THE EUROPEAN PIPELINE RESEARCH GROUP:
RECENT RESEARCH ACTIVITIES DIRECTED TOWARDS IMPROVED PIPELINE
SAFETY AND RELIABILITY

Gerhard Knauf, Salzgitter Mannesmann Forschung GmbH, Germany

Roger Howard, BP, UK

Abstract

The membership and organisation of the European Pipeline Research Group (EPRG) has evolved during the 35 years since it was formed, reflecting the changing patterns within both the pipe manufacturing and the pipeline operation industries in Europe. At the end of 2007, EPRG members were responsible for pipe manufacturing capacity of around 2,000,000 tonnes/year, and for over 100,000 km of operational high-pressure gas transmission pipelines spanning six European countries.

EPRG has been active in undertaking research and disseminating information relevant to pipeline safety, reliability and performance limits of both existing and new pipelines. Selected topics focus on corrosion, materials and design, are highlighted in the report describing recent technical achievements.

1. INTRODUCTION

For more than 50 years, steel pipelines have proven to be an extremely safe, reliable and economically attractive means for transporting oil and gas. As the requirements for energy transport have increased, both to bring energy from remote oil and gas fields and to distribute it to the major population centres, oil and gas companies have committed substantial funding into research and development to ensure both the continued safe operation of the existing infrastructure and the cost-effective construction of new pipelines. To comply with the needs, pipe manufacturers have improved pipe properties and developed new steels and pipe grades and hence there is considerable benefit to be gained from cooperative and collaborative research.

The European Pipeline Research Group (EPRG) has provided a forum for identifying, prioritising and undertaking collaborative research projects on common-interest areas of pipeline operators and pipe manufacturers for more than 35 years. At the end of 2007, EPRG members (Figure 1) were responsible for pipe manufacturing capacity of around 2,000,000 tonnes/year, and for over 100,000 km of operational high-pressure gas transmission pipelines spanning throughout Europe.

EPRG utilises the combined expertise of its member companies to address issues of common interest concerning the technical integrity of gas transmission pipelines, in the areas of pipe manufacture, pipeline design, construction, operation and maintenance.
EPRG’s overall aims are:

- To identify methods and practices for improving the integrity of existing and new pipelines, thereby ensuring the continued excellent record of pipeline safety and reliability demonstrated by gas transmission pipelines in Europe and elsewhere
- To establish research programmes in response to the identified needs and priorities, and to develop recommendations and guidelines based on the results obtained
- To promote and encourage the acceptance and implementation of the recommendations and guidelines by the gas pipeline industry

Recent research activities have been associated with both existing and new pipelines. For the existing pipelines, managing and mitigating the threats of leaks and failures during service – due for example to corrosion, mechanical impact, or load cycling of defects – have been a major focus of attention. For new pipelines, the ever-expanding European gas grid, and the growing requirements for long-distance transportation from remote gas fields, have focused attention on the application of higher strength steels and the utilisation of advanced design methods; these developments necessitate a more sophisticated understanding of the behaviour of pipeline materials as they approach their performance limits.

EPRG publishes research results, recommendations and guidelines in journals and at conferences, enabling the findings to be utilised by the pipeline industry at large as well as being subjected to critical review. Much of the work undertaken by EPRG in past years has been incorporated in national and international standards for pipeline design, construction and operation, and this still continues today. General overviews were given in [1-2]. A more detailed list of publications can be found in [20-21].
Within EPRG the research work is coordinated through three Technical Committees, focusing on corrosion, materials and design respectively. Activities overseen by the three Committees are highlighted in the following sections describing recent technical achievements.

2. CORROSION AND CORROSION PROTECTION

EPRG’s recent activities in the field of corrosion and corrosion protection have focused on stress corrosion cracking and hydrogen induced cracking [3] as well as on the performance of coatings and the influence of the external environment on the lifetime of mechanically damaged pipes.

Research projects have been launched to improve methods suitable for fit for purpose HIC testing and to simulate the interaction of mechanical damage and cathodic overprotection which may result in rapid failure due to hydrogen embrittlement.

