Long-Term Performance of a Microsilica Based Cement Liner In Aggressive Sewer Manhole Wastewater Environments

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Abstract:

Cement (cementitious) liners are being used in numerous applications and hence their long-term durability under various chemical environments is becoming more and more important. In this study, the long term durability of a microsilica based cement liner used in several manholes in the Houston, Texas area was investigated. Core samples (25 mm in diameter) obtained for this investigation were from manholes in service for up to 15 years. The samples were visually inspected and were subjected to series of tests. Immersion tests were performed to determine the water uptake of the specimens. Microstructral analyses included X-ray diffraction study (XRD) and thermal-gravimetric analysis (TGA).

Inspection of the core samples obtained from the field indicated some discoloration in the samples with age. Immersion testes indicated greater water uptake with older samples. XRD and TGA analyses identified the reaction products formed in the liner with age. The investigation indicated that the cement liner material was in good condition, based on composition and structural integrity, after 15 years in active service.

Keywords: Concrete, chemical resistance, microsilica, durability, longevity, sulfate.

1. Introduction

Although cementitious materials are being widely used, there are rising concerns about the changes in mechanical and physical properties of cementitious materials under long-term exposure to adverse wastewater environments. Hence, cement concrete response to chemical environments must be investigated. The cement material deterioration may be caused by many factors, including carbonation, alkali-aggregate reaction, and attacks by sulfates, acids, and other chemicals [1]. It is seldom found that the deterioration of the cementitious materials is caused solely by one of the aforementioned processes. Mostly it is due to the combined effect of the several factors at the same time or successively. The mechanism of attack is also different, depending on the condition and type of concrete. In the case of a dry environment, the formation of reaction products may cause expansion in the pores and capillaries due to the salt crystallization [2]. Micro-cracks may develop, which will allow deeper penetration of the ions and accelerate the rate of corrosion. In a wet environment, acid droplets interact and make soluble salts, which are subsequently formed and leached out. Due to leaching of the soluble salts, the cement binder is affected and concrete loses its strength. Due to acid attack, the concrete surface becomes more porous and permeable, making it easier for further chemical attack [2].

Aardt and Visser [3] studied the influence of alkali on the sulfate resistance of Ordinary Portland Cement (OPC) mortars. The aggressive solutions used were 5% Na_2SO_4 and 1% H_2SO_4. The dynamic modulus, the length change and the mass change during the exposure period of the specimens were recorded. It was concluded that the alkali content of an OPC had an influence on the sulfate resistance of mortars made with the cements but that the alkali content should be considered in relation to C_3S and SO_3 contents. Gimenez, Garcia, Blanco and Palomo [4] studied the behavior of cement in sodium sulfate and seawater media and 4% Na_2SO_4 and an artificial salt water (ASTM D 1141-76) were used in their study. It was concluded that the new cement due to its different chemical composition was much more resistant to chemical attack than an OPC. They also reported that the cement mortar specimens immersed in Na_2SO_4 solution had a greater chemical resistance than those cement mortar specimens immersed in water due to the gypsum formation at the expense of $Ca(OH)_2$ that makes the system become more dense. Sarkar [5] reported that the leaching of lime is a major weakening factor for concrete submerged in water.

Gallop and Taylor [6] studied the effect of sulfates on cement pastes. The specimens were immersed for 6 months in solutions of sodium and magnesium sulfate. Micro structural changes such as replacement of monosulfate by ettringite, disappearance of calcium hydroxide and further decalcification and leaching were studied. The sulfate and calcium concentration decreased by 5% and 50 % respectively with time at the end of the 6 month cycles for specimens immersed in sodium sulfate. Also, no significant change in pH was reported. Kumar and Rao [7] suggested that the consequence of sulfate attack, loss in compressive strength is caused by both internal expansion due to the formation of ettringite and gypsum and by leaching of calcium hydroxide.

Normally, if the sulfate concentration is less than 150 ppm, there will not be any significant attack [7]. Concrete can be used without secondary protection in a sulfate environment provided the sulfate concentrations are less than 6000 mg/l. If the sulfate concentration is more than about 6000 mg/l, usually surface coatings are applied on concrete to protect the concrete from corrosion. Degradation takes place in the form of cracking, pop-outs resulting from loss of coarse aggregate, and disintegration of hydrated cements. Sulfate ions present in soil, ground water, seawater, decaying organic matter and industrial effluents are known to have an adverse effect on long-term durability of concrete.

