White Paper

Identification of Pipe with Low and Variable Mechanical Properties in High Strength, Low Alloy Steels

Energy Pipeline Industry
Pipe Quality Action Plan
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This work was initiated and sponsored by the INGAA Foundation with participation from the energy pipeline industry. This white paper is the work of Group 1 of eight separate work groups organized to determine the nature, extent and response to the phenomenon of low strength or excessively expanded pipe found in recent projects and the subject of PHMSA Advisory Bulletin ADB-09-01.

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BACKGROUND

During 2007 and 2008 there was a significant increase in new pipeline construction in the United States. This construction boom put almost unprecedented demands on both pipe and other material manufacturers and pipeline constructors. To meet the demands for high yield line pipe, both traditional and newer pipe mills, utilizing plate and coil from both established and non-traditional steel suppliers, were used. During post-commissioning test (field hydrostatic test) inspection of some of these lines, a small number of pipe joints were detected that had expanded well beyond the dimensional tolerance limits of the pipe manufacturing specification, API Specification 5L. In most cases, the point at which this expansion occurred has not been definitively determined. As the investigation of this phenomenon progressed, it became apparent that it was not limited to one pipe mill, one steel supplier, or one manufacturing process. Through experience of a limited number of operators, it appeared that this issue was a rarity, affecting an extremely small percentage of pipe joints produced. However because the phenomenon could not be isolated or traced to a single source, PHMSA issued Advisory Bulletin ADB-09-01, Docket PHMSA-2009-0148, dated May 21, 2009 and titled "Potential Low and Variable Yield and Tensile Strength and Chemical Composition Properties in High Strength Line Pipe" to advise the industry of this issue. The Advisory Bulletin is summarized below.

> *"Summary: PHMSA is issuing an advisory bulletin to owners and operators of natural gas pipeline and hazardous liquid pipeline systems. This bulletin advises pipeline system owner and operators of the potential for high grade line pipe installed on projects to exhibit inconsistent chemical and mechanical properties. Yield and tensile strength properties that do not meet the line pipe specification minimums had been reported. This advisory bulletin pertains to microalloyed high strength line pipe grades, generally Grade X-70 and above. PHMSA recently reviewed metallurgical testing results from several recent projects indicating pipe joints produced from plate or coil from the same heat may exhibit variable chemical and mechanical properties by as much as 15% lower than the strength values specified by the pipe manufacturer."*

The advisory states the following points:

- PHMSA wants to ensure that owners and operators of recently constructed pipeline systems are aware of the need to investigate whether their pipelines contain joints of pipe that do not meet minimum specification requirements.
- Pipeline owners and operators should review all manufacturing procedure specifications (MPS), mill test reports and other appropriate documentation with their pipe suppliers to determine if specification requirements have been met.
- Pipeline owners and operators are advised to review their pipe specification, pipe steel making and rolling MPS, pipe mill test reports, deformation tool results and all hydrostatic test failure results to ensure that inconsistent mechanical and chemical properties are not inherent in microalloyed line pipe grades on all API 5L – PSL 2, X70 and X80 line pipe installed during recent construction projects.
- Pipeline owners and operators should conduct technical document reviews on this pipe installed during this period and consider using methods to detect pipe expansion such as

running deformation tools that detect expanded pipe in these systems if they have any knowledge, finding or pipe history that lead them to believe their newly constructed high grade line pipe systems contain line pipe joints that do not meet specification requirements.
- Should a pipeline owner or operator have knowledge of other high grade pipe vintages supplied at earlier dates they should consider reviews as outlined above.

The INGAA Foundation sponsored a workshop on June 11, 2009 to review and discuss issues surrounding pipe quality and specifically the implications of line pipe with low mechanical properties. The energy pipeline industry, through INGAA and the INGAA Foundation, developed a Pipe Quality Action Plan. The hazardous liquid pipeline operators were represented by operators who are members of AOPL and API. This plan involves eight separate work groups with each pursing the issues identified through the advisory bulletin and industry experiences.

Work Group 1 was charged with the development of a plan to address how to implement the specifics of the advisory bulletin and, more broadly, how to identify and/or avoid pipe with low mechanical properties. As this task progressed, the work group met and discussed the plan with PHMSA to ensure that all aspects of the advisory were addressed. The results of those efforts are presented in this White Paper.

In this paper, there are some end states that do not require high-resolution in-line dimensional inspection of a pipeline. This is not to be interpreted as conflicting with or superseding any regulatory requirements to conduct various types of in-line inspection, including dimensional inspection. Those requirements address multiple issues and must still be met. For the purposes of this paper, such an end state merely means that the inspection need not be conducted as part of an investigation for low strength or expanded pipe.

REVIEW OF THE RECENT HISTORY OF FAILURES OF PIPE WITH STRENGTH LESS THAN SPECIFIED

A review of pipeline reportable incident data on the PHMSA web site for the years 2002 through 2008 showed only eight incidents involving Grade X70 pipe and no incidents on pipe with a SMYS greater than X70. Three involved a failure of the butt weld, two involved excavation damage, one involved corrosion, one involved a gouge on the body of the pipe and one involved a seam failure. Of the eight incidents, none appear to involve a failure due to low strength or expanded pipe.

