NIST Special Publication 1044

Advanced Coatings R&D for Pipelines and Related Facilities

The proceedings of a workshop held
June 9-10, 2005 at the
National Institute of Standards and Technology,
Gaithersburg, MD 20899 USA

Edited by:
Richard E. Ricker

Sponsored by:
The Office of Pipeline Safety
U.S. Department of Transportation
Pipeline and Hazardous Materials Administration

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American Gas Association
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Technology Administration
Phillip J. Bond, Under Secretary for Technology

National Institute of Standards and Technology
William Jeffrey, Director

Preface

The first suggestion that a workshop be held at NIST on pipeline coatings was made at the February 2005 meeting of the Pipeline Safety Coordination Council. Since NIST is a popular location for meetings, reservations were made immediately for the only dates available for the summer of 2005. The normal delays in obtaining approvals prevented final approvals until mid April. A Steering and Advisory Committee, which was assembled immediately; deliberated and decided to hold this meeting on the originally scheduled dates of June 9-10, 2005. This was an ambitious goal, as it left the committee only a little over two months to organize the meeting. The contributions of the steering committee to the organization of this meeting cannot be over emphasized. The success of this meeting is largely due to the contributions of this committee.

Preparing a successful meeting with little time requires three things. First, a steering committee is necessary to help organize the sessions, identify speakers, and promote attendance. Second, a good location and excellent support staff are vital. Knowledgeable attendees, insightful discussions, and considerate debate complete the third requirement. Fortunately, this meeting had all three. This meeting would not have happened without the efforts of the steering committee and I express my sincere gratitude to the members of this committee for their contributions. In addition, I thank Kathy Kilmer of the NIST Conference and Facilities Division who made dealing with the planning details a pleasure. I also thank all who attended for their contributions and their willingness to openly present and discuss their issues and opinions. Finally, I thank the Office of Pipeline Safety (OPS) for providing support for this meeting and to J. Merritt and R. Smith of OPS for serving on the Steering Committee and for their innumerable contributions to the success of this meeting.

I dedicate this volume to my father, who became terminally ill shortly before this meeting. Harry H. Ricker, Jr. (May 13, 1917-Aug. 4, 2005) was one of the hundreds of NASA engineers who helped put man in space. According to the history of NASA website (www.hq.nasa.gov/office/pao/History), he was one of the 45 people transferred to the manned space program when it was founded in 1958. As Head of the On Board Systems Branch in 1959, he sat on NASA's New Projects Panel, which proposed following the manned satellite program with a program to construct a three person spacecraft to travel to the moon and identified 1970 as a reasonable target date for a lunar landing. He spent most of his career studying reliability and safety; and while he worked on very different systems, he would have appreciated the subject and goals of this meeting.

- Richard E. Ricker

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Executive Summary

In the early 1920s, the National Bureau of Standards initiated a study into the underground corrosion of uncoated steel pipes. Very early in this study it became clear that coatings would be required for some environments, and a second study of coated pipes was initiated immediately. Pipeline coatings have been the subject of research and development ever since, and coatings, coating application methods, in-field application and repair technologies, and inspection technologies have evolved dramatically since these first studies. Today, a wide variety of high-quality coating systems are available for new pipeline construction, but the existing infrastructure of pipelines is protected with a wide range of coating types with varying ages. Therefore, the R&D needs of the pipeline community with respect to coatings ranges from testing protocols for evaluating new coatings and standards for quality control, to methods for evaluating of the performance and remaining life of coatings in service and remediation. The objective of this workshop was to bring the pipeline community together to discuss, identify, and prioritize coating R&D needs for improving the safety of pipelines.

This workshop was held at the National Institute of Standards and Technology's Gaithersburg Maryland campus June 9-10, 2005 with support from the Office of Pipeline Safety of the U.S. Department of Transportation. To organize this meeting, a steering committee was assembled that was composed of 20 representatives from the pipeline industry, industry consortia, pipeline standards developing organizations, government agencies, and regulatory agencies from the US and Canada. This committee planned the agenda, identified speakers, determined the number and nature of the working groups, and helped promote attendance. The workshop had 56 registered attendees representing pipeline operators, coatings manufacturers, pipeline fabricators, pipeline industry consortia, standards developing organizations, universities, government agencies, and regulatory agencies. The workshop consisted of 14 presentations on US and Canadian standards, current research, operating experience, and failure mechanisms followed by break out into four working groups to identify, discuss, and prioritize research needs. The working groups reported their findings. The workshop concluded with a summation and tours of laboratories at NIST conducting pipeline relevant research.

The workshop started with a presentation of the workshop goals, followed by a report on the findings of the most recent related workshop on offshore coatings. These presentations were then followed by a review and summary of existing coating standards and standards under development including their status and utility. Presentations on ongoing research into coatings performance and test methods followed along with presentations on owner-operator experience and a survey of coating failure modes observed in the field. Three issues were frequently raised throughout during these presentations. First, coating performance depends on the environment. The optimum coating for one environment may perform unsatisfactorily in another environment. Therefore, understanding the service environment and the range of conditions that the coating will be exposed to; not just in service, but during shipping, storage, and handling, is a very important step in optimizing performance. Second, since accelerated laboratory tests are used for coating development and selection, the coatings are actually optimized for performance in these tests and not necessarily for performance in service. Performance in service is optimized only if these tests accurately represent conditions in service or otherwise allow evaluation of the relative rates of the processes that limit performance in service for different types of coatings. Therefore, the design, development, evaluation, and standardization of better test methods will yield improvements in performance. Third, actual in-service failures almost always occur at flaws in the coatings. This indicates that the failure rates are related to the coating flaw size distribution and the ability of the coating system to resist the propagation of corrosion at coating flaws instead of the inherent degradation mechanisms of the as-designed coating system. As long as failures occur at preventable flaws, improvements in coating application technologies and quality control will yield improvements in performance. Comparisons were frequently made to welds, where recent developments in welding technology, standards, and practices have dramatically reduced failure rates.

After the presentations, the workshop broke up into four working groups to discuss and evaluate R&D needs in different areas:

(I) Coatings Test Methods and Materials Development,
(II) Coating Application Technologies and Quality Control (Mill Applied),
(III) Coating Identification, Inspection, and Evaluation Technologies, and
(IV) In-Field Technologies for Joint, Repairs, and Rehabilitation.

These working groups met in the afternoon of the first day to identify and discuss the issues and then in the morning of the second day to evaluate and rank the identified issues. Each group identified five critical issues:

(I) Coatings Test Methods and Materials Development,

1. Short Term Laboratory Tests to Determine Long Term Performance in the Field,
2. Modeling Tools for Predicting Long Term Field Performance,
3. Database of Coating Performance in the Field,
4. Smart Coatings (Sensors for Detecting Coating Failure), and
5. Mechanism of Cathodic Disbondment.

(II) Coating Application Technologies and Quality Control (Mill Applied),

1. Database of Coating Failures and Mechanisms,
2. Effect of Coating Application Methods on Properties of Steels,
3. Better Characterization of Service Conditions,
4. Relationships Between Application Parameters and Performance, and
5. Universally Accepted Standard(s) for Pipeline Coatings.

(III) Coating Identification, Inspection, and Evaluation Technologies,

1. NDE Tools and Models for Inspection and Characterization of Flaws,
2. Coatings Life-Cycle Database (Exposure Conditions and Performance),
3. Standardized Tools, Procedures, and Training,

4. Better Understanding of Interactions between Welds and Coatings, and
5. Smart Coatings (coatings designed to aid inspection and evaluation).

(IV) In-Field Technologies for Joint, Repairs, and Rehabilitation,

1. Database of Coatings Formulations, Technical Data, Procedures, and Expiration,
2. Evaluations of Abrasive Blast Materials and Development of Selection Guides,
3. Standardized Applicator and Inspector Certification and Training,
4. Selection Guides for Coatings and Repairs, and
5. NDE Tools for Coatings and Evaluation of Corrosion Under Coatings.

The reports of the working groups are included in the workshop proceedings, and they contain more descriptive information on the nature of these issues, as well as other needs that were not ranked as highly. One should refer to these reports for more detailed information or description.

After the working groups reported their findings, the workshop concluded with a brief summary of the objectives, purpose, and findings by J. Merritt of the Office of Pipeline Safety. Following the conclusion of the workshop, participants toured the NIST laboratories conducting research relevant to pipeline safety concerns. More details on the findings and conclusions of the working groups can be found in the working group reports sections of this proceedings (pages 239-251) or from the Office of Pipeline Safety website http://primis.phmsa.dot.gov/rd/mtg_060905.htm, where the sections of this proceedings are available for download.

Summary of Findings

The Chairs of the Working Groups reported the findings of each group, and the entire workshop discussed them. The workshop made no attempt to develop overall rankings of the individual issues or needs identified. Frequently, different groups identified similar or related R&D needs. These needs were rarely identical, and sometimes working groups combined similar or related topics while others did not. In addition, some working groups avoided discussing and ranking topics clearly in the area of other groups. For these reasons, and since the purpose of breaking the workshop up into smaller working groups was to identify specific needs, developing overall quantitative rankings on the basis of numerical analysis of the frequency of appearance or average ranking was inappropriate. Therefore, one should refer to the individual working group reports on pages 239-251 (also available at http://primis.phmsa.dot.gov/rd/mtg_060905.htm) for detailed analysis, description, comparison and ranking of the individual topics identified by the working groups. For this summary, the topics were sorted by the nature of the proposed R&D and then similar or related projects grouped until a relatively small number of categories could be identified for discussion.

The working groups were instructed to identify the basic nature of the R&D need by classifying the type of work to be performed into one of three areas:

(1) development of knowledge or scientific understanding,
(2) development of new technology or tools using existing knowledge, and
(3) development of standards and databases.

Of course, most R&D projects will contain elements of all three types of work, but the working groups were asked to make this assessment based on the primary nature of the work performed in the project. The R&D needs identified by the working groups were sorted according to the type of work proposed and then grouped to form categories. These categories were then ranked based on the average rankings of the topics in the categories under each type of work. This created a crosscutting view of the workshop findings.

1. Development of Knowledge or Scientific Understanding

1.1 Methods for Testing and Prediction of Coating Performance in Service

The objectives of the R&D topics in this category are to develop standardized and universally accepted testing methods that can be used to accurately predict the service life of different coatings or coating systems in the pipeline service environment. These test methods and subsequent laboratory measurement-based life-prediction models are needed to enable other R&D projects to be conducted in a reasonable time with reliable results. In addition to the development of better mill and field applied coatings, these test and life prediction methods are required to enable better coating selection and life cycle cost analysis. It was clear at this workshop that this community does not consider the existing test methods sufficient to meet their R&D needs. It is currently impossible to develop reliable test methods because the understanding of the degradation mechanisms of coatings in service is insufficient.

1.2 Evaluation of the Influence of Processing Variables on Performance

Research topics were suggested that involved measuring and evaluating the influence of environmental and loading variables on coating performance. Loading variables included (a) soil stresses, (b) cyclic stresses, (c) thermal stresses, (d) residual stresses (e) stresses at welds, (f) residual stresses in the coating (curing stresses), (g) unusual event stresses, and (h) changes in stresses in the coating during aging of the coating or coating systems. The environmental variables included the normal range of pH, temperature, salt concentrations, found in ground waters. Extreme conditions could also be investigated, such as those encountered in mining or industrial by-products or the hydrocarbons that the coating might be exposed to if a leak occurred elsewhere and contaminated the back fill.

1.3 Effects of Loading and Environmental Variables on Performance

Research topics were suggested that involved measurement and evaluation of the influence of environmental and loading variables on coating performance. Loading variable suggested for study included (a) soil stresses, (b) cyclic stresses, (c) thermal stresses, (d) residual stresses (e) stresses at welds, (f) residual stresses in the coating (curing stresses), (g) unusual event stresses, and (h) changes in stresses in the coating during aging of the coating or coating systems. The environmental variables included the normal range of pH, temperature, salt concentrations, found in ground waters, but it was also suggested that extreme conditions be investigated such as one would encounter in mining or industrial by-products or the hydrocarbons that the coating might be exposed to if a leak occurred elsewhere and the back fill became contaminated.

1.4 New Materials Research

The working group discussions suggested that there was still considerable interest in developing new coating materials that resist degradation and failure better than existing coatings and coating systems. Concerns were expressed that coatings development research is limited by the available accelerated test methods. In addition to standard coating development, new materials research into (a) non-metallic pipes, (b) special coating or shielding materials for extreme conditions, (c) multilayer and multifunctional coatings, (d) improved materials for repairs (coatings, sleeves, and patches), and (e) improved materials for seams and welds. For in-field repairs and weld seam coatings, this area overlaps technology development as the objective shifts to developing in-field application techniques for coating materials that are essentially identical to those developed for mill application.

2. Development of new technology or tools using existing knowledge

2.1 Better NDE Tools and Techniques

While this category did not dominate the discussion of any particular working group, all discussed it and raised NDE-related topics that fit into the knowledge, technology, and standards development areas. Some suggested development of standards for interpreting and guiding decision making based on NDE results. Others suggested developing new NDE tools and technologies or models for predicting signals from defects of known types. In addition to enabling better detection and identification of coating failures, NDE tools should be developed to (a) identify unknown coating materials, (b) assess the extent of coating degradation and estimate remaining service life, and (c) inspect multilayered coating systems. Inspecting the outside surface coating of a pipe from an NDE device mounted on a pig inside the pipe is extremely attractive. The suggestion with the greatest potential for wide ranging impact is that of developing a technique for non-intrusively assessing the extent of polymer degradation (as opposed to finding flaws or defects). This would enable estimation of remaining life of a coating and the development of reliable accelerated laboratory testing methods as discussed above in R&D category 1.1.

2.2 Smart Coating Systems

The importance of NDE to pipeline safety should not be understated. However, no one sets out to design a system that will require frequent or costly NDE inspections. One approach to reducing NDE inspection costs is to design a coating system that either enables easier, quicker, and cheaper inspection or continuous monitoring. These coatings could integrate sensors or be designed such that some property, which can be remotely monitored or periodically inspected, changes when failure initiates. A less ambitious approach is to design a coating system that assists or makes it easier for existing NDE techniques to find and identify flaws or regions of coating failure.

2.3 New and Improved Repair Technologies

In addition to materials development, the workshop participants identified new or improved technologies for in-field repairs for both newer and old coatings as R&D needs. Research topics included (a) techniques to remove old coatings, (b) in-field surface cleaning and preparation techniques, (c) sleeves and other innovative repair technologies, and (d) development of better procedures.

2.4 New and Improved Coating Techniques for Weld Joints

Welds represent discontinuities in the surface of the steel pipe. In-field joint welds being less consistent than seam welds they represent a greater challenge. The development of special coating techniques and procedures that ensure good quality, lasting coatings over these regions were deemed a special problem worthy of study separate from other coatings issues by many of the attendees. The larger stresses in the coatings and the irregularities in the coating to steel interface at these joints place greater demands on the coating system.

3. Development of standards and data

3.1 Coatings Databases

Virtually every group suggested a coating database of one type or another at some point in their list of suggested R&D topics. Databases should be developed six areas: (a) coating technical data, (b) coating repair matrix of techniques for different situations and experience, (c) coating repair experience, (d) coating field performance (life-cycle data), (d) NDE analysis techniques, (e) failure analysis techniques (forensics) and identification of failure mechanisms, and (f) coating failures.

3.2 Standardized Training

The development of standardized training of mill and field applicators and inspectors is the topic area where investment will have the highest probability of positive benefit. However, the rate of return must not be attractive enough to prevent underinvestment in this area. Specialized and standardized training are necessary in (a) mill and field application of coatings, (b) handling of coated pipes, (c) coating of weld joints, (d) field repairs, (e) information resources on coatings and procedures (i.e. the coating repair technology matrix discussed above), and (f) safety in both the mill and the field.

3.3 Improved Standards for Performance Testing and Life Prediction

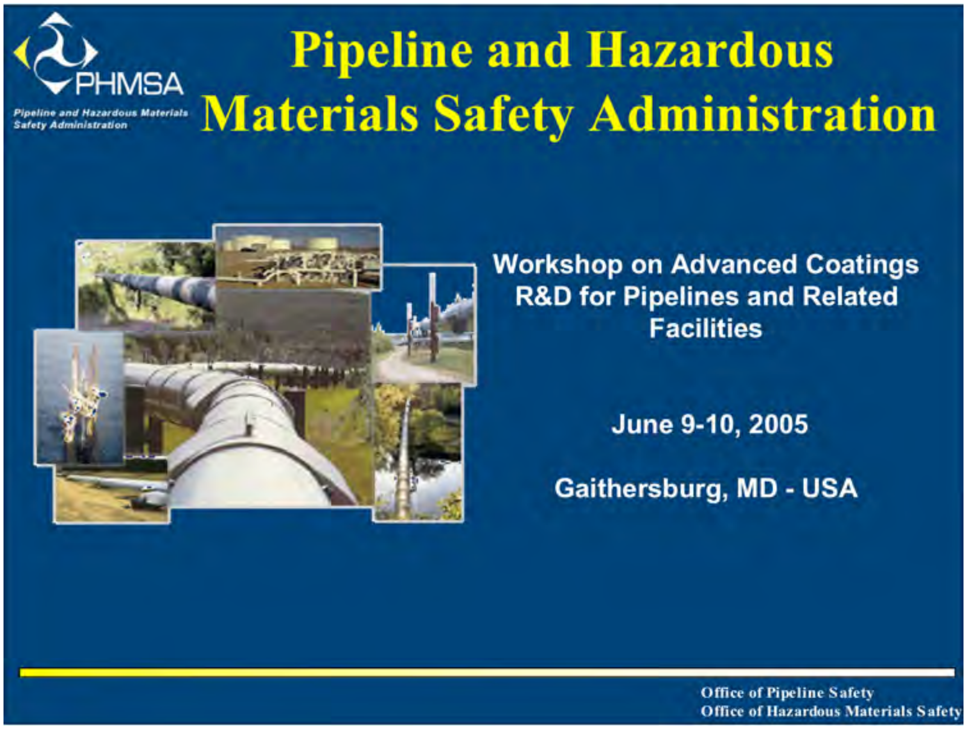
Development of a definitive accelerated laboratory test method may require considerable time. In addition, it will almost certainly take years of tests and field experience to prove the effectiveness of any new technique to the point of universal acceptance and standardization. Therefore, the community will continue to use the existing standardized test methods for the foreseeable future. A conservative industry will have considerable overlap when both new and old techniques are used. Continual evaluation and updating of the existing standards was suggested. The review presented by Papavinasam and Revie in this workshop illustrates this point. The pipeline industry will realize considerable benefit by improving these techniques and standards.

3.4 Pipeline Coatings User Group and Data Sharing

Workshop participants advocated forming a pipeline coatings users group to develop recommendations for recording pipeline handling and coating performance data. Many of the database and standardization suggestions require pipeline users to provide information on the performance of their pipelines. Clearly, many of the database suggestions will occur more easily if the pipeline operators take the initiative and formulate the approaches. At this meeting, representatives from NACE International offered to facilitate the organization of this users group. NACE International is a

Standards Developing Organization with a long history of working with and helping the pipeline industry.

This workshop successfully identified and ranked R&D needs and challenges for improving the performance of pipeline coatings. The needs were identified and ranked by each working group according to the defined scope of their group. These needs were then gathered, sorted, combined, and ranked into the above crosscut according to nature of the work required to fulfill the need. This crosscut should enable the identification and description of programs without inhibiting creativity in the formulation of specific projects. The pipeline safety community should find this documentation of pipeline coatings R&D needs useful and a good source for helping prioritize R&D investment in this critical area.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Workshop on Advanced Coatings R&D for Pipelines and Related Facilities
June 9-10, 2005
Gaithersburg, MD - USA
Office of Pipeline Safety
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WELCOME
WELCOME from " Our Steering Committee
First (on-shore) Advanced Coatings Workshop
Building on Past workshop and forum success
Consensus, Coordination & Collaboration
Today's Approach: Contest, Brainstorming, & Gap Analysis
Safety and Comfort Announcements
Fire Exits, Restrooms, Cell Phones
Show of Hands Please
Government, Industry, Vendors
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Steering Committee Members
Government Organizations
• DOT Office of Pipeline Safety (OPS)
• DOC National Institute of Standards and Technology (NIST)
• DOI Minerals Management Service (MMS)
• DOE National Energy Technology Laboratory (NETL)
• National Energy Board of Canada
• CANMET Materials Technology Laboratory
Private Organizations
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• Pipeline Research Council International, Inc. (PRCI)
• National Association of Corrosion Engineers (NACE)
• Gas Technology Institute (GTI)
• Interstate Natural Gas Association of America (INGAA)
• ASTM
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Why are we here?
Corrosion still remains a major cause of accidents
Coatings are important - Some consider coatings as the primary cathodic protection system
Coating durability, application, and in-field assessment remains suspect
Desire for solving coating issues usually ends up as low priority at larger events
Problems with coatings are seen onshore, offshore & internationally
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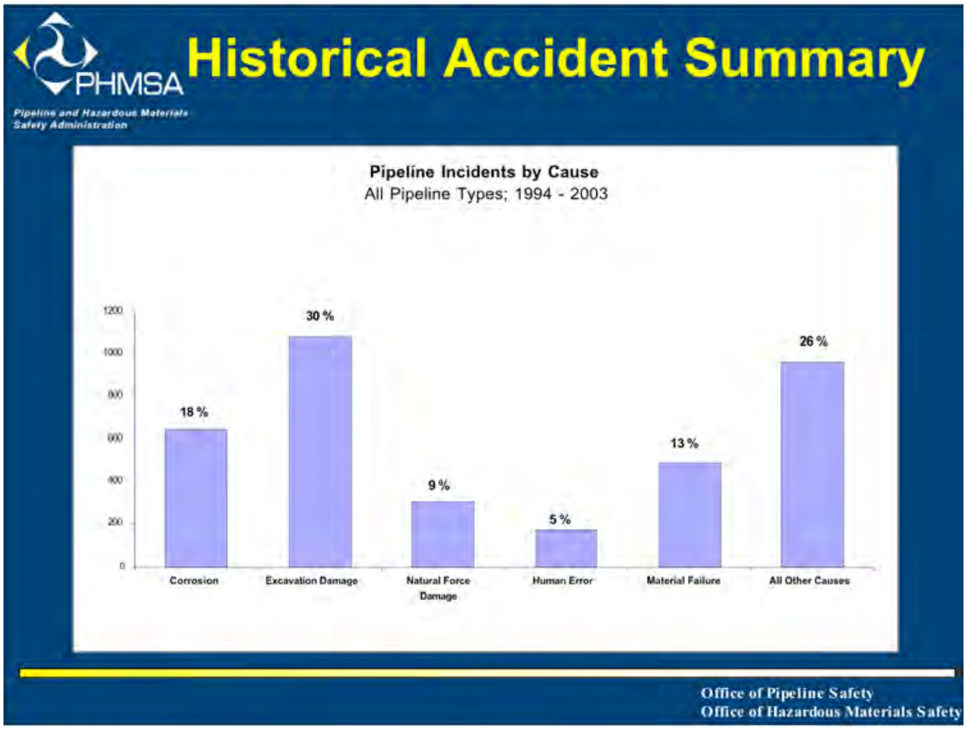
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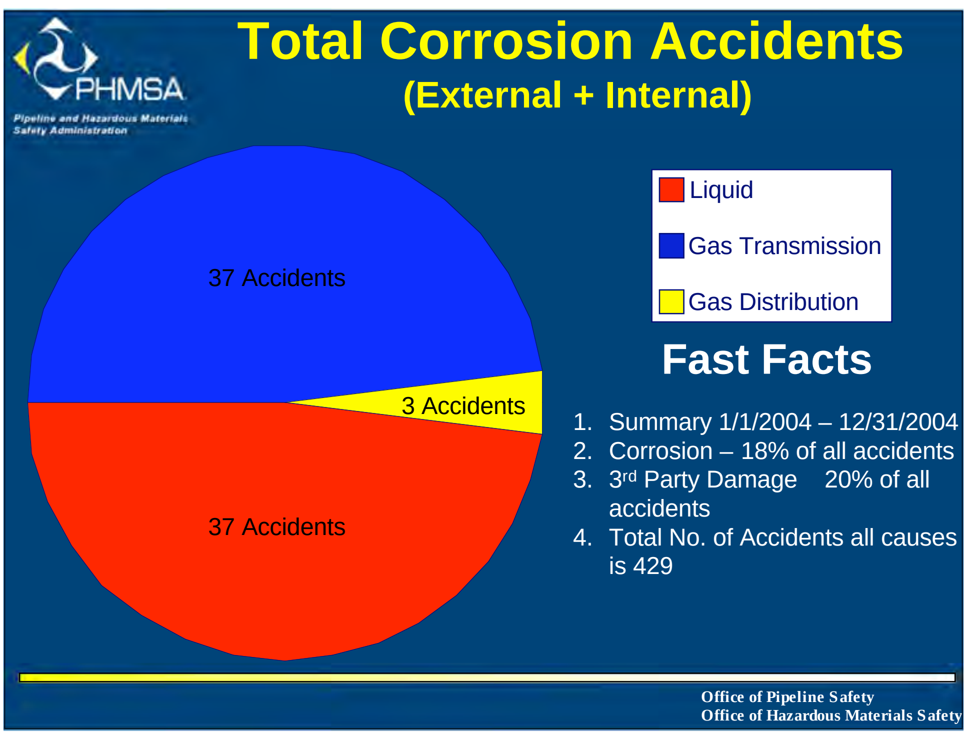
Historical Accident Summary
Pipeline Incidents by Cause
All Pipeline Types; 1994 - 2003
1200
1000
800
600
400
200
0
18 %
30 %
9 %
5 %
13 %
26 %
Corrosion
Excavation Damage
Natural Force Damage
Human Error
Material Failure
All Other Causes
Office of Pipeline Safety
Office of Hazardous Materials Safety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Total Corrosion Accidents
(External + Internal)
37 Accidents
3 Accidents
37 Accidents
Liquid
Gas Transmission
Gas Distribution
Fast Facts
1. Summary 1/1/2004 – 12/31/2004
2. Corrosion – 18% of all accidents
3. 3rd Party Damage 20% of all accidents
4. Total No. of Accidents all causes is 429
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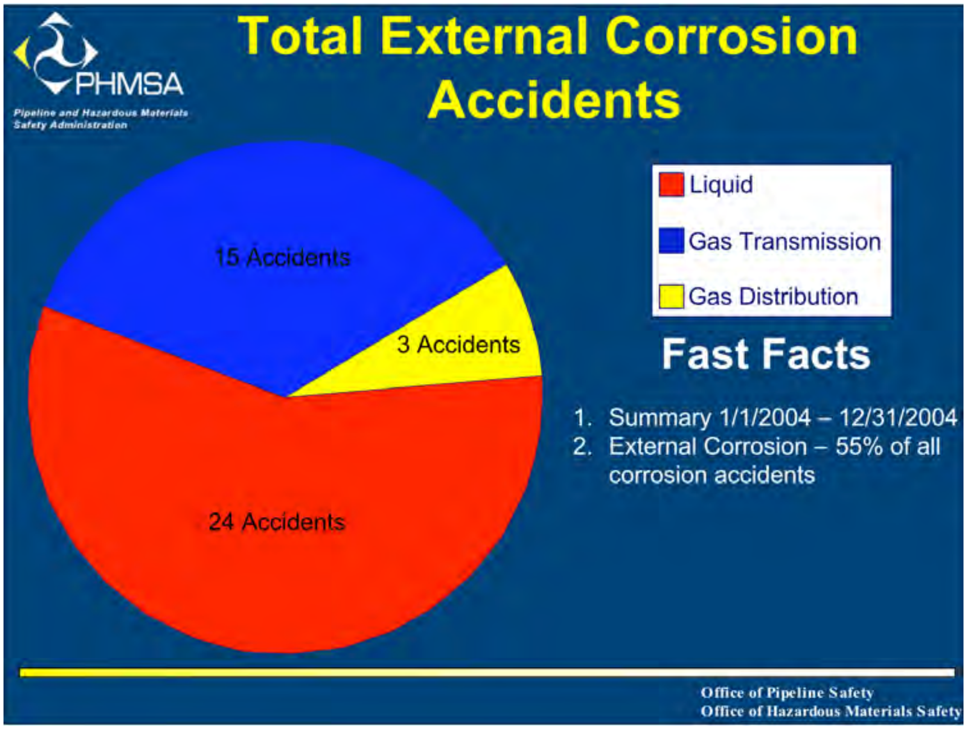
Office of Hazardous Materials Safety


PHMSA
Pipeline and Hazardous Materials Safety Administration
Total External Corrosion Accidents
Liquid
Gas Transmission
Gas Distribution
15 Accidents
3 Accidents
24 Accidents
Fast Facts
1. Summary 1/1/2004 – 12/31/2004
2. External Corrosion – 55% of all corrosion accidents
Office of Pipeline Safety
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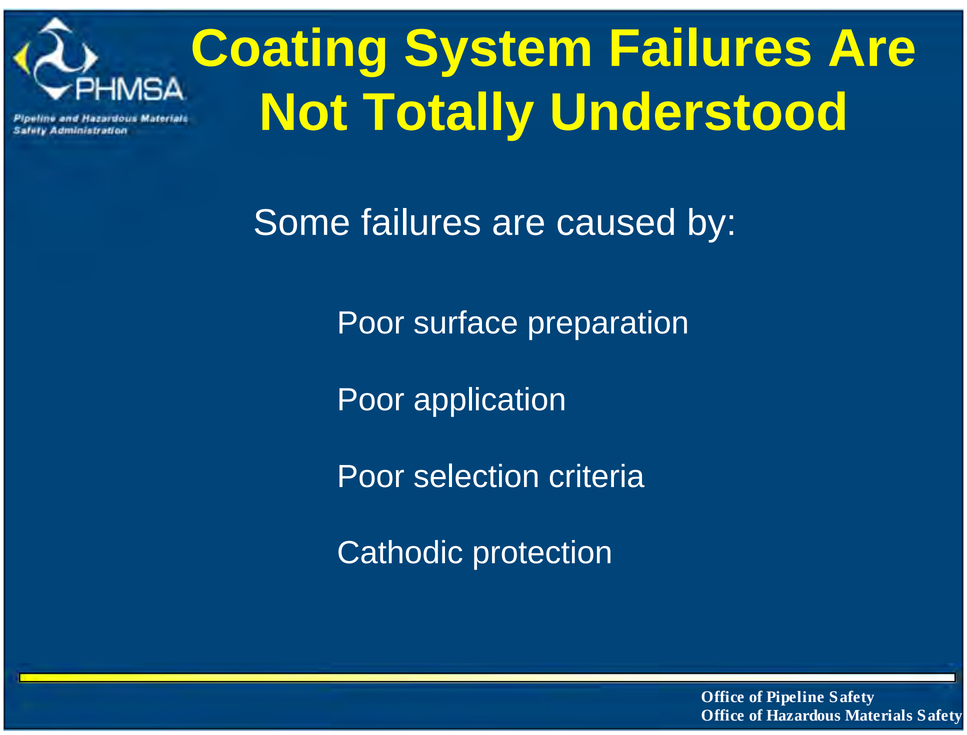
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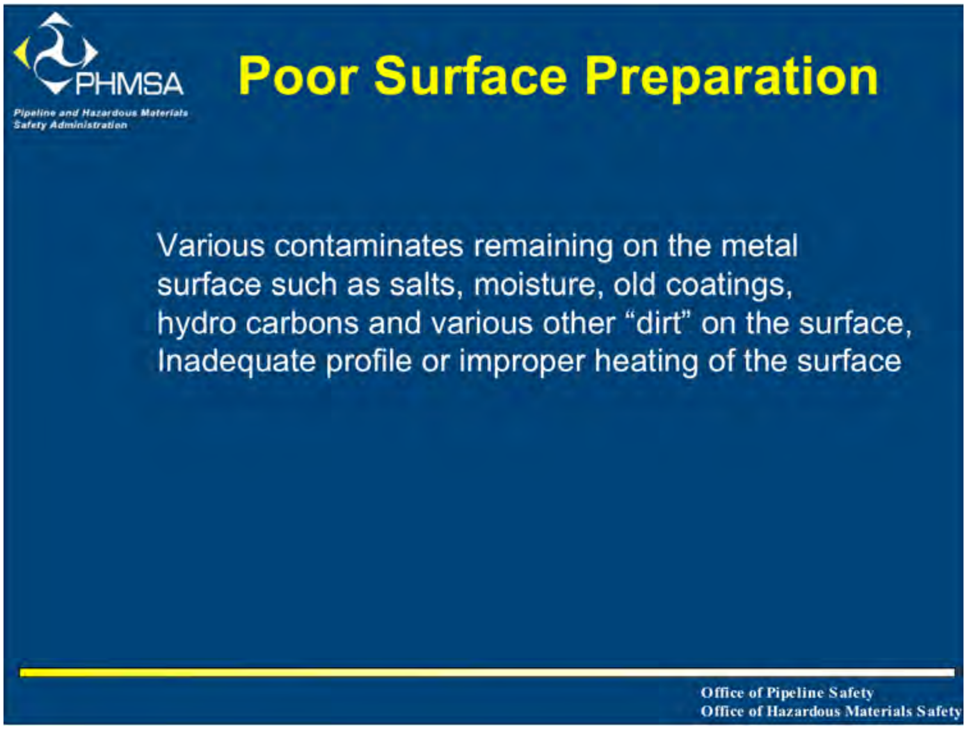
Coating System Failures Are Not Totally Understood
Some failures are caused by:
Poor surface preparation
Poor application
Poor selection criteria
Cathodic protection
Office of Pipeline Safety
Office of Hazardous Materials Safety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Poor Surface Preparation
Various contaminates remaining on the metal surface such as salts, moisture, old coatings, hydro carbons and various other "dirt" on the surface, Inadequate profile or improper heating of the surface
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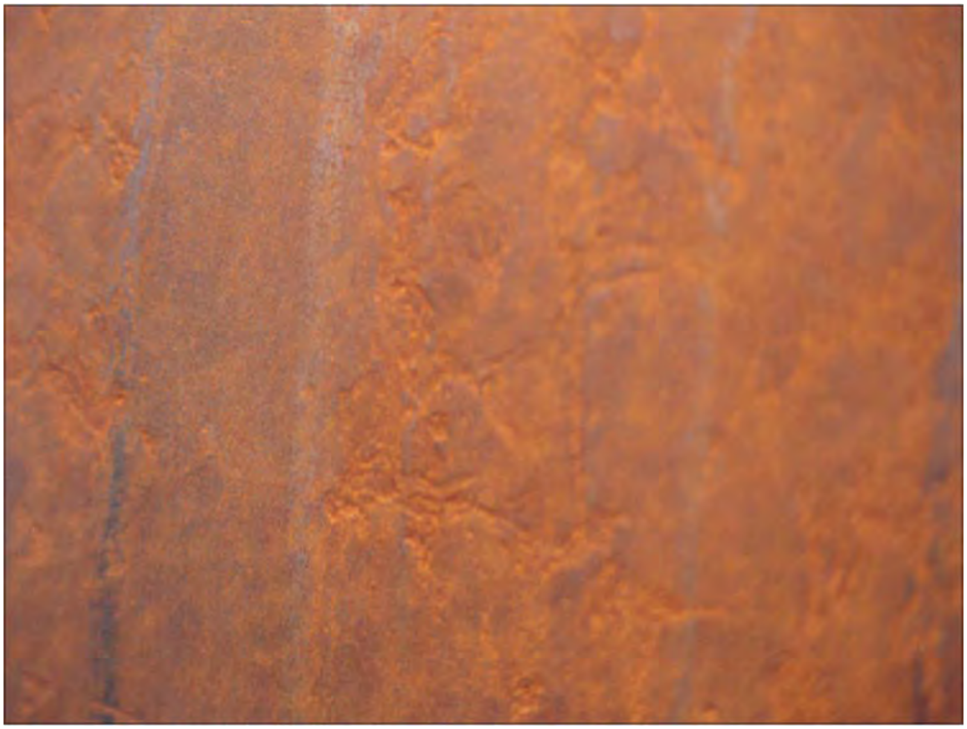

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Poor Application Technologies

Different coating types have particular application methods that must be followed:

- FBE's require several critical steps for proper application to take place
- Liquid coatings must be mixed and applied using the proper techniques
- Use of the correct primer for a particular coating system is critical

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Poor Application Technologies

When using tape type coatings, proper tension and overlap are very critical

Application of Shrink Sleeves must include proper heating of both the metal and the sleeve

Proper curing is critical to many different types of coatings before handling or back filling

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Poor application techniques

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Poor Coating Selection Criteria

Choosing high dielectric strength coatings that will shield CP currents if the coating fails may not always be the best choice

Soil stress must be considered when choosing a coating system. Many types of coatings are affected by soil stress, especially coatings that stretch easily

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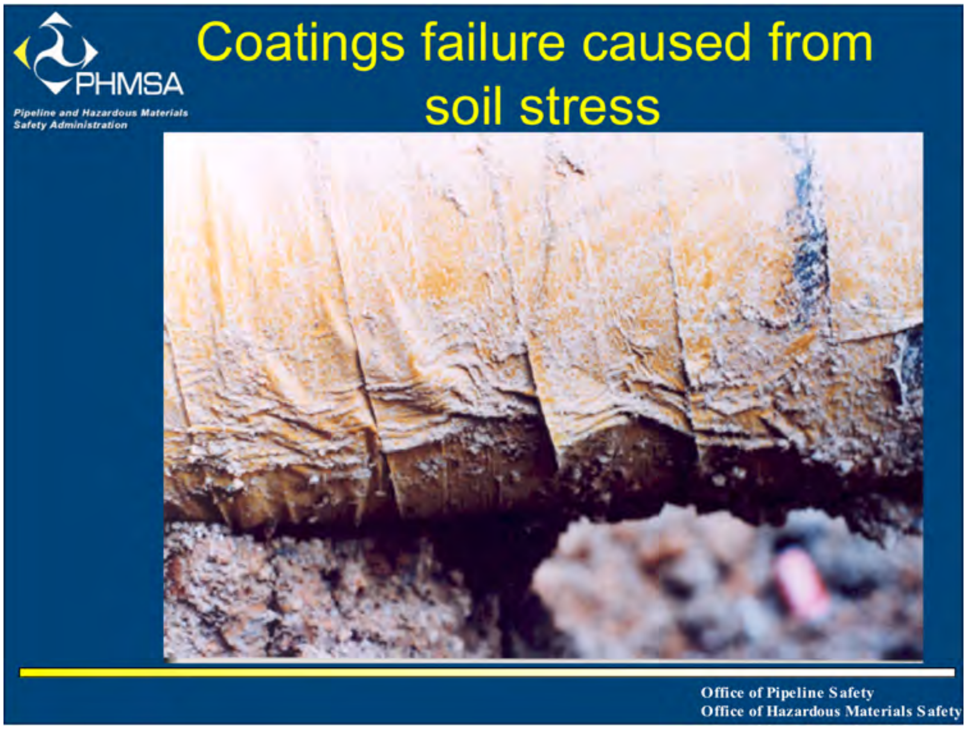
Coatings failure caused from soil stress
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A poorly applied shrink sleeve on a 10" products line


515
6:20
Results of adhesive failure without
cohesive failure


Some Coatings Crack &
Move Because of Soil Stress
PHMSA
Pipeline and Hazardous Materials Safety Administration
Dig 3
3:00
Office of Pipeline Safety
Office of Hazardous Materials Safety

PHMSA
Pipeline and Hazardous Materials Safety Administration

Mechanical damage may start the water Penetration & the shielding process

Office of Pipeline Safety
Office of Hazardous Materials Safety

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Cathodic Protection

Cathodic protection is blamed for many coating failures *(The real reason for coating failures are many times overlooked)*

Many think that a high pH under the coating indicates that coating has failed because of cathodic protection *(This may simply mean that you have a "fail safe coating system)*

Too many worry over meeting certain criteria when failed coatings that shield CP are the main reason for corrosion problems

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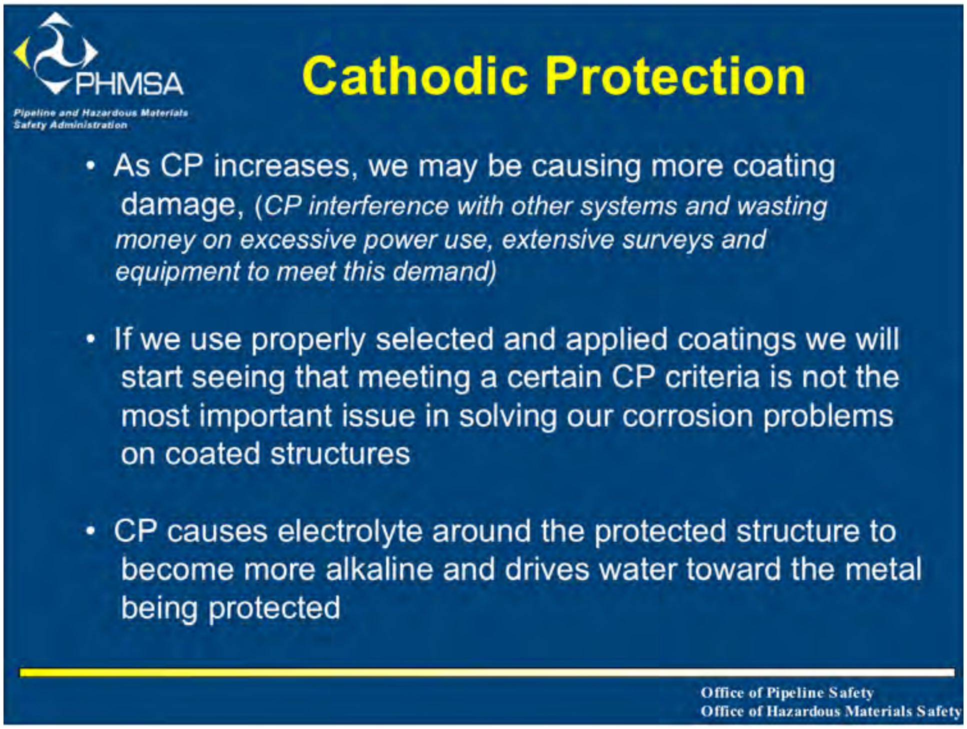
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Cathodic Protection
• As CP increases, we may be causing more coating damage, (CP interference with other systems and wasting money on excessive power use, extensive surveys and equipment to meet this demand)
• If we use properly selected and applied coatings we will start seeing that meeting a certain CP criteria is not the most important issue in solving our corrosion problems on coated structures
• CP causes electrolyte around the protected structure to become more alkaline and drives water toward the metal being protected
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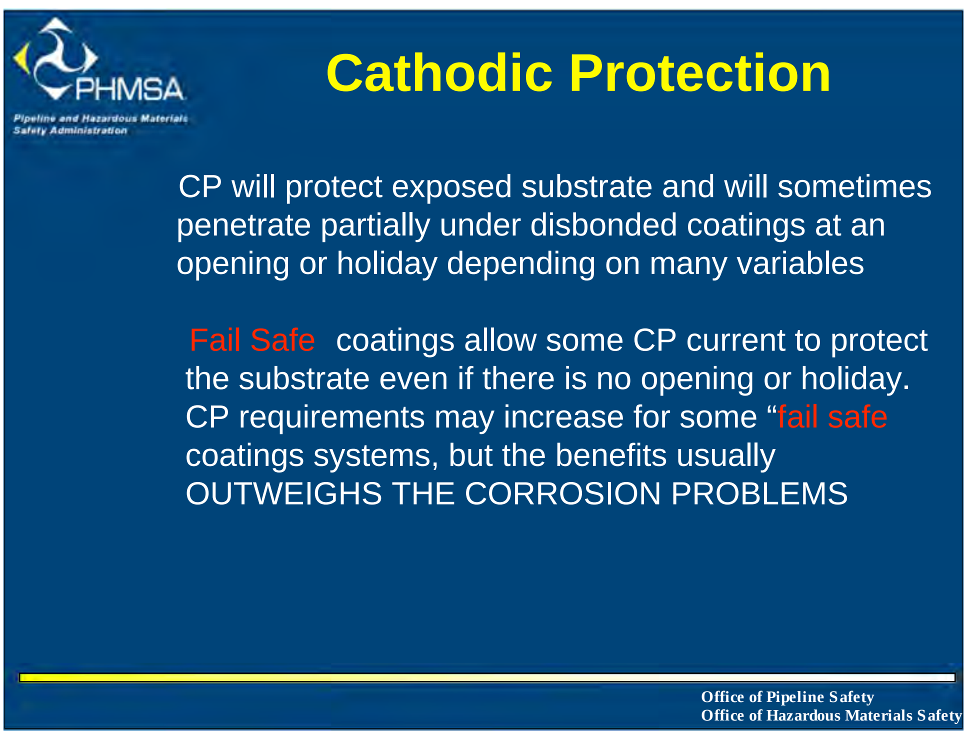
PHMSA
Pipeline and Hazardous Materials Safety Administration
Cathodic Protection
CP will protect exposed substrate and will sometimes penetrate partially under disbonded coatings at an opening or holiday depending on many variables
Fail Safe coatings allow some CP current to protect the substrate even if there is no opening or holiday. CP requirements may increase for some "fail safe coatings systems, but the benefits usually OUTWEIGHS THE CORROSION PROBLEMS
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PHMSA
Pipeline and Hazardous Materials Safety Administration
Future of Collaborative Research
• Plenty of incentives for any pipeline company
• Collaboration Maximizes value of input
• Collaboration means targeting technology gaps
▪ knowledge, Tools and or Standards
• Industry determines needs
• Almost always needs are common
(everyone has problems whether they admit to them or not)
• Collaboration provides new answers to old problems
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PHMSA
Pipeline and Hazardous Materials Safety Administration
Future of Collaborative Research
We must remind members of our industry (owners, consultants, contractors, service providers) that they must manage their risks
Failure to supply, Public risk Litigation, Fines,
Loss of revenue, Loss of share value
Obligations to their shareholders and the public
Collaboration research is the best way of mitigating risks
Research is for the betterment of the industry
Industry & Government Agencies must partner on research
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PHMSA
Pipeline and Hazardous Materials Safety Administration
Incentives for Research
• We don't want a catastrophe as a catalyst –but:
• Some failures or near misses concentrate the mind
• Research & its application to solving real world problems provide best defence against:
▪ Failure to supply
▪ Public risk
▪ Litigation
▪ Fines
▪ Loss of revenue
▪ Loss of share value
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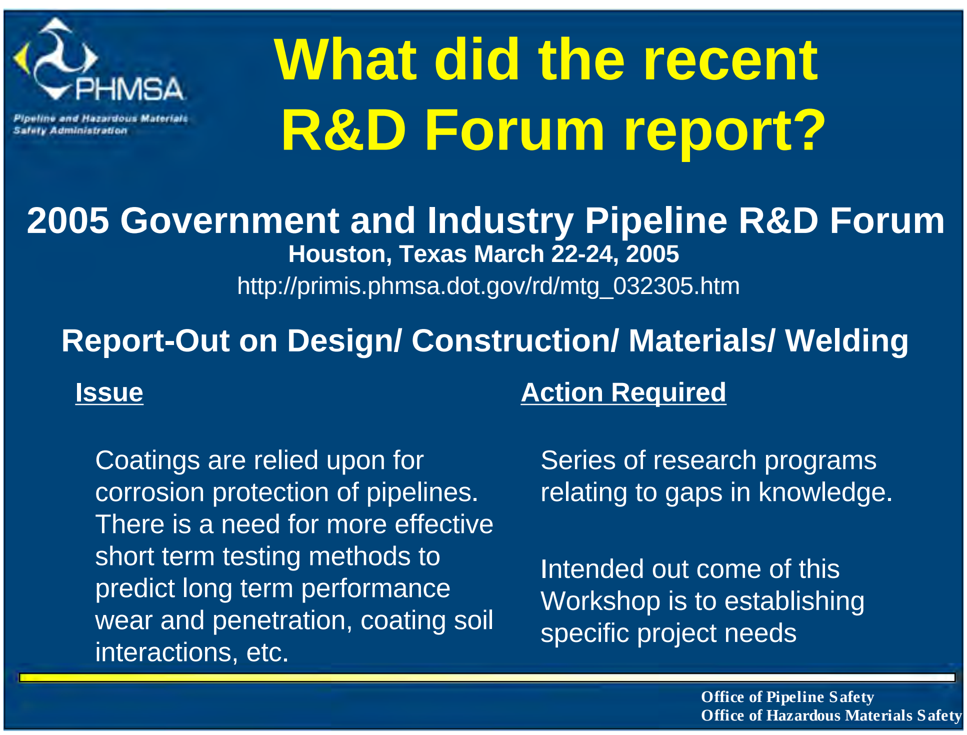
PHMSA
Pipeline and Hazardous Materials Safety Administration
What did the recent R&D Forum report?
2005 Government and Industry Pipeline R&D Forum
Houston, Texas March 22-24, 2005
http://primis.phmsa.dot.gov/rd/mtg_032305.htm
Report-Out on Design/ Construction/ Materials/ Welding
Issue
Action Required
Coatings are relied upon for corrosion protection of pipelines. There is a need for more effective short term testing methods to predict long term performance wear and penetration, coating soil interactions, etc.
Series of research programs relating to gaps in knowledge.
Intended out come of this Workshop is to establishing specific project needs
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PHMSA
Pipeline and Hazardous Materials Safety Administration
Conclusions
Government supported Research is critical to filling the gaps in Knowledge, developing new industry Tools and improving Standards
There must be a balance between a coatings overall performance and the CP system
Continued government/industry partnership in evaluation and testing will provide the information needed to continue to make the best coating choices to protect the pipeline infrastructure
Office of Pipeline Safety
Office of Hazardous Materials Safety

Coatings for Corrosion Protection: Offshore Oil and Gas Operation Facilities, Marine Pipeline, and Ship Structures

April 14-16, 2004 Biloxi, Mississippi

NIST Publication 1035

Edited by: Charles Smith, Tom Siewert, Brajendra Mishra, David Olson, Angelique Lasseigne

Coatings for Corrosion Protection: Offshore Oil and Gas Operation Facilities, Marine Pipeline and Ship Structures

- This workshop of 150 attendees drew participation by internationally recognized:
  - Marine coating experts
  - Material specialists
  - Inspection specialists
  - Coatings manufacturers
  - Maintenance engineers
  - Designers

Coatings for Corrosion Protection: Offshore Oil and Gas Operation Facilities, Marine Pipeline and Ship Structures

- **This workshop was crafted to include multiple view points including:**
  - Industrial
  - Academic
  - Environmental
  - Regulatory
  - Standardization
  - Certification

Coatings for Corrosion Protection: Offshore Oil and Gas Operation Facilities, Marine Pipeline and Ship Structures

- **Workshop is to Assess Opportunities for Research and Development in:**
  - Coating Practice
  - Coating Materials
  - Coating Application
  - Repair
  - Non-Destructive Evaluation
  - Extended Coating Life Prediction

USS Ogden old technology tank coatings after 3years

USS Ogden new technology tank coatings after 6 years

Coatings for Corrosion Protection: Offshore Oil and Gas Operation Facilities, Marine Pipeline and Ship Structures

- **Papers generated during this workshop include:**
  - Keynote
  - Topical Information
  - Discussion Groups

Coatings for Corrosion Protection: Offshore Oil and Gas Operation Facilities, Marine Pipeline and Ship Structures

- Keynotes and Invited Topical Papers Define State of the Art
  - To assess current practices and their limitations
  - To discuss field experiences
  - To chart a course for the best corrosion protection methodology
    - Including serving and monitoring

Coatings for Corrosion Protection: Offshore Oil and Gas Operation Facilities, Marine Pipeline and Ship Structures

- **Keynotes and Invited Topical Papers**
  - Research and Development of Coatings for Alaska Tanker Company
  - Practical Experience to Combat Corrosion on Floating Production Units (FSO/FPSO's)
  - Inspection and Repair of Coatings
  - Past, Present, and Future "Smart" Protective Coatings
  - Risk Assessment and Economic Considerations When Coating Ballast Tanks

Coatings for Corrosion Protection: Offshore Oil and Gas Operation Facilities, Marine Pipeline and Ship Structures

- **Keynotes and Invited Topical Papers**
  - Decision Making in Coating Selection in Marine/Offshore Environments
  - Corrosion Protection for Offshore Pipelines
  - Experience with Coatings for Corrosion Protection from the Norwegian Continental Shelf
  - U.S. Navy Ships: Developments and Status
  - Single Coat and Rapid Cure Tank Coating Systems

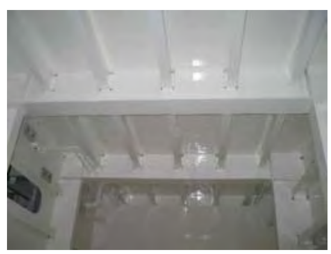
Coatings for Corrosion Protection: Offshore Oil and Gas Operation Facilities, Marine Pipeline and Ship Structures

- **Six Discussion Groups:**
  - To Address Specific Issues Identified
  - To Prioritize the Issues
  - To Recommend Specific Research and Development Topics for:
    - Government
    - Industry

Coatings for Corrosion Protection: Offshore Oil and Gas Operation Facilities, Marine Pipeline and Ship Structures

Discussion Groups "White Papers"

1. U.S. Shipyard Paint Shops: Current Issues and Future Needs
2. Rationalization and Optimization of Coatings Maintenance Programs for Corrosion Management on Offshore Platforms
3. Coatings for Pipelines
4. Coatings for Port Facilities
5. Near 100 Percent Solids Tank Linings



6. Evaluating the Current State of Inspection Practices for Protective Coatings (In Process and Continued Evaluation) and the Exploration of Opportunities for Improvement of these Practices

Recommendations from the Discussion Groups

- **Research**
  - **Quantitative evaluation of the long-term field performance of pipeline coatings**. One project should install coated pipe samples in the field at carefully selected locations representative of different environmental conditions. Several monitoring methods should be used. In addition, the coating performance evaluation should include both consistent and fluctuating temperatures with transient and cyclic temperature fluctuations. A one-day scoping meeting prior to this investigation should be held with good representation of the interested parties.
  - **Development of practices for evaluating pipeline coatings for service under extreme conditions** such as: Offshore-deep sea, Offshore-Arctic, Onshore-equator is recommended. These investigations should include three types of coatings: Anti-corrosion coatings, Abrasion-resistant coatings, and Insulation coatings.

