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THE RESISTANCE OF ADVANCED PIPELINE COATINGS TO PENETRATION AND ABRASION BY HARD ROCK

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ABSTRACT

The resistance to rock penetration and abrasion damage of four advanced pipeline anti-corrosion coatings on buried steel linepipe was quantified by means of controlled pipe burial tests. Production-coated steel linepipes were buried in three different gradations of crushed hard rock, and a Caterpillar 966D wheel loader was driven directly over the buried pipes twice daily for 12 consecutive days. Subsequent excavation and inspection of the pipes showed that the coatings experienced progressively more damage (quantified by the number of holidays) with increase in rock size and progressively less damage with increase in coating thickness. A quantitative relationship between coating damage and coating thickness was defined for the two larger rock sizes.

Keywords: abrasion resistance, penetration, backfill, pipeline, corrosion coating

INTRODUCTION

During installation of a pipeline in areas where the soil contains rocks and/or boulders, extra measures should be taken to prevent damage to the exterior coating of the pipeline. These measures include selective backfill, additional protective coatings, and protective material laid over the pipeline prior to backfilling operations.[1] The pipeline project engineer must choose which of these measures is the most cost-effective for his design.

One of the methods that can be used to determine the extent of damage to the coating is to simulate burial conditions in a burial test. This paper describes a burial test where four different coatings were subjected to three different gradations of crushed hard rock in order to examine what sort of relationship might exist between abrasion damage and coating type, coating thickness, and rock size.

COATING TYPES

The pipe coatings evaluated were fusion bonded epoxy (FBE), two thicknesses of High Performance Composite Coating (HPCC), and a dual powder system FBE (DPS). Coatings thicknesses are reported in Table 1.

FBE is used as a standard anti-corrosion pipeline coating at a nominal thickness of 350-400 microns. FBE does not offer the same degree of mechanical protection as a polyethylene coating. The FBE coating used for the burial trial was applied according to CSA Z245.20-M98.

HPCC is a multicomponent powder-coated coating consisting of an anti-corrosion FBE layer, a copolymer adhesive, and a polyethylene topcoat. [2,3] The copolymer adhesive is used to bond the FBE to the polyethylene. All three raw materials are applied sequentially in powder form to the pipe surface. The top layer thickness is varied for additional mechanical protection. The “standard” thickness HPCC consists of a minimum 150 microns of FBE, minimum 150 microns of copolymer adhesive, and a minimum 500 microns of polyethylene. The “heavy” thickness, which has typically been specified for horizontal directional drill crossings or road bore crossings, consists

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of a minimum 150 microns of FBE, minimum 150 microns of copolymer adhesive, and a minimum 1250 microns of polyethylene.

The DPS FBE used for the burial trial consisted of two layers of FBE applied sequentially to the pipe surface. Typically both layers are applied to an anti-corrosion specification, such as CSA Z245.20-M98. The total coating system thickness ranges from 700 –1250 microns. This coating system has been designed to give a higher temperature performance than the stand-alone FBE system.

BURIAL TEST PROCEDURE

Based on previous burial trial results from Leith, Scotland, [4] coated pipes were buried in three different gradations of crushed, hard rock (Mhos hardness 6 -7). The rock gradations were selected to result in different amounts of mechanical damage to the coatings during an accelerated burial test.

Rocks and pipe burial

A trench was dug approximately 55 m long to accommodate the four test pipes, each approximately 12 m long, placed end-to-end in the trench. (Figure 1) The trench was dug to provide a minimum depth of 152 mm of rock beneath and a minimum of 457 mm of rock on both sides of the buried pipe. The top surface of the buried pipes was covered with approximately 254 mm of rock (to ground level). (Figure 1)

The open ends of adjacent pipes were abutted to a sheet of plywood (~12 mm thick) to cover the pipe ends and to prevent rocks from entering the pipes during backfilling and during the burial test. The top edge of these plywood sheets was ultimately buried about 75-125 mm beneath ground level and left in place during the test. Plywood separators were also used during backfilling to separate each pipe into three ~4 m lengths to facilitate surrounding equal lengths of each pipe with each of the three rock sizes and to limit intermingling of adjacent different rocks. These separators were subsequently removed after backfilling and prior to start of the test.