Coating degradation and long-term performance

The primary means of preventing corrosion of buried pipelines is a combination of a protective coating and an impressed current to maintain cathodic protection (CP). As the pipeline age increases, the ability to maintain corrosion-free conditions is related to the resistance of the coating to ageing processes and local degradation. Hence, for existing underground pipelines it is important to understand the degradation mechanisms and how they impact on the coating’s performance during 50 years or more service life.

EPRG commissioned a study to gather information on coating performance and degradation. Among EPRG members, 60% of existing pipelines have thermoplastic coatings (asphalt, coal tar and bitumen), with the majority of the remainder being polyolefin coatings (extruded polyethylene and polypropylene). However, coating technology has changed over the years, and over 75% of newly-constructed pipelines are coated with 3-layer polyethylene incorporating fusion-bonded epoxy as the primer layer.

Figure 2: Coating cracking at 12 o’clock (a) and wrinkling at 3 & 9 o’clock (b), due to excessive soil loading
For these coating systems the main causes of premature degradation (Figure 2) are found to be

- inappropriate specification, leading for example to selection of a material with inadequate thermal stability, permeability or stress crack resistance
- inadequate control of metal surface cleaning and preparation, leading to the presence of residual mill scale or dust and insufficient adhesion
- high or uncontrolled operating temperatures, allowing accelerated thermally-induced degradation, creep and cracking
- excessive loading due to the surrounding soil, encouraging creep and cracking

These findings reinforce the need for unambiguous and rigorously-enforced performance specifications and testing procedures, particularly for surface preparation and coating application. Areas identified for further research include the long-term adhesion of coatings, and the relationship between coating condition and CP shielding.

**External stress corrosion cracking (SCC)**

External SCC has been a concern for pipeline operators since the first in-service failures occurred in the US in the mid-1960s, although it has been extremely rare in Europe. Two types of SCC have been identified; high pH SCC and near-neutral pH SCC.

Early phases of EPRG’s work [1] concentrated on establishing the critical combination of environmental and loading conditions. Recent work [3] has shown that steels with ferrite-pearlite banded microstructures were more prone to crack initiation than a steel with a fine ferrite-bainite microstructure, and that different inclusion distributions in the steels did not have a significant influence.

![Figure 3: Dynamic threshold for stress corrosion cracking in several line pipe steels](image-url)
However, all the steels showed similar crack propagation characteristics, with a ‘dynamic’ threshold stress intensity that was considerably lower than the static threshold (Figure 3).

The results suggest that for existing pipelines that are experiencing SCC, reducing the operating pressure or pressure fluctuations may arrest shallower cracks. For new pipeline construction, selecting steels with fine, uniform, initiation-resistant microstructures may be preferable.

3. MATERIALS AND PIPE MANUFACTURING

Research topics of the materials committee have focused on the influence of the yield to tensile ratio on pipeline safety, the applicability of ultra high strength line pipe grades and also the fracture control of older, lower toughness pipelines.

A review of strength de-rating factors in codes and standards on the basis of experimental data and limited supplementary testing identified the need for more systematic work to understand differences of the de-rating behaviour of pipe material in combination with the pipe production route.

3.1 X100 Grade steel for pipelines

In recent years EPRG has played a significant role in supporting initiatives to enhance the knowledge base for X100 line pipe and its applicability to highly-rated pipelines [1, 5-8]. In particular, EPRG has partially sponsored an RFCS (European Research Fund for Coal and Steel) Demonstration Project – Demopipe - to establish the pipe production, mechanical properties, field welding, field bending and fracture control methodology for 914 mm diameter pipe.

During the course of this work some 50 full-length longitudinal SAW pipe joints were produced in accordance with the specified requirements. Welding procedures were developed and qualified for automated and manual girth welds (Figure 4). Field bending procedures were developed and successfully tested [9].

