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Cathodic Shielding Effects of In-Trench Pipeline Supports

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ABSTRACT

When installing pipelines in rocky areas, additional mechanical safeguards may be necessary to protect the coating. These safeguards may take the form of intermittent supports which elevate the pipeline off the trench bottom. As such supports are non-metallic and are installed directly against the pipeline coating, the pipeline at the location of the supports may be shielded from cathodic protection current.

The cathodic shielding effects of two such supports, a plastic pipeline support and a standard spray-in polyurethane foam support, are investigated and compared. Coating defects were simulated with coupons installed under both supports on the surface of a fusion bonded epoxy coated NPS24 pipe section, with an additional coupon installed to act as a control. The pipe, coupons and supports were immersed in a tap water electrolyte until stable corrosion potentials were reached. Cathodic protection, supplied by a magnesium anode, was applied until the system reached a steady-state. At suitable intervals, the cathodic protection current for each coupon was measured independently and the cathodic protection current density was calculated. In addition, coupon instant-off potentials were measured in order to assess the polarization characteristics of each coupon. The current density and potential results are compared to one another to assess the relative cathodic shielding effects.

Key words: Cathodic Shielding, Foam, In-Trench Pipeline Supports, Shielding.

INTRODUCTION

In-trench pipeline supports are used to provide mechanical protection, particularly when installing pipelines in rocky trenches, by supporting a pipeline so that it does not rest on the bottom of the trench. These supports are non-metallic and are installed directly against the pipeline coating. As part of the pipeline's mechanical damage protection system, the provisions of section 5.1.3.1 of NACE SP0169-2013 apply: that mechanical protection should be applied, "without inhibiting or interfering with CP requirements." In NACE Standard SP0169-2013, "Electrical Shielding", is defined as, "Preventing or diverting the cathodic protection [CP] current from its intended path."[1]

At present, the typical pipeline support is sprayed or pre-formed closed cell urethane foam, so it was desirable to assess the electrical (cathodic) shielding characteristics of this type of pipeline support against a baseline unshielded condition. In the NACE Technical Committee Report "Effectiveness of Cathodic Protection on Thermally Insulated Underground Metallic Structures," it states that, "Sufficient CP current generated externally cannot reach the metallic surface because of the shielding effect of the thermal insulation."[2] The Canadian Association of Petroleum Producers (CAPP)[(1)] Best Management Practice on Mitigation of External Corrosion agrees, stating that, "[foam] insulation will shield cathodic protection."[3]

However, the 1992 Pipeline Research Council International (PRCI)[(2)] report #PR-208-631 entitled "Shielding Effects of Concrete and Foam External Pipeline Coatings" found the opposite. The report concluded that urethane foam did not shield the steel from cathodic protection currents under the conditions tested and that, "urethane foam [is] compatible with obtaining adequate levels of cathodic protection to provide corrosion control." This was attributed to the foam absorbing sufficient moisture after a period of two to three weeks to be electrically conductive despite the observation that the foam still had a resistivity ranging from 10 to 100 kΩ-m.[4]

The cathodic shielding characteristics of an alternate design of an injection molded plastic pipeline support are also assessed. The base material, either polypropylene or polyethylene is an electrical insulator, but this type of support was engineered to address cathodic shielding concerns.[5] As such, voids which minimize the contact area between the pipe and the support were included to permit the passage of CP current.

The objectives for this experiment were to investigate the cathodic shielding effects of both a conventional foam pipeline support and a plastic pipeline support. The experiment was designed to simulate a pipeline installed using both types of supports under back-filled conditions. Holidays on the pipeline were simulated under both supports, and a control holiday was also simulated.

To address uncertainty regarding the impact of time on foam's shielding effects, the experiment was conducted over a period of four months. In addition, the feasibility of overcoming any cathodic shielding effects with an increased driving voltage was considered.

EXPERIMENTAL PROCEDURE

Apparatus

At installation, there is no electrolytic contact provided by either the foam pipeline support (FS) or plastic pipeline support (PP). Under these conditions it is expected that the corrosion mechanism would be atmospheric corrosion. In this case, CP cannot reach the holiday, but the corrosion rate would typically be low. Through the passage of time, there would be soil and water ingress into and around the pipeline supports. Under these conditions the corrosion rate is expected to be higher on unprotected steel and CP may or may not be effective.

A 1.2 m long section of fusion bond epoxy (FBE) coated NPS24 (0.61 m diameter) pipe was instrumented with steel coupons glued to the pipe surface prior to placing the instrumented pipe on two pipe supports. The six coupons are described in Table 1. Five of the coupons (all except the PP embedded) were silver soldered to AWG14 XLPE copper cables and the coupons were affixed to the pipe surface at the 6:00 position with two-part epoxy. Care was taken to ensure the solder joint was completely coated with epoxy and that only the front coupon surface was not coated with the epoxy. The PP embedded coupon was made smaller than the other coupons so as to be completely contained within the widest, flattest point of contact between the pipe and the PP and was silver soldered to AWG12 RWU90 copper cable. To minimize

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(1) Canadian Association of Petroleum Producers (CAPP), 2100, 350 – 7 Avenue S.W., Calgary, Alberta, Canada T2P 3N9.
(2) Pipeline Research Council International (PRCI), 3141 Fairview Park Drive, Suite 525, Falls Church, Virginia, USA 22042.

the passage of electrolyte along the cables, each cable was coated with silicone seal and/or positioned so as to minimize the impact on how the pipe section rested on the support.