The gradations of crushed rock (Mhos hardness 6-7) were nominally minus 50 mm, minus 25 mm, and approximately 14mm diameter. (Table 2) Approximately one-third of each pipe length was buried in (completely surrounded by) each of three rocks.

After placing the bed of rocks at the bottom of the trench (in ~4 m sections of pipe) and lowering the coated pipes into to trench, with plywood separators in place, rocks were carefully placed on the sides and subsequently on the top of pipes using a small loader. Rocks were placed along the sides of the pipes and allowed to overflow the tops of pipes as backfilling progressed. Figure 1 shows the completed burial site with the three rocks alternating along the length of the trench.

Test procedures

Prior to burial each of the four coated pipes was electrically inspected for coating holidays using an inspection voltage of approximately 5.3 volts/micron. All holidays were repaired prior to burial of the pipe.

Within around 18 hours after burial the buried pipe was driven over with a Caterpillar 966D wheel loader weighing 19,508kg. The wheel loader was driven over the full length of the buried pipes twice per day (once each in the morning and afternoon) for a total of 12 days. The wheel loader was always driven over the full length of the buried pipes with the wheels on one side of the loader directly above the buried pipes.

After 12 days, a second, shallow trench was dug with a backhoe adjacent and parallel to the buried pipes to allow rocks to slide off of the top and away from one side of the pipes. This prevented additional coating holidays while excavating the pipes. (Figure 2) The pipes were removed, visually inspected, washed, allowed to dry, and electrically inspected for holidays using the same test voltage as before.

RESULTS/DISCUSSION OF BURIAL TRIAL

The burial trial was held in Camrose, Alberta during the month of September 1999 when ambient temperatures were around 20C during the day. It did not rain during the 12-day trial so the ground remained dry.

During the trial, it was noticed that the area containing the two graded rocks (50mm and 25mm) compacted extensively during the test, whereas the 14mm single size rock did not. The latter rock readily shifted during driving the wheel loader over the buried pipes and was raked smooth again after each time of driving the loader over the pipes. It was assumed that the compaction occurred due to the extensive amount of fines contained in the two graded rocks.

After the buried pipes were removed from the trench, they were holiday tested using the same procedures as those used prior to burial. Table 3 reports the results for each coating and rock type. It was found that 98% of holidays occurred on the top half of the pipes. For this reason the holidays/m^2 were calculated based on half of the surface area of the buried pipe. The coatings experienced progressively greater damage (number of holidays) with increase in rock size and progressively less coating damage with increase in coating thickness. The latter was independent of generic coating type.

A quantitative relationship between coating damage and coating thickness was well defined as shown in Figure 3. The plots show an exponential decay in the extent of coating damage with increase in coating thickness for the two larger rock sizes. The extent of coating damage was minimal for the 14 mm diameter rock.

CONCLUSIONS

The results of the burial trial described in this paper lead to the following conclusions:

1. The burial trial demonstrated that the extent of mechanical damage to anti-corrosion pipe coatings on buried pipelines could be predicted and quantified with controlled testing.
2. The results can be useful in selecting the most cost-effective combination of coating type and thickness, backfill gradation, and rock hardness to minimize long-term mechanical damage to pipe coatings on buried pipelines.
3. The results can be useful in providing improved coating design factors to better meet the long-term, cathodic-protection needs of buried pipelines and therefore to minimize the long-term cathodic protection needs and costs of buried pipelines.

ACKNOWLEDGEMENTS

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Table 1 Coating types and thicknesses used for burial trial

Coating Type	Pipe diameter in. (mm)	Pipe wall thickness (mm)	Average coating thickness(mm)
FBE	36 (915)	9	0.414
HPCC (standard)	30 (760)	10.3	0.970
HPCC (heavy)	30 (760)	10.3	1.559
DPS FBE	18 (460)	14.7	1.242

