STRESS ENGINEERING SERVICES INC.

an employee-owned company

# Evaluation of Underwater Coating Repairs for Enbridge Line 5

## Addendum 1 to Final Report

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# Limitations of This Report

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# Executive Summary

Stress Engineering Services, Inc. (SES) was contracted by Enbridge Pipeline to evaluate an epoxy coating repair system that is being considered for use on a section of Enbridge's Line 5, which runs through the Straits of Mackinac in Northern Michigan. During the initial test program in this project, the proposed repair system—X-100 UW Heavy Duty Epoxy—was applied to representative pipe samples by the supplier, PRT. The simulated repairs were applied while the pipe was submerged in 40°F water having a mineral composition similar to that of the Straits. The hardness of the repaired areas was then tested using a Shore D durometer over 7+ days to document the curing characteristics of the epoxy. The configuration of each repair area was examined using standard metallographic techniques. Additionally, adhesion testing per ASTM D4541 was conducted in both the original and repaired areas of the coating to determine their relative adhesion after full curing. Results of the original testing and evaluation program by SES were fully documented in a report[1] previously submitted to Enbridge.

Subsequent to this earlier water tank testing, Enbridge conducted a field test where a full-scale repair was performed in the Straits. Described as modified method 2 (MM2), a section was repaired at depth in approximately 43 °F water. The repair layers were held in place using a "precast stricture", rather than the 360° full wrap stricture described in our original report. The precast stricture consisted of several layers of the repair fabric and X-100-UW resin that were cured on a 19" pipe in order to have a slightly smaller radius than the 20" pipe of the sample. The "precast stricture" went about 220° around the pipe. Sand bags were attached to the precast stricture and provided the bulk of the force that held the patch repair in place until it was cured. The repair was allowed to cure in place for 7 days.

Enbridge then shipped the sample from the MM2 repair to SES's laboratory and asked SES to evaluate the bonding characteristics of the repair. Results of SES's analysis of samples from this recent MM2 test are documented in this Addendum to the Final Report.

Results indicated that the MM2 repair material was poorly bonded to the pipe surface and did not constitute a successful repair. Any additional testing of the repair was suspended.

[1] See "Evaluation of Underwater Coating Repairs for Enbridge Line 5 – Final Report," SES Document No. 1254493-PL-RP-01 (Rev 0), dated 8 September 2017.



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# 1. Introduction

Stress Engineering Services, Inc. (SES) was contracted by Enbridge Pipeline to evaluate the application of an epoxy repair system that is being considered for use on a submerged length of Line 5, located in the Mackinac Straits of northern Michigan (the "Straits"). During the initial test program in this project, the proposed repair system—X-100 UW Heavy Duty Epoxy—was applied to representative pipe samples by the supplier, PRT of Hempstead, Texas. The simulated repairs were applied while the pipe was submerged in 40°F water having a mineral composition similar to that of the Straits. The hardness of the repaired areas was then tested using a Shore D durometer over 7+ days to document the curing characteristics of the epoxy. The configuration of each repair area was examined using standard metallographic techniques. Additionally, adhesion testing per ASTM D4541 was conducted in both the original and repaired areas of the coating to determine their relative adhesion after full curing. Results of the original testing and evaluation program by SES were fully documented in a report[2] previously submitted to Enbridge.

Subsequent to this earlier water tank testing, Enbridge conducted a field test where a full-scale repair, identified as modified method 2 (MM2), was performed in the Straits. A section of pipe was repaired at depth in approximately 43 °F water. The repair layers were held in place using a "precast stricture", rather than the 360° full wrap stricture described in our original report. The precast stricture consisted of several layers of the repair fabric and X-100-UW resin that were cured on a 19" pipe in order to have a slightly smaller radius than the 20" pipe of the sample, Figure 1. The "precast stricture" went about 220° around the pipe. Sand bags were attached to the precast stricture and provided the bulk of the force that held the patch repair in place until it was cured. The repair was allowed to cure in place for 7 days.

Enbridge then shipped a sample from the MM2 repair to SES's laboratory and asked SES to evaluate the bonding characteristics of the repair. Results of SES's analysis of samples from this recent MM2 test are documented in Sections 2 and 3 of this Addendum.

[2] See "Evaluation of Underwater Coating Repairs for Enbridge Line 5 – Final Report," SES Document No. 1254493-PL-RP-01 (Rev 0), dated 8 September 2017.



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Figure 1: Photograph showing the MM2 repair with precast stricture in place.

