Field Corrosion Monitoring of Steel-Strip Laminate (SSL) Pipe

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ABSTRACT

A patented electrical potential monitoring technique can be used for acceptance of a steel-strip laminate (SSL) pipeline and for periodically assessing whether external or internal corrosion of individual pipe sections has occurred. Electrical potential of steel encased in resin, such as fiberglass-resin systems, cannot be measured unless an electrolyte diffuses through the wall or coating or flows through cracks or disbonded areas of the resin and makes contact with the metal. By electrically connecting an insulated wire from the encased steel to the terminal of a voltmeter and connecting another insulated wire from the other terminal of the voltmeter to a reference electrode, potential readings can be taken. If the potential is unstable, the electrolyte has not reached the encased steel and no corrosion is occurring. If the potential is stable, the electrolyte has made contact with the encased steel and corrosion is occurring. Stable potentials are usually found on coated steel pipe due to flaws and pinholes found in the coating.

INTRODUCTION

Bondstrand® SSL pipe is an entirely new concept in high-pressure, corrosion-resistant piping for a wide variety of demanding oil and gas services, including gathering lines, subsea flow lines, and water injection lines. It is a breakthrough in high-performance pipe and is a result of a nine-year collaboration with British Aerospace, which has been using steel strip technology to manufacture rocket casings for more than three decades.

SSL refers to "Steel Strip Laminate," a patented, hybrid composite that combines the strength of high tensile steel with the proven corrosion resistance of fiberglass to produce a low-profile, high-flow, lightweight pipe that can handle operating pressures up to almost 400 bar (5750 psig) and operating temperatures ranging from -46°C to +93°C (-50°F to +200°F).

SSL pipe features a high-strength steel strip core completely encapsulated between two impervious jackets of glass-reinforced epoxy (GRE) as shown in Figure 1. It consists of a filament-wound inner jacket, three to ten helically-wound high strength steel strip layers, and a filament-wound outer jacket.

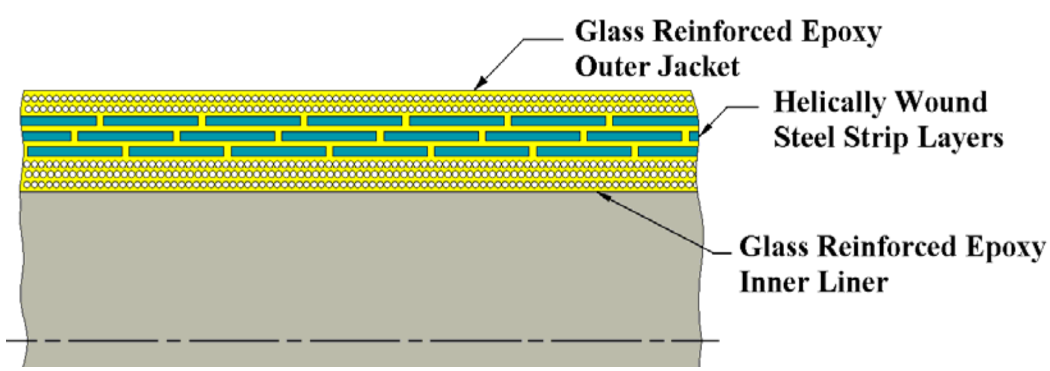


Figure 1. Wall Construction of SSL Pipe.

The pipe has an integral spigot at both ends or an integral spigot and an integral bell, shown in Figure 2, formed by filament winding that fully encases the steel strips. It provides resistance to oil and gas, CO_2, H_2S, hot saline water, aggressive soils, and other forms of corrosion.