Table 1
Coupon Locations

Coupon Designation	Location Along Pipe	Size	Purpose
Control	66 cm	1.5 in. x 0.5 in. (3.8 cm x 1.3 cm)	Simulate an unshielded holiday. Located between the pipeline supports
PP Embedded	15 cm	0.375 in. diameter (0.95 cm. dia.)	Simulate a holiday located under the widest, flattest contact point of the PP
PP Centre	31 cm	1.5 in. x 0.5 in. (3.8 cm x 1.3 cm)	Simulate a holiday located in the centre cavity of the PP
PP Side	50 cm	1.5 in. x 0.5 in. (3.8 cm x 1.3 cm)	Simulate a holiday located in the cut-out on one end of the PP
FS Edge	78 cm	1.5 in. x 0.5 in. (3.8 cm x 1.3 cm)	Simulate a holiday located near the edge of the FS
FS Centre	92 cm	1.5 in. x 0.5 in. (3.8 cm x 1.3 cm)	Simulate a holiday located in the centre of the FS

The coupon placement for each pipeline support is shown in Figure 1. The deposit of sand visible in the "From Above" Foam Support view and the "Perspective" Plastic Pipeline Support view indicate where the pipe was *not* in contact with each support.

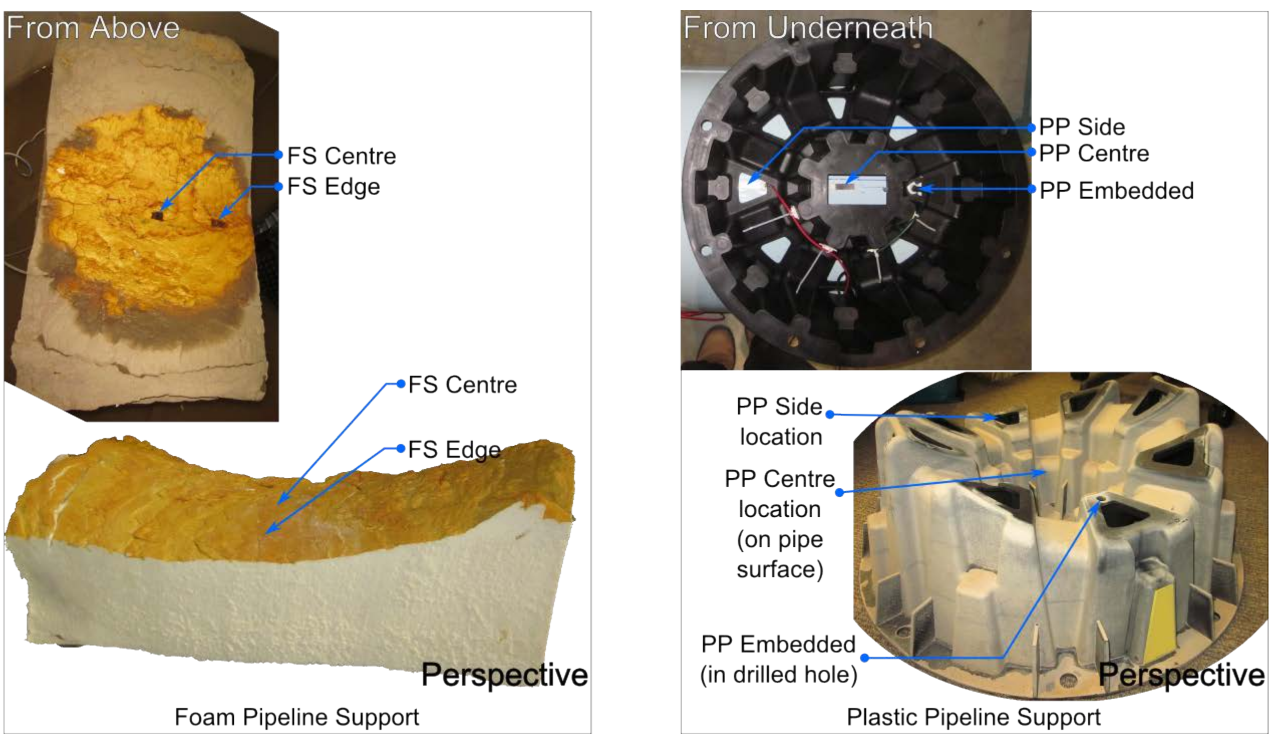

Figure 1: Pipeline Supports with Coupon Locations

The instrumented pipe section was mounted on the PP, a 24" PipePillo[†] injection molded plastic pipeline support, on one end and on the FS, a closed-cell polyurethane sprayed foam pipeline support, on the other end as shown in Figure 2. The FS was pre-crushed to conform to the pipe section and trimmed to fit within the apparatus. To simulate in-trench conditions where cathodic protection current can reach the under-side of the pipeline supports, open-walled plastic crates were placed and secured under each pipeline support. The supports and crates were aligned with the coupons and strapped snugly in position. To more closely simulate in-trench conditions, the pipe was filled with bags of pea gravel. The instrumented pipe section complete with supports and coupons was then lowered into a 635 gallon (2400 L) tank filled with tap water.

