AK Steel

ALUMINIZED STEEL TYPE 2 CORRUGATED STEEL PIPE DURABILITY UPDATE: 1995

FIELD PERFORMANCE OF PIPES IN SERVICE FOR 42-43 YEARS

February 8, 1996

LAWRENCE BEDNAR
SENIOR STAFF CORROSION ENGINEER
PRODUCT RESEARCH
RESEARCH & TECHNOLOGY
AK STEEL CORPORATION

ALUMINIZED STEEL TYPE 2 CORRUGATED STEEL PIPE DURABILITY UPDATE: 1995

FIELD PERFORMANCE OF PIPES IN SERVICE FOR 42-43 YEARS

INTRODUCTION

Increasing durability requirements for drainage pipe in recent years have motivated longer-term field testing to prove the adequacy of different materials. To determine how well ALUMINIZED STEEL Type 2 meets increasing durability demands, AK Steel Research undertook a program of updating the performance trends of riveted pipe installed in 1952-1953 by highway departments at culvert sites in several states. These were evaluated comprehensively in 1982-1983 at about 30 years of age.[(1)] The pipe sites encompass a wide variety of environmental conditions in climates ranging from very wet to very dry. In the studies on 30-year-old pipes, extrapolation to 50-year performance was undertaken with a high degree of confidence, and pipe condition at the present 42- to 43-year age level shows that this confidence was fully justified. Pipe condition at the present age level provides a new index for extrapolation of performance to times well beyond 50 years. Extrapolation of performance to 75 years is undertaken now with a high degree of confidence.

Also included in the survey were a number of 10 - 15-year-old pipes produced with the improved aluminized coating technology introduced in 1977. While these pipes showed no evidence of any limitations on service life, no attempt was made to use them in projecting 75-year performance.

In each state, D.O.T. personnel and personnel from other government agencies and from private agencies were invited to participate in the site surveys, and some were present at most of the sites (see listing on page 9).

FIELD EVALUATION DETAILS IN THE PRESENT STUDY

The number of riveted pipe sites surveyed was 34, and the states included were Iowa, Illinois, Missouri, Mississippi, Texas, Kansas, Oklahoma, Colorado, New Mexico, California and Washington. Certain aluminized/galvanized tandem-section pipes were not available for inspection because they have been removed since the last inspection about 13 years ago due to deterioration of the galvanized half. This was particularly a problem in Missouri where several Type 2 pipe sections were removed that were known to be, or in some cases believed to be, in very good condition. In Oklahoma, several sites were inaccessible due to complete submergence in a new man-made Corps of Engineers lake. Certain pipes included in the survey 13 years ago were not inspected again due to a coating quality abnormality (discussed on page 4). Also, certain pipes exposed to environmental extremes of severe abrasion or pH/resistivity environmental parameters well outside the recommended limits (5-9 & ≥ 1500 ohm x cm) were not reinspected. These pipes already showed advanced deterioration in the 1982-1983 inspection as expected, and further study would serve no purpose. One pipe in California was removed due to deterioration by severe abrasion.

At each site evaluated, metal corings were taken from pipe inverts in areas representative of any corrosion that occurred in order that a more detailed evaluation of coating condition and pit penetration might be accomplished. Galvanized pipes were included in the riveted pipe evaluations except at certain sites where they were unavailable or inaccessible (Green Co., IL; San Juan Co., WA; Fairplay Co., CO; Benton Co., MS; Oklahoma Co., OK - one site; and Montgomery Co., TX - the Texas site had a 23-year-old galvanized culvert about 100 yards away on the same roadway available for comparison). For the sites with post-1977 aluminized pipes, galvanized pipes or galvanized end sections were available for comparison in most cases.

Native soil specimens were obtained from each site, as were groundwater specimens wherever these were available, groundwater being of lower resistivity than surface run-off.

Among the post-1977 pipes, a total of 24 were surveyed, and corings were taken from some. These were located in relatively wet environments in the states of Maine, Oregon, Washington, Louisiana, Maryland, Georgia and South Carolina. They were located from studies of others[2, 3] and from supplier sales records.

BACKGROUND ON ALUMINIZED COATING PROTECTION

The manner in which the aluminized coating imparts longevity to steel pipe has been expounded in the past but bears repeating.

The passive nature of the overlying aluminum layer of the coating assures a low consumption rate in typical environments. This has again been demonstrated in the present survey, pipes typically showing most of the original aluminum layer thickness remaining outside pit locations even after 42-43 years (see Figure 1). Typically, the aluminum layer will eventually be penetrated by tiny scattered pits to expose the underlying coating Al-Fe intermetallic alloy layer which is also passive and very corrosion resistant. Pits encountering the alloy show propagation that is deflected in the lateral direction until sizable areas of alloy are exposed. The alloy is very hard, and normally contains tiny fissures at which the substrate is exposed, but these plug quickly with reaction product upon initial exposure so that subsequent corrosion of the substrate is greatly retarded for a considerable time. Thus the plugged alloy presents a durable second line of defense against corrosion propagation. The alloy is also abrasion resistant, and while substantially abrasive conditions may cause premature removal of the aluminum coating layer, the combined corrosion/abrasion resistance of the alloy provides good pipe longevity under moderate abrasive conditions. Both the aluminum and the alloy layers contribute to erosion protection, erosion being the acceleration of steel corrosion that occurs as a consequence of scouring of the surface by rapid or turbulent water (sometimes called erosion corrosion). Of course erosion/abrasion effects are associated with surface run-off during heavy rainfall, and the aluminized coating confers very enhanced resistance to all surface run-off except that accompanied by severe abrasion.

In the normal course of service, pitting of the material does eventually occur since substrate corrosion at cracks in the alloy eventually begins to progress. While the alloy itself shows very little deterioration, it is eventually undermined and spalled locally by substrate corrosion at alloy micro cracks. This eventually exposes a visible area of substrate at which a tiny pit cavity begins to form. Pit cavity propagation is slow (except in excessively severe environments) for reasons which must be determined under actual long-term field conditions, laboratory testing being of little value in this regard. The mechanism of retardation of substrate pit growth that has been deduced from field observations is one involving partial electrochemical protection by low-level galvanic activity and partial barrier protection due to some enhancement of adherence of substrate corrosion-product scale. Increased adherence of corrosion-product scale is likely associated with galvanic activity, there being some limited tendency toward formation of a more adherent and more protective Fe_3O_4 scale in preference to the normal less-protective hydrated Fe_2O_3 scale. This is probably associated with cathodic reduction of substrate corrosion product arising from galvanic activity. There would also be a degree of pitting sluggishness in any normal environment due to retardation of the anodic reaction in a pit cavity arising from an inability of surrounding oxide-filmed aluminum and exposed passive alloy layer surfaces to act as a cathode necessary to support the anodic reaction. The aluminum layer is particularly ineffective as a cathode to support pitting since it functions as a galvanic anode and thus tends to retard pitting galvanically. The pitting corrosion reaction would thus be somewhat hindered as a consequence of there being no very effective sizable cathodic surface needed to support the anodic corrosion reaction in the pit cavity.

The 1982-1983 study showed that the hard alloy layer of the coating on the 1952-1953 material (early production line quality) occasionally gave rise to severe cracking, especially lateral cracking, that compromised coating adherence and protective quality on corrugation crests and valleys. Most of the time, even with relatively severe cracking, pipe durability was very good. But there were a few abnormally severe cases where it accelerated pitting enough to shorten service life somewhat and a few extreme cases where it caused coating delamination and failure in service. This type of problem was brought under control with the coating technology improvement of 1977. This was important for waterside pipe surfaces where corrosion at alloy layer cracks might be accentuated in relatively severe environments if cracking was too severe to permit the normal plugging tendency.

