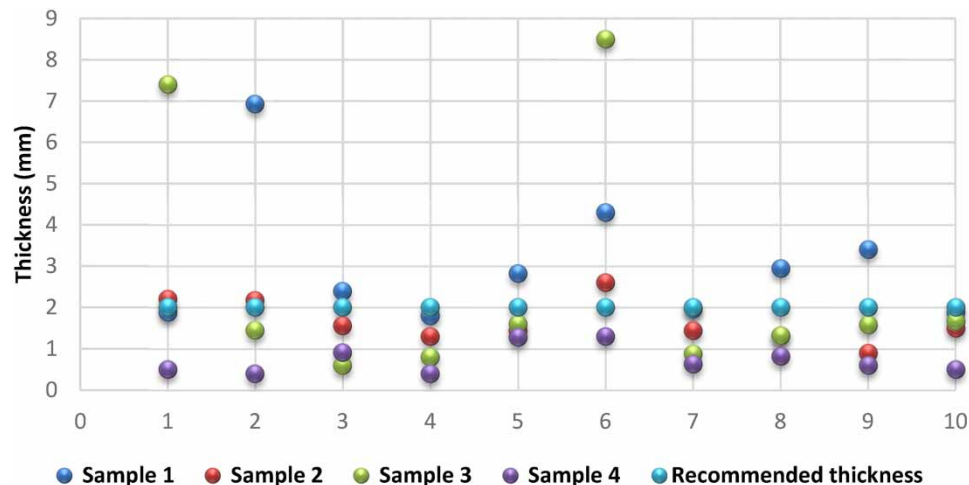


Figure 1 | Ten thickness measurements (five points from each edge of each sample) for samples 1 to 4 (relined with epoxy) and compared with the recommended thickness.

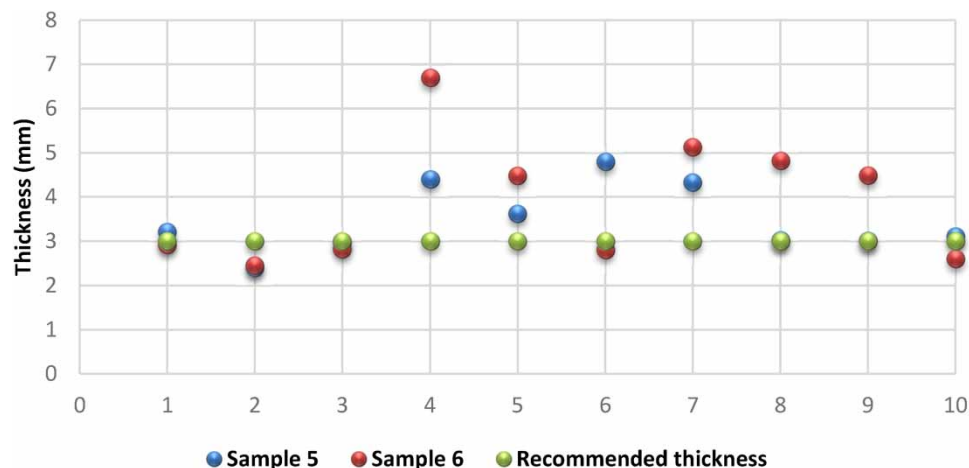


Figure 2 | Ten thickness measurements (five points from each edge of each sample) for samples 5 and 6 (relined with polyester) compared with the recommended thickness.

details of the rehabilitation work already carried out, pipe condition before renewal, and information about liner materials, makes it difficult to analyze the defects and identify the reasons for them.

RECOMMENDATIONS FOR COMPREHENSIVE QC/QA PROCEDURES

Many factors can influence the quality of rehabilitation (Table 4). The more important factors should be prioritized and considered carefully. One of the most important is the steps needed to achieve a uniform liner film, which should be conducted following the manufacturer's recommendations. Uneven liner material application was a common issue identified in the study, and can lead to defects like cracks, mechanical failure and difficulties in maintenance. The measurement of wet and dried film thickness of the cured sample *in situ* can provide information about the thickness inside the relined pipe. CCTV inspection and ultrasound measurements are other ways to inspect certain areas, particularly those with inadequate material coverage and dry spots. In this context, liner in a flexible sleeve should be saturated with a minimum resin coverage of 95% (Selvakumar *et al.* 2011).

