LONG TERM CORROSION BEHAVIOR OF 304 AND 316 STAINLESS STEEL REPAIR SLEEVES IN MUNICIPAL SEWER LINE SERVICE

Prepared for

Mr. Lembit Maimets, P.Eng.
Link Pipe Inc.
2-27 West Beaver Creek Road
Richmond Hill
Ontario L4B 1M8
Canada

By
Arthur H. Tuthill P. E.
Tuthill Associates Inc.
P.O. Box 204
2903 Wakefield Drive
Blacksburg, VA 24060
Tel: 703-953-2626, Fax: 703-953-2636
September 5, 1996

EXECUTIVE SUMMARY

LONG TERM CORROSION BEHAVIOR OF 304 AND 316 STAINLESS STEEL

GROUTING SLEEVES FOR REPAIR OF MUNICIPAL SEWER LINES

The excellent 25 year plus performance of 304 and 316 in sewage service in municipal waste water treatment plants provides strong support for projecting 100 plus year service life for 304 and 316 repair sleeves in municipal sewage collection systems.

Published data show types 304 and 316 to have more than adequate resistance to general corrosion in the presence of chemical species likely to be present in municipal sewage to justify 100 year plus design life. An exception could occur in a low, stagnant section of the system where sulfuric and sulfurous acid had collected.

MIC, crevice type corrosion beneath adherent pads of sewage, or general pitting from high residual chlorine might lead to some localized corrosion. Such localized corrosion, if it did occur, would be unlikely to affect the structural integrity of the repair sleeves. Localized corrosion of stainless steel is of the pinhole type, not massive general corrosion as occurs with carbon steel and copper base alloys.

In some coastal cities the chloride content of local waters is likely to exceed 1000 ppm and may apprach the 18,000 ppm chloride content of seawater. In these cases, upgrading from 316L to a 6% molybdenum austenitic stainless steel is suggested in order to insure good long term performance in these hight chloride content waters.

REPORT

LONG TERM CORROSION BEHAVIOR OF 304 AND 316 STAINLESS STEEL GROUTING SLEEVES FOR REPAIR OF MUNICIPAL SEWER LINES

ASSIGNMENT:

Evaluate the long term corrosion behavior of types 304 and 316 stainless steel as repair sleeves in municipal sewer piping system environments.

BACKGROUND:

Link-Pipe purchases 18-26 gage cold rolled 304 and 316 stainless steel to ASTM Specifications A267 and A240 from warehouse stock. The sheet is cut to size and punched to form the locking device. The cut to size sheet is deburred and rolled to the required diameter. The outside is covered with an adsorbent gasket. The gasket is filled with a resin that cures in contact with water or moisture once the sleeve is installed. Individual sleeves are 18", 24" and 36" in length. Longer gaps are covered by installing multiple sleeves with an overlap. Link-Pipe has the rights to three patented repair sleeves, Link-Pipe, Snap Lock and the Grouting Sleeve. Each a has mechanically sealed, longitudinal butt joint. Corrosion, when it occurs, is most likely to initiate in this longitudinal joint. Snap-Lock was patented in 1989 and the Grouting sleeve in 1993. Some 12,000 repair sleeves have been placed in service in North America, Europe and the Pacific Rim with no reported corrosion problems to date.

THE ENVIRONMENT:

EXTERNAL: The 1/2" to 3/4" thick grout layer seals and protects the outside from the soil/backfill environment.

INTERNAL: The internal environment is raw municipal sewage in local tap water with other chemical species found in common household waste streams. Most tap waters have less than 1,000 ppm chlorides, although a few coastal locations may have more, in some cases approaching the 18,000 ppm chloride content of seawater. Industrial wastes are increasingly neutralized or handled in separate systems and are not considered separately in this analysis of municipal sewage waste environments. Most sewer piping is designed to handle peak loads of storm discharge and domestic sewage at about 60% of maximum capacity. Under normal flow sewer pipe is only partially filled, i. e. the bottom of the line is exposed to sewage and the upper part to moist vapors and noncondensible gases. Flow is usually gravity flow at 1-3, occasionally as much as 6 feet per second.

MATERIALS:

Sewer piping is vitrified clay, concrete, asbestos cement, cast iron, corrugated galvanized iron, PVC with powdered limestone filler and high density polyethylene. The non metallic materials have no galvanic effect on the stainless steel repair sleeves. The galvanic effect with cast iron and corrugated galvanized steel is discussed under Galvanic Effects.