Kurtis, Monteiro and Madanat [8] studied concrete expansion caused by sulfate attack. Concrete cylinders were submerged in a 2.1% sodium sulfate solution over 40 years. Empirical models to predict concrete expansion were developed. Santhanam, Cohen, and Olek [9] quantified the gypsum and ettringite when cement mortars were submerged in a

4.44% sodium sulfate solution and concluded that the expansion of concrete under sulfate attack was caused by the combined effect of gypsum and ettringite formation.

Vipulanandan et al. [11-15] have investigated the performance of various coating and liner materials for protecting the concrete in a wastewater environment. The studies included hydrostatic test to determine the applicability of liners and coating on to concrete surfaces under a backpressure of 15 psi (105 kPa). Also studies were focused on the performance of coated concrete and clay bricks with pinholes in sulfuric acid solutions. Bonding strength of various coatings and liners with concrete and clay bricks were also investigated over a period of several years [11-15].

Manholes are a very critical component of the wastewater collection system. They are designed as access points to wastewater systems pipelines allowing for inspection, maintenance and rehabilitation. The manhole has long been overlooked as a major source of inflow and infiltration and this has proven to be a costly mistake. Understanding the environmental effects on cement liners is becoming important for designers and material developers. Effects on cement liners due to long-term exposure to the wastewater environment have not been fully examined. This study was focused on quantifying the performance of a microsilica based cement liner in service for 5, 10 and 15 years.

Houston, Texas: It is the fourth largest city in the U.S. with a population of 1.8 million. The wastewater system has over 33,000,000 liner-ft of pipelines, 425 lift stations and over 100,000 manholes. The city is currently spending over $100 million per year to clean and rehabilitate its' wastewater systems. The City of Houston has placed a large emphasis on the relining of their manholes.

2. Objective

The overall objective is to investigate the effect of aging on a microsilica based cement liner material in a wastewater environment using field samples. Core samples were obtained from various manholes for this study. The specific objectives were (1) to visually inspect the quality of the core samples (2) to quantify the water uptake by the core samples (3) to determine the constituents of the core samples using XRD and other methods; and (4) to relate the age of samples to quality of the samples.

3. Materials

The microsilica based cement liner material is a blend of highly reactive polymers, finely divided cement and pozzolanic materials, a dry densified microsilica powder admixture, synthetic fibers and other selected admixture ingredients that enhance the workability during placement.

The manhole is cleaned and repaired before spray applying the cementitious liner. The application process is a follows. Dampen the manhole wall surface. Allow some dampness without noticeable free water droplets or running water. Spray apply the cementitious liner material to a uniform thickness. Use a stainless steel trowel to hand work and compact the manhole cementitious liner material into all the voids and crevices. Spray apply the cementitious liner material to a minimum thickness of ½ to 2 inches

(1.25 – 5.0 cm) in one pass. To achieve structural reinforcement apply a minimum of 1 inch (2.5 cm) of manhole lining material. Use a penetrometer or depth gauge to measure applied cement material thickness at three sections of the manhole, cone/corbel section, middle of the barrel, and the barrel near the invert. Finish with a stainless steel trowel to a smooth and even surface to meet ACI 302.1R finishing requirements. Using a hand trowel technique to seal the surface effectively lowers porosity and permeability levels.
Once the lining has cured it should be tested. The vast majority of manholes utilizing the full depth lining system should be tested by using either a vacuum or water ex-filtration test. This testing should follow the manufacturer's recommendations for proper and safe procedures.

This cement liner material has been used in maintaining and protecting over 20,000 manholes, 36 to 72 inches diameter, in and around the City of Houston.

4. Experimental Program

This study included immersion tests and microstructural analysis of the field samples. A Siemens D 5000 X-ray diffractometer (XRD) was used for identifying the chemical compounds in the liner samples. Thermalgravimetric analysis (TGA) was performed in nitrogen environment using a Dupont TGA 951 analyzer.

4.1 Cement Liner Samples

Core samples, 1-inch in diameter, were obtained from active Houston area wastewater sewers. The samples were obtained from near the bottom of 36 to 48-in diameter manholes that were lined using the cement material a number of year ago. The age of the field core samples varied from 5 to 15 years. Over a dozen samples were obtained from the field. In order to compare the performance of the aged microsilica based cement liner to a new liner, the properties and constituents of new liner material was also investigated.

4.2 Immersion Test

Dry cement specimens are immersed in water and tested for the weight change with time for a period of 3 hours. The weight changes in the samples were normalized with the initial weight of the samples tested. The higher the weight changes the greater the affinity to retain water and more porous will be the material.