Recommendations from the Discussion Groups

- **Research**
  - **Development of a non-destructive method of evaluating the application of coating systems.** Programs need to explore the feasibility of thermography, magnetic flux leakage, electrical impedance, and eddy current phase array. Modeling using EIS is not reliable.
  - **Development of specific advancements in coating materials.** A project for **non-skid deck coating systems** that will last when applied over less than perfect surface preparations. Parameters that control **coating performance**. Modeling of performance of all coatings (not only FBE). A project should include the evaluation of coatings at higher temperature in the laboratory. Performance of insulation coating should be investigated. Research project to develop coating systems that respond to exposure stresses needs to be performed.

Recommendations from the Discussion Groups

- **Development**
  - **Improvement in the effective use of coatings for port facilities and the development of the necessary performance-based specifications. The development of generally accepted design standards and practices for port authorities needs to be established.** These standards and practices need to be beneficial to the owner. Also the program needs to develop generally accepted design standards and acceptances for port facilities. This development may need to be geographically specific such as: blue water specific or brown water specific.
  - **Advanced methodologies for applications of coatings.** A project needs to address paint application issues without the use of brushes and rollers to increase productivity, lower costs, and less personnel exposure. The proposed investigation should include concerns of issues such as: curing time compared to burial or immersion time and adhesion of field-applied coatings to mill-applied coatings. An investigation to assess the effects of stockpiling of coating products on pipeline coatings performance including the effect of temperature, ultra-violet light, and time needs to be established. Development of high solid products, which meet VOC requirements that have less tendency to embrittle over time. Develop a mechanism to aid the painter in being able to achieve more uniform film thicknesses with high solid coatings in the field. The use of a capture device at the spray gun versus total encapsulation of the space to be painted should be investigated. Evaluate the need to increase the investment in coating application technology R&D. Establishment of a welding procedure for welding on painted surfaces is recommended.

Recommendations from the Discussion Groups

- **Development**
  - **Assessment of new technologies for surface preparation before coating.** This program should include projects on the feasibility of using microwave technology for surface preparation, hand-held x-ray fluorescence system to detect salts on the surface, and a project to improve the dissemination and clarity of information on allowable surface chlorides. Improvement of application equipment to facilitate applying high solid coatings in the field to inaccessible areas. A project investigating the effects of minor variations in surface preparation and effects of variation in composition of surface contamination, including mill scale, on long-term coatings performance is necessary. A project on secondary surface preparation critera / Standards (example: exceeding the recoat window of an epoxy- Methodology for evaluation) needs to be established. The cost of surface preparation and coating application for underwater hull areas is going up and the designs of coating technology for this area has not kept pace.

Recommendations from the Discussion Groups

- **Administrative**

  – **Standardized methodology for data collection and management.** An unbiased third party to compile an industry wide historical data base on pipeline coating performance and evaluate the data critically needs to be established and funded. A program to establish user-friendly standardization needs to be initiated and performed. The program would include a project on the standard/ recommended practices for implementation of inspection for protective coatings projects.

  – **Formulation of a roadmap for coatings research and/or development that indicates the proper sequence of projects.** The roadmap needs to be periodically updated by industrial organizations as well as government research agencies and industrial users of coated structures. Such a roadmap would be helpful in prioritizing national and international needs and to assist in obtaining the necessary funding. The roadmap program will need to be annually updated by NACE International and SSPC (The Society for Protective Coatings).

Recommendations from the Discussion Groups

- **Administrative**

  – **A working group, national or regional, to increase exchange of information on the performance of coating products and application.** The working group can formulate through user conscience new performance based specifications, design standards, and practices for port facilities. There already exists the working structure for such a working group in the existing coating and corrosion societies. It needs an initiator. (Note: Loosely exists at SSPC).

  – **Evaluation of the economic issues of coating materials, their application, and their service behavior.** A specific project on the study of the measurable economic contribution of the inspection of coatings project successes and performance needs to be performed. A project to study economics of coating technology to suggest and recommend the most cost effective use of the present technology should be implemented. The issue is that use and deployment of new coating technology is hampered by high cost of new equipment. Look into what can be done to utilize existing equipment; lower the cost of new equipment; or provide the financial incentives needed. Consumer and coating industry feedback loop needs to be improved. Problems are generally reported and investigated; however, successful applications rarely are investigated to confirm good practice.

Recommendations from the Discussion Groups

- **Operations**
  - **Advanced methods for coating repair.** This program should include a project on standards for quantification of performance and repair criteria and a project to quantify the effect of "repairs" on newly installed coatings system's performance.
  - **Training, education, and certification of painters, corrosion engineers, and inspectors in the marine and pipeline industry.** Develop a certification and training program for painters in the marine industry. Help develop an engineering technologist degree / vocational training program for coating specification. Guidelines/Practices/Standards for evaluating In-Service Coatings and the training of Coating Survey Inspectors, with focus on Inspection and Evaluation of In-Service Coatings and tools for evaluation needs to be organized. A special program for educating Coast Guard and MMS inspectors to establish consistency with the offshore industrial standards. Development of a hiring program offering training and certification plus weekly pay, which would have an impact on safety, employee morale, and salary.

Recommendations from the Discussion Groups

- **Operations**
  - **Development of coating/corrosion assessment criteria and acceptable corrosion levels** for use by corrosion engineers and regulators in the development and assessment of Asset Integrity Management Programs. Development of a criteria for determining the most cost effective maintenance effort and tools to quantify: coatings age and degradation, ability to apply over-coatings, and consistent evaluation needs to be established.
  - **Address the environmental and health and safety issues regarding paint materials and their application.** A project for the determination of the effects of environmental conditions and variations in coating procedures on the performance of field-applied pipeline coatings needs to be instituted. A project on the development and research of environment tolerant coatings that can be used year round with increased quality. The development of pipeline coatings with anti-microbial properties. This development must achieve coating acceptable ecological concerns.

Pipeline Papers

#1 Corrosion Protection for Offshore Pipelines

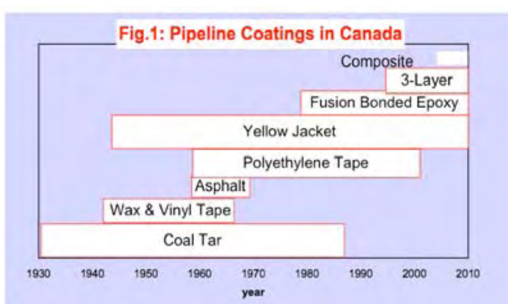
By Ernest W. Klechka, Jr., P.E.
CC Technologies, Dublin, Ohio

- Corrosion Control - Integrity Management
- Evaluation of Corrosion Potential
- Coating Selection
- Design Considerations
- Cathodic Protection Design
- Monitoring and Inspection

Pipeline Papers: Discussion Group Paper

#2 Coatings for Pipelines

By S. Paapavinasam and R. Winston Revie
CANMET Materials Technology Laboratory
Ottawa, Ontario, Canada



Pipelines Paper: "Coatings for Pipelines"

Identified Research Needs and Opportunities

- Consolidation of laboratory methods to develop generic tests, leading to specific test methods for specific coatings, should be considered.
- A comprehensive model to predict long-term performance of coatings should be developed based on carefully controlled laboratory experiments as well as from field experience with older coatings, such as coal tar and asphalt, and modern coatings, such as FBE and urethane, using the power of modern computers and intelligent systems, e.g., artificial neural networks.
- Based on a systematic study, the temperature limits of existing tests should be explored, and tests to evaluate products for elevated temperature applications should be developed.

Pipelines Paper: "Coatings for Pipelines"

Identified Research Needs and Opportunities

- Whereas many of the issues of mainline coatings are well understood and standards for mainline coatings have been developed, there is now a need to focus on field applied coatings, both repair and joint coatings.
- The effects of minor variations in surface preparation on long-term coatings performance need to be established.
- Relationship between application temperature and coating performance needs to be established.
- Influence of stockpiling on coating performance should be established.

Pipelines Paper: "Coatings for Pipelines"

Identified Research Needs and Opportunities

- A systematic study on the effects of field conditions and variations of procedure during the application of joint coatings, including the field performance of the coating, is recommended. This study should include the cohesive and adhesive strength of joint coatings.
- Realistic backfill impact testing that includes a method to evaluate the compaction produced by backfilling should be carried out to determine the effect of backfilling on coating performance.
- Focused effort to understand soil forces (both physical and chemical) on coating performance will provide useful information for developing strategies to protect coatings.

Pipelines Paper: "Coatings for Pipelines"

Identified Research Needs and Opportunities

- Recommended practices for evaluating coatings for northern pipelines need to be developed and incorporated in standards.
- Tests to evaluate repair coatings, including evaluation of cohesion within the repair coating and adhesion to the mainline coating and to steel pipe, should be developed.
- Development of a remote, accurate monitoring technique to evaluate the status of the coating (including the shielding effect) will greatly enhance pipeline integrity and decrease the number of pipeline incidents caused by corrosion.

Pipelines Paper: "Coatings for Pipelines"

Identified Research Needs and Opportunities

- Development of an industry-wide coating database to share the experience of older and modern coatings is an essential logical step to develop an integrity management program. Continuous updating and sharing of such a database will be very useful.
- The performance of coatings should be compared at constant and fluctuating temperatures.
- An objective study to develop a method that monitors microbial population and coating biodegradation will clarify the effects of microbes on coatings.

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Standards for Pipeline Coatings

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[b]Phone: 613-992-1703, Email: wrevie@nrcan.gc.ca

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2

Outline

- Introduction
- Historical Perspective
- Standards for Coating Evaluation
- Summary

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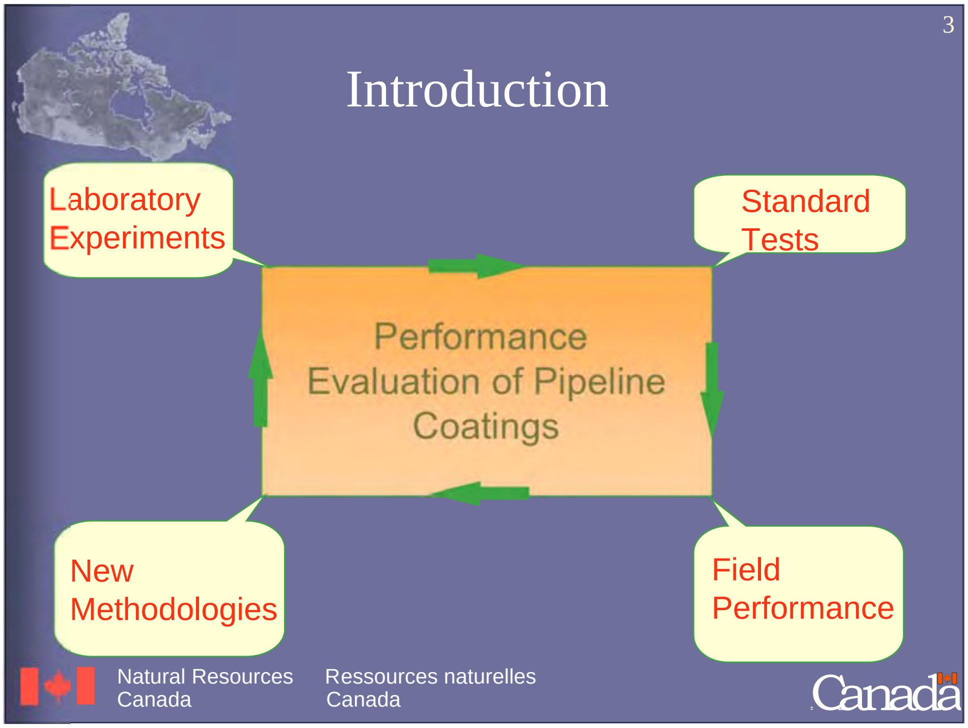
3
Introduction
Laboratory Experiments
Standard Tests
Performance Evaluation of Pipeline Coatings
New Methodologies
Field Performance
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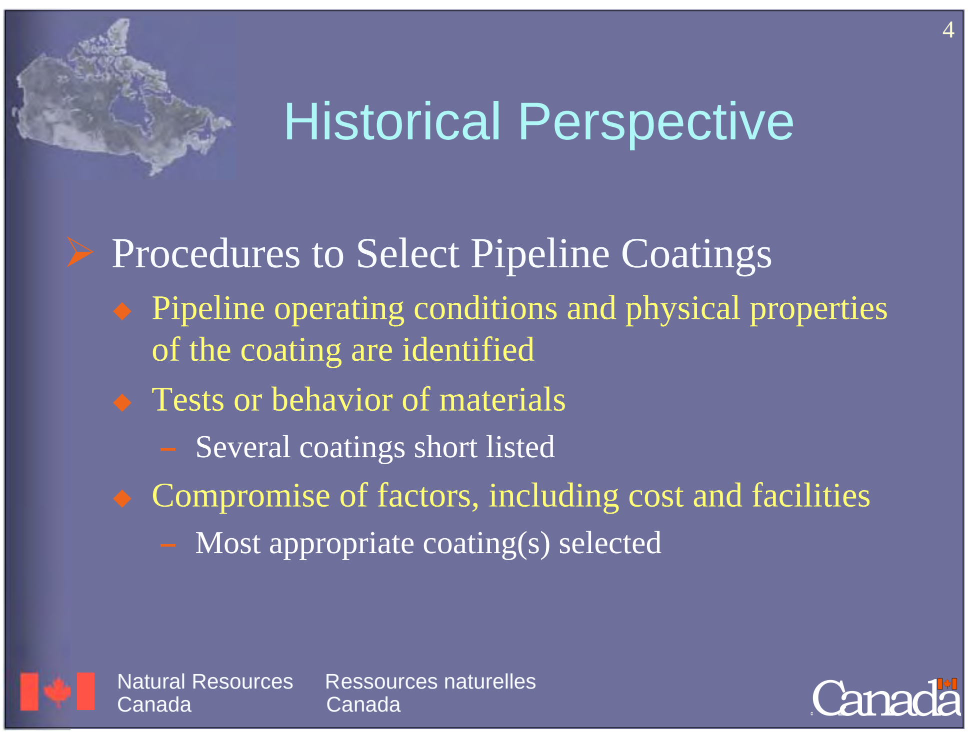
4
Historical Perspective
Procedures to Select Pipeline Coatings
Pipeline operating conditions and physical properties of the coating are identified
Tests or behavior of materials
– Several coatings short listed
Compromise of factors, including cost and facilities
– Most appropriate coating(s) selected
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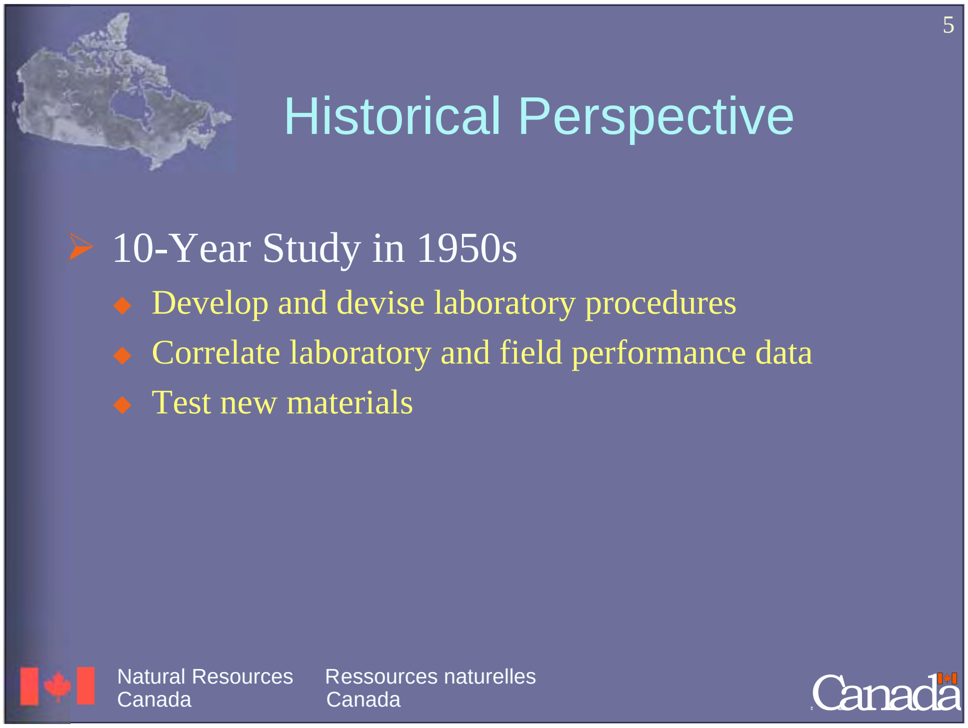
5
Historical Perspective
10-Year Study in 1950s
Develop and devise laboratory procedures
Correlate laboratory and field performance data
Test new materials
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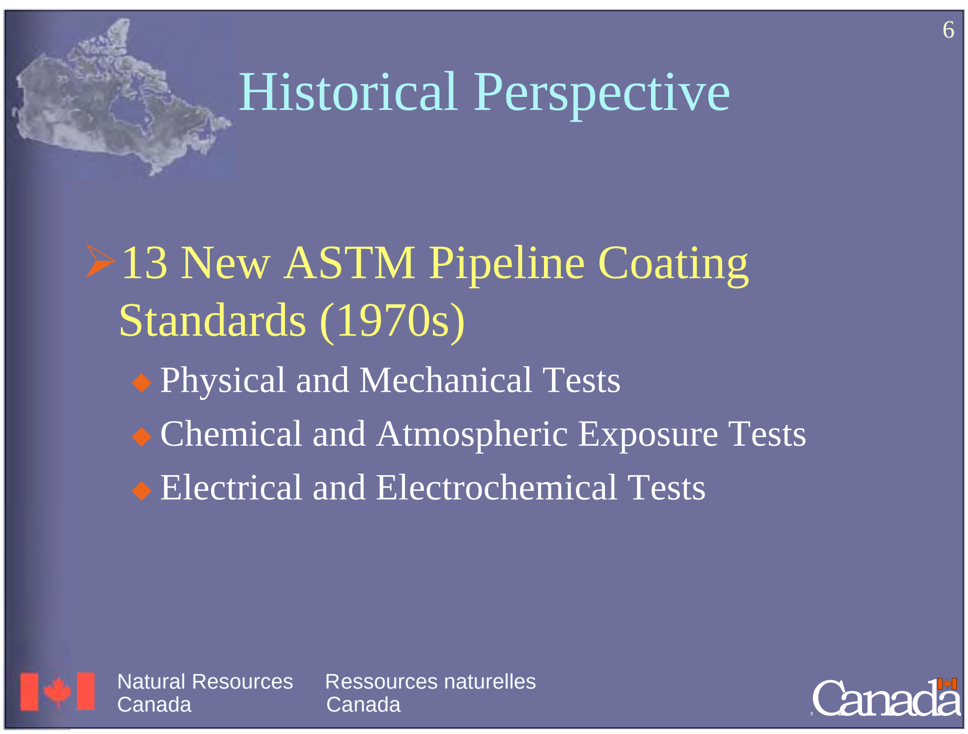
6
Historical Perspective
13 New ASTM Pipeline Coating Standards (1970s)
Physical and Mechanical Tests
Chemical and Atmospheric Exposure Tests
Electrical and Electrochemical Tests
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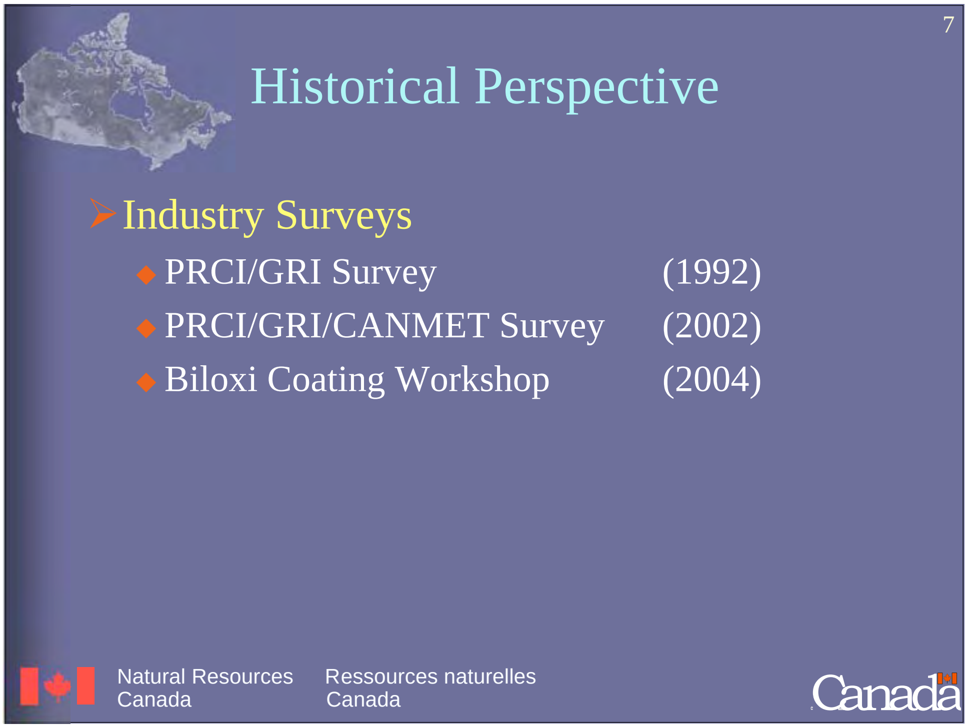
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Historical Perspective
Industry Surveys
PRCI/GRI Survey (1992)
PRCI/GRI/CANMET Survey (2002)
Biloxi Coating Workshop (2004)
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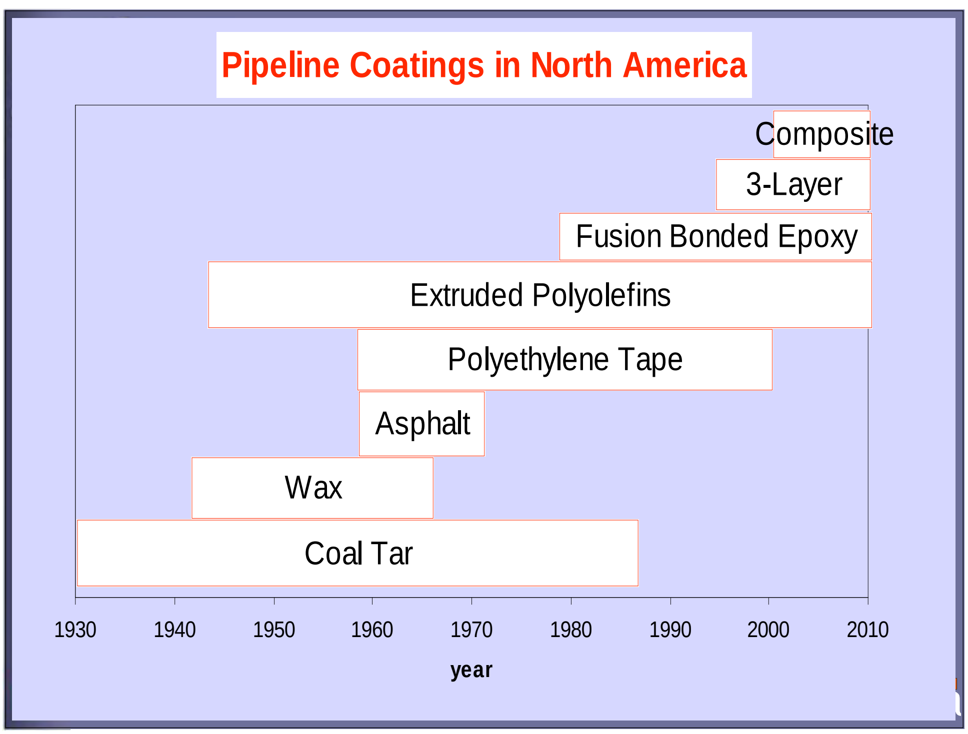
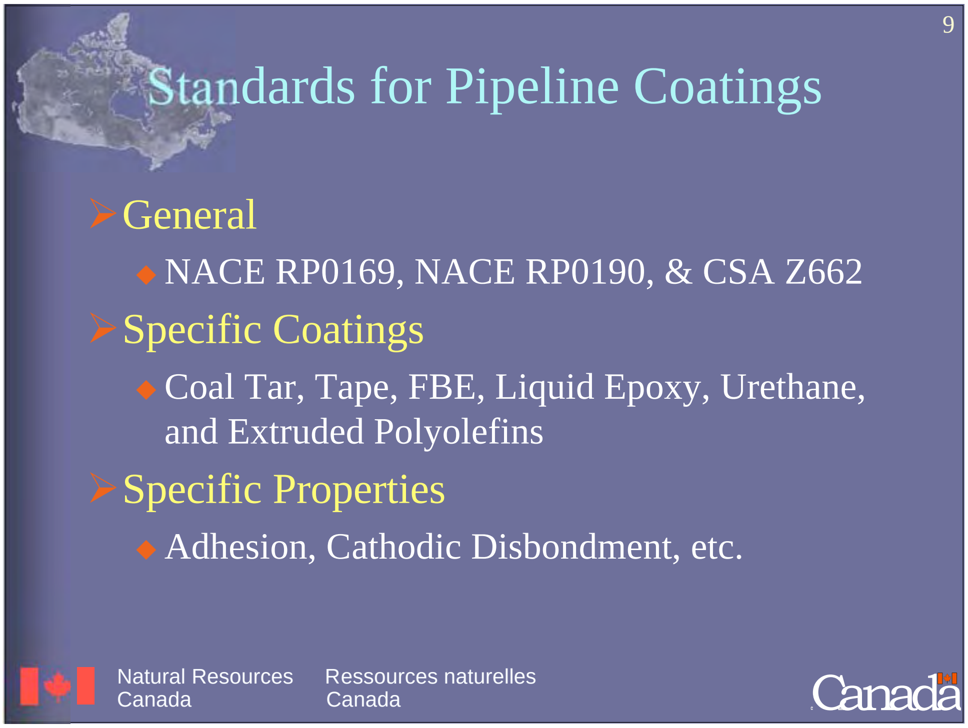

Pipeline Coatings in North America
Composite
3-Layer
Fusion Bonded Epoxy
Extruded Polyolefins
Polyethylene Tape
Asphalt
Wax
Coal Tar
1930
1940
1950
1960
1970
1980
1990
2000
2010
year


9
Standards for Pipeline Coatings
General
NACE RP0169, NACE RP0190, & CSA Z662
Specific Coatings
Coal Tar, Tape, FBE, Liquid Epoxy, Urethane, and Extruded Polyolefins
Specific Properties
Adhesion, Cathodic Disbondment, etc.
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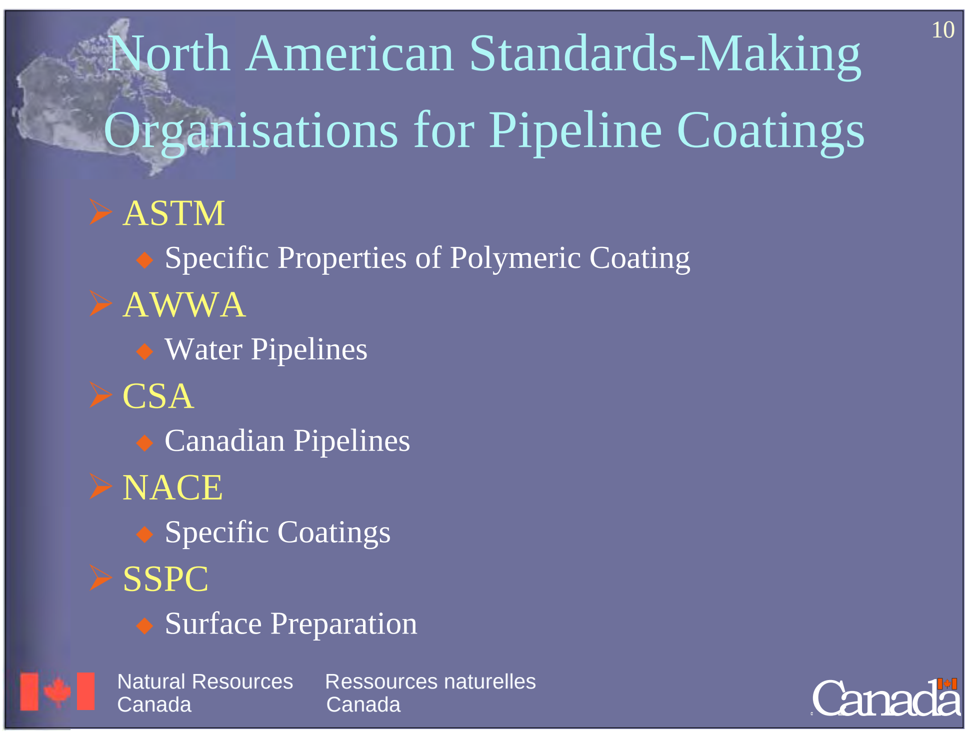
10
North American Standards-Making Organisations for Pipeline Coatings
ASTM
Specific Properties of Polymeric Coating
AWWA
Water Pipelines
CSA
Canadian Pipelines
NACE
Specific Coatings
SSPC
Surface Preparation
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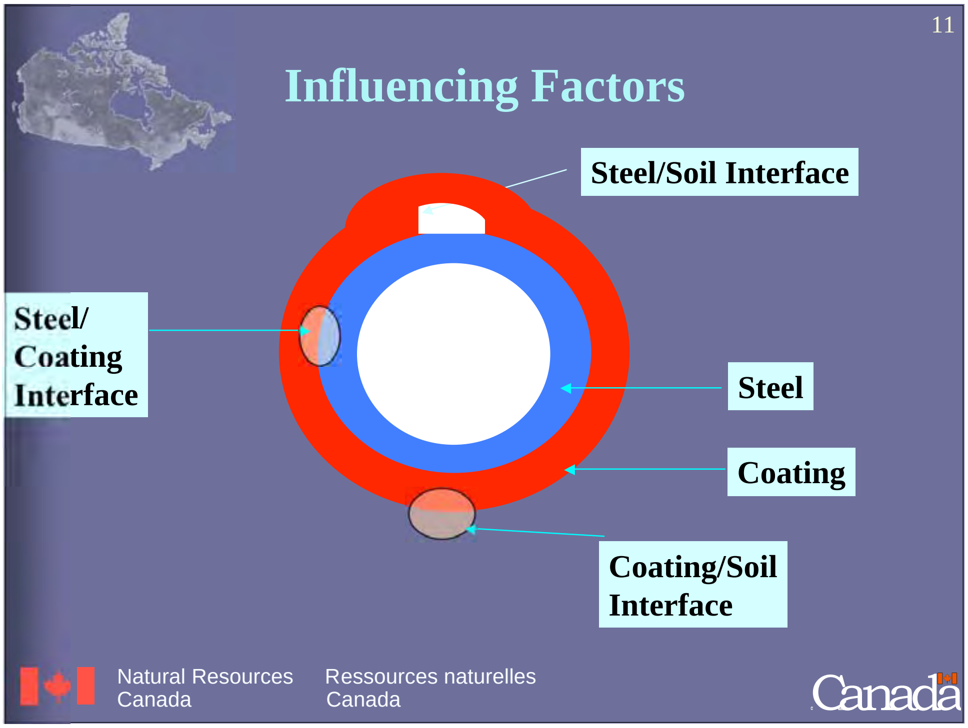
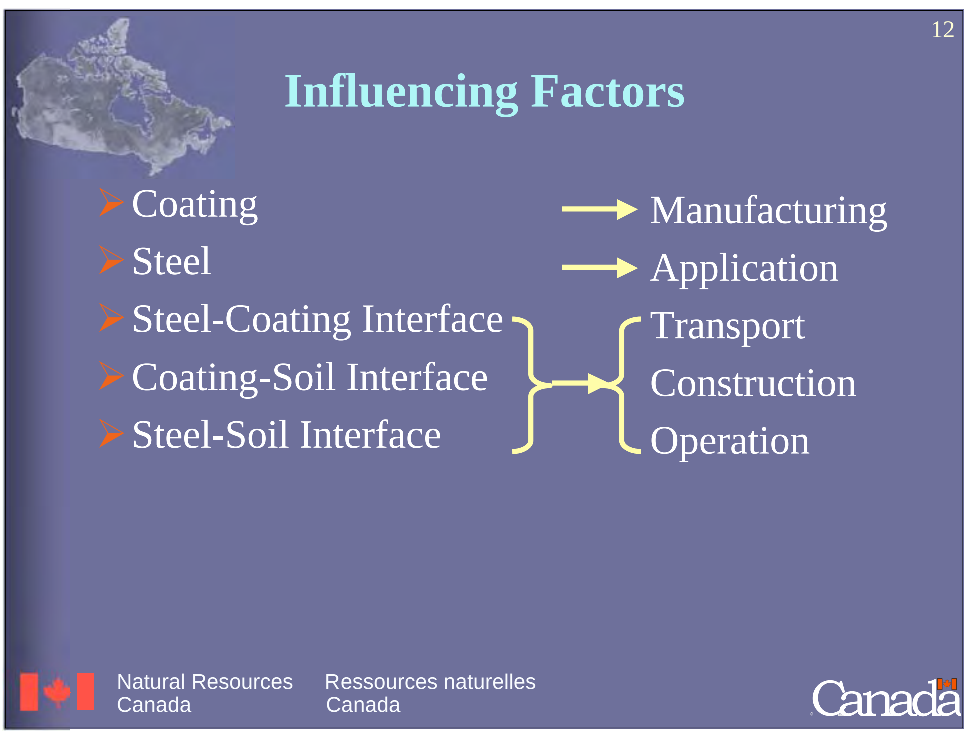

11
Influencing Factors
Steel/Soil Interface
Steel/
Coating
Interface
Steel
Coating
Coating/Soil
Interface
Natural Resources
Canada
Ressources naturelles
Canada
Canada


12
Influencing Factors
Coating
Steel
Steel-Coating Interface
Coating-Soil Interface
Steel-Soil Interface
Manufacturing
Application
Transport
Construction
Operation
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13

Standards: Steel

- Cleaning
- Surface profile
- Chemical contamination
  - Visible and Non-visible

Standards agree with each other with respect to the influence of steel

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14

Standards: Steel-Coating Interface

- Adhesion
  - Hot-Water Soak
  - Peel
  - Sheer
  - Pull-off
- Cathodic Disbondment
- Bendability/Flexibility

Harmonization of Standards by Various Organizations Useful

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15

Standards: Coating (Common)

- Thermal Conductivity
- Dielectric Strengths
- Electrical Conductivity
- Hardness
- Penetration Resistance
- Water Permeation
- Blistering
- Chemical Resistance
- Weathering
- Cohesion
- Stress-Cracking Resistance
- Resistance to Oxidation
- Compressive Properties
- Thermal Expansion
- Brittleness Temperature
- Film Thickness

Harmonization of Standards from Various Organizations to Evaluate Water Permeation and Blistering will be useful.

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Standards: Coating (Specific)

- Composition
- Gel Time (FBE)
- Particle Size
- Total Volatile Content
- Porosity
- Viscosity
- Flow
- Softening Point
- Shelf Life
- Filler Content
- Tear Strength
- Curing
- Tensile Strength
- Sag
- Low-Temperature Cracking Test
- Pliability
- Breaking Strength
- Insulation Resistance
- Density/Specific Gravity

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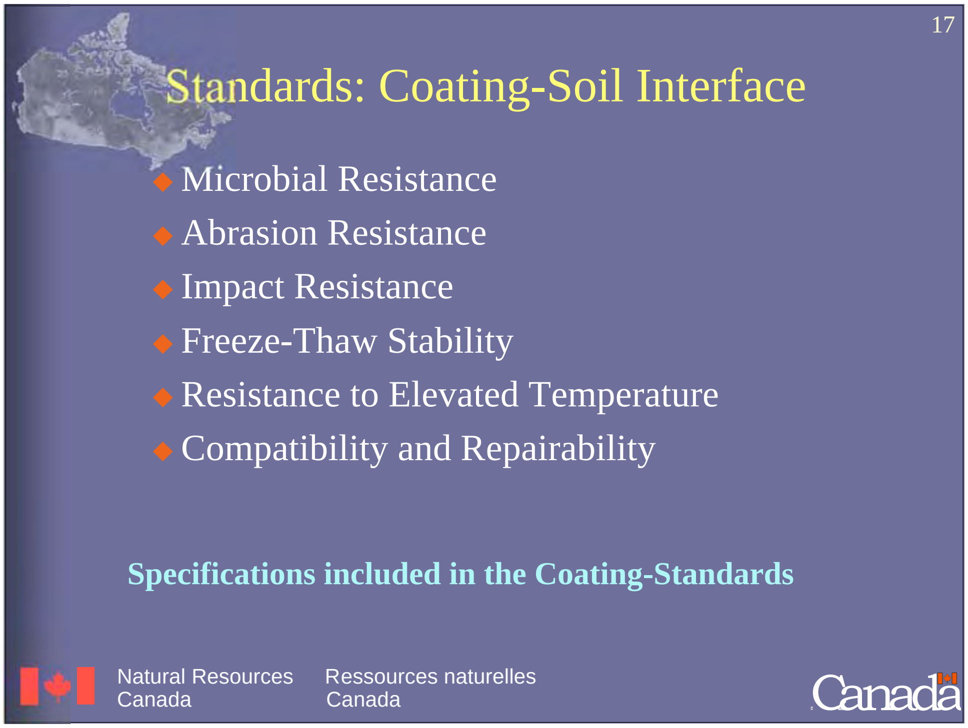
17
Standards: Coating-Soil Interface
Microbial Resistance
Abrasion Resistance
Impact Resistance
Freeze-Thaw Stability
Resistance to Elevated Temperature
Compatibility and Repairability
Specifications included in the Coating-Standards
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18
Standards: Steel-Soil Interface
Detection of Holidays and Disbondments
– Cathodic Protection Current
– DC Potential (Soil) Gradient
– Close Interval Survey
– Coating Conductance
– AC Voltage Gradient
– Inline Inspection
– Bellhole Inspection
Development of standards required
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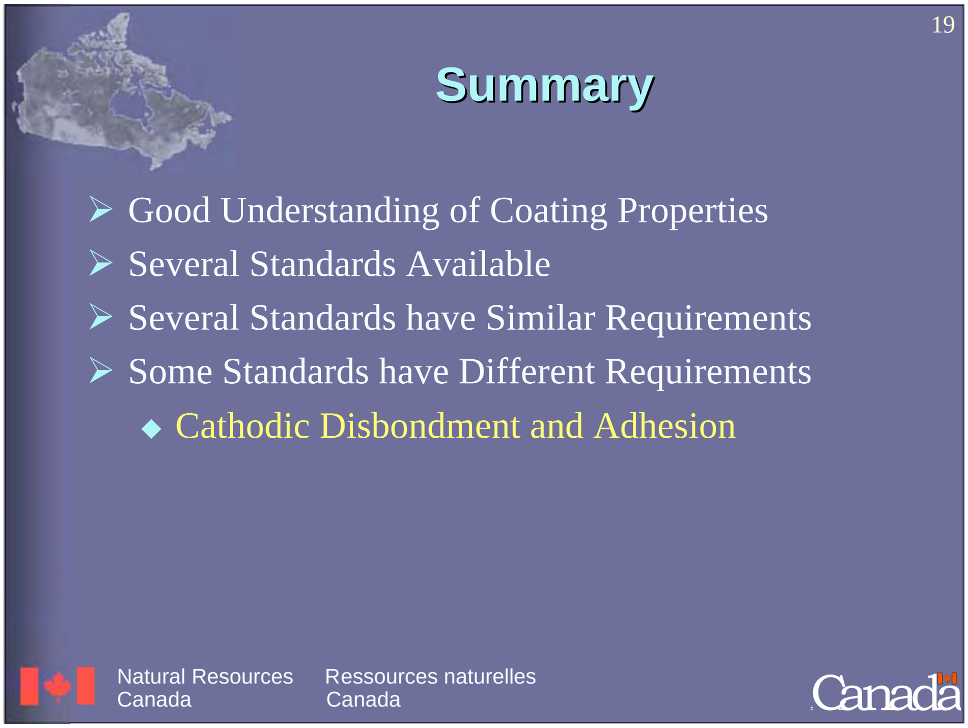
19
Summary
Good Understanding of Coating Properties
Several Standards Available
Several Standards have Similar Requirements
Some Standards have Different Requirements
Cathodic Disbondment and Adhesion
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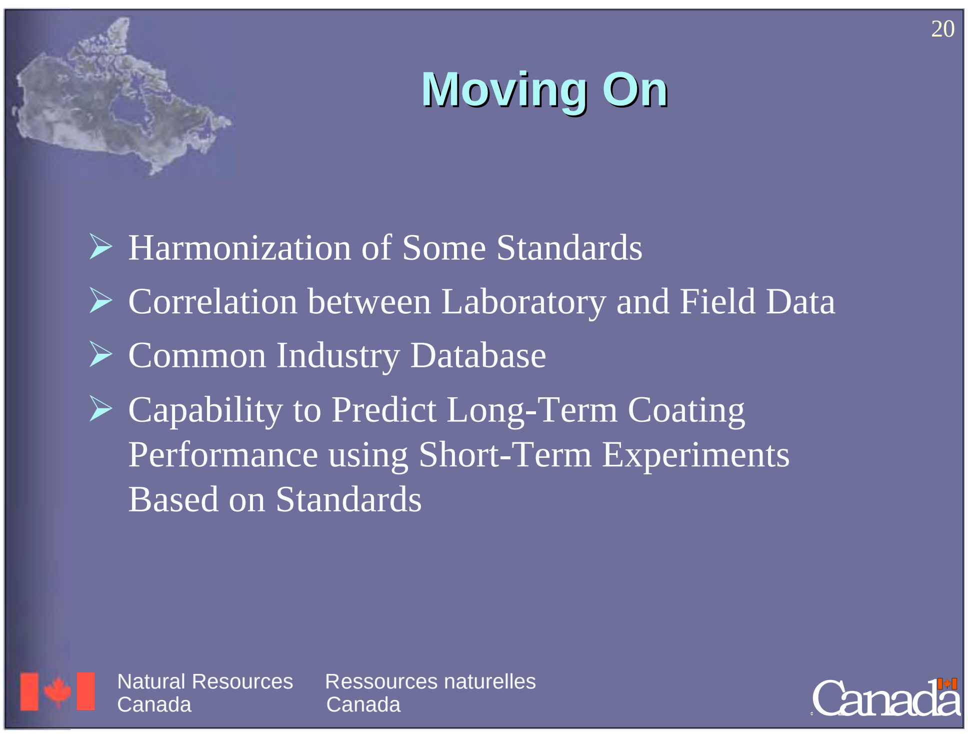
20
Moving On
Harmonization of Some Standards
Correlation between Laboratory and Field Data
Common Industry Database
Capability to Predict Long-Term Coating Performance using Short-Term Experiments Based on Standards
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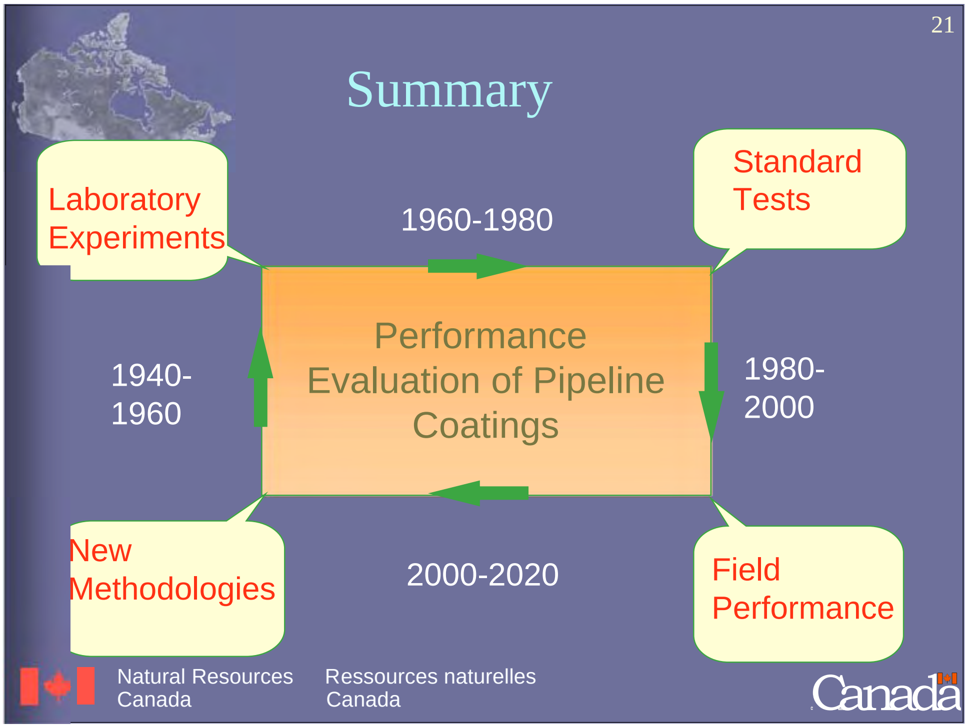
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Summary
Laboratory Experiments
Standard Tests
1960-1980
Performance Evaluation of Pipeline Coatings
1940-1960
1980-2000
New Methodologies
2000-2020
Field Performance
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STANDARDS FOR EVALUATING PIPELINE COATINGS

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EXECUTIVE SUMMARY

A review of standards used in U.S.A. and Canada for evaluating pipeline protective coatings is presented. The standards covered in this review were developed by ASTM, AWWA, CSA, NACE, and SSPC. Limited information on standards used in Europe is also presented in this paper. Commonality and differences in these standards are discussed. Some important features are:

- There is a good understanding in the industry of the important properties that are detrimental to pipeline coating behaviour.
- Several standards are available to test those properties that are detrimental to pipeline coatings.
- Standards developed by different organisations have essentially the same requirements for evaluating some properties of the coating (e.g., surface profile), but different requirements for evaluating other properties (e.g., cathodic disbondment and adhesion).
- Properties for which standards from different organizations have different requirements are also properties considered important for the coating performance; i.e., cathodic disbondment and adhesion. Harmonization of standards to evaluate these properties will be very useful.
- Correlation of performance of coatings in standard tests and in the field has not been well documented, nor is such a correlation a specified requirement in any of the standards.
- To date, no studies have been successful in establishing a correlation between field performance and performance in standard tests.
- No common industry database on the performance of coatings in the field is available.
- Development of a capability to predict long-term coating performance from test data established in short-term standard tests is an industry priority.