Discussions with pipeline operators revealed no in-service failures are known to have existed due to low strength or expanded pipe.

ANALYSIS OF EXISTING PIPELINES

The Work Group believes there is a series of questions and actions that are relevant to the identification of a potential low strength condition. These questions and actions have been organized into a flow chart, shown in Figures 1 and 2, that provides guidance to an operator to determine if the operator has a potential issue with pipe quality and if so, what actions should be taken to address those issues. Figure 1 addresses pre-pipe production activities, while Figure 2 addresses pipe production and construction and post-construction activities.

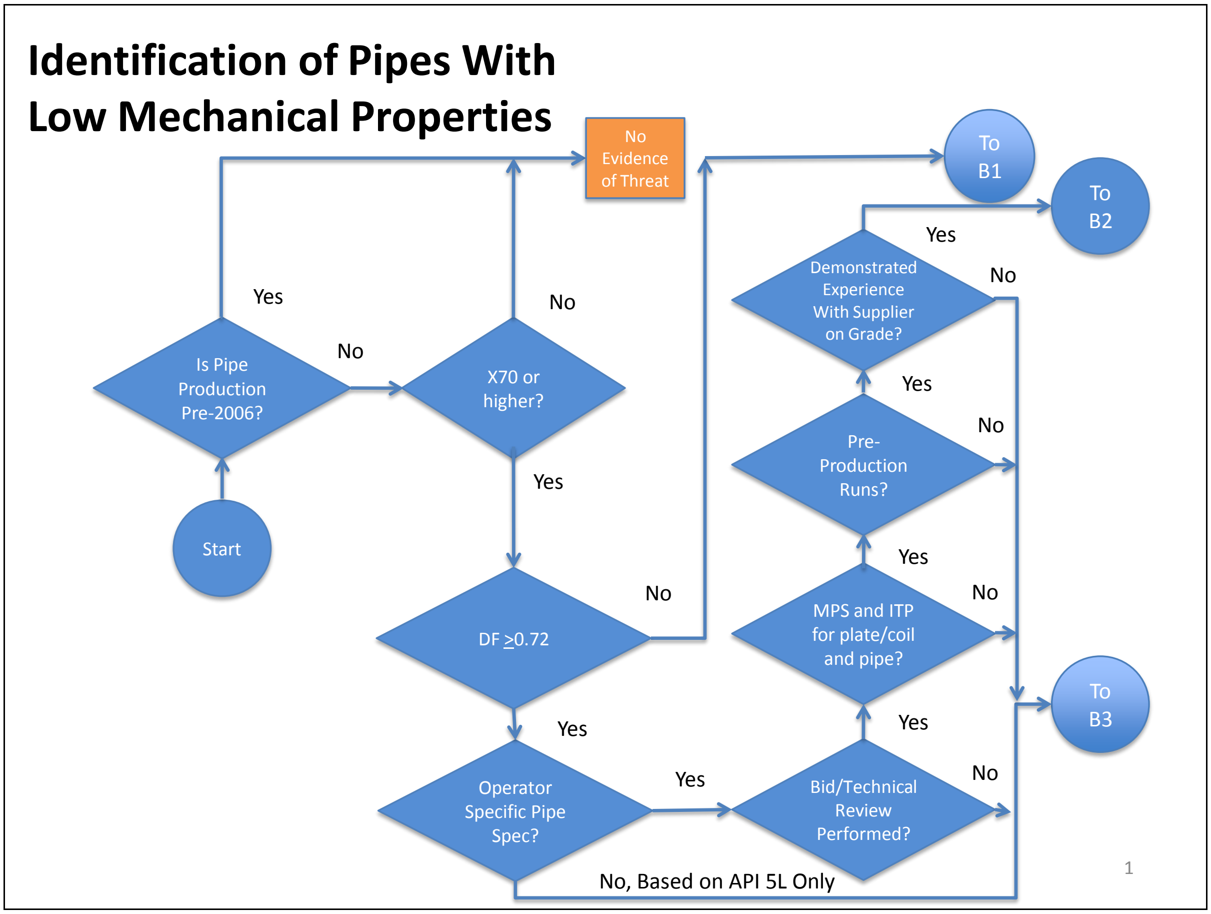

Figure 1

Explanation for the Flow Chart Elements

An explanation of the decision points in the flow chart is discussed in the text that follows:

Figure 1 Elements

Is pipe production pre-2006?
The year 2006 was chosen in part to address the PHMSA concern for "recently constructed pipelines" and in part based on industry experience with the pipe mills and steel providers that were traditionally suppliers of pipe. In 2006 there was a considerable increase in pipeline projects, not only in the US but worldwide, as oil and gas prices rose sharply. This trend was quite apparent in the number of applications for certificates for new construction of natural gas transmission pipeline projects. Beginning in 2006, energy pipeline companies purchased pipe from pipe mills that were not traditionally used because of the increase in numbers of new projects. In addition, new pipe mills came onto the market and new suppliers of the steel plate and coil not traditionally used by the pipe mills also came onto the market.