4.3 Micro-structural Analysis

The study included both XRD and TGA analyses. Based on XRD analysis it will be possible to identify the chemical compounds in the materials. The interest was on identifying ettringite, gypsum ($CaSO_4$) and calcium carbonate, since these are the typical reaction products expected in the wastewater environment. TGA analysis will give the weight loss in the material with temperature and may possibly identify those compounds that may be decomposed during the heating.

5. Results and Discussions on Test Results

5.1 Physical Characteristics

New Liner: The core samples were intact with no loose materials or fragments on the surface. No visible cracks were observed. No discoloration was observed. The dry unit weight was 95 pcf.

5-Year Old Liner: The core samples were intact with no loose materials or fragments on the surface. No visible cracks were observed. Slight discoloration was observed.

10-Year Old Liner: The core samples were intact with no loose materials or fragments on the surface. No visible cracks were observed. Some discoloration was observed. The dry unit weight was 87 pcf (Table 1). Reduction in unit weight indicated loss of some materials from the cement liner during its 10 years of service life.

15-Year Old Liner: The core samples were intact with no loose materials on the surface. No visible cracks were observed. Some discoloration was observed (sample was darker in color). The dry unit weight was 82 pcf (Table 1). Reduction in unit weight indicated loss of some materials from the cement liner during its 15 years of service life.

Table 1. Summary of Test Results on the Liner Materials

Age of Liner	Visual Inspection	Dry Unit Weight (pcf)	Maximum Water Absorption (%)
New Liner	No discoloration. No fragments or loose material on the cored samples.	95	2.86
5 Year Old Liner	Slight discoloration. No fragments or loose material on the cored samples.		3.61
10 Year Old Liner	Some discoloration. No fragments or loose material on the cored samples.	87	5.32
15 Year Old Liner	Some discoloration. No fragments or loose material on the cored samples.	82	7.32

5.2 Immersion Test

Typical percentage weight change with immersion time for the cement liner materials are is shown in Figs. 1 and 2 for a period of three hours.

New Liner: The immersion test results are shown in Fig. 1. The percentage of weight change indicates the affinity to water to the liner and the porosity of the material. The weight change was 2.86% for the new liner.

5-Year Old Liner The weight change was 3.61% for the 5-year old liner. The increased percentage of weight change, compared to the new liner, indicates the affinity of water to the new reaction products and an increase in the porosity of the material.

10-Year Old Liner: The weight change was 5.32% for the 10-year old liner. The increased percentage of weight change, compared to the new liner, indicates the affinity of water to new reaction products (XRD analysis results) and an increase in the porosity of the material. This study is the first of its kind and hence there is no information in the literature to compare the results

15-Year Old Liner: The weight change was 7.32% for the 15-year old liner. The increased percentage of weight change, compared to the new liner, indicates the affinity of water to new reaction products (XRD analysis results) and an increase in the porosity of the material.

5.3 Micro-structural Study

XRD Analysis

New Liner: Cured samples were obtained from the material supplier for this part of the study. The X-ray analysis for the new cement liner material is shown in Fig. 1. The peaks observed are typical for cement mortar. The strong calcium hydroxide peak was observed at 34.1^o. The strongest peak was quartz which represents the sand in the cement liner materials. Also peaks were observed for CaO and $CaCO_3$.

5-Year Old Liner: Based on the XRD analysis, as shown in Figure 2, the calcium hydroxide peak was reduced and the intensities of CaO and CaCO3 peaks were increased. During the service life, the cement liner materials are in contact with the wastewater which could dissolve the excess crystalline calcium hydroxide in the liner. The wastewater environment is also resulting in more carbonation of the cement liner with time. Also a CaSO4 peak was detected, indicating an environmental condition, such as the presence of H_2S, in the sewer.

10-Year Old Liner: Based on the XRD analysis, as shown in Figure 3, the calcium hydroxide peak was reduced and the intensities of ettringite (9^o) CaO and CaCO3 peaks were increased. Presence of ettringite indicates the existence of sulfate attack in the manhole. As mentioned before, during the service life, the cement liner materials are in contact with the wastewater which could dissolve the excess crystalline calcium hydroxide in the liner. The wastewater environment is also resulting in more carbonation of the cement liner with time. Also a CaSO4 peak was detected, indicating an environmental condition in the sewer.