Figure 4: Wide plate test on a curved section of X100 pipe containing a girth weld
Two full-scale fracture propagation tests (Figure 5) were conducted, demonstrating that extrapolation of the standard fracture propagation methods to higher strengths is very questionable and that crack arrestors will be needed for highly-rated applications. To disseminate the findings of this work and promote the use of X100 for long-distance pipeline applications two RFCS-funded seminars have been organised, the first in Duisburg and the second in Sardinia. Both were supported by EPRG [10].

![Figure 5: Full scale fracture propagation test on X100 pipe](image)

### 3.2 Pipe properties: yield-to-tensile ratio (Y/T)

Over the years, pipeline designers have sought to make increasingly effective use of the properties of the pipe material without jeopardising pipeline safety. Consequently, it has become increasingly important to understand how the behaviour of a pipe-wall test specimen relates to the behaviour and performance of the pipe itself. For these reasons, EPRG has been concerned over many years [1] to ensure that appropriate measures for Y/T are incorporated in specifications and the results from several research projects have been reported in previous publications [11].

EPRG studies [12] have focused on the use of probabilistic structural reliability analysis methods to quantify the influence of Y/T on safety margins with respect to various most-probable failure modes; corrosion, equipment impact or ground movement. The results showed that failures due to corrosion or equipment impact were only slightly influenced by Y/T (Figure 6), but that deformation-induced bending caused by ground movement was more significantly affected. Based on this work, a Y/T limit of 0.95 on basis of round bar specimen tests appeared feasible for design situations where no high longitudinal strains could be expected. Ongoing activity concerns the manner in which such limits can be transferred into line pipe standards.
Figure 6: Effect of Y/T on the safety factor

4 DESIGN AND OPERATION

External damage of pipes and the implications on pipeline integrity have been a major research topic for the Design Committee. Studies on pipeline hooking [13] and the effect of gouge damage on low toughness pipes have been carried out. Also the effect of internal pressure fatigue at high mean stress [14] and the improvements in predicting the burst pressure of pipes [15] have been investigated. Further research on girth weld defect assessment [5] motivated EPRG to launch work to extend the girth weld defect guidelines [16]. In the field offshore pipelines, the impact of reeling on the collapse behaviour of seamless pipe has been investigated.

4.1 The effect of mean stress on the fatigue behaviour of pipes

When pipelines are operated for prolonged periods under fluctuating loads, the issue of design against failure by fatigue becomes important. Fatigue loading has not explicitly been considered in most pipeline design codes, and codes for other applications do not generally address the high mean stress loading seen by pipelines. To address this concern, EPRG has undertaken a programme of 26 full-scale fatigue tests on welded and seamless pipes, and compared the results with design approaches.

The results were compared initially with the former DIN 2413, which applies a Wöhler (stress-life) approach (Figure 7). The original DIN 2413 formulation was then modified to incorporate the effect of mean stress. In general it appeared that the seam weld type and manufacturing route (including the mill hydrostatic test) had as much influence on fatigue life as mean stress, resulting in substantial scatter; however, a lower bound to overall behaviour could be discerned. The design
approach adopted in IGE/TD/1, based on growth of a defect surviving the hydrostatic test, appeared quite conservative when applied to the nominally defect-free pipes tested.

![Figure 7: Fatigue test data on flaw-free pipes (corrected where necessary according to mean stress) compared to DIN 2413](image)

### 4.2 Extension of the EPRG guidelines for assessing girth weld defects

Guidelines for assessing defects in girth welds were published by EPRG in 1996 [16]. They contained a number of restrictions on their application; in particular, the through wall depth of a defect was assumed not to exceed 3 mm, wall thickness was restricted to between 7 mm and 25 mm, and the material strength to X70 or below.

![Figure 8: Remote strain at failure versus normalised flaw length, and proposed acceptance limit for girth weld defects](image)
Recently-completed work by EPRG now supports extension of the guidelines up to X80 grade material. Using a reference stress (collapse) analysis, through-wall depths of 5 mm can be allowed so long as the defect length is reduced, and the same approach can be used to extend the range of allowable wall thickness. A simple approach based on elastic stress concentration has been used to relate allowable misalignment to the applied stress (Figure 8).