# 2. Examination of MM2 Repair

SES examined the pipe that was repaired using MM2 in the Mackinac Straits. The sample as received is shown in Figure 2. Following initial visual examination, SES removed samples for metallographic examination near the center of the repair and at the edge of the fiber wrap over the original coating (Figure 3).



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Figure 2: Photograph showing the as-received pipe sample with MM2.

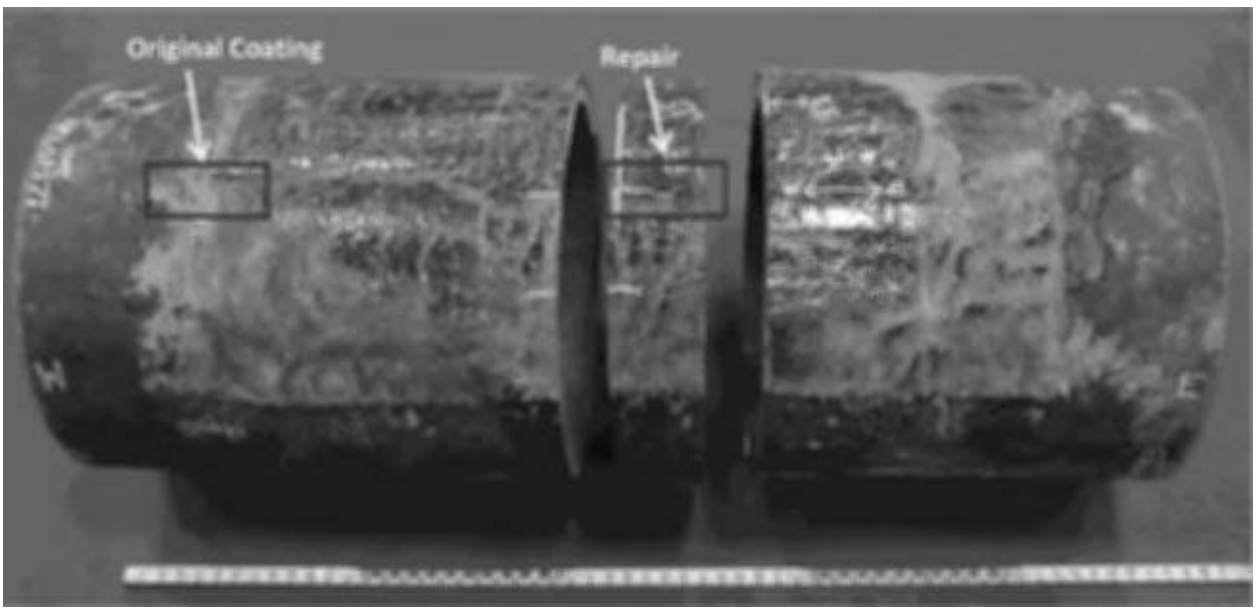



Figure 3: Photograph showing the sections of MM2 repair for metallographic examination.

When the sample taken from the repaired area was further isolated (Figure 4), the repair material disbonded from the pipe OD surface; i.e., there was little to no adhesion between the base filler material and the pipe steel.

Note that the photograph in Figure 4 shows the sample prior to further isolation. No photographs were taken after the repair disbonded.



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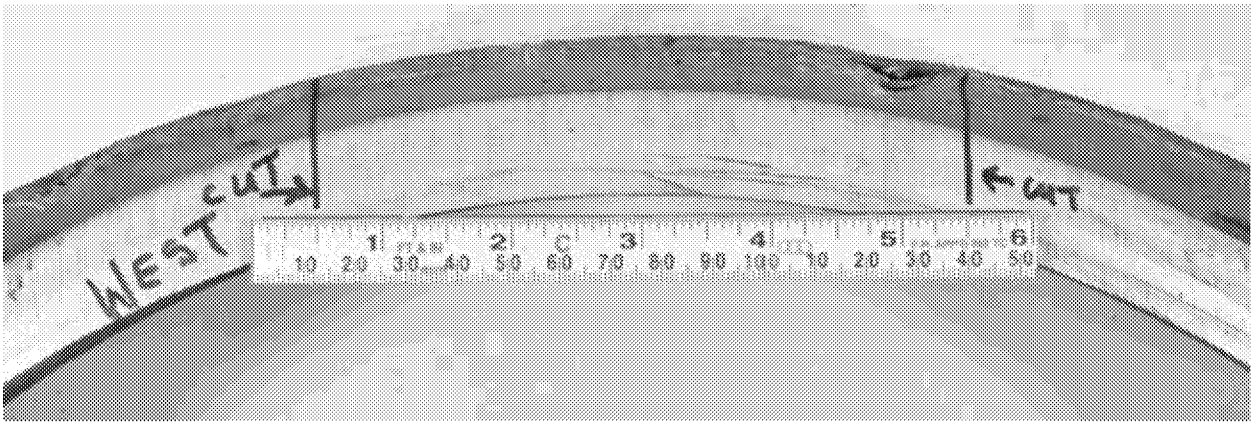