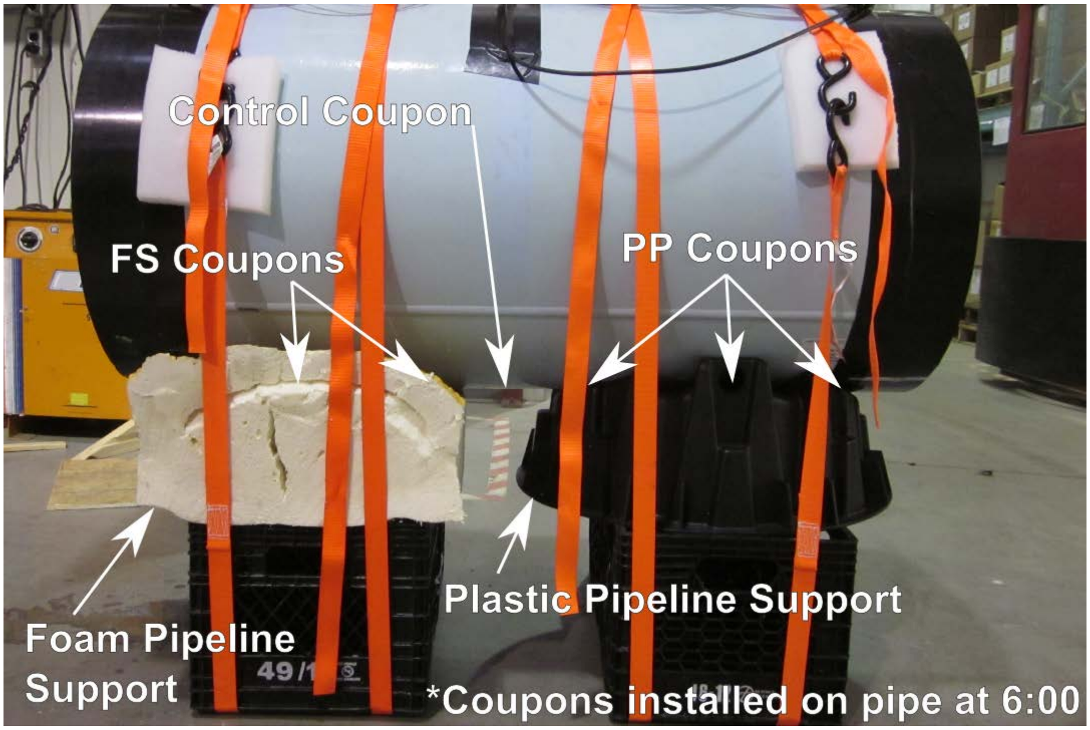

Figure 2: Section of NPS24 Pipe on Pipeline Supports

The tap water had an initial resistivity of 41 Ω-m at 12°C. As the water warmed to room temperature (approximately 20°C), the resistivity dropped to 33 Ω-m. The resistivity continued to fall as the experiment progressed, reaching 25 Ω-m by the end of phase 1 of the testing and falling to 18 Ω-m by the conclusion of the phase 2 testing. The pH gradually decreased throughout the experiment from 7.5 to 7.1.

A 5 pound magnesium anode was bonded to all of the coupons through a junction box to act as the source of cathodic protection current. The junction box was designed to permit the interruption of the anode current to obtain IR-drop free potential measurements, the isolation of each coupon from the other coupons, and the direct measurement of the cathodic protection current at each coupon.

Test Methodology

In order to evaluate the shielding effects of each support, the following parameters were measured: coupon-to-pipe resistances, coupon corrosion currents, and coupon polarized potentials at a variety of cathodic protection operating points. Additional measurements including electrolyte resistivity, temperature, and pH were also made to monitor the state of the system.

[†] Trade name

Coupon-to-pipe resistances were measured using a two-pin technique with an AC soil meter (Tinker & Rasor SR-2†).

Potential measurements were recorded quickly after disconnecting the anode and each coupon from each other. Measurements were an average of the first 100 ms following disconnection, excluding any fast transients, and were recorded using a 1 MΩ-input impedance USB oscilloscope (PicoScope 2204†). Measurements were with respect to a saturated copper-copper sulfate electrode (CSE) placed in the tank at the surface of the water. The CSE calibration was confirmed against a new CSE and stayed within 15 mV of the new CSE throughout the experiment. Note that potential measurements were confirmed against a meter with a higher input impedance (100 MΩ) to confirm that there was negligible error in measured potentials due to a high-resistance measurement circuit.