1. INTRODUCTION

Many test procedures have been developed and methods of using them have been described to evaluate pipeline protective coatings. Standards have been developed by various standards-making organisations for these tests. In this paper, historical perspective of coating evaluation, laboratory methodologies used over the years and their significance are discussed; standards from various standards-making organisations for testing a particular property are compared; opportunities for harmonizing standards are identified; and areas for developing new standards are identified.

2. HISTORICAL PERSSPECTIVE

The procedure to be followed in selecting a protective pipeline coating has remained essentially the same since the 1940s. Three steps are involved[1]:

- First, the requirements from the standpoints of pipeline operating conditions and physical properties of the coating are identified;
- Second, from the tests or information based on similar tests or general background knowledge of the behaviour of materials, several coatings that will meet the requirements are placed on a "short list"; and
- Finally, a compromise of all the related factors, including cost and available facilities, is made to select the most appropriate coating.

In 1958, a 10-year coating evaluation testing program, involving experiments in the laboratory and in the field was completed[2]. This test program consisted of three phases to:

1: Develop and devise laboratory procedures and apparatus suitable for evaluation of pipe coatings;

2: Evaluate commonly used coatings and to correlate laboratory evaluations with field performance data; and

3: Test new materials with the techniques developed and evaluate their performance against coatings in common use.

Field burial tests were lengthy, and because of the variable conditions, results could not be evaluated with any precision. On the other hand, laboratory tests were considered suitable for evaluating <u>one property</u> of the coating <u>at a time</u>. Correlation between laboratory results and field performance was not established in this study.

In the laboratory program, the objectives were to develop methods to determine the performance characteristics of coatings under carefully controlled conditions. To do this, methods were devised so that each test would determine one coating property under controlled, reproducible conditions. It was also the intent to determine, as far as possible, the service performance characteristics on a completed coating structure.

Coating characteristics tested in the laboratory were:

1. electrical resistance;
2. rate and amount of water adsorption;
3. resistance to deformation under pressure;
4. resistance to cracking and spalling under impact;
5. resistance to cracking in bending;
6. adhesion to pipe metal;
7. deterioration in soil environment;
8. deterioration in petroleum oils; and
9. effects of cathodic protection.

Since 1964, industry undertook to develop standardized tests for the evaluation of pipeline coatings. From 1964 to 1977, nearly 200 existing tests for non-metallic materials were reviewed for their potential value in the evaluation of pipeline coatings. Many tests could not be adapted to evaluate pipeline coatings and were, therefore, rejected. Others were dropped from further consideration because they produce data of marginal value. The tests retained for critical evaluation were those that would begin to yield definitive performance data within the first 90 days of testing and not require more than 18 months to complete. Many methods selected could be completed in 30 days. The most promising of these tests were subjected to an intensive series of inter-laboratory, round robin testing for final verification. Additional rejections occurred at this level, principally due to lack of precision or undue complexity of the test apparatus and its associated method.

By 1978, this systematic process had produced 13 ASTM standard test methods to determine properties of non-metallic coatings applied to steel pipe. These standard test methods are[3]:

Physical and Mechanical Tests		
1.	Abrasion Resistance of Pipeline Coatings	ASTM G 6 -77
2.	Bendability of Pipeline Coatings	ASTM G 10-72
3.	Limestone Drop Test for Pipeline Coatings	ASTM G 13-72
4.	Falling Weight Test for Pipeline Coatings	ASTM G14-72
5.	Penetration Resistance of Pipe Coatings	ASTM G 17-72
Chemical and Atmospheric Exposure Tests		
6.	Chemical Resistance	ASTM G 20-72
7.	Effects of Outdoor Weathering on Pipeline Coatings	ASTM G11-72
Electrical and Electrochemical Tests		
8.	Cathodic Disbondment of Pipeline Coatings	ASTM G 8-72
9.	Disbondment of Pipeline Coatings by Direct Soil Burial	ASTM G 19-72
10.	Water Penetration into Pipeline Coatings	ASTM G 9-72
11.	Tests for Joints, Fittings, and Patches in Coated Pipelines	ASTM G 18-72
12.	Cathodic Disbonding of Pipe Coatings Subjected to Elevated or Cyclic Temperatures	ASTM G 42-75T
13.	Evaluating Pipeline Coating Patch Materials	ASTM G 55-77

In the 1980s, a major transmission pipeline company evaluated predictability of long-term coating performance from laboratory tests. This study found that, at best, prediction is difficult and, at worst, is inaccurate and misleading[4]. Properties of pipeline coatings most useful for comparing laboratory test results and field performance are:

- adhesion,
- resistance to soil stresses,
- chemical and physical stability,
- resistance to impact, and
- resistance to cathodic disbonding

Table 1 gives the qualitative correlation found between laboratory testing and field observations/testing of major coating systems. Data for laboratory testing was taken from manufacturers' literature and testing by others for polyethylene tape, coal tar, and asphalt enamel and mastic. Laboratory data for epoxy and urethane is from the pipeline company's own testing. Based on the general observations on field performance, asphalt enamel and mastic coatings had become very brittle and the soil stress resistance of tape was very poor.

No relationship between degree of disbonding in laboratory testing and field performance over time could be established. It was observed that modifications to existing test procedures, apparatus, test electrolyte, and sample preparations are required to predict the long-term performance.

Table 1: Correlation between laboratory evaluations and field performance of pipeline coatings.

Coating	Physical and chemical stability	Resistance to soil stress	Resistance to impact	Adhesion	Resistance to cathodic disbonding
Polyethylene tape	Good	Poor	Good	Poor	Good
Asphalt enamel	Fair	Poor	Good	No lab. data	Good
Asphalt mastic	Poor	Poor	Good	No lab. data	Good
Epoxy	Good	Good	Good	Good	Good
Coal-tar enamel	Good	Fair	Good	No lab. data	Fair
Urethane	Good	Good	Good	Good	Good

In 1992, as part of a program to develop quantitative techniques for predicting the rate of disbonding of anti-corrosion coatings on buried natural gas pipelines, an assessment of the state-of-the-art for the selection and use of pipeline coatings was performed[5]. Information was gathered through questionnaires, interviews, and a review of the published literature. The results are summarized in Table 2 and Table 3. This study found that the three parameters most detrimental to the performance of pipeline coatings are:

- adhesion
- cathodic disbondment
- water penetration.

Table 2: Criteria considered to be the most and least important during the selection of pipeline coatings*.

Relative importance	Avg.	S.
Field experience	1.82	0.91
Laboratory test results	2.05	0.95
Initial cost	2.06	1.17
Applicator	2.45	1.11
Soil stress resistance	2.46	1.31
Service temperature	2.47	1.49
Cost (operation and maintenance)	2.58	1.3
Logistical convenience	2.61	1.17
Ease of application	2.7	1.17
Soil type	2.88	1.33
Pipe diameter	3.05	1.17
Ground water - fluctuation	3.12	1.35
Repair methods available	3.13	1.08
Ground water chemistry	3.25	1.33
Pipeline class location	3.45	1.34
Cathodic protection type	3.75	1.37

*Respondents were asked to rank the importance of the various criteria from 1-5, with 1 being very important and 5 being not important. The "Avg." refers to the average values of the responses and the values in the row labelled "S." are the standard deviations of the responses. A criterion considered to be very important would have a low average. A low value for the standard deviation indicates good agreement among the respondents concerning the given importance of a criterion.

Table 3: Coating properties considered to be the most and least important to the performance of a pipe coating.

Pipeline Companies			Coating Applicators		
Properties	Avg.	S.	Properties	Avg.	S.
Adhesion/Peel strength	1.22	0.59	Adhesion/Peel strength	1.08	N/A
Cathodic disbondment	1.45	0.77	Cathodic disbondment	1.38	N/A
Water penetration	1.81	0.92	Soil stress-resistance	1.38	N/A
Electrical resistivity	1.81	0.88	Handling damage resistance	1.46	N/A
Penetration resistance	1.98	0.77			
Construction damage resistance	2.02	0.85			
Impact resistance	2.13	0.97			
Resistance to soil stress	2.15	1.23			
Tensile strength/elongation	2.48	1.05			
Biological resistance	2.62	1.19			
Ease of repair	2.63	0.93			
Ease of application	2.65	0.95			
Hardness	2.7	1	Hot-water resistance	2.77	N/A
Weathering resistance	3.23	1.14	Tensile elongation	2.92	N/A
UV resistance	3.37	1.06	Tensile strength	3	N/A
Hot-water resistance	3.62	1.34	UV resistance	3.69	N/A

A paper in 1993 reviewed the process of coating evaluation over 50 years and observed the following[6]:

- $ Selection of appropriate coating and correct application are very important.
- $ CP must supplement the coating for 100% protection.
- $ Soil stress is one of the main problems.
- $ Pipeline coatings should have resistance to cathodic disbondment, soil stress, good adhesion, adequate thickness, low moisture absorption/transfer, chemical resistance (especially alkalis from CP), and flexibility.
- $ Field performance test are more reliable than laboratory tests.
- $ Cathodic disbondment tests are the most reliable tests to measure coating performance.
- $ The current required for CP is a good measure of coating performance.
- $ Results of adhesion tests do not correlate with those of cathodic disbondment tests.
- $ A test specifically to evaluate adhesion of the coating to the pipeline and cohesion within itself should be developed.
- $ A comprehensive model to predict long-term performance of coatings should be developed.
- $ Consolidation of laboratory methods to develop generic tests, leading to specific tests for specific coatings is recommended.

In the late 1990s and early 2000s, attempts were made to predict long-term performance of coatings using kinetic and thermodynamic methods[7-9]. Based on only one data parameter (e.g., cathodic current demand) and/or one coating (e.g., FBE) these predictions would fail to predict the failures caused by other mechanisms and/or failures of other coatings.

In 2002[10], another study was undertaken to analyse the gaps in our knowledge to develop a reliable model to predict field performance from laboratory studies. Based on an online survey, literature survey and analysis, the following steps were recommended to fill the technical gaps. In this recommendation, items indicated with ***** are of highest priority and items indicated with * are of lowest priority.

*****	Whereas most of the issues of mainline coatings are well understood and the standards for mainline coatings are recognized, the focus should now be on field applied coatings, both repair and joint coatings.
*****	The effects of minor variations in surface preparation on long-term coating performance need to be established.
*****	The relationship between application temperature and coating performance needs to be established.
*****	Focused effort to understand soil forces (both physical and chemical) on coating performance will help develop strategies to protect the coatings.
*****	Development of an industry-wide coating database to share the experience of older and modern coatings is an essential logical step to develop an integrity management program. Continuous updating and sharing of such a database will be very useful.
*****	An objective study to develop a method that monitors microbial population and coating biodegradation will clarify the effects of microbes on coatings
****	A comprehensive model to predict long-term performance of coatings should be developed based on carefully controlled laboratory experiments as well as from field experience with older coatings, such as coal tar and asphalt, and modern coatings, such as FBE and urethane, using the computing power of modern computers and intelligent systems, e.g., artificial neural networks.
****	Development of a remote accurate monitoring technique to determine the status of the coating will greatly enhance pipeline integrity and decrease the number of pipeline corrosion incidents.
***	Consolidation of laboratory methods to develop generic tests, leading to specific testing of specific coatings
***	Based on a systematic study, the temperature limits of existing tests should be explored and products for elevated temperature applications should be developed.
***	A systematic study on the effects of conditions and variations of procedure during the application of joint coatings and the performance is recommended. This study should include the cohesive and adhesive strength of joint coatings.
**	Influence of stockpiling on coating performance should be established.
**	The performance of coatings at constant and fluctuating temperatures should be compared.
*	The relationship between coating chemistry and corrosion protection is not clear.

In 2004, at the workshop held in Biloxi, Mississippi, a white paper on pipeline coatings was developed[11]. Following are the main R&D issues that were identified in the area of coatings for pipelines, listed in decreasing order of priority; i.e., item 1 is the top priority item for R&D. Items with the same number were ranked equally in terms of relative priority.

I. Database on Coating Performance

An unbiased 3rd party will compile an industry-wide historical database on coating performance and evaluate the data critically.

II. Performance of Field-Applied Coatings

Effects of environmental conditions and variations in coating procedure on performance of field-applied coatings
Curing time compared with time to burial or immersion
Adhesion of field-applied coating and mill-applied coating

II. Long-term field evaluation of pipeline coatings

A national or international program.
Coated pipe samples to be installed in the field at carefully selected locations representative of different environmental conditions.
Several monitoring methods to be used.
In addition, evaluate coating performance at constant and fluctuating temperatures with transient and cyclic temperature fluctuations.
1-day scoping meeting to be held, most likely in the fall of 2004

III. Effects of stockpiling on coating performance

Temperature
UV
Time

III. Develop practices for evaluating coatings for service under extreme conditions

Offshore, deep-sea
Onshore Arctic
Onshore Equator
Include 3 types of coatings:
Anti-corrosion coatings,
Abrasion-resistant coatings, and
Insulation coatings

IV. Standardization of test methods for evaluating coatings

IV. Development of coatings with anti-microbial properties

3. PIPELINE COATINGS

Over the past 50 years, several pipeline protective coatings have been used. Figure 1 presents the timeline of usage of the coatings. Standards that provide general guidelines to select and evaluate pipeline coatings are:

NACE RP0169:	Control of External Corrosion on Underground or Submerged Metallic Piping Systems
NACE RP0190:	External Protective Coatings for Joints, Fittings, and Valves on Metallic Underground or Submerged Pipelines and Piping Systems
CSA Z662:	Oil and Gas Pipeline Systems (Annex L: Test Methods for Coating Property Evaluation).

Specific standards to qualify the coatings are:

Cold-tar

[A]NACE RP0399	Plant-Applied External Coal Tar Enamel Pipe Coating Systems: Application, Performance, and Quality Control
[B]ANSI/AWWA C203	Coal-Tar Protective Coatings and Linings for Steel Water Pipelines – Enamel and Tape- Hot Applied
[C]NACE RP0602	Field-Applied Coal Tar Enamel Pipe Coating Systems: Applications, Performance, and Quality Control

Tape

[D]ANSI/AWWA C214	Tape Coating Systems for the Exterior of Steel Water Pipelines
[E]ANSI/AWWA C209	Cold-Applied Tape Coatings for he Exterior of Special Sections, Connections, and Fittings for Steel Water Pipelines
[F]NACE MR0274	Material Requirements for Polyolefin Cold-Applied Tapes for Underground or Submerged Pipeline Coatings

FBE

[G]NACE RP0394	Application, Performance, and Quality Control of Plant-Applied, Fusion-Bonded Epoxy External Pipe Coating
[H]CSA Z245-20	External Fusion Bond Epoxy Coating for Steel Pipe
[I]ANSI/AWWA C213	Fusion-Bonded Epoxy Coating for the Interior and Exterior of Steel Water Pipelines
[J]NACE RP0402	Field-Applied Fusion-Bonded Epoxy (FBE) Pipe Coating Systems for Girth Weld Joints: Application, Performance, and Quality Control

Liquid Epoxy

[K]ANSI/AWWA C210	Liquid-Epoxy Coating Systems for the Interior and Exterior of Steel Water Pipelines

Liquid Urethane

[L]ANSI/AWWA C222	Polyurethane coatings for the Interior and Exterior of Steel Water Pipe Fittings

2-layer, 3-layer, and composite

[M]DIN 30670	Polyethylene-Coatings for Steel Pipes and Fittings Requirements and Testing
[N]NACE RP0185	Extruded Polyolefin Resin Coating Systems with Soft Adhesives for Underground or Submerged Pipe
[O]CSA Z245-20	External Polyethylene Coating for Pipe
[P]ANSI/AWWA C215	Extruded Polyolefin Coatings for the Exterior of Steel Water Pipelines

Wax

[Q]NACE RP0375	Wax Coating Systems for Underground Piping Systems

4. REVIEW OF TESTS AND STANDARDS TO EVALUATE PIPELINE COATINGS

In this section, the existing laboratory methodologies are described. Standards developed by various organisations are compared. These methodologies/standards are classified according to which properties are being evaluated. For each property, the background information of the tests was provided, general standards to evaluate the properties are listed, and finally the relevance of these standards for each coating system is presented. The standards are classified based on the properties that these standards are used to evaluate:

- Steel
- Steel/coating interface
- Coating
- Coating/soil interface
- Steel/soil interface

4.A: STEEL[12]

The steel surface plays an important role in the performance of the coating. Surface imperfections can cause premature failure. Coatings tend to pull away from sharp edges and projections. Before the application of coatings, the steel surface is blast cleaned, the surface profile is established, and chemical contaminants, if any, e.g., chlorides, sulphates, and nitrates, are removed. The test methodologies and standards for determining steel properties are discussed in this section.

4.A.1: Cleaning

The primary functions of cleaning before coating are (a) to remove material from the surface that can cause early failure of the coating system, and (b) to obtain a suitable surface roughness and to enhance the adhesion of the coating. The steel surface is cleaned either by solvents or by tools. Blast cleaning is being increasingly used. The hierarchy of blast cleaning is as follows:

- white metal blast cleaning
- near-white metal blast cleaning
- commercial blast cleaning
- industrial blast cleaning
- brush-off blast cleaning
- water-jetting.

4.A.1.a: Standards

SSPC-SP 1:	Solvent Cleaning
SSPC-SP 2:	Hand Tool Cleaning
SSPC-SP 3:	Power Tool Cleaning
SSPC-SP COM:	Surface Preparation Specifications Surface Preparation Commentary
ISO 8504-1:	Preparation of Steel Substrates Before Application of Paints and Related Products Surface Preparation Methods - Part 1: General Principals

ISO-8504-2:	Preparation of Steel Substrates Before Application of Paints and Related Products Surface Preparation Methods - Part 2: Abrasive Blast-Cleaning
ISO-8504-3:	Preparation of Steel Substrates Before Application of Paints and Related Products Surface Preparation Methods – Part 3: Hand- and Power-tool cleaning.

4.A.1.b: Coatings

Surface preparation depends on the type of coating. Surface profile requirements for various coatings as recommended by various standards are presented in Table 4.

Table 4: Requirements of surface preparation for various coatings.

Coatings	Surface Preparation Requirements		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)[A, B]	(SSPC-SP1) SSPC SP6/NACE #3 or ISO 8501-1		(SSPC-SP1) SSPC SP6/NACE #3/SSPC SP 10/NACE #2
Coat tar (field) [C]	(SSPC-SP1) SSPC SP6/NACE #3 or ISO 8501-1		
Tape [D, F]	Not specified		(SSPC-SP1) SSPC-SP 6/NACE #3
Tape (for joints) [E]			(SSPC-SP1) SSPC-SP 6/NACE#3
FBE (plant) [G, H, I]	SSPC-SP 10/NACE #2[F] or ISO 8501-1	SSPC-SP 10/NACE #2[G]	(SSPC-SP1) SSPC-SP 10/NACE #2
FBE (field) [J]	(SSPC-SP1) SSPC-SP 10/NACE #2		
Liquid epoxy [K]	*Work in progress (NACE Committee TG 247)*		(SSPC-SP1) SSPC-SP 10/NACE #2
Liquid urethane [L]	*Work in progress (NACE Committee TG 281)*		(SSPC-SP1) SSPC-SP 10/NACE #2
2-layer [N, O, P]	SSPC-SP 6/NACE#3[L]	SSPC-SP 6/NACE#3	(SSPC-SP1) SSPC-SP 6/NACE#3
3-layer [O]		SSPC-SP 10/NACE #2	
Composite [O]		SSPC-SP 10/NACE #2	
Wax [Q]	(SSPC-SP 1) SSPC-SP 2		

4.A.2: Surface Profile

The allowable minimum/maximum height of profile usually depends on the thickness of the coating to be applied. Various methods for measuring surface profiles have been presented[6].

<u>4.A.2.a: Standards</u>

<u>Visual</u>

SSPC-VIS 1: Visual Standard for Abrasive Blast Cleaning Steel

- Provides color photographs for various grades of surface preparation as a function of the initial condition of steel.

NACE RP0178 Visual Comparator for Surface Finishing of Weld Prior to Coating"

- It is a plastic weld replica that complements NACE Standard RP0178, "Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to be Lined for Immersion Service."

<u>Non-Visual</u>

ASTM D4417: Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel

NACE RP0287: Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape

- The measurement technique utilizes a tape that replicates the surface profile. The thickness of the tape (with the profile replicate) is then measured with a dial micrometer to determine the surface profile.

ISO 8502-3: Preparation of Steel Substrates Before Application of Paints and Related Products - Tests for the Assessment of Surface Cleanliness - Part 3: Assessment of Dust on Steel Surfaces Prepared for Painting (Pressure-Sensitive Tape Method)

ISO 8503-1: Preparation of Steel Substrates Before Application of Paints and Related Products - Surface Roughness Characteristics of Blast - Cleaned Steel Substrates - Part 1: Specifications and Definitions for ISO Surface Profile Comparators for the Assessment of Abrasive Blast-Cleaned Surfaces

ISO 8503-2: Preparation of Steel Substrates Before Application of Paints and Related Products - Surface Roughness Characteristics of Blast - Cleaned Steel Substrates - Part 2: Method for the Grading of Surface Profile of Abrasive Blast-Cleaned Steel - Comparator Procedure

ISO 8503-4: Preparation of Steel Substrates Before Application of Paints and Related Products - Surface Roughness Characteristics of Blast - Cleaned Steel Substrates - Part 4: Method for the Calibration of ISO Surface Profile Comparators and for the Determination of Surface Profile - Stylus Instrument Procedure

<u>4.A.2.b: Coatings</u>

The minimum/maximum height of profile depends on the thickness of the coating. The surface profile requirements for various coatings are presented in Table 5

Table 5: Requirements for Surface Profiles for Various Coatings

Coatings	Surface Profile Requirements, mils (μm)		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	1.5-3.5 (38-89)		1.5-3.5
Coat tar (field)	1.5-3.5 (38-89)		
Tape	Not specified		1-3 (25-75)
Tape (for joints)			Not specified
FBE (plant)	1.5 (38)	1.5-4.5 (40-110)	1.5-4.0 (38-102)
FBE (field)	2.5-4 (64-100)		
Liquid epoxy			Not specified
Liquid urethane			2 (50)
2-layer	1.5 – 4.0 (38 – 102)	1.5-4.5 (40-110)	1.5-4.0 (38-102)
3-layer		1.5-4.5 (40-110)	
Composite		1.5-4.5 (40-110)	
Wax	Not specified		

4.A.3: Chemical Cleaning

The steel surface may be contaminated with visual and non-visual contaminants. Steel contaminated with soluble salts (e.g., chlorides and sulfates) develops rust-back rapidly at intermediate and high levels of humidity. The presence of varnish or previous coating on the pipe, phosphoric acid treatment, water, and grit or shot quality all contribute to the interaction between the pipe and coating[14-16]. The effects of surface contamination on FBE coatings have been widely studied. Based on field experience over the years, surface contamination affects all coatings[17, 18].

<u>4.A.3.a: Standards</u>

<u>Visual Contaminants</u>

NACE RP 0394: Appendix P: Test for Interface Contamination of the Coating

CSA Z.245.20: Section 12.9: Interface Contamination of the Coating

<u>Non-visual Contaminants</u>

SSPC-TU 4: Field Methods for Retrieval and Analysis of Soluble Salts on Substrates

ASTM D4940: Standard Test Method for Conductometric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives

- This test method indicates the concentration of total water-soluble ions based on their electrolytic mobility. Thus it provides an indication of ionic corrosion potential. This method is used to determine contamination to the pipeline surface caused by abrasive blasting.

ISO 8501-1-1988: Preparation of Steel Substrates Before Application of Paints and Related Products - Tests for the Assessment of Surface Cleanliness - Part 2: Laboratory Determination of Chloride on Cleaned Surfaces (1992)

ISO 8502-2-1992: Preparation of Steel Substrates Before Application of Paints and Related Products - Tests for the Assessment of Surface Cleanliness - Part 2: Laboratory Determination of Chloride on Cleaned Surfaces (1992)

ISO 8502-6:1995: Preparation of Steel Substrates Before Application of Paints and Related Products - Tests for the Assessment of Surface Cleanliness - Part 6: Extraction of Soluble Contaminants for Analysis - The Bresle Method (1992)

ISO 8502-9:1998: Preparation of Steel Substrates Before Application of Paints and Related Products - Tests for the Assessment of Surface Cleanliness - Part 9: Field Method for the Conductometric Determination of Water-Soluble Salts (1998)

4.A.3.b: Coatings

The importance of both visual and non-visual contamination is recognized in the standards. Only two standards for FBE specify maximum levels of visual contamination requirements (Table 6). Standards for non-visual contaminations are being developed (NACE TG259).

Table 6: Specifications for Visual Interface Contamination of Various Coatings

Coatings	Maximum Interface contamination, %		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	Not specified		Not specified
Coat tar (field)	Not specified		
Tape	Not specified		Not specified
Tape (for joints)			
FBE (plant)	30	30	Not specified
FBE (field)	Not specified		
Liquid epoxy			Not specified
Liquid urethane			Not specified
2-layer	Not specified	Not specified	Not specified
3-layer		Not specified	
Composite		Not specified	
Wax	Not specified		

4.B. STEEL-COATING INTERFACE

4.B.1. Adhesion

There is some evidence that good adhesion may be related in part to flexibility. This may account for the use of instruments that measure hardness to provide a measure of adhesion. It is evident that many adhesion tests are essentially subjective. This is not peculiar to adhesion tests, but may be more important than in other tests because of the absence of an absolute criterion against which a test value may be compared. It is also true that results of an adhesion test, subjective or otherwise, are not necessarily an unequivocal criterion of coating quality. This is true even at the laboratory level because of the largely uncontrollable variables that exist in the preparation of test samples. When application under field conditions is considered, the value of adhesion tests may be even less significant.

It is almost impossible to rate the various adhesion tests by their merits. It may be assumed that a test producing results in numerical values is more useful than a subjective test relying solely on the subjective assessment of the tester[19].

Adhesion is a summation of a wide variety of forces that hold a coating to a substrate. Although adhesion is widely considered as a single property, it has not been identified as such, nor has it been measured directly. It is usually measured by the removal force, which combines many factors, including adhesion.

Numerous test procedures have been developed specifically for evaluating the strength of adhesive joints. Many of these tests have been used for evaluating adhesive forces. It must be emphasized that the tests do not measure adhesive forces, but measure removal forces. Both adhesive and removal forces depend on the same forces, including surface conditions, surface geometry, wetting, and brittleness of the coating.

4.B.1.a. Standards

Hot-Water Sock

CSA.Z245.20:	Section 12.14: Hot-Water Sock (75°C, 24 hours)
NACE RP394:	Appendix N: Hot-Water Sock (66 ± 3 °C, 24 hours)

Peel Test

- ASTM D1000: Standard Test Method for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications

Shear Test

ASTM D1002:	Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)

Pull-Off Test

ASTM D4541	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

Others

ASTM D2197: Adhesion	Standard Test Method for Adhesion of Organic Coatings by Scrape

- ASTM D3359: Standard Test Methods for Measuring Adhesion by Tape Test

4.B.1.b. Coatings

Adhesion of coatings is measured differently for different coatings. The commonly used tests are hot-water sock, pull-off, shear, and peel. Because of the different types of tests, no meaningful comparison can be made either within the standards from one organisation or between various standards-making organisation (Table 7).

Table 7: Specifications for Determining Adhesion of Various Coatings

Coatings	Minimum adhesion strength		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	(Pull) ASTM D 4541 2.4 MPa (350 psi)		(Peel) AWWA C203 (No peeling)
Coat tar (field)	(Pull) ASTM D 4541 2.4 MPa (350psi)		
Tape	(Peel) ASTM D1000 Inner layer: 60-250 ozf/in. (6.6-27 N/10-mm) width Outer layer: 40-80 ozf/in. (4.4-8.9 N/10-mm) width		(Peel) ASTM D1000 Inner layer: 200 ozf/in. (2190 N/m) width Outer layer: 20 ozf/in. (200 N/m) width
Tape (for joints)			(Peel) ASTM D1000 20 ozf/in (220 g/cm) width
FBE (plant)	(Hot) NACE RP 394 (Rating 1-3)	(Hot) CSA Z245.20 (Rating 1-3)	(Shear) ASTM D1002 3000 psi (20,685 kPa)
FBE (field)	(Peel) NACE RP 0402 (No specification)		
Liquid epoxy			(Pull) ASTM D4541 400 lb/in (2,758 kPa)
Liquid urethane			(Pull) ASTM D4541 1500 psi (10,350 kPa)
2-layer	Not specified	(Peel) CSA Z245.21 3.0 N	Not specified
3-layer		(Peel) CSA Z245.21 19.6 N	
Composite		(Peel) CSA Z245.21 150.0 N (Hot) CSA Z245.20 (75^oC + 28 days) 1-3	
Wax	Not specified		

4.b.2. Cathodic Disbondment

This test is an accelerated method for determining comparative characteristics of buried pipeline coatings that are designed to function as an electrical barrier. This test measures the coating disbondment caused by electrical stress during cathodic protection. The test evaluates the coating ability not to loosen or disbond in long-term underground use. The results of this test provide only a comparative indication, but no accurate assessment of the coating life in this respect in the field performance. The cathodic disbondment test was known in earlier days as the Salt Crock test[20].

During the CD test carried out over a one-year period, a continuous increase in the disbonded area with time was observed. The data were scattered, but suggested a linear time dependence after an initial period with a higher disbondment rate. The disbondment rate, or time dependence, varies with coating systems. This study suggests that an exposure time of ~ 250 days was necessary to evaluate the coatings[21]. The results from long-term exposure do not correlate with those from short-term experiments.

Table 8 shows that increased negative potential does not increase the disbonded area[22]. The differences between the individual results for all types of coating are not significant and are within the range of accuracy of the method. The current, both initial and final, increased significantly with increased potential on all types of coating. Irrespective of the applied potential, in no case was the polarized potential lower than -1.2 V vs. CCS.

The standard electrode potential for hydrogen evolution is -1.15 V vs. CCS. At and more negative then this potential, the reaction kinetics is governed by diffusion control (when gas evaluation occurs), not charge control. Increasing the applied potential beyond a certain negative potential does not result in any acceleration. As a consequence, there is nothing to be gained by using applied potentials more negative than -1.15 V vs. CCS in cathodic disbondment tests[23].

Cathodic disbondment test results depend on the soil pressure, resistivity, temperature, and experiment duration. The cathodic disbondment test results may be misleading if these effects are not considered[24].

A direct method for determining the area of disbondment during a CD test is the measurement of double layer capacitance. Since the disbonded area is in contact with the electrolyte, the disbonded area is directly related to the double layer capacitance. This technique is nondestructive, *in situ*, and determines the area disbonded automatically. This technique has been successfully tested in the laboratory[25].

Table 8: Area disbonded vs. applied potential in a cathodic-disbondment test.

	Disbonded Area, mm^2						
Coating	No applied potential	Applied Potential (V) vs. $Cu/CuSO_4$				Magnesium anode	Mean
		-1	-1.5	-3	-6		
A	520	910	380	440	345	430	501
B	37	95	100	120	115	56	97
C	260	230	110	240	105	145	166
D	65	130	150	150	285	330	209
E	60	200	180	160	175	185	180
F	230	550	430	360	465	250	411
G	128	290	387	300	85	505	313
Mean	186	344	248	253	225	272	268

4.B.2.a. Standards

A comparison of cathodic disbondment standards is presented in Table 9.

ASTM G8: Standard Test Methods for Cathodic Disbonding of Pipeline Coatings
ASTM G19: Standard Test Method for Disbonding Characteristics of Pipeline Coatings by Direct Soil Burial
ASTM G42: Standard Test Method for Cathodic Disbonding of Pipeline Coatings Subjected to Elevated Temperature
ASTM G80: Standard Test Method for Specific Cathodic Disbonding of Pipeline Coatings
ASTM G95: Standard Test Method for Cathodic Disbondment Test of Pipeline Coatings (Attached Cell Method)

Table 9: Comparison of CD standards

Std. Dev. Org.	Std.	Coating Thickness	Holiday # and size	Potential, $Cu/CuSO_4$	Minimum Surface Area	Temp. °C (°F)	Electrolyte	Duration, days	Current Meas.
ASTM	G8	Not specified	3, Not less than 3 times the coating thickness, min. 6.35 mm (0.250 in)	-1.45 to – 1.55	Not specified	Room	1% NaCl	30	Not required in Method A, Required in Method B
ASTM	G19	Not specified	3 holidays (304.8 mm (12 in); 457.2 mm (18 in.); and 609.6 mm (24 in.)).	-1.45	Not specified	Room	Soil	30 to 18 months	Current and pipe-to-soil potential at 0 and 30 days.
ASTM	G42	Not specified	1 Holiday, diameter 3 times thickness of coating (min. 6.35 mm (0.25 in.)	-1.5	23200 mm^2 (36 in^2)	60 (min)	Distilled water with 1 wt% ea NaCl, Na_2SO_4, Na_2CO_3	30	Current requirement in uA
ASTM	G80	Not specified	3, Not less than 3 times the coating thickness, min. 6.35 mm (0.250 in)	-1.45 to – 1.55	92,900 mm^2 (1 sq.ft)	Room	Pot. tap water with 1 wt% ea NaCl, Na_2SO_4, Na_2CO_3	60	Not reported.
ASTM	G95	Not specified	1, 3.2 mm (0.125 in)	3	76.2 mm (3 inch)	Room	Distilled water with 3% NaCl	90	Not reported

CSA	Z245.20 (Sec.12.8)	300 um	1, 3.0 or 3.2 mm	-1.5	6.4 (pipe wall thickness) x100x100 mm	20	Distilled water with 3% NaCl	28	Not reported
				-3.0		65		1	
CSA	Z245.20 (Sec. 12.13 (strained at –30oC)	300 um	1, 3.0 or 3.2 mm	-1.5	6.4	20	Distilled water with 3% NaCl	28	Not reported
CSA	Z245.21 (sec.12.3)	Varies	6.4 mm	-1.5	pipe wall thickness x100x100 mm	20	Distilled water with 3% NaCl	28	Not reported
CSA	Z245.21 (sec.12.3)	Varies	6.4 mm	-1.5	pipe wall thickness x100x100 mm	Max. design temp.	Distilled water with 3% NaCl	28	Not reported
CSA	Z245.21 (sec.12.3)	Varies	6.4 mm	-3.5	pipe wall thickness x100x100 mm	65	Distilled water with 3% NaCl	1	Not reported
NACE	RP0394 (Sec.H)	360 ± 50 um	3 mm	-3.5	100 mm sq. x 6 mm thick	66 (150 F)	Distilled water with 3% NaCl	28	Not reported
NACE	RP0394 (Sec.H)	360 ± 50 um	3 mm	-1.5	100 mm sq. x 6 mm thick	66 (150 F)	Distilled water with 3% NaCl	1	Not reported
NACE	RP0394 (Sec.M) (Strained at –18oC)	360 ± 50 um	3 mm	-3.5	100 mm sq. x 6 mm thick	66 (150 F)	Distilled water with 3% NaCl	28	Not reported

4.B.2.b. Coatings

All coatings are evaluated for their cathodic disbondment resistance. Although Standards standards developed in various organisations have almost similaressentially the same procedure, but the conditions of the experiments and the criteria for coating selection differ vastly so much that precludes meaningful comparison of the coatings with respect to their cathodic disbondment resistance is not possible (Table 10).

Table 10: Requirements of Cathodic Disbondment Resistance of Various Coatings

Coatings	Maximum Disbonded Area Radius, mm (inch)		
As required by (Standards)	NACE	CSA	AWWA
Asphalt			
Coal tar (plant)	ASTM G8 8 (0.3), 60 days		Not specified
Coat tar (field)	ASTM G8 8 (0.3), 60 days		
Tape	ASTM G8 50 (2), 30 days		Not specified
Tape (for joints)			Not specified
FBE (plant)	RP0394 (Appn. H) 12	CSA Z245.20 (12.8) 6.5 in 24 hour or 8.5 in 28 day or 11.5 in 24 hour for production	Not specified
FBE (field)	RP0394 (Appn. H) 12		
Liquid epoxy			Not specified
Liquid urethane			Not specified
2-layer	ASTM G8 & ASTM G42 Not specified.	CSA Z245.21 (12.3) 12 in 28 d at 20^{o}C or max.design temp. or 12 in 24 h (production)	Not specified
3-layer		CSA Z245.21 (12.3) 12 in 28 d at 20^{o}C or max.design temp. or 7 in 24 h (production)	
Composite		CSA Z245.21 (12.3) 12 in 28 d at 20^{o}C or max.design temp. or 7 in 24 h (production)	
Wax	Not specified.		

4.B.3. Bendability/Flexibility

Because pipelines expand or contract in response to temperature changes, it is desirable that coatings have some flexibility. The methods to assess bendability involve bending a coated substrate over a mandrel and determining the amount of bending that takes place before the coating cracks.

The effects of short-radius bends on coating on small-diameter pipe are determined, which reflects on the ability of coatings to resist cracking, disbonding, or other mechanical damage. Coating failures are detected visually and electrically. This method is useful in coating selection and quality control needs.

Flexibility is also measured in terms of elongation, and the breaking point of the coating.

4.B.3.a. Standards

Bendability

ASTM G10: Standard Test Method for Specific Bendability of Pipeline Coatings

ASTM G70: Standard Method for Ring Bendability of Pipeline Coatings (Squeeze Test)

Elongation

- ASTM D522: Standard Test Method for Elongation of Attached Organic Coatings with Conical Mandrel Apparatus
- ASTM D638: Standard Test Method for Tensile Properties of Plastics
- ASTM D1000: Standard Test Method for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications
- ASTM D1737: Standard Test Method for Elongation of Attached Organic Coatings With Cylindrical Mandrel Apparatus

Breaking point

- ASTM D882: Standard Test Method for Tensile Properties of This Plastic Sheeting

ASTM D146: Standard Test Methods for Sampling and Testing Bitumen-Saturated Felts and Woven Fabrics for Roofing and Waterproofing

Others

- ASTM D790: Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

4.B.3.b. Coatings

For all coatings, flexibility/bendability is determined. But the testing to determine this property differs considerably. In general, flexibility testing includes determining flexibility, bendability, elongation, and breaking point of the coatings (Table 11).

Table 11: Requirements of Flexibility of Various Coatings

Coatings	Flexibility		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	Not available	Not available	Not available
Coal tar (plant)			
Coat tar (field)	Not specified		
Tape	100 – 400 % (ASTM D1000)		
Tape (for joints)			
FBE (plant)	NACE RP0394 (App.K) (2^o/PD at –18^{o}C) Or (1.5^o/PD permanent strain, for production rings) No cracks, tears or delamination		
FBE (field)	Not specified		
Liquid epoxy			
Liquid urethane			
2-layer	ASTM D 638 Min. 100%		
3-layer		ASTM D 638 Min. 300%	
Composite			
Wax	Not specified		

4.C. COATING

Both the properties of the coating material and the quality control during the application of coating determine the reliability of the coating. Several tests are performed to evaluate the properties of the raw materials and of the coating material. These tests are classified as common (to all coatings) and specific (to a particular coating) tests and are discussed in the following paragraphs.

Common Tests

4.C.1. Thermal Conductivity

During pipeline operations, the temperature of the pipe varies, depending on weather conditions and on operating requirements. The measure of thermal conductivity provides information on the performance of the coating at different temperatures.

4.C.1.a. Standards

ASTM C611: Standard Test Method for Electrical Resistivity of Manufactured Carbon and Graphite Articles at Room Temperature

ASTM E1225: Standard Test Method for Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique

4.C.1.b. Coatings

The requirements of thermal conductivity for various coatings are presented in Table 12.

Table 12: Requirements of Thermal Conductivity for Various Coatings

Coatings	Thermal Conductivity		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	0.16 W/M-K (1.1 BTU/ft^2/n/F/in) (ASTM E1225)		Not specified
Coat tar (field)	0.16 W/M-K (1.1 BTU/ft^2/n/F/in) (ASTM E1225)		
Tape	Not specified		Not specified
Tape (for joints)			Not specified
FBE (plant)	Not specified	Not specified	Not specified
FBE (field)	Not specified		
Liquid epoxy			Not specified
Liquid urethane			Not specified
2-layer		Not specified	Not specified
3-layer		Not specified	
Composite		Not specified	
Wax	Not specified		

4.C.2. Dielectric Strength

Polymeric coatings are insulators and should have high dielectric strength.

4.C.2.a. Standards

ASTM D149: Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies

ASTM D495: Standard Test Method for High-Voltage, Low-Current, Dry Arc Resistance of Solid Electrical Insulation

4.C.2.b. Coatings

The requirements of dielectric strength for various coatings are presented in Table 13.

Table 13: Requirements of Dielectric Strength for Various Coatings

Coatings	Dielectric Strength		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	>10 V/um (250 V/mil) (ASTM D495)		Not specified
Coat tar (field)	>10 V/um (250 V/mil) (ASTM D495)		
Tape	18,000-22,000 V/mm (450 to 550 V/mil) (ASTM D1000)		400 V/mil (15 V/um)
Tape (for joints)			6,000 V/single thickness & 12,000 V total system
FBE (plant)	Not specified	Not specified	
FBE (field)	Not specified		1,000 V/mil (39.4 V/mm) (ASTM D149)
Liquid epoxy			Not specified
Liquid urethane			Not specified
2-layer	20 kV/mm (500V/mil) (ASTM D149)	Not specified	(500 V/mil)
3-layer		Not specified	
Composite		Not specified	
Wax	14-79 V/um (350-2000 V/mil) (ASTM D149)		

4.C.3. Electrical Conductivity/Insulation Resistance

The value of electrical resistivity data in studying the properties of polymers has long been recognized. Accordingly, it is useful in studies of pipeline coatings. Electrical resistivity measurements are used to study rates and extent of polymerization, glass transition temperature, solid state and dielectric properties, degradation, and related properties.

The resistance of polymeric coatings is high (10^{14} ohms). This high resistance protects the pipeline from corrosion. Sophisticated equipment is needed to obtain accurate measurements at high resistance. However, the resistance decreases as ground water containing ionic species enters into the coating. The ion transport of a freestanding coating can be monitored by using the polymeric coating as a diaphragm in an electrolysis cell and by monitoring the electrolysis that takes place through, and in spite of, the polymeric coating.

4.C.3.a. Standards

ASTM D257:	DC Resistance or Conductance of Insulating Materials
ASTM C611:	Standard Test Method for Electrical Resistivity of Manufactured Carbon and Graphite Articles at Room Temperature
ASTM D1000:	Standard Test Methods for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications

4.C.3.b. Coatings

The requirements of electrical resistance for various coatings are presented in Table 14.