RESULTS OF PRESENT STUDY

Pipe Condition

ALUMINIZED STEEL Type 2 pipe showed only minor deterioration at all sites surveyed, except for a few with resistivities well below the 1500 ohm x cm lower limit normally recommended. At typical sites, Type 2 showed a range of minor pitting. Among typical sites, pitting was sometimes very minimal, amounting to just scattered localized penetrations of the aluminum layer of the coating and consequent exposure of the Al-Fe intermetallic alloy coating layer (see Figure 2). At other typical sites, small scattered pits extending into the steel substrate to a degree were observed (see Figure 3). Propagation of pitting in the steel substrate is quite slow in normal environments, judging by comparison of approximate pit depths now and 13 years ago (see enclosed table). It is somewhat difficult to determine pitting progress since the earlier inspection because pitting is scattered and varies in severity with pipe location. Thus pitting on specimens at one pipe location can be significantly different from that at another. Indeed in one extreme case at Snohomish Co., WA, the latest corings did not encompass the soilside pitting observed 13 years ago. However, the overall comparison of pit depths now with those determined 13 years ago indicates that pitting progress overall for the last 13 years has been quite slow. For all sites involving normal environments, perforation at pits would appear to be a very long-term event. Pipe function and structural stability would not be significantly affected when perforation at such pits does occur eventually since pits are typically quite small as Figure 3 illustrates. Two sites (one in DeSoto Co., MS, and one in Lafayette Co., MO) show larger pits than is typical due to some effect of the previously noted excessive alloy-cracking problem associated with older production methods, but this pitting, too, was not indicative of functional or structural problems in the foreseeable future.

Figures 3-6 illustrate, for those site environments that were most severe for galvanized, the typical comparative condition of Type 2 and galvanized steel. The most widespread severe problem for galvanized steel pipe in the study and throughout the nation as a whole, as various studies have shown[2, 3, 4, 5], is soft and slightly acidic groundwater or surface run-off. At sites with such run-off, the survey results indicate that a very large advantage of the Type 2 material over galvanized will be realized. In milder environments, very long exposure times are required to verify the degree of Type 2 aluminized superiority, but trends indicate that the degree of superiority drops somewhat as galvanized behavior improves notably so that both materials give good longer-term life (see Figure 7). In milder environments where galvanized service life is projected to be 50+ years, Type 2 aluminized service life should clearly be far in excess of 75 years (at 16 gage). In overly severe environments too far outside the recommended environmental limits of pH or resistivity (pH 5-9 and resistivity ≥ 1500 ohm x cm), past studies have shown that superiority may be minimal with neither material performing satisfactorily[(4)].

Studies of others have shown the superiority of Type 2 aluminized abrasion resistance[(5)], and in our present survey as in our past one, we identified certain sites that demonstrated the Type 2 superior abrasion/erosion performance over that of galvanized steel (see Figures 8-9).

The superior performance of post-1977 Type 2 aluminized steel is illustrated in Figures 10-14. These pipes showed no evidence of limitations on service life in normal environments. One pipe requiring a little further study showed small pits extending into the substrate somewhat.

Service Life Projection

The conservative projections of 30-year riveted pipe condition to 50-year performance in earlier studies have now been fully justified in the observed condition of 42- to 43-year-old pipes quite close to the 50-year age level. All pipes evaluated in this study that were previously projected to provide a 50-year minimum life at 16 gage are now seen to be on the verge of exceeding this projected performance to a considerable degree, including some that are exposed at pH/resistivity levels somewhat outside the recommended limits. With this conservative extrapolation having been shown to be valid, accurate conservative extrapolation from the 42- to 43-year condition to the 75-year level now seems quite assured. Actually, in most cases coating condition is indicative of service life well beyond 75 years. A few that were subject to a significant degree of abrasion or coating quality interference would perhaps more realistically have projected service lives in the 50- to 75-year range.

Such results suggest ALUMINIZED STEEL Type 2 pipe as a potential replacement for asphalt coated and paved galvanized in the many normal pipe environments where pavement is utilized only to improve longevity of galvanized.

CONCLUSIONS

1. The performance of ALUMINIZED STEEL Type 2 at highway culvert sites over a variety of environmental conditions for exposure times of 42-43 years is indicative of projected service life of 75 years minimum at 16 gage in normal environments. Projections are based on extension of a demonstrated accurate extrapolation used to project 50-year performance on the basis of 30-year pipe condition in earlier studies. Our projection method is very conservative and thus does not permit accurate estimation beyond 75 years, but in most cases coating condition is indicative of service life well beyond 75 years.
2. The superiority of ALUMINIZED STEEL Type 2 over galvanized steel in the most prevalent environments troublesome for galvanized can now be seen to be very large. This observation is supportive of the use of Type 2 for resolution of the most prevalent galvanized corrosion problems.

REFERENCES

1. G. E. Morris and L. Bednar, "Comprehensive Evaluation of ALUMINIZED STEEL Type 2 Pipe Field Performance," Transportation Research Record 1001, TRB, Washington, DC, 1984.
2. FHWA Report, FHWA-FLP-91-006. "Durability of Special Coatings for Corrugated Steel Pipe," USDOT, Washington, DC, June 1991.
3. M. D. Alley, "Culvert Study - Interim Report, Experimental Construction 73A," Maine DOT, Tech. Services Div. - Research and Dev. Section, November 1987.

4. L. Bednar, “Updated Environmental Limits for ALUMINIZED STEEL Type 2 Pipe Application,” Transportation Research Record 1393, TRB, Washington, DC, 19935.
5. R. M. Psykadlo and J. P. Ewing, “Coatings for Corrugated Steel Pipe.” Special Report #90 - Research Project 154-1. Engineering Research and Development Bureau, NYDOT, Albany, NY, September 1987.

DOT OBSERVERS AND OTHERS AT SURVEY SITES IN THEIR STATES

1.	California DOT	Deane M. Coats, Assoc. Transportation Engineer Timothy Kennelly, Transportation Engineer Mike Wagner, Materials & Research Engineer
	Sacramento State University	Dr. Les Gabriel, Prof. Emeritus
2.	Georgia DOT	James F. Gaskill, Asst. Materials & Research Engineer Don Wishon, Branch Chief, Physical & Chemical Testing Brad Young, Transportation Engineer
3.	Illinois DOT	H. Byron Nesbitt, Physical Tests Coordinator
4.	Louisiana DOT	Douglas Westley, Engineering Specialist
5.	Maine DOT	Victor Smith, Asst. Engineer
6.	Maryland COE HQ Washington, DC	Greg Hughes, P.E.
7.	Mississippi DOT	Glynn Gatlin, P.E., Constructions Applications Engineer
8.	Missouri DOT	John A. Masek, District Materials Engineer James R. Smith, Materials Research Asst. Dave Amos, Field Testing Tech.
9.	South Carolina DOT	Bobby Clair, District Construction Engineer Jim Frick
	Columbia, SC	Furman Gilmore, Street & Storm Drain Supervisor
	Berkeley Co.	Gary Southerland, PW
	Davis & Floyd Engineering	Pamela Fusonie
	Davis & Floyd Engineering	Michael Horton
10.	Washington DOT	Robert Christopher, Hydraulic Engineer

<u>Performance Table</u>

Degree of Corrosion Penetration on ALUMINIZED STEEL
Type 2 and Galvanized Steel Culvert Pipe

<u>Table Notes</u>

A. On Aluminized Type 2, penetration takes the form of very small, scattered pits, and corrosion progress is best reported in the form of pit depth on each surface separately, waterside (W) and soilside (S). Outside the pits, the Type 2 surface is essentially unaffected, material thickness reflecting essentially the original gage, and one thickness value serves to illustrate the specimen thickness outside pits.

B. On galvanized steel, penetration usually takes the form of non-uniform general corrosion that usually advances most rapidly from the waterside, but sometimes significantly from the soilside. Corrosion progress is best reported in terms of remaining thickness, including minimum thickness and overall thickness for both sides together. It is necessary usually to report overall thickness as a range to denote the extremes of non-uniform penetration. The extent of the range illustrates the degree of non-uniformity of attack, and pitting corrosion is indicated when the lower value of the range is considerably greater than the value for the minimum remaining thickness.

C. Some variability in groundwater and soil pH and resistivity values between some sites sampled 13 years ago and those sampled recently is most likely due in part to differences in weather between the two field surveys, the most extreme values being achieved in the driest weather.

