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Durability of Polymer-Coated Corrugated Steel Pipe

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ABSTRACT

Corrugated steel pipe has been in use for nearly 90 years. Various coatings have been employed to increase its service life and to provide durability in severe environments. Methods have been developed to precoat the culvert stock with a polymer material, either as a liquid dispersion or as a thermoplastic film applied by lamination, before fabrication. The coating materials selected have proved to be easy and economical to use in the fabrication process and can pass stringent tests and specifications as required by AASHTO and ASTM. Test locations and actual field service installations have established the validity of the concept of coating galvanized culvert stock with polymer material. Actual conditions of use in severe environments, which range from acidic to alkaline soils and effluents, abrasive bedloads, extremes of temperature, and varying conditions of wetting, have demonstrated the durability of polymer-coated steel culvert pipe. In this paper the reasons for the development of the polymer-coated corrugated steel pipe are presented, the manufacturing processes used to make and fabricate the coated sheet and corrugated culvert pipe are described, the tests that the coated material must pass to be acceptable are explained, and data on the actual field performance of installed polymer-coated culverts, which demonstrates its performance in a variety of severe service environments, are presented.

Corrugated steel pipe has been used for drainage applications since 1896. Continuing effort has been made in the years since then to improve the performance of corrugated steel pipe to ensure its durability and efficiency.

In the early 1900s iron and steel culvert sheets were hot-dip galvanized to improve corrosion resistance. Around 1925 the use of an asphalt coating applied over the zinc was developed to reduce corrosion potential. This remained the state of the art until, in the early 1960s, trial installations of culvert pipe made of a chromium grade stainless-steel sheet were placed in highly aggressive acid mine runoff areas in Ohio and Pennsylvania. Coal tar enamel, an effective and often used coating for gas pipelines, was also tried. Results indicated that coal tar enamel and stainless steel can provide extended service life. However, material costs are expensive, often doubling the cost of conventional zinc-coated pipe, and are not necessary for most corrugated steel pipe installations not subject to such severe environments under typical conditions of use. For moderate to severe environments, an asphalt coating over mill-galvanized steel remained the economical choice.

The need for an even better protective system was recognized that would provide enhanced durability and service life. A polymer coating applied under controlled mill conditions would provide such a system. Such a coating would have to be easy and cost effective to apply with consistent high quality. Specific requirements would be good adherance to the zinc surface under a full range of exposure temperatures; good impact properties throughout such a temperature range; good abrasion resistance under a range of typical bedload conditions; superior corrosion protection over the full range and concentrations of acid and alkalai soils and effluents that would be encountered in use; a tough, substantially holiday-free film; immunity to bacterial attack; and be self-extinguishing. Several plastic polymer resins have been developed to fulfill these requirements, and the concept of bonding a polymer coating to the galvanized sheet before pipe fabricating was conceived.

Development of polymer-coated steel began with research laboratory testing of a large variety of polymers to determine their relative suitability for corrosion and abrasion protection for storm sewer, sanitary sewer, and culvert applications. The best coating candidates were then subjected to typical fabrication processes, including corrugating, lock seaming, cutting, punching, and shearing. Only a few survived the severity of such testing. These few were then tested in pilot production runs on commercial coating lines to select the plastic-steel combinations that could be applied to galvanized sheet coils with high reliability.

To further qualify the selected polymers, independent laboratories were employed to design and execute appropriate laboratory tests in consultation with materials engineers from a number of specifying agencies. This laboratory test program, conducted over a wide range of abrasion and corrosion conditions, compared the performance of pipe fabricated from polymer-coated steel sheet with material that used traditional protective systems. Test results indicated that the basic corrosion protection of all the coating materials was good and generally equivalent. The polymer precoated pipe specimens were markedly superior in several respects, including repetitive uniformity of coating, resistance to shipping and handling damage, resistance to freeze-thaw cycles, resistance to atmospheric exposure degradation, and resistance to delamination.