Table 14: Requirements of Insulation/Electrical Resistance for Various Coatings

Coatings	Insulation Resistance		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	1 x 10^{14} ohm-cm (ASTM C611)		Not specified
Coat tar (field)	1 x 10^{14} ohm-cm (ASTM C611)		
Tape	450,000 – 550,000 Megohms		500,000 megohms
Tape (for joints)			500,000 megohms
FBE (plant)		Not specified	1.1 x10^{15} (ASTM D257)
FBE (field)			
Liquid epoxy			Not specified
Liquid urethane			Not specified
2-layer	Not specified	Not specified	Not specified
3-layer		Not specified	
Composite		Not specified	
Wax			

4.C.4. Indentation/Hardness

Hardness measurements reflect the resistance of coatings to damage from loads during yard life and backfilling. During the service life, the hardness of a pencil needed to rupture a coating is recorded and termed the "pencil hardness." Since the technician uses hand pressure on the pencil, the result of the test is somewhat subjective and can vary from technician to technician. Nevertheless, a trained technician can obtain fairly consistent results. Hardness of the thick film products should be tested using indentation testers. The resistance of the coating to penetration by an indenter is measured using the Knoop or Pfund indentation hardness for coatings applied on rigid substrates.

4.C.4.a. Standards

ASTM D1474: Standard Test Methods for Indentation Hardness of Organic Coatings
ASTM D2240: Standard Test Method for Rubber Property—Durometer Hardness
ASTM D2583: Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor
ASTM D785: Standard Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials
ASTM D3363: Standard Test Method for Film Hardness by Pencil Test

4.C.4.b. Coatings

The requirements of hardness for various coatings are presented in Table 15.

Table 15: Requirements of Indentation/Hardness for Various Coatings

Coatings	Indentation/Hardness		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	Not specified		Not specified
Coat tar (field)	Not specified		
Tape	Not specified		Not specified
Tape (for joints)			Not specified
FBE (plant)	Not specified		Not specified
FBE (field)	Not specified		
Liquid epoxy			
Liquid urethane			
2-layer	Min. 60 Shore D (ASTM D2240)	Min. 45 Shore D (ASTM D2240)	
3-layer		Min. 50 Shore D (ASTM D2240)	
Composite		Min. 60 Shore D (ASTM D2240)	
Wax	Not specified.		

4.C.5. Penetration Resistance

This method determines the penetration or deformation resistance of a coating under blunt rod loading**.** The depth or penetration as a result of the blunt rod load is measured with a micrometer depth gauge. The result indicates the effects on coatings of concentrated loading from soil and other buried objects.

4.C.5.a Standards

ASTM D5:	Standard Test Method for Penetration of Bituminous Materials
ASTM G17:	Standard Test Method for Penetration Resistance of Pipeline Coatings (Blunt Rod)
ASTM D937	Standard Test Method for Congealing Point of Petroleum Waxes, Including petrolatum

4.C.5.b. Coatings

The requirements of thermal conductivity for various coatings are presented in Table 16.

Table 16: Requirements of Penetration Resistance for Various Coatings

Coatings	Penetration Resistance		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	2-55 at 50-100 g/s (or 1.8-3.53 oz/s) (ASTM D5)		5-55 at 50-100 g weight per sec (or 1.8-3.53 oz/s) at 25-46^{o}C (ASTM D5)
Coat tar (field)	2-55 at 50-100 g weight per sec (or 1.8-3.53 oz/s) at 25-46^{o}C (ASTM D5)		
Tape	20% (or 30%) with no holiday at 22^{o}C (60^{o}C) (ASTM G17)		25% with no holiday at 22^{o}C (ASTM G17)
Tape (for joints)			Not specified
FBE (plant)	<10% at 93^{o}C (ASTM G17)	Not specified	<10% at 60^{o}C (ASTM G17)
FBE (field)	Not specified		
Liquid epoxy			Not specified
Liquid urethane			Not specified
2-layer	3.0-12.0 mm (0.12 to 0.47 in) (ASTM D5)	Not specified	2.5-12 mm at 25^{o}C, 100 g/5 s (ASTM G5)
3-layer		Not specified	
Composite		Not specified	
Wax	160-290 at 25^{o}C (ASTM D937)		

4.C.6. Water Permeation

Coatings function as a barrier by physically isolating the substrate from moisture. Entry of water is the first step in the development of corrosion cells. It is important to detect the permeation of water.

Coated samples are immersed and suspended in an aqueous electrolyte for the test duration. Electrical measurements (coating capacitance and dissipation factor) are used to measure water absorption rate into the material.

The water vapour sorption isotherms on freestanding coatings are measured in an apparatus that consists of a Cahn Electrobalance in a high-vacuum environment. The free film[26] is weighed and hung on the electrobalance. The initial weight of the sample is recorded before evacuation. The evacuation is continued until no further weight loss is observed, at which point the water vapour (~ 10% relative humidity) is introduced. The weight increase is recorded and the measurement continued until little or no further weight increase is observed.

4.C.6.a. Standards

Water Absorption

ASTM D570:	Standard Test Method for Water Absorption of Plastics

Water Permeability

ASTM D163:	Test Method for Water Vapour Permeability of Organic Coating Films
ASTM D1434:	Standard Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting
ASTM G9:	Standard Test Method for Water Penetration into Pipeline Coatings

Water Transmission

ASTM D3985:	Oxygen Gas Transmission Rate Through Plastic Film and Sheeting Using a Coulometric Sensor
ASTM E96:	Standard Test Methods for Water Vapor Transmission of Materials
ASTM F 372:	Standard Test Method for Water Vapour Transmission Rate of Flexible Barrier Materials Using an Infrared Detection Technique

Moisture Content

ASTM D95:	Standard Test Method for Water in Petroleum Products and Bituminous Materials by Distillation
ASTM D2247:	Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity

4.C.6.b Coatings

The requirements of water permeation for various coatings are presented in Table 17.

Table 17: Requirements of Water Permeation for Various Coatings

Coatings	Water Permeation		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	0.2% or 0.3 g/30 cm^2 (0.1 oz/50 $in.^2$) (ASTM D95) 6.5 x 10^3 perms (ASTM E96)		Not specified
Coat tar (field)	0.2% or 0.3 g/30 cm^2 (0.1 oz/50 $in.^2$) (ASTM D95) 6.5 x 10^3 perms (ASTM E96)		
Tape	0.025 to 0.035 g/24 h/100 cm2 (0.15 to 0.25 g/24 h/100 in.2) (ASTM E96)		0.2% by wt. (ASTM D570) 0.2% perm (1.15 x10^{-11} kg (pascal.sec.$metre^2$) max. (ASTM E96)
Tape (for joints)			0.25 perm (1.44 ng[Pa.s.m2]), max. (ASTM E96)
FBE (plant)	0.5% max. & Rating 1-3		1-3 pass 4-5 Fail (AWWA C213)
FBE (field)	Rating 1-3	0.5%-0.6% max (CSA 245.20)	
Liquid epoxy			Not specified
Liquid urethane			3% max (ASTM D570)
2-layer	0.02 wt % (ASTM D570)	Wt % 0.1 max (ASTM D570)	0.2% max. (ASTM D570) 0.2% perm (1.1 x10^{-11} kg (pascal.sec.$metre^2$) max. (ASTM E96)
3-layer		Wt % 0.1 max (ASTM D570)	
Composite		Wt % 0.1 max (ASTM D570)	
Wax	Not specified.		

4.C.7. Chemical Resistance

Pipeline coatings should be resistant to soil contaminants. The resistance of polymeric coatings to the liquid and vapour phases is determined by visible examination and by tests for any loss of mechanical or bonding properties.

4.C.7.a. Standards

ASTM G20: Standard Test Method for Chemical Resistance of Pipeline Coatings

ASTM D543: Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents

4.C.7.b. Coatings

The requirements of chemical resistance for various coatings are presented in Table 18.

Table 18: Requirements of Chemical Resistance for Various Coatings

Coatings	Chemical Resistance		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	Not specified		Not specified.
Coat tar (field)	Not specified		
Tape	Not specified		Not specified
Tape (for joints)			Not specified
FBE (plant)	No blistering (HCl, HNO3, NaCl+H2SO4, NaCl, distilled water, NaOH) (CSA 245.20.Appendix I)	Not specified.	
FBE (field)	Not specified		
Liquid epoxy			Immersion for 30 days at 24^{o}C Deionized water, Sulphuric acid, 1%; & NaOH, 1% No blistering, peeling, and disbondment
Liquid urethane			10% H2SO4, 30% NaCl, 30% NaOH and #2 Diesel fuel (5% change after 30 days, max) (ASTM D543)
2-layer	ASTM G20 – no specification	Not specified	
3-layer		Not specified	
Composite		Not specified	
Wax	Not specified.		

4.C.8. Blistering

Blister formation is one of the common modes of failure of FBE coatings when immersed in water. The blister formation tendency is evaluated by immersing the coated samples in hot water. The temperature should be less than the glass transition temperature of the coating. The processes of formation and growth of blisters (including chemical and/or physical breaking of bonds between the metal and the film) can be detected by monitoring acoustic emission signals. The delaminated areas and the blisters can be detected because of the differences in light reflection through the coating[27, 28].

4.C.8.a. Standards

ASTM D714: Standard Test Method for Evaluating Degree of Blistering of Paints

4.C.8.b. Coatings

No specific coating standards require evaluation of blister formation.

4.C.9. Weathering

Effects of outdoor exposure are determined by parallel sets of samples that are aged indoors and outdoors. The coatings deteriorate due to atmospheric corrosion.

4.C.9.a. Standards

ASTM G11: Standard Test Method for Effects of Outdoor Weathering on Pipeline Coatings

4.C.9.b. Coatings

Except for NACE document (RP0185) on extruded polyolefin (which refers to ASTM G11)**,** no other standard specifies this test.

4.C.10 Cohesion

Cohesion tests are similar to adhesion tests except that the specimen plates are designed so that the adhesion area is greater than the specimen cross-sectional area, thus assuring a cohesion failure within the coating rather than an adhesion failure at the steel-coating interface[29].

When bonds between the metal and the coating break or when hydrogen gas evolves, measurable acoustic emission signals are emitted.

4.C.10.a. Standards

ASTM D879:	Specification for Communication and Signal Pin-Type Lime-Glass Windows (withdrawn in 1981; there is no replacement)
ASTM D1000:	Standard Test Method for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications
ASTM D1002:	Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)
ASTM D2197:	Standard Test Method for Adhesion of Organic Coatings by Scrape Adhesion
ASTM D3359:	Standard Test Methods for Measuring Adhesion by Tape Test

ASTM D4541: Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

4.C.10.b. Coatings

Same as for adhesion.

4.C.11. Environmental Stress-Cracking Resistance

Computerized visual imaging based on high-resolution colour image processing is used in highway coating inspection. The usefulness of this technique for underground pipelines is not known[30]. Due to soil stress and wet-dry cycles, the coatings may crack during pipeline corrosion. Internal stresses in coatings can be determined by the cantilever and strain gauge methods. A coated panel will curve or bend due to forces exerted at the substrate-coating interface as a result of stress in the coating. The curvature (deflection) can be measured using an optical microscope (cantilever method) or using a strain gauge [31].

4.C.11.a. Standards

ASTM D1693: Environmental Stress-Cracking of Ethylene Plastics

4.C.11.b. Coatings

The requirements of environmental stress-cracking for various coatings are presented in Table 19.

Table 19: Requirements of Environmental Stress-Cracking for Various Coatings

Coatings	Environmental Stress-Cracking		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	Not specified		Not specified.
Coat tar (field)	Not specified		
Tape	Not specified		Not specified
Tape (for joints)			Not specified
FBE (plant)		Not specified.	
FBE (field)			
Liquid epoxy			
Liquid urethane			
2-layer		300 minimum for 100% lgepal (ASTM D746)	300 minimum for 100% lgepal (ASTM D746)
3-layer		300 minimum for 100% lgepal (ASTM D746)	
Composite		300 minimum for 100% lgepal (ASTM D746)	
Wax	Not specified.		

4.C.12. Resistance to Oxidation

The environment surrounding a pipeline coating can range from a relatively inert environment (for example, sandy soil) to a more hostile environment (for example, acidic marsh). When a pipeline is operated at elevated temperature (up to 85^{o}C) in hostile environmental conditions, anti-oxidants are incorporated into the coatings. It is advantageous to have a rapid and reliable laboratory method to determine the resistance of anti-oxidative additives to degradation. One such method is the measure of oxidative induction time. The OIT is the time required for oxidation of the coating (for example, polyethylene) to begin.

Chemiluminescence is a measure of the light given off in the normal oxidation of organic materials. In the oxidation sequence, activated peroxides are generated which give off light when they fall to their ground state. Chemiluminescence is a measure of that light.

4.C.12.a Standards

No standard available

4.C.12.b. Coatings

No coating requirement specifies this property.

4.C.13. Compressive Properties

The change in mechanical properties, including modulus, should be determined under various loading conditions.

4.C.13.a. Standards

ASTM D695: Standard Test Method for Compressive Properties of Rigid Plastics

4.C.13.b. Coatings

No coating requirement specifies this property.

4.C.14. Thermal Expansion

The coating material should have very low thermal expansion

4.C.14.a. Standards

ASTM D696: Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between -30C and 30C With a Vitreous Silica Dilatometer

4.C.14.b. Coatings

No coating requirement specifies this property.

4.C.15. Brittleness Temperature

The temperature and impact conditions at which pipeline coatings exhibit brittle failure should be determined.

4.C.15.a. Standards

ASTM D746: Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact

4.C.15.b. Coatings

The requirements of brittleness temperature for various coatings are presented in Table 20.

Table 20: Requirements of Brittleness Temperature of Various Coatings

Coatings	Brittleness Temperature		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	-29oC (-20oF) (AWWA C203)		-29oC (-20oF) (AWWA C203) (No cracking)
Coat tar (field)	-29oC (-20oF) (AWWA C203)		
Tape	Not specified		Not specified
Tape (for joints)			Not specified
FBE (plant)	Not specified		
FBE (field)	Not specified		
Liquid epoxy		Not specified	
Liquid urethane		Not specified	
2-layer		-70oC or lower for F_{20} (ASTM D746)	
3-layer		-70oC or lower for F_{20} (ASTM D746)	
Composite		-70oC or lower for F_{20} (ASTM D746)	
Wax	Not specified		

4.C.16. Film Thickness

Coating thickness is an important factor in determining the coating service life and cost. Nondestructive measurement of the dry film thickness of coatings on an external steel pipe surface is important. Variation in magnetic flux or magnetic attraction due to the presence of coating can be calibrated into a thickness measurement.

4.C.16.a. Standards

ASTM G12:	Standard Test Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel
ASTM D4138:	Standard Test Methods for Measurement of Dry Film Thickness of Protective Coatings Systems by Destructive Means
ASTM D4414:	Standard Practice for Measurement of Wet Film Thickness by Notch Gages
TAPPI T414	Thickness (Calliper) of Paper, Paperboard, and Combined Board (Technical Association of the Pulp and Paper Industry)

4.C.16.b. Coatings

The requirements of film thickness for various coatings are presented in Table 21.

Table 21: Requirements of Thickness of Various Coatings

Coatings	Thickness, mm (mil)		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	3.0-3.6 (120-140)		1.1 (43) (inner + outer wrap) 1.2 (TAPPI T 411)
Coat tar (field)	3.0 (120)		
Tape	1.250 (50)		0.75 (30)
Tape (for joints)			1.2-2.2 (46-88)
FBE (plant)	0.3(12)	0.3 (12)	0.406(16)
FBE (field)	0.64 (25)		
Liquid epoxy			0.406 (16)
Liquid urethane			0.5(20)
2-layer (varies with pipe diameter, for CSA&AWWA)	0.78 (31)	0.7 – 1.25	0.789 (31) – 1.7 (69)
3-layer (varies with pipe diameter, for CSA)		2-3.22	
Composite		0.67	
Wax	0.15 – 0.36 (6-14) (ASTM D1000)		

Specific Tests

4.C.17. Low-Temperature Cracking Test

Below certain temperatures, polymer coatings lose elasticity due to solidification and crack.

4.C.17.a. Standards

ANSI/AWWA C203 Section 5.3.5: Laboratory Low-Temperature cracking Test

4.C.17.b. Coatings
This is a good Q.C. test for coal tar coatings.

4.C.18. Composition
This test provides documentation of the general composition of the coating material. The attenuated total reflectance (ATR)-IR technique is an excellent analytical tool and can be used to determine if changes are occurring at the metal-coating interface as the system ages. This technique detects changes in the spectra due to aging. The main difficulty with this system is the requirement of coating onto the ATR cell (cured to the surface). Difficulties are also encountered in duplicating the curing conditions that are observed on real pipe and on test panels. The initial cure conditions should have a significant effect on the type and amount of bonds formed at the interface. A technique needs to be developed to coat the whole cell without coating the end surfaces.

4.C.18.a. Standards
ASTM D1652: Standard Test Methods for Epoxy Content of Epoxy Resins

4.C.18.b. Coatings
This is a good QC test for FBE and epoxy coatings.

4.C.19. Sag
As the pipeline coating ages, it will sag (that is, stretch and droop). To simulate the effect of aging, the sag test is conducted at higher temperatures than the operating temperature of the pipeline.

4.C.19.a. Standards
ANSI/AWWA C203 Section 5.3.4: Laboratory High-Temperature Sag Test

4.C.19.b. Coatings
This is a good QC test for coat tar coatings.

4.C.20. Pliability
Pliability is a measure of the strength of the external layer of a protective coating.

4.C.20.a. Standards
ANSI/AWWA C203: Section 5.3.9: Outerwrap Pliability Tests and Section 5.3.14.3: Pliability Test

4.C.20.b. Coatings
This is a good QC test for coal tar coatings.

4.C.21. Gel Time
Measurement of gel time of a coating material provides information on the duration of coating application.

4.C.21.a. Standards

CSA Z245.20:	Section 12.2: Gel Time of the Epoxy Powder
NACE RP0394:	Appendix D: Gel Time Determination
AWWA C213:	Section 5.3.2.3: Gel Time - Hot Steel Plate

4.C.21.b. Coatings

This is a good QC test for FBE and epoxy coatings.

4.C.22. Particle Size

The size of the raw material determines the density of the finished coatings. The particle size is controlled carefully during the application of the coating.

4.C.22.a. Standards

CSA Z245.20: Section 12.5: Particle Size of the Epoxy Powder

4.C.22.b. Coatings

This is a good QC test for FBE coating.

4.C.23. Total Volatile Content

Release of volatile contents from a coating leads to the formation of voids.

4.C.23.a. Standards

NACE RP0394: Appendix G: Determination of Total Volatiles

4.C.23.b. Coatings

This is a good QC test for FBE coating.

4.C.24. Porosity

To maintain integrity, the coating must be as non-porous as possible.

4.C.24.a Standards

CSA Z245:	Section 12.10: Porosity of the Coating
ANSI/AWWA C203:	Section 5.3.14.4: Porosity test • Refers to ASTM D737
ASTM D737:	Test Method for Air Permeability of Textile Fabrics
NACE RP0394:	Appendix J: Test for Porosity of the Coating

4.C.24.b. Coatings

This is a good QC test for FBE coating.

4.C.25. Viscosity

The viscosity determines the flow, wetting and spreading during application of the coating.

4.C.25.a. Standards CSA Z245.21: Section 12.1: Viscosity
ASTM D4212: Standard Test Method for Viscosity by Dip-Type Viscosity Cups

4.C.25.b. Coatings
This is a good QC test for 2-layer, 3-layer and composite coatings.

4.C.26. Flow
To apply the coating uniformly at different locations and to maintain the efficiency of the spray gun, the flow should be maintained. In the flow test, the rate of extrusion of molten resins through a die of a specified length and diameter is measured under prescribed conditions of temperature, load, and piston position in the barrel.

4.C.26.a. Standards

ASTM D1238:	Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer
AWWA C215:	Section 5.3.1.4: Melt-Flow Rate, Type B Adhesive (Refers to ASTM D1238)
CSA Z245.21:	Section 12.2: Flow Test

4.C.26.b. Coatings
This is a good QC test for 2-layer, 3-layer and Composite coatings.

4.C.27. Softening Point
This is a measure of the fluid property of the coating.

4.C.27.a. Standards

ANSI/AWWA C203:	Section 5.3.13.4: Softening Point Test (Refers to ASTM D36)
ANSI/AWWA C215:	Section 5.3.1.1: Softening Point Type A Adhesive (Refers to ASTM E28)
ASTM D36:	Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)
ASTM E28:	Standard Test Methods for Softening Point of Resins Derived from Naval Stores by Ring-and-Ball Apparatus
ASTM 1525:	Standard Test Method for Vicat Softening Temperature of Plastics

4.C.27.b. Coatings
This is a good QC test for coal tar coating.

4.C.28. Shelf Life
This test is used to estimate the shelf life of coating materials.

4.C.28.a. Standards
NACE RP0394: Appendix C: Shelf Life Determination

4.C.28.b. Coatings
This is a good QC test for FBE coating.

4.C.29. Filler Content
This test is used to estimate the filler content

4.C.29.a. Standards

AWWA C203:	Section 5.3.13.6: Filler Content Test (Refers to ASTM D2415)
ASTM D2415:	Standard Test Method for Ash in Coal Tar and Pitch

4.C.29.b. Coatings
This is a good QC test for coal tar coating.

4.C.30. Density/Specific Gravity
The weights of free coating in air and water are measured. The loss in weight in water is due to the displaced volume of water. The weight in air divided by this volume is the density. An analytical balance is used for all weighing.

4.C.30.a. Standards

CSA Z245.20:	Section 12.6: Density of the epoxy powder
AWWA C215:	Section 5.3.1.3: Specific Gravity, Type A Adhesive (refers to ASTM D71)
AWWA C215:	Section 5.3.1.5: Density, Type B Adhesive (Refers to ASTM D1505) and Section 5.3.1.6: Density of Polyolefin resin
NACE RP0394:	Appendix B: Specific Gravity Determination
ASTM D71:	Standard Test Method for Relative Density of Solid Pitch and Asphalt (Displacement Method)
ASTM D 792:	Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
ASTM D1505:	Standard Test Method for Density of Plastics by the Density-Gradient Technique

4.C.30.b. Coatings
This is a good QC test for all powder coatings.

4.C.31. Tear Strength
This test is used to determine the tear strength in both the longitudinal direction and in the transverse direction.

4.C.31.a. Standards

AWWA C203:	Section 5.3.14.1: Elmendorf Tear-Strength Test

4.C.31.b. Coating
This is a good QC test for coal tar coating.

4.C.32. Curing

The extent of curing determines the strength of the coating, whether it is sprayed or brushed[32-36]. Shear rheology measurement is extremely useful in determining the rate of build-up of physical properties as the curing process proceeds. The measurement is performed by pressing the epoxy powder between two flat parallel plates. One plate is oscillated at a constant amplitude while the force due to the rheological property of the sample is measured on the other. The plate arrangement is surrounded by an environmental chamber providing temperature control. It demonstrated that the rheology method provides information on processes occurring in the final stages of cure[34].

The strength of curing is determined by Differential Scanning Calorimetry (DSC) and Differential Thermal Analysis (DTA) or by solvent extraction methods[37, 38].

<u>4.C.32.a. Standards</u>

CSA Z245.20:	Section 12.1: Cure Time of the Epoxy Powder
CSA Z234.20:	Section 12.7: Thermal Characteristics of the Epoxy Powder and Coating (This test is used to determine the glass transition temperature and the exothermic heat of reaction of epoxy powders and coating and the percentage conversion of coatings).
NACE RP0394:	Appendix E: Glass Transition and Heat of Reaction Determination (Glass transition temperature by DSC). Round-robin comparisons between laboratories have resulted in significant variations in all parameters measured. Achieving comparable results between laboratories will require strict compliance with this test procedure followed by laboratory comparison testing.
AWWA C210:	Section 5.2.2. Refers to ASTM D4752 (Solvent rub test) and ASTM D 3363 (Pencil hardness) or both. A coating system that has not been cured in accordance with the manufacturer's written instructions may be rejected
AWWA C222:	Section 5.5.1: The coating manufacturer shall be consulted to ascertain the proper cure time of the coating prior to inspection and testing.

<u>4.C.32.b</u>. Coatings

This is a good QC test for liquid epoxy, FBE, and urethane coatings.

4.D. COATING-SOIL INTERFACE

4.D.1. Microbial Resistance

Microbial degradation of coating materials is well known because the coating components can feed microbes. A mixed population of microorganisms, including sulphate-reducing bacteria (SRB) and acid-producing bacteria (APB), may be involved in coating degradation. Sandy soils favour APB and high-clay soils support populations of both kinds of organisms. Fungi also alters optical, mechanical, and electrical properties of polymeric coatings. The resin portion of the coating is generally fungus-resistant. Other components such as plasticizers, stabilizers, and colouring agents may be susceptible to microbial attack[39].

Despite these indications, a quantitative relationship between bacteria and coating damage has been difficult to establish. Large samples of most coating materials will sustain extensive microbial growth under realistic field conditions for many months without apparent damage to the coating. Exposing very small coating samples to large volumes of bacterial culture leads to mixed effects. For most coatings, loss of components through water dissolution is the primary effect. Bacteria grow through the use of dissolved extracts rather than direct attack on the coating. Further, the physical and chemical changes that can be specifically attributed to biodegradation are difficult to relate to field performance.

Generally, the test protocol to evaluate resistance of coatings to microbes involves exposure to a naturally occurring microbial environment, followed by performance tests (for example, the CD test).

4.D.1.a. Standards

ASTM G21:	Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi
ASTM G22:	Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Bacteria
ASTM E2180:	Standard Test Method for Determining the Activity of Incorporated Antimicrobial Agent(s) in Polymeric or Hydrophobic Materials

4.D.1.b. Coatings

No specification

4.D.2. Abrasion Resistance

The relative resistance of steel pipeline coatings to abrasion by a slurry of coarse abrasive and water during construction should be evaluated. Information on abrasion resistance can be used to specify optimum coating thickness.

4.D.2.a. Standards

ASTM G6:	Standard Test Method for Abrasion Resistance of Pipeline Coatings
ASTM D968:	Standard Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive
ASTM D1044:	Standard Test Method for Resistance of Transparent Plastics to Surface Abrasion
ASTM D4060:	Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser

4.D.2.b. Coatings

The requirements of resistance to abrasion for various coatings are presented in Table 22.

Table 22: Requirements for Abrasion Resistance of Various Coatings

Coatings	Thickness, mm (mil)		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	Not specified		Not specified
Coat tar (field)	Not specified		
Tape	Not specified		
Tape (for joints)			
FBE (plant)	300 mg per 5000 cycles (ASTM D4060)	Not specified	0.3 (5000 cycles-gm loss) (ASTM D1044)
FBE (field)	Same as FBE Plant		
Liquid epoxy		Not specified	
Liquid urethane		100 mg loss per 1000 cycles (ASTM D4060)	
2-layer	Requirement not specified (ASTM G6)	Not specified	Not specified
3-layer		Not specified	
Composite		Not specified	
Wax	Not specified		

4.D.3. Impact Resistance

The resistance of pipeline coatings to mechanical damage during shipping, handling, installation and impacts from backfilling should be determined. The effects of backfilling rocks in damaging the coatings are determined visually, or electrically, by measuring the amount of dropped material required to pierce through the coating to bare metal.

4.D.3.a. Standard

ASTM G13: Standard Test Method for Impact Resistance of Pipeline Coatings (Limestone Drop Test)

ASTM G14: Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)

ASTM D256: Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics

ASTM D2794: Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)

4.D.3.b. Coatings

The requirements of impact resistance for various coatings are presented in Table 23.

Table 23: Requirements for Impact Resistance of Various Coatings

Coatings	Impact Resistance		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	Not specified		650 g ball, 8-ft drop (25oC) (AWWA C203) 1016 in^2 (6,452 – 10,323 mm^2) – max.
Coat tar (field)	Not specified		
Tape	30 lbf.in. (3.4 J) (ASTM G14) No holidays after 30 drops (ASTM G13)		25 lbf.in. (2.8 N.m) (ASTM G14)
Tape (for joints)			Not specified
FBE (plant)	1.5 J (13 in.-lb) min (ASTM G14)	1.5 J	100 in-lbf (11.3 Nm)
FBE (field)	1.5 J (13 in.-lb) min (ASTM G14)		
Liquid epoxy			Not specified
Liquid urethane			40 in.lbs (0.46 kg.m). minimum (ASTM D2794)
2-layer	(ASTM G14) No specification	3.0 J/mm of actual total coating thickness	25 lbf.in (2.8 N.m) min. (ASTM G14)
3-layer		3.0 J/mm of actual total coating thickness	
Composite		3.0 J/mm of actual total coating thickness	
Wax	Not specified.		

4.D.4. Freeze-Thaw Stability

This test determines the effect of freezing and thawing on coating adhesion. This test is important for operation in low-temperature climates. A freeze-thaw test can be performed by changing either the frequency of the freeze/thaw conditions or the temperature differential. Coating properties (usually adhesion) are determined before and after the freeze-thaw test.

4.D.4.a. Standards
ASTM D2243: Test Method for Freeze-Thaw Resistance of Waterborne Paints
ASTM D2337: Test Method for Freeze-Thaw Stability of Multicolour Lacquers

4.D.4.b. Coatings
No coating standard specifies this requirement.

4.D.5. Resistance to Elevated Temperature
Operating temperatures of pipelines continue to increase; =e.g., pipelines carrying oils and operate at temperatures up to 150^{o}C. The performance of coatings should, therefore, be evaluated at operating temperatures.

4.D.5.a. Standards
ASTM D2485: Standard Test Methods for Evaluating Coatings for High Temperature Service
ASTM D3012: Standard Test Method for Thermal-Oxidative Stability of Propylene Plastics Using a Specimen Rotator Within an Oven

4.D.5.b. Coatings
The requirements of minimum operational temperature requirements of various coatings are presented in Table 24.

Table 24: Requirements of Maximum Operational Temperature of Various Coatings

Coatings	Temperature, max, ^{o}C (^{o}F)		
As required by (Standards)	NACE	CSA	AWWA
Asphalt	N/A	N/A	N/A
Coal tar (plant)	71-110(160-230)		Not specified.
Coat tar (field)	71-110(160-230)		
Tape	-30-90 (-22-194)		Not specified
Tape (for joints)			Not specified.
FBE (plant)	Not specified	Not specified	
FBE (field)			
Liquid epoxy			Not specified
Liquid urethane			Not specified
2-layer		Not specified	
3-layer		Not specified	
Composite		Not specified	
Wax			

4.D.6. Compatibility and Repairability
Coating materials used on joints, couplings, irregular fittings and patched areas should be compatible with main-line coatings. The performance of joint and repair coatings depends on the

bond to the substrate and to the original coating, the moisture seal at the joints, and water absorption.

4.D.6.a. Standard

ASTM G18: Standard Test Method for Joints, Fittings, and Patches in Coated Pipelines
ASTM G55: Standard Test Method for Evaluating Pipeline Coating Patch Materials

4.D.6.b. Coatings

Specific standards to qualify joint/repair/rehabilitation coatings are available. Standards to determine compatibility of mainline and joint coatings are not available.

4.E. PIPE-SOIL INTERFACE (PRESENCE AND/OR FORMATION OF HOLIDAYS)

4.E.1. Holiday Detection

Discontinuities or thin spots in dielectric pipeline coatings are determined by an impressed voltage. Electrical leakage paths indicate coating discontinuity holidays such as uncoated regions, bubbles, voids, cracks, thin spots, metallic inclusions or contaminants. With over 10,000 km of pipelines buried in widely varying soil types, environments, and terrain conditions, pipeline companies rely on the corrosion protection of coatings as a primary method for maintaining the integrity of their pipelines. More than 150 years ago, in his book *Two Years Before the Mast*, Richard Henry Dana Jr. wrote of the “holyday,” a reference to the application of tar to the ship’s rigging as a protection against the sea water. The term “holiday” has carried over to general use in the pipeline industry, retaining its original meaning, as a defect in the coating[40]. One of the major concerns of using polymer coatings to protect pipelines is the presence or development of holidays. Various electrical methods have been developed for detecting coating faults before installation of the pipe. The most common method uses an electrical probe energized by alternating or pulsating high voltage. Such devices are commonly referred to as “jeepers” or “holiday detectors”[41]. Any holidays detected at the time of installation are repaired.

During operation, some coatings lose their integrity and ultimately fail to provide the service for which they were intended to perform according to the specifications. When a coating fails, the problems can be more serious than just a failed coating. Therefore, a failed coating may be more harmful and costly than a bare pipeline. For example, when shielding occurs, increased current is required. . But, very little, if any, of this increased current reaches the steel surface. The investment made in the coating and their applications are lost. Therefore, it is not only important to choose and apply the best coating, but also to monitor the performance of the coating on a buried pipeline continuously. Most of the techniques for monitoring the coating quality are electrical in nature. The techniques can be divided into DC (direct current) methods and AC (alternating current) methods.

Because the techniques are electrical in nature, calcareous deposits resulting from the application of cathodic protection or large accumulations of loose corrosion products may increase the electrical resistance of a coating defect, making detection of defects difficult. Some techniques that monitor pipeline capacitance may be used to detect coating damage even if the bare pipe is not directly contacting the soil.

The four DC methods all involve the application of cathodic protection current to the pipeline, the cyclical interruption of this current, and the measurement of the resulting "on" and "off" DC potentials.

The measurement of pipe-to-soil potentials is a common component of all four DC techniques. The success of the DC method depends on the ability to measure both the on-potential and the off-potential, and to interrupt cathodic protection synchronously.

All DC methods are susceptible to errors resulting from stray DC current interference. Wherever practical, sources of such interference, such as foreign cathodic protection rectifiers and DC welding generators, should be de-energized during the test period.

The close-interval survey (CIS) and the DC voltage gradient (DCVG) methods are very similar, and can be conducted using standard instrumentation (reference electrodes, voltmeter, current interrupter). Both methods involve the evaluation of DC voltages in the vicinity of coating defects; the only difference between them is that the CIS method uses pipe-to-soil potential measurements, whereas the DCVG method uses voltage gradients measured in the soil between two reference electrodes.

Since the CIS method requires that the trailing pipe lead wire be picked up following the test, it is the more laborious of the two methods, but it has the added benefit of providing cathodic protection potential data.

Both methods produce a fault severity rating, which can be correlated with pipe depth and soil resistivity to provide an indication of percent coating damage. Both methods require complete access to the pipeline, and become less sensitive to coating defects as pipe depth increases.

The cathodic protection current requirements (CPCR) and the coating conductance (CC) methods are also similar, and can be conducted using standard instrumentation. Both require the measurement of CP currents at each of the pipe sections, so that the CP current density being applied to that pipe section can be determined. This determination requires a magnetometer or clamp-on ammeter, or *IR drop* test lead (that is, as a voltage drop over that pipe section). Although it is preferable to monitor potentials at several locations along the pipe, potentials measured at each end of the pipe may be sufficient. Both tests are applicable regardless of pipe depth.

The CPCR technique requires that cathodic polarization (that is, polarized off potential minus static potential) be determined, whereas the CC technique requires the measurement of the voltage drop across the coating. The CPCR technique provides information on the polarization occurring per unit of applied current density (in $mV/mA/ft^2$), whereas the CC technique provides coating conductance (in $siemens/ft^2$).

The polarization per unit of current density determined using the CPCR technique is generally indicative of the quality of the coating. Polarization also depends on soil moisture, temperature, and aeration. As a result, it would be difficult to correlate the results with percent coating damage consistently for a wide range of soil conditions. Furthermore, this technique requires that static potentials be measured prior to the application of cathodic protection current, and that a sufficient amount of time be allowed for polarized potentials to reach a steady state.

The CC technique can be conducted without any knowledge of static potentials and requires only that the polarized potentials be at a steady state. Since coating conductance depends primarily on defect size and soil resistivity, an index could be formulated relating percent bare area with coating conductance over a range of soil resistivities.

AC methods all require the use of special equipment. The AC voltage gradient (ACVG) technique, more commonly known as the Pearson method, involves the detection and measurement of voltage gradients at coating defects resulting from the application of an AC signal to the pipeline. Since it is similar to the DCVG and CIS techniques, it is subject to the same limitations of access required to the entire pipeline. The other two AC methods, current attenuation (CAT), and transwave system (TS), do not share these limitations, but require more technical sophistication.

Electrochemical impedance spectroscopy (EIS) is a technique that has been used to conduct laboratory evaluations of coatings, but has seen limited field use due to the complexity of the instrumentation and analysis. The required equipment is expensive and analysis procedures are complex. As a result, EIS is not widely used to monitor pipeline coatings in the field.

The TS technique involves the analysis of waveforms generated by CP rectifiers. Attenuation of these waveforms along the pipelines is a function of the characteristics of the pipe, soil, and waveform frequency, as well as the quality of the coating. Waveform readers at each end of the pipe section record information that is subsequently analyzed to provide attenuation data, which can then be correlated with coating quality. The measurement and analysis of the TS technique is complex.

The DC techniques are susceptible to stray current, whereas the AC techniques are susceptible to induced AC, although electronic filtering can be used to minimize the effects of induced AC. All eight techniques were evaluated for their ability to monitor coatings on a bored crossing. The techniques were scored based on their accuracy, applicability, efficiency, equipment availability and on the ease of use[42,43].

The CC technique evaluating coating quality received the highest score in this assessment, and is the only DC method that can practically be considered for use on pipelines. It can be conducted by a single corrosion technician with no special training, using only standard equipment, except for some means of measuring pipe current. It does not require complete access to the pipeline, and it is applicable regardless of pipe depth.

Of the four AC techniques, the SA technique received the highest score, and is the only AC technique that could be considered for this application. It too can be conducted by a single corrosion technician. It does not require complete access to the pipeline, and it is applicable regardless of pipe depth. However, this technique was rated slightly lower than the CC technique because of the special equipment and training requirements.

The EIS and TS techniques were reported to be accurate, and are applicable to bored crossings, but the special expertise and equipment required for these techniques prohibits their use for pipeline coating monitoring.

4.E.1.a. Standards

ASTM G62: Standard Test Methods for Holiday Detection in Pipeline Coatings

4.E.1.b. Coatings

No specific standard is available either for above ground or for in-the-ditch techniques to monitor underground coating deterioration.

5. SUMMARY

- There is a good understanding in the industry of the important properties that are detrimental to pipeline coating behaviour.
- Several standards are available to test those properties that are detrimental to pipeline coatings.
- Standards developed by different organisations have essentially the same requirements for evaluating some properties of the coating (e.g., surface profile), but different requirements for evaluating other properties (e.g., cathodic disbondment and adhesion).
- Properties for which standards from different organizations have different requirements are also properties considered important for the coating performance; i.e., cathodic disbondment and adhesion. Harmonization of standards to evaluate these properties will be very useful.
- Correlation of performance of coatings in standard tests and in the field has not been well documented, nor is such a correlation a specified requirement in any of the standards.
- To date, no studies have been successful in establishing a correlation between field performance and performance in standard testsNo common industry database on the performance of coatings in the field is available.
- Development of a capability to predict long-term coating performance from test data established in short-term standard tests is an industry priority.

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ASTM D 01.48

Durability of Pipeline Coatings and Linings
Committee Chair, Don Kathrein, Tapecoat/Royston,
Sub-committee of ASTM D 01, Paints and Related Coatings, Materials and Applications
Staff Manager, Timothy Brooke, ASTM

Scope: ASTM D 01.48 Committee creates, approves fox ballot, rejects, reviews, modifies and ballots the ASTM standards that directly relate to pipeline coatings and linings. All new standards, standard renewals and non-editorial changes are re-balloted.

Membership: Open to members of ASTM (annual fee required). Committee normally consists of volunteer members representing pipeline owners and operators, steel pipe manufacturers, pipeline coating manufacturers, pipeline;lining manufacturers, testing laboratories, contractors, academics, government agency members and interested individuals.

Meeting: Traditionally, twice per year (Jan. & Jun.). Extra meetings if necessary. All standards are reviewed at least every five years. Task groups may be formed to deal with special issues regarding standards or standards themselves.

Standards: ASTM D 01.48 is currently responsible for 18 standards. These are well established pipeline coating industry, minimum testing standards for:

- abrasion resistance
- cathodic disbondment resistance (6 standards)
- water penetration resistance
- outdoor weathering resistance
- impact resistance
- blunt rod penetration resistance
- chemical resistance
- bendability (2 standards)
- holiday detection
- non-destructive thickness determination
- joints, fittings and patching materials evaluation (2 standards)

These ASTM standards are widely referenced in other organization's standards or recommended procedures (ANSI/AWWA, NACE, etc.)

Status: Eight standards have been reviewed, re-balloted and re-approved since 2001. Seven additional standards have been reviewed and will be re-balloted this summer. The remaining three standards in the five year cycle will be reviewed at the Jun 2005 meeting in Pittsburgh, PA.

The most common revision is the addition of Precision and Bias statements to standards that have not previously addressed Precision and Bias.

One standard, ASTM G l3, the impact resistance by limestone drop standard, was reviewed and removed from the list of standards. Reasons for the removal of the standard included:

1. lack of use by testing laboratories contacted
2. lack of use by coating manufacturers contacted
3. lack of correlation to actual field conditions (improper design of test apparatus)
4. availability of ASTM G 14 impact resistance standard
5. possible OSHA concerns with dust generated in the laboratory from the numerous limestone drops.

Task Group: A task group has been formed to investigate and resolve the controversy between the "current divider" school and the "voltage divider" school of circuit design for cathodic disbondment testing.

Trends: ASTM D 01 meetings with ISO counterparts to harmonize individual standards between ASTM and the international standards community.

Challenges: Keeping ASTM D 01.48 committee membership and attendance at a sufficient level to prevent being absorbed into a committee with a larger scope and membership that could switch the control of the pipeline industry standards away from the Pipeline industry community.

ASTM D 01.48
Sub-Committee on Durability of Pipeline Coating and Linings
18 ACTIVE standards and 9 WORK ITEMS in progress (May 2005)

18 ACTIVE standards under the jurisdiction of D01.48:

D6676-01e1	Standard Test Method for Cathodic Disbonding of Exterior Pipeline Coatings at Elevated Temperatures Using Interior Heating
G6-88(1998)	Standard Test Method for Abrasion Resistance of Pipeline Coatings. *See also WK2881 for information on a proposed revision to this standard.*
G8-96(2003)	Standard Test Methods for Cathodic Disbonding of Pipeline Coatings
G9-87(1998)	Standard Test Method for Water Penetration into Pipeline Coatings. *See also WK2882 for information on a proposed revision to this standard.*
G10-83(2002)	Standard Test Method for Specific Bendability of Pipeline Coatings
G11-04	Standard Test Method for Effects of Outdoor Weathering on Pipeline Coatings. *See also WK5645 for information on a proposed revision to this standard.*
G12-83(1998)	Standard Test Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel *See also WK2883 for information on a proposed revision to this standard.*
G14-04	Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test) *See also WK5646 for information on a proposed revision to this standard.*
G17-88(1998)	Standard Test Method for Penetration Resistance of Pipeline Coatings (Blunt Rod)
G18-88(1998)	Standard Test Method for Joints, Fittings, and Patches in Coated Pipelines. *See also WK2884 for information on a proposed revision to this standard.*
G19-04	Standard Test Method for Disbonding Characteristics of Pipeline Coatings by Direct Soil Burial. *See also WK5647 for information on a proposed revision to this standard.*
G20-88(2002)	Standard Test Method for Chemical Resistance of Pipeline Coatings

G42-96(2003)	Standard Test Method for Cathodic Disbonding of Pipeline Coatings Subjected to Elevated Temperatures
G55-88(1998)	Standard Test Method for Evaluating Pipeline Coating Patch Materials
G62-87(1998)e1	Standard Test Methods for Holiday Detection in Pipeline Coatings
G70-81(1998)	Standard Test Method for Ring Bendability of Pipeline Coatings (Squeeze Test)
G80-88(1998)	Standard Test Method for Specific Cathodic Disbonding of Pipeline Coatings. *See also WK2885 for information on a proposed revision to this standard.*
G95-87(1998)e1	Standard Test Method for Cathodic Disbondment Test of Pipeline Coatings (Attached Cell Method). *See also WK2886 for information on a proposed revision to this standard.*

9 WORK ITEMS in progress under the jurisdiction of D01.48:

WK2881 Proposed Revision of G6-88(1998)
WK2882 Proposed Revision of G9-87(1998)
WK2883 Proposed Revision of G12-83(1998)
WK2884 Proposed Revision of G18-88(1998)
WK2885 Proposed Revision of G80-88(1998)
WK2886 Proposed Revision of G95-87(1998)e1
WK5645 Proposed Revision of G11-88(1996)e1
WK5646 Proposed Revision of G14-88(1996)e1
WK5647 Proposed Revision of G19-88(1996)e1

NACE International & Pipeline Coatings

Cliff Johnson
Director, Education
Larry Christie
Coatings Market Manager

NACE INTERNATIONAL

Presentation Overview

- Who is NACE International
- How Standards are Developed
- External Coating Standards for Pipelines
- Test Methods & Technical Committee Reports for Pipeline Coatings
- NACE Committee Listings for Pipeline Coatings
- Coating Applicator Training Program
- NACE Legislative Efforts

NACE INTERNATIONAL

Leaders in Corrosion Control Technology

NACE International
About us

History

- Founded in 1943
- Began with the Oil & Gas Industry
- Goals – Protect the environment, public safety, and reduce the economic impact of corrosion

Since 1943 NACE International has:

- Produced over 100 standards
- Developed numerous training and certification courses
- Grown to almost 15,000 members worldwide

NACE INTERNATIONAL

Leaders in Corrosion Control Technology

How NACE Standards
Are Developed

- More than 300 NACE technical committees
- The committees serve as the technical arm of the association
- Committee members develop NACE standards, reports, and conduct informative meetings, symposia, and open forums to exchange state-of-the-art technical information.
- NACE International publishes 3 classes of standards: material requirements (MR), recommended practices (RP), and test methods (TM).