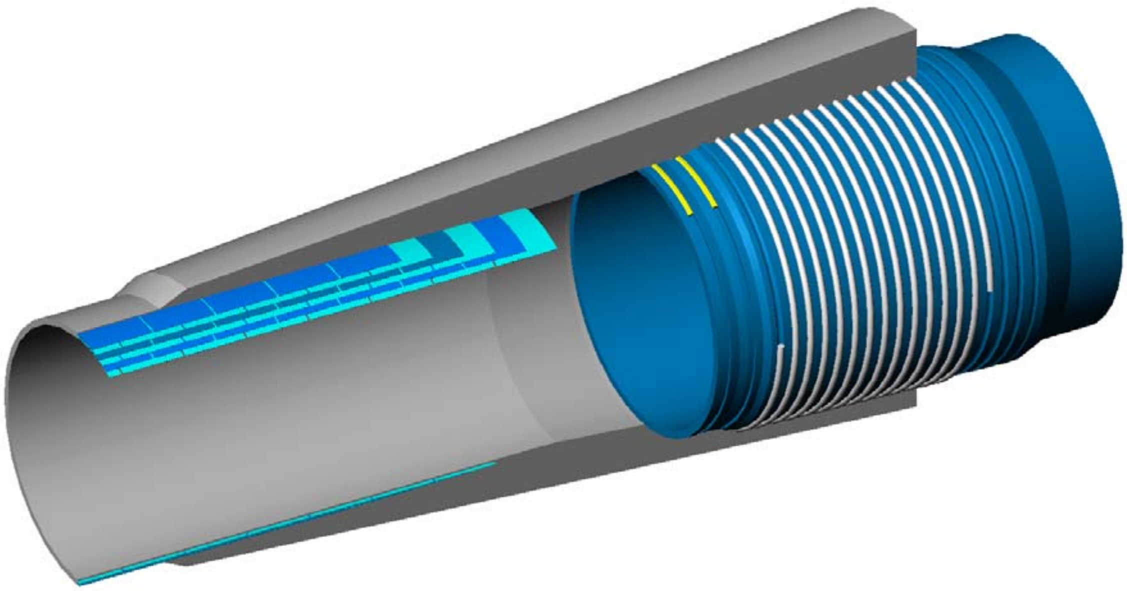


Figure 2. Integral Spigot and Integral Bell Formed by Filament Winding that Fully Encases the Steel Strips and with the Coil-Lock™ Joining System.

A newly-developed Coil-Lock™ joining system, shown in Figure 2, requires no welding and just a few pipe rotations make up a tapered, threaded joint with a ductile spiral locking key. This joining system allows individual pipe sections (12 m, 40 ft long) of pipe to be monitored separately for both external or internal corrosion of the steel strips.

CORROSION MONITORING CONCEPT

Monitoring corrosion of the external surface of steel pipelines using potential or voltage techniques have been used for many years [1]. Monitoring corrosion of steel gas and oil pipelines to determine the state of corrosion is required by law in the United States. The technique requires an electrical connection to the pipeline, a high-input impedance voltmeter, and a reference electrode. The potential (or DC voltage) between the pipe and the reference electrode placed on the ground surface indicates the state of corrosion of the pipeline in the immediate vicinity of the reference electrode. The potential measured is that generated at pinholes or flaws in the coating on the pipeline. Since coated steel pipelines have pinholes and flaws in their coating, corrosion potentials are relatively stable and easily measured. The corrosion occurring at the flaws and pinholes in steel pipelines is mitigated using cathodic protection. Potential measurements also indicate the degree of protection under the influence of cathodic protection.

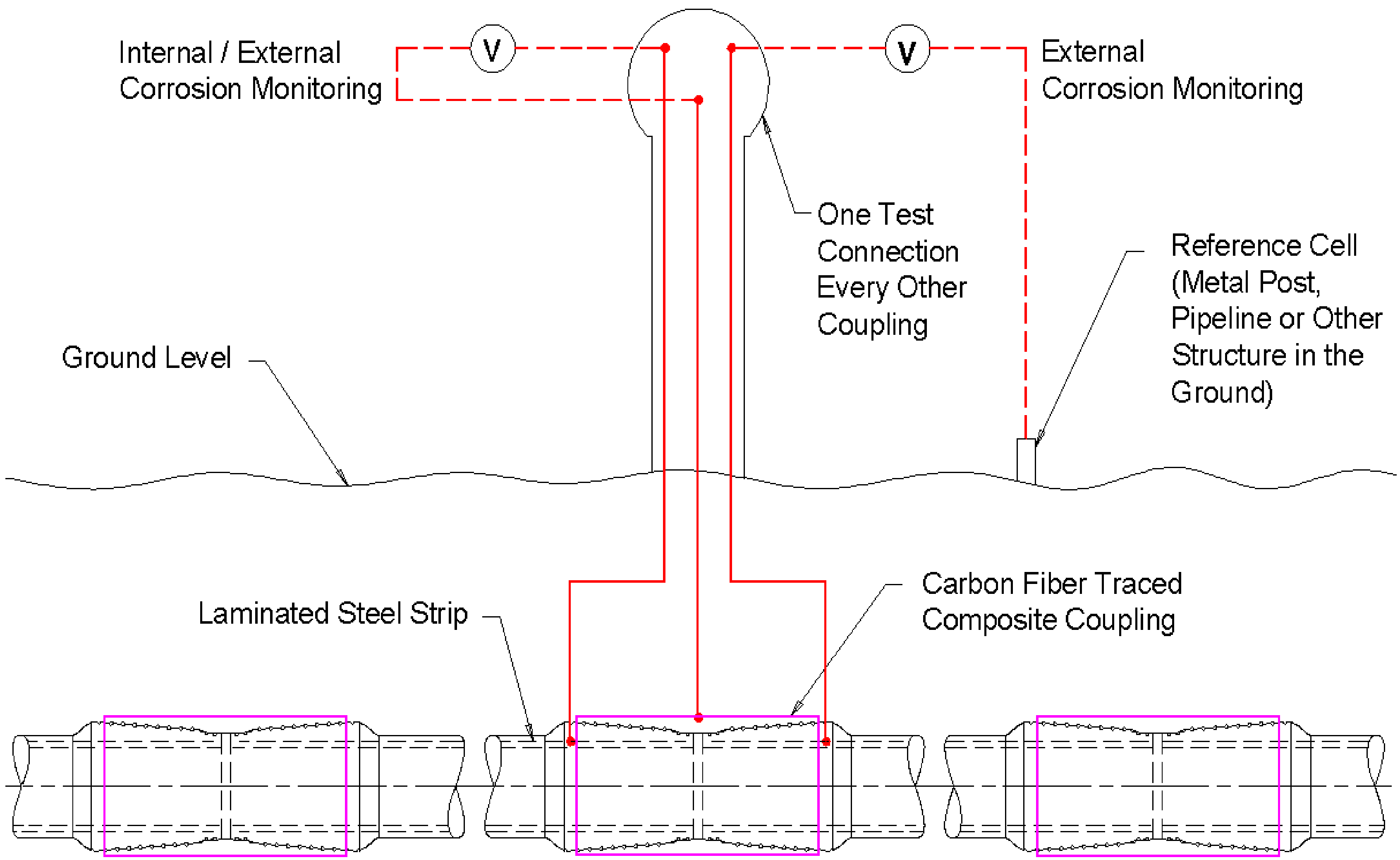
Corrosion monitoring of SSL pipe is unique in that **unstable** potentials indicate that the encased steel is not corroding and that **stable** potentials indicate that the surrounding soil or water or the transported corrosive fluid has reached the steel surface. This patented [2] technique is similar to the potential survey used on cathodically protected steel pipelines and can be used for initial acceptance of the pipeline and for periodically assessing whether external or internal corrosion of individual SSL pipe sections is occurring. By electrically connecting a wire from the encased steel and another wire from a reference electrode to a voltmeter, potential readings can be taken.