Table 2 Gradations of crushed rock used in the pipe burial test

Sieve Opening (µm)	Nominal Minus 50 mm		Nominal Minus 25 mm		Nominal 14 mm	
	Cumulative Retained (wt.%)	wt.% Finer	Cumulative Retained (wt.%)	wt.% Finer	Cumulative Retained (wt.%)	wt.% Finer
50,800	0	100	0	100	0	100
38,100	8.54	91.46	0	100	0	100
19,050	49.85	50.15	55.4	44.6	0	100
13,335	62.31	37.69	77.36	22.64	6.77	93.23
12,700	63.44	36.56	77.88	22.12	6.88	93.12
9,550	67.87	32.13	84.03	15.97	55.25	44.75
6,350	73.8	26.2	87.44	12.56	89.74	10.26
4,750	76.36	23.64	89.27	10.73	98.01	1.99
3,353	78.63	21.37	90.99	9.01	98.87	1.13
1,181	82.84	17.16	93.03	6.97	99.2	0.8
1,001	83.19	16.81	93.28	6.72	99.23	0.77
709	84.25	15.75	93.8	6.2	99.27	0.73
425	86.81	13.19	94.83	5.17	-	-
250	91.12	8.88	96.6	3.4	-	-
180	93.63	6.37	97.68	2.32	-	-
75	96.8	3.2	99.28	0.72	-	-
Pan	98.15	0	99.9	0	100	0

Table 3. Number of holidays in coatings on buried pipe

Coating	Number of Holidays/m^2		
	Nominal minus 50mm	Nominal minus 25mm	Nominal 14mm
FBE	16.19	11.40	0.79
HPCC (standard)	4.19	0.63	0
HPCC (heavy)	0.72	0.44	0
DPS FBE	1.39	0	0

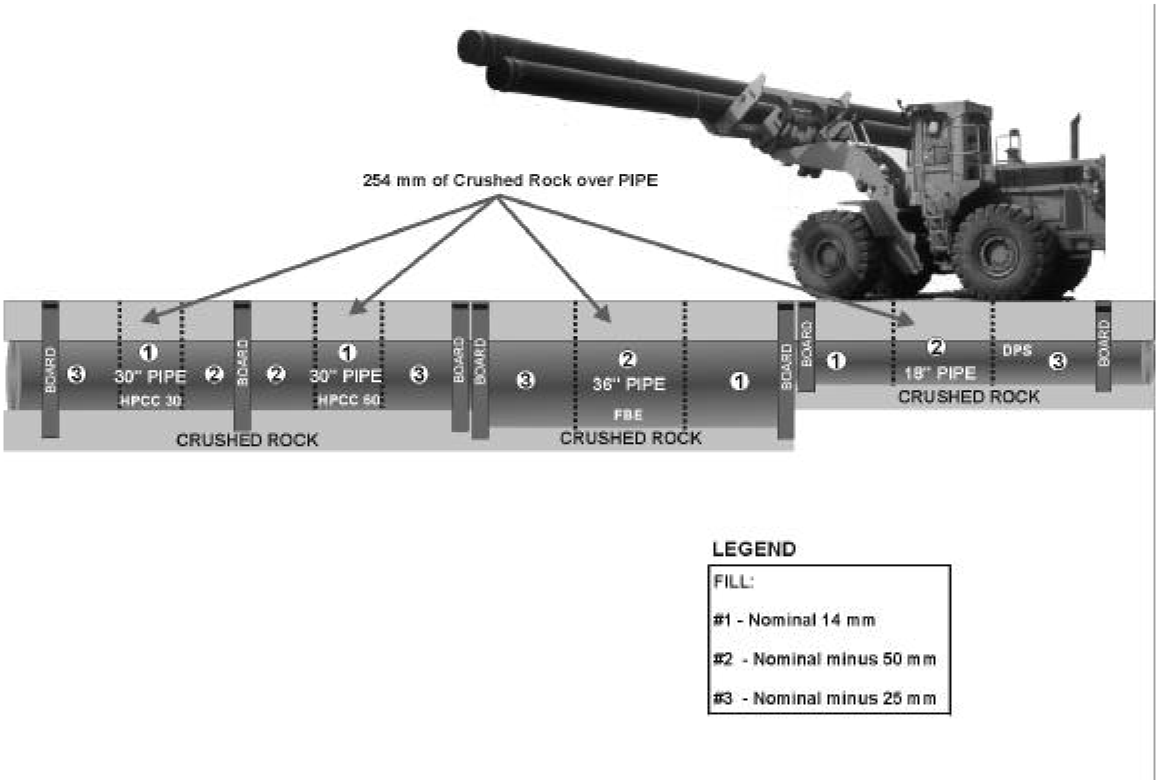

Figure 1. Layout of test pipe and crushed rock in burial test

Figure 2. Completed test burial site for test pipes. The three gradations of crushed rock alternate in 4-m lengths along the full length of the trench.