CHEMICAL SPECIES PRESENT:

ASTM F 1216 "Standard Practice for Rehabilitation of Existing Pipelines and Conduits by Inversion and Curing of a Resin Impregnated Tube", while not addressing stainless steel, does present a list of chemical solutions "that serve as a recommended minimum requirement for the chemical resistant properties" of nonmetallic containment materials in standard domestic sanitary sewer applications. These follow:

Species	Concentration %
Tap water (pH 6-9)	100.0
Nitric acid	5.0
Phosphoric acid	10.0
Sulfuric acid	10.0
Gasoline	100.0
Vegetable oil	100.0
Detergent	0.1
Soap	0.1

In addition to the chemical species listed in ASTM Practice F 1216, other chemical species likely to be present in municipal sewers include:

- Sewage
- Ammonia
- Fruit juices
- Sugar
- Vinegar
- Muriatic acid
- Hydrogen sulfide (from decomposition of sewage)

Many specifications for sewer repair materials simply require the liner material to be able to withstand the attack by chemicals and their byproducts in the sewage. This report will present and evaluate published data on the resistance of stainless steel to each of the chemical species listed above as well as data on localized corrosion in weak electrolytes such as tap water.

CORROSION BEHAVIOR OF 304 AND 316 STAINLESS STEEL

Types 304 and 316 stainless steels derive their excellent resistance to corrosion from a thin, adherent oxide film that forms almost instantaneously in air as the sheet is removed from the pickling bath at the steel mill. This film is very durable and is self-replenishing in aerated media when damaged. This oxide film provides excellent resistance to general corrosion in weak electrolytes at near neutral pHs. Stainless steels are subject to general corrosion in some acidic environments; to general pitting attack in some oxidizing environments; and to localized corrosion in some shielded areas in aqueous environments.

Localized corrosion in shielded areas is termed crevice corrosion and can occur in environments, such as fresh and saline waters, that are not aggressive enough to corrode unshielded areas. Each of these types of corrosion and microbiologically influenced corrosion, which is similar to, but different from, crevice corrosion will be addressed separately.

RESISTANCE TO GENERAL CORROSION

Resistance to general corrosion is assessed from data obtained by laboratory and field exposure to each individual chemical species of interest. These data are compiled by various corrosion authorities in tables, which are unfortunately, not all in the same format. The basic units of corrosion behavior are inches per year, (ipy). Inches per year are calculated by measuring weight loss, converting weight loss to volume and dividing by the total exposed area. Corrosion rates of 0.005-0.010 ipy are usually tolerable for most industrial services where some metal loss from the surface can be tolerated. Corrosion rates of 0.001-0.002 ipy are indicative of excellent resistance. Corrosion rates of 0.0001 or less than 0.0001 ipy are indicative of materials that retain their original surface condition for years.

GENERAL CORROSION RESISTANCE IN SPECIFIC CHEMICAL SPECIES

The data for 304 in Table 1 are from Uhlig's "Corrosion Handbook", 1947. Resistance of 316 is not reported. However, it is well known that the molybdenum content of 316 gives it greater resistance to corrosion than 304 in these environments. Table 1 shows type 304 has a nil corrosion rate in HNO_3, H_3PO_4 and acetic acid (vinegar), fruit juices and sodium hydroxide (soap). Table 2 shows nil corrosion rates for 304 and 316 in detergents, household cleaners and ammonia. Table 3 shows the highest rating, "very good", for resistance to gasoline, sodium hydroxide(soap), cane juice(sugar) and vegetable oils. Table 4 shows 304 and 316 have excellent resistance to hydrogen sulfide, a decomposition product of sewage. The data in Tables 1-4 show types 304 and 316 to have excellent corrosion resistance to all chemical species likely to be present in municipal sewer systems, except sulfuric and muriatic(HCl) acids. Performance for these two chemicals is addressed below.

