Paper No. 53

CORROSION 99

ABRASION RESISTANCE OF LININGS IN FILAMENT WOUND COMPOSITE PIPE

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ABSTRACT

Fiberglass filament wound composite pipe has numerous industrial applications including transportation of petroleum and natural gas. Its corrosion resistance is well known but it can be susceptible to abrasion and erosion when it is used to transport slurries or dry gas containing sand particles. However, composite pipe can be manufactured integrally with abrasion resistant linings which protect the pipe from abrasion and erosion and increase its life.

Laboratory investigations were performed to determine the effect of abrasive flows through polyurea-lined and unlined glass-reinforced epoxy (GRE) pipe, ultra-high molecular weight (UHMW) polyethylene (PE) pipe, and unlined steel pipe. Results are provided for the abrasion resistance, chemical resistance, adhesion strength, elongation, tensile strength, impact resistance and hardness of selected linings. The abrasion resistance of polyurea-lined composite pipe proved to be almost as resistant to abrasion and erosion as unlined steel pipe without the electrochemical corrosion associated with steel pipe.

Keywords: Fiberglass pipe, linings, abrasion resistance, erosion resistance, polyurea.

INTRODUCTION

Fiberglass filament wound composite pipe has numerous industrial applications including transportation of petroleum and natural gas. Its corrosion resistance is well known but it can be susceptible to abrasion and erosion when it is used to transport slurries or dry gas containing sand particles. This susceptibility is predominantly at turns and corners in the pipeline such as at elbows. However, composite pipe can be manufactured integrally with abrasion resistant linings which protect the pipe from abrasion and erosion and increase its life while not suffering the electrochemical corrosion which occurs in steel pipe.

Laboratory investigations were performed to determine the effect of abrasive flows through polyurea-lined and unlined composite pipe, UHMW polyethylene pipe, and steel pipe. Results are provided for the abrasion resistance, chemical resistance, adhesion strength, elongation, tensile strength, and hardness of selected linings. Abrasion resistance of the interior of UHMW PE pipe, fiberglass-reinforced epoxy (GRE) pipe, GRE pipe lined with Amercoat® 4127 (a polyurea), and unlined steel pipe was determined. This paper documents the test procedure, results, and conclusions.

TEST PROCEDURES

Abrasion Resistance

The specimens consisted of one 2-inch (5.1-cm) diameter UHMW PE pipe, one 0.020-inch thick polyurea-lined and one unlined 2-inch (5.1-cm) diameter glass-reinforced epoxy (GRE) pipe, and one 2-inch (5.1-cm) diameter unlined steel pipe. Each pipe specimen was cut into fifteen 2-inch (5.1-cm) long ring sections. The PE pipe rings were weighed to 0.1 gram and the GRE and steel pipe rings were weighed to 0.0001 gram. The thickness of the pipe wall at four selected locations at both ends of each ring was measured using a caliper and averaged to 0.001 inch. The rings were reassembled in the order and position in which they were cut, mounted rigidly and horizontally, and sandblasted axially. The sandblast nozzle was placed flush at the end of the pipe and centered to the bore of the pipe. A number 20 silica sand was used because the average grain size was closest to the 1-mm (0.0004 inch) diameter particles expected in a copper sulfate slurry line. The sand was discharged at about 50 to 60 lbs (22 to 27 kg) per minute at an air pressure of 60 psig (410 kPa). After sandblasting, the weight and wall thickness of each ring were determined as described above. The pipe specimens were sandblasted three times in 10 minute intervals. Figure 1 shows the apparatus and setup.