Is pipe Grade X-70 or higher?
The X-70 grade was chosen based on industry experience and the PHMSA concerns for pipe of grade X-70 and higher. Issues with expanded pipe have not been observed in grades below X-70. Also, the properties of pipe of grades below X-70 are much less dependent on thermo-mechanical treatment (controlled rolling) and more dependent on just chemistry. Thus the probability of this phenomenon affecting the lower grades is believed to be virtually negligible.

Is the project DF greater than or equal to 0.72?
The design factor was chosen based on industry experience. Companies constructing and operating pipelines with a maximum project design factor of less than 0.72 have generally not observed expanded pipe. This may be due in large part to a lower mill pressure test, typically at 90% of SMYS, and a post construction pressure test of 1.25 times MAOP or 90% of SMYS. Nonetheless, even for lower design factor pipe, any history or observations of low mechanical properties or excessive expansion will then require further examinations, inspections and evaluations.

Is there a rigorous operator specific pipe specification?
The degree of specificity and rigor in operating companies' pipe specifications beyond the requirements of API Spec 5L are variable. Where the pipe specification has a great degree of specificity in steel source and pipe mill requirements and where rigor is maintained during the manufacturing process, thereby providing a high degree of consistency and a high confidence level that all important manufacturing variables have been maintained in the proper ranges, the potential for issues of pipe not meeting specification is significantly reduced.

Is a bid review and technical review of the mill performed?
The pipe mill response to a bid request includes those provisions that are proposed as an alternative to the pipe specification. A detailed review and acceptance process is required to confirm that the company and the manufacturers agree on the product to be produced. Additionally, a technical review of the steel and pipe mills and the pipe making process may have been conducted prior to pipe purchase so that the company is satisfied that the mills can produce the pipe per specification. This review includes looking at the quality management system and documentation requirements.

Are there an MPS and ITP produced governing the rolling and pipe production?

Many companies and mills develop detailed Manufacturing Procedure Specifications (MPS) and Inspection and Test Plans (ITP). The development of these documents shows a rigor in the quality control program and provides clarity and certainty on every aspect of the pipe production, including steel production. They are used in conjunction to detail the procedures to be followed, set the acceptance criteria, and specify all the inspections and tests to be performed. While it is possible to produce the same pipe without such MPS and ITP, it is difficult to provide the same level of assurance of management and maintenance of quality.

Are there pre-production meetings and pre-production runs?

Pre-production meetings are conducted to review and finalize the MPS and ITP and to ensure that all aspects of the pipe production have been covered and that expectations are fully understood and will be managed. Pre-production runs are typically a day of pipe production and will demonstrate the ability of the pipe manufacturer to meet the requirements of the MPS and the ITP. Previous experience with or demonstrated performance of a mill and supplier combination can also satisfy the same concerns a pre-production run addresses.

Is there demonstrated experience with supplier on the grade of pipe?

The proficiency of the steel suppliers and pipe mills, as demonstrated by records including histograms and mill historical data, will confirm the ability of the mill to produce quality pipe that meets specification. Certain mills, in conjunction with their historical steel suppliers, whether integrated or not, have shown proficiency over the years in producing quality pipe that meets specifications. In addition, a review of the pipe data, including the preparation of histograms, shows the quality of the pipe produced.