MANUFACTURING PROCESS

There are two basic types of polymer coating. One is a liquid dispersion that is applied by a roll coating process. The other is a self-adhesive thermoplastic film that is applied by lamination. Both types are applied on modern continuous coil coating lines under stringent quality control procedures. The process to apply the coating begins with a coil of galvanized steel sheet conforming to AASHTO specification M 218. The coil is placed on a payoff stand and the sheet is passed through a cleaning station, where both sides are cleaned with a detergent solution from pressure jets. Mechanical scrubbing by rotating brushes follows to remove all grease, oil, loose oxide, and foreign matter to provide uncontaminated wettable surfaces. After rinsing, the sheet enters a pretreatment tank where the surface is chemically treated to improve coating adhesion. The treated surfaces are again rinsed and then chemically neutralized and thoroughly dried. These steps are carefully controlled to ensure the effectiveness of the bond between the coating and substrate. This is particularly important for a galvanized substrate surface.

Next, the sheet contacts a roll coater that applies a primer. The primer is dried and cured in an oven. The primed coil then contacts another roll coater that applies the polymer topcoat. Another oven cures the topcoat. Careful quality control checking of the roller coating process is maintained to ensure a uniform and holiday-free coating across the entire sheet.

The laminated film application process is somewhat different from the roll coating process. The same basic type of continuous facility is used. However, after surface treatment the steel sheet is preheated in an oven and a preformed polymer film is applied with considerable pressure by water-cooled nip rolls. The coated sheet is then air and water quenched and recoiled. In both processes the finished product is labeled in accordance with AASHTO M 246.

SPECIFICATIONS

Use of polymer precoated sheets for storm sewer, sanitary sewer, and culvert installations has been accepted by the issuance of AASHTO specifications M 245, Precoated, Galvanized Steel Culverts and Underdrains; M 246, Precoated Galvanized Steel Sheet for Culverts and Underdrains; and federal specification WW-P-405B, Pipe, Corrugated (Iron or Steel, Zinc Coated).

COATING TESTS

Consistent quality and specification compliance is ensured by comformity with the performance requirements of AASHTO specification M 246.

Section 7.1, Adhesion: This section requires that a coupon with the thicker coating on the outside shall be bent 180 degrees over a 0.5-in.-diameter mandrel without spalling or cracking of the coating. Also, a cut through the polymer coating shall be made across the outside radius without disbonding the coating at the cut.

Section 7.2, Impact: This section requires that on a coupon impacted with a standard impact tester, there shall be no break in the polymer coating at 35 in.-lb of force on a minimum coating thickness of 0.010 in. when tested at approximately 25°C (77°F).

Section 7.3, Thickness of Coating: This section requires a thickness of 0.010 in. (0.25 mm) minimum on the thicker coating, as measured with a dial indicator or micrometer in accordance with ASTM D 1005.

Section 7.4, Holidays: This section requires that the polymer coating on the steel shall be substantially free of holidays when tested with a wet sponge holiday detector.

Section 7.5, Abrasion Resistance: This section requires that the relative abrasion resistance of the polymer coating be determined in accordance with ASTM D 658 by the amount of a specific abrasive required to wear through a unit film thickness of the coating when the abrasive is allowed to impinge on the coating at a uniform rate under the action of a controlled air blast.

Section 7.6, Imperviousness: This section requires that a number of chemical reagents be held in separate confined areas on the precoated sheet for a period of 48 hr, during which time no loosening or separation of the coating from the substrate shall have taken place.

Section 7.7, Freeze-Thaw Cycling Resistance: This section requires that coupons soaked in water for 2 weeks be subjected to an extended period of freeze-thaw cycling, alternately cooled to -18°C (0°F) and immediately immersed in water at room temperature for 100 cycles, without detrimental brittleness, disbonding, or spalling.

Section 7.8, Weatherability: This section requires that coupons of the precoated sheet be subjected to accelerated weathering in a weatherometer with a 2-hr cycle, including 18 min of waterspray and a top temperature of 60°C (140°F). The specimens must withstand 1,000 hr of weathering with no observable deterioration, delamination, or cracking.

Section 7.9, Additional Tests on Polymer Coatings: This section stipulates other standard tests to which the polymer-coated sheet is subjected:

- Water Absorption: A 24-hr water immersion test that determines the relative amount of water absorbed by coatings, in accordance with ASTM D 570.
- Resistance to Microbial Attack: A test, in accordance with ASTM G 22, that determines the effect of bacteria on the properties of coatings, which stipulates no attack (bacterial growth) or degradation of the physical properties.
- Adhesive Peel Strength: A test, in accordance with ASTM D 903, that measures the comparative adhesive bond or peel strength of the coating to the substrate.