Coupon corrosion currents were measured with a zero-resistance ammeter (Corrosion Service ZM3P†) capable of measuring current in the micro-ampere range.

RESULTS

Prior to Applying CP Current

After filling the tank with water, the coupons were bonded together and allowed to freely corrode until the potentials stabilized, as shown in Figure 3.

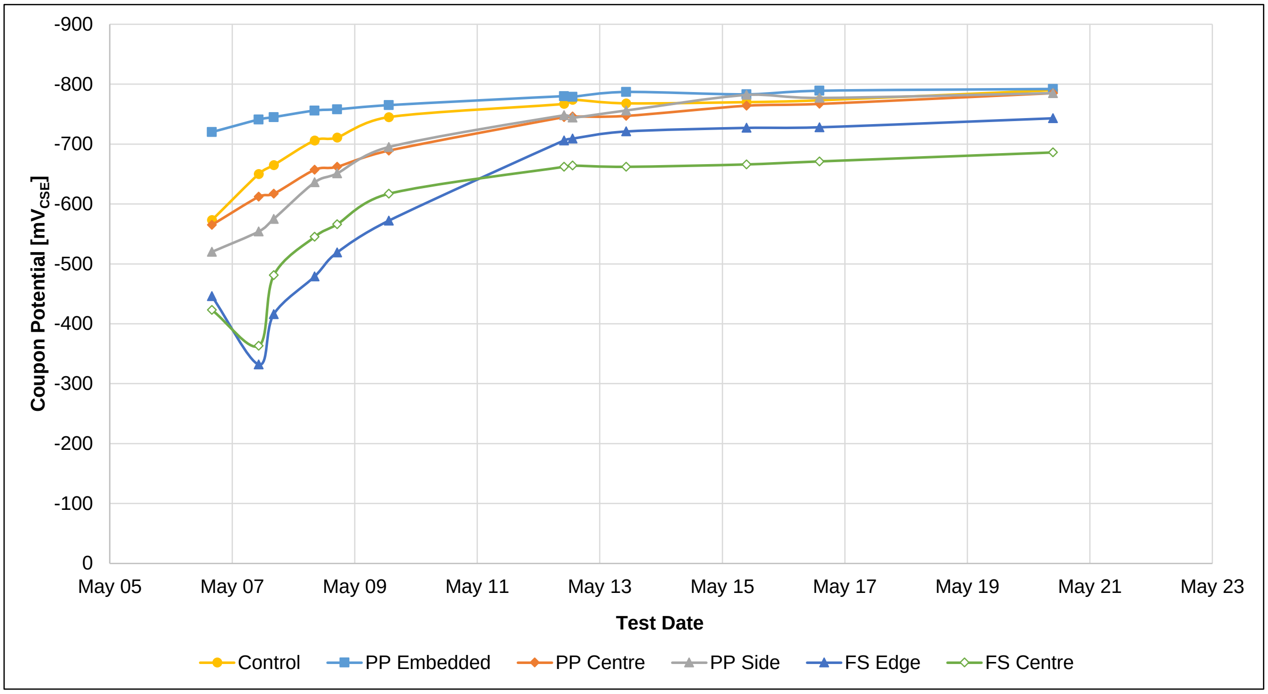

Figure 3: Coupon Corrosion Potentials

† Trade name

The coupons under the PP and the control all settled around -785 mV_{CSE} while the FS edge and centre coupons settled to -743 mV_{CSE} and -687 mV_{CSE}, respectively.

In addition to measuring the corrosion potentials, the AC resistance between each individual coupon and the pipe was measured. The resistances associated with the control, PP centre and PP side coupons were low and remained relatively constant throughout the test. The PP embedded coupon's resistance varied from three to five times the control coupon's resistance, due in part to a smaller surface area. The FS coupon resistances were initially measured at approximately four times the control coupon's resistance but quickly showed a trend of increasing resistance before settling at fifteen to twenty times the control coupon resistance.

Magnesium Anode Connected

The protection characteristics were adjusted by varying the anode circuit resistance. Using this technique the instant-OFF potential as measured on the control coupon was varied between -829 mV_{CSE} and -1159 mV_{CSE}. Under these conditions, the cathodic protection current supplied to the coupons by the anode varied between 0.05 mA and 1.47 mA. After each adjustment in circuit resistance, the coupon potentials were left to stabilize at the new operating condition.

As a sample, the potentials with an initial anode resistance of 2.13 kΩ are shown in Table 2.

Table 2
Measured Parameters with Anode Circuit Resistance of 2.13 kΩ

Coupon	Polarized Potential (mV_{CSE})	Corrosion Current (mA)	Current Density (mA/m^2)
Control	-1016	0.038	52
PP Embedded	-993	0.010	133
PP Centre	-990	0.041	56
PP Side	-1005	0.053	72
FS Edge	-844	0.005	7
FS Centre	-800	0.007	10

The coupon polarized potentials versus the total anode current being supplied to the coupons is graphed in Figure 4. At the lowest operating current (0.05 mA), none of the coupons satisfied the NACE -850 mV_{CSE} criterion for cathodic protection. Both of the FS coupons, however, did not satisfy the -850 mV_{CSE} criterion at the three lowest operating points and remained unprotected even when the control coupon exceeded a polarized potential of -1000 mV_{CSE}.