MONITORING SSL PIPE FOR EXTERNAL CORROSION

A possible set-up for field monitoring of SSL pipe for external and internal corrosion is shown in Figure 3. During installation, an insulated copper wire is electrically connected to the steel within the fiberglass/resin build-up at one end of the pipe. This connection is then coated to prevent groundwater from contacting the electrical connection. The wire is brought up through the ground and permanently fastened to a test station. A reference electrode, such as a copper-copper sulfate electrode (CSE), is placed on the ground above the pipe section. The reference electrode and the wire connected to the pipe are connected to the positive and negative terminal of a high-input impedance digital voltmeter (>10 Megohms) that has an accuracy of 0.01 mV (4-1/2 digit). The voltmeter is set on its lowest DC voltage scale and the potential between the pipe and the reference electrode is observed.

Figure 3

Set-up for Field Monitoring of SSL Pipe for Corrosion



If the potential changes by more than 0.03 mV during the initial 2 to 5 seconds of connection, the potential is unstable and there is no corrosion occurring to the external surface of the pipe section. Typically, the potential will change erratically if no corrosion is occurring. If the potential stays constant within 0.01 mV during the initial few seconds it takes to observe the reading, the potential is stable and water has reached the external steel surface causing corrosion. The potential of corroding steel is typically between -400 and -750 mV with respect to CSE and constant during the few seconds it takes to read the potential. This negative polarity of the corrosion potential is obtained when the wire from the pipe is connected to the positive terminal of the voltmeter and the reference electrode is connected to the negative terminal. Since the steel within each 40-ft (12 m) length of pipe is electrically isolated from the adjacent section, the individual section of pipe that is corroding can be located with this technique.

A metal post, another nearby pipeline, a chain link fence, or other metallic structure in the ground can also be used as a reference electrode to locate external corrosion on SSL pipe. These metallic objects must have been present for many weeks to months to insure that the potential of the metallic structure is stable, that is, acting as a stable reference electrode.

MONITORING SSL PIPE FOR INTERNAL CORROSION

To determine, but not differentiate, whether external or internal corrosion is occurring, a metallic pipe or fitting or a carbon-fiber traced fitting connected to the SSL pipe and in contact with both the transported corrosive fluid and surrounding soil or groundwater can be used as the reference cell. As shown in Figure 3, during installation, an insulated copper wire is electrically connected to the steel within the fiberglass/resin build-up at one end of the pipe. This connection is then coated to prevent groundwater from contacting the electrical connection. The wire is brought up through the ground and permanently fastened to a test station.