The corrosion rate for 304 in 10% HCl at room temperature is given as 0.065 ipy and in 10% H_2SO_4 at room temperature as 0.079 ipy. For a specimen fully immersed in these acids for a year, the 0.065 and 0.079" ipy corrosion rates would indicate a short service life and be unacceptable. However, in a sewer system, such high concentrations of these acids seem likely to occur only as short slugs in waste from household drains. If it were possible for a 10% concentration of either acid to exist over a 1 foot length of sewage, the exposure time as this slug passed over the stainless steel repair sleeve would be about one, or at most, two seconds. The number of slugs of acid likely to be encountered in a year is an unknown. Assuming 1000 slugs of these acids might be encountered in a year, this would translate to 10,000 seconds of exposure in any one year. There are 31,536,000 seconds in a year. Therefore, it would take 3,153.6 years for the equivalent of a years exposure to occur. For a thousand discharges each year, the metal loss in a 100 years would be negligible.

There is one worst case scenario where sulfuric acid might accumulate, either from household waste or oxidation of H_2S, in low points in the piping system. If there were concurrently, little or no flow in the low points where acid had accumulated, metal loss and corrosion rates could be significant until increased flow flushed out such stagnant pockets. Assuming the time period between storms when the flow would be sufficient to flush out such pockets, was 30 days, corrosion metal loss might reach 0.006-7" per year if a repair sleeve happened to be in such a location.

CONCLUSION I - Types 304 and 316 can be expected to provide 100-200 year resistance to general corrosion as repair sleeves in municipal sewer piping under normal conditions. If the repair sleeve were to be located in a low point in the system where semi-stagnant conditions and an accumulation of sulfuric or sulfurous acid also accumulated and remained for several weeks or more before being flushed out, metal loss could be significant.

LOCALIZED CORROSION, (CREVICE CORROSION), IN SHIELDED AREAS

Crevice corrosion of stainless steel has been studied intensively over the past 20 years and is reasonably well understood. In pre 1970 literature, crevice corrosion was often referred to as "oxygen concentration cell" corrosion. The corrosion occurred in a shielded, or creviced, area where oxygen was rapidly depleted, surrounded by an oxygen rich area outside the crevice, hence the term "oxygen concentration cell" corrosion. Continuing studies of crevice corrosion revealed very low pHs and high chloride concentrations in the crevices, conditions conducive to corrosion of stainless steel. Oldfield and Sutton have measured the pH and chloride concentrations at which crevice corrosion of stainless steel will initiate. (1)

Oldfield and Sutton found that at a pH of 1.65 and 88,750 ppm chlorides, crevice corrosion would initiate on 304; and at 1.25 pH and 142,000 ppm chlorides, crevice corrosion would initiate on 316 under simulated crevice conditions in the laboratory. Other studies by Kain et al have shown that it is possible for the critical pHs and chloride concentrations to be reached and corrosion to initiate in a small percentage of very tight crevices in low chloride waters.(2)

Kain reports that initiation, when it occurs, occurs only in a small percentage of apparently identical crevices. Table V shows the results of crevice corrosion testing under carefully controlled laboratory conditions in waters of different chloride content. There were 40 identical crevice sites on each specimen.
These data show that for 304, crevice corrosion initiated in < 2% of the sites in waters containing 200 ppm chlorides. These data also show that at 1000 ppm chlorides, the sites initiating ranged from zero to 2.5 to 5 to 12.5%. Based on these tests and field exposures in a wide variety of natural waters reported by Flint(3), it has been generally accepted that crevice corrosion of type 304 is unlikely to occur in waters of less than 200 ppm chlorides and that crevice corrosion of 316 is unlikely to occur in waters of less than 1000 ppm chlorides.

CONCLUSION II - Since most natural waters have considerably less than 200 ppm chlorides, Link-Pipe's selection of 304 stainless steel for the repair sleeve is logical and in accordance with existing data and good practice. Type 316 can, and should, be used for waters with greater than 200 ppm chlorides.

HIGHLY SALINE WATERS

There are some coastal locations where seawater intrudes into the sewage piping. Although 316 does not suffer general corrosion in seawater, and has numerous successful applications in marine environments, the tendency towards crevice corrosion is so enhanced that 316's long term performance in highly saline environments cannot be predicted with any reasonable degree of confidence. When chlorides exceed, 1000 ppm, for most of the time in sewage piping, upgrading to a 6% Mo austenitic stainless steel, such as AL6XN, 254SMO or 1925hMo would be wise.