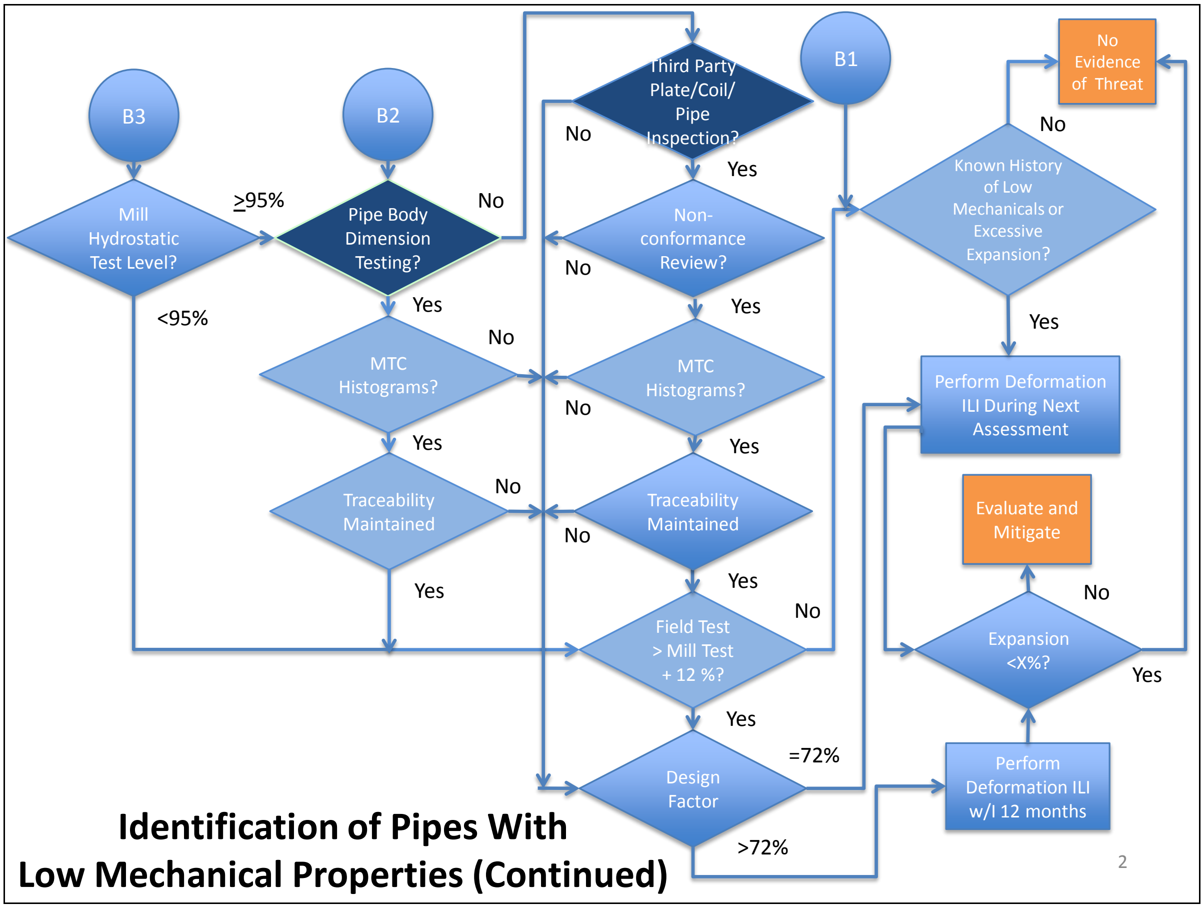

Figure 2

Figure 2 Elements

<u>Is the mill hydrostatic test level below 95% of SMYS?</u>
It is possible for pipe to be expanded beyond allowable limits during the mill pressure test. This is especially true if the test is conducted at a pressure (gauge) producing greater than or equal to 95% of SMYS. When end loading (sealing pressures) are considered, this pressure is likely to produce an effective stress in the pipe wall of approximately 100% of SMYS. Pipes tested at less than 95% are less likely to have expanded during the mill pressure test.

<u>Is pipe body dimension testing/measurement performed?</u>
If the mill hydrostatic pressure test produced a stress of 95% or more of SMYS and diameter dimensions were taken at intervals along the length of each joint, in addition to the required end dimension measurements, it can be confirmed that expansion of the pipe beyond the set tolerances in the pipe specification did not occur. If unacceptable expansion has occurred, those pipe joints can be identified and eliminated at this point.

Does the company receive material test reports and material histograms?

The Material Testing Reports (MTR) (or Mill Test Certificates – MTC) document the various tests performed on the steel and the pipe and show whether the pipe met the specification. Histograms are developed to graphically present required property values relative to the material specifications. This form of presentation of data is especially useful in identifying trends, performing statistical analyses, and finding any outliers. If this information was produced, it provides quality assurance results that confirm the pipe has met specification.

Is material traceability maintained through the steel production and pipe manufacturing?

Material traceability is an important quality assurance step and provides assurances that the pipe specified is what was delivered. The material is formally tracked from the steel making process, through the pipe manufacturing process, including coating, loading and shipment, with appropriate records of test provided as part of the MTR. This is essentially the genealogy of each joint of pipe produced.

Is there third party inspection at the plate/coil and pipe mill?

As an additional quality assurance check, many companies specify that a third party inspection service witness and verify key steps in the pipe production process. Some companies may use their own personnel, or a combination of company and third-party inspection service personnel, to perform these inspection services. Such inspection adds a level of quality assurance to the entire pipe production process, providing additional assurance that the provisions of the MPS and the ITP were met.

Is a non-conformance review conducted?

The non-conformance review is a formal system conducted as a quality assurance step. This review specifically identifies situations of non-conformance with the MPS and ITP, brings these to the attention of the manufacturer, and details both how the non-conformance was addressed by the manufacturer and the disposition of any affected product.

Is the post construction pressure test less than the mill pressure test plus 12% of SMYS?

If the pipe was measured and did not expand at the mill as a result of the mill pressure test and the post construction pressure test is less than about 12% of SMYS above the mill pressure test, based on gauge pressures, expansion of the pipe is extremely unlikely to have occurred during the post construction pressure test. This conclusion comes from an examination of the von Mises, or equivalent, stresses produced by internal pressure and varying longitudinal restraints or loadings. See Appendix A for a more complete description of these stresses. This analysis demonstrates that an internal (gauge) pressure difference of about +12% is required for a field hydrostatic test to produce a stress in the pipe wall equivalent to that produced in the mill hydrostatic test.

Is there a known history of low mechanical properties or excessive expansion?

Regardless of the preceding steps, if the company, through its normal review of the pipe data, such as is conducted during pipe production, and any other operational data or field observations, such as during tie-ins, installing taps, making coating repairs or performing pipe replacements, has made a determination that the threat of expanded pipe exists, then it must look further for such deformation during the next in-line inspection of the pipeline. If there is no evidence of low strength or excessively expanded pipe, no further action is required. Examples of such evidence include coating flaws caused by pipe strain and improper tie-in of a repair due to strain. This step does not contemplate extraordinary evaluations or inspections, but rather relies on those normally conducted as operations and maintenance activities.