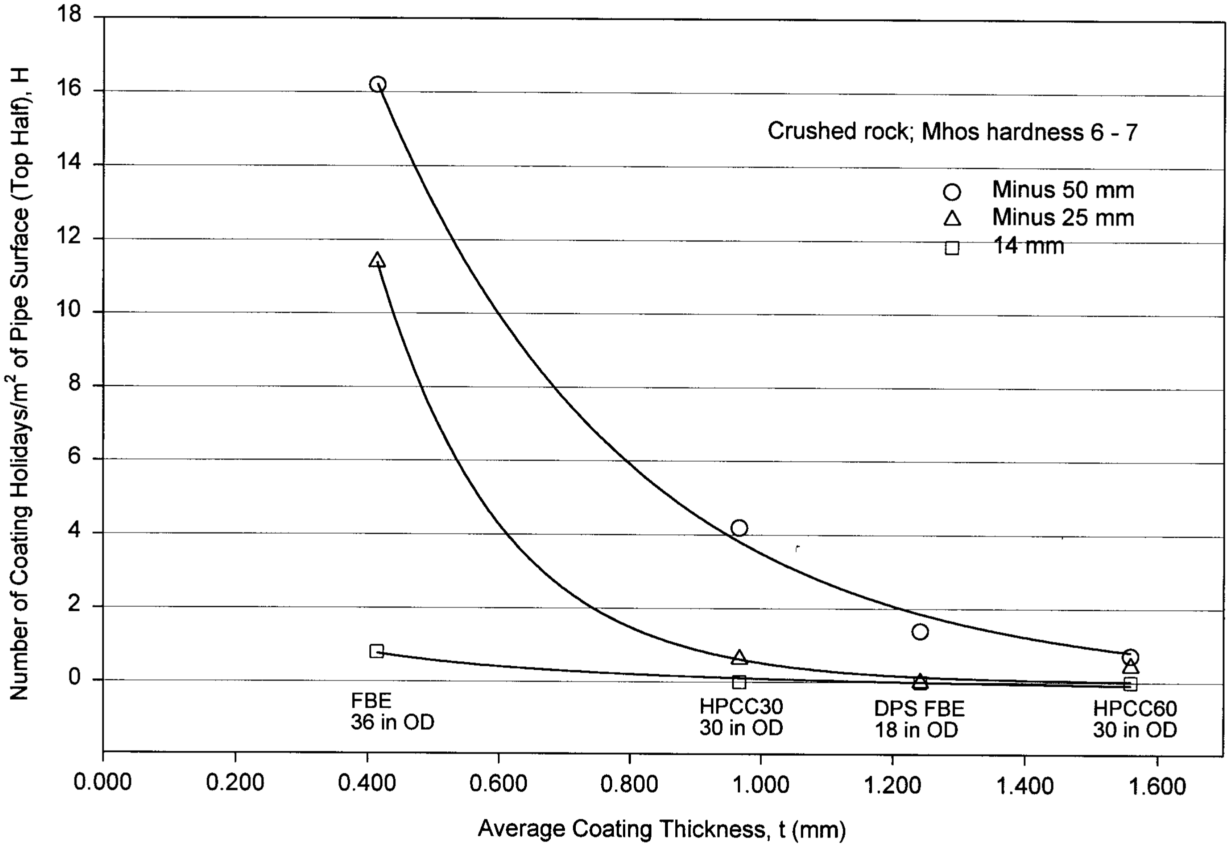

Figure 3. Number of coating holidays/m^2 of pipe surface (top half) caused during a 12 day test of coating performance on buried pipe