1952/1953 ALUMINIZED STEEL TYPE 2 MATERIAL
42-43 YEARS OLD

							Aluminized T2				Galvanized	
State & County				Pipe Gage	pH	Minimum Resistivity (ohm x cm)	Maximum Pit Depth (mils) 1982	Maximum Pit Depth (mils) 1995	Pres. Gen. Thick & Est. 16 Ga. Life (mils)	(Yrs.)	Remaining Minimum Thickness (mils) 1995	Remaining Overall Thickness (mils)
1.	**W**	IL	Morgan	12	7.0	1600	2	1	111	>75	0	20 - 50
	S				6.6	5705	1	1				
2.	**W**	IL	Morgan	12	6.6	1510	1	1	111	>75	95	102 - 105
	S				7.5	3005	1	1				
3.	**W**	IL	Sangamon	12	-	-	2	5	112	>75	0	Widely
	S				6.9	2402	1	1				Perforated
4.	**W**	IL	Greene	12	7.8	670	2	6	114	>75	-	-
	S				7.3	3860	2	3				
5.	**W**	MO	Lafayette	14	6.9	770	1	5	80	>75	0	Widely
	S				6.1	4004	1	6				Perforated
6.	**W**	MO	Lafayette	12	7.4	1930	13	41	110	$\sim 75^{+}$	0	Widely
	S				6.2	4290	1	5				Perforated
7.	**W**	MO	Livingston	14	-	-	6	4	79	>75	0	Widely
	S				7.6	2574	1	1				Perforated 1982
8.	**W**	MO	Nodaway	12	7.1	1086	7	7	114	>75	74	85 - 96
	S				7.3	2290	4	10				
9.	**W**	MO	Carter	12	-	-	1	1	111	>75	41	83 - 100
	S				7.8	4147	1	1				
10.	**W**	MO	Carter	14	6.7	4167	5	11	80	50-75*	0	18 - 58
	S				6.5	3432	1	2				
11.	**W**	IA	Marshall	12	-	-	1	4	119	>75	0	52 - 90
	S				6.7	3150	1	6				
12.	**W**	IA	Marshall	12	-	-	1	1	110	>75	104	105 - 108
	S				7.5	2360	1	1				
13.	**W**	IA	Marshall	12	-	-	1	3	112	>75	59	72 - 97
	S				7.0	4290	1	8				
14.	**W**	IA	Marshall	12	-	-	1	1	115	>75	83	85 - 98
	S				6.9	3720	1	1				
15.	**W**	IA	Marshall	12	-	-	1	4	111	>75	29	38 - 8
	S				7.6	2860	1	1				
16.	**W**	IA	Marshall	12	-	-	1	2	114	>75	82	88 - 98
	S				6.7	3720	1	4				
17.	**W**	KS	Dickinson	12	7.8	770	$-^{x}$	5^{x}	110	>75	27	38 - 75
	S				5.4	7436	2	10				
18.	**W**	KS	Pratt	14	7.5	2175	4	3	81	>75	45	52 - 73
	S				5.3	5860	1	8				
19.	**W**	KS	Decatur	12	7.3	4545	1	2	108	>75	97	100 - 104
	S				7.0	1716	2	4				

						Aluminized T2				Galvanized	
		State & County	**Pipe Gage**	**pH**	**Minimum Resistivity** (ohm x cm)	**Maximum Pit Depth** (mils) 1982	1995	**Pres. Gen. Thick & Est. 16 Ga. Life** (mils)	(Yrs.)	**Remaining Minimum Thickness** (mils) 1995	**Remaining Overall Thickness** (mils)
20.	**W**	OK Oklahoma	14	-	-	1	1	80	>75	35	65 - 74
	S			6.7	6864	1	1				
21.	**W**	OK Oklahoma	14	-	-	1	1	79	>75	Inaccessible	
	S			7.9	6860	4	9				
22.	**W**	MS Benton	16	-	-	1	1	63	>75	-	-
	S			4.75	9940	1	1				
23.	**W**	MS DeSoto	14	4.85	17,240	5	35	78	50-75+	0	Invert
	S			5.80	6016	1	17				Destroyed
24.	**W**	MS Tate	14	5.20	14,290	3	5	80	>75	0	Widely
	S			6.05	33,460	1	1				Perforated
25.	**W**	CA El Dorado	16	-	-	1	1	65	>75	57	59 - 63
	S			6.7	11,580	3	5				
26.	**W**	CA San Benito	14	-	-	3	5	80	>75	0	35 - 73
	S			5.7	5720	1	2				
27.	**W**	WA Snohomish	14	6.6	2083	8	2	84	>75	0 (1981)∇	Widely
	S			5.1	10,010	22	2				Perforated 1981∇
28.	**W**	WA San Juan	14	-	-	-	7	64	>75	-	-
	S			5.8	12,870	-	7				
29.	**W**	WA San Juan	16	-	-	-	7	64	>75	-	-
	S			6.1	5290	-	7				
30.	**W**	WA San Juan	16	-	-	16	29	64	>75	-	-
	S			5.9	8580	16	27				
31.	**W**	WA San Juan	16	-	-	16	32	64	>75	-	-
	S			5.9	8580	9	20				
32.	**W**	TX Montgomery	12	6.0	5550	8	12	106	>75	0	Invert
	S			7.8	4720	16	18				Destroyed ◊
33.	**W**	NM Bernalillo	14	-	-	1	1	80	>75	59	70 - 78
	S			8.1	8580	1	1				
34.	**W**	CO Fairplay	16	-	-	1	3	64	>75	-	-
	S			7.2	10,580	8	3				

W = waterside, **S** = soilside

x Due to abrasion rather than pitting.

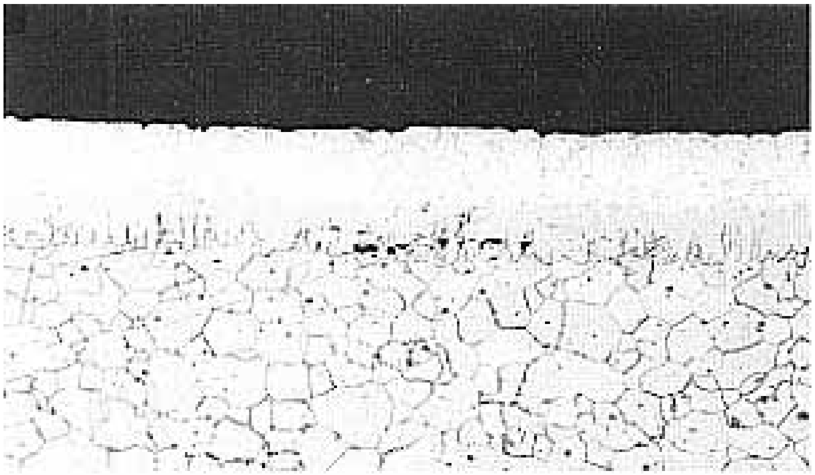
* Relatively severe abrasion at this site.

\+ Somewhat excessive alloy layer cracking in pipe manufacture has accelerated pitting corrosion abnormally.

◊ Galvanized 14 gage.

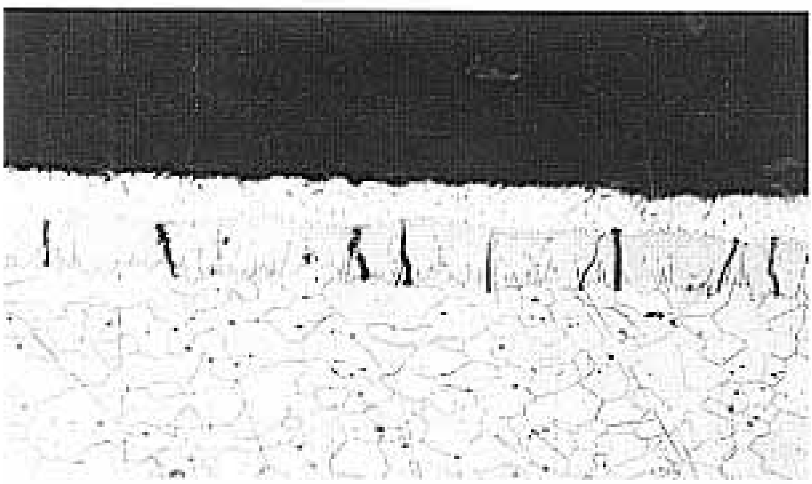
∇ D.O.T. replaced with Type 2 Aluminized in 1981.