Table 4 | Factors important in inspection and documentation

Pre-relining documentation and monitoring	Inspection and documentation related to the pipe to be relined	Material Length Diameter Time in operation Defects Location
	Inspection and documentation related to cleaning	TV-inspection before cleaning Cleaning methods and equipment CCTV inspection after cleaning
	Preparation for application/installation	Rehabilitation method and reasons for choosing it Compatibility between liner material and pipe Chosen curing method (e.g., light, hot water, steam, ambient) Materials' technical data sheet (TDS) checking and approval Application equipment Preparation of an on site reference sample with the same material as the host pipe to be relined the same way, time and location of the rehabilitation project, to be kept for future references
Documentation and monitoring during relining	Inspection and documentation related to environmental conditions	Temperature Humidity Dew point Ventilation
	Inspection and documentation related to application/installation	CCTV inspection Record of problems occurring during blending polymer and hardener Record of problems occurring during application/installation
	Inspection and documentation related to the field-cured reference sample	Visual inspection Wet thickness measurement Comparison of wet thickness with recommendation in manufacturer's TDS Tracking the curing rate Comparison of rate of curing with material's TDS
Post-relining documentation and monitoring	Final field inspection	Final cleaning inside sewer system Final CCTV inspection
	Reference sample	Test result of field-cured sample after curing (e.g. hardening time, measurement of adhesion to the host pipe, dry thickness measurement, mechanical properties, and glassy transition temperature (T _g), and comparison with the material's TDS
	Planning future inspection and maintenance	Scheduling follow-up inspection CCTV inspection video prior to the end of the service-life guarantee so that any defect can be repaired before finishing the end of the period

Another major issue observed was inadequate pre-cleaning. The cleaning methods selected and used are important, and can be a key factor in the success or failure of a rehabilitation project (Selvakumar *et al.* 2012). Ensuring adequate preparation and cleaning before rehabilitation begins is vital. Thorough cleaning and drying facilitates adhesion for polymeric coating systems. Another consideration during cleaning is that drag scraping and jetting must be used carefully to avoid worsening the condition of an already aged pipe, as this can lead to collapse or blockage, making relining difficult or impossible.

Most polymeric rehabilitation systems have multiple components comprising at least resin and hardener, and possibly additional components. The amount of curing agent to be mixed with the resin before application is very important; the proportions used should be exactly as recommended

by the manufacturer to assure the desired curing rate. Another important factor affecting curing, apart from the type and amount of curing agent, is the environmental/climatic conditions, which should be measured and meet the manufacturer's recommendations. For example, resin-based coating application is usually recommended if the dew point (calculated from the ambient temperature and humidity) is at least 4 °C (Jotun 2016).

CCTV inspection is a useful and important part of any quality control procedure. However, it must be conducted to provide an accurate view. It is recommended that it be conducted with the camera approximately in the pipeline's center, moving slowly and with suitable lighting to allow for a full view of the pipe and liner (Selvakumar *et al.* 2012). The pipeline also needs to be reasonably clean and dry, and free of water.

CONCLUSIONS

Although some quality checks and rehabilitation project documentation already exist, the technology can progress by allocating more attention and time to monitoring in accordance with comprehensive QC/QA practices. Studies of relined pipes have shown that some of the most common issues were not related to lining material deterioration, and could have been prevented by quality installation. Commonly observed issues included inadequate pre-rehabilitation pipe surface preparation, non-uniform application of lining film (i.e. thicker or thinner application than recommended), and inconsistent or inadequate resin impregnation of the flexible sleeve. These issues resulted in defects like liner delamination from the pipe, peeling, cracking, runs, dry areas, etc, which could be prevented by improved monitoring during rehabilitation.

The study's results revealed a gap between the quality expected in theory and that achieved in practice, as well as that more monitoring is required during installation. An extended/extensive QC routine, in which the most important steps in quality monitoring are prioritized, should increase the effectiveness of installation.

ACKNOWLEDGEMENTS

This paper was part of a study supported financially by The Swedish Research Council Formas. Advice from Professor Folke Björk and Dr Tord af Klintberg during the study was greatly appreciated. The relined pipe samples were provided by BRiF (Branschföreningen för Relining i Fastigheter) and the microscopy study was conducted in the SP Technical Research Institute of Sweden.

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