Figure 4: Photograph showing the MM2 repair area (transverse section) isolated for metallographic examination. Coating disbonded from pipe surface upon further cutting.

SES next examined the repair installed over the original coating (see Figure 2). This section exhibited similar disbonding between the layers (Figure 5), with little to no adhesion.

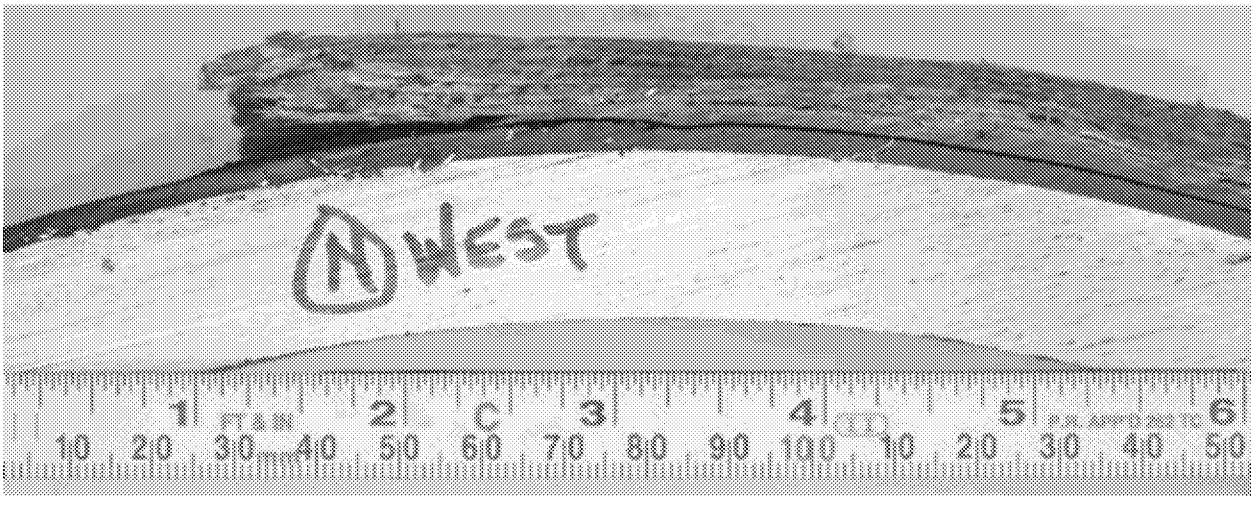



Figure 5: Photograph showing the MM2 repair located over original coating. Repair material was visibly disbonded from original coating.

# 3. ASTM D4541 Coating Adhesion Tests of MM2 Repair

SES completed several ASTM adhesion tests on specimens from the MM2 pipe repair. Results (summarized in Table 1) exhibited a large amount of scatter. While some areas exhibited good adhesion, others showed little to no adhesion. Additionally, as noted in Table 1, several of the adhesion test specimens broke during testing. It is notable that the same types of failures were observed during adhesion testing of some of the repairs completed previously in the water tank.



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**Table 1: Results of ASTM D4541 Coating Pull-Off Strength Tests.**

| Sample Location | Readings (psi) | Average (psi) |
|---|---|---|
| A – Close to mounted section | 106/38/0[1] | 72 |
| B – Opposite side of ring from mount west side of patch | 126/403/311 | 280 |
| C – Transition area; no epoxy, fiberglass on coal tar | 0[1]/0[1]/61 | 61 |
| D – ASTM dolly epoxied directly to coal tar | 163/342/314 | 273 |

Notes: [1] Sample broke during isolation cutting.

# 4. Summary

The MM2 repair procedure, which used a precast stricture rather than the 360° stricture wrap during the epoxy repair cure, was unsuccessful. The epoxy repair material exhibited poor adhesion to the pipe surface in several areas of the patch. Further testing of the modified repair method was then suspended.



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