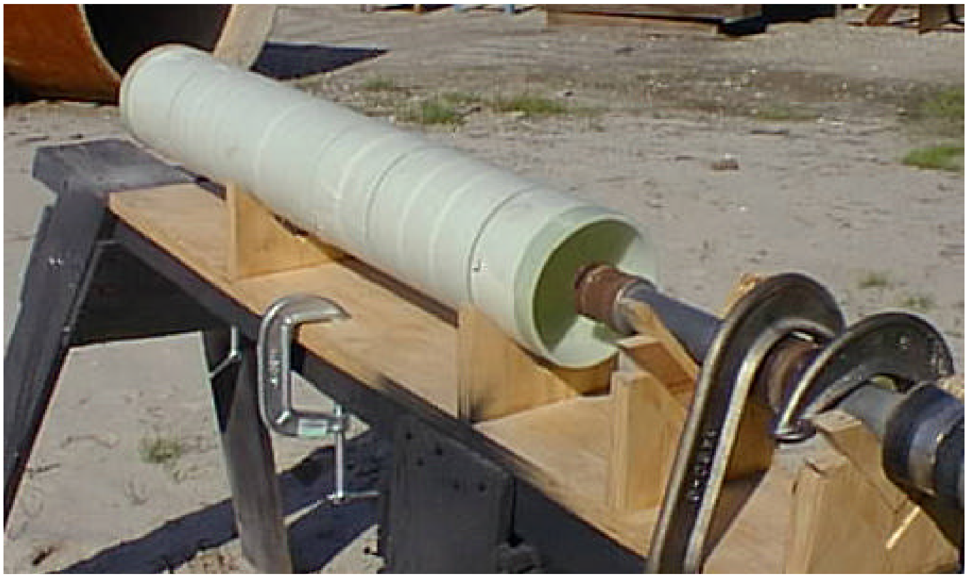

FIGURE 1 - Test setup for sandblasting assembled pipe specimen.

Chemical Resistance

Two-inch (5.1-cm) diameter by 12-inch (30-cm) long polyurea-lined GRE pipe specimens were partially filled with seawater, crude oil, 10% sulfuric acid, and 20% hydrochloric acid and placed in an oven at 180ºF (82ºC) for 5 months. The specimens were visually checked monthly. At the end of 5 months, the adhesion strength of the polyurea to the fiberglass pipe in the immersed and non-immersed areas was determined in accordance with ASTM D4541-95.

Three 2-inch (5.1-cm) long specimens were cut from a 6-inch (15-cm) diameter polyurea-lined fiberglass pipe. One ring was split into two 180º sections and another was cut into eight 45º sections. The whole ring and the eight 45º sections were immersed in boiling water for 8 hours followed by 16 hours of water exposure at ambient temperature. The boiling/ambient water exposure continued for up to 100 cycles. Upon removal from exposure, the sections were visually examined and an attempt to manually peel the lining from the underlying laminate was performed. The Shore A hardness of one 180º section was determined and the section was visually examined before and after 336 hours of immersion in water at 72ºF (22ºC).

Tensile Strength, Elongation, and Impact Resistance

The tensile strength and elongation of the polyurea lining were determined on thin films in accordance with ASTM D4060. Direct impact resistance was determined in accordance with ASTM D2794 on a polyurea-coated sandblasted-steel plate.

RESULTS AND DISCUSSION

Abrasion Resistance

The individual and average percent weight loss and the average loss of wall thickness along the length of the polyurea-lined GRE, unlined GRE, UHMW PE, and steel pipe specimens are shown in Figures 2, 3, and 4, respectively. The conical blast pattern exiting the nozzle expanded radially producing an array of incident angles and particle velocities. The highest wear rates occurred between 6 and 16 inches (15 and 41 cm) down the pipe bore of the 2-inch (5.1-cm) specimens where the majority of the particles contacted the pipe wall initially. The wear rates declined further down the pipe length as a result of the particles bouncing off of the pipe wall, losing velocity, and aligning with the pipe bore.