NACE INTERNATIONAL

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Committee Listings for Pipeline Coatings

<u>Specific Technology Group (STG 03)</u> "Coatings and Linings, Protective: Immersion and Buried Service"

- **<u>Task Group (TG 247)</u>** Coatings, Liquid Epoxy for External Repair, Rehabilitations, and Weld Joints on Buried Steel Pipelines
- **<u>Task Group (TG 251)</u>** Coatings, Tape for External Repair, Rehabilitations, and Weld Joints on Pipelines
- **<u>Task Group (TG 265)</u>** Coating Systems, Polyolefin Resin: Review of NACE Standard RP0185-96

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Committee Listings for Pipeline Coatings

- **<u>Task Group (TG 281)</u>** Coatings, Polyurethane for Field Repair, Rehabilitation, and Girth Weld Joints on Pipelines
- **<u>Task Group (TG 294)</u>** Above Ground Techniques for the Evaluation of Underground Pipeline Coating Condition
- **<u>Task Group (TG 296)</u>** Coating Systems, Wax for Underground Piping Systems: Review of NACE Standard RP0375

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Committee Listings for Pipeline Coatings

Specific Technology Group (STG 35) - "Pipelines, Tanks, Well Casings"

- **Task Group (TG034)** Pipeline Coatings, External : Gouge Test
- **Technology Exchange Group (TEG) 033X** Pipeline Rehabilitation Coatings

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NACE External Coating Standards for Pipelines

- RP0399-2004 Plant-Applied, External Coal Tar Enamel Pipe Coating Systems: Application, Performance, and Quality Control
- RP0602-2002 Field-Applied External Coal Tar Enamel Pipe Coating Systems: Application, Performance, and Quality Control
- RP0394-2002 Application, Performance, and Quality Control of Plant-Applied Fusion-Bonded Epoxy (FBE) External Pipe Coating
- RP0402-2002 Field-Applied Fusion-Bonded Epoxy (FBE) Pipe Coating Systems for Girth Weld Joints: Application, Performance, and Quality Control

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NACE External Coating Standards for Pipelines

- RP0303-2003 Field-Applied Heat-Shrinkable Sleeves for Pipelines: Application, Performance, and Quality Control
- RP0490-2001 Holiday Detection of Fusion-Bonded Epoxy External Pipeline Coatings of 250 to 760 µm (10 to 30 mils)
- RP0185-96 Extruded Polyolefin Resin Coating Systems with Soft Adhesives for Underground or Submerged Pipe
- RP0375-99 Wax Coating Systems for Underground Pipeline Systems

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Test Methods for Coatings

- TM0102-2002 - Measurement of Protective Coating Electrical Conductance on Underground Pipelines
- TM0174-2002 - Laboratory Methods for the Evaluation of Protective Coatings and Lining Materials for Immersion Service

NACE Technical Committee Reports on Pipeline Coatings

- NACE Publication 10D199 - Coatings for the Repair and Rehabilitation of the External Coatings of Buried Steel Pipelines

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Standards Under Development

Committee Number	Document Type	Title	Status	Expected Publication Date
TG 247	Standard	Coatings, Liquid Epoxy for External Repair Rehabilitations, and Weld Joints on Buried Pipelines	Re-balloted	October 2005
TG 251	Standard	Tape Coatings for External Repair, Rehabilitations, and Weld Joints on Pipelines	Completing Draft	October 2005
TG 265	Revision of NACE Standard RP0185-96	Review of NACE Standard RP0185-96 "Extruded Polyolefin Resin Coating Systems with Soft Adhesives for Underground or Submerged Pipe"	Ballot closed 08/2002; Open review held at C/2003	October 2005

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Standards Under Development

Committee Number	Document Type	Title	Status	Expected Publication Date
TG 281	Standard	Field-Applied Polyurethane Coatings for Field Repair, Rehabilitation, and Girth Weld Joints on Pipelines: Application, Performance, and Quality Control	Ballot closed 01/2003 Open Review held at CTW/2003	January 2006
TG 294	Standard	Aboveground Techniques for the Evaluation of Underground Pipeline Coating Condition	Just received draft from committee	June 2006
TG 296	Revision of NACE Standard RP0375-99	Wax Coating System for Underground Piping Systems	Re-Ballot closed 3/9/05	October 2005

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Coating Applicator Training Program

- Action spurred by the U.S. Navy and the International Union of Paint and Allied Trades (IUPAT)
- NACE International and SSPC are co-developing a comprehensive credentialing program for coating applicators that includes a standard on performance qualifications, training & certification

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Leaders in Corrosion Control Technology

Coating Applicator Training Program

- Task groups have been established to work on the standard and the training and certification programs.
- Tentative plan is to offer four levels of training ranging from the "helper" level to the "master" level.
- Plan to publish standard in January 2006. Training and certification will follow.
- Approaching development stages
- Hands-on training + lecture

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Invest in the Future
"Request to Congress"

- Corrosion Prevention Tax Credit
- Propose a 15% Tax Credit on Implementation of Corrosion Prevention Strategies and Methodologies
- Tax Credit to all businesses and in all industries based on new initiatives

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Questions?

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Leaders in Corrosion Control Technology

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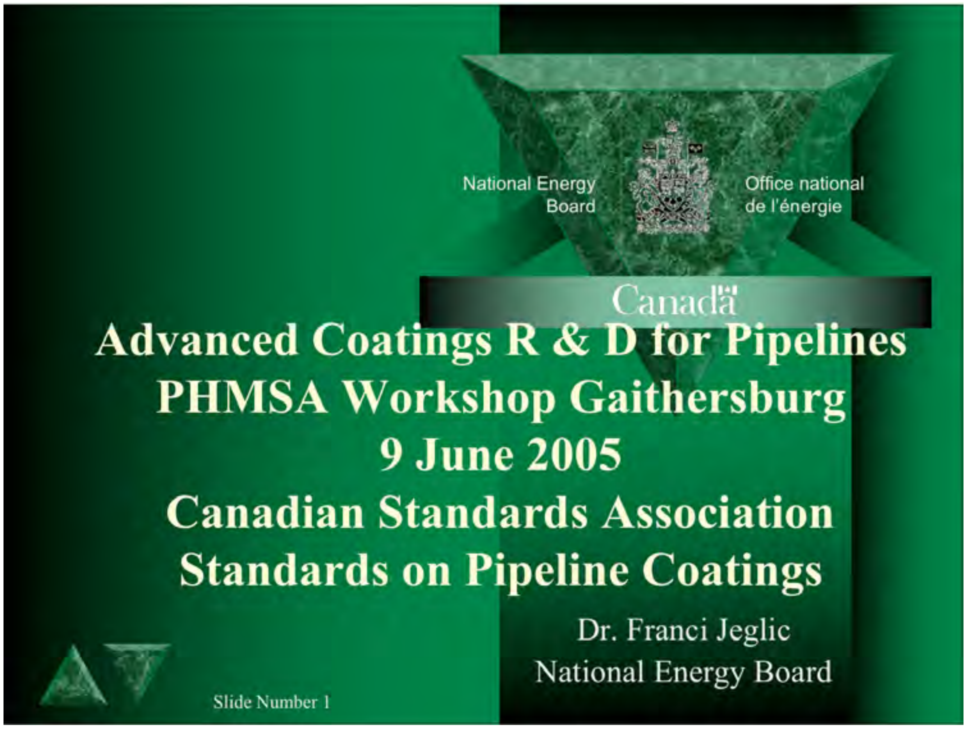
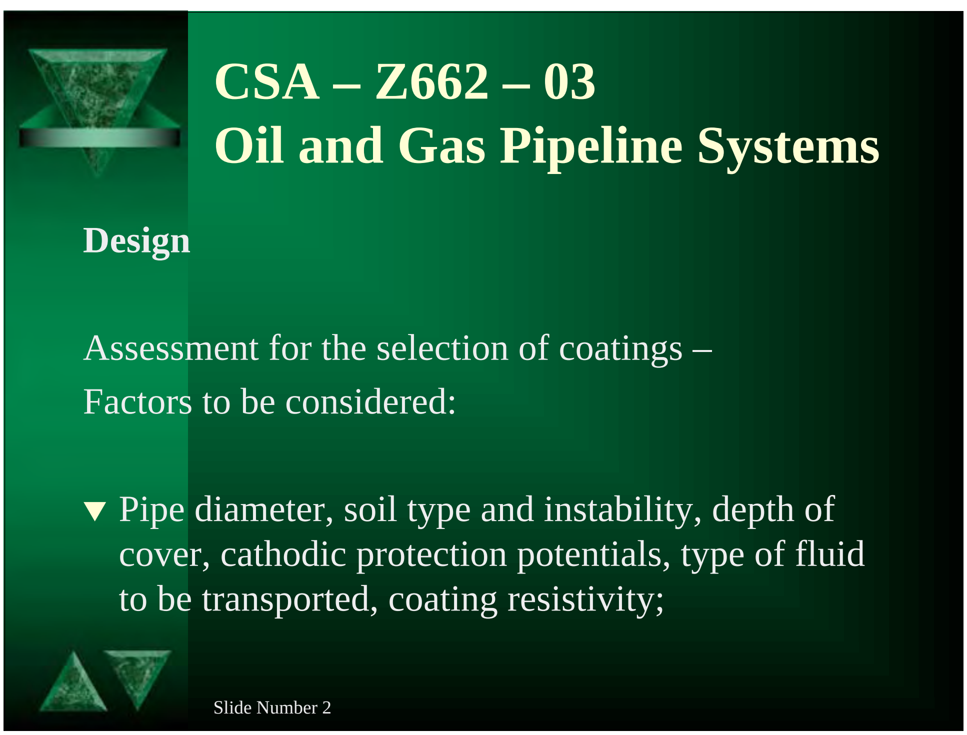
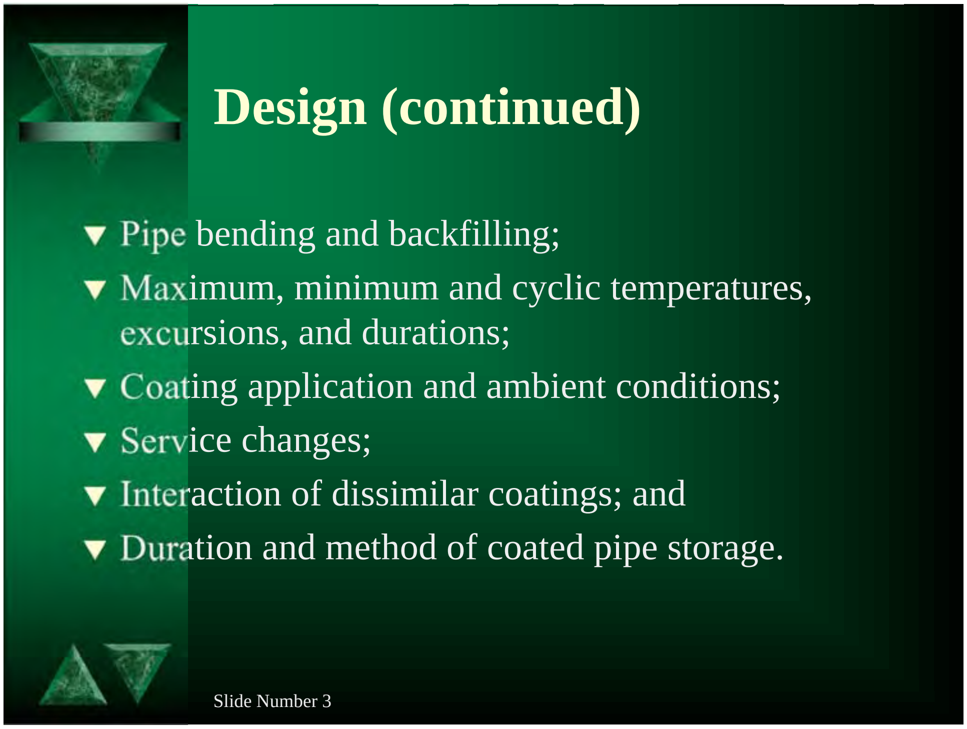
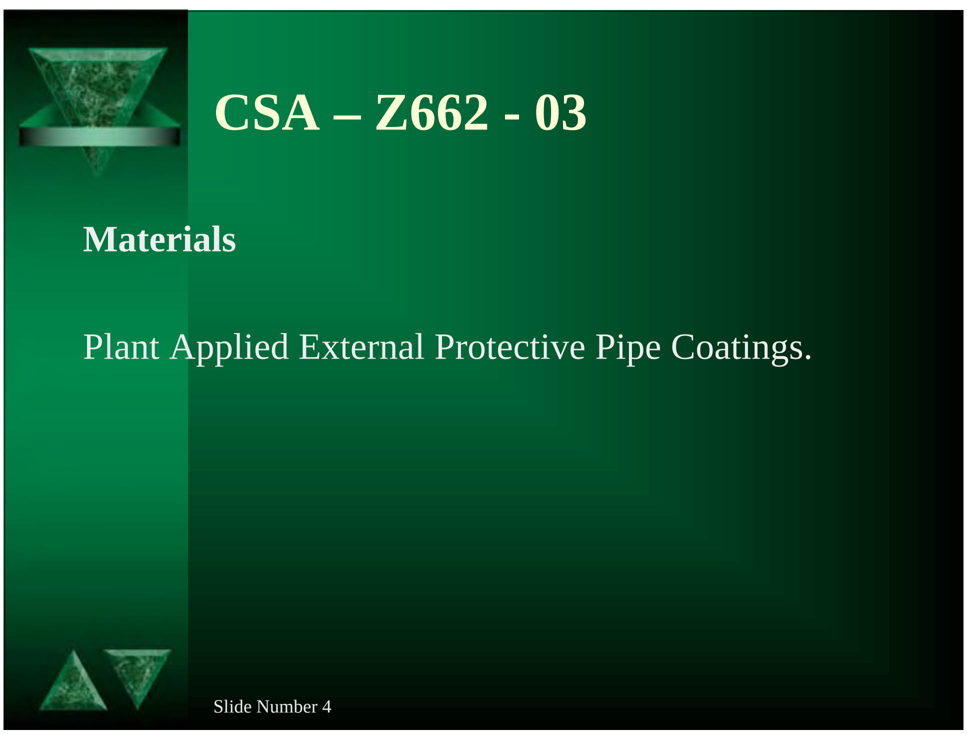
Office of Pipeline Safety Workshop on
Advanced Coatings R&D for Pipelines and Related Facilities
June 9, 2005


National Energy Board
Office national de l'énergie
Canada
Advanced Coatings R & D for Pipelines
PHMSA Workshop Gaithersburg
9 June 2005
Canadian Standards Association
Standards on Pipeline Coatings
Dr. Franci Jeglic
National Energy Board
Slide Number 1


CSA – Z662 – 03
Oil and Gas Pipeline Systems
Design
Assessment for the selection of coatings –
Factors to be considered:
▼ Pipe diameter, soil type and instability, depth of cover, cathodic protection potentials, type of fluid to be transported, coating resistivity;
Slide Number 2


Design (continued)
Pipe bending and backfilling;
Maximum, minimum and cyclic temperatures, excursions, and durations;
Coating application and ambient conditions;
Service changes;
Interaction of dissimilar coatings; and
Duration and method of coated pipe storage.
Slide Number 3


CSA – Z662 - 03
Materials
Plant Applied External Protective Pipe Coatings.
Slide Number 4

CSA Z662 - 03

Non-mandatory Annex L

Test Methods for Coatings Property Evaluation

Test Methods for:

- Volume resistivity;
- Cathodic disbondment;

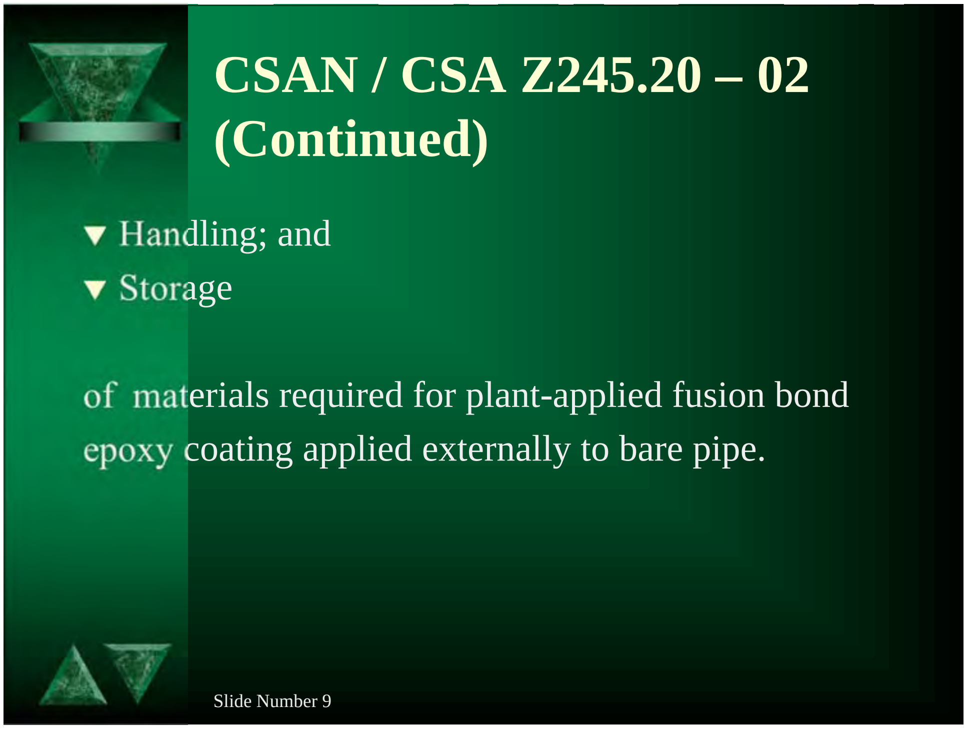
Slide Number 5

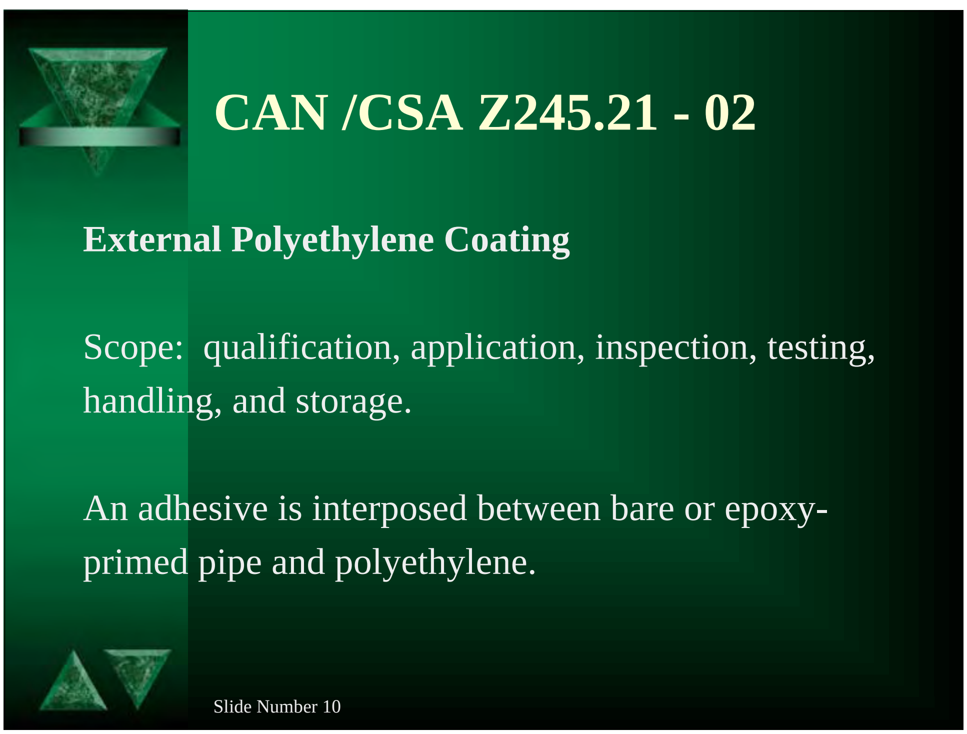
- Adhesion;
- Water absorption;
- Water vapour transmission;
- Coating flexibility;
- Peel adhesion;
- Shear adhesion;
- Pull off adhesion;
- Impact resistance;

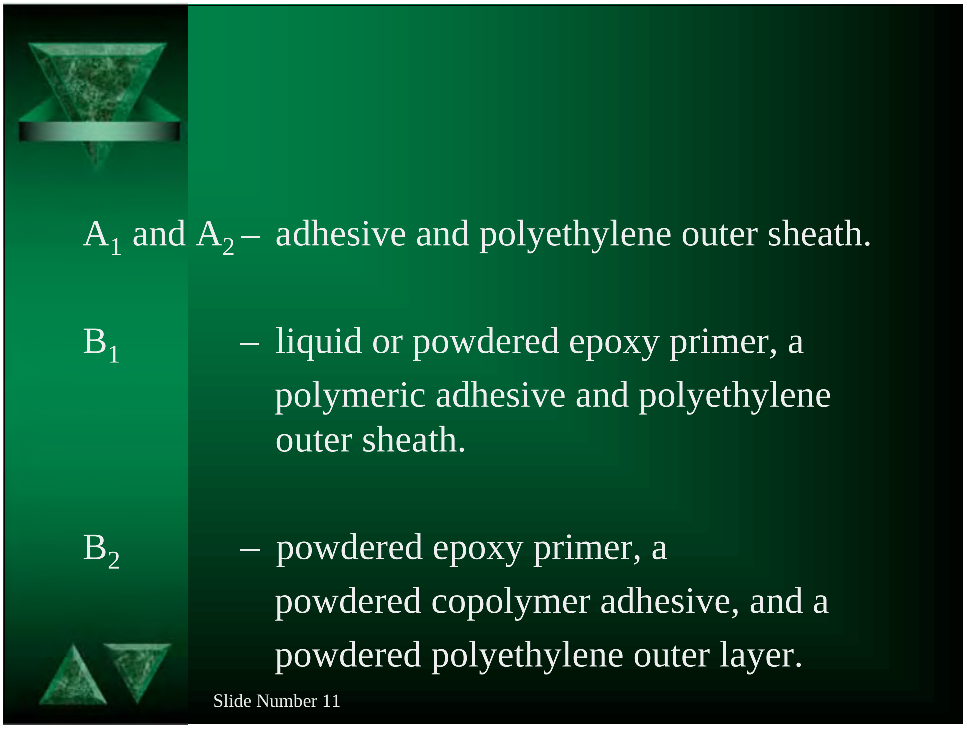
Slide Number 6


▼ Wear abrasion;
▼ UV stability;
▼ Penetration;
▼ Temperature resistance;
▼ Chemical resistance;
▼ Microbial resistance;
▼ Oxidative stability; and
▼ Heat aging.
Slide Number 7


CAN / CSA Z245.20 - 02
External Fusion Bond Epoxy Coating for Steel Pipe
Standard covers:
▼ Qualification;
▼ Application;
▼ Inspection;
▼ Testing;
Slide Number 8


CSAN / CSA Z245.20 – 02
(Continued)
▼ Handling; and
▼ Storage
of materials required for plant-applied fusion bond epoxy coating applied externally to bare pipe.
Slide Number 9


CAN /CSA Z245.21 - 02
External Polyethylene Coating
Scope: qualification, application, inspection, testing, handling, and storage.
An adhesive is interposed between bare or epoxy-primed pipe and polyethylene.
Slide Number 10


A_1 and A_2 – adhesive and polyethylene outer sheath.
B_1 – liquid or powdered epoxy primer, a polymeric adhesive and polyethylene outer sheath.
B_2 – powdered epoxy primer, a powdered copolymer adhesive, and a powdered polyethylene outer layer.
Slide Number 11

A Pipeline Operators Viewpoint on Underground Coatings Issues

Jeff Didas
Colonial Pipeline Company

Major Issues

- Existing Pipeline Coatings
- Coatings for New Construction
- Coatings for Pipeline Rehabilitation
- Coatings for Pipeline Repairs

Existing Pipeline Coatings

- Coal Tar Enamel
- Asphalt Enamel
- Extruded Polyethylene
- Fusion Bonded Epoxy
- Somastic
- Pritec
- Liquid Epoxy
- 3 Layer
- Tape
- Wax

What is the issue with existing coatings?

- Age
- Condition
- Failure Mode
- Reparability
- Compatibility with Repair Coatings
- Hazards & Toxicity
- Transition Zones

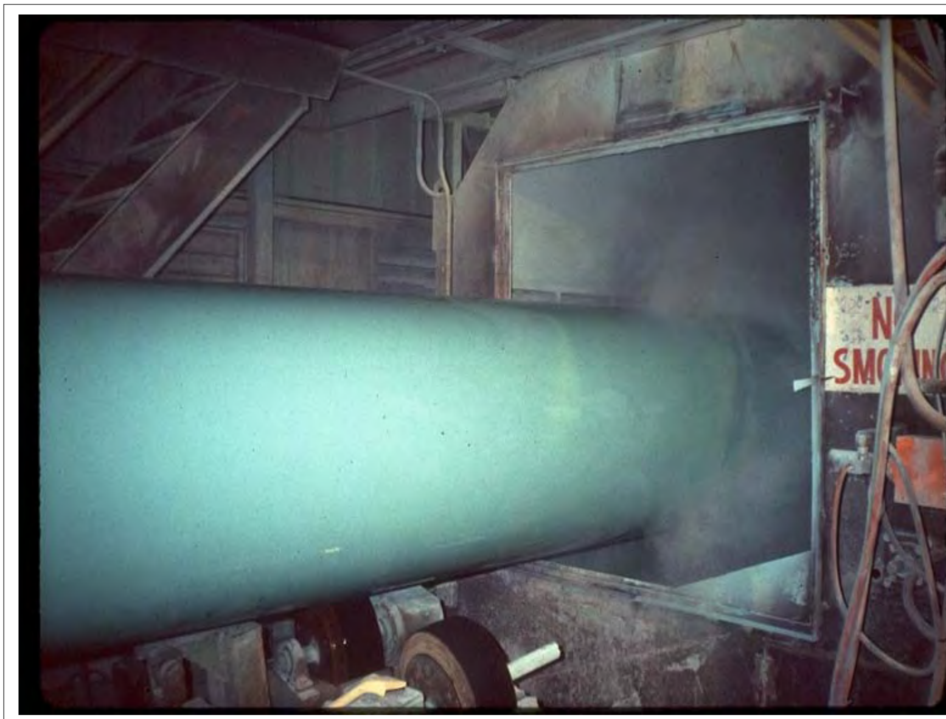
Transition Zones

Issues

- CP Shielding
- Increased CP Levels
- Recoating

Coatings for New Construction

- Most common is Fusion Bonded Epoxy – FBE
- Multi – Layer Systems Gaining in Popularity
- Issues are Coating the Weld Joints, Handling Damage, Flexibility and Coating Repair Methods – Quality Control & Inspector Standards.



Weld Joint

Flexibility

Handling Damage

Handling Damage

Coatings for Pipeline Rehabilitation Issues

- Compatibility with Existing Coatings
- Cure/Dry Time
- Performance
- Application
- Ambient Conditions
- Quality Control
- Inspector Standards

Job Site

Abrasive Blasting

Holiday Testing

Coatings for Pipeline Repairs

- Keyhole Coatings
- Wet ditch/hole Coatings
- Winter Grade/Summer Grade Coatings
- Cure/Dry Time

Repair Coatings

Repair Coatings

Keyhole Coating

Summary of Issues

- Repair & Rehabilitation Coatings are the major issue for pipeline operators.
- Deterioration & Aging of Existing Coatings are an ongoing issue for pipeline operators.
- Improving handling properties for new pipeline coatings, flexibility of new coatings, as well as weld joint coatings (quality) and in field repairs (quality) for the coating are major issues for pipeline operators.

Additional Issues

- Development of new or standardization of existing short term testing methods to reliably predict long term coating performance.
- Investigate the effects of pipeline preheating or thermal treatment used in the application of new coatings may affect the strain aging in steel substrates.

Thank You


PRCI COATINGS
RESEARCH
GREG RUSCHAU
CC TECHNOLOGIES
DUBLIN, OH


PRCI RECENT STRATEGY
HAS SHIFTED FROM MAINLINE COATINGS TO REPAIR/REHAB COATINGS
FIELD-APPLIED COATINGS ARE CURRENT FOCUS OF "PURE" COATINGS RESEARCH
ASSESSMENT OF IN-SERVICE CONDITION VERY IMPORTANT
VERY LITTLE FOCUS ON FUNDAMENTALS OF HOW, WHY COATINGS PERFORM
ALWAYS HAS BEEN FOCUSED ON RESULTS WHICH OPERATORS CAN USE

WHY THE STRATEGY SHIFT?

- OPERATORS FEEL THEY KNOW HOW TO SELECT PLANT-APPLIED COATINGS
- MOST ARE DEALING WITH OLD SYSTEMS OF COAL TAR AND ASPHALT ENAMELS WHICH NEED REPAIR OR REHABILITATION
- NO QA/QC STANDARDS FOR REPAIR COATINGS – UNCERTAIN INTEGRITY

RECENTLY COMPLETED (SINCE 2000) PRCI PROJECTS RELATED TO COATINGS

Performance of Blistered FBE Coating (2000)

Development of Predictive Accelerated Test Methods for Pipeline Coatings (2002)

Compatibility of Repair Coatings to Existing Below Grade Pipeline Coatings (2002)

Coating Repairs for Thermite Welds and Keyhole Excavations (2003)

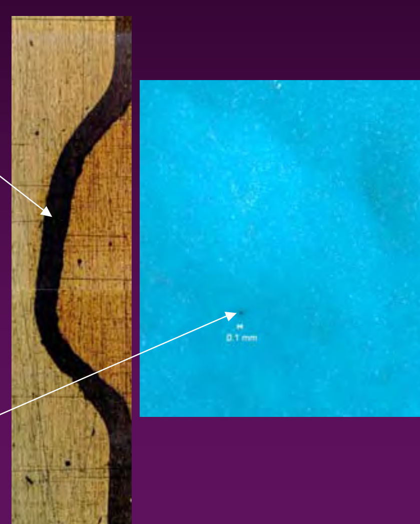
PERFORMANCE OF BLISTERED FBE COATED PIPE

- WHEN FBE COATED PIPE IS UNCOVERED AND THERE ARE BLISTERS, WHAT SHOULD BE THE REMEDIAL ACTION? RECOAT, INCREASE CP, LEAVE ALONE?
- DOES FBE COATING REALLY ALLOW CP TO PENETRATE?

RESULTS/CONCLUSIONS

BLISTERS FORMED AT HIGH TEMPERATURES (>T_g) DID NOT PASS CP CURRENT

BLISTERS FORMED AT LOW TEMPERATURES WILL ALLOW CP CURRENT, BUT LIKELY BECAUSE OF MICROCRACKS



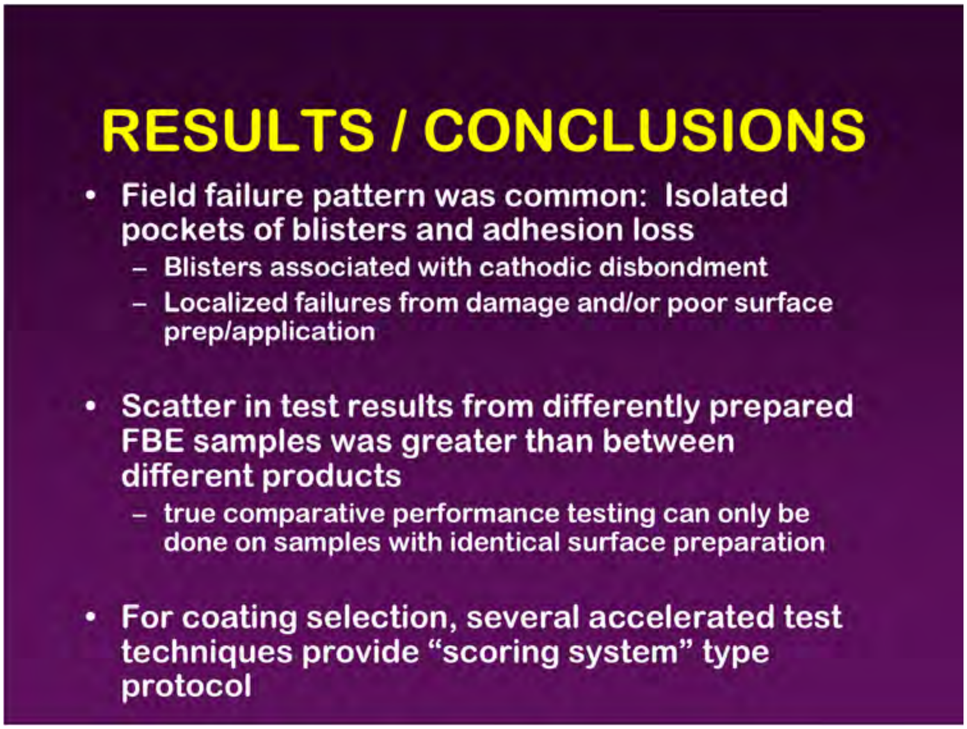
DEVELOPING ACCELERATED PREDICTIVE TEST METHODS FOR EXTERNAL PIPELINE COATINGS

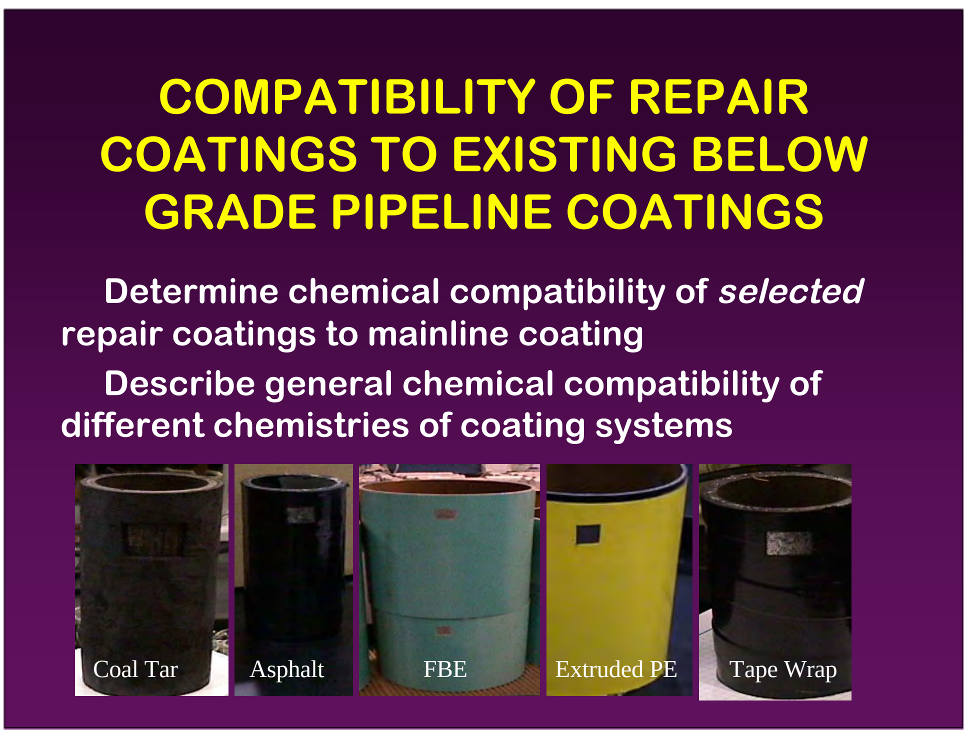
Develop laboratory testing for FBE pipeline coatings which is:

- –Accelerated to provide answers in a short time frame
- –Predictive of future performance
- –Realistic in that it accentuates the degradation of properties which are likely to degrade in service

APPROACH

- CATALOGUE FIELD FAILURES AND FOCUS ON TESTS WHICH PRODUCE THESE FAILURES
- USE SUITE OF TESTS RATHER THAN SEARCH FOR “MAGIC” ANSWER
- INVESTIGATE ANALYTICAL TECHNIQUES FOR POTENTIAL BREAKTHROUGHS


RESULTS / CONCLUSIONS
• Field failure pattern was common: Isolated pockets of blisters and adhesion loss
– Blisters associated with cathodic disbondment
– Localized failures from damage and/or poor surface prep/application
• Scatter in test results from differently prepared FBE samples was greater than between different products
– true comparative performance testing can only be done on samples with identical surface preparation
• For coating selection, several accelerated test techniques provide "scoring system" type protocol


COMPATIBILITY OF REPAIR COATINGS TO EXISTING BELOW GRADE PIPELINE COATINGS
Determine chemical compatibility of *selected* repair coatings to mainline coating
Describe general chemical compatibility of different chemistries of coating systems
Coal Tar
Asphalt
FBE
Extruded PE
Tape Wrap

CONCLUSIONS FROM PROJECT

- Epoxy mainline coatings provide best chemical surface for bonding – epoxy and epoxy polyurethane repairs both excellent
- Thermoplastic coatings (asphalt, coal tar enamel, PE tapes, extruded PE) provide only physical surface for bonding
  - Only in a molten state can the repair coatings bond with the mainline coatings
- Short term chemical aging failed to significantly affect performance ranking in any systems

COATING COMPATIBILITY AT THERMITE WELDS AND FOR KEYHOLE EXCAVATIONS

For special pipeline excavations involving thermite welds and other anode connections

The requirements for achieving an acceptable coating repair at these excavations differ from standard bellhole survey repairs

APPROACH

- Lab – look at adhesion to different components
- Simulation of keyhole application

RESULTS/CONCLUSIONS

•Adhesion to insulation is weakest link – PVC insulation better than Polyethylene for this application

•Epoxies have superior compatibility and adhesion, most also apply easy

•For application ease, best combination is a moderately thick viscosity and rapid drying time (not necessarily rapid cure time)

CURRENT PRCI COATING PROJECTS AT CC TECHNOLOGIES

Cathodic Protection Shielding of Girth Weld Coatings

Effects of Surface Preparation on the Performance of Repair and Rehabilitation Coatings

Performance of Coatings Applied to Wet Surfaces

Effective Methods of Coating Removal During Investigative Excavations

Assessment of Aboveground Techniques for Locating Coating Defects (OPS co-funding)

COMMENTS ON CURRENT STATE OF PIPELINE COATING TECHNOLOGY

PIPELINE INDUSTRY HAS VERY LIMITED FUNDAMENTAL UNDERSTANDING OF THE TECHNICAL ISSUES WITH COATINGS

COATINGS ARE FORMULATED TO PASS PERFORMANCE TESTS RATHER THAN TO PERFORM IN THE FIELD (IS IT THE SAME?)

COATINGS ARE CONSIDERED A COMMODITY PRODUCT, NOT MATERIALS SCIENCE

- NOT AS COMPLEX AS ALLOYS, SMART PIGS, INSPECTION TOOLS

Role of Coatings in Direct Assessment and Risk Analysis

Jenny Been
NOVA Research and Technology Centre
Calgary, Alberta

OPS Workshop on Advanced Coatings R&D, June 9-10, 2005

The Challenge and The Approach

- DA and other maintenance activities rely on our ability to identify locations for direct examination of the pipe
- Site selection is typically based on data from a number of techniques and sources, including:
  - Pipe, coating and other operational data
  - Above-ground electrical measurements
  - Site characteristics (Soil, slope, drainage, land use, depositional mode, etc.)
- But, of course, the rate and extent of external corrosion and SCC depend on the local environmental conditions at the pipe surface under the disbonded coating
- The challenge, therefore, is to predict conditions at the pipe surface based on above-ground measurements and observations
- The approach, a combination of experimental mechanistic studies + mathematical modeling + field studies

Recent PRCI and TCPL projects

- The Role of Coatings in the Generation of Environments that Promote Environmentally Assisted Cracking (PRCI)
  - ✓ High pH
  - ✓ Near-neutral pH
- Factors Affecting the Rate and Extent of Disbondment of FBE Coatings (TCPL)
- Laboratory and Field Investigations of the Performance of HPCC Coatings (TCPL)
- A New Technique for the Characterization of High Impedance Coatings (TCPL)
- The Effect of Degradation Treatments on CD of HPCC and Two Common Joint Coatings (TCPL – current project)

Effect of Aging Coating

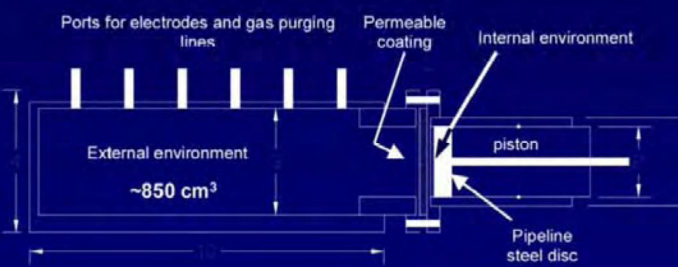
Degraded pipeline coatings are generally classified as either CP shielding or permeable

Asphalt coating ⇒ more permeable with time
- more groundbeds, more current needed

YEAR	Groundbeds (#/m^2)	Current (A/m^2)
1970	4×10^{-6}	0.8×10^{-4}
1980	7×10^{-6}	1.4×10^{-4}
1990	16×10^{-6}	3.5×10^{-4}

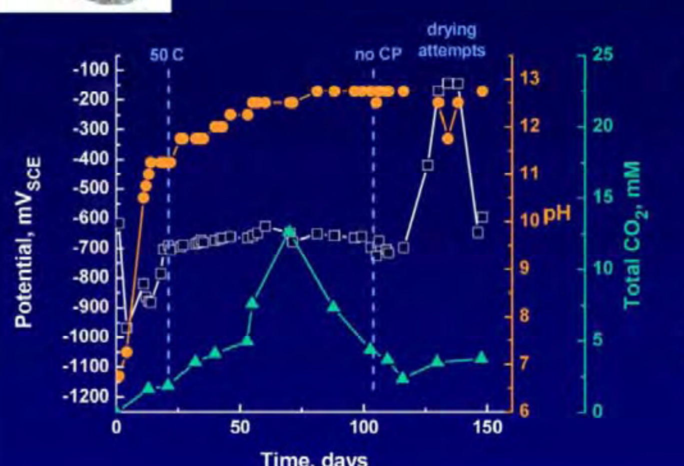
Pipe surface conditions underneath a permeable coating

- High-pH SCC is associated with concentrated electrolytes produced by evaporation or the action of CP on permeable coatings:
  - ✓ pH > 9.3
  - ✓ Potential between –600 to –750 mV_{CCS}
  - ✓ Bicarbonate concentration > 0.1 M
- To identify those coating properties and environmental conditions that can lead to the development of SCC environments under degraded coatings



Pipe surface conditions underneath a permeable coating

Asphalt coating, 50 C, -0.001 mA/cm^2



- **Outer Compartment:**
  - **0.437 M NaCl + 0.005 M $NaHCO_3$, 5% CO_2**
- **Inner Compartment:**
  - **distilled water**
- **Could not get carbonate concentration to increase**

Pipe surface conditions underneath a permeable coating

- It seems that an extremely permeable coating with pinholes or holidays may be more conducive to high pH SCC
- Transitional conditions provide easier access of atmospheric and soil gas to the disbondment environment
- Results were modeled by the Permeable Coating Model (PCM)
- PCM simulations suggest that the rate of CO_2 generation in the disbondment, coating, and/or soil is important in generating the concentrated HCO_3^-/CO_3^{2-} conditions necessary for high-pH SCC
- CO_2 generation rate could be a useful site-selection criterion for high-pH SCC

Field study on large diameter gas lines

Worthingham, Cetiner, paper IPC04-0570, IPC Proceedings (2004)

- Despite excellent protection and long-term service, blistering and disbondment FBE have been observed in the field
- A series of pipeline excavations were performed to investigate the causes and effects of operational parameters on the long-term performance of FBE
- No correlation was found between the extent of disbondment and:
  - pipeline age
  - soil type
  - temperature
  - CP potential
  - coating adhesion
- It was concluded that disbondment of FBE did not present an integrity threat as long as CP was present
- Most of the damage likely happened during the first years of operation as determined by initial coating quality and construction damage

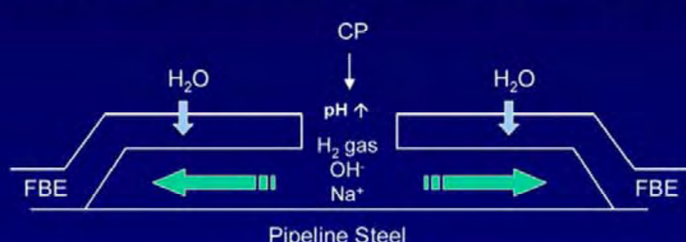
Laboratory study on Factors Affecting the Rate and Extent of Disbondment of FBE Coatings

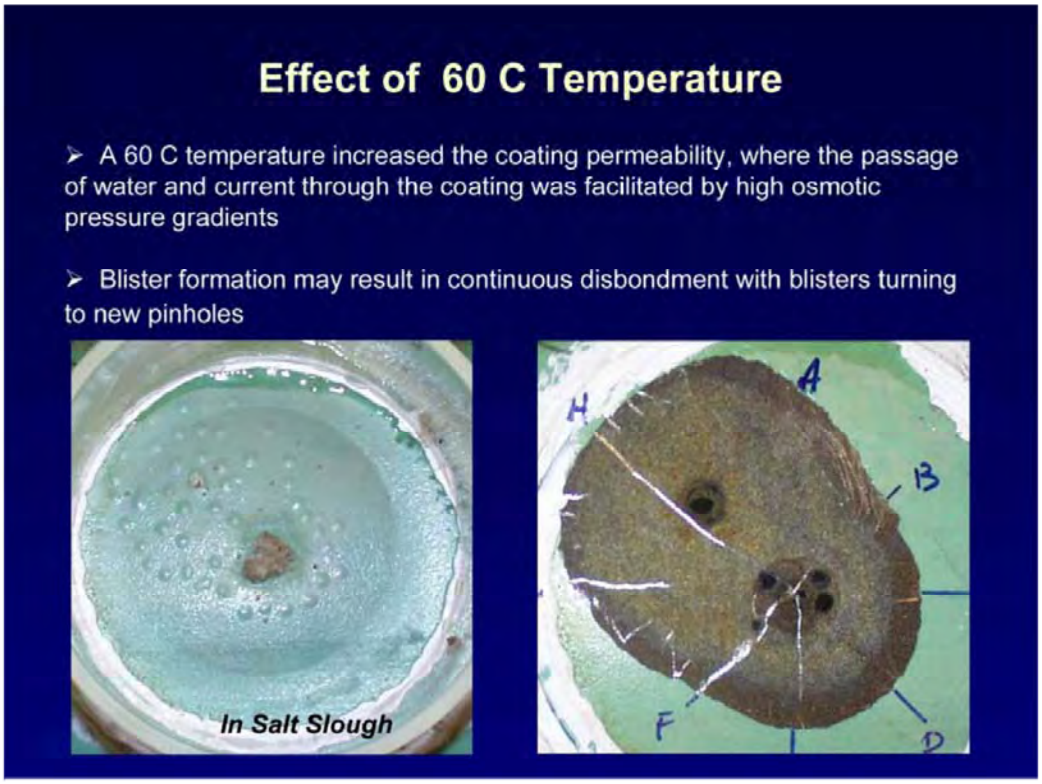
Been, Given, Ikeda-Cameron, Worthingham, paper 05138, CORROSION 2005

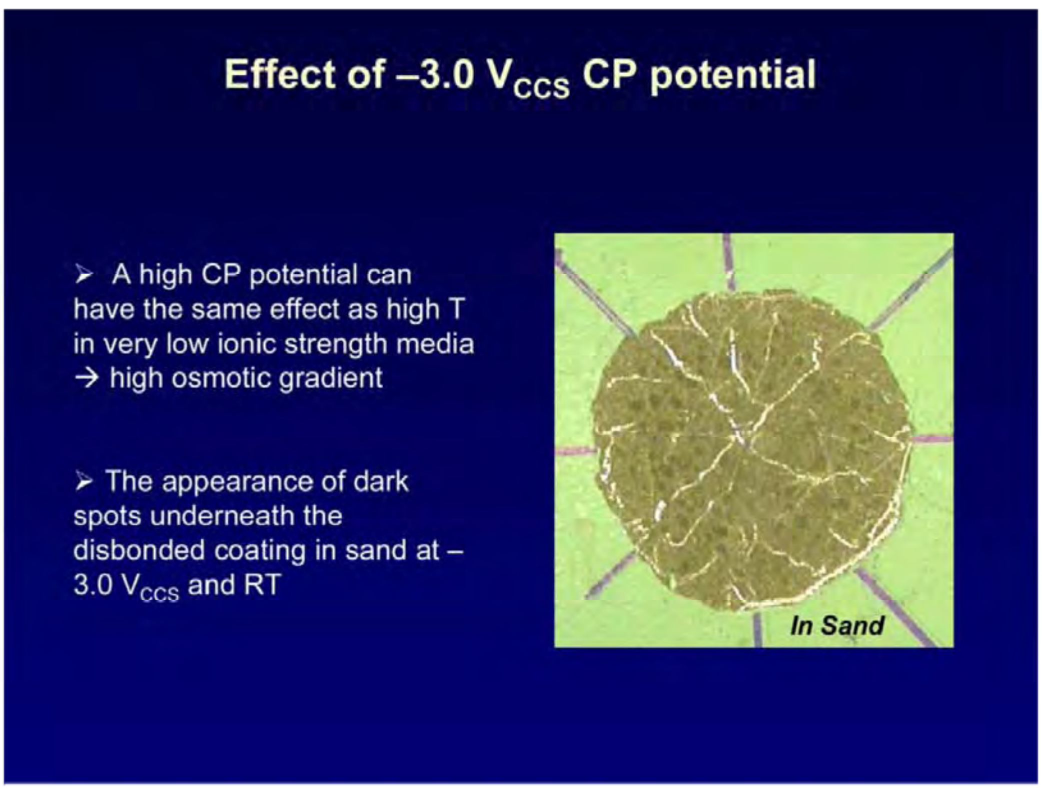
- Typical Cell:
  - ✓ 0.4 to 6.0 mm holidays
  - ✓ 15 cm dia. coating area
  - ✓ 1.5 L volume
  - ✓ 300 cm^3 sand (to restrict mixing)
- Solutions:
  - ✓ Fresh Water
  - ✓ Salt Slough
  - ✓ Sand
  - ✓ Clay
- -0.85 to -3.0 V
- RT and 60 C
- 1 - 18 months
- Measurements included potential, current, EIS, CD area