Figure 1A: Aluminum layer of coating outside pits appears to be essentially undiminished in thickness after 42-43 years. Variation from one pipe location to another and from pipe to pipe appears to be due to known large variation in original thickness characteristic of early production practice. (Mag. = 200X)



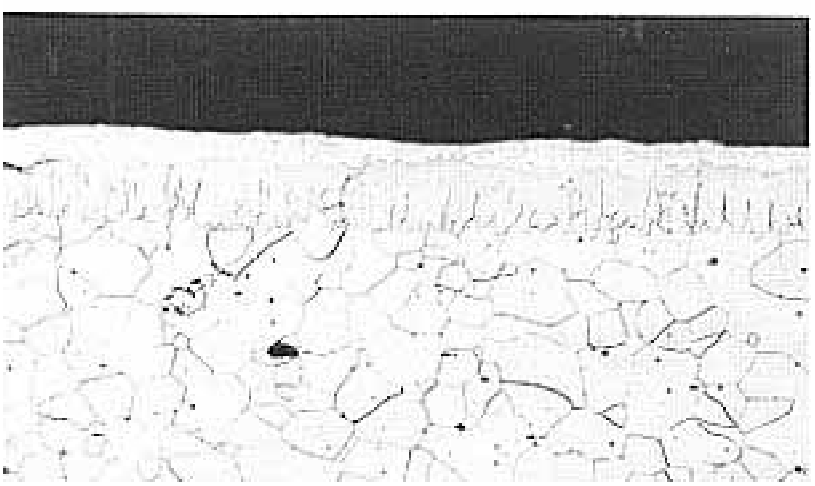
Morgan County, IL
Invert - Waterside

Thickness of aluminum layer outside pits undiminished significantly from original.



Lafayette County, MO
Invert - Soilside

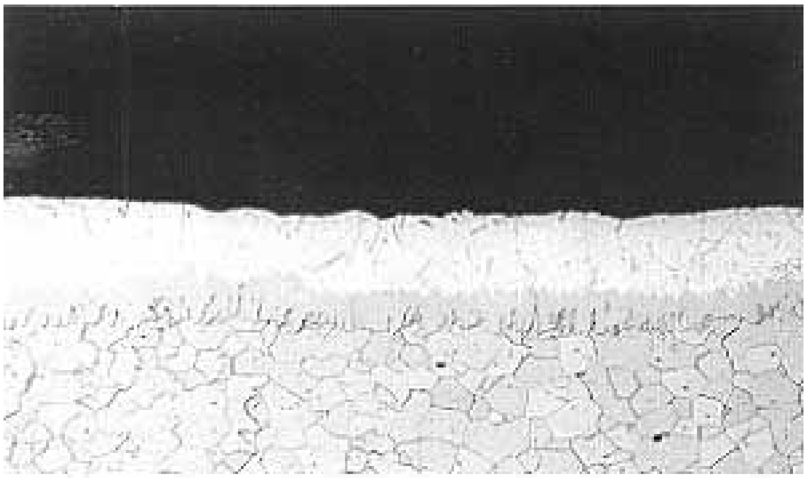
With highly variable thickness characteristic of early production practice, this is likely original aluminum layer thickness essentially. There is no general attack of aluminum layer that suggests otherwise.



Montgomery County, TX
Invert - Waterside

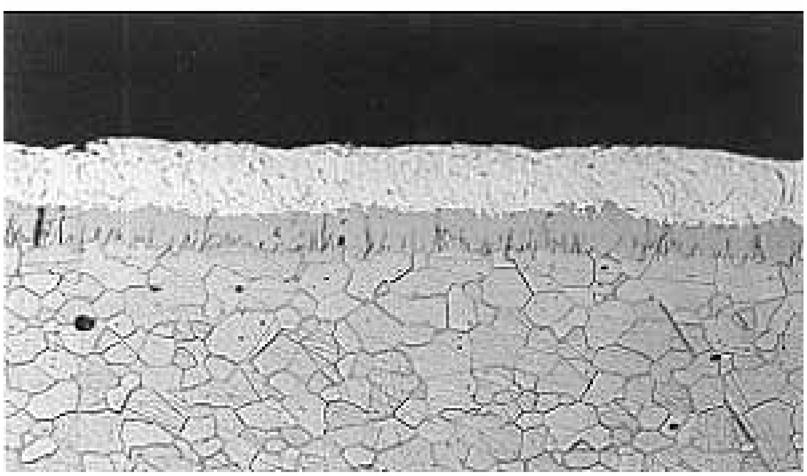
Thinnest Al layer thickness observed - appears to be original undiminished thickness since no surface attack is seen.

<u>Figure 1B:</u> **Post-1977 product shows no evidence of aluminum layer deterioration outside incipient pits in the layer after 10 to 15 years in service. Variation in aluminum layer thickness was much better controlled after the 1977 coating technology improvements, but higher than typical thickness is observed on occasion. (Mag. = 200X)**