<u>Is the design factor for the pipe greater than 72% of SMYS?</u>
This question is partially addressed earlier, but is asked again here in a different context. Here it is used as an inspection timing criterion. At this step in the flow chart, if the pipe has a design factor of 72% of SMYS, the pipe should be monitored for expansion or excessive yielding during the next deformation or other in-line inspection to be conducted per the company's integrity management program or per any Special Permit Requirements relative to in-line inspection. If the design factor is greater than 72% of SMYS, the deformation or other in-line inspections should be conducted within twelve months of either the commissioning of the pipeline or the publication of this guideline, whichever is later.

<u>Perform deformation ILI to assess for threat of expanded pipe within twelve months</u>
For a pipeline operating at greater than 72% of SMYS, where the threat exists, the operator should assess for the threat by conducting an in-line inspection of the pipe to look for evidence of expansion. The potential threat in this case is deemed to be of higher concern due to the higher operational stress level, and assessment should be scheduled within twelve months of completion of this analysis.

<u>Perform deformation ILI to assess for threat of expanded pipe per integrity management program, special permit schedule or risk analysis</u>
For a pipeline operating at or less than 72% of SMYS, where the threat exists, the operator should assess for the threat by conducting an in-line inspection of the pipe to look for evidence of expansion. The potential threat in this case is not deemed to be an immediate concern, and assessment can occur during the next scheduled assessment of the pipeline as required by the operator's integrity management program, special permit conditions or assessment of likely risk. The latter may be based on the operator's analysis or expectation for a particular pipeline utilizing the work products of Groups 6 (Stress-Strain Behavior), 7 (Integrity Implications) and 8 (Coating Effects) in much the same way the need and timing to address other threats such as low frequency ERW seams and materials and construction defects are handled.

<u>Does the pipe expand by more than X%?</u>
Following an in-line inspection prescribed in the preceding steps, a determination as to whether the pipe has expanded to a degree requiring additional action must be made. This determination includes consideration of pipe diameter tolerances, testing specifics, and possibly other factors. Expansion beyond X% requires evaluation and possible mitigation. Determination of this X% limit and the evaluation criteria is the subject of ongoing consideration by Groups 6 (Stress-Strain Behavior), 7 (Integrity Implications) and 8 (Coating Effects). Based on current tool capability and expected elastic expansion at operating pressure, the practical detection limit may be about 1%. If subsequent operation or testing subjects the pipe to higher stress levels than

previously experienced, a subsequent deformation or other in-line inspection may again be required.

Evaluate and Mitigate

This is the end state of this analysis that is achieved when an in-line inspection has been performed and that inspection has revealed pipe that has expanded beyond the acceptable limits that are established. The company must set evaluation and mitigation criteria. These are still being developed, but are expected to include the implications of an increasing degree of expansion on actual pipe properties, on coating integrity and performance, and on the various threats to pipeline integrity. Based on the evaluation criteria, mitigation levels and actions will be established. These may range from no action being required to reinforcing or replacing joints or pups of pipe.

No Threat

This is the end state of the analysis that can be achieved by one of two paths. If an in-line inspection was required and performed and that inspection determined no pipe had expanded beyond the acceptable limits, then the threat implied by low strength or excessively expanded pipe does not exist. If an in-line inspection is not required due to a lower design factor (B1 path) or due to the performance of adequate testing, inspection and controls (B2 path with a mill test more severe than the field test), and there is no known evidence of low strength or excessive expansion, the threat likewise is determined to not exist. If an inferential route is taken through the flow chart, as opposed to a route requiring in-line inspection, note that such route must include consideration of actual knowledge or history of the line, and cannot be purely inferential.

ANALYSIS OF FUTURE PIPELINES

Future or prospective projects can be managed according to the same process, with the advantage of being able to implement the most optimal steps. The steps recommended for prospective projects are those shown as the green route in Figures 3 and 4. This path assumes new, high grade and high design factor pipe, and highlights the process steps, data, analysis, testing and inspection recommended to confirm that low strength or excessive expansion phenomenon is not occurring. In addition, it precludes the need to assess for expanded pipe with in-line inspection.

While some operators may already have this process in place and can take advantage of it now, others not currently performing all these steps may want to strongly consider making them part of their standard process for pipe procurement.