An insulated copper wire is also connected to a metallic pipe, a metallic fitting, or a carbon-fiber-traced composite coupling within the pipeline and brought up to the ground surface and permanently fastened to a test station. This metallic pipe, metallic fitting, or carbon fiber coupling can serve as a reference electrode as explained in the previous section. The wire to the pipe, fitting, or coupling and the wire connected to the SSL pipe are connected to the negative and positive terminals of a high-input impedance digital voltmeter that has an accuracy of 0.01 mV (4-1/2 digit). The voltmeter is set on its lowest DC voltage scale and the potential between the SSL pipe and the electrically conductive pipe or fitting is observed. If the potential changes by more than 0.03 mV during the initial 2 to 5 seconds of connection, the potential is unstable and, therefore, no corrosion is occurring to both the internal AND external surface of the pipe section. Typically, the potential will change erratically if no corrosion is occurring. If the potential stays constant within 0.01 mV during the initial few seconds it takes to observe the reading, the potential is stable and water has reached either the external or internal steel surface or both causing corrosion. However, this technique cannot differentiate between external and internal corrosion. Table 1 is a guideline that can be used to determine whether external and/or internal corrosion is occurring.

TABLE 1
GUIDELINE FOR MONITORING EXTERNAL AND INTERNAL CORROSION OF SSL PIPE

Monitoring Method	Potential	
	Unstable	Stable
CSE or Buried Structure Method	No External Corrosion; Unknown Internal Corrosion	External Corrosion; Unknown Internal Corrosion
Metallic Pipe/Fitting or Carbon Traced Fitting Method	No External Corrosion; No Internal Corrosion	Either External or Internal Corrosion or Both

DIFFERENTIATION BETWEEN EXTERNAL AND INTERNAL CORROSION

To differentiate between external or internal corrosion, a potential must be taken using a reference electrode such as a CSE placed on the ground surface (or another buried metallic structure as explained in a previous section). If an unstable potential is found using the CSE method and a stable potential is found using the conductive fittings, corrosion is occurring internally and not externally. Guidelines to differentiate between external and internal corrosion of SSL pipe are given in Table 2.

Table 2 also indicates that the combination of both external and internal corrosion cannot be determined using the Fitting Method. To determine whether internal corrosion is occurring when external corrosion is also occurring, a corrosion-resistant metallic rod (Interior Metallic Rod Method) can be inserted through the coupling wall at the time of coupling manufacture or pipeline installation and used as the reference cell. The portion of the rod exterior to the coupling must be thoroughly coated to prevent erroneous stable potential readings.

TABLE 2
GUIDELINES TO DIFFERENTIATE BETWEEN
EXTERNAL AND INTERNAL CORROSION OF SSL PIPE

Combined Methods	Potential Stability	External Corrosion	Internal Corrosion
CSE Method with Fitting Method	CSE Method - Unstable Potential; Fitting Method - Unstable Potential	No	No
	CSE Method - Unstable Potential; Fitting Method - Stable Potentials	No	Yes
	CSE Method - Stable Potential; Fitting Method - Unstable Potential	Combination not possible	Combination not possible
	CSE Method - Stable Potential; Fitting Method - Stable Potential	Yes	Cannot determine
CSE Method with Interior Metallic Rod Method	CSE Method - Unstable Potential; Interior Metallic Rod Method - Unstable Potential	No	No
	CSE Method - Unstable Potential; Interior Metallic Rod Method - Stable Potential	No	Yes
	CSE Method - Stable Potential; Interior Metallic Rod Method - Unstable Potential	Yes	No
	CSE Method - Stable Potential; Interior Metallic Rod Method - Stable Potential	Yes	Yes

POTENTIALS OF CORRODING STEEL

The value of the stable potential of corroding steel in SSL pipe will depend on the type of metallic or conductive pipe or fitting being used as a reference electrode. If a mild steel fitting is being used then the potential of the corroding SSL pipe will be approximately 0 mV since the potential of steel in SSL pipe and mild steel should be similar in similar environments. If the fitting is a non-corroding (passive) stainless steel alloy, the potential will be roughly +200 to +500 mV and constant during the few seconds it takes to read the potential. The polarity of the reading is obtained when the wire from the pipe is connected to the positive terminal of the voltmeter and the conductive pipe or fitting, acting as the reference electrode, is connected to the negative terminal.

LOCATION OF CORRODING PIPE SECTION

Since the steel within each 40-ft (12 m) length of pipe is electrically isolated from the adjacent section, the individual section of pipe that is corroding can be located with the above methods. Using both the external and internal methods, internal corrosion can be differentiated from external corrosion.

REFERENCES

1. Peabody, A. W., *Control of Pipeline Corrosion*, National Association of Corrosion Engineers, Houston, TX, 1967.

2. S. C. Hall, U.S. Patent No. 5,529,668, *Detection of Potential for Corrosion of Steel Reinforced Composite Pipe*, June 25, 1996.