<u>Snohomish County, WA</u>
Invert - Waterside

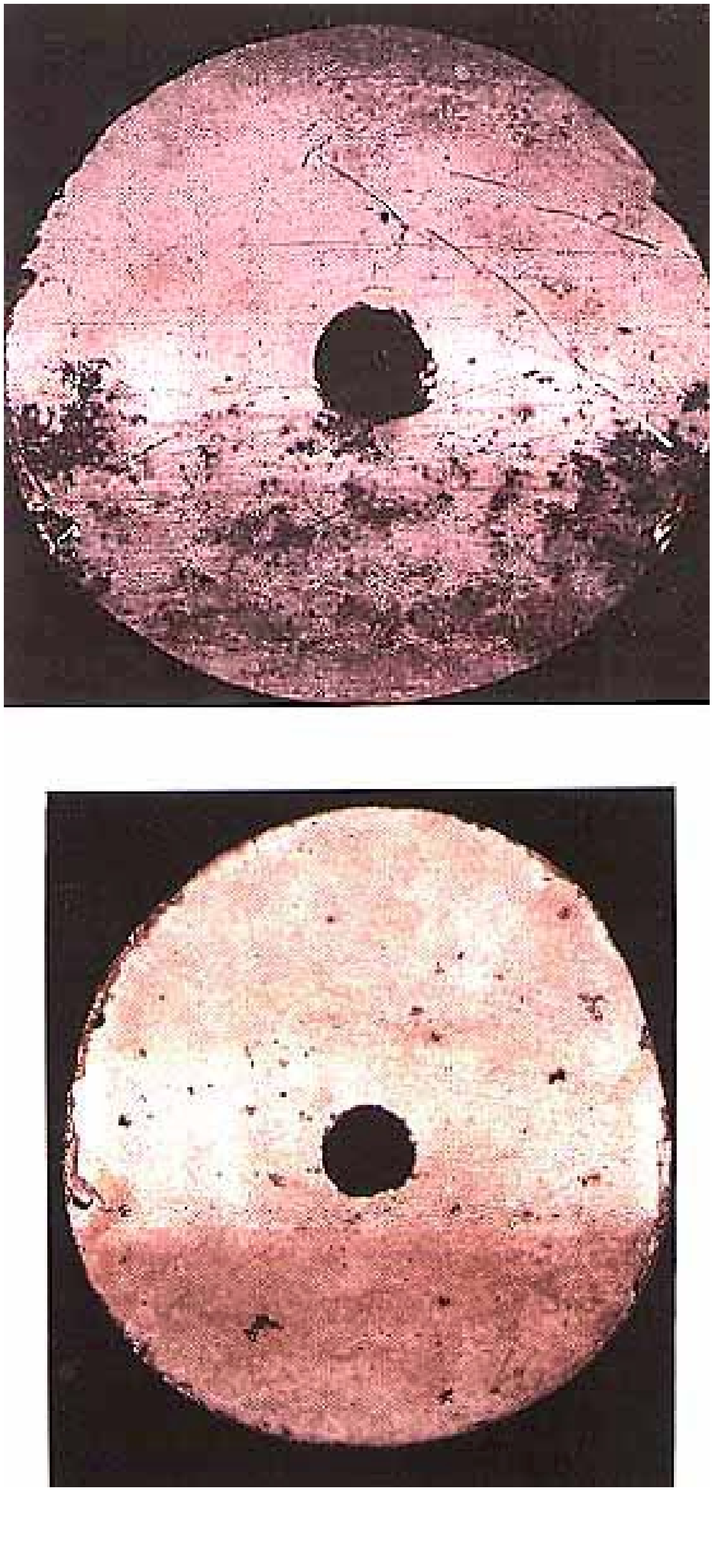
14-year-old material

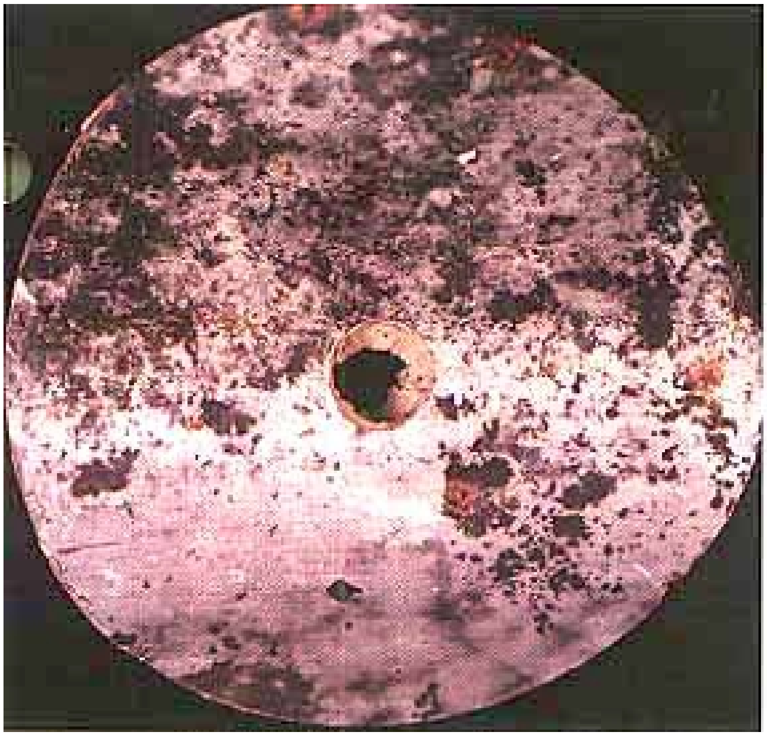


<u>Penobscot County, ME</u>
Invert - Soilside

15-year-old material

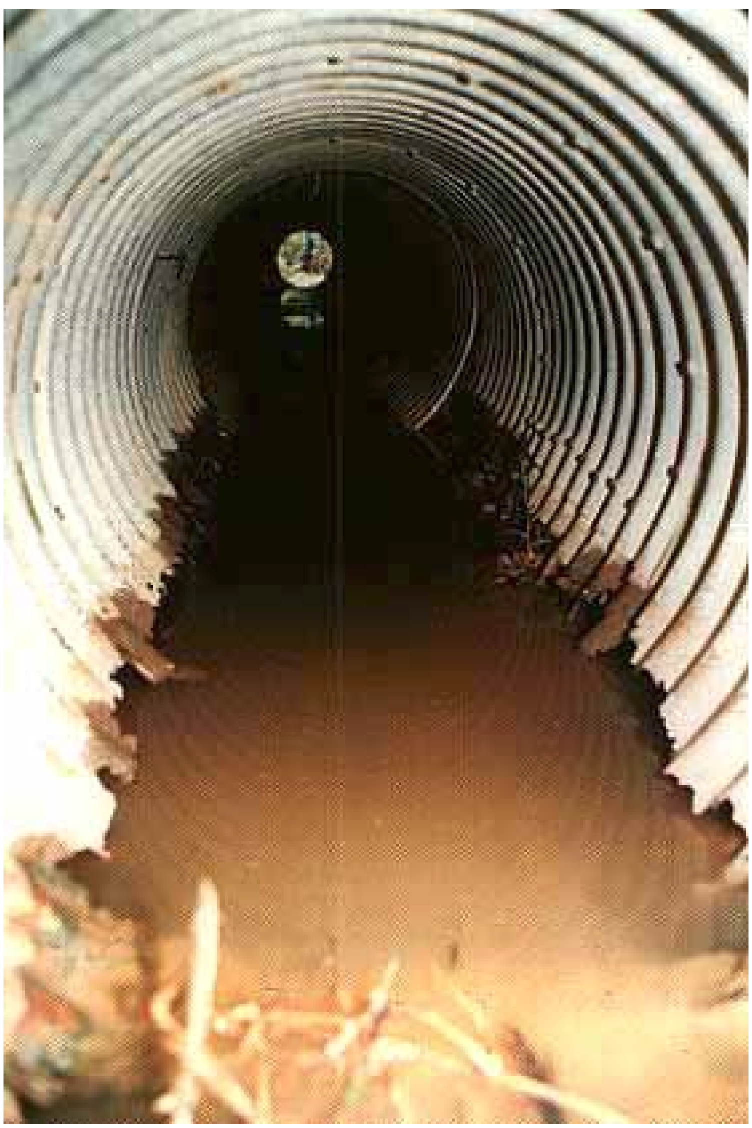
<u>Figure 2:</u> Pits in the coating Al layer on 42-year-old material that expose the coating intermetallic alloy layer with no further penetration





ALUMINIZED Type 2 - Invert - Waterside
Mag. = 2X

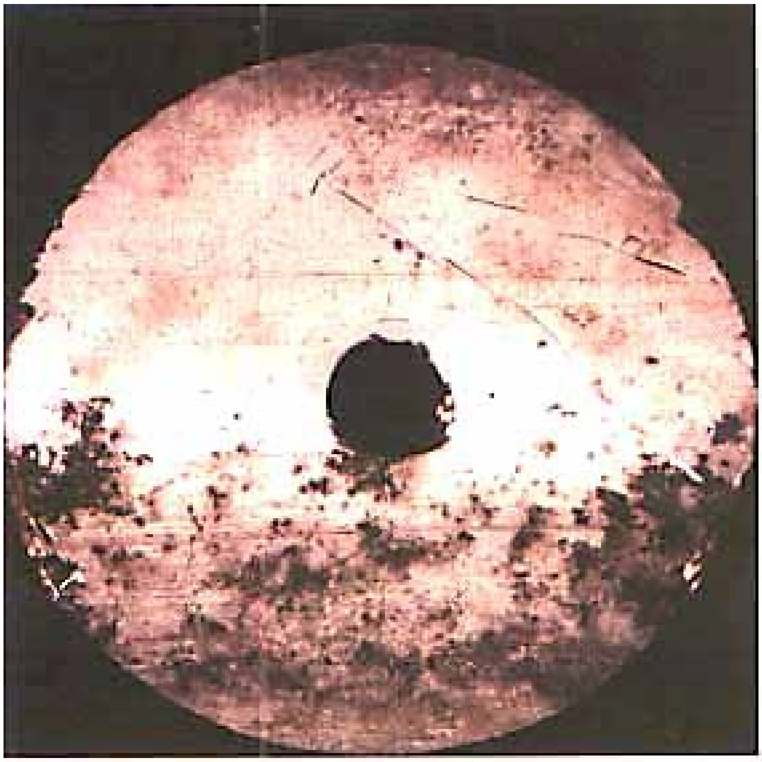
ALUMINIZED Type 2 - Invert - Soilside
Mag. = 1.6X



Galvanized Invert Destroyed
ALUMINIZED Type 2 is between two galvanized sections. Galvanized section in foreground is a later road widening addition extending the pipe length without coupling to the Aluminized. The invert of this galvanized section was badly deteriorated when inspected 13 years ago at less than 30-years age.