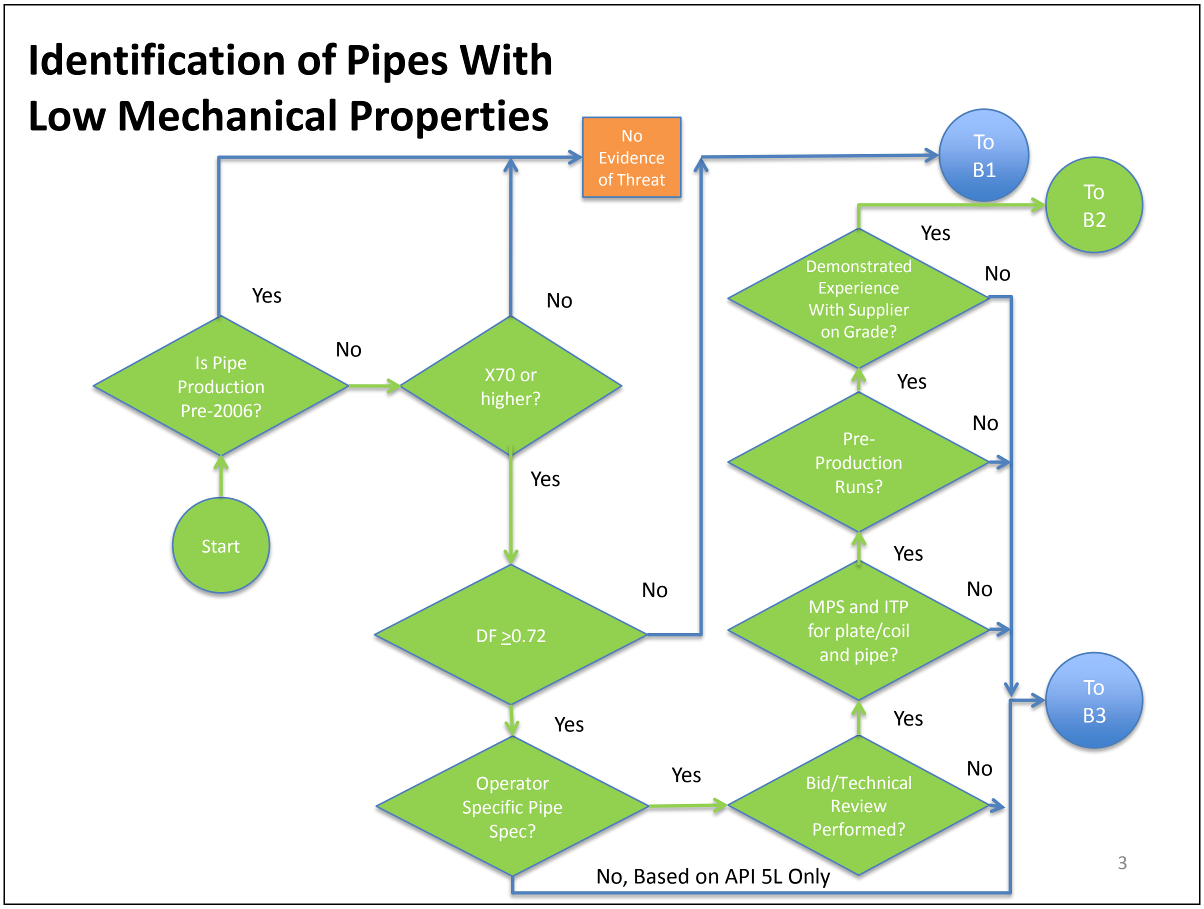
Identification of Pipes With Low Mechanical Properties
No Evidence of Threat
To B1
To B2
Yes
Demonstrated Experience With Supplier on Grade?
No
Yes
No
Is Pipe Production Pre-2006?
No
X70 or higher?
Yes
Pre-Production Runs?
No
Yes
Start
Yes
No
No
MPS and ITP for plate/coil and pipe?
DF ≥0.72
To B3
Yes
Yes
Yes
No
Operator Specific Pipe Spec?
Bid/Technical Review Performed?
No, Based on API 5L Only
3