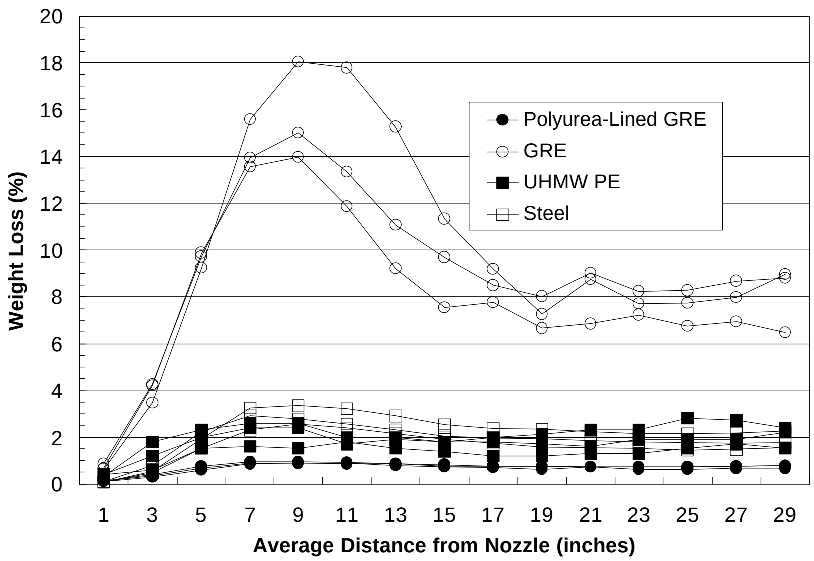

FIGURE 2 - Individual weight loss along the length of the pipe specimens after 10 minutes of sandblasting.

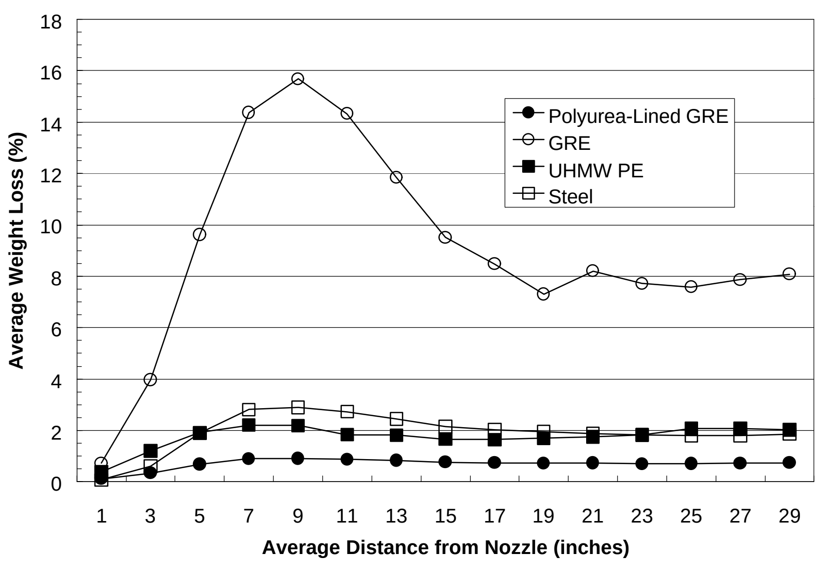

FIGURE 3 - Average weight loss along the length of the pipe specimens after 10 minutes of sandblasting.