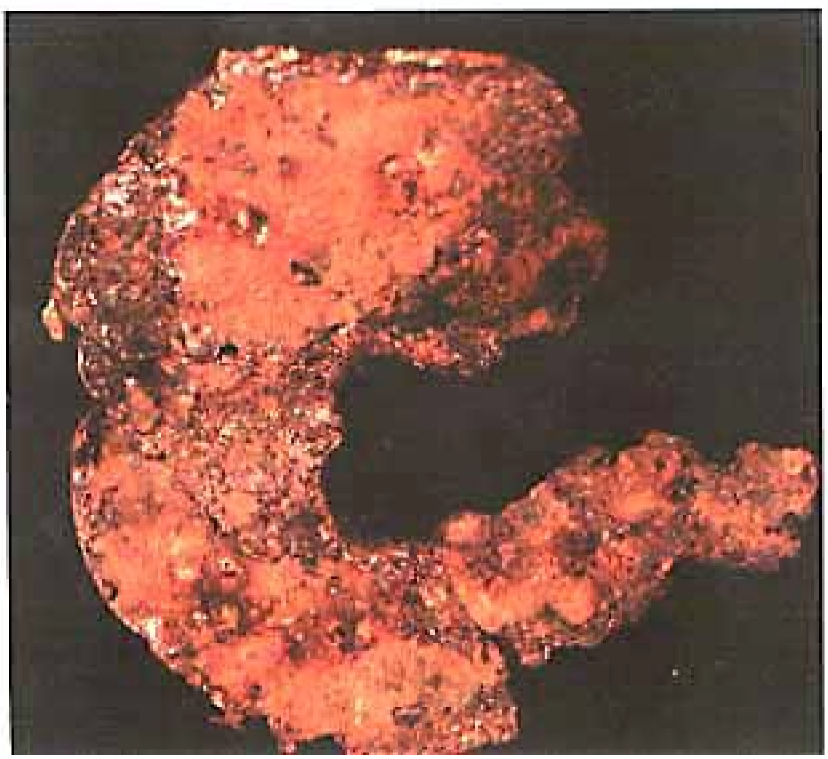
Figure 3
Comparative behavior of 42-year-old ALUMINIZED Type 2 and newer galvanized pipe at one of the most severely corrosive sites (located in Tate County, MS)

<u>Figure 4</u>: Comparative behavior of 43-year-old ALUMINIZED Type 2 and galvanized pipe in Morgan County, IL



<u>ALUMINIZED Type 2</u>
Invert - Waterside

<u>ALUMINIZED Type 2</u>
Invert - Soilside

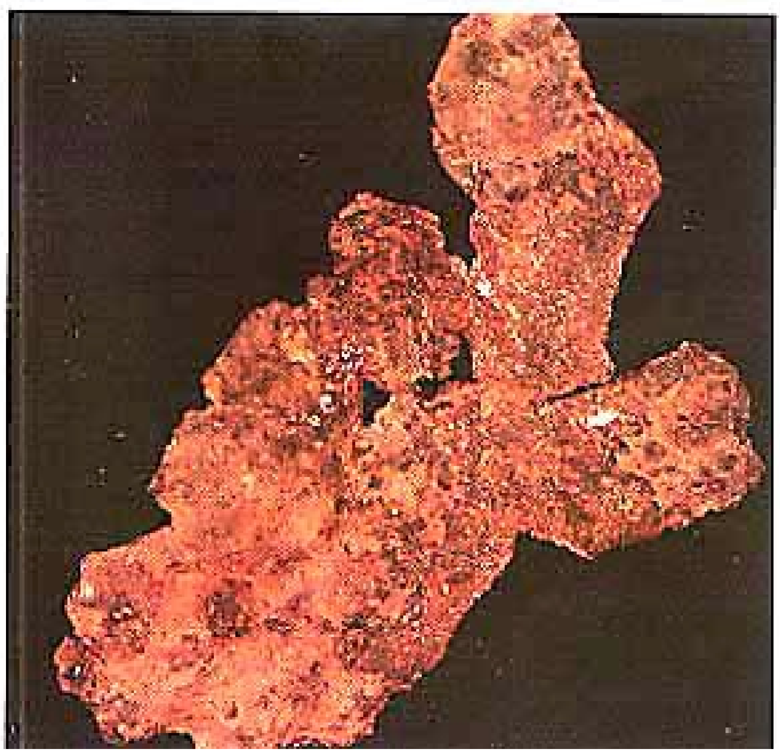


<u>Galvanized</u>
Invert

Figure 5: Comparative behavior of 43-year-old ALUMINIZED Type 2 and galvanized pipe in Lafayette County, MO

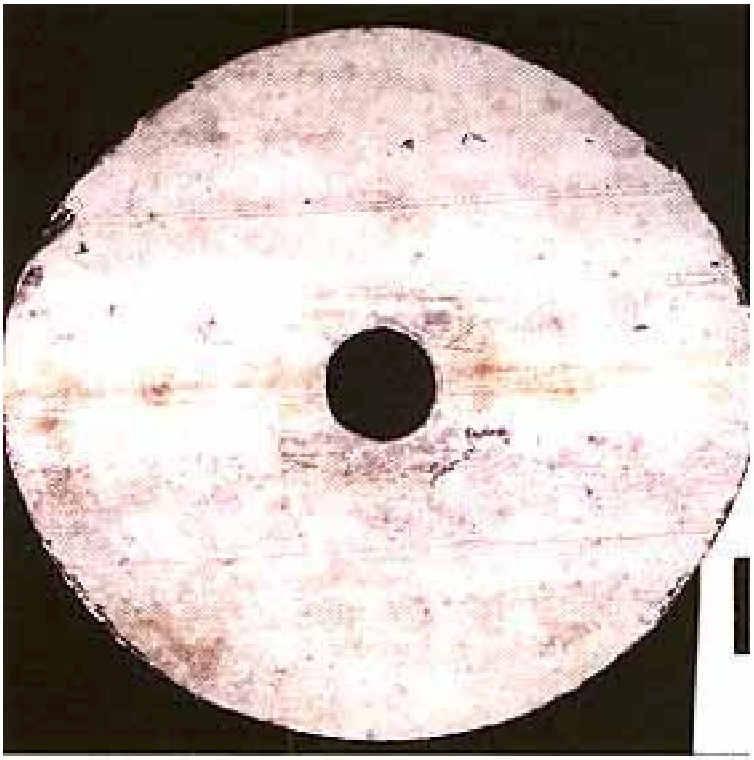
ALUMINIZED Type 2
Invert - Waterside

ALUMINIZED Type 2
Invert - Soilside



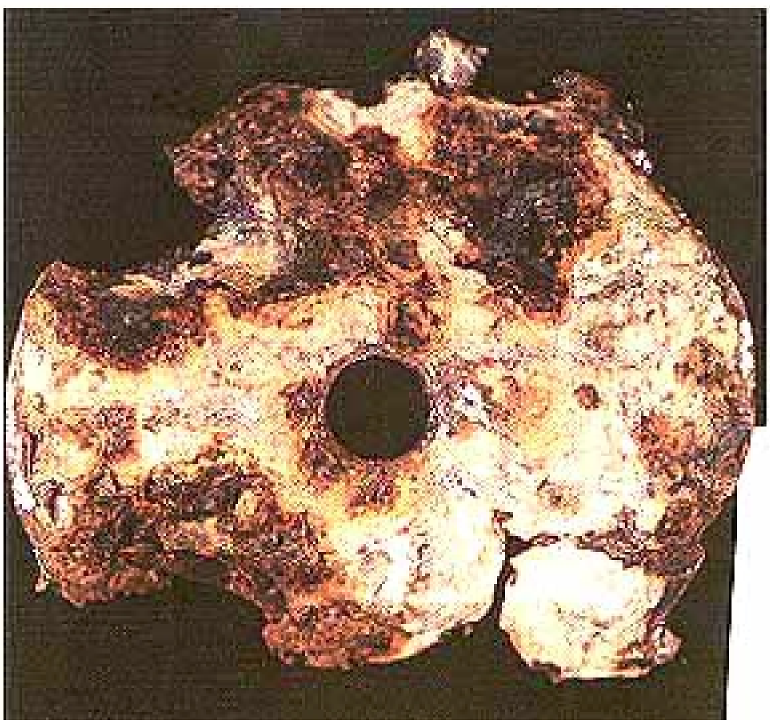
Galvanized
Invert

<u>Figure 6</u>: Comparative behavior of 43-year-old ALUMINIZED Type 2 and galvanized pipe in Marshall County, IA



<u>ALUMINIZED Type 2</u>
Invert - Waterside

<u>ALUMINIZED Type 2</u>
Invert - Soilside



<u>Galvanized</u>
Invert

Figure 7: Comparative behavior of 43-year-old ALUMINIZED Type 2 and galvanized pipe in relatively mild El Dorado County, CA site

