Final Report

Contractor's Name: Integran Technologies USA, Inc.

Address: 2541-Appletree Drive, Pittsburgh, PA 15241-2587

Contract Number: DTRT57-08-C-10070

SBIR Topic Number, Title: 081-PH1, Pipeline Safety: Development of Tools for In-Field Pipeline Repairs

Project Title: Structural Repair of Steel Piping by In-Situ Sleeving of Nanostructured Materials.

Period Covered by the Report: from January 15, 2009 to March 16, 2009

Principal Investigator, Telephone Number, Fax Number, and E-Mail:
Dr. Virgil Provenzano, 301-675-3730, vprovenzano@integranusa.com

Classification: N/A

Report Narrative:

[Note: while the original schedule called for this project to conclude on March 16th, 2009, a 2-month no-cost extension was requested on February 12th, 2009 and it is expected to be granted. Therefore, the project is anticipated to be concluded in mid-May 2009.]

The objective of this six month Phase I effort is to establish the technical and economic feasibility of a nanotechnology-based repair concept for the specific application area of in-field gas pipeline repair. Preliminary sleeving experiments performed before the onset of this program have shown that the high strength nanocrystalline metal can successfully "fill" cracks in pipeline steel. However, very few proof-of-concept repair patches have been applied to actually degraded pipeline steel sections and the presumed structural reinforcement effect that is expected to be imparted by these high strength nanometal layers has not been yet verified experimentally and properly quantified. Furthermore, information on how much the in-field pipeline repair process will cost is yet to be determined.

The original Phase I proposal was therefore comprised of the following three (3) main tasks:

Task 1 – Proof-of-Concept Demonstration of the Repair Technique: gather degraded pipeline sections from industry contacts, apply nanometal repair sleeves, characterize the crack filling/bridging effect via metallography, and experimentally verify that the nanometal repair patch adhesion to the steel substrate is excellent

Task 2 – Laboratory Scale Mechanical Testing – demonstrate that the nanometal repair patch results in a considerable increase in the strength of the degraded pipeline section.

Task 3 – Preliminary Cost Modeling

1.1. Task 1 – Proof-of-Concept Demonstration of the Repair Technique

The focus of Task 1 is to demonstrate the repair of degraded pipeline steel using patches of high strength nanocrystalline metal. As mentioned in Bi-Monthly Research Progress Report #2, the cracking caused by corrosion damage in the steel pipe section provided by TransCanada PipeLines via Dr. Fraser King (supporting scientist to Integran USA) was not substantial. Hence, the decision was made to create more severe steel pipe damage in an artificial manner to demonstrate the effectiveness of the nanometal sleeving repair technique using the artificially degraded pipeline steel sections.

The first type of artificial damage was a simple 40% wall loss geometry created by mechanically gouging the surface of the pipeline section. Being of a 3/8" (9.5mm) wall thickness, the artificial wall loss measured approximately 4 mm in depth. These gouges were oriented parallel to the pipe length and were generally 1.5" to 2" wide. Since the goal of the program is to restore the mechanical integrity of the degraded pipeline sections, an equivalent strength (thickness x material yield strength) of nanometal was applied to the gouged region. As a rule of thumb, the nanocrystalline metal is approximately twice as strong as the X65 pipeline steel. Therefore, for example, only a 2 mm thick nanometal layer should be required to "replace" a 4 mm thick wall loss in the damaged pipeline section.

A series of practical nanocrystalline metal repair development trials were undertaken using this geometry and a typical example is shown in Figure 1(a) below. Here a 7" x 3" section of pipe has been gouged and subsequently filled in with a 3 mm-thick highly adherent patch of nanometal. A high magnification image of the same sample is shown in Figure 1(b) and Vickers microhardness indentations made on both the steel (bottom) and nanometal patch (top) are shown in Figure 1(c). The relative size of the indentations (made under the same load) is roughly indicative of 2.4 times increase in strength of the nanometal over the X65 steel. The X65 steel microhardness value was ~165 VHN (σ_{UTS} = 77ksi/530MPa) while the nanocrystalline Ni microhardness value was 380-410 VHN (σ_{UTS} = 184ksi/1270MPa). Samples of this geometry are currently being evaluated for Task 2 Mechanical Testing of the project.

As mentioned in Bi-Monthly Research Progress Report #2, David McColske of NIST Boulder (Material Reliability) has also kindly offered to provide cracked pipeline sections to Integran. David has shipped two 12"x12" sections to Integran. Unfortunately, the Magnetic Particle Inspection (MPI) powder has worn off and the cracks in the pipeline sections cannot be pinpointed either by the naked eye or via optical microscopy. These pipe sections are presently being MPI'd by a third party in the hope that they can be used for this program. In the event that the cracks are unsuitable, David has offered another pipeline steel section for shipment to Integran.

Figure 1 – (a) artificially degraded (gouged) X65 pipeline steel section filled with a 3mm-thick nanometal patch; (b) higher magnification cross-sectional image; (c) microhardness indentations on the steel (bottom, 165 VHN) and nanometal (top, 380-410 VHN) indicating that the nanometal is roughly 2.4x stronger than the pipeline steel substrate.

Task 2 – Laboratory Scale Mechanical Testing

The original Phase I Task 2 Workplan called for burst testing of the repaired pipeline samples produced in Task 1. However, through dialogue with Dr. Fraser King and members of the pipeline industry, a consensus was reached that burst testing is much too costly and therefore unfeasible to be carried out as part of the current Phase I effort. This view was echoed by Mr. James Merritt (DoT) in our Integran USA-DoT meeting of December 11th, 2008. Subsequent to that meeting, a program of simple 3-point bend testing of nanometal-coated cracked pipeline steel coupons was undertaken using an apparatus similar to that shown in Figure 2, below.