EPRG intends to develop an updated version of the girth weld defect acceptance guidelines, based largely on the results described above. In the first instance, basic guidance will be produced concerning defect acceptance criteria that are not based on workmanship. Subsequent parts will give guidance on the sizing criteria and errors inherent in automated ultrasonic testing systems, and will resolve discrepancies between acceptance criteria based on experimental testing and those based on analytical predictions. The overall approach has been formulated in co-operation with the International Pipeline and Offshore Contractors Association (IPLOCA), and it is hoped that its general applicability can be enhanced through the tripartite links between EPRG, the Pipeline Research Council International (PRCI) and the Australian Pipeline Industry Association (APIA).

4.3 Seamless line pipe for offshore applications

Offshore pipelines are being installed in ever-increasing water depths and the design of deep-water pipelines places additional constraints on the properties and dimensional tolerances of the linepipe. As part of a longer-term project to establish the properties of line pipe for offshore applications EPRG commissioned a study to determine the influence of reeling and straightening on seamless pipe properties (Figure 9).
Reeling increased the pipe ovality, but there was no discernible variation in compressive strength around the pipe circumference and no significant change in collapse pressure. Ageing at 250°C, in line with DNV rules, was effective in restoring and improving the collapse resistance. The work showed the significant influence of end-caps on the measured collapse pressure of thick pipes. Collapse tests on pipes with and without end caps and supplementary finite element calculations have shown that the effect of end caps can be compensated by using a simple model when predicting collapse pressure.

5 International collaboration

Since its formation in 1972, EPRG has had regular technical exchange with the US-based Pipeline Research Council International (PRCI) [18]. From 2003 the technical exchanges have broadened to include the Australian Pipeline Industry Association (APIA) [19]. These three organisations provide technology packages and guidance to support the improvement of industry practices and regulations, underpinning the safe and reliable operation of the existing and new energy pipeline infrastructures.

Technical exchanges between EPRG, PRCI and APIA have occurred regularly over many years. The shared experiences of their members have provided excellent understanding of the issues determining pipeline performance, and invaluable insights into how the geographical, political and regulatory environments influence the overall approach to maintaining the safety and reliability of pipeline systems.

One of EPRG’s overall aims is to establish guidelines and recommendations and promote their acceptance. This is achieved either through the direct involvement of EPRG or via individual member companies who are representatives on standards committees. For example, modifications to the girth weld defect assessment methods in the European Standard EN 12732 and the British Standard BS 7910 have largely been based on recent work by EPRG. EPRG was also involved in the initiatives to harmonise international pipeline standards API 5L and ISO 3183, especially in the field of safe crack arrest in gas transmission pipelines.

6 Concluding remarks

Over the last 35 years EPRG has maintained an active involvement in developing new knowledge, methods and procedures to support the safe and reliable manufacture, installation and operation of pipes and pipelines in Europe. The examples highlighted above provide insight into the recent work and the directions of future studies, in line with the aims of the organisation. Looking further ahead, the drive to provide a more flexible mix of renewable and fossil energy sources, and to achieve yet higher extraction and transportation efficiencies from gas and oil fields, will necessitate increasing flexibility in the selection of materials and designs, including for example the transportation of carbon dioxide, hydrogen and biofuels. At the same time there is increasing pressure to reduce the use of the scarce alloying element additions that impart high-performance steel properties. These challenges will increasingly be addressed through international collaborative R&D involving pipeline operators, pipe manufacturers and pipeline constructors, together with safety regulators and code-making bodies; setting and achieving new performance targets,
and developing new standards to enable their safe implementation for the pipeline industry worldwide.

7 Acknowledgments

The authors wish to thank EPRG member companies for permission to publish this paper and in particular acknowledge contributions from the Technical Committee chairmen, Jean-Pierre Jansen (Corrosion), Paul Roovers (Materials) and Mures Zarea (Design) as well as David Batte (Consultant) in the preparation of this paper.

8 References

[10] http://diskx100.c-s-m.it/


[18] [www.prci.org](http://www.prci.org)

[19] [www.apia.net.au](http://www.apia.net.au)

[20] [www.eprg.net](http://www.eprg.net)