15-Year Old Liner: Based on the XRD analysis, as shown in Figure 4, the relative intensities of ettringite (9^o) peak had increased compared to the 10 year old sample. Presence of ettringite indicates the existence of sulfate attack in the manhole. As mentioned before, during the service life, the cement liner materials are in contact with the wastewater which could dissolve the excess crystalline calcium hydroxide in the liner. The waster water environment is also resulting in more carbonation of the cement liner with time. Also CaSO4 peak was detected, indicating an environmental condition in the sewer.

5.4 TGA Analysis

The change in weight with temperature is another indicator of the quality of the material.

5-Year Old Liner: The TGA analysis results are shown in Figure 5, where the initial weight loss of 5% up to 100^oC was due to the removal of free water in the specimen. Continuous loss of weight up to about 600^oC indicated the removal of bound water and the decomposition of other compounds in the liner material. Total weight loss observed was 10%

10-Year Old Liner: The trend observed was very similar to what was observed with the 5 year old specimens. The initial weight loss of 5% up to to 100^oC was due to the removal of free water in the specimen. Continuous weight loss of up to 15% about 650^oC indicated the removal of bound water and the decomposition of other compounds in the liner material. Total weight loss observed was 15%, higher than what was observed with the 5-year specimens.

15-Year Old Liner: The trend observed up to 100^oC was very similar to what was observed for the 5 and 10 year old specimens. The initial weight loss of 5% up to 100^oC was due to the removal of free water in the specimen. Continuous weight loss of up to 10% about 650^oC indicated the removal of bound water and the decomposition of other compounds in the liner material. Notable weight loss of 5% was observed in the temperature range of 650 to 700^oC indicating the decomposition of CaCO3. Total weight loss observed was 15%, similar to what was observed with the 10-years old specimens.

6. Conclusions

The durability of a cementitious liner used for protecting the manholes in the wastewater sewers in Houston, Texas was investigated using core samples from the field. Samples were obtained from the sewers after 5, 10 and 15 years in service. Based on the test results, the following conclusions are advanced.

(1) Visual inspection of the specimens showed that the core samples obtained from the sewers were in good condition with some discoloration. The condition at the

aggregate-mortar interfaces were good and no spalling was observed. The fact that the cores were complete and intact was a positive indicator as to their long term durability.

(2) Immersion test results showed that the water uptake by the liner samples varied from 5 to 8% and increase with the age of the samples. The changes reflect the high usage of the manholes. Even with these changes the liner samples were in good condition.

(3) XRD analyses of the samples identified the constituents in the liner matrix. While typical cementitious constituents such as calcium hydroxide were identified in the aged liner materials, additional compounds such as ettringite, calcium carbonate and calcium sulfate were also identified. Additional compounds also reflect the nature of the environmental condition in the sewer system. Although various compounds were identified in the liner, they were still in good condition. TGA analyses showed greater weight loss in aged specimens. Loss in weight due to calcium carbonate was observed in 15 year old specimens. Total loss in weight was similar for the 10 and 15 year old specimens. Based on this result, aging did not affect the lining.

(4) Various test methods indicated relative changes in the liner material over the years in service. The changes noted did not affect the quality or integrity of the liner.

Acknowledgement

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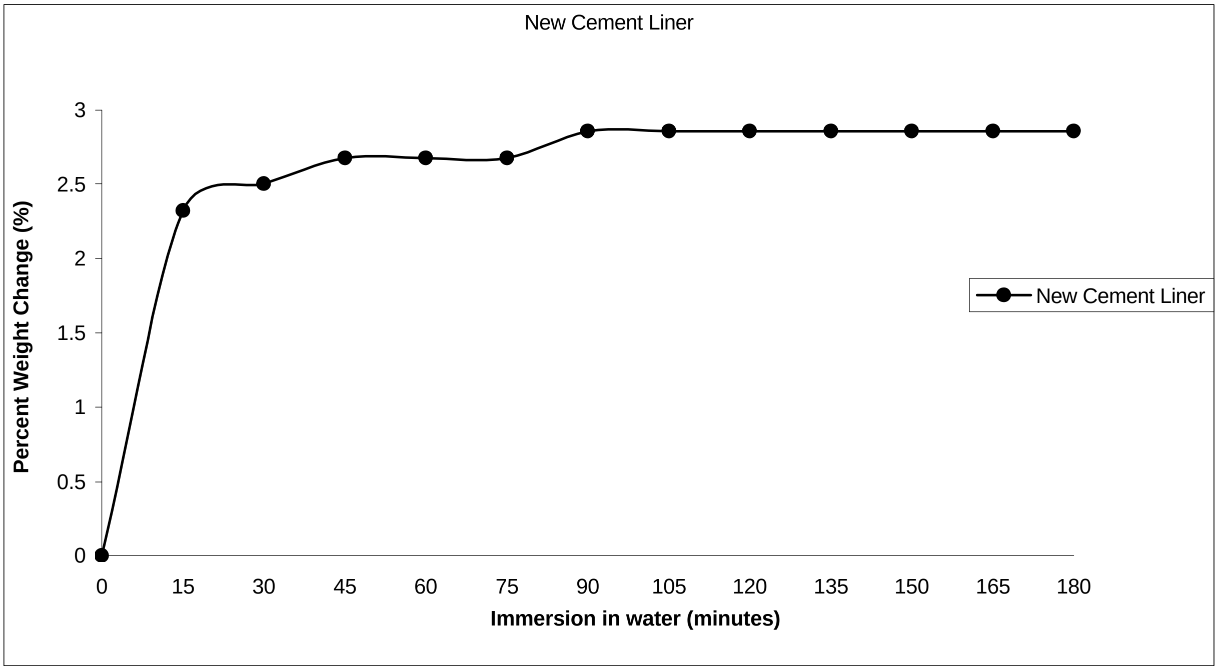