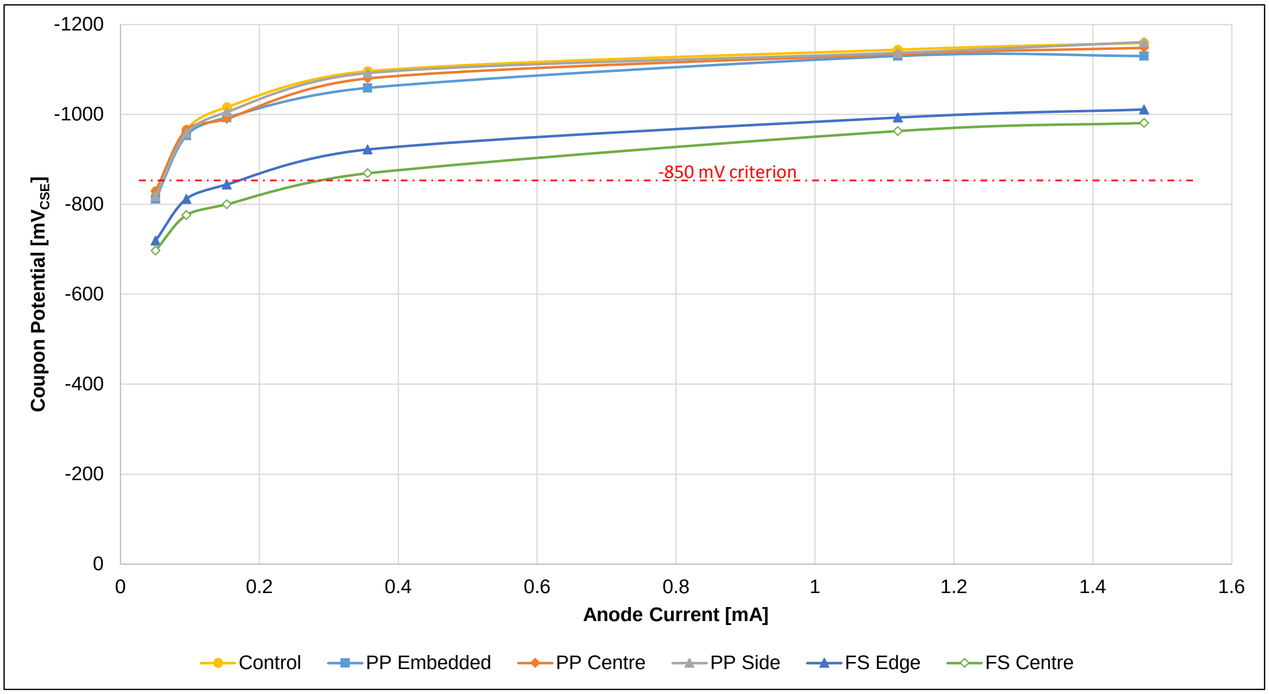

Figure 4: Coupon Potential vs. Anode Current

The protection level of each test coupon can also be plotted versus the protection level of the control coupon, as shown in Figure 5. The control, corresponding to the no shielding case, has a slope of 1. Any lowering of protection level can be seen visually as a shift towards zero (down) on the y-axis.