Table VI shows the relative crevice corrosion resistance of 316L and the higher molybdenum content stainless steels as measured in ASTM's G48 critical crevice corrosion test, CCT, in ferric chloride. Note that there is continued improvement in resistance to crevice corrosion as molybdenum content increases. Up to 4.5 % Mo the increases are small. However, the CCT for 6% Mo is almost double the CCT for the 4.5%Mo alloy. The 6% Mo alloys have been widely, and successfully, used - as piping in seawater Reverse Osmosis units and offshore oil platforms; as condenser tubing in coastal power plants; and in numerous other seawater applications in preference to the 4.5% Mo and other lower Mo content alloys. The lower Mo contend alloys lack full resistance to crevice corrosion in seawater.

CONCLUSION III - For those coastal cities where seawater. or diluted seawater is likely to be found in the sewage piping system, repair sleeves can and should be made of a 6% austenitic stainless steel such as AL6XN, 254SMO and 1925hMo.

GALVANIC CORROSION

Nonmetallics are not good electrical conductors. There is no galvanic corrosion from contact of a nonmetallic piping material with a stainless steel repair sleeve. Although the grout and resin tend to insulate the stainless steel repair sleeve from contact with cast iron and galvanized iron, it would be wise to check the for metal to metal contact between the stainless steel repair sleeve with a resistance ohmmeter when installed in a cast iron or galvanized iron pipe. Even inadvertent metallic contact with cast iron or galvanized iron could lead to substantial galvanic corrosion of cast iron or galvanized iron close to the point of contact.

CONCLUSION IV - The electrical resistance between a stainless steel repair sleeve and either cast iron or galvanized iron should be checked with an ohmmeter after installation, to insure the grout and resin fully protect the stainless steel from any contact with metallic piping.

MICROBIALLY INFLUENCED CORROSION

There is a mechanism by which localized corrosion of 304 and 316 can occur in waters with less than 200 ppm chlorides. Kobrin has authored an excellent summary of Microbially Influenced Corrosion or MIC as it is termed.(4) MIC is most likely to occur in stagnant waters where there are nutrients, and where there are sufficient bacteria of the types that can initiate corrosion of stainless steels. The heat affected zones of welds are preferred locations for MIC, although there are a few instances where MIC has occurred in type 304 and 316 base plate material well away from welds.

The author has encountered one instance of MIC in sewage service. In this instance, MIC occurred at the welds of a type 409 support arm of a rotating biological contactor, (RBC). RBC's rotate slowly at 1-2 RPM per minute into and out of the sewage. Clumps of sewage had clung to the type 409 stainless steel support arms. Multiple MIC formed corrosion nodules were found along the welds of the horizontal support arms. RBCs, though once hailed as a major new development in treatment, have not lived up to expectations and are no longer a factor in municipal waste water treatment.

SEWAGE SERVICE

Municipal sewage systems collect municipal wastes and deliver these to a municipal waste treatment plant. Since the late 1960's, over 1600 municipal waste treatment plants have been built with stainless steel piping in the basin where the incoming sewage from the collection system piping is aerated.(5) Excellent 25 year plus performance is reported for 304 and 316 piping in municipal waste water treatment plants, with the older installations still in service and performing well. A few instances of crevice corrosion in stainless steel piping have been encountered.

Two types of underdeposit crevice corrosion of stainless steel in waste water treatment plant piping were reported. 1) There have been several instances where under deposit crevice corrosion occurred under small hardened pads of sludge on the outside of aeration basin piping that were not dislodged in the normal wash down cleaning operation. 2) There was also one instance of under deposit crevice corrosion in a sludge transfer line where a mechanical joint left a recess in the line where sludge was packed into the recess.

Since the possibility of MIC and underdeposit crevice coronion cannot be completely ruled out, it becomes necessary to consider what the consequences might be. Both MIC and underdeposit crevice corrosion can result in pinhole type pitting and through wall penetration. Weepage through such pinholes could soften the ground and require excavation and an outside wrapper type patch in a worst case scenario, although the grout would certainly moderate weepage after the wall was penetrated. Structural strength of the repair sleeve would not be affected by a few pinhole penetrations, only by massive pinholing over a large enough area to require mechanical reinforcement, as provided by applicable ASME codes. The author has encountered a few cases of "loss of structural integrity" from massive intergranular corrosion and massive stress corrosion cracking of stainless steel, but not from massive pinholing from crevice corrosion.

The 25 plus year good experience with 304 and 316 in waste water treatment plants provides strong support for 100 year plus design life for 304 and 316 repair sleeves in municipal sewage collection systems.