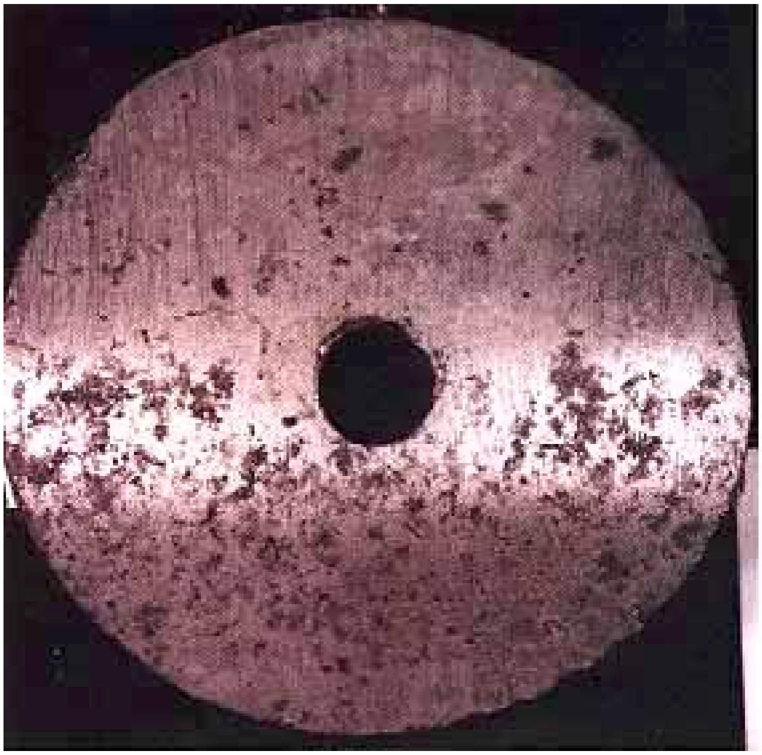
ALUMINIZED Type 2
Invert - Waterside

ALUMINIZED Type 2
Invert - Soilside

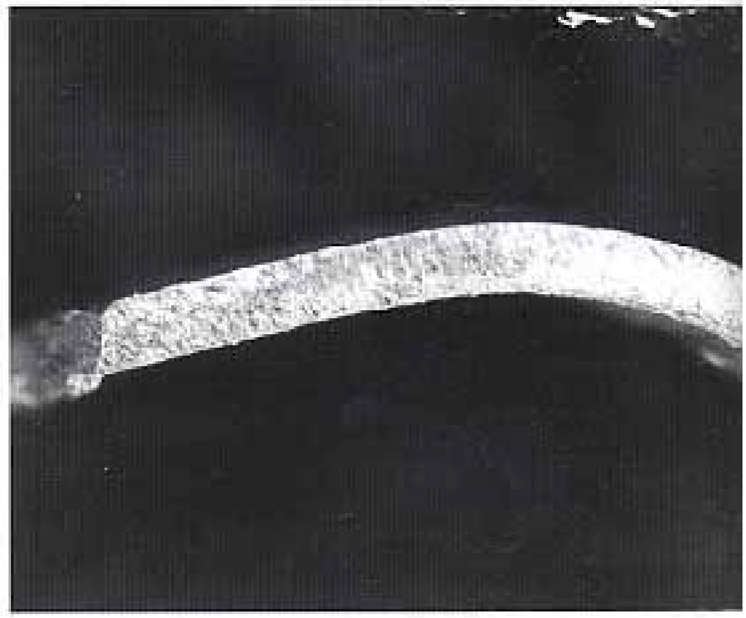
Galvanized
Invert - Waterside

Galvanized
Invert - Soilside

<u>Figure 8</u>: Comparative behavior of 43-year-old ALUMINIZED Type 2 and galvanized pipe in San Benito County, CA, under mild abrasive conditions on a roadway adjacent to a moderately steep embankment. Bottom half of coring is upslope side of corrugation crest.

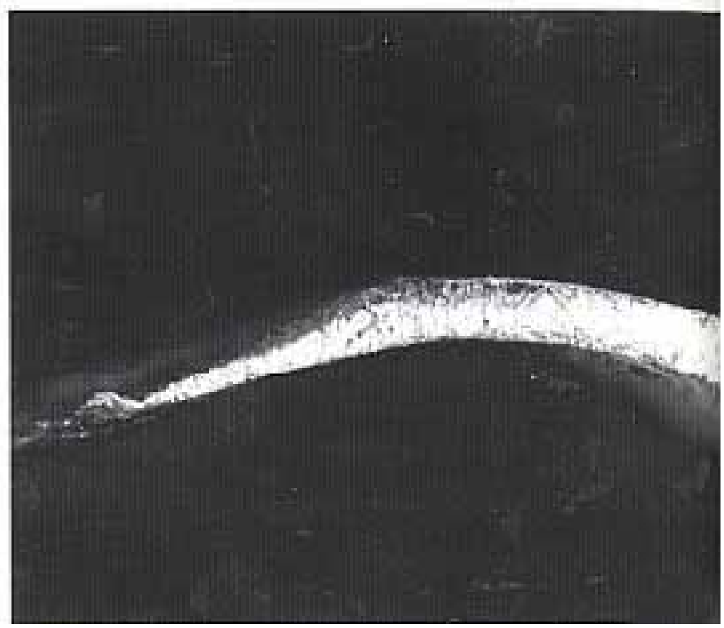


<u>ALUMINIZED Type 2</u>
Invert - Waterside



<u>ALUMINIZED Type 2</u>
Invert Cross-Section
(No thickness loss)

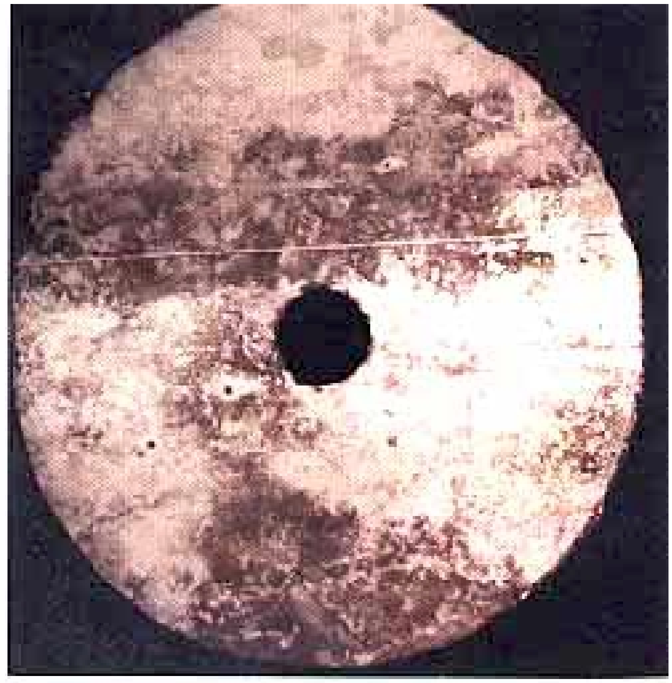
<u>Galvanized</u>
Invert - Waterside



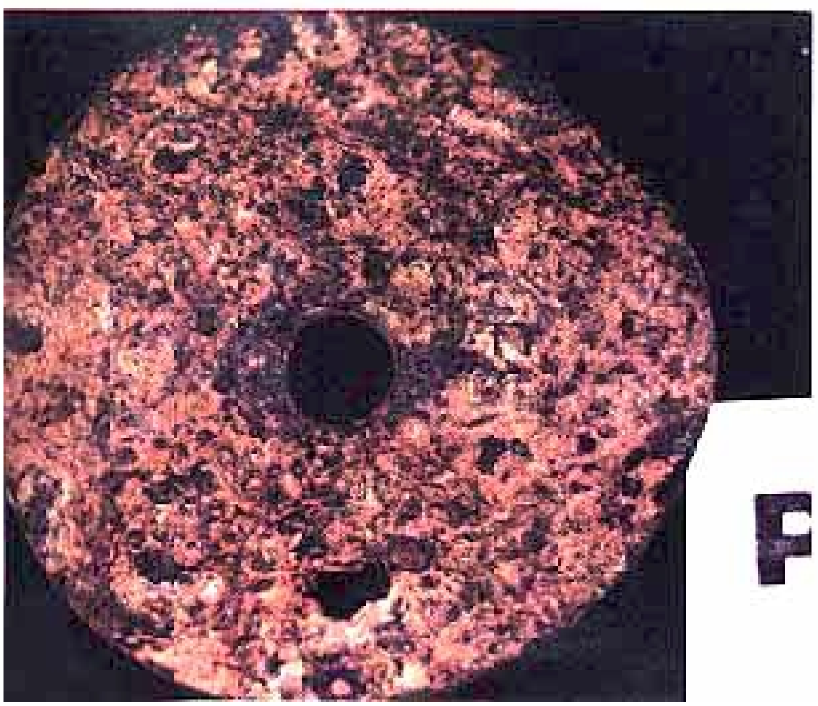
<u>Galvanized</u>
Invert Cross-Section
(Abrasive thinning on upslope side of corrugation crests)