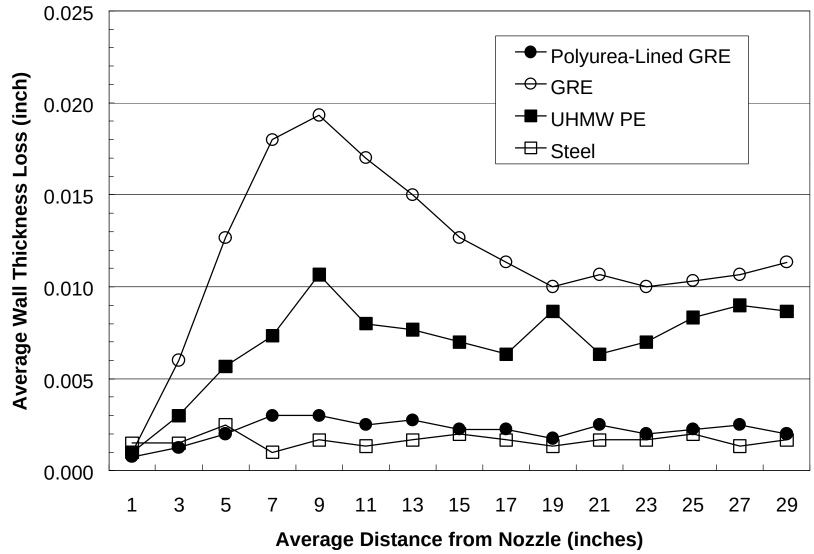

FIGURE 4 - Average wall thickness loss along the length of the pipe specimens after 10 minutes of sandblasting.

The polyurea-lined GRE pipe experienced the lowest weight loss and a wall thickness loss similar to steel pipe. The PE pipe produced weight loss similar to steel but a wall thickness loss roughly half way between steel and the unlined GRE pipe. The steel pipe experienced the highest weight loss but the lowest thickness loss. This apparent contradiction is due to the differences in the specific gravity of the materials. Figure 5 shows the volume loss, and resulting thickness loss, calculated using the weight loss and specific gravity, or density, of the materials. This corresponds to the thickness loss shown in Figure 4 since thickness is a unit of volume. Calculating the volume loss from the weight loss and specific gravity produces a more accurate measurement of the loss of material due to the greater sensitivity of the balance than the calipers.

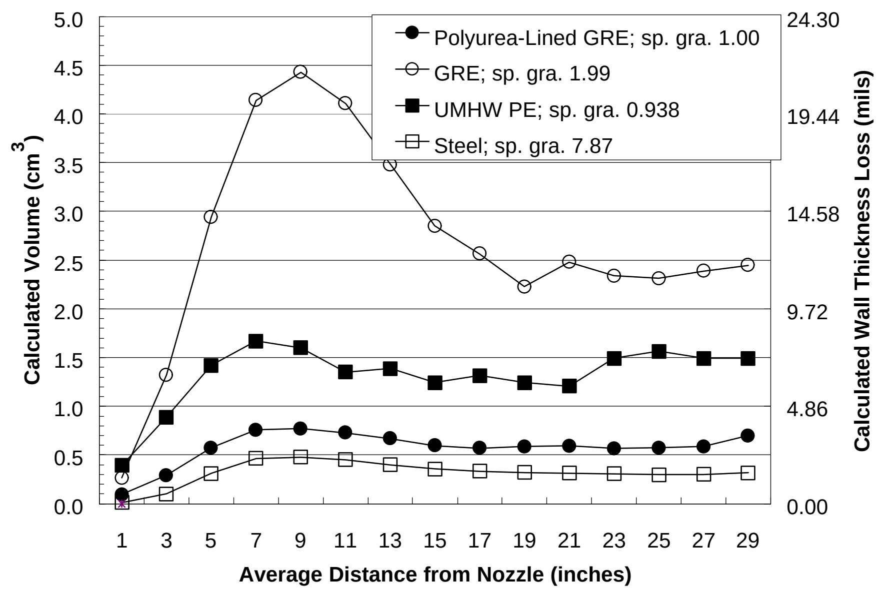

FIGURE 5 - Calculated volume loss and wall thickness loss along the length of the pipe specimens after 10 minutes of sandblasting based on the average weight loss and specific gravity of the materials.

Based on the volume and wall thickness losses, polyurea-lined GRE was almost as abrasion resistant as the steel pipe without the electrochemical corrosion associated with steel pipe.

Chemical Resistance

The visual evaluation, Shore A and D hardness, and the adhesion strengths and type of failure in the non-immersed and immersed areas of the polyurea-lined GRE pipe specimens are given in Table 1. The polyurea lining was not visually affected by exposure to crude oil and the lining hardness was not significantly different between the immersed and non-immersed areas. The adhesion strengths were good. At one location, oil was found between the polyurea and GRE pipe interface causing a low adhesion strength.