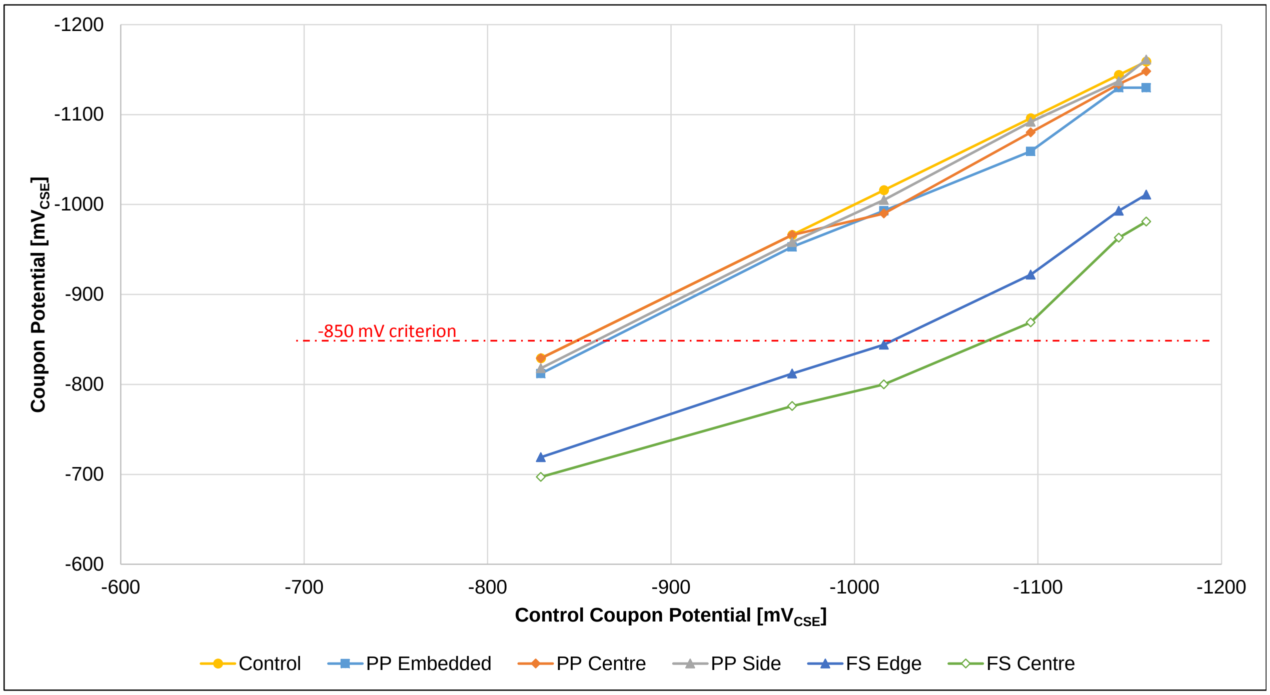

Figure 5: Coupon Potential vs. Control Coupon Potential

The polarized potentials measured on the PP coupons remained within 50 mV of the control coupon polarized potentials under all operating conditions. The polarized potentials measured on the FS coupons varied between 110 mV and 227 mV less than the control, with the largest difference observed at intermediate operating conditions (moderate protection levels).

A third way of comparing the level of shielding is by considering the CP current density at various operating points, as shown in Figure 6. Note that all the coupons have the same surface area, 0.75 sq. in. (4.8 cm^2), except the PP embedded coupon with a surface area of 0.11 sq. in. (0.71 cm^2). The two FS coupons experienced significantly lower current densities than the control coupon. At the lowest operating point, the FS coupons received 35% of the control coupon current density. This difference increased at higher operating points and exceeded one order of magnitude at the two highest operating points.

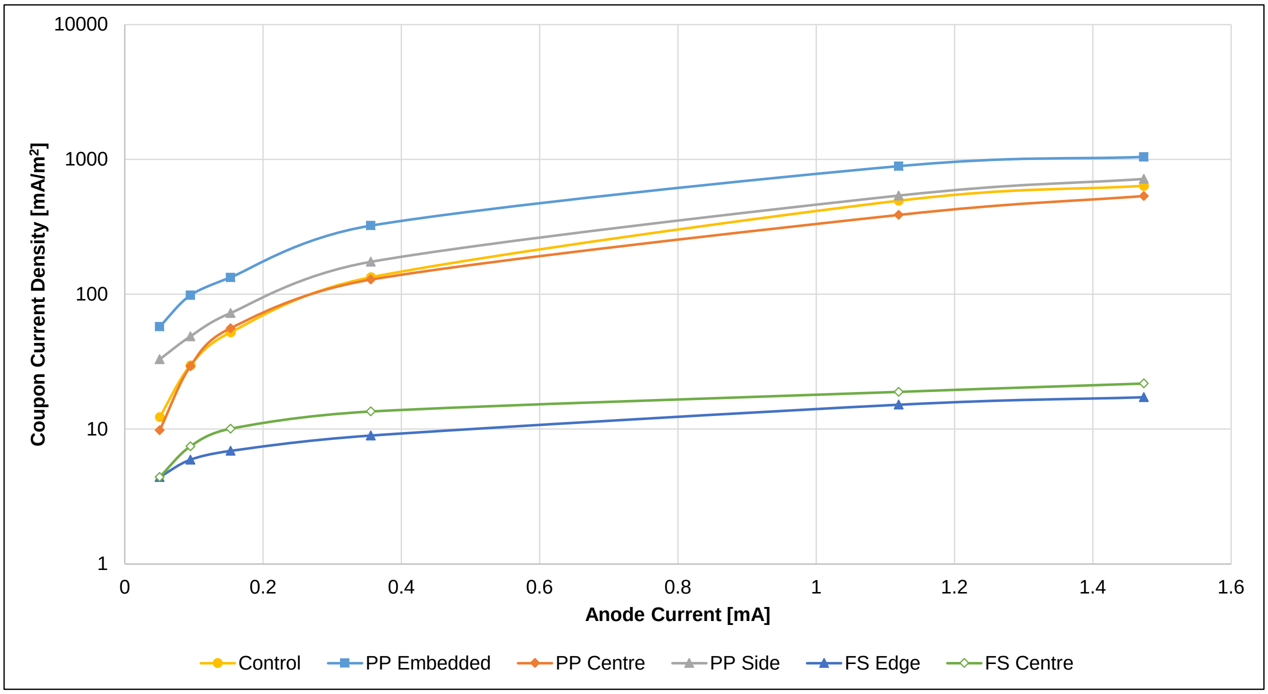

Figure 6: Coupon Current Density vs. Anode Current

After completing these tests it was hypothesized that the two FS coupons were receiving CP via an electrolytic path rather than via a water absorption mechanism. This was suggested by the fact that potentials could be measured immediately after immersion in the water (that is, without waiting for the foam to absorb water) and because there was no decrease in the measured AC resistance as time passed. In addition, the PP embedded coupon measurements clearly indicated the presence of an electrolytic path because this coupon was sandwiched directly between the pipe and the PP, which does not absorb water.