Rate-of-disbondment-controlling factors

- An increase in pH at the holiday site as a result of cathodic reduction reactions
- High pH environment will attack the coating / metal bond
- Rate of disbondment controlled by:
  1. The creation, diffusion and migration of hydroxyl ions
  2. Movement of cations to the coating/metal interface
  3. The diffusion of water molecules through the coating




Effect of 60 C Temperature
➢ A 60 C temperature increased the coating permeability, where the passage of water and current through the coating was facilitated by high osmotic pressure gradients
➢ Blister formation may result in continuous disbondment with blisters turning to new pinholes
In Salt Slough
A
H
B
F
D


Effect of –3.0 V_{CCS} CP potential
➢ A high CP potential can have the same effect as high T in very low ionic strength media → high osmotic gradient
➢ The appearance of dark spots underneath the disbonded coating in sand at –3.0 V_{CCS} and RT
In Sand

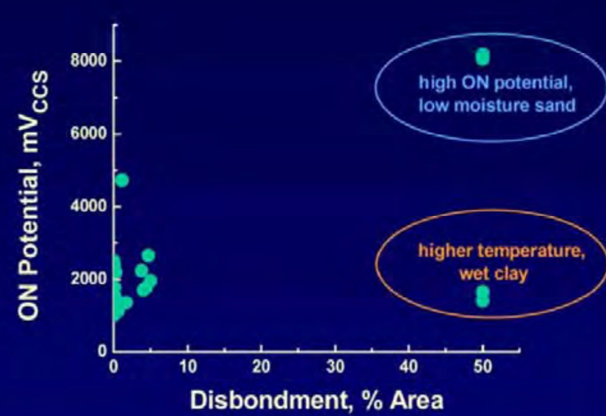
Implications to FBE Disbondment in the Field

Summary of conditions resulting in no further disbondment growth or continuous growth in the presence of a defect

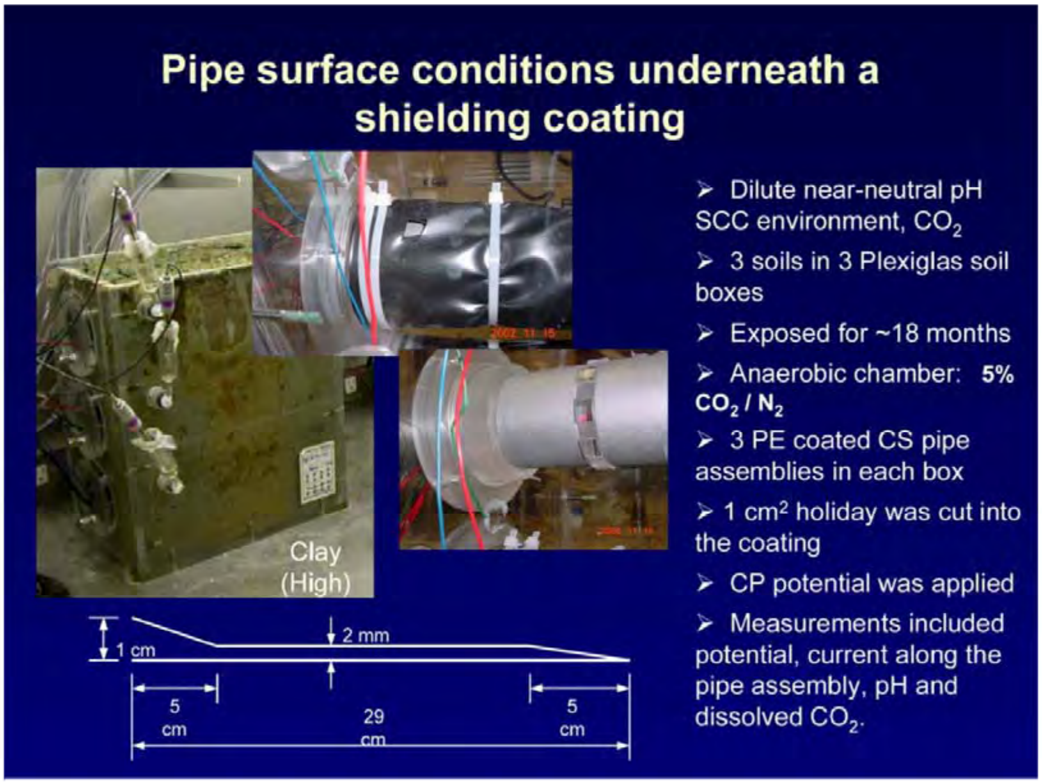
<table>
<tr><th colspan="4">Conditions</th><th>Observed Behavior</th></tr>
<tr><th>Potential</th><th>Temperature</th><th>Ionic Strength</th><th>Duration</th><th>Disbondment</th></tr>
<tr><td rowspan="4">-1.5 V_{CCS}</td><td>RT</td><td>all</td><td></td><td rowspan="2">no further growth</td></tr>
<tr><td rowspan="3">60</td><td rowspan="2">Intermediate</td><td>3-4 months</td></tr>
<tr><td>> 6 months</td><td rowspan="2">continued to grow</td></tr>
<tr><td>Low or high</td><td></td></tr>
<tr><td rowspan="3">-3.0 V_{CCS}</td><td>60</td><td>Clay</td><td></td><td rowspan="2">continued to grow</td></tr>
<tr><td rowspan="2">RT</td><td>Low</td><td></td></tr>
<tr><td>Intermediate and high</td><td></td><td>growth may level off</td></tr>
</table>

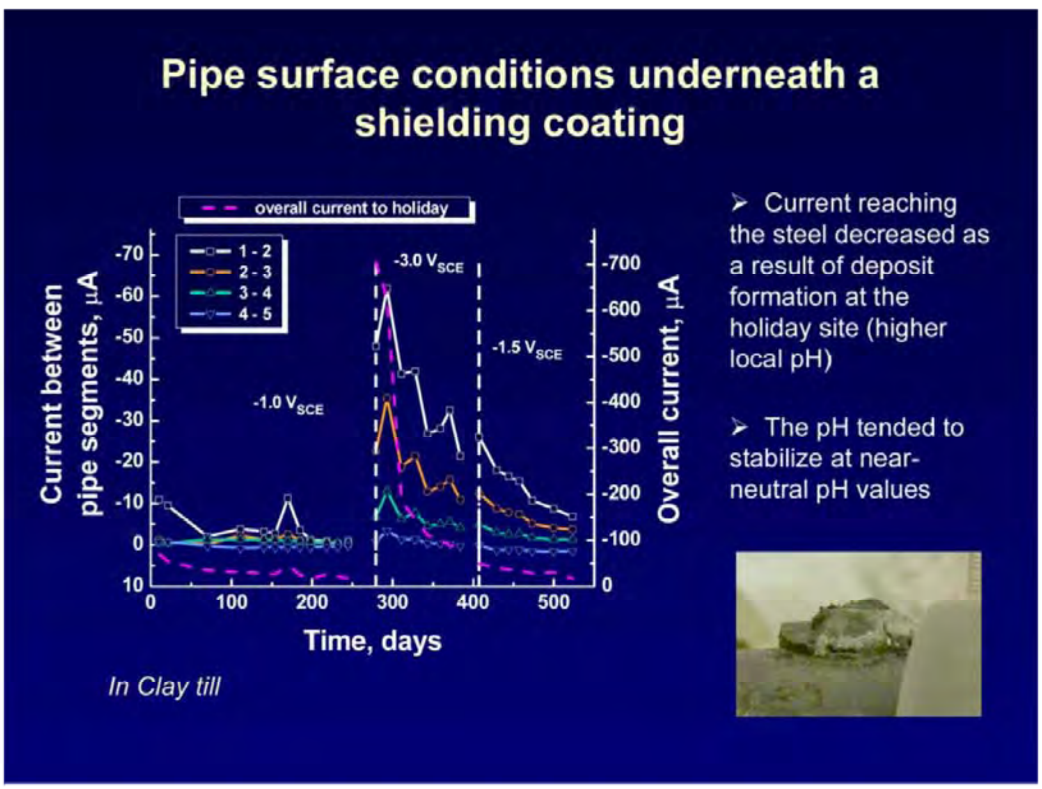
Implications to FBE Disbondment in the Field

- Correlations of disbondment area with T and V were not observed in the field study
- Consideration of multiple parameters may provide further insight
- In the field, all operating conditions should be considered, including upset conditions



- The pipe will remain protected in the presence of CP and blistering and coating disbondment does not present an integrity threat to a pipeline


Pipe surface conditions underneath a shielding coating
Clay (High)
1 cm
2 mm
5 cm
29 cm
5 cm
➢ Dilute near-neutral pH SCC environment, CO2
➢ 3 soils in 3 Plexiglas soil boxes
➢ Exposed for ~18 months
➢ Anaerobic chamber: 5% CO2 / N2
➢ 3 PE coated CS pipe assemblies in each box
➢ 1 cm2 holiday was cut into the coating
➢ CP potential was applied
➢ Measurements included potential, current along the pipe assembly, pH and dissolved CO2.


Pipe surface conditions underneath a shielding coating
overall current to holiday
1 - 2
2 - 3
3 - 4
4 - 5
-1.0 VSCE
-3.0 VSCE
-1.5 VSCE
Current between pipe segments, μA
Overall current, μA
Time, days
In Clay till
➢ Current reaching the steel decreased as a result of deposit formation at the holiday site (higher local pH)
➢ The pH tended to stabilize at near-neutral pH values

Pipe surface conditions underneath a shielding coating

- Near-neutral pH SCC environments are supported by shielding coatings and intermediate conductivity soils:
  - A high conductivity soil (clay till) provides better current penetration, which results in a slightly higher pH → less susceptible to NNpH cracking
  - A soil with a low carbonate content (sand) has a low buffering capacity and applied current increases the pH
- Results modeled by TECTRAN (SWRI)
- TECTRAN simulations suggest that it is necessary for CO_2 to permeate through coating to maintain near-neutral pH at tip of disbondment
- Coating CO_2 permeability, soil conductivity, carbonate concentration, and drainage could be used as site-selection criteria for near-neutral pH SCC

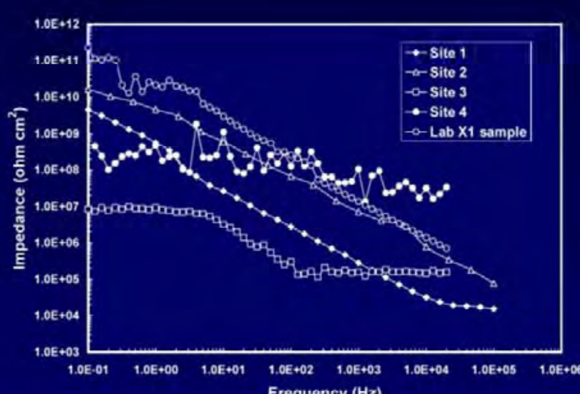
The performance of HPCC coatings

- Interested in long-term performance in the field
  - Standard QA/QC tests do not indicate long-term performance
  - Instead, we have used a combination of:
    - lab tests with simulated field exposure (impact damage + 60 C hot water or microbially active soil exposure + CD)
    - field measurements on HPCC exposed to service conditions for 11 years
  - Developed new impedance-based technique for studying the dielectric properties of high impedance coatings (EIS*Plus*)
- Laboratory Results:
  - A combination of impact and environmental exposure gave greater disbondment radii than without degradation treatments
  - Standard CD disbondment tests at 65 and 95 °C were more severe yet

Assessing Coating Condition

- Visual inspection and holiday detection
- Electrochemical Impedance Spectroscopy (EIS) can be used to assess coating condition

Impedance and Pipeline Coatings



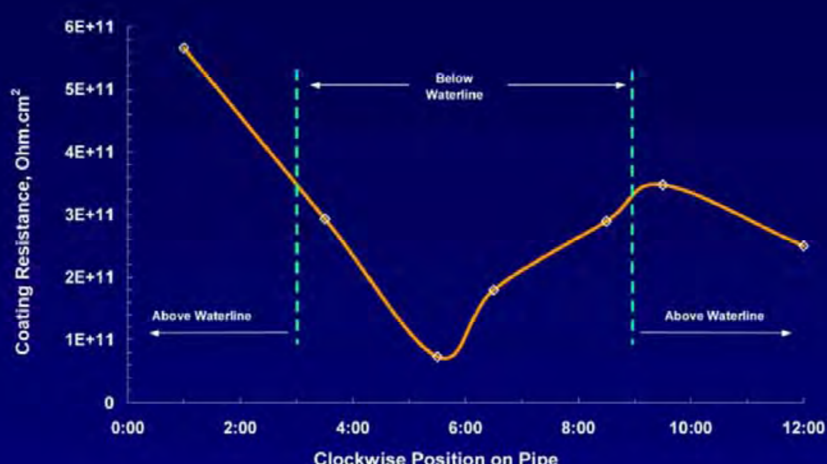
excellent coating	good coating	coating with pinholes		poor coating with holidays	
10^9	10^7	10^5	10^4		characteristic coating impedance ($\Omega.cm^2$) at 0.1 Hz

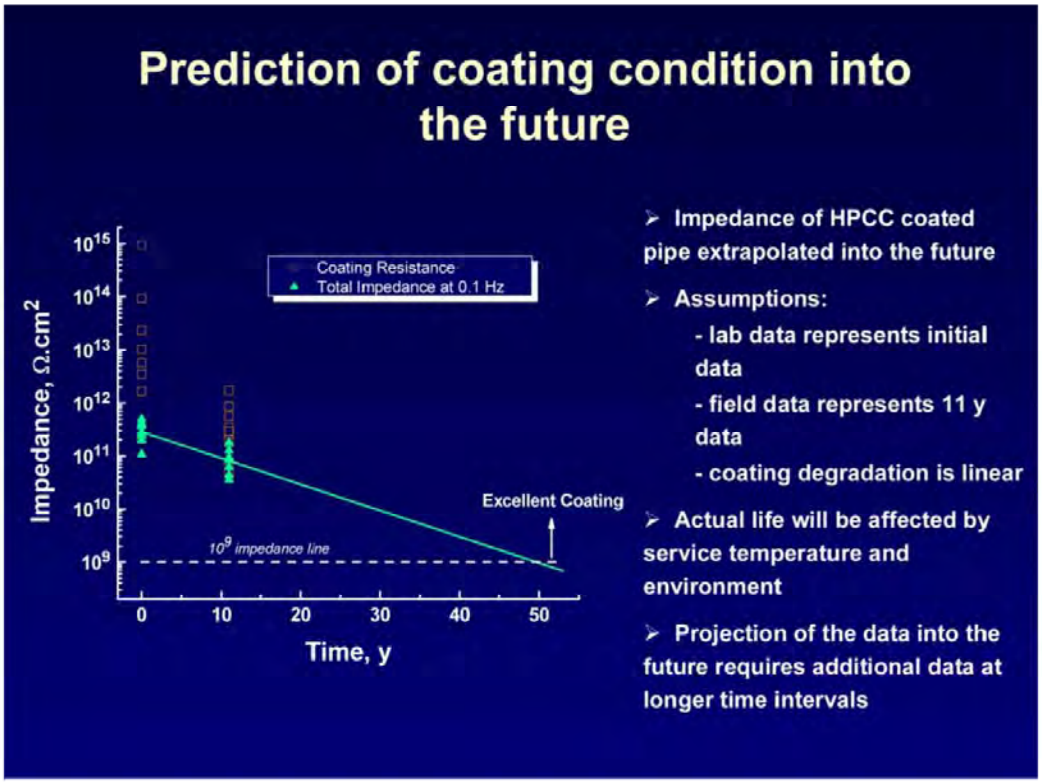
Inspection of excavated HPCC coated pipe using EISPlus

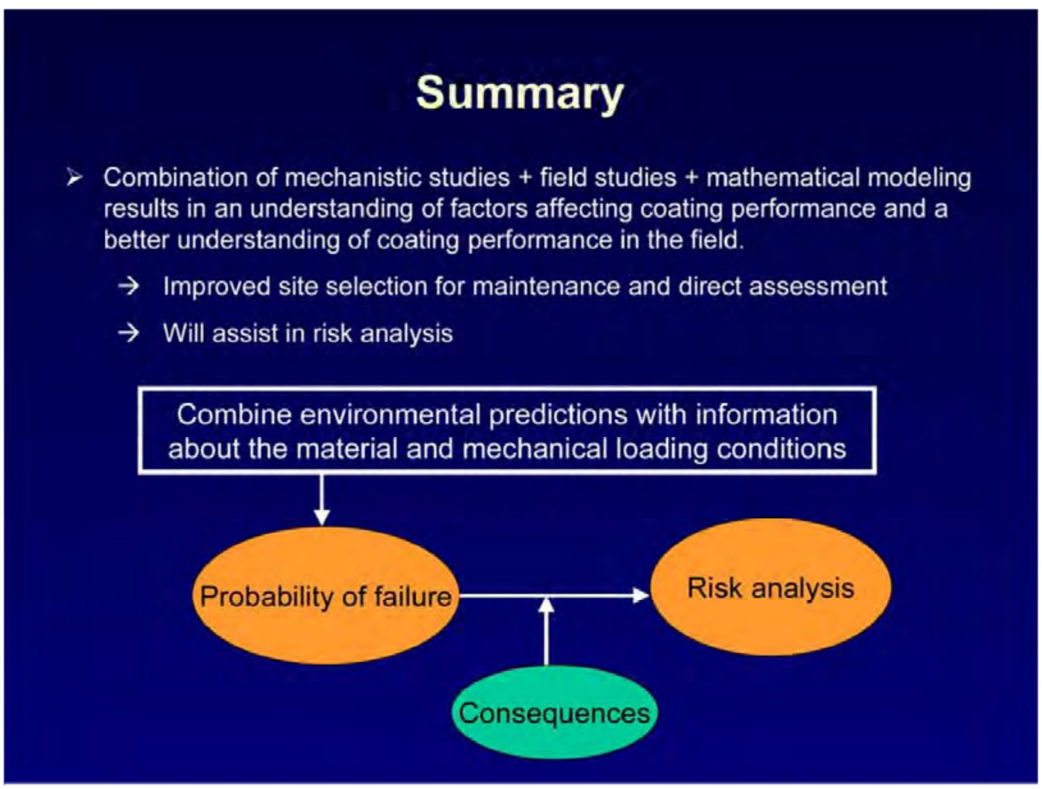
- dielectric interface enhances the capabilities of the FRA to yield valid low frequency data
- 2-electrode system
- no liquid electrolyte
- EIS*Plus* measurements were made
- Belt can be replaced with a magnet
- HPCC coating was in excellent condition after 11 y of service

Inspection of excavated HPCC coated pipe using EISPlus

- **EIS*Plus* measurements were obtained around the circumference of the pipe**
- **There may have been some damage at the 12:00 0'clock position**




Prediction of coating condition into the future
Impedance, Ω.cm²
10¹⁵
10¹⁴
10¹³
10¹²
10¹¹
10¹⁰
10⁹
Coating Resistance
Total Impedance at 0.1 Hz
Excellent Coating
10⁹ impedance line
0
10
20
30
40
50
Time, y
Impedance of HPCC coated pipe extrapolated into the future
Assumptions:
- lab data represents initial data
- field data represents 11 y data
- coating degradation is linear
Actual life will be affected by service temperature and environment
Projection of the data into the future requires additional data at longer time intervals


Summary
Combination of mechanistic studies + field studies + mathematical modeling results in an understanding of factors affecting coating performance and a better understanding of coating performance in the field.
→ Improved site selection for maintenance and direct assessment
→ Will assist in risk analysis
Combine environmental predictions with information about the material and mechanical loading conditions
Probability of failure
Risk analysis
Consequences

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GTI Field Applied Coatings Research Program

Presented to OPS Advanced Pipeline Coatings Workshop

June 9, 2005

Paul Beckendorf
Gas Technology Institute

Pipeline Integrity and Coatings

- Maintaining pipeline integrity: Critical for continued safe operation of gas distribution and transmission systems
- Accomplished through a comprehensive corrosion control program which includes correctly specified and applied coatings used in conjunction with cathodic protection
- Large selection of coating systems on the market
  - Endless new product introductions
  - Many product reformulations
    - Improvements
    - Changes to meet new regulations
  - The multiple choices present a challenge for Corrosion Engineer and Integrity Managers

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GTI's Project

- To thoroughly test the full range of available coating systems
  - Determine which coating systems are most suitable for various environments and situations
  - Provide pipeline operators with information needed to make critical decisions regarding coating systems
- Project results to date will be issued in 3Q05
  - Gas Transmission Company funders - comprehensive results
  - Manufacturers
    - Overall generic results
    - Product-specific results to each manufacturer for their products only

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Pipeline Coatings Evaluations Underway at GTI

- In 2002 – FBE Compatible Test – Over 700 applications of 70+ pipeline coating systems made to 24" & 8" welded pipe sections
  - The pipe sections, except for the weld joints, coated with FBE
  - Weld joints coated with the full range of available coating systems
  - Manufacturers applied their respective coatings
  - Samples excavated and analyzed in 2004 and early 2005
  - All work performed per agreed-to specifications (handouts)

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Pipeline Coatings Evaluations Underway at GTI

> In 2004 – 3-Layer PE Compatible Test - Over 300 applications of 30+ pipeline coating systems made to 8" welded pipe sections

- Pipe sections, except for the weld joints, coated with 3-layer PE
- Weld joints coated with full range of available coating systems that are compatible with 3-layer PE
- Manufacturers applied their respective coatings
- All work performed per agreed-upon specifications

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Pipeline Coatings Evaluations Underway at GTI

> Generic Coating Types Tested

- Epoxies (coal tar, 100% solids, water tolerant, fusion-bonded, dual coat systems)
- Polyurethanes (epoxies, moisture cures)
- Polymer concretes
- Shrink sleeves and tape coatings (cold applied, heat-shrinkable, hot-applied, wax-type)
- Wax coatings (hot-applied, cold applied mastics)
- Hybrid systems - combinations of two or more of the above

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Phase One – FBE Parent Pipe

> Environment
- Three extreme soil types (rocky soil, clay, sand)
- Both ambient and elevated temperatures (> 212 F)
- Under short and long-term burial (2 to 5 years)

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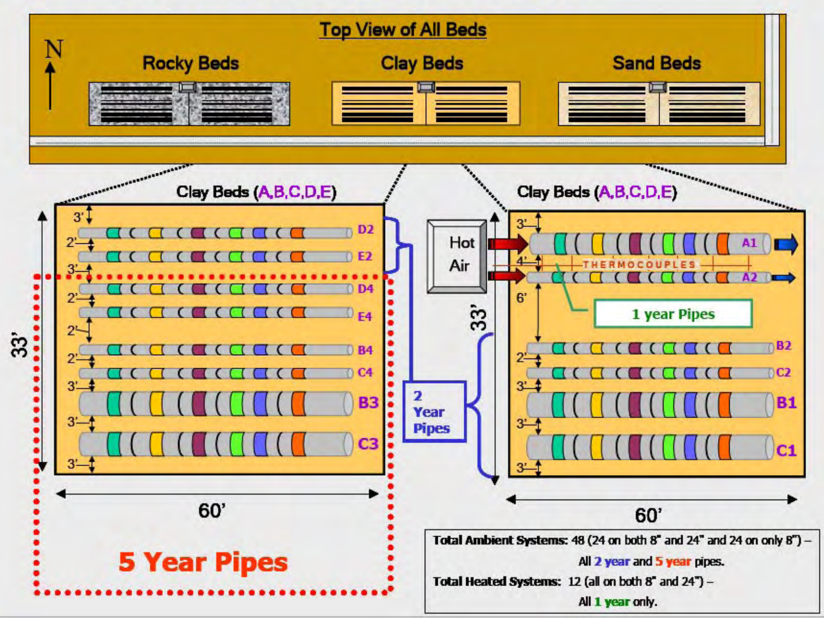
GTI Soil Bed Construction



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Geotextile & Geomembrane Installation – Moisture & Washout Control

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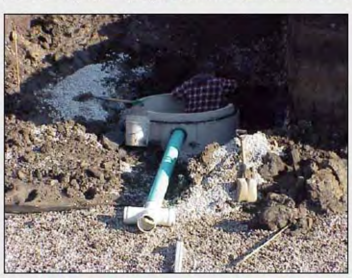
Installation of Drainage System



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Pipeline Coatings Evaluation Cutback Mark Off

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Pre-grooving and Welding of Cut Back Areas

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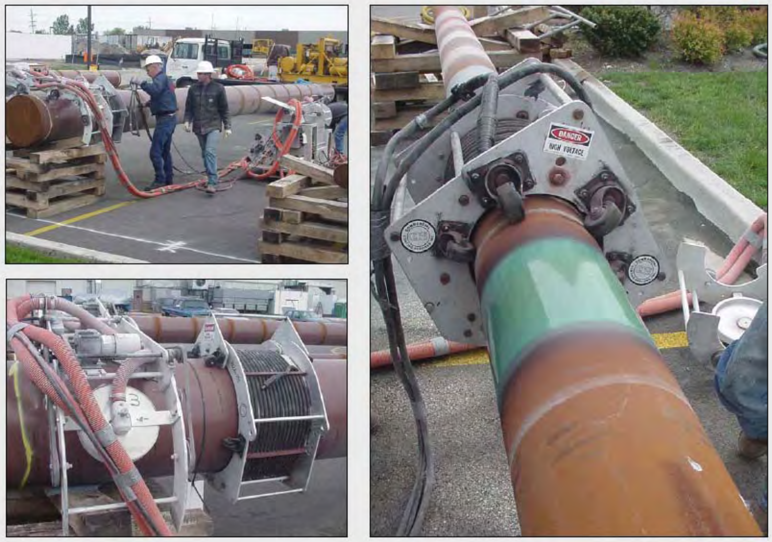
Test Joints As Welded and Feathered

Surface Preparation of Pipes

Fusion Bonded Epoxy Field Applications



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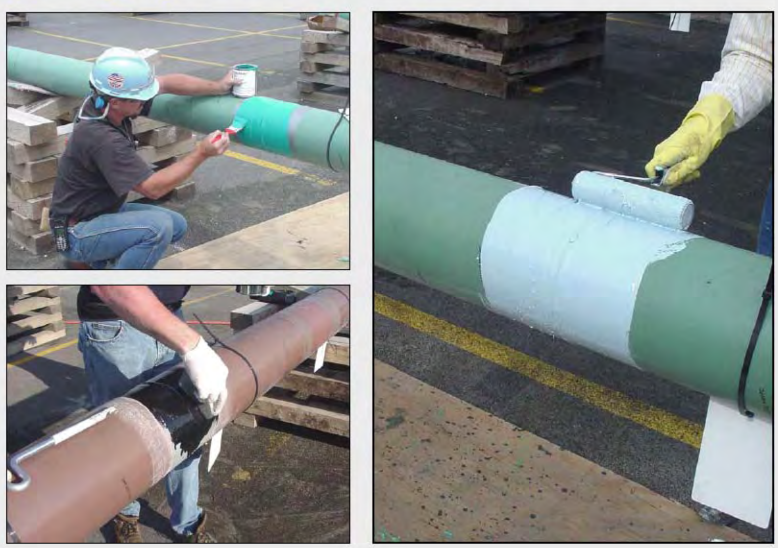
Liquid Applications – Brush, Sponge, and Roller



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Liquid Applications – Poured into Casting

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Flame Spray and Shrink Sleeve Applications

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Polymer Concrete and Tape Applications

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Airless and Plural Component Applications

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Heat Shrink Sleeve Applied by Torch Over 3-Layer PE

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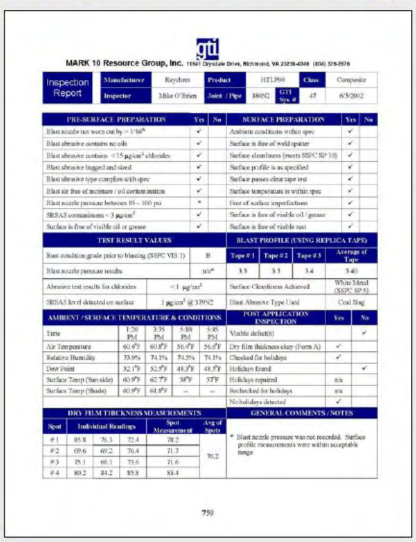
Comprehensive Inspection Report on Every Joint



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MARK 10 Resource Group, Inc. 11841 Drysdale Drive, Richmond, VA 23236-4040 (804) 379-2876

Inspection Report	Manufacturer	Raychem	Product	HTLP80		Class	Composite
	Inspector	Mike O'Brien	Joint / Pipe	380N2	GTI Sys. #	47	6/5/2002

PRE-SURFACE PREPARATION	Yes	No	SURFACE PREPARATION	Yes	No
Blast nozzle not worn out by > 1/16"	✓		Ambient conditions within spec	✓	
Blast abrasive contains no oils	✓		Surface is free of weld spatter	✓	
Blast abrasive contains <15 μg/cm² chlorides	✓		Surface cleanliness (meets SSPC SP 10)	✓	
Blast abrasive bagged and sized	✓		Surface profile is as specified	✓	
Blast abrasive type complies with spec	✓		Surface passes clear tape test	✓	
Blast air free of moisture / oil contamination	✓		Surface temperature is within spec	✓	
Blast nozzle pressure between 85 – 100 psi	*		Free of surface imperfections	✓	
SRSAS contaminants < 3 μg/cm²	✓		Surface is free of visible oil / grease	✓	
Surface is free of visible oil or grease	✓		Surface is free of visible rust	✓	

TEST RESULT VALUES		BLAST PROFILE (USING REPLICA TAPE)			
		Tape # 1	Tape # 2	Tape # 3	Average of Tape
Rust condition grade prior to blasting (SSPC VIS 1)	B				
Blast nozzle pressure results	n/a*	3.3	3.5	3.4	3.40
Abrasive test results for chlorides	<1 μg/cm²	Surface Cleanliness Achieved			White Metal (SSPC SP 5)
SRSAS level detected on surface	1 μg/cm² @ 379N2	Blast Abrasive Type Used			Coal Slag

AMBIENT / SURFACE TEMPERATURE & CONDITIONS					POST APPLICATION INSPECTION	Yes	No
Time	1:20 PM	3:35 PM	5:10 PM	5:45 PM	Visible defect(s)		✓
Air Temperature	60.4°F	60.8°F	56.4°F	56.6°F	Dry film thickness okay (Form A)	✓	
Relative Humidity	73.9%	74.1%	74.5%	74.1%	Checked for holidays	✓	
Dew Point	52.1°F	52.5°F	48.3°F	48.5°F	Holidays found		✓
Surface Temp (Sun side)	60.9°F	62.7°F	58°F	57°F	Holidays repaired	n/a	
Surface Temp (Shade)	60.9°F	61.8°F	--	--	Rechecked for holidays	n/a	
					No holidays detected	✓	

DRY FILM THICKNESS MEASUREMENTS					
Spot	Individual Readings			Spot Measurement	Avg of Spots
# 1	85.8	76.3	72.4	78.2	76.2
# 2	69.6	69.2	76.4	71.7	
# 3	75.1	66.1	73.6	71.6	
# 4	80.2	84.2	85.8	83.4	

GENERAL COMMENTS / NOTES

* Blast nozzle pressure was not recorded. Surface profile measurements were within acceptable range.

759

FBE Coated Pipes Covered in Tyvek and Awaiting Final Holiday Testing

gti

Controlled Placement of Coated Pipe in Test Facility

gti

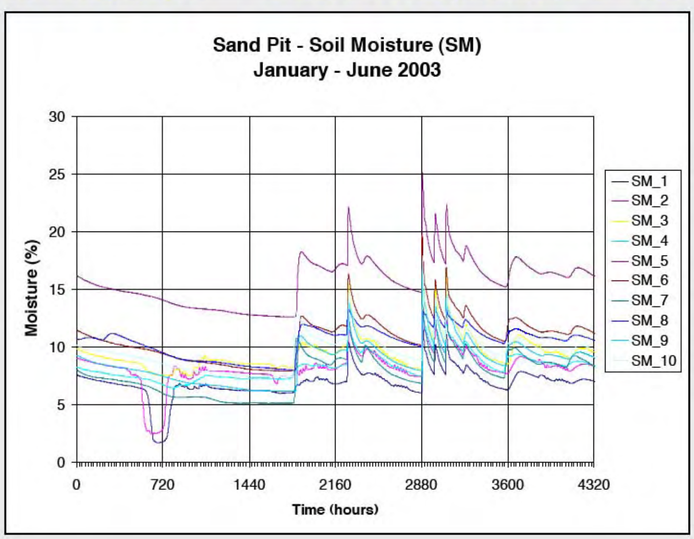
Triangulation, Sensor Placement, and CP Hook Up

Backfill Operation

Internal Pipe Heating System

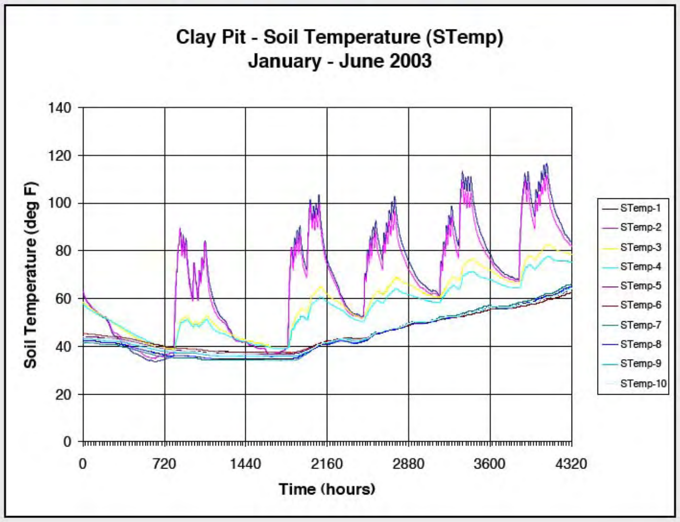
gti

Field Applied Coatings Research – Soil Moisture Data

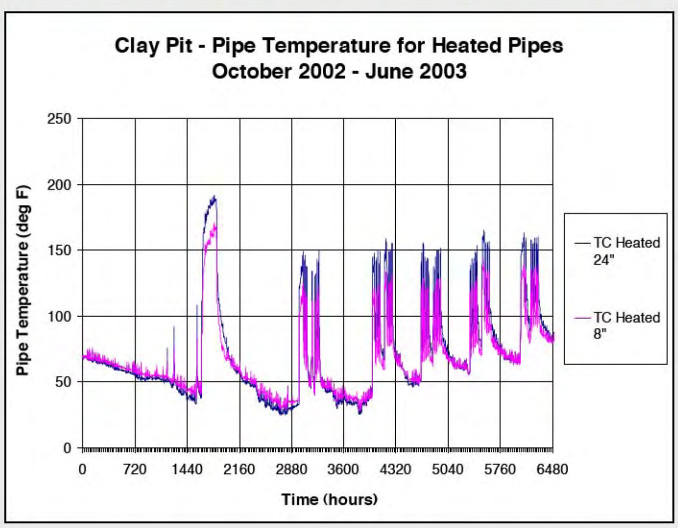


gti

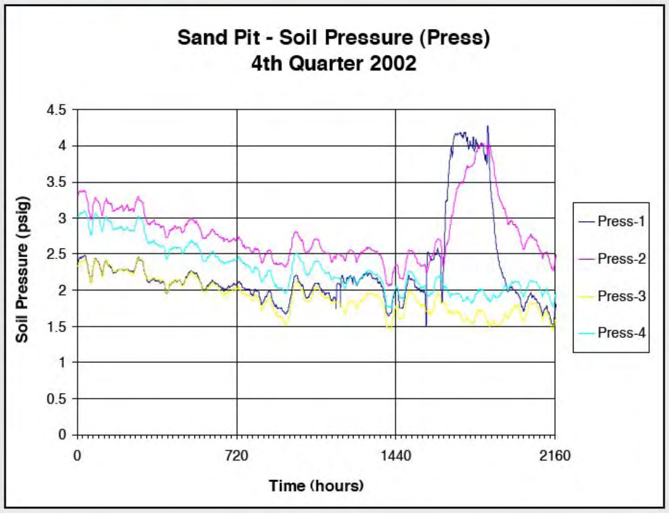
Field Applied Coatings Research – Soil Temperature Data



Field Applied Coatings Research – Pipe Surface Temperature Data



Field Applied Coatings Research



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Pipeline Coatings Quantitative Testing – Control and Field Samples

> Impact Resistance (ASTM G-14).

> Adhesion (ASTM D-4541).

> Hardness (ASTM D-2240, 2583).

> Penetration Resistance (ASTM G-17).

> Abrasion Resistance (Tabor)

> Cathodic Disbondment (ASTM G-8, 42, 95).

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Visual Inspection of Excavated Coating Systems

- Indentions
- Abrasions
- Deformations
- Rust
- Blistering
- Wrinkles
- Peeling
- Delamination

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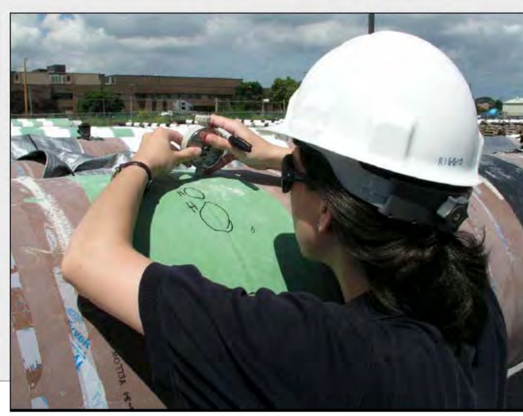
Post-Excavation Hardness and Holiday Testing

- All joints tested for pinholes and cracks
- Hardness testing measurements taken to compare to original hardness



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Adhesion Testing



- Adhesive and cohesive failures
- Adhesion strength measured up to 3,000 psi

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Peel Testing

- Some field-joint systems, such as the heat shrink sleeves, tapes, wraps and composites were not suitable for adhesion testing due to their composition
- For these systems, a specially modified GTI peel test protocol was established and used.

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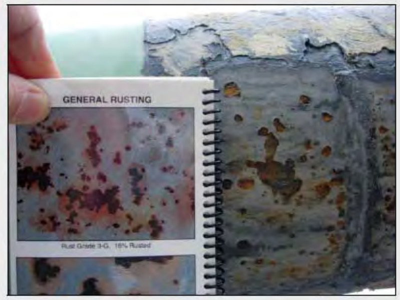
Failure Analysis



> In some cases, the failure investigation revealed serious deficiencies in the coating system that resulted in severe rusting and pitting on the substrate, under the coating

> During failure investigation, the condition of the underlying substrate was documented and photographed for future reference and evaluation

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Next Steps

> 3Q05 – Issue Report of Findings to Date

> 2007 – Excavate 5 year FBE Compatible Coating Systems for Failure Analysis and Testing

> 2007-2008 – Excavate 3 year 3-Layer PE Compatible Coating Systems for Failure Analysis and Testing

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GTI Field Applied Coatings Research Program

Questions ???

For further, detailed information, contact

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847.768.0663
daniel.ersoy@gastechnology.org

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GTI Field Applied Coatings Research Program

Presented to OPS Advanced Pipeline Coatings Workshop

June 9, 2005

Paul Beckendorf
GTI
847.768.0889
paul.beckendorf@gastechnology.org

Coating Fabrication Issues

BREDERO SHAW

A SHAWCOR COMPANY

Peter Singh

Presented to:
Office of Pipeline Safety Workshop on
Advanced Coatings R&D for Pipelines and Related Facilities
June 9-10, 2005
National Institute of Standards and Technology
Gaithersburg, MD USA

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Pipeline Coatings

The role of external pipeline coatings is to complement cathodic protection systems in protecting pipelines from corrosion and subsequent failure

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Demands

- Improved pipeline integrity
- Improved coating performance.
  - increased reliability
  - less risk of failures
  - longer expected lifetime
  - less maintenance
- Improved quality
- Increased capabilities
  - higher pipeline operating temperatures
  - low temperature construction in arctic regions
- Environmental concerns
- Improved life cycle economics
  - material costs
  - construction & operating costs

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Strategy for Achieving Pipeline Integrity

- Develop understanding of coating performance requirements
- Design and select coatings properly
- Ensure meaningful specifications are written
- Apply coating under optimum process with adequate quality control
- Carry out construction according to plan
- Operate system within specification
- Periodic monitoring and feedback on performance
- Research & Development of new technologies

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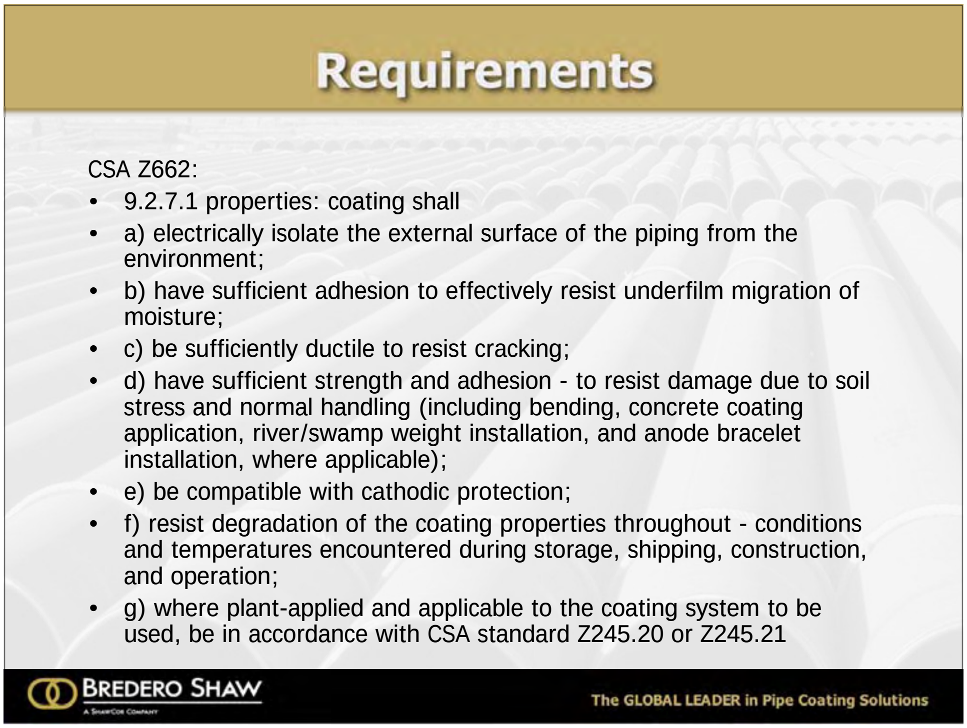
Requirements
CSA Z662:
• 9.2.7.1 properties: coating shall
• a) electrically isolate the external surface of the piping from the environment;
• b) have sufficient adhesion to effectively resist underfilm migration of moisture;
• c) be sufficiently ductile to resist cracking;
• d) have sufficient strength and adhesion - to resist damage due to soil stress and normal handling (including bending, concrete coating application, river/swamp weight installation, and anode bracelet installation, where applicable);
• e) be compatible with cathodic protection;
• f) resist degradation of the coating properties throughout - conditions and temperatures encountered during storage, shipping, construction, and operation;
• g) where plant-applied and applicable to the coating system to be used, be in accordance with CSA standard Z245.20 or Z245.21
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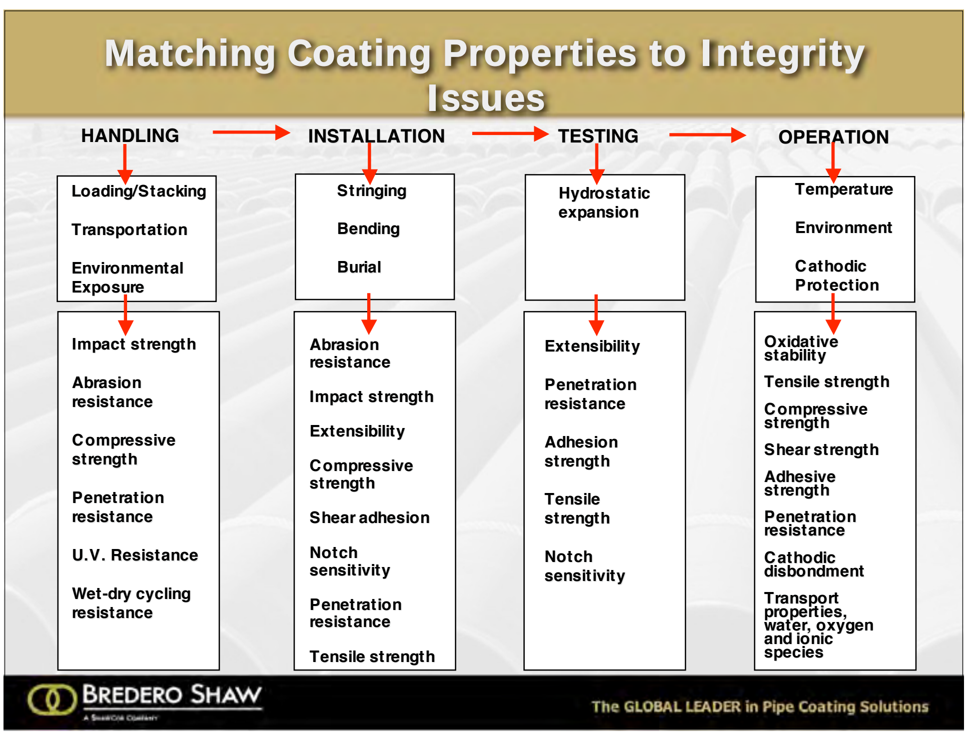
Matching Coating Properties to Integrity Issues
HANDLING
INSTALLATION
TESTING
OPERATION
Loading/Stacking
Transportation
Environmental Exposure
Stringing
Bending
Burial
Hydrostatic expansion
Temperature
Environment
Cathodic Protection
Impact strength
Abrasion resistance
Compressive strength
Penetration resistance
U.V. Resistance
Wet-dry cycling resistance
Abrasion resistance
Impact strength
Extensibility
Compressive strength
Shear adhesion
Notch sensitivity
Penetration resistance
Tensile strength
Extensibility
Penetration resistance
Adhesion strength
Tensile strength
Notch sensitivity
Oxidative stability
Tensile strength
Compressive strength
Shear strength
Adhesive strength
Penetration resistance
Cathodic disbondment
Transport properties, water, oxygen and ionic species
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Plant Coating Technologies

- Powder Applied Coatings
  - FBE
    - Single layer: corrosion and specialty
    - Multi-layer: abrasion, anti-slip, protective topcoat
  - HPCC
    - Multi-component: FBE, adhesive, PE or PP topcoat
- Extrusion Applied Coatings
  - 2 layer PE / PP
    - Mastic adhesive, butyl, hot melt
  - 3 layer PE / PP
    - FBE, adhesive, PE or PP topcoat
- Liquid Applied Coatings
  - Polyurethane, epoxy, coal tar enamel, asphalt enamel