TABLE 1
VISUAL EVALUATION, ADHESION STRENGTH, AND SHORE A AND D HARDNESS OF POLYUREA LINING IN THE IMMERSED AND NON-IMMERSED AREA IN VARIOUS SOLUTIONS AT 180^{O}F (82^{O}C) FOR 5 MONTHS

Solution	Visual Evaluation of Polyurea Lining	Shore Hardness				Adhesion			
		Non-Immersed		Immersed		Non-Immersed		Immersed	
		A	D	A	D	Strength (psi)	Type of Failure	Strength (psi)	Location of Failure
Seawater	Four 0.01" wide x 2" long longitudinal cracks at water line. No signs of delamination.	74 73 75	40 38 37	76 77 80	43 44 39	416 248	Within GRE pipe Within GRE pipe	256 326 338	Within GRE pipe Within GRE pipe Within GRE pipe
Crude Oil	No apparent degradation or delamination in immersed or non-immersed areas.	86 84 85	42 42 41	80 81 85	37 33 34	>608 20 >458	At aluminum dolly At polyurea/GRE surface, oil present At aluminum dolly	404 188 300	At polyurea/GRE surface At polyurea/GRE surface Within polyurea
10% Sulfuric Acid	The immersed area was severely degraded, delaminated, & blistered. Non-immersed area was unaffected.	82 92 80	50 50 41	38 21 19	42 4 1	778 730 238	Within polyurea Within polyurea Within GRE pipe	*	*
20% Hydrochloric Acid	The immersed and non-immersed areas were severely degraded, delaminated, & blistered.	53 53 42	13 10 8	52 40 35	10 11 9	*	*	*	*

* Adhesion strengths were not determined due to deterioration of the lining.

Longitudinal cracks in the polyurea lining exposed to seawater were present and the lining hardness was not substantially different between the immersed and non-immersed areas. The adhesion strengths were excellent with the mode of failure being cohesive within the GRE pipe.

The area immersed in the 10% sulfuric acid solution was severely degraded with a substantial decrease in hardness. The non-immersed area was not affected and the adhesion strengths were good with failure being cohesive either within the GRE or within the polyurea.

The non-immersed and immersed areas of the 20% hydrochloric acid were completely deteriorated with a substantial decrease in hardness. Adhesion strength could not be determined due to the deteriorated condition of the lining.

Two 45^{o} sections of the polyurea-lined pipe removed from cyclical boiling water exposure at 36 and 86 hours of total boiling showed no visible signs of blistering or delamination to the GRE pipe. Upon peeling the polyurea lining from the underlying laminate, glass fibers and epoxy resin adhered to the lining indicating a good bond between the epoxy laminate and the polyurea lining. The average shore A hardness of the polyurea at 86 hours of total boiling was 58 with a variation of 2 compared to an average hardness of 60 with a variation of 1 prior to exposure.

Tensile Strength, Elongation, and Impact Resistance of the Polyurea Lining

The tensile strength, elongation, and impact resistance of the polyurea lining are given in Table 2. These properties make it an excellent choice for exposure to abrasive slurries and gases containing particles.

TABLE 2
TENSILE STRENGTH, ELONGATION, AND IMPACT RESISTANCE OF POLYUREA LINING

Property	Value	ASTM
Tensile Strength	2090 psi	D4060
Elongation	40% to 140%	D4060
Impact Resistance	>160 in-lb; no delamination	D2794

SUMMARY

- Polyurea-lined glass-reinforced epoxy pipe developed for use in abrasive conditions is resistant to abrasion and erosion.

- Polyurea-lined GRE pipe is resistant to crude oil at 180ºF (82ºC).

- Abrasion resistance, impact resistance, tensile strength, and elongation properties of the polyurea-lined GRE pipe makes it an excellent choice for exposure to abrasive slurries and particle-containing gases.