Polymer-precoated galvanized stock steel sheet is especially well-suited for fabrication on spiral corrugated, lock-seam pipe mills. Differentially coated coils can be accommodated such that the finished pipe can be fabricated with the thicker coating on either the inside or the outside (soil side) of the pipe to suit site service requirements. The pipe mill machinery forms the coated steel sheet into spiral corrugated, lock-seamed pipe in a continuous operation. The lock-seam provides a strong, secure joint. The finished, continuously formed pipe is cut to stock length with an abrasive saw. The corrugated steel pipe made from a polymer precoated steel sheet can be fabricated into a variety of fittings, elbows, wyes, and tees. It can be perforated, arched, and the ends can be rerolled to accommodate substantially watertight couplings. Any accidental handling damage to the coating is readily repaired in the shop and in the field with compatible touchup materials. The polymer coatings also provide good adhesion for asphalt paving, should such an asphalt paving be desired for flow purposes or for additional protection for extreme slopes and abrasive bedloads.

PRODUCERS

Polymer-coated galvanized steel sheet is supplied by major steel producers under a variety of trade names. The individual coated stock consists of various chemical formulations and colors. Some are Bethlehem Steel Corporation "Beth-Cu-Loy PC" [polyvinyl chloride (PVC) plastisol], brown color; Inland Steel Company "Blac-Klad" (laminated with Dow ethylene-acrylic acid film), black color; National Steel Corporation "Duracoat" (PVC plastisol), gray color; Republic Steel Corporation "PolyCote" (PVC plastisol), brown color; United States Steel Corporation "USS Nexon" (coal-tar-based resin), black color; and Wheeling-Pittsburgh Steel Corporation "PlastiCote" (PVC plastisol), green color.

FIELD TEST AND SERVICE INSTALLATIONS

Field test installations of polymer-coated corrugated steel pipe were begun in late 1969 by steel companies and by state and county agencies in cooperation with the steel companies. Specific sites were selected to provide performance information under the most severe condition--a combination of high corrosion and abrasion. In addition, state and county agencies have used polymer-coated culverts in actual service installations. Periodic inspection of these typical (and atypical) installations, often in comparison with competing polymer-coated culvert installations and competitive culvert materials (galvanized steel, aluminum, and concrete), have indicated good to excellent performance in the severest test conditions.

Coal-Tar-Based Resins

Eleven test installations of coal-tar-based polymer-coated culverts were placed in aggressive locations in Ohio and Pennsylvania. Many were in streams considered mildly corrosive to corrosive, contaminated with considerable acid runoff from coal strip-mining areas, and with varying degrees of abrasion. All installations were full culverts (not short test sections) with spiral lock-seams. Inspections were made over a period of almost 10 years. Results have indicated that these polymer-coated culverts have been unaffected by streams with nearly neutral waters and no highly abrasive bedload. Very low pH waters (pH < 3.0) have caused minor disbondment at cut edges in the coating (which were installed with exposed metal at the cut ends rather than with a field-applied protective coating), but no metal perforation. Abrasive bedloads caused some coating loss at crests of corrugations and at lock-seams, but did not cause disbondment and metal loss in neutral waters. In highly aggressive, low pH waters, disbondment and perforation did occur, but a culvert was still serviceable after 9.5 years at a location (pH 2.7) where plain galvanized culverts were replaced yearly. The data in Table 1 (1) describe the performance of coal-tar-based polymer-coated culverts at various locations.

At Ohio Site 48 (Table 1), a bare galvanized-steel culvert section added on to the polymer-coated section 1 year later perforated in the invert in less than 6 months because of the high corrosivity. A concrete culvert in a nearby stream that contained water of the same pH lost enough concrete to expose the reinforcing steel in the culvert.