Figure 1. Weight Change with Time During the Immersion Test on New Cement Liner Material

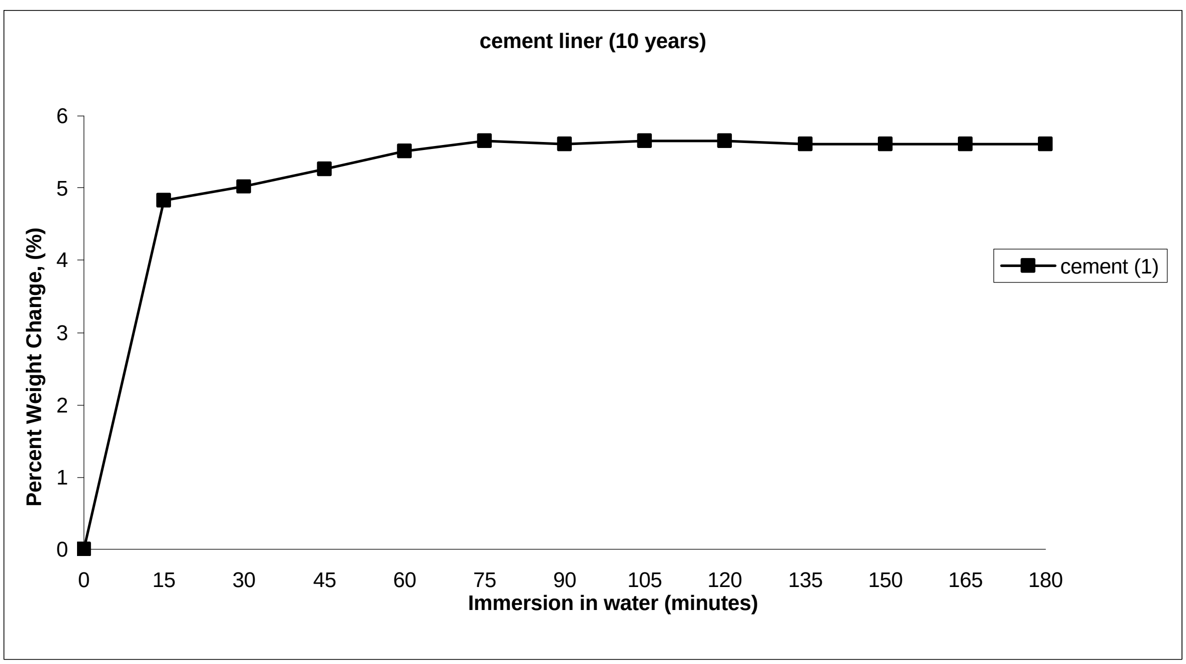

Figure 2. Weight Change with Time During the Immersion Test on 10 Years Old Cement Liner Material