Figure 3

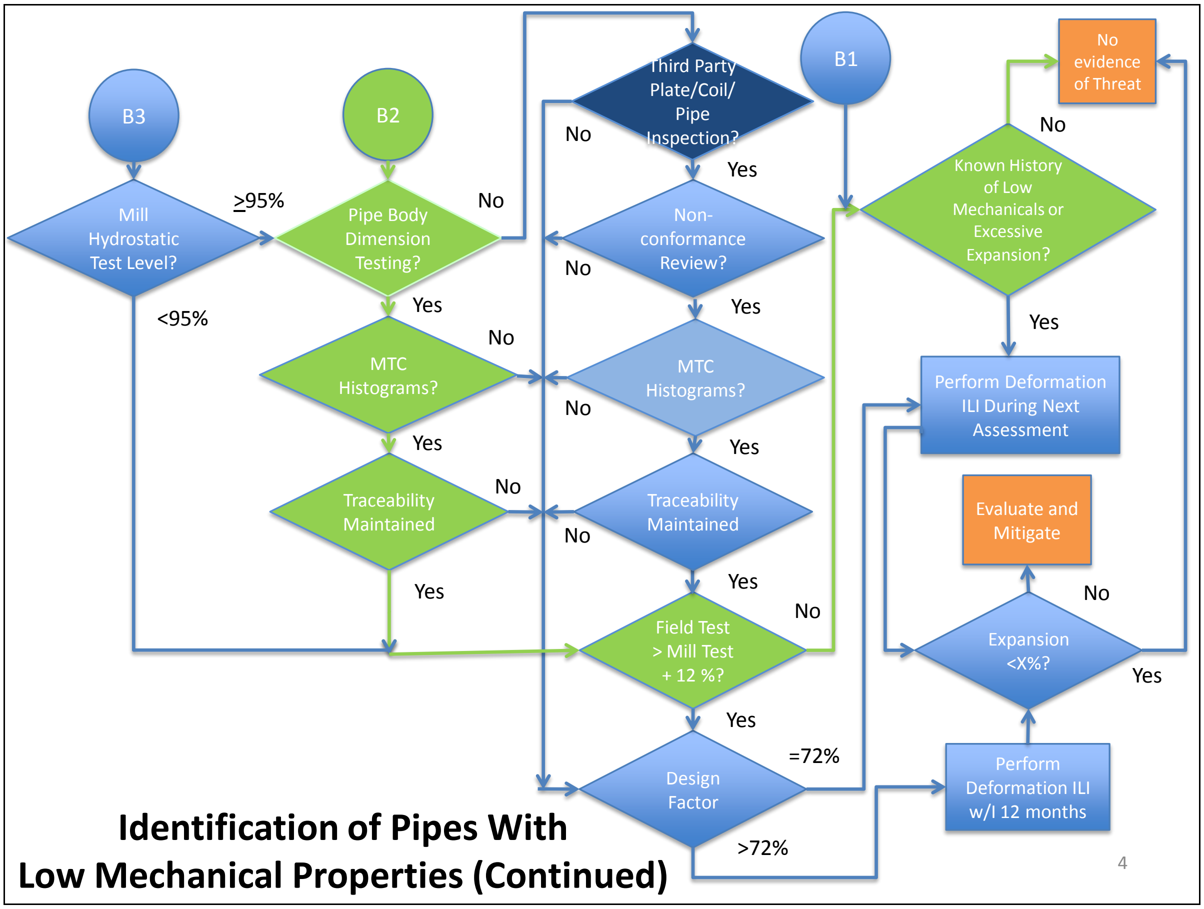

Figure 4

DISTRIBUTOR PIPE

While this analysis focuses primarily on actions that can be specified by the operator, the same logic can be applied to smaller pipe orders typically obtained from a distributor or from a mill overrun, for which all of the steps cannot be confirmed. Examination of Page 1 of the flow chart (Figure 1) shows that, for newer X-70 or higher grade pipe to be operated at or above 72% of SMYS, the path very quickly leads to a detailed analysis of the pipe. For this pipe, only lower range mill and field hydrostatic tests can realistically lead to the "No Threat" conclusion. At such test levels, where the mill test is more severe than the field test and both are well below expected yield stresses, expansion is judged very unlikely. In that case, further inspection is likewise very unlikely to reveal any pipe with low strength because it has not been stressed to a level to cause it to expand. If tested to operate at higher levels, either in the mill or in the field, it is much more likely that evaluation of this pipe will lead through the "Design Factor" diamond on Figure 2 or Figure 4. From that point, in-line inspection to look for deformation is required, either within a short time period or on a "next scheduled" basis.

CONCLUSION

A process has been developed whereby a pipeline operator can determine the susceptibility of any particular pipeline project to risks that may be associated with incorporation of pipe joints with yield strengths below specified minimums or which have experienced expansion in excess of acceptable limits. The process identifies key factors and tests and has several decision points that lead either to a "No Threat" end point or to recommended actions, including inspection, evaluation and remediation. The process is identical for either recent or prospective projects, with a recommended path for prospective projects. Some of the limits and criteria have not been included. These are the focus of other work groups and will be incorporated as they become available.

APPENDIX A

Combined Stresses and the Impact on Mill and Field Hydrostatic Tests

In initial discussions on the fundamental mechanics of a mill hydrostatic test and also the field hydrostatic test, there was a desire among the industry to define a path to identifying pipes with low mechanical properties in the mill so as to preclude their ever getting into the ground.

While the Barlow equation is the basis for pipeline design as reflected in B31.8 and 49 CFR 192.105, the equation is a simplified expression of the hoop stress. A more accurate way to consider stress is to view the pipe in the context of combined effective stress, the combination of axial (longitudinal) as well as hoop stress using the von Mises equation[1]. The mill and field hydrostatic pressure tests are described below and then contrasted with respect to combined stresses and the way in which they work together to cause yielding.

In the mill, the pipe contracts axially (gets slightly shorter) during the hydrostatic test due to Poisson's ratio. This is the same phenomenon that causes a tensile specimen to neck in as it is pulled. The hydraulic ram that seals the end of the pipe follows that contraction, maintaining a seal, usually an o-ring seal. The only axial stress in the pipe is due to the ram force that is in excess of the force needed to counteract the pressure in the pipe. The axial stress is compressive thereby reducing the combined stress level to cause yielding.

In the field, soil friction along a length of pipeline prevents the pipe from contracting, which results in a tensile (positive) axial stress. This tensile stress when combined with the hoop stress results in a greater combined stress required to achieve yielding to compensate for the effect of the tensile stress. This has the effect of strengthening the pipe, as shown by the well-known von Mises equation.

The von Mises equation has been depicted in Figure A.1. The figure depicts what is referred to as a yield ellipse. It is a plot of the point at which the specified minimum yield strength is reached based on actual combined stresses.

The mill test is represented by the green line (A). As described above, during that test the pipe is acted upon by a ram, which results in a compressive or negative axial stress. The result is a combined stress that is actually less than the Barlow equivalent hoop stress to achieve through thickness yielding.

By contrast in the field hydrostatic test, represented by the red line (B), soil friction tends to axially restrain the pipe, which results in a positive, tensile axial stress known to be about one

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[1] The von Mises equation does include a radial component but that has a de minimus effect on the combined stress in this application.

third of the circumferential stress. The result in this case is a requirement for a combined stress higher than the Barlow equivalent hoop stress to cause through thickness yielding.

