2005

Advanced Coatings R&D for Pipelines and Related Facilities

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

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

With support from:
American Gas Association
ASTM International
CANMET, Minerals and Metals Sector, Natural Resources Canada
Gas Technology Institute
Minerals Management Service, U.S. Department of the Interior
NACE International
National Energy Board, Canada
National Institute of Standards and Technology
Pipeline Research Council International

September 7, 2005

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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.

The following pages are the presentations slides given at the workshop. These presentations can be found on the main webpage for the Advanced Coatings Workshop and follow the agenda for the event.