



REINFORCED COMPOSITE PIPELINES- BEST MANAGEMENT PRACTICES

John J. Baron
J. Baron Project Services Inc
509 Centre Street
Box 22, Site 2, RR 3,
High River, Alberta, Canada T1V 1N3

Mike Peters
Canadian Association of Petroleum Producers
2100, 350 – 7 Avenue SW
Calgary, Alberta T2P 3N9

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ABSTRACT

At the Banff Pipeline Workshop in April, 2007 a review of the performance of reinforced composite pipelines used in the upstream oil and gas production industry was presented. It was reported that pipeline incident statistics for reinforced composite pipelines were disproportionately frequent (on a per km basis) compared to metallic pipelines, and some common repetitive primary causes were identified. The presentation was based on Alberta pipeline incident statistics. Conference participants felt that more could be done to improve performance in this area and an initial step would be to document and publish an industry best management practices guide that addressed the design, installation and operation of reinforced composite pipelines. An industry committee of corrosion and materials specialists was formed and operated under sponsorship of the Canadian Association of Petroleum Producers (CAPP) to undertake this task, which resulted in a guide document entitled *Best Management Practices: Use of Reinforced Composite Pipe Non-Metallic Pipelines*¹. This paper presents some of the key findings of that document, including both individual length stick pipe and continuous length spoolable pipe materials. CAPP will publish the guide, which is currently undergoing a final review process, during 2010.

Keywords: reinforced composite pipelines, failure statistics, CAPP, best management practice

INTRODUCTION

Reinforced composite pipe (RCP), more commonly known as fiberglass pipe