As such, a second phase of tests was conducted to determine whether increasing the load on the pipe would impact the shielding characteristics. To accomplish this, the pipe section was weighed down with 710 kg of sand.

The results of the coupon potential vs. anode current are shown in Figure 7. To facilitate comparison with Figure 4, the limits of the axes have been set to the same values. Note that although similar levels of polarization were obtained, the anode current required was substantially lower. This may be due to slightly deeper water and less oxygen availability resulting from the sand and plastic used to weigh down the pipe.

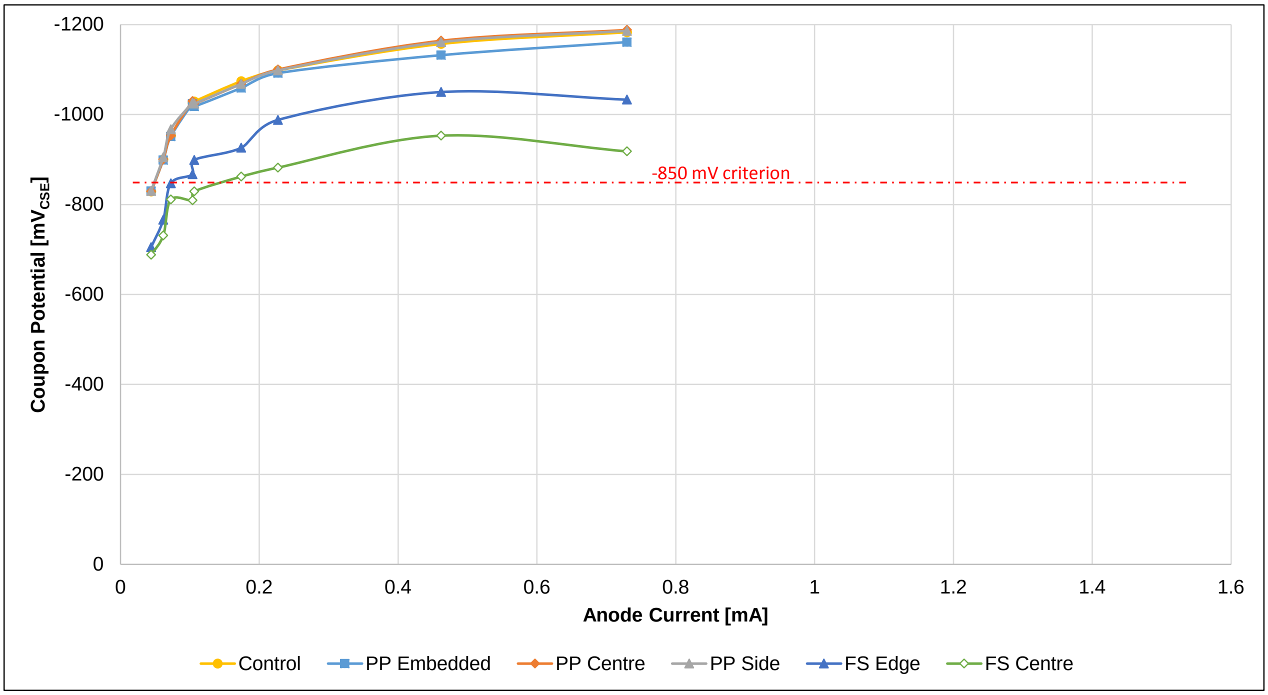

Figure 7: Coupon Potential vs. Anode Current with Increased Pressure

The results of the tests conducted under increased pressure were similar to the original tests. Due to time constraints, some of the differences in potentials are attributed to insufficient time to polarize or depolarize. This was particularly applicable to the foam coupons because changes in polarization took more time.

Some of the data indicated more polarization of the FS edge coupon, but this may have been impacted by the insufficient time. Also apparent in the figure is that the FS centre coupon in particular did not polarize as effectively at the highest operating point, but this was not observed as a trend at the lower operating points. The only clear difference was a lower ratio of PP Embedded coupon current density to control coupon current density. However, the PP embedded coupon polarized to similar levels.

DISCUSSION

The results clearly indicate that the control coupon and the PP coupons polarized more and received more cathodic protection current than the FS coupons under both test conditions. The foam coupons received some cathodic protection and with sufficient driving voltage polarized above the -850 mV$_{CSE}$ criterion.

Based on the similarity between the results from the first and second phase of tests, which were conducted consecutively, there was little if any change due to the passage of time.