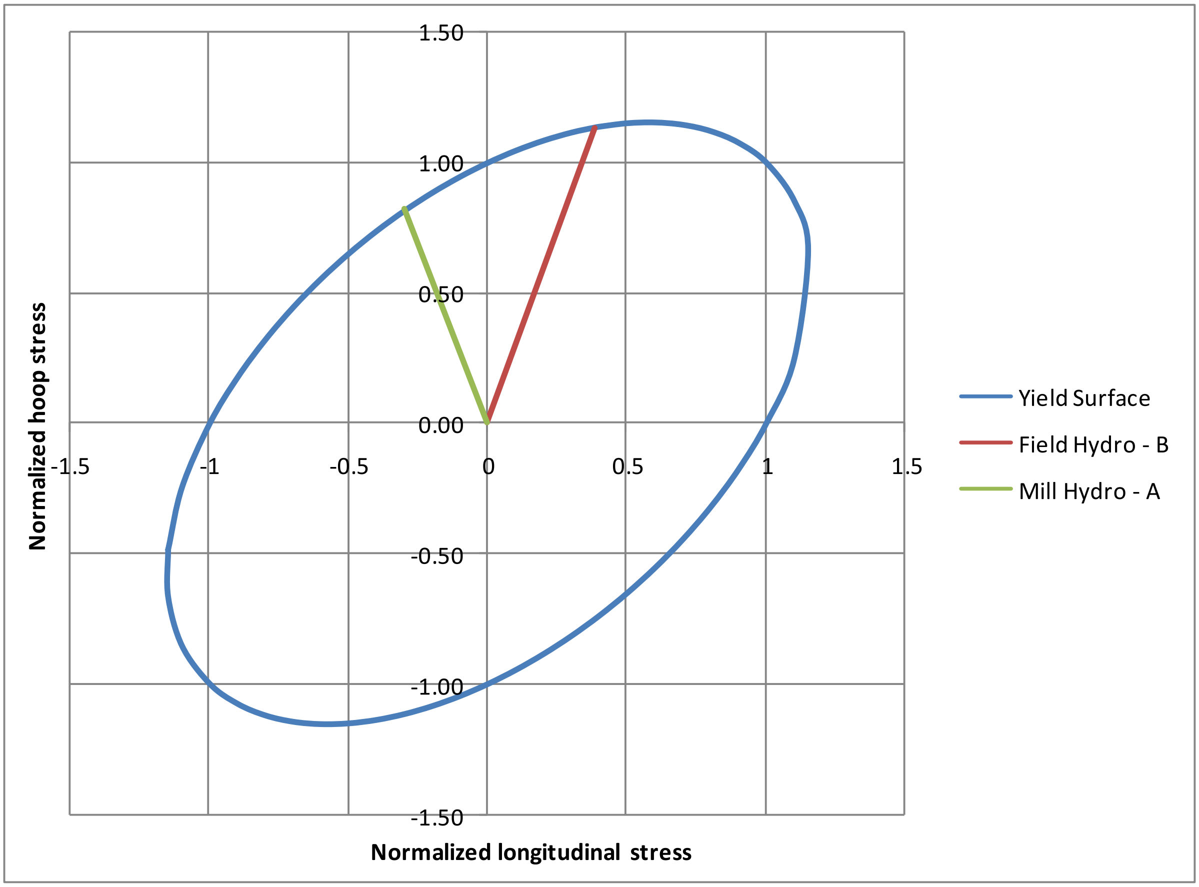

Figure A.1
von Mises Equation Represented as a Yield Ellipse

For example, a mill test conducted with a hoop stress of 95% SMYS and a compressive axial stress provided by a ram results in a combined stress of approximately 100% SMYS. In contrast, a field test must be conducted to approximately 108% SMYS to compensate for the axial tensile stress provided by the friction acting on the pipe for yielding to occur, thereby achieving the same combined stress level as the mill test. Consequently, the pressure to cause through thickness yielding in a buried pipe is about 13% higher than for a pipe under hydrostatic test in the mill.

The effect of considering combined stresses in the mill test is that a test to a gauge pressure of 95% of SMYS produces a combined stress level of very nearly 100% SMYS. From a practical standpoint this means that pipes with lower than expected mechanical properties can be identified in the mill. It does require that the pipe body be measured in a sufficient number of locations along the pipe joint to be able to identify pipes with expansions greater than the API 5L tolerance in the pipe body[2]. To provide perspective, the pipe body tolerance on diameter is 0.16 inches for both 36 and 42-inch pipe as specified in Table 10 of the 44th Edition of API 5L, effective October 1, 2008. This tolerance has been decreased from the 43rd Edition, which allowed 0.27 inches for 36-inch and 0.25 inches for 42-inch pipe. From a practical standpoint, an operator will likely want to specify that each pipe be checked for dimensions in the pipe body as part of the inspection and test plan (ITP) or quality assurance plan (QAP).

[2] API 5L, 44th Edition, Table 18 for PSL 2, only requires that the pipe body dimensions be tested once every four hours or whenever there is a change in pipe size during a shift.