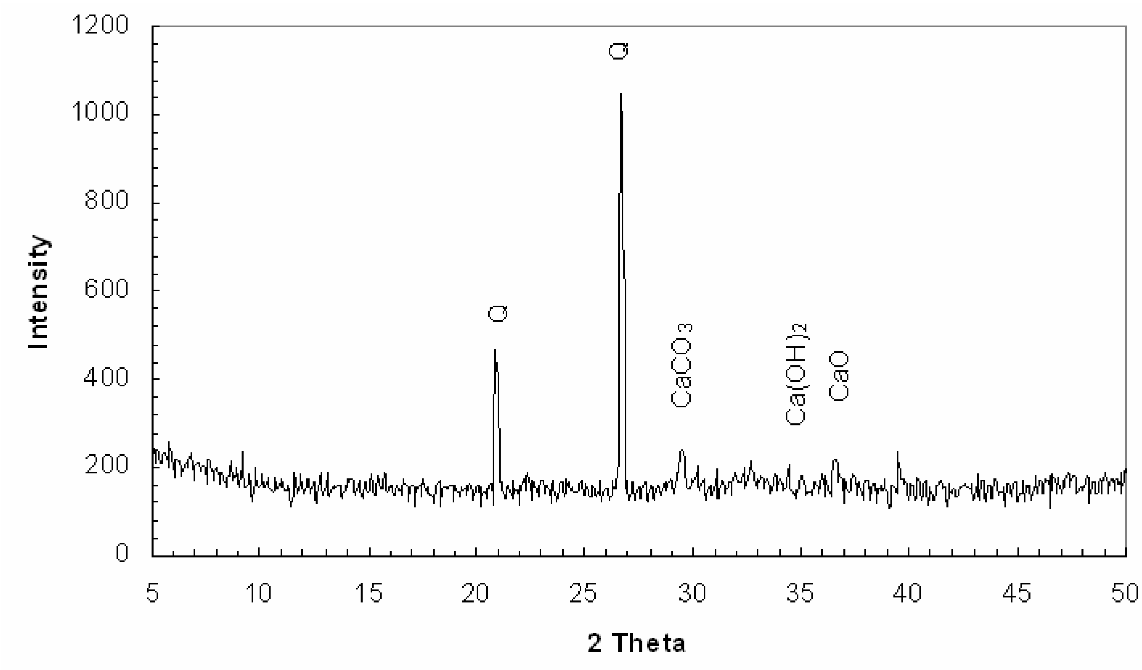

Figure 3. XRD Analysis Results on New Cement Liner Material

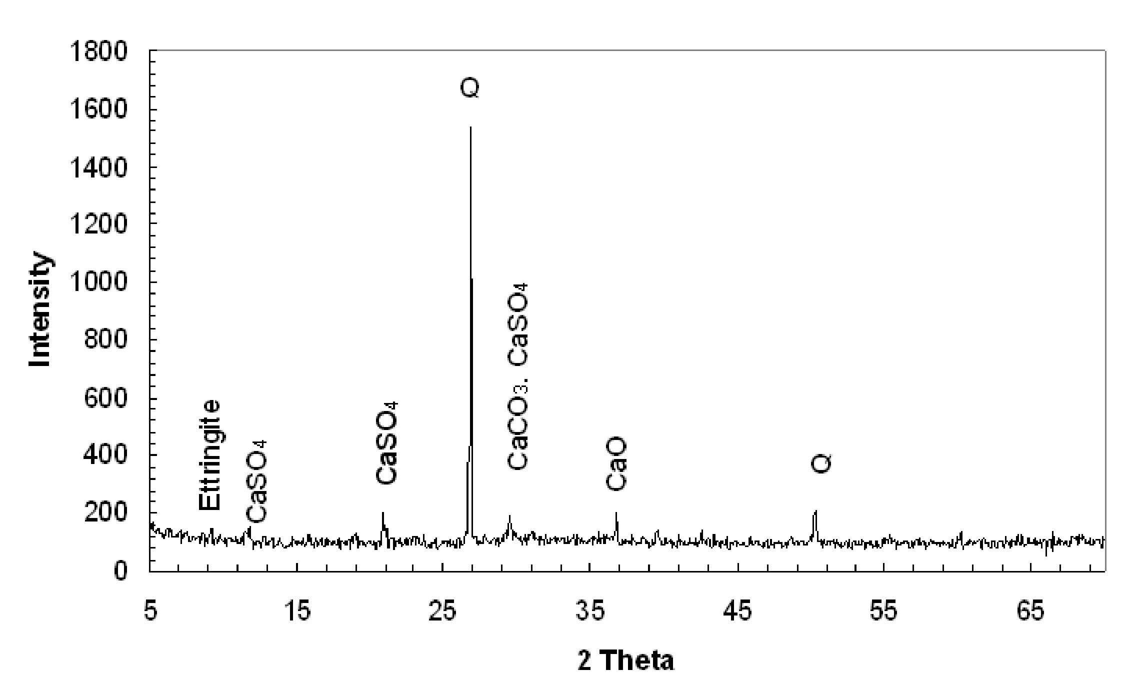

Figure 4. XRD Analysis Results on Five Years Old Cement Liner Material