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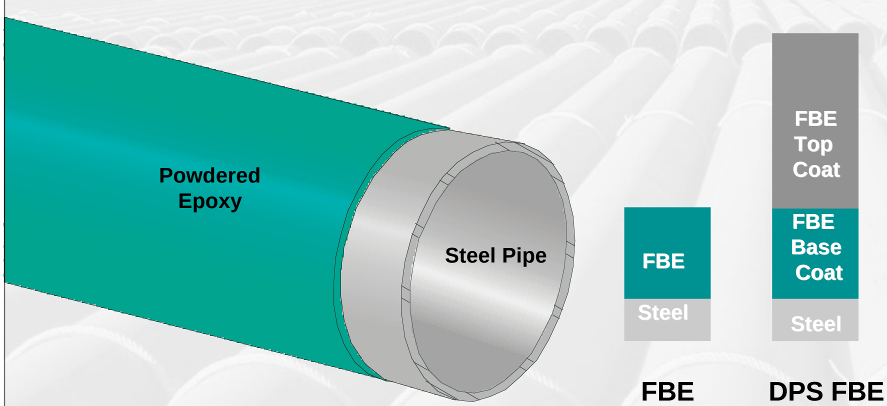
Fusion Bonded Epoxy



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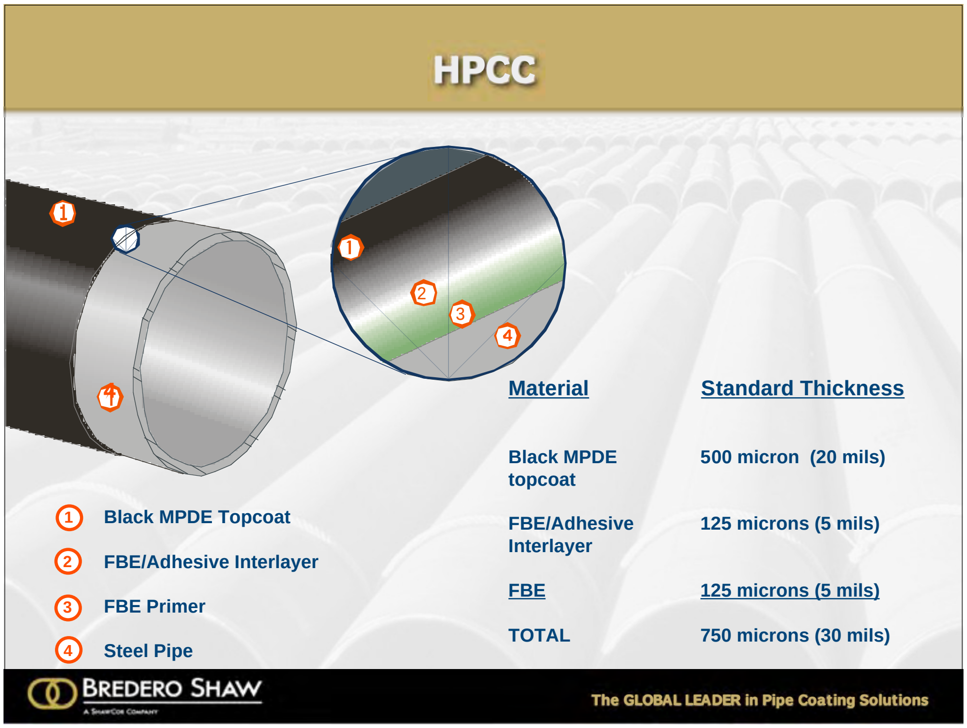
HPCC
Material
Standard Thickness
Black MPDE topcoat
500 micron (20 mils)
FBE/Adhesive Interlayer
125 microns (5 mils)
FBE
125 microns (5 mils)
TOTAL
750 microns (30 mils)
1 Black MPDE Topcoat
2 FBE/Adhesive Interlayer
3 FBE Primer
4 Steel Pipe
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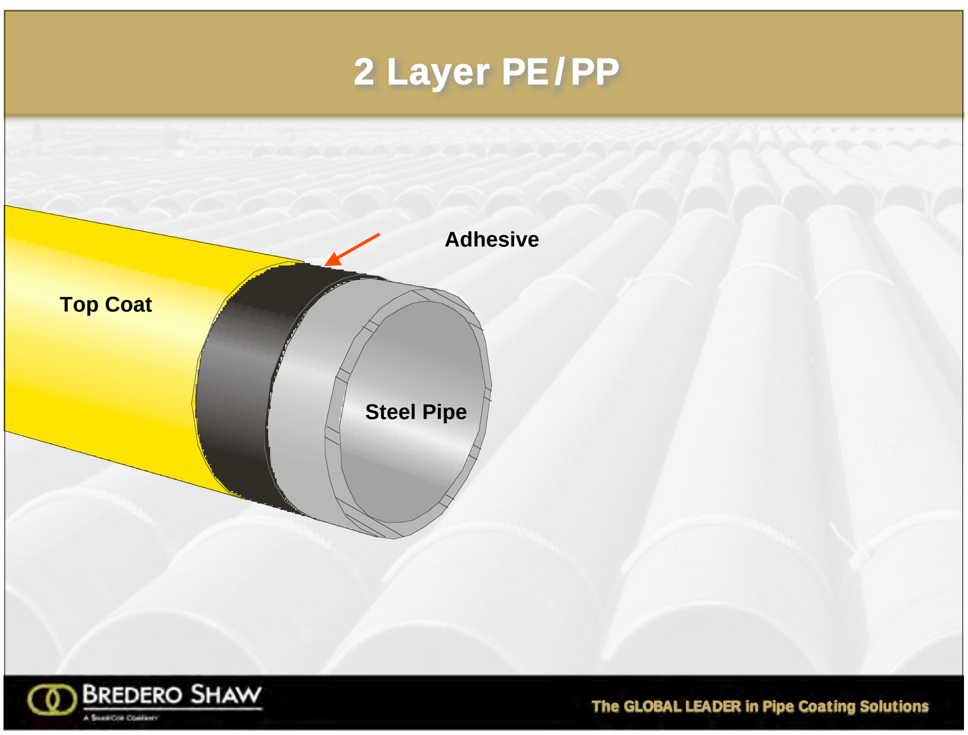
2 Layer PE / PP
Adhesive
Top Coat
Steel Pipe
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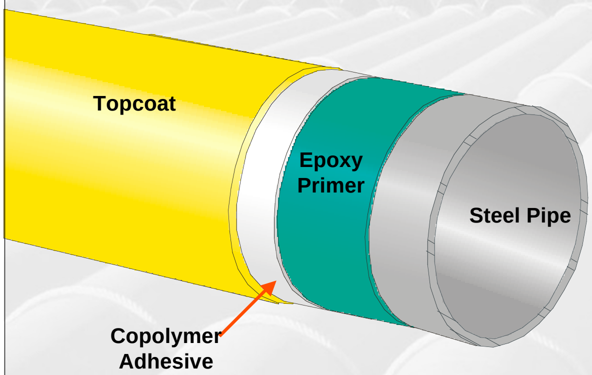
3 Layer PE/PP



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Field Coating Technologies

- Powder Applied Coatings
  - FBE
    - Single layer
    - Multi-layer
  - Multi-component
    - FBE, adhesive, PE or PP topcoat
- Liquid Applied Coatings
  - Polyurethane, epoxy
- Heat Shrink Sleeves
  - Crosslinked PE/PP with/out liquid epoxy
- Others
  - Tapes, sleeves, etc.

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Heat Shrink Sleeve
CANUSA-CPS
1
2
3
4
5
6
Adhesive Directly To Line Coating
CrossLinked Backing
Force Cured Epoxy System
Pre-attached Closure System
"Open" Adhesive Technology
Epoxy On Steel Only
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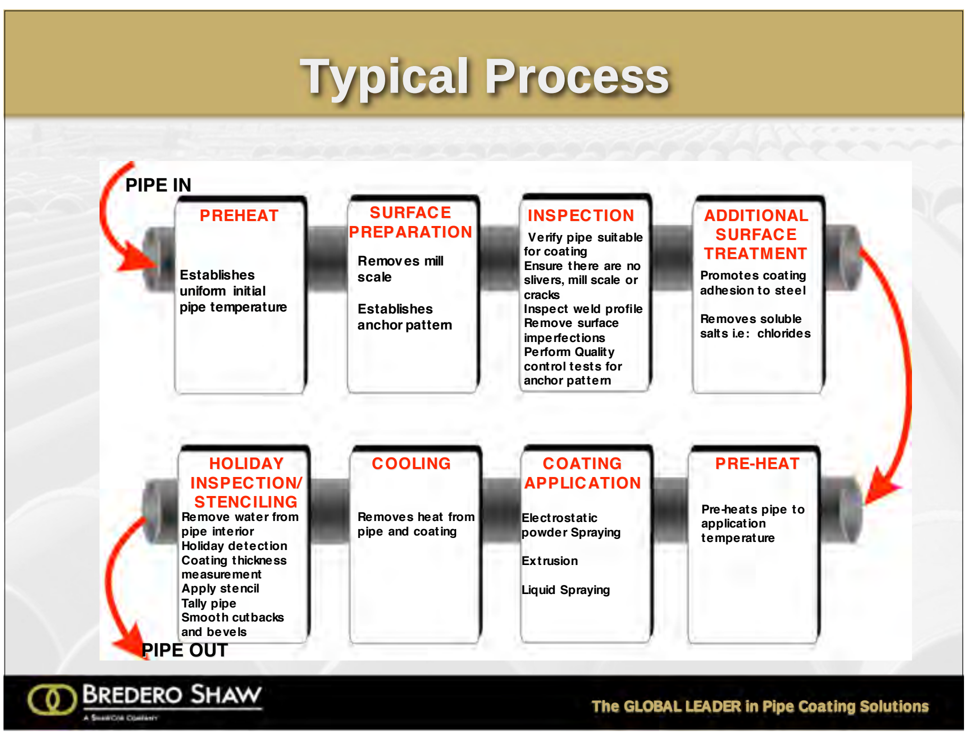
Typical Process
PIPE IN
PREHEAT
Establishes uniform initial pipe temperature
SURFACE PREPARATION
Removes mill scale
Establishes anchor pattern
INSPECTION
Verify pipe suitable for coating
Ensure there are no slivers, mill scale or cracks
Inspect weld profile
Remove surface imperfections
Perform Quality control tests for anchor pattern
ADDITIONAL SURFACE TREATMENT
Promotes coating adhesion to steel
Removes soluble salts i.e: chlorides
PRE-HEAT
Pre-heats pipe to application temperature
COATING APPLICATION
Electrostatic powder Spraying
Extrusion
Liquid Spraying
COOLING
Removes heat from pipe and coating
HOLIDAY INSPECTION/ STENCILING
Remove water from pipe interior
Holiday detection
Coating thickness measurement
Apply stencil
Tally pipe
Smooth cutbacks and bevels
PIPE OUT
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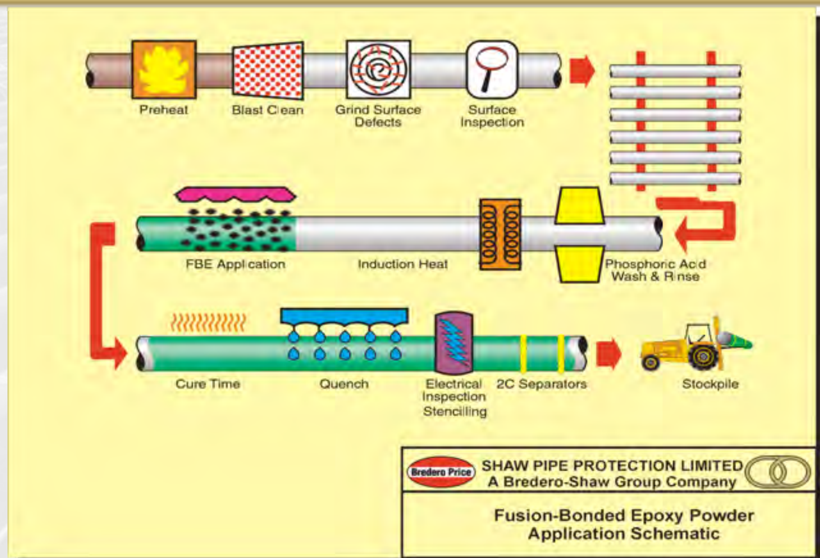
FBE Coating Process



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Design & Selection

Need better understanding of performance requirements to quantify and select

Many studies on various properties, for example:

- Impact
- Shear adhesion
- Thermal aging
- UV degradation
- Cathodic disbondment
- Cathodic protection

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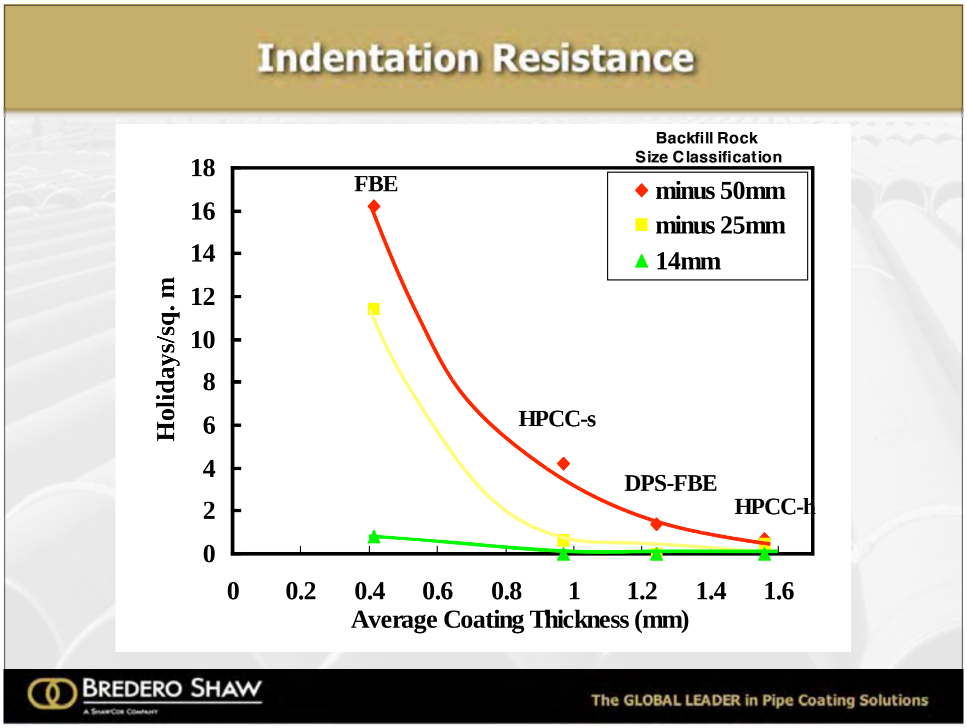
Indentation Resistance
Backfill Rock
Size Classification
minus 50mm
minus 25mm
14mm
FBE
HPCC-s
DPS-FBE
HPCC-h
Holidays/sq. m
Average Coating Thickness (mm)
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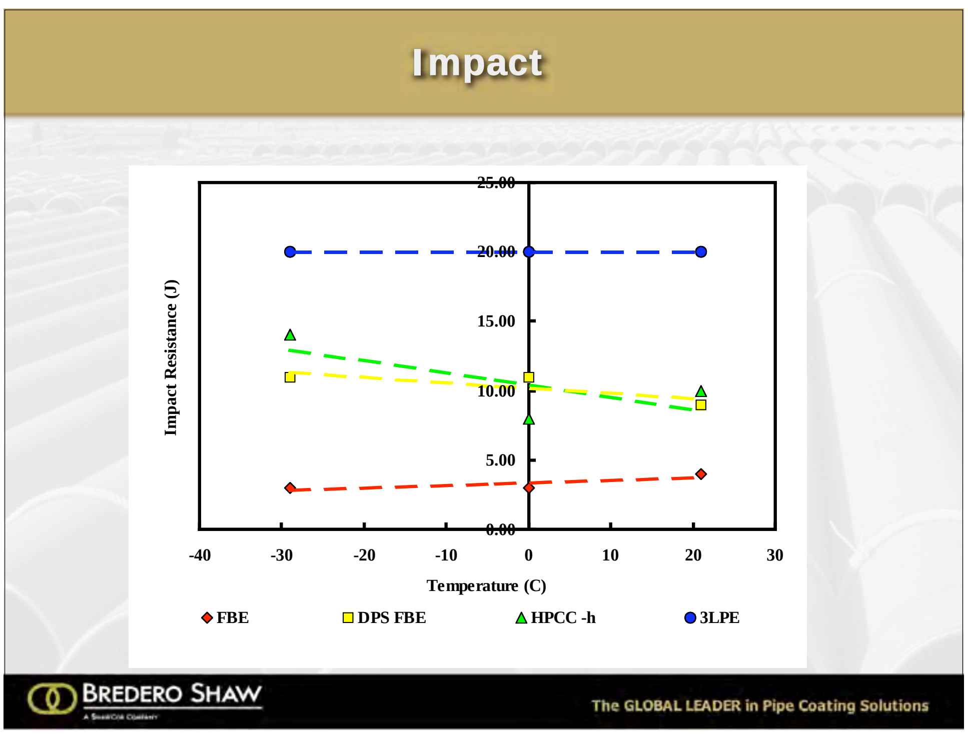
Impact
Impact Resistance (J)
Temperature (C)
FBE
DPS FBE
HPCC -h
3LPE
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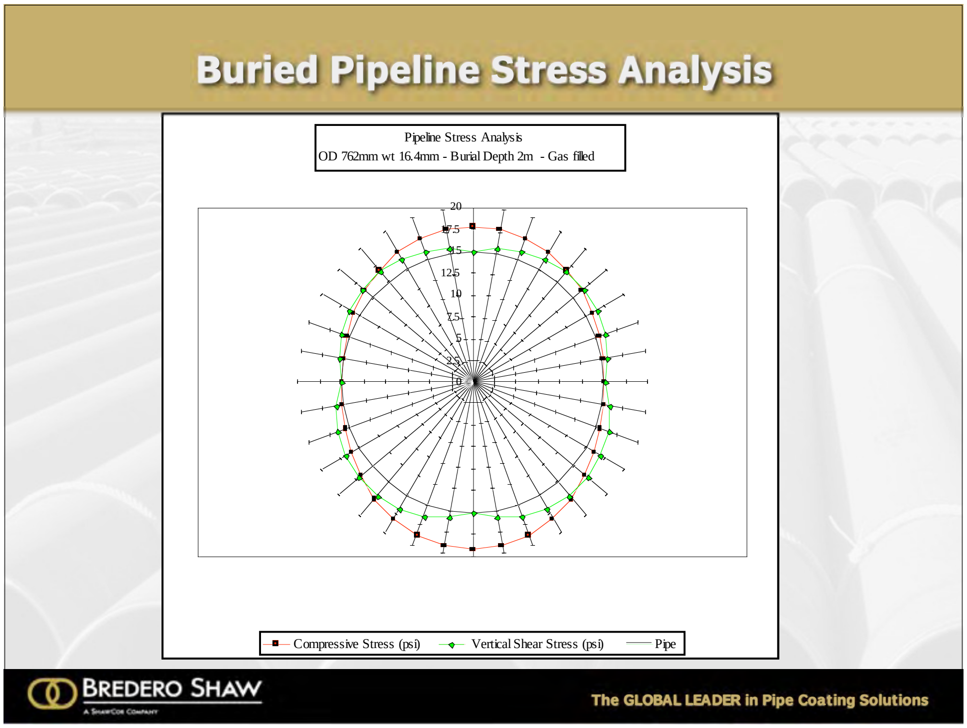
Buried Pipeline Stress Analysis
Pipeline Stress Analysis
OD 762mm wt 16.4mm - Burial Depth 2m - Gas filled
20
17.5
15
12.5
10
7.5
5
2.5
0
Compressive Stress (psi)
Vertical Shear Stress (psi)
Pipe
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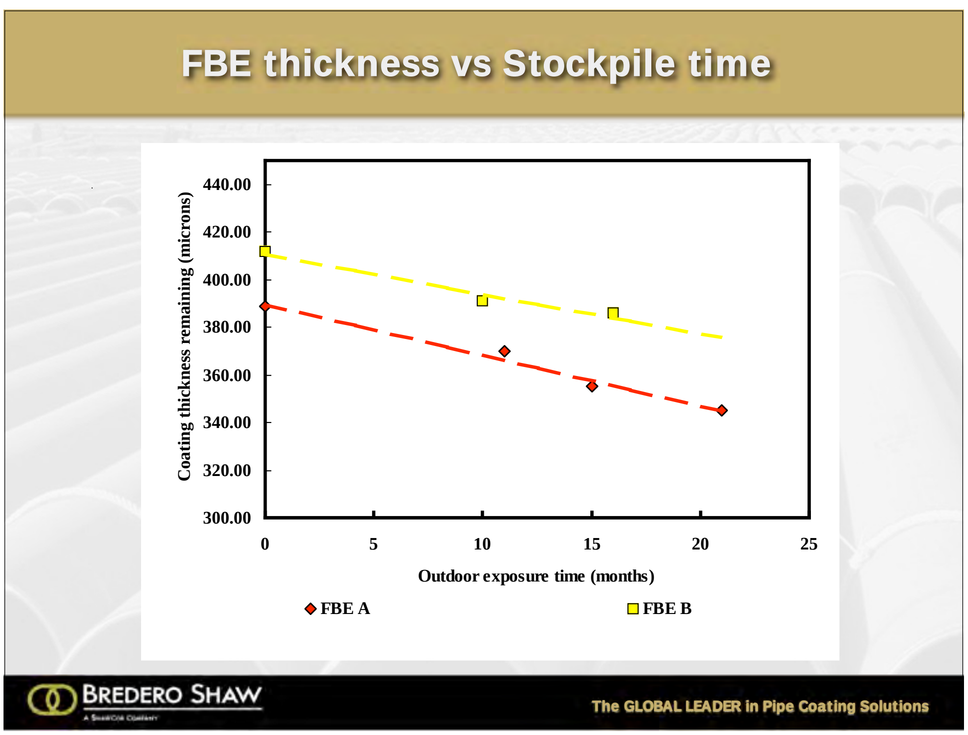
FBE thickness vs Stockpile time
Coating thickness remaining (microns)
440.00
420.00
400.00
380.00
360.00
340.00
320.00
300.00
0
5
10
15
20
25
Outdoor exposure time (months)
FBE A
FBE B
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Specifications

- Need for standardization
  - Proliferation of company exclusive specifications
  - Many differences, some good, some bad
  - ISO standards being developed
- Need for performance based specifications
  - Define performance requirements not manufacturing process
  - End result can be to stifle innovation, build in mediocrity with poor specifications
- Need for meaningful specification
  - More requirements, tighter criteria not often better
  - Focus on important properties and limits
  - Can deteriorate into testing project

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Manufacturing Issues

- Complex application process
  - Many diverse processes to apply coatings: from heating, surface preparation, materials application
- Little consensus on best process/parameters
  - Some research on various parameters such as profile, contamination, surface treatments
  - Studies often not very conclusive
- Realistic expectations
  - Large heavy part/surface area to be coated
  - Process time limitations (delivery schedules)
  - Cost limitations as % of steel cost
  - Cannot treat in same manner as small components

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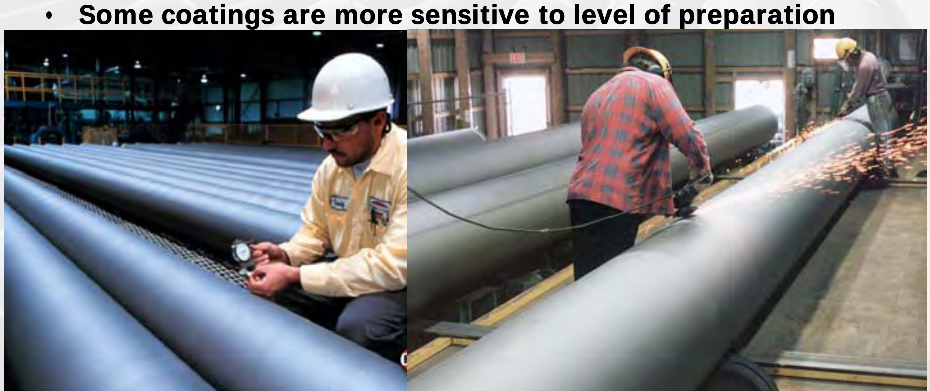
Surface Preparation

- **Most important process in determining coating quality**
- **Need to determine optimum parameters and how to measure during process**
- **Many companies do not understand importance**
- **Some coatings are more sensitive to level of preparation**



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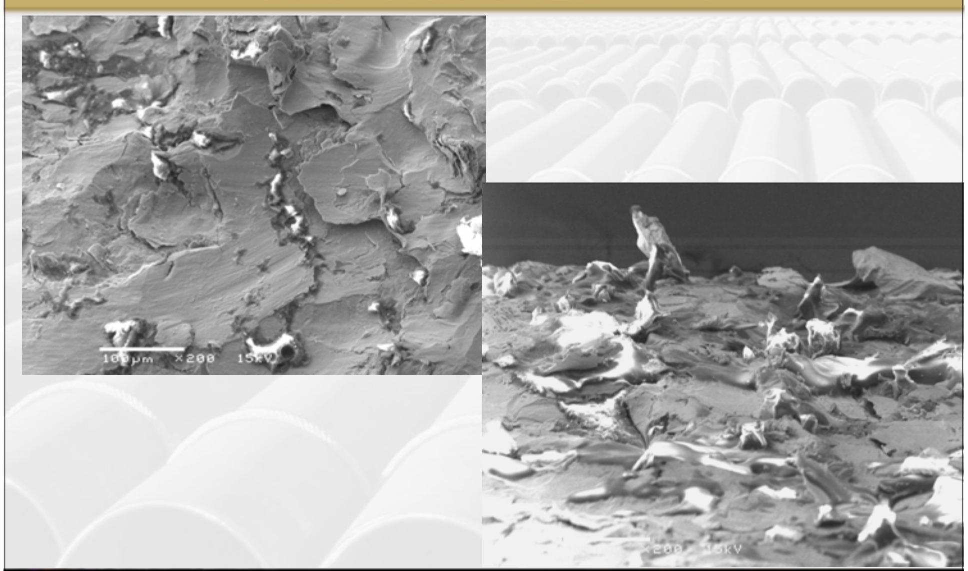
Optimum Blast Profile?



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Cross-head/side extrusion?

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Manufacturing Issues

- Not ideal manufacturing process
  - Cannot schedule, inventory management, etc)
- More similar to project driven business
  - Customer supplied pipe
  - Wait for pipe to be delivered and then coat
- Problems inherent to project driven industries
  - Inefficient if work is not steady
  - Issues on maintenance of skilled labour

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Incoming Pipe Quality

- May not be critical for pipeline itself but important for processing and coating application
- Condition of pipe on delivery
  - Wall thickness
  - Roundness
  - Camber
  - Weld profile
  - Steel cleanliness
  - Contamination
  - Joint length
- Steel pipe specification
  - Need to address not only pipeline design issues but also subsequent ability to process for coating

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Quality Assurance

- Should be internally driven by coating applicator
  - customer should expect a high level QA program
- Quality improvement programs
  - awareness
  - preventative
  - inspection and audit
- Use of ISO 9001
  - Program regularly audited by third party

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Industry Feedback is Important

- Assessment of coating performance in independent digs
- Confirmation of predictive analysis on long term coating properties
  - Adhesion
  - Permeability
  - Material properties
- Joint development of corrective strategies
- Operators, contractors, coaters, regulators, and engineering companies need to work as a team

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Failure Modes

- Damaged Coating
  - Impact damage
  - Cracking
  - Deterioration
- Shielding Disbondment
  - Over the ditch tapes
- Permeable Coating
  - Asphalts and to some extent FBE
- Blistered Coating
  - Has been observed with FBE
- Disbondment
  - Has been observed with 3 layer PE and PP coatings

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Blistered FBE

Photograph 3: Disbonded coating around holiday.

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3LPE Disbondment

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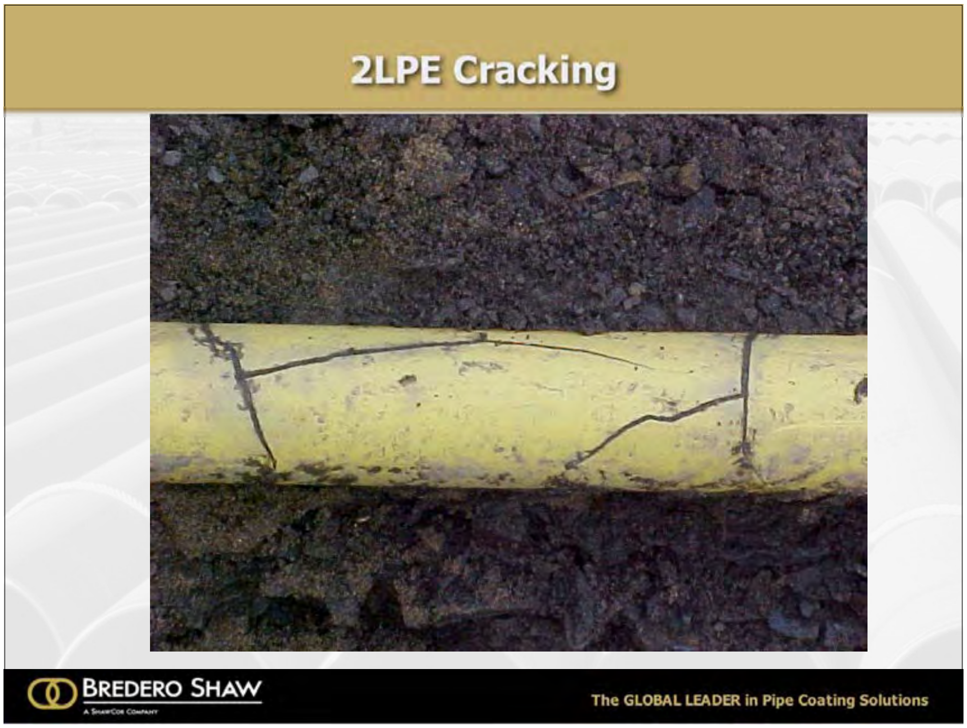
2LPE Cracking
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Tape Disbondment & Wrinkling
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Research

- Predictive studies
  - Predictive analysis of properties (long term)
  - Relation of lab measured properties to field performance
  - Development of models to use in design & selection of coatings
- Product / process development
  - New products to reduce failures, increase performance, increase reliability, lower cost
  - Standards need to be flexible to allow new developments
- Failure Analysis
  - Understanding coating failures
    - Blistering
    - Disbondment
    - Cracking

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Competitive Issues

- Protection of innovative technologies
  - Patents, secrecy agreements
- Limits to access
  - Conflicts with end users specifying full access
- Intentional and accidental sharing of technologies
- Protection of R&D investment

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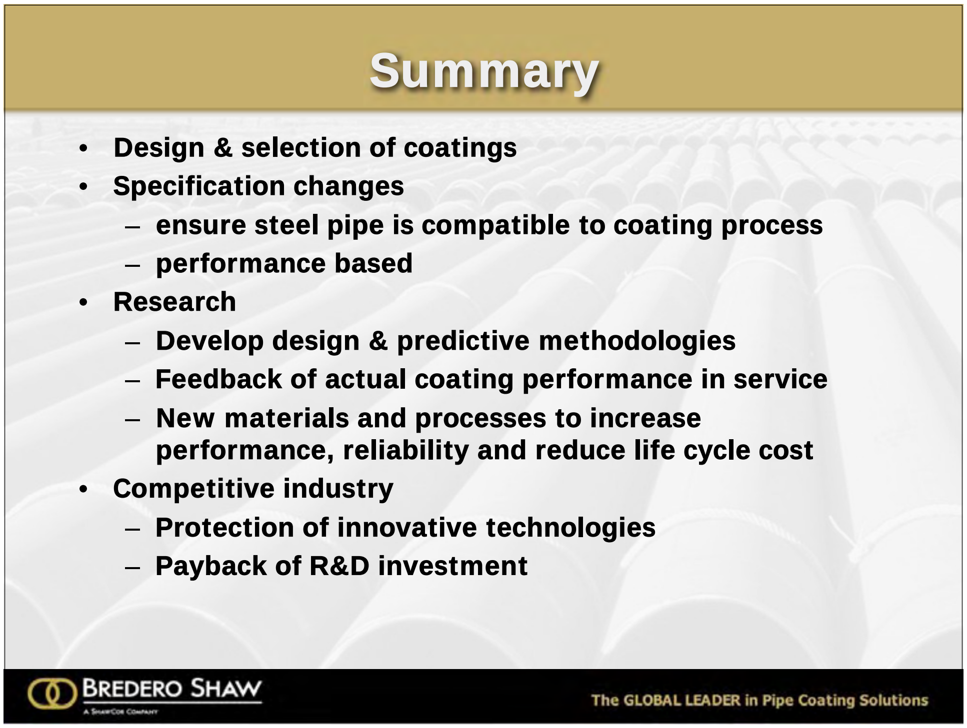
Summary
• Design & selection of coatings
• Specification changes
– ensure steel pipe is compatible to coating process
– performance based
• Research
– Develop design & predictive methodologies
– Feedback of actual coating performance in service
– New materials and processes to increase performance, reliability and reduce life cycle cost
• Competitive industry
– Protection of innovative technologies
– Payback of R&D investment
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THE MATERIALS JOINING EXPERTS

NDE AND EDDY CURRENT METHODS FOR PIPELINE COATING INSPECTION

NIST Workshop on Advanced Coatings R&D for Pipelines and Related Facilities June 05

Evgueni Todorov, Ph.D.
Engineering and NDE
EWI
PH. 614-688-5268, FAX 614-688-5001

THE MATERIALS JOINING EXPERTS

Contents

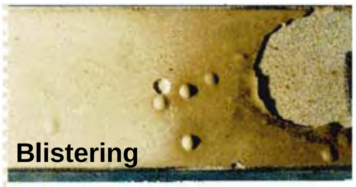
THE MATERIALS JOINING EXPERTS

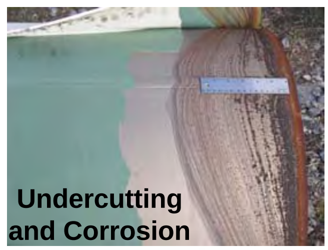
NDE of Coatings - General

- Most ASTM standards address the use of Eddy Current and Magnetic methods for thin coating thickness measurement (ASTM E 376, G12)
- Except visual inspection technique, few examples if any are available for characterization of thick coatings on the pipelines
- Typical tasks
  - Coating (or substrate) thickness measurement
  - Quality of coating (or substrate) material – degradation, porosity, voids, cracks
  - Adhesion of coating to the substrate – quality of bond, disbond areas, undercutting

THE MATERIALS JOINING EXPERTS

NDE of Coatings - Coating Failures





THE MATERIALS JOINING EXPERTS

NDE of Coatings - Ultrasonics (UT)

- General description and areas of application
  - Time-of-flight technique usually used for coating thickness measurements
  - Well established acoustically reflective interface between the coating and the substrate required
  - UT method C-Scan used for disbonds and voids detection and sizing
- Limitations
  - Organic or other highly attenuative coatings difficult or impossible to examine
  - If the interface is not acoustically reflective, the UT inspection is impossible
  - Small porosity or coating property variations that do not affect significantly the velocity of sound propagation are not detectable
  - In general, coating thickness has to be larger than 1-2 mm
  - Couplant is required
  - Multiple coating layers are difficult to evaluate

THE MATERIALS JOINING EXPERTS

NDE of Coatings - Magnetic Method

- General description and areas of application
  - Magnetic attraction or magnetic flux measurements usually used for coating thickness inspection
  - Ferromagnetic substrate or coating is required
  - Coating thickness may range from 0 to 2 mm
- Limitations
  - The substrate or coating has to be ferromagnetic
  - Coating properties such as porosity, degradation, and flaws are not measured
  - Disbond between the coating and the substrate cannot be detected with magnetic methods
  - The method is not used for multiple coating layers

EWI THE MATERIALS JOINING EXPERTS

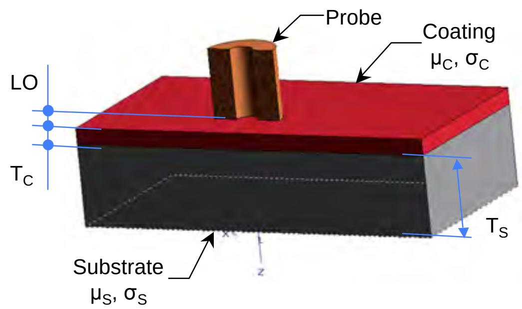
NDE of Coatings - Infrared Thermography

- General description and areas of application
  - Heat distribution in substrate-coating combination is studied under pulse or continuous heating
  - The method can potentially be used for evaluation of disbonds and coating degradation
- Limitations
  - Coating thickness may be difficult to assess
  - Thin metal coatings may be difficult to inspect

EWI THE MATERIALS JOINING EXPERTS

Eddy Current (EC) - Definitions

LO - lift off
T_C – coating thickness
T_S – substrate thickness
f – current frequency
μ_S, σ_S – magnetic permeability and electrical conductivity of substrate
μ_C, σ_C – magnetic permeability and electrical conductivity of coating



RULES OF THUMB

To detect any coating changes

$$\frac{3}{\sqrt{\pi f \mu_C \sigma_C}} > T_C \qquad \mu_C\sigma_C > 1.5\mu_S\sigma_S \qquad \mu_S\sigma_S > 1.5\mu_C\sigma_C$$

To eliminate substrate thickness changes on coating thickness measurements

$$\frac{3}{\sqrt{\pi f \mu_S \sigma_S}} < T_S$$

EWI THE MATERIALS JOINING EXPERTS

EC - Tasks

- Parameters to be measured
  - Coating (or substrate) thickness
  - Coating (or substrate) properties – e.g., degradation that affects μ_C and σ_C (μ_S and σ_S)
  - Coating (or substrate) cracks, corrosion, and other flaws
- Coating-substrate combinations regarding EC
  - Metal coating on non-conductive and non-ferromagnetic substrate – metallic film on glass, ceramics or plastics
  - Non-ferromagnetic and non-conductive coating on metal non- or ferromagnetic substrate – paint, cement, rubber, other insulation organic coatings

  NOTE: Major case for pipelines
  - Non-ferromagnetic and conductive coating on metal non- or ferromagnetic substrate – aluminum, copper, cadmium, or zinc on carbon steel, pure aluminum on aluminum alloy
  - Ferromagnetic and conductive coating on metal ferromagnetic substrate – cobalt or nickel on carbon steel

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EC - Typical Probes and Equipment

Impedance Plane
Screen Of Typical
ET Instrument

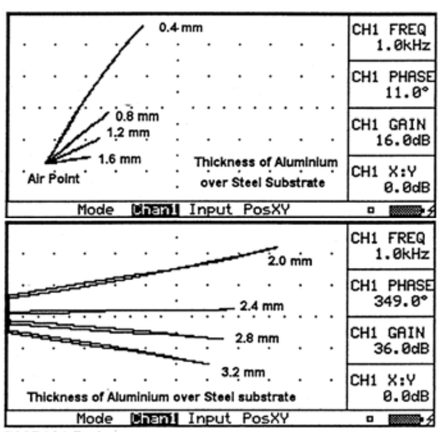
Spot
Probe

Pencil
Probe

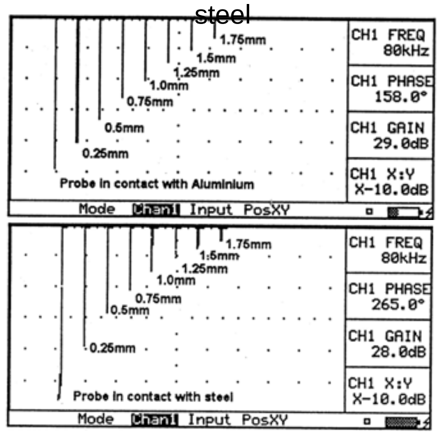
THE MATERIALS JOINING EXPERTS

EC - Examples of Current Procedures

Aluminum coating
over carbon steel



Paint coating over
aluminum and carbon
steel



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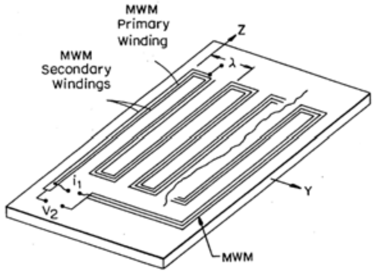
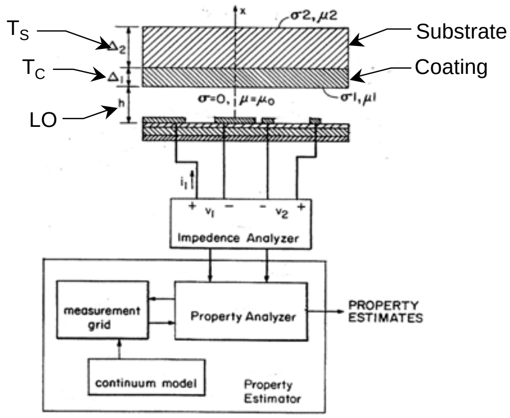
EC Magnetic Winding Magnetometer (MWM) - Principle



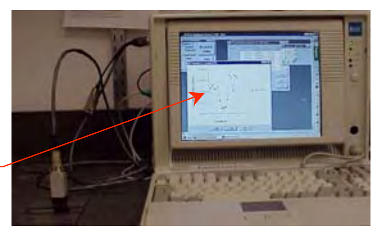


THE MATERIALS JOINING EXPERTS

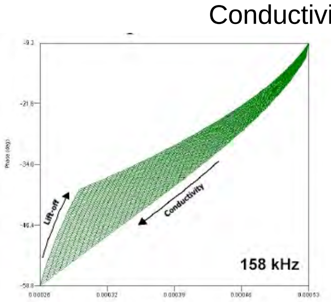
MWM - Typical Equipment and Grids

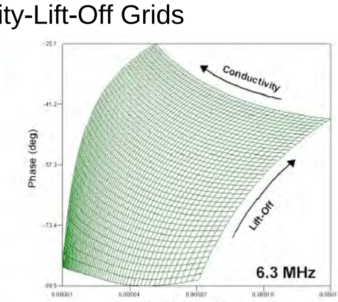
MWM Conformable Probe

MWM Instrument



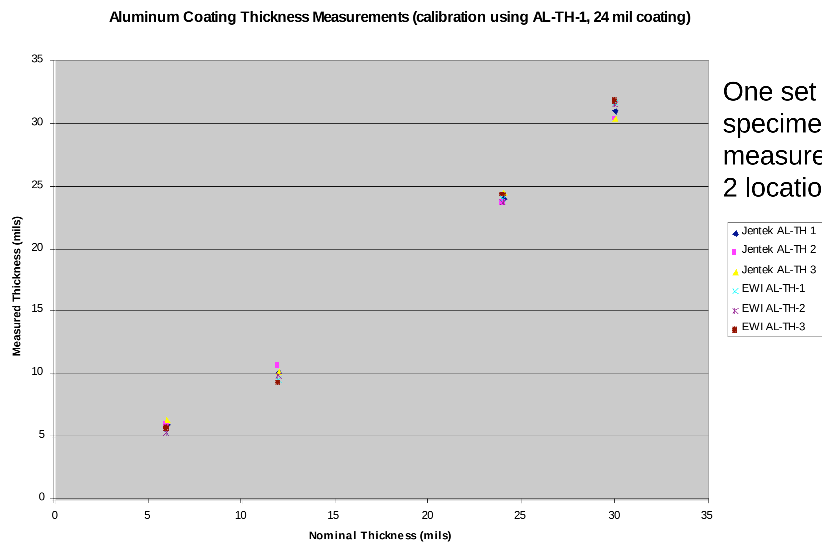
Conductivity-Lift-Off Grids





THE MATERIALS JOINING EXPERTS

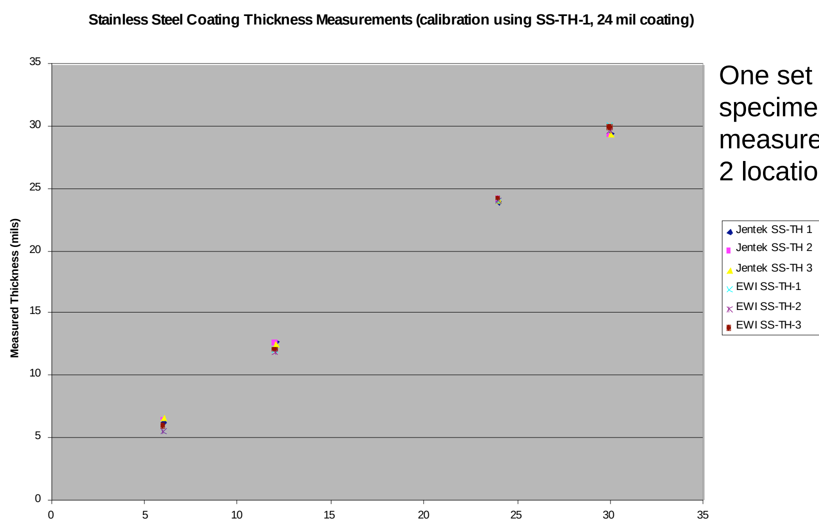
MWM - Aluminum over Carbon Steel



One set of 3 specimens measured at 2 locations

THE MATERIALS JOINING EXPERTS

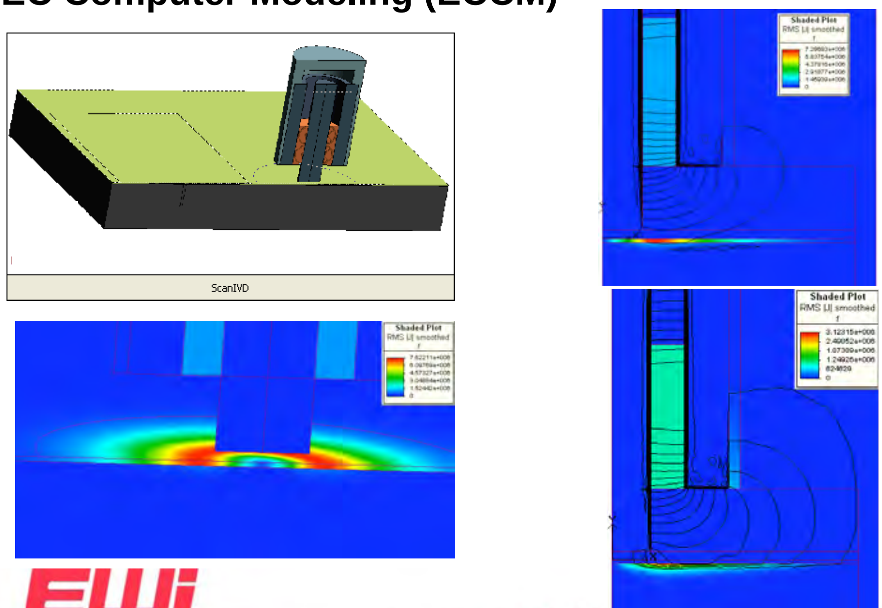
MWM - Stainless Steel over Carbon Steel



One set of 3 specimens measured at 2 locations

THE MATERIALS JOINING EXPERTS

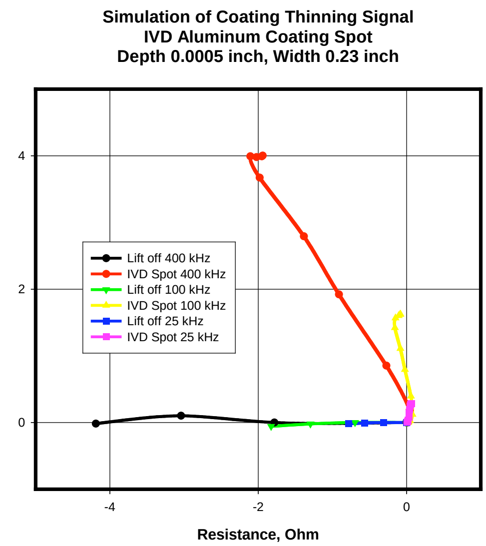
EC Computer Modeling (ECCM)