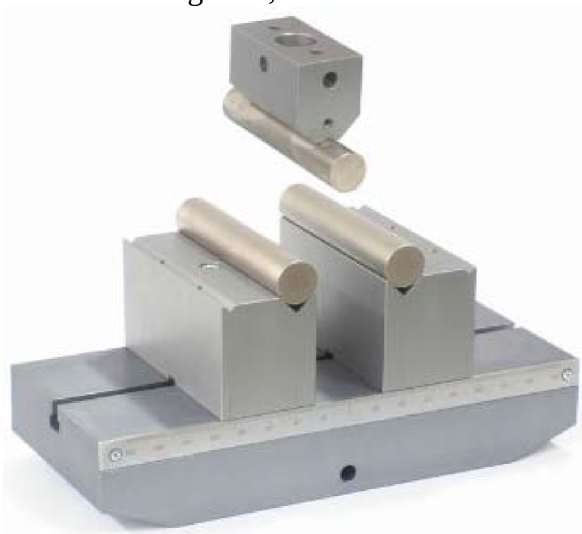

Figure 2- 3-point bend test apparatus (image from: www.testresources.com);

The primary goal of this task has been to demonstrate on a proof-of-concept scale that thick, highly adherent nanocrystalline metal patches can restore mechanical strength to X65 pipeline steel sections that have experienced severe wall loss. Strips were cut from the pipe such that the longest dimension of the strip samples were oriented perpendicular to the direction of gas flow in the pipe. As all the strip samples exhibited some degree of curvature, the samples were bent *with* the natural bend of the pipe. This is illustrated in Figures 2(b) and (c). The sample set is as follows:

1. As-received X65 steel (full 3/8" wall thickness - see Figure 3 (top))
2. As-received X65 steel with ~40% wall loss (see Figure 3 (bottom(a) 3-point bend test apparatus (image from: www.testresources.com););)
3. As-received X65 steel with ~40% wall loss + Nanometal patch

Mechanical testing commenced last week and it is anticipated that a demonstration of the structural reinforcement effect imparted by the nanometal layer will be available by the end of the project.

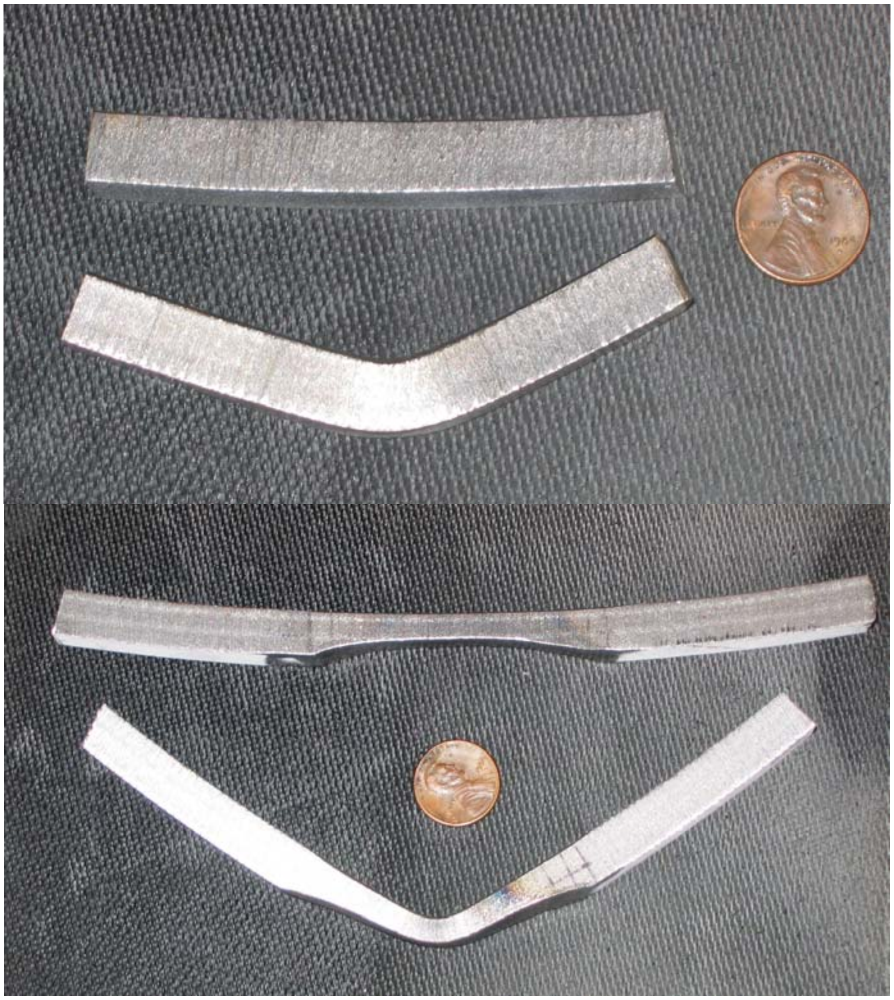

Figure 3 –(top) "as-received" X65 steel strip sample before and after bending; (bottom) "as-received+40% wall loss" X65 steel strip sample before and after bending.

1.2. Task 3 – Preliminary Cost Modeling

No activity so far.

1.4 (a) 3-point bend test apparatus (image from: www.testresources.com); **Project Future Plans**

The following are our plans for the final two months of this SBIR Phase I project:

1. Carry out 3-point bend testing of nanometal-coated cracked pipeline steel samples
2. Task 3 cost modeling