Ethylene-Acrylic Acid Film

Service installations have been made of polymer-coated culverts coated with ethylene-acrylic acid film in various locations in the United States. Sites are located in Arkansas, Colorado, Louisiana, Michigan, Montana, and Wisconsin, and the culverts have been in place for periods of from 3 to 9 years in storm drainage locations. The environments have varied from acidic to neutral to alkaline (pH 4.0 to 6.6 to 8.4). Bedloads have been extremely abrasive in certain locations, with large rocks (up to 24 in. diameter) carried through one particular site. Performance of the polymer-coated culverts has been excellent. The severely abrasive bedload at one site caused some nicks and cuts at the crests of corrugations along a 6- to 12-in.-wide path in one culvert, but no signs of rusting were evident (2).

PVC Plastisol

PVC plastisol-coated culvert service installations have been inspected in severely aggressive acid mine effluents and soils characteristic of coal regions in Ohio, Pennsylvania, and West Virginia. All installations consisted of one or more full-length (20-ft) sections of pipe with diameters from 21 to 84 in. in various gauges. Effluents conducted through the culverts ranged from neutral to highly acidic.

The durability performance of these installations with PVC plastisol has been found to be good at all sites. The polymer-coated culverts performed particularly well in aggressive acid mine drainage

TABLE 1 Performance of Coal-Tar-Based Polymer-Coated Corrugated Steel Pipe Culverts at Various Locations *(1)*

Site	Age (years)	Water pH	Flow Conditions: Water Depth[a] (in.)	Flow Conditions: Bedload[b]	Condition of Invert When Inspected: Lock-Seam	Condition of Invert When Inspected: Inlet End	Condition of Invert When Inspected: Outlet End
Ohio							
Site 131	9.5	2.7	2	Considerable amount of stones	Film abraded; disbondment	Disbondment and some metal loss and perforation in invert throughout, but culvert still serviceable	
Site 48	9	2.4	1	Small amount of solids (hard deposit in invert)	No damage visible	Minor disbondment but no metal loss	Inaccessible
Site 1	8	2.3	4	Very little	No damage visible	Minor disbondment and metal loss at first 3 in. from end	Minor disbondment and metal loss at first 1 in. from end
Site 142	8.5	4.0	2	Small amounts of silt and stones	No damage	Disbondment at first 2.5 in.; no metal loss	Disbondment at first 1.5 in.; no metal loss
Pennsylvania							
Site SB	9.67	6.5	3	Considerable amount of stones	Film abraded; minor disbondment	Minor disbondment; no metal loss	Minor disbondment; no metal loss
Site SJ	8.75	6.7	2	Few small stones	No damage visible	Minor disbondment; no metal loss	Inaccessible
Ohio							
Site 660	8	6.8	4	Very little	Minor disbondment at areas of fabrication damage	No disbondment or metal loss	No disbondment or metal loss
Site 665	7	6.3	1	Silt and mud; small amount of abrasives	No damage	No disbondment or metal loss	No disbondment or metal loss
Site 564-11	8	2.6	2	Considerable amount of stones	Lock-seams defective when fabricated	Severe disbondment and metal loss	Inaccessible
Site 145-12	8	2.9	1	Very large stones and sand	Film abraded; disbondment	Severe disbondment and metal loss	Severe disbondment and metal loss
Site 145-13	8	3.5	2	Small amount of silt and stones	Disbondment at areas of fabrication damage	Minor disbondment; no metal loss	Inaccessible

[a]Water depth was observed at the time of inspection (conditions considered normal). Culverts range from 24 to 36 in. in diameter and slopes are estimated to be in the typical 1 to 2 percent range.

[b]Bedload refers to the solid materials (rocks, stones, sand, silt) in the stream bed or inside the culvert.

environments, where effluent pH ranged from less than 3.0 to almost 7.0. The effluent in this acid mine drainage region was found to have high salt mineral concentrations with electrical resistivity as low as 150 ohm-cm. The data in Table 2 (3) summarize the performance of these PVC plastisol-coated culverts at the various locations.

PVC plastisol-coated culverts were installed in New York State on the Genesee Expressway (I-390) in 1977 and 1978. The culverts are located at the bottoms of steep ravines and are fairly steeply pitched. An inspection revealed the culverts to be in good condition after 4 years of service. Numerous nicks, cuts, and gouges into but not through the coatings, suffered shortly after installation as the result of a heavy bedload from a severe storm, have not caused undercutting, loss of adhesion, or rusting as a result of coating damage. After slope stabilizacion, no additional coating damage was observed. Measurements have been made at several positions in the culverts comparing thickness at the sidewalls above the flow line with the thickness at the pipe invert to determine if the coating had sustained any loss because of abrasion. No statistically supportable loss has been found. By contrast, uncoated galvanized aprons and pipe sections are rusting at the invert after only 1 to 2 years of service. The results of the inspection are given in Table 3 (4).