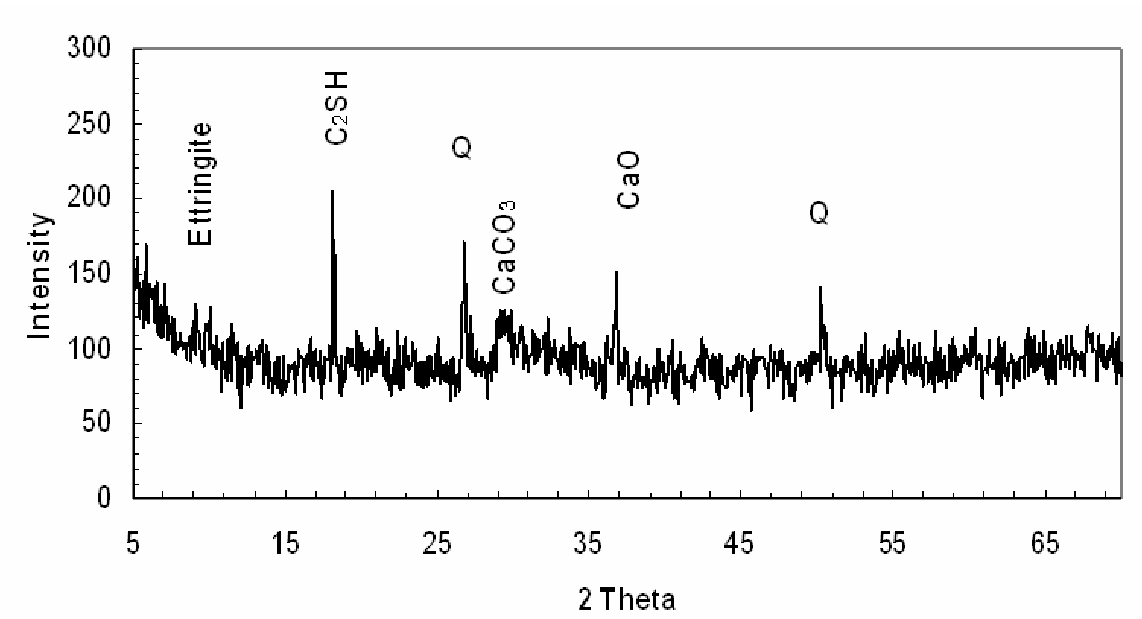

Figure 5. XRD Analysis Results on 10 Year Old Cement Liner Material

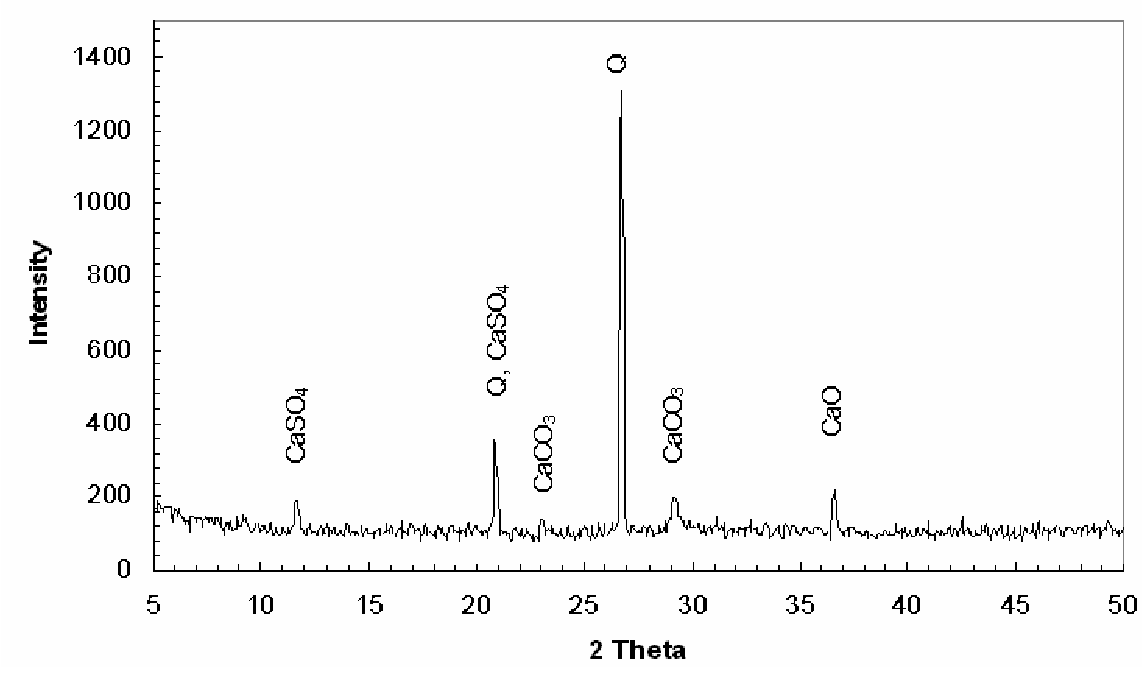

Figure 6. XRD Analysis Results on 15 Year Old Cement Liner Material