In order to judge the severity of the foam support's cathodic shielding, as well as any cathodic shielding of the PP, it is necessary to expand upon the definition of electrical shielding in SP0169-2013.

As a starting point, the control coupon can be defined as unshielded and a hypothetical coupon which does not receive any CP current is completely shielded. Shielding is indicated by a coupon with the same geometry receiving less CP current under the same applied voltage. The degree of severity of the shielding is related to the difference in received CP current. Note: this does not yet address the severity of any particular shielding condition, which should also take into account polarization.

Plastic Pipe Support

Based on this definition and under these test conditions, no trend of shielding of either the PP centre or PP side coupons was detected.

Due to the smaller size of the PP embedded coupon, the current density is expected to be higher than for the control coupon. During the initial testing the current density on the PP embedded coupon always exceeded the control coupon current density by at least 60%. Under the increased pressure of the second round of tests, there was up to 37% lower current density on the PP embedded coupon, indicating some degree of shielding. However, at higher operating points the current density of the PP embedded coupon again exceeded that of the control coupon.

The polarization characteristics of the PP centre and PP side coupons were almost identical to the polarization characteristic of the control coupon under both test conditions. As such, the shielding of these coupons was negligible.

Under both test conditions the PP embedded coupon polarized slightly less than the control coupon. During the first phase this polarized potential was always within 37 mV of the control coupon. Despite the relatively lower current density ratio during the second phase, the polarized potential was always within 25 mV of the control coupon. As such, it can be concluded that there was also no significant shielding on the PP embedded coupon.

Foam Pipe Support

The two foam support coupons showed a definite trend of shielding. Under all test conditions, the foam coupons' current densities did not exceed 35% of the control coupon's current density. At the higher operating conditions (corresponding to the control coupon polarized to potentials more electronegative than -1050 mV_{CSE}), the FS coupons had current densities less than 10% of the control coupon's current density. For the two highest operating conditions, the FS coupons had less than 5% of the control coupon's current density. This indicates that current is picked up more readily on the less shielded coupons and demonstrates that high current densities on unshielded holidays do not provide information about the current densities on shielded holidays. This contrasted with the results measured on all the PP coupons and may be indicative of significant shielding.

At the start and end of the testing, the foam support was weighed. The weight had increased from 2.6 kg to 7.2 kg, indicating significant water absorption, and the central part of the foam support (which had supported the pipe) was wet to the touch. In this area, the foam resistivity was measured using the 4-pin Wenner technique and ranged from 35 to 94 kΩ-m after drying for one day. The two sides of the foam which had not been crushed under the weight of the pipe did not appear to be saturated and the resistivity was too high to measure (exceeded 800 kΩ-m). When the foam was cut and measured in the most visually saturated area, the resistivity ranged from 2.6 kΩ-m to 12 kΩ-m. Note that this is two orders of magnitude greater than the bulk electrolyte resistivity (18 Ω-m to 33 Ω-m). Despite the decreased resistivities measured in the saturated foam, the test data did not indicate significantly less shielding as the experiment progressed.

One of the concerns with a shielded condition is the inability to detect unprotected steel using standard techniques. Due to the higher resistance associated with a shielded holiday, an above-ground potential measurement will not represent a shielded holiday if there is an unshielded holiday nearby. During this experiment, for example, an instant OFF potential of -960 mV_{CSE} was measured with all coupons connected together. When measured individually, the PP and control coupons ranged from -974 mV_{CSE} to -988 mV_{CSE}, but the FS edge and centre coupon potentials were -847 mV_{CSE} and -797 mV_{CSE}, respectively.

It is expected that the specific size, shape and placement of the foam support will impact the shielding characteristics of foam support. Therefore, although during this specific experiment the FS coupon potentials exceeded -850 mV_{CSE} when the control coupon potentials exceeded -1050 mV_{CSE}, no general rule can be devised. An increased driving voltage may be effective in overcoming the shielding effects of the foam, but this cannot be judged based on measured potentials due to the problem discussed above.

Although the native potentials shown in Figure 3 are significantly lower for the FS coupons, during both tests there existed operating points when the control and PP coupons were fully protected, but the FS coupons were not. The data for the second lowest operating point from Figure 4 is given in Table 3. In this case, the FS coupon potentials were both more electropositive than -850 mV_{CSE} and had less than 100 mV of polarization.

Table 3
Operating Point with Insufficient Polarization

Coupon	Native Potential (mV_{CSE})	Polarized Potential (mV_{CSE})	Polarization (mV)
Control	-790	-966	176
PP Embedded	-792	-953	161
PP Centre	-785	-966	181
PP Side	-785	-958	173
FS Edge	-743	-812	69
FS Centre	-686	-776	90

CONCLUSIONS

The results of an experiment evaluating the cathodic shielding effects of a conventional foam pipeline support and a plastic pipeline support were evaluated. The plastic pipeline support was determined to have negligible cathodic shielding effects. The foam pipeline support was determined to have significant cathodic shielding effects. In addition, potentials measured on-grade would not be capable of detecting sub-criterion potentials.

ACKNOWLEDGEMENTS

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