TABLE 2 Field Inspection of Performance of Polymer-Coated Corrugated Steel Pipe *(3)*

Site	Description	Years in Service	Effluent: Type	Effluent: pH	Effluent: Resistivity (ohm-cm)	Bedload	Condition of Pipe
Ohio	Culvert cross drain	9	Acid mine drainage	5.6-6.6	150-200	Minimal	Heavily encrusted with mineral deposit; no effect on plastisol coating
West Virginia							
1	City storm drain	4	Groundwater	Neutral		Minimal	Excellent condition
2	Soil conservation reclamation project	–[a]	Acid mine drainage	5.4	1,320	Minimal	Invert heavily encrusted with mineral deposit after 3 weeks in service; no effect on plastisol coating
Pennsylvania							
1	Coal mine drainage pipe	4	Deep mine acid drainage	3.7	370	Minimal	Excellent condition
2	Coal mine drainage pipe	4	Deep mine acid drainage	3.0-4.0		Minimal	Heavily encrusted with mineral deposit; no effect on plastisol coating
3	Impoundment crossover	3	Impoundment drainage	Neutral		Minimal	Heavily encrusted with mineral deposit; no effect on plastisol coating
4	Slurry pond crossover	4	Impoundment drainage	6.7	400	Minimal	Excellent condition
5	Storm drain system	1	Groundwater	Neutral		Minimal	Excellent condition

[a]New installation.

TABLE 3 Condition of PVC Plastisol-Coated Corrugated Steel Pipe Culverts on Genesee Expressway in New York State After 4 Years of Service (4)

Culvert	Location on I-390 (north of Dansville)	Material[a]	Condition of Culvert
55	Marker 1040; under southbound lane	PVC plastisol CSP, 16 gauge, 42 in. diameter	Some nicks in coating; no undercutting or worsening from 1980 inspection
56	Marker 1040; under northbound lane	PVC plastisol CSP, 16 gauge, 42 in. diameter	Some nicks in coating, particularly at ends of culvert; about 2 x 10-in. area of delamination at edge of pipe at entry; no other failure, and no corrosion; uncoated galvanized apron rusting
90	Marker 1050; service road, west of southbound lane	PVC plastisol CSP (except galvanized at outlet), 48 in. diameter	Occasional nicks in coating; no corrosion or undercutting; uncoated galvanized rusting at invert
91	Marker 1050; under southbound lane	PVC plastisol CSP, 48 in. diameter	Few nicks in coating, small area (1 in. x 2 ft) along lock-seam peeled, no other failure
92	Marker 1050; under northbound lane	PVC plastisol CSP, 48 in. diameter	Some nicks in coating, small area (1 in. x 6 in.) of delamination at edge of pipe at entry; no other undercutting; no corrosion
102	Marker 1052; under southbound lane	PVC plastisol CSP, 30 in. diameter	Few nicks in coating; no undercutting or corrosion
103	Marker 1052; under service road west of southbound lane	PVC plastisol CSP, 42 in. diameter	Few nicks in coating, reroll damage to metal at exit; no undercutting or corrosion
104	Marker 1052; under southbound lane	PVC plastisol CSP, 42 in. diameter	1-in.-wide path of delamination at lock-seam spiraling around one 20-ft pipe length; some nicks in coating; no undercutting or corrosion

[a]CSP = corrugated steel pipe.

SUMMARY

Test conditions and actual field service installations of polymer-coated corrugated steel culvert pipe have established that the concept of combining a nearly inert polymer coating with the proven corrosion resistance of galvanized steel will provide extended life for highway culverts and storm sewer applications. The performance to date in a variety of severe environments--acidic and alkaline soils and effluents, heat and cold, abrasive bedloads, and continuously or intermittently wet conditions--has indicated that polymer-coated corrugated steel pipe can provide the durability, low maintenance, and long service life necessary for economic and engineering value to users.

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