THE MATERIALS JOINING EXPERTS

ECCM - Coating Thinning at Different Frequencies

- Coating thickness and property (e.g., conductivity) variations can be assessed in advance

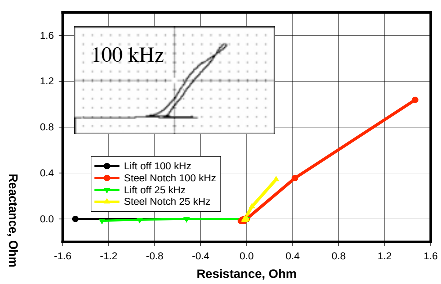


THE MATERIALS JOINING EXPERTS

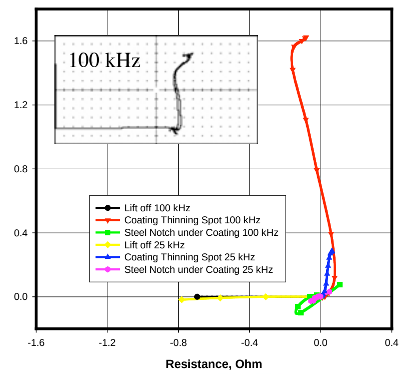
ECCM - Substrate Inspections

Large cracks in the substrate may be completely masked by coating thickness variations

Simulation of Steel Notch Signals without IVD Coating



Simulation of Coating Thinning Signals and Steel Notch under Coating Signals at Lower Frequencies



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Advantages and Disadvantages of EC

- Advantages
  - Does not require couplant
  - Very accurate for thin layers
  - Capable of examining multiple layers when aided with modeling and advanced technologies
  - Fast and easy to set up for field inspections
  - One instrument can perform thickness and flaw inspections on both coating and substrate
  - Change of coating properties (degradation, porosity, corrosion) that affect coating conductivity and/or magnetic permeability can be detected
- Disadvantages
  - Disbond between coating and substrate is difficult or impossible to detect
  - Depending on the application, one or several layers have to be conductive and/or ferromagnetic
  - Only thickness (to certain range) is measured if the coating is non-conductive and non-ferromagnetic (paint, organic insulation, others)

EWI THE MATERIALS JOINING EXPERTS

Conclusions and Recommendations

- New technologies and modeling approach allow development of new techniques for problems that have been outside of the scope of current procedures
- Computer modeling especially for complex cases brings the following benefits:
  - Significantly reduced time for development and validation of procedures used for inspection of complex geometry structures where NDT technique performance is unknown
  - Significant cost benefits due to elimination and reduction of experimental specimens and mock-ups needed for technique and procedure validation
  - Increased inspection reliability and repeatability
  - Fast interpretation of field NDE data and reduction of unnecessary repairs
  - Quick customer support turnaround
- Several NDE techniques may be required to fully characterize the coating-substrate structure on the pipelines

THE MATERIALS JOINING EXPERTS

Failure Modes of Pipeline Coatings

Matt Dabiri
Williams Gas Pipeline
Houston, TX

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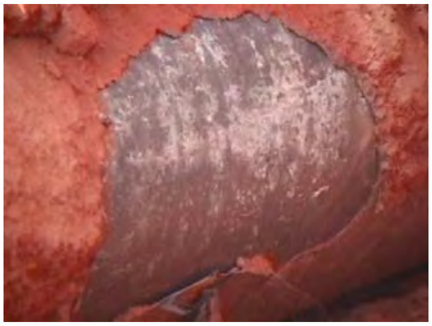
Today's Discussion

- Why Coatings Fail
- What is the Life of a Coating
- Failures
- Lessons Learned
- Wrap Up

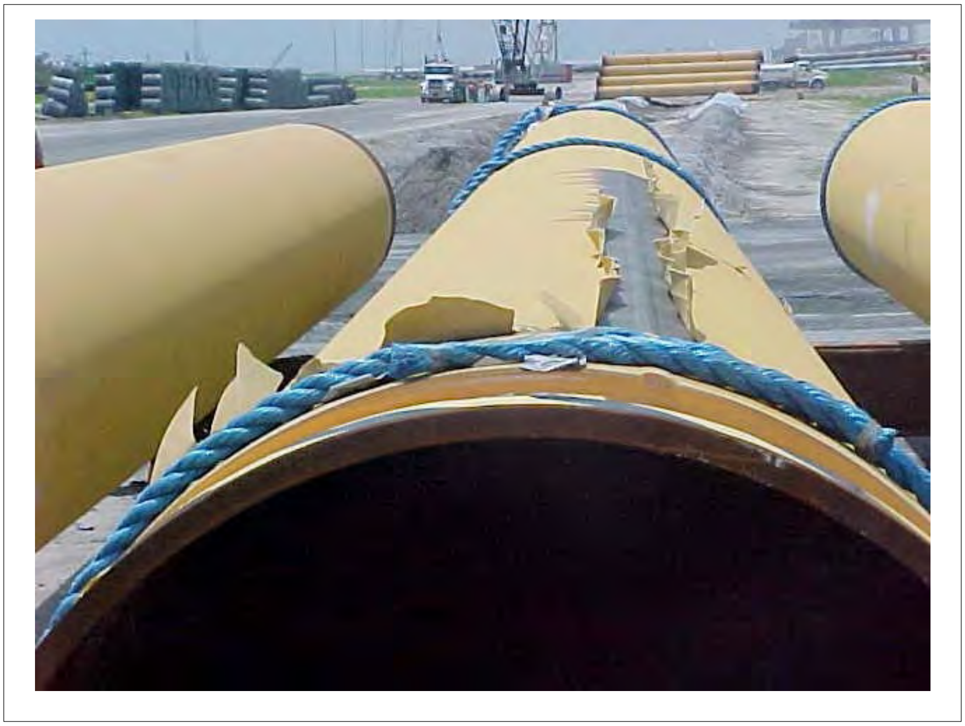
Why Coatings Fail

- Age
- Selection
- Application



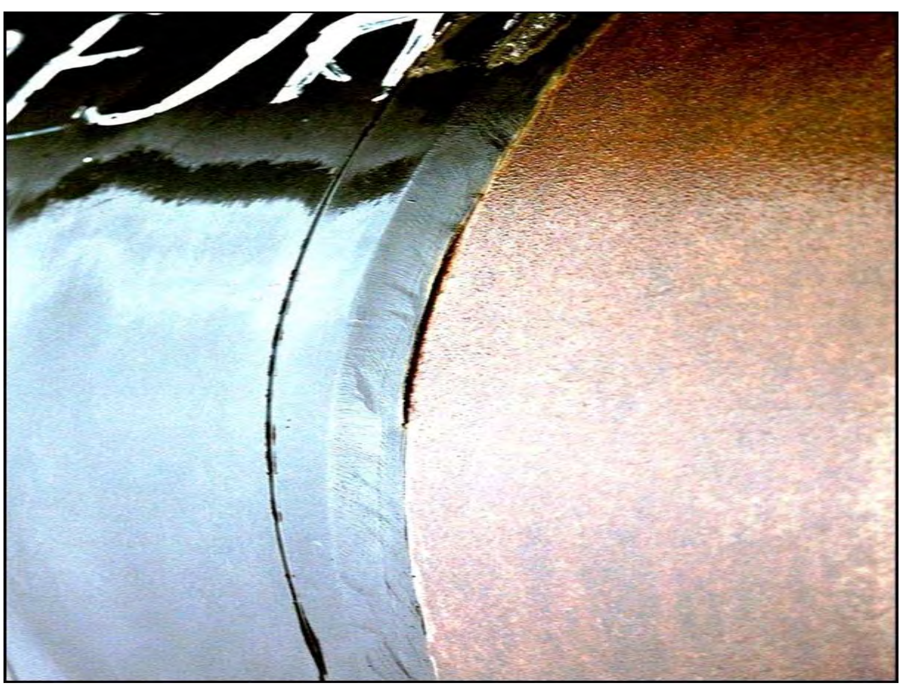
What is the Life of a Coating?

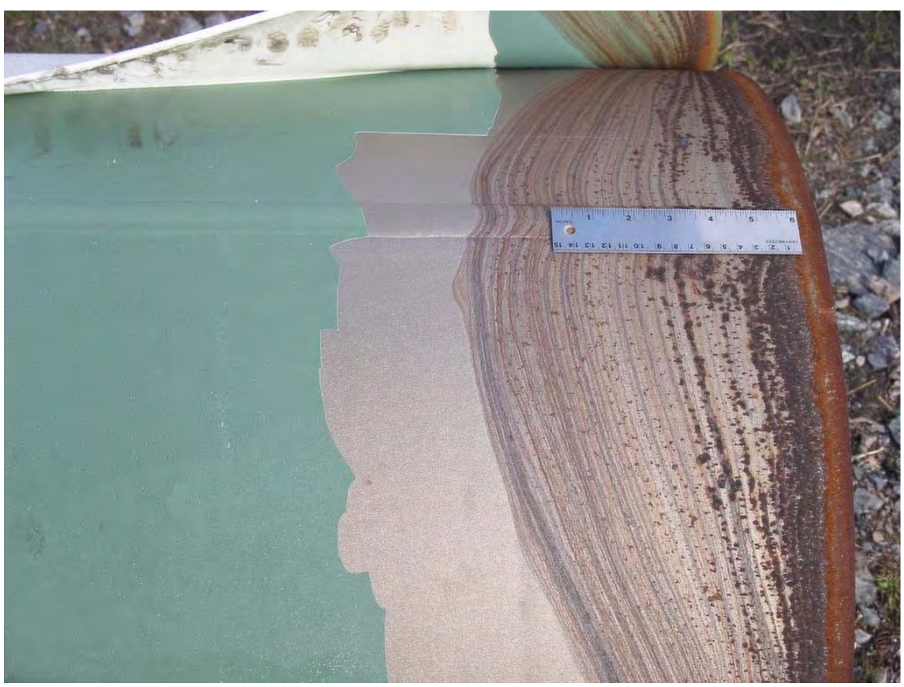
- Determined by design
- Determined by use
- Determined by selection
- Determined by application

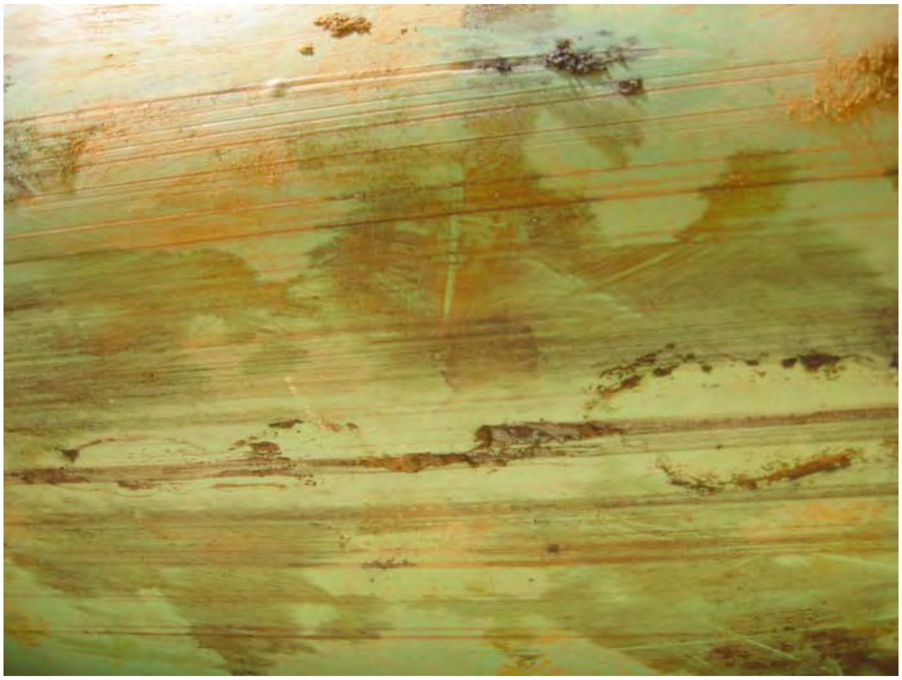


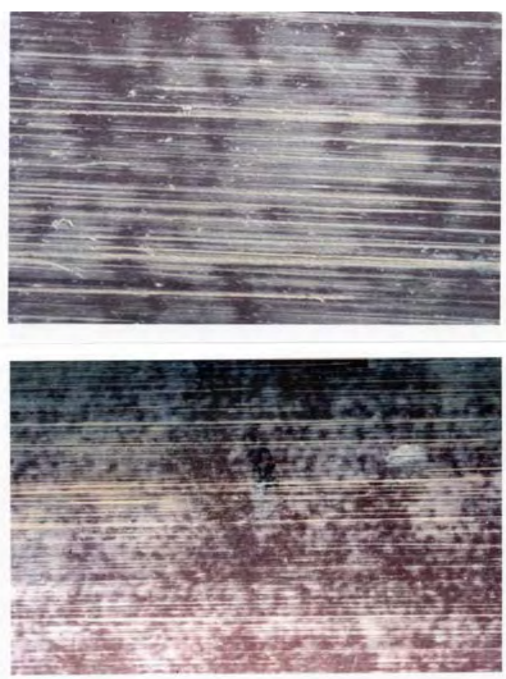

SfA-150

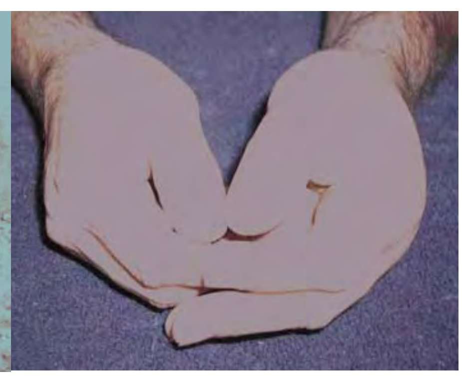

STA- 150









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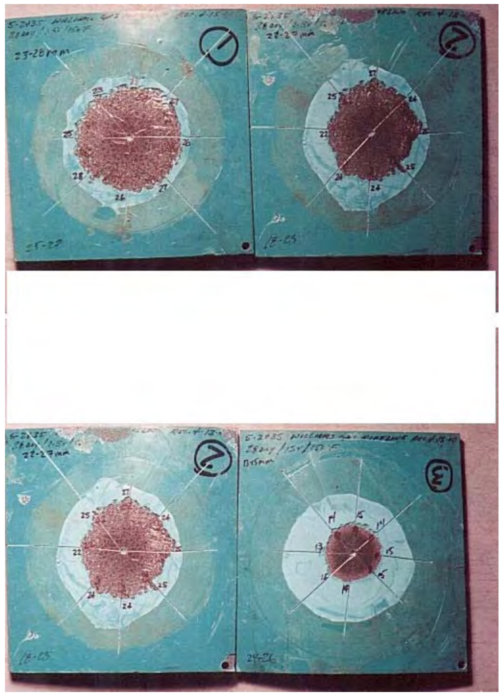

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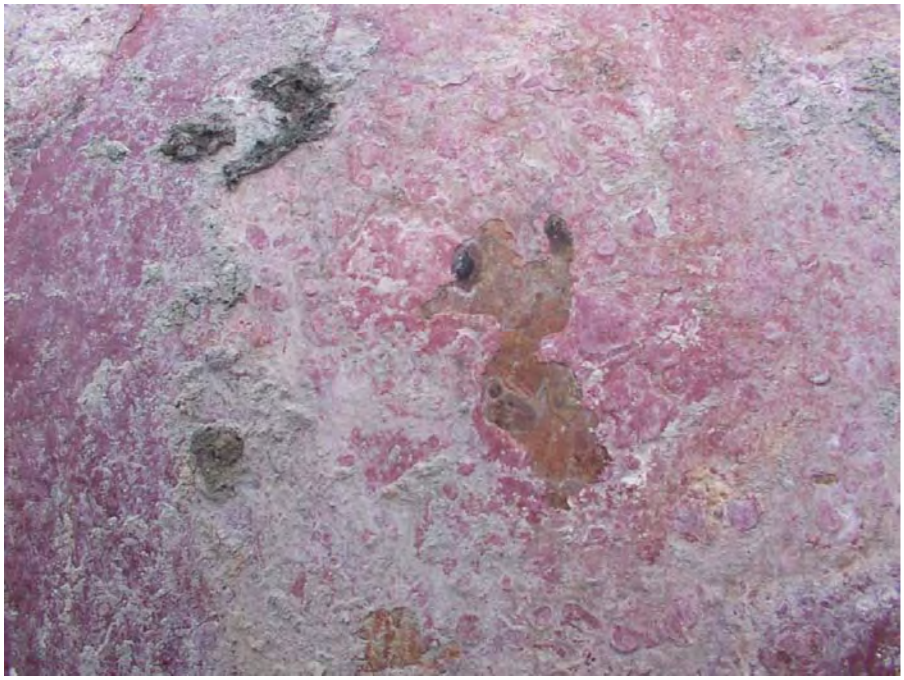

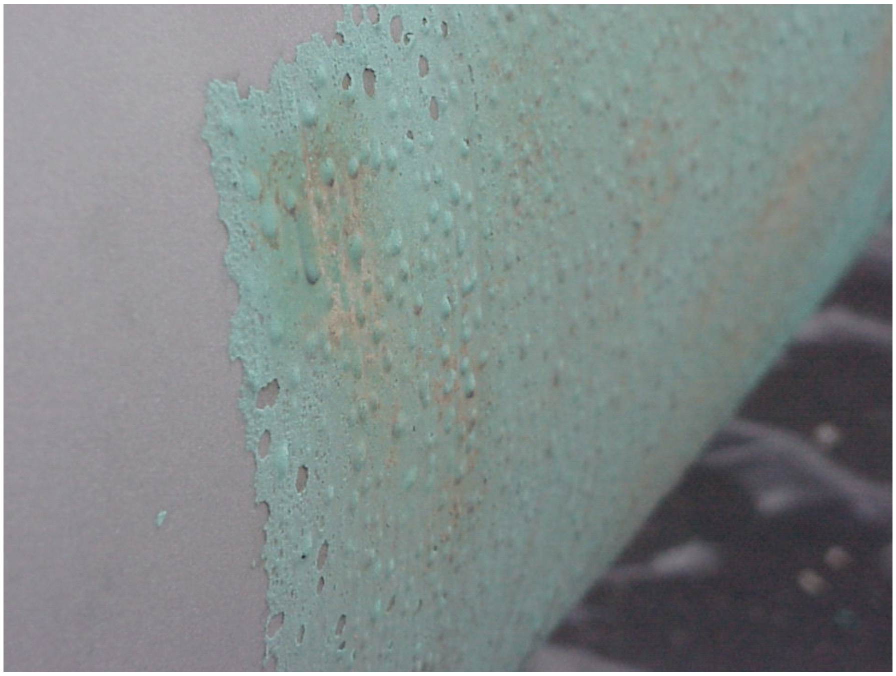

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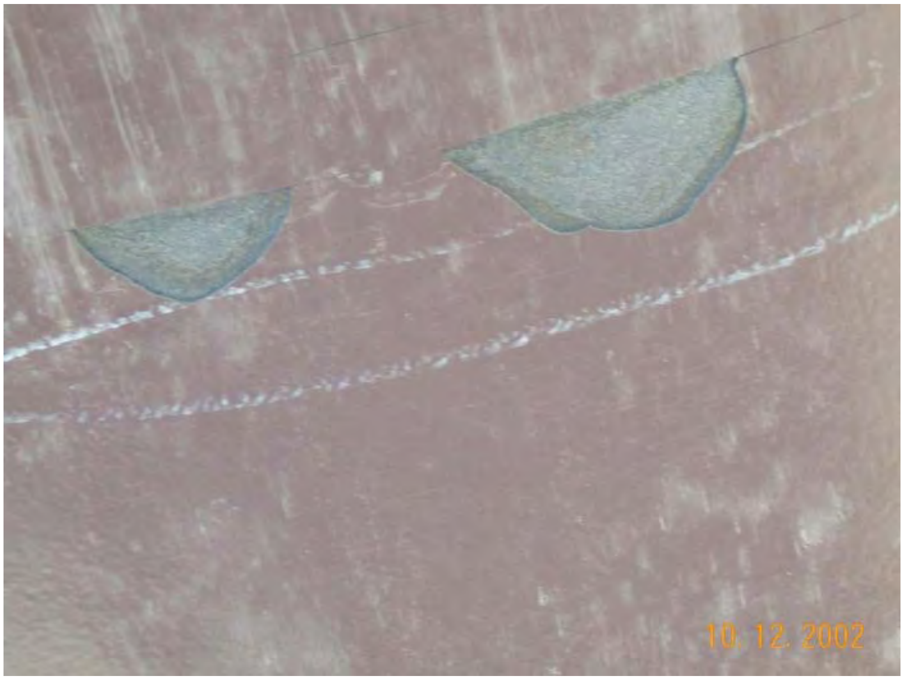
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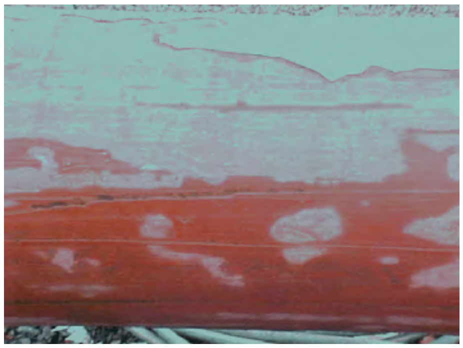

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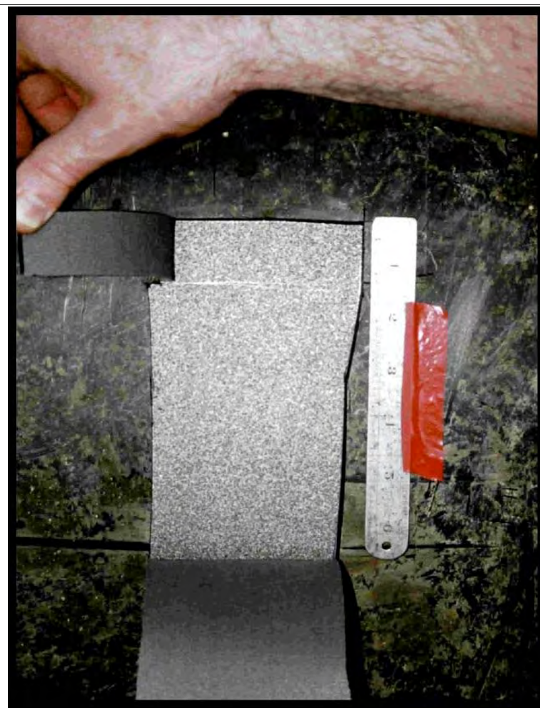

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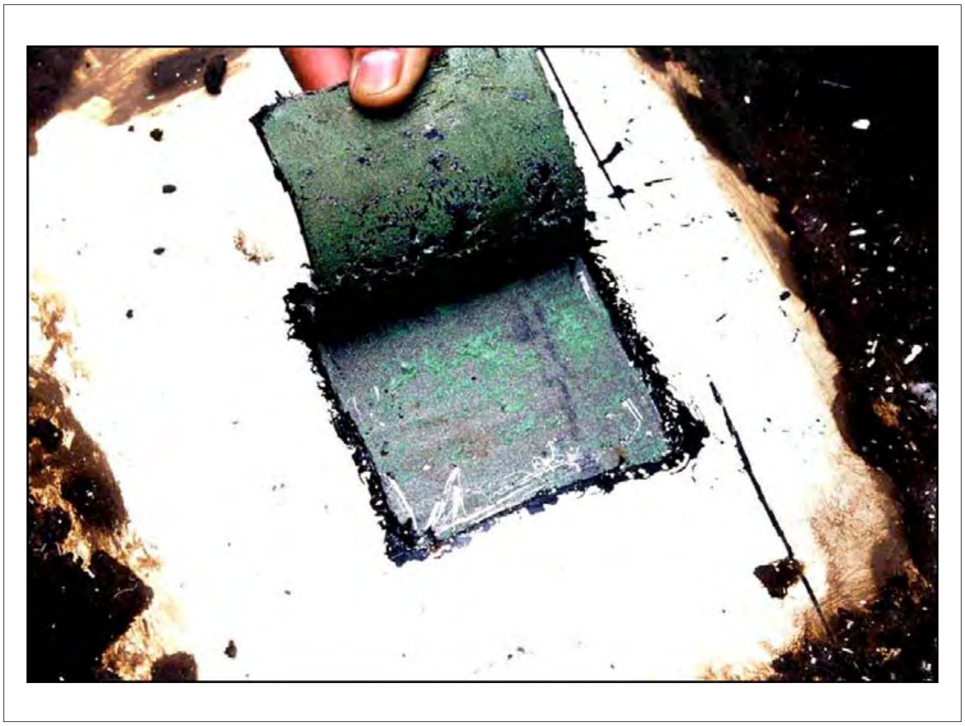



20" Spokane Line vault


Calcareous deposits on 10" Wenatchee Line
vault removal project PIN#48319

57

58

59


9. 23. 2002


9.23.2002

71

73

75


30 12 80

87

89


H


708


T2
18.5


T1 Dry
28

Lessons Learned

- Select Coatings by Service Conditions
- Do not select coatings by price
- Use a Quality Specification
- Use a Quality Applicator
- Use a Qualified Inspector

93

Three players

- Coating manufacturer
  "We have the very best materials – no second-best here!"
- Coating applicator
  "We're the best and the greatest coating applicators – no improper coating jobs!"
- Customer
  … is left holding the bag when the coating fails

95

96

Wrap Up

- Any more discussion?

98

Coating Test Methods and Materials Development

Group 1

Chairs

M. Dabiri (Williams)
B. Chang (Shell)

Rank	Nature (K,T,S)	Description	Priority	Comments / Benefits
1	k,T,s	Short term lab testing, to determine long term field performance *Identify and develop novel and/or standard techniques to evaluate coating performance and correlate to long term field performance*	8	Lab Performance
2	k	Develop modelling tool to predict long term field performance *Identify critical coating material properties and integrate into the modeling, validate with the data for prediction of coating life*	7	Modeling
3	s	Database of coating performance in the field *Collect and catelog the field coating performance data*	6	Field Performance
4	k	Smart coating, use sensor to detect early coating failure *Develop integrated sensor technology for real time monitoring of the coating condition*	5	Monitoring
5	k	Cathodic disbondment mechanism *Determine the fundamental mechanism for the cathodic disbondment*	4	Material Development N. Hamner, MP 9(1970) 31, AGA catalog # L00037, 1978
6	k,T	Effect of hydrocarbon, soil type on coating performance	3	Lab Performance

7	s	Forensic technology documentation	3	Field Performance
8	k	Coating on substandard surface preparation	3	Standard
9	k,s	2L FBE	3	Standard
10	k	Stress distribution on pipelines in circuferential and lateral directions	3	Modeling
11	k	Coupling agent btw steel and coatings	2	Material Development
12	k,t	Combination of various parameters(including thermal fatigue,) on coating performance	2	Lab Performance
13	T,k	Residual stress measurement of thick FBE and 3L polyolefin coatings	2	Lab Performance
14	s	Standard development for tapes and shrink sleeves	2	Standard
15	T	Remote monitoring coating failure	2	Monitoring
16	k	Polymer aging	1	Material Development
17	K	Nonmetallic pipes	1	Material Development
18	s	Soil Backfill resistance	1	Field Performance
19	T	ID inspection on external coating condition	1	Monitoring
20	k	Use EIS to detect disbonding	1	Monitoring
21	T	Real time coating quality assessment	0	Field Performance

Coating Application Technologies and Quality Control (Mill Applied)

Group 2

P. Singh (Bredero Shaw)
R. Lewoniuk (NOVA Chem.)

Rank	Nature	Description	Priority	Comments Benefits
1	KTS	There is a need to gather information on pipeline coating failures in order to determine failure mechanisms. A list of required information on each of the incident(s) will have to be developed. Create a database and make accessible to study.	1	Immediate Need
2	K	What is the effect of the coating application process on steel pipe properties? - Preheat temperature on strain hardening behaviour (important for strain based design) - Abrasive blast cleaning on SCC resistance - Other effects?	2	Immediate Need
3	KS	There is a need to define service conditions as well as other intermediate conditions that may impact the integrity of the coating, i.e. - Construction - Storage - Handling - Transportation - Plant Cutback - Develop plant cutback/end treatment to make plant coating systems compatible with field joint coating, and protection during storage	2	Immediate Need

4	K	There is not a good understanding of what application parameters affect the long term integrity performance of coatings - Lack of knowledge on what coating parameters affect the failure mechanism in the disbondment of 3LPP/PE. - There is no consensus on what is a good surface profile/preparation and how to measure this property - There is lack of understanding of the effect of extrusion of multi -layer coatings on residual stresses. - What affects disbondment of 3LPE/PP coating? How is this property measured on a pipeline coating?	2	2
5	S	There is a strong need for a universally accepted standard for pipeline coating. - This will result in everyone being on the same page with respect to design, manufacturing and testing parameters - Development of perf/prescriptive based standards - Performance based may be good for innovation - Difficulty in determining long term performance - End user may not be comfortable with this approach - Conservative nature of industry (proven methods) - How to measure long term perf with short term tests - Qualification of coating system - Verify critical parameters - Assessment of plant capability - Test equipment to measure parameters	2	3
6	KTS	Training of Personnel - Training on safety - Address experience and turnover of personnel - Cross -training between all aspects of the industry, including plant and field - Develop training programs specific to pipeline coating application - Provide equipment and tools for knowledge	3	2
7	KT	There are many different techniques and equipment for applying coatings. Some are proprietary. It is unclear what the consequences are. There is a need to understand the impact of these parameters on coating performance. - There are concerns on the process for applying high temperature FBE. There is a need to develop coatings with lower application temperature to prevent: Melting of multi -layer coatings, Strain aging of steel. - There is a need to research testing techniques to measure critical parameters on a continuous (online) basis: - Steel pipe temperature (especially important is the pipe temperature prior to coating application) . Steel surface profile . Steel surface contamination . Coating thickness (over body and weld)	4	4

COMMENTS

C1	Define critical parameters and limits, i.e. - Profile - Contamination - Application temperature - Powder moisture content - Residual stress (multi -layer) - Adhesion
C2	Once critical parameters and limits are defined, then determine QC program - Continuous, intermittent, audit, qualify? - End user will want to monitor - Problems with confidentiality - High risk product can lead to large potential loss - Both end user and coater need to be stakeholders (impact on schedule, construction costs)
C3	It is not clear whether research should be carried out on the entire application process or focus in on perceived key processes such as surface preparation and application temperature. A research strategy has to be formulated.

C4	Define Application, i.e. - Process - People - Equipment - Training - Quality Control - Materials - Handling & Storage - Environmental conditions - Specifications - Design - Manufacturing - Etc.

Coating Identification, Inspection, and Evaluation Technologies

Group 3
Robert (Bob) Smith (DOT)
Suresh Babu (EWI)
Participants (Government & Industry Researchers)

Three major topics are defined as following.

- Identification: Define the problem
  - Making sure that there is a coating problem as opposed to assuming that there is a coating performance problem.
- Inspection: Characterize the problem
  - Techniques to characterize the problem, where, when
- Evaluation: Evaluate the impact of the problem
  - Make sure that what we detect is a problem
  - Now what do we do about it?
  - Solution is not covered here – hand off to Group 4.

Identification: Priorities

- How big is the problem that coating failure leads to pipeline performance? (Knowledge)
  - Economics
  - Risk
  - Statistics
- Collection of lice-cycle data (Knowledge and Standards)
  - Material
  - Construction
  - Transportation
  - Operational
  - Environmental
- Techniques to identify of disbonded and shielding locations (Tools)
  - New and existing pipes

Inspection: Priorities

- Better techniques characterize flaws (Tools)
- Modeling the inspection techniques (Knowledge and Tools)
  - Optimization of inspection
- Training to prevent damage (Knowledge and Standards)
  - Matt's pictures on failures

Evaluation & Assessment Priorities

- Establish evaluation standard (Knowledge, Tools and Standards):
  - How to evaluate what is a good coating?
  - Validate the evaluation
  - Validate manufacturer claims
- Re-evaluate the minimum standards (Knowledge and Standards)
  - Is the current minimum standard good enough?
  - Documentation of the life-cycle data
- Welding and coatings communications (Knowledge, Standard)
  - Implication of interactions needs to be understood
- Develop Smart coatings (Tools)
  - May be the focus of group 1; but the coating should be designed so that it will aid in the identification, inspection and evaluation easily.

Summary

- How big is the problem?
  - We need to make a convincing case.
- We need to make sure that “best” coating goes into specific application which minimizes repair.
  - Pro-active design for specific environment

Identification: All issues

- Training – Standards
- Poor Records
  - Basic Parameters of Coatings
  - Basic Parameters of defects
- Reducing Digs or minimize dig size (size, key hole)
- Minimize damage during
- Disbond – defects and no defects
- Failure modes
- Modeling life cycle of coating integrity
- Improve the detection of disbond and shielding
  - Sometimes lack of cathodic protection may be the problem
- Information sharing
  - Data structure, fields of data
  - Standard

Inspection – All issues

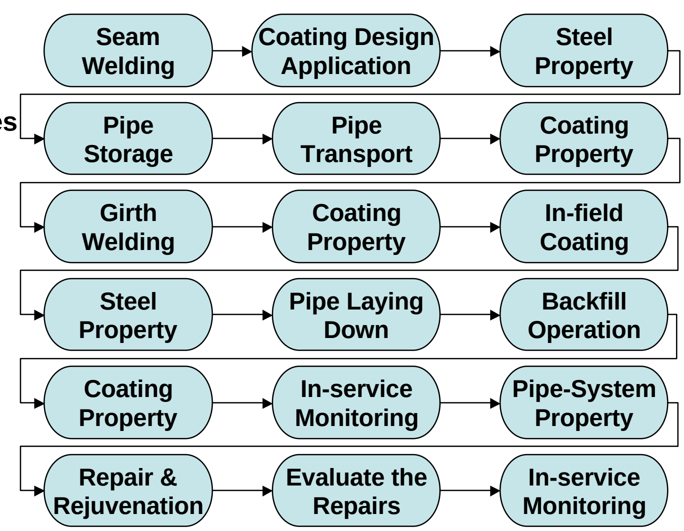
- Modeling
- Improve GUT / Emag
- Training
- Limiting Digs
- Preventing damage while inspection
- Data
  - Standardization, collection, sharing, flaw sizing and bond strength
- Develop / improve infield bond assessment and technology (real time)

Evaluation and Assessment: All issues

- How good is the standard?
  - Is it very discriminative or strict?
  - Are standards use in beginning, good enough – minimum standard?
- Data
  - Define/standards
- Risk
- Economic
- Validating manufacturing application claims
- Smart coatings

Identification, Inspection, Evaluation and Assessment must be integral part of life-cycle.

- **List of Issues were identified**
- **Nature of Issues were identified**
  - **Knowledge**
  - **Tools**
  - **Standards**
- **Urgency of issues were discussed**
- **Ranking was done in each category.**



In-Field Technologies for Joints, Repairs, and Rehabilitation

Group 4

Chairs
J. Didas (Colonial Pipeline)
P. Nidd (PGNGroup)

Approach involved open discussion & selection of possible projects followed by initial vote (Show Of Hands)

Second vote & Discussion of top 4 items

Rank	Nature (K,T,S)	Description	Priority (1)	Priority (2)	Comments / Benefits
1	K/T	Data base of coating technical data sheets, coating formulation history, testing results (based on accepted standard) & MSDS sheets. Technical data sheets – standard formats. Updating technical data sheets for reformulated coatings for all customers. Automatic updates – time limit for coating validity. Materials storage standards. Expiration dates for coating materials. Minimum third party evaluation of new or reformulated coatings.	9	10	Knowledge sharing/ Development of up to date standards
2	S	Applicator & Inspector certification / Training Outcome – develop standards for applicators & inspectors.	9	9	Provide standardized application & QC
3	K/S	Repair coating matrix – based on pipe diameter & temperature & soil stress. Coating Selection & Risk Assessment Profile & Results of Improper Selection	8	8	Provide coating selection tool for operators
4	R&D	Perform performance testing & environmental assessment of abrasive blasting materials.		4	Separated out/ no initial vote
5	NACE	Pipeline Coatings Industry Users Group			Agreed to let NACE TEG to initiate
6	R&D	NDE & guided wave through coating corrosion evaluation- How accurate - assess existing techniques – develop new techniques.	6	4	Provide operator knowledge regarding defect detection techniques.
7	R&D	Non intrusive disbondment testing – adhesion testing, wet film & dry film, hardness & % cure new & existing coatings.	4		No damage to coating during testing.
8	R&D	Repair Sleeves – Composite & Steel - Field Applied Repairs. Required to coat. Coating of transition bridge. Compatibility issues. Setup and curing issues.	3		Provide operator knowledge re sleeve reapairs
9	R&D	Research more effective coating removal methods. Technology transfer from DOE or NSF.	4		Cost savings for operators/ efficiencies
10	R&D	Wet surface coatings operated at high temperatures – R&D for new materials.	1		Problem solution
11	R&D	Repair coatings used in high or low pH environments. Mine run off – flue ash.	2		Problem solution

12	R&D	Alternative methods of concrete removal for marsh areas	1		Problem solution
13	R&D	Backfill – pipe support after backfill – piers – breakers – sand bags – research technologies.	1		Problem solution
14	R&D	Time dependent coating compatability testing & minimum level requirements.	1		Increased information regarding coating durability.

Notes:

1 Number of votes: Approach involved open discussion & selection of possible projects followed by initial vote (Show Of Hands)

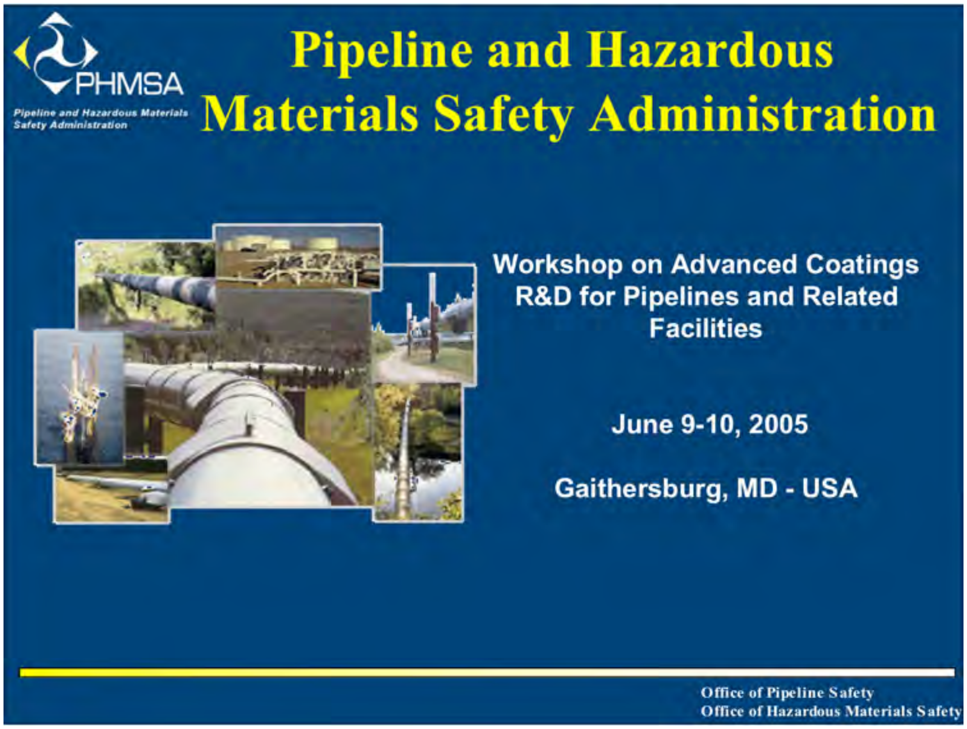
2 Number of votes: Second vote & Discussion of top 4 items

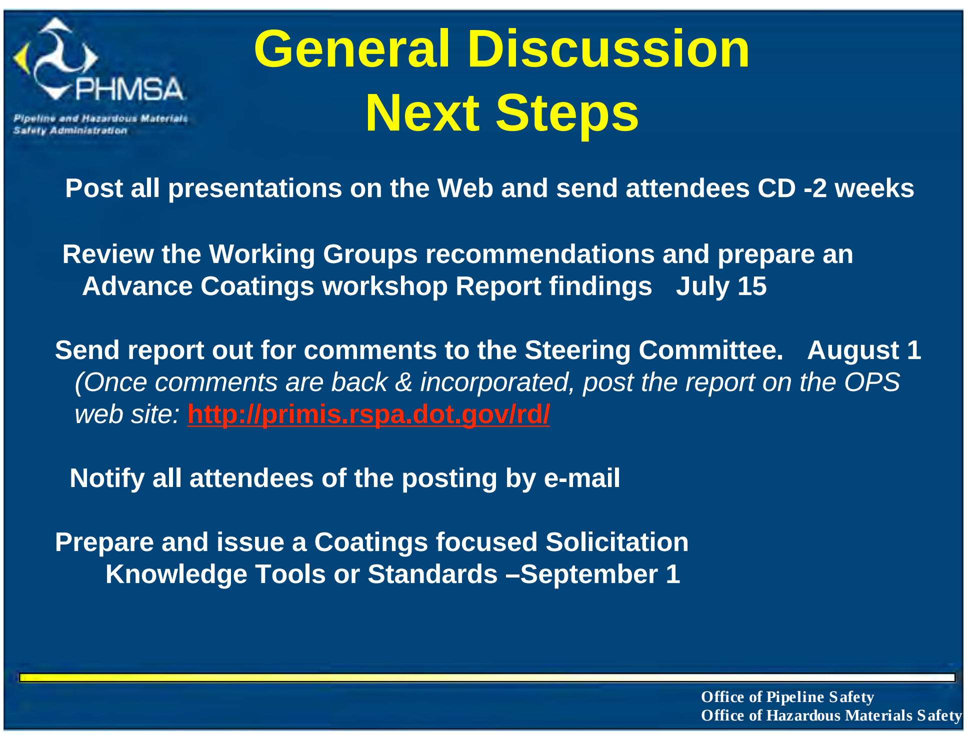
Natue

K= Knowledge, Scientific Understanding

T= Technology or tool development

S= Standardization of tools or procedures


PHMSA
Pipeline and Hazardous Materials Safety Administration
Pipeline and Hazardous
Materials Safety Administration
Workshop on Advanced Coatings
R&D for Pipelines and Related
Facilities
June 9-10, 2005
Gaithersburg, MD - USA
Office of Pipeline Safety
Office of Hazardous Materials Safety


PHMSA
Pipeline and Hazardous Materials Safety Administration
General Discussion
Next Steps
Post all presentations on the Web and send attendees CD -2 weeks
Review the Working Groups recommendations and prepare an
Advance Coatings workshop Report findings July 15
Send report out for comments to the Steering Committee. August 1
(Once comments are back & incorporated, post the report on the OPS
web site: http://primis.rspa.dot.gov/rd/
Notify all attendees of the posting by e-mail
Prepare and issue a Coatings focused Solicitation
Knowledge Tools or Standards –September 1
Office of Pipeline Safety
Office of Hazardous Materials Safety

OPS R&D Program Contacts

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Office of Pipeline Safety
Office of Hazardous Materials Safety


PHMSA
Pipeline and Hazardous Materials Safety Administration
Thank You
for Attending
Office of Pipeline Safety
Office of Hazardous Materials Safety

Appendix A - Meeting Agenda

Advanced Coatings for Pipelines and Related Facilites Workshop
National Institute of Standards and Technology
Gaithersburg, MD 20899 USA

Thursday June 9, 2005

7:30 **Bus from Hotel to NIST**
7:45 **On-site registration** - Lecture Room A
8:00 **Welcome** - Richard Ricker, NIST
8:05 **Workshop Objectives** - Jim Merritt/Bob Smith, OPS
8:15 **Report on Findings of MMS Offshore Coatings Workshop**
D. Olson and B. Mishra, Colorado School of Mines
8:45 **Review of Existing Pipeline Coatings Standards**
Sankara Papavinasam and R. Winston Revie, CANMET, Natural Resources, Canada
9:15 **Update on Current Standards Activities**
ASTM - R. Ricker for Don Kathrein, Tapecoat and Chair ASTM D01.48
NACE - Cliff Johnson, NACE
CSA - Franci Jeglic, National Energy Board, Canada
9:45 **Break**
10:00 **Keynote Overviews**
1. Owner/Operator Viewpoint on Coatings Issues
- Jeff Didas, Colonial Pipeline
2. PRCI Activities and Coatings Deterioration Studies
- Greg Ruschau, CC Technologies
- Jenny Been, NOVA Chemicals Corporation
3. GTI Activities and Preliminary Results from Coatings Test Program
- Paul Beckendorf, GTI
11:30 **Lunch** - NIST cafeteria (at attendees expense)
12:30 **Keynotes (cont.)**
4. Coatings Fabrication Issues (Field and Factory)
- Peter Singh, Bredero Shaw
5. NDE and Eddy Current Methods for Pipeline Coating Inspection
- S. Babu and E. Todorov, Edison Welding Institute
6. Coatings Failure Modes
- M. Dabiri, Williams Pipeline
2:00 **Break**

2:30 **Working Groups Convene**

1) Coating Test Methods and Materials Development
   - Admin Bldg (#101) Lecture Room A
2) Coating Application Technologies and Quality Control (Mill Applied)
   - Materials Bldg (#223), Rm. A250
3) Coating Identification, Inspection, and Evaluation Technologies
   - Materials Bldg (#223), Rm. B307
4) In-Field Technologies for Joints, Repairs, and Rehabilitation
   - Materials Bldg (#223), Rm. B307

5:00 **Adjourn for the Day**

5:10 **Bus from NIST to Hotel**

Reception and Cook/Out at the Home of R. E. Ricker 12809 Talley Lane

<u>Friday June 10, 2005</u>

7:30 Bus from Hotel to NIST

8:00 **Working Groups Reconvene** - Various Meeting Rooms (TBD)

10:00 **Break**

10:15 **Working Group Reports** (20 minutes each)

1) Coating Test Methods and Materials Development
   - Admin Bldg (#101) Lecture Room A
2) Coating Application Technologies and Quality Control (Mill Applied)
   - Materials Bldg (#223), Rm. A250
3) Coating Identification, Inspection, and Evaluation Technologies
   - Admin Bldg (#101) Lecture Room D
4) In-Field Technologies for Joints, Repairs, and Rehabilitation
   - Admin Bldg (#101) Lecture Room E

11:35 **General Discussion / Next Steps** - Jim Merritt/Bob Smith, OPS

12:00 **Adjourn Workshop / Lunch** - NIST cafeteria (at own expense)

1:00 **Tours of NIST Laboratories – Admin Lecture Rm A**

- 1:15 Residual Stress Measurements in Pipeline Steels
  - M. Law , T. Gnaeupel-Herold, and H. Prask (NCNR)
- 2:00 High Speed Deformation Lab (Kolsky Bar)
  - S. Mates and S. Ridder (Metallurgy Div.)
- 2:45 Coatings Adhesion and Appearance Labs
  - T. Nguyen (BFRL, Building Materials Div.)
- 3:30 Corrosion, SCC, and CF Labs
  - R. E. Ricker and D. Pitchure (Metallurgy Div.)

4:00 **Conclude**

Appendix B - Registration List

Advanced Coatings for Pipelines and Related Facilites Workshop
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Gaithersburg, MD 20899 USA
June 9-10, 2005

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