Figure 9: **Comparative behavior of 43-year-old ALUMINIZED Type 2 and galvanized pipe in Carter County, MO, under relatively severe abrasive conditions on a roadway adjacent to a steep embankment. Bottom half of coring is upslope side of corrugation crest.**

ALUMINIZED Type 2
Invert - Waterside
(Shallow abrasion-induced pits)



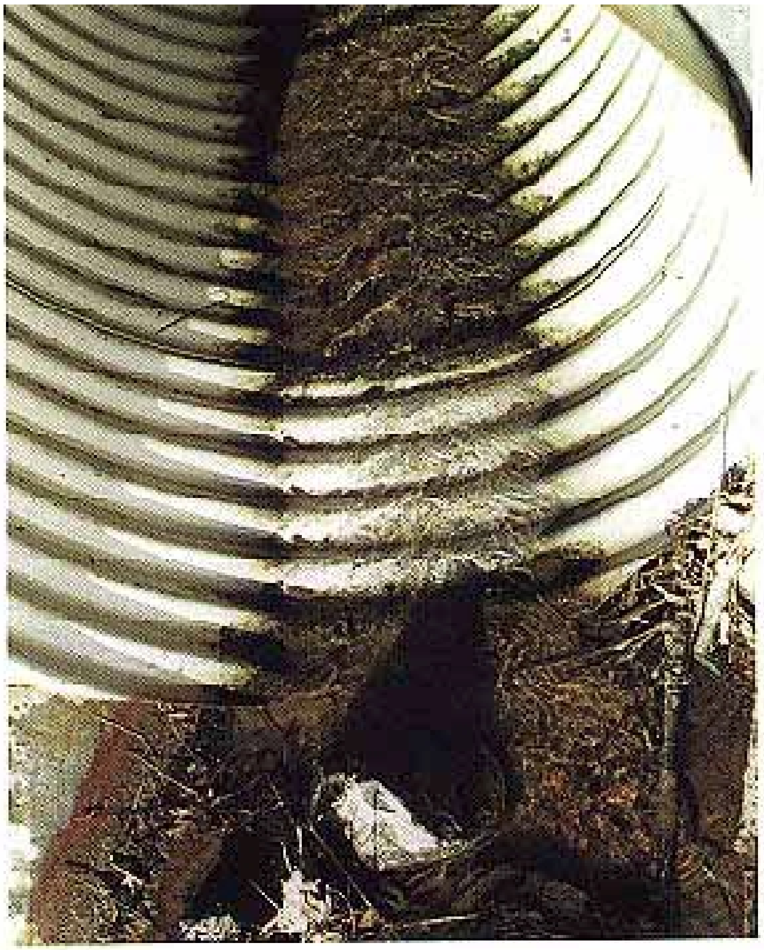
ALUMINIZED Type 2
Invert - Soilside



Galvanized
Invert - Waterside
(Perforated by abrasion)

Galvanized
Invert - Soilside

<u>Figure 10</u>: Comparative behavior of 15-year-old modern ALUMINIZED Type 2 pipe and galvanized end section in Montgomery County, MD



<u>ALUMINIZED Type 2</u>
Pipe

<u>Galvanized</u>
End Section
(Widely perforated throughout up to waterline - grass growing through)

Figure 11: Comparative behavior of 10-year-old modern ALUMINIZED Type 2 and galvanized pipe at same site in Penobscot County, ME

ALUMINIZED Type 2

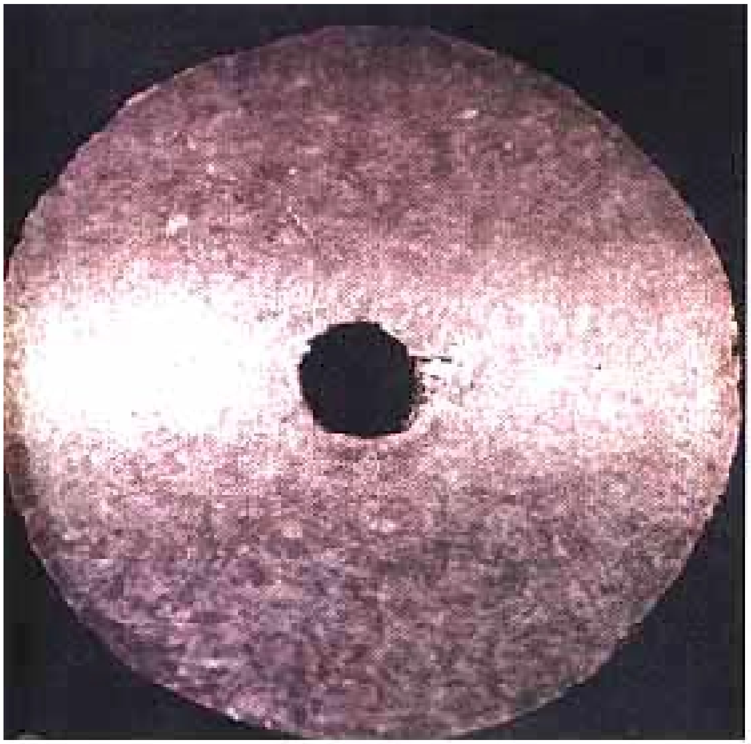
Galvanized

Figure 12: **Behavior of modern ALUMINIZED Type 2 pipe material**

Snohomish County, WA
14-year-old ALUMINIZED Type 2 pipe is performing comparably with 42-year-old riveted Type 2 pipe with which it was joined in tandem 14 years ago.

Gwinnett County, GA
10-year-old ALUMINIZED Type 2 pipe and headwall galvanized pipe stub with galvanized coupling band.

Figure 13: Comparative behavior of 15-year-old modern ALUMINIZED Type 2 pipe and galvanized end section in Montgomery Co., MD

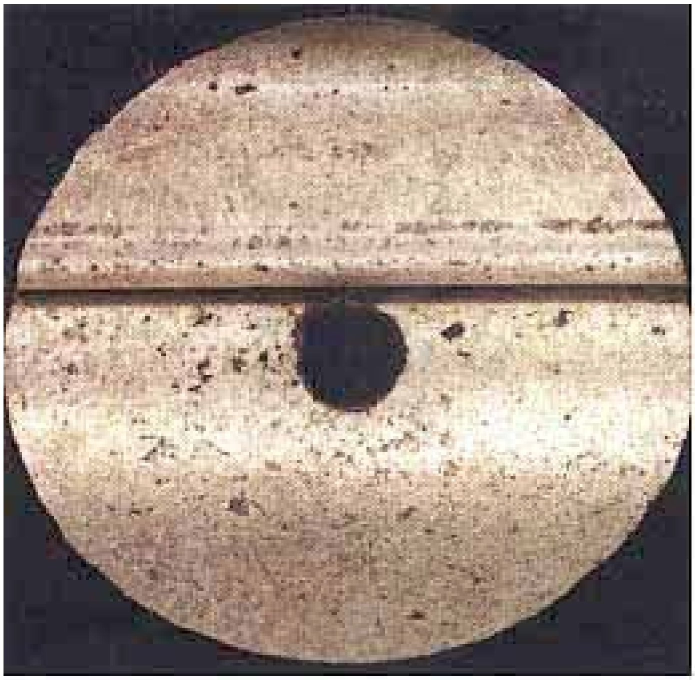


ALUMINIZED Type 2
Invert - Waterside

ALUMINIZED Type 2
Invert - Soilside

Galvanized
Invert of end section

Figure 14: Comparative behavior of 10-year-old ALUMINIZED Type 2 pipe and galvanized pipe in Penobscot Co., ME



ALUMINIZED Type 2
Invert - Waterside

ALUMINIZED Type 2
Invert - Soilside

Galvanized
Invert