CONCLUSION V - The stainless steel sleeves are quite resistant to MIC as there are no welds, the preferential site for MIC. These sleeves are also quite resistant to underdeposit crevice corrosion as the flow tends to move sewage clumps along.

CONCLUSION VI - There are worst case scenarios where MIC or underdeposit crevice corrosion might lead to pinhole type pitting under unusual conditions. Typical pinhole corrosion that might occur under these worst case scenarios would have very little, if any, effect on structural integrity.

MOIST VAPORS AND NONCONDENSIBLE GASES

The noncondensible gases in the vapor space in sewage piping would include, air, CO_2, H_2S, possibly ammonia and possibly chlorine from tap water. Air, oxygen, is beneficial to performance of stainless steel. The excellent resistance to ammonia and H_2S has been documented above. The "Handbook of Corrosion Data" ASM, Metals Park, Ohio, 1989 reports a nil corrosion rate for 304 and 316 exposed to CO_2 which is supported by long term service experience with these alloys in steam condensate service.

There remains chlorine to consider. Chlorine is added and adjusted at the water treatment plant so that there will be a low residual at the household tap. Chlorine is an oxidizer, which at low concentrations is beneficial, but at high concentrations, may lead to a general pitting type attack in aqueous solutions; and to a general pitting attack in the vapor phase. At 3-5 ppm residual chlorine in potable water treatment plants, type 304 in 12 month plus exposures, base plate was slightly affected, <0.001 ipy, and had 0.004-0.014 thousandths depth of crevice attack on test rack specimens.(6) Type 316 base plate was resistant, but there was 0.001-0.005 depth of crevice attack. The author's experience has been that shower piping in chlorination stage washers suffers general pitting attack in the vapor phase, when the liquid phase contains 50-100 ppm chlorine.

There remains to examine the residual chlorine concentrations that might be carried into the sewage collection piping from the tap water. The residual concentration leaving the treatment plant is normally in the 1-5 ppm range, the higher readings occurring in waters with more oxidizable species that tend to consume residual chlorine before reaching the point of use. Sewage is readily oxidized by chlorine and has a high chlorine demand. It is unlikely that chlorine residuals would persist for any great distance into sewage collection piping. In a worst case scenario, where somehow high residual chlorine concentrations did persist in sewage piping such pitting would not be expected to affect structural integrity until it became massive.

CONCLUSION VII - Chlorine is the only noncondensible that might lead to general pitting in the vapor phase. However, it is most likely that any chlorine residual reaching the waste collection piping would be rapidly consumed by the sewage and other oxidizable species present, minimizing the possibility that high residual chlorine would lead to significant corrosion of 304 or 316 stainless steel repair sleeves.

OVERALL SUMMARY AND CONCLUSIONS

The excellent 25 year plus performance of 304 and 316 in sewage service in municipal waste water treatment plants provides strong support for projecting 100 plus year service life for 304 and 316 repair sleeves in municipal sewage collection systems.

Published data show types 304 and 316 to have more than adequate resistance to general corrosion in the presence of chemical species likely to be present in municipal sewage to justify 100 year plus design life.

There are worst case scenarios that can be projected where mic, crevice type corrosion beneath adherent pads of sewage, or general pitting from high residual chlorine, or general corrosion in low stagnant pockets in the system might lead to some localized corrosion. For such senarios, upgrading the repair sleeve material to a 6% Mo stainless steel would insure the long term performance desired.

TABLES

REFERENCE

1 Oldfield, J. W. and Sutton, W. H., Brit.. Corrosion J. Vol 13(2)

2 Kain, R. M., Tuthill, A. H., and Hoxie, E. C. "The resistance of types 304 and 316 stainless steels to Crevice corrosion in natural waters" J. Materials for Energy Systems, Vol. 5(4) March 1984

3 Flint, N. "Resistance of stainless steel to corrosion in naturally occurring waters" Inco publication 1262, Available from Nickel Development Institute, 214 King Street West, Toronto, Ontario, Canada

4 Kobrin, G. "Microbiologically influenced corrosion" NACE, Houston, Texas, 1993

5 Tuthill, A. H., "Stainless steel in waste water treatment Plants", Water Engineering and Management, July 1990

6 Tuthill, A. H., Stainless steel piping" AWWA Journal, June 1994