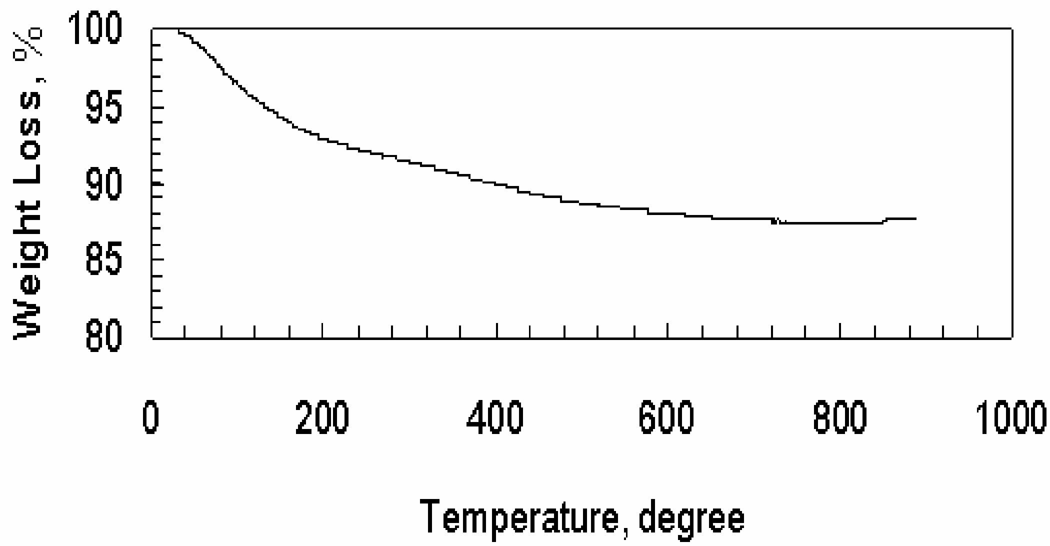

Figure 7. Thermograviometric Analysis on 5 Year Old Cement Liner Material

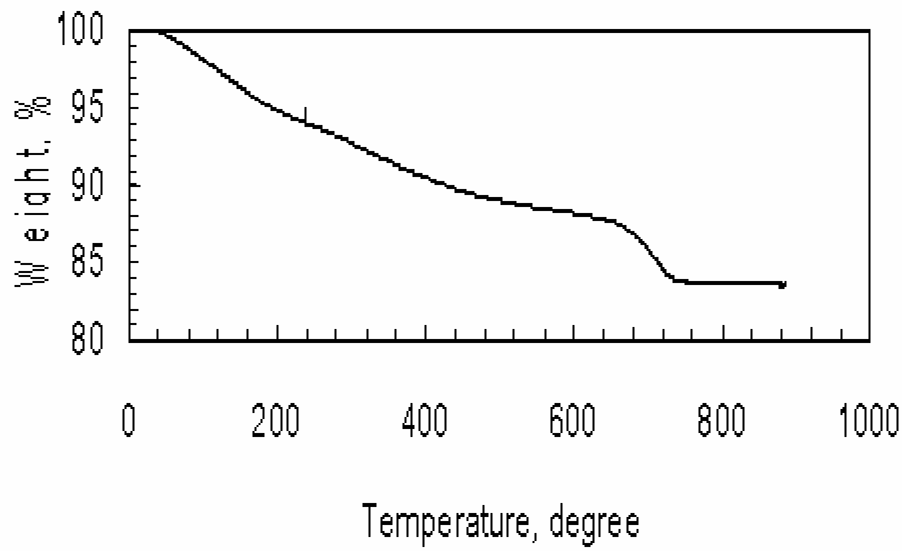

Figure 8. Thermal-gravimetric Analysis on 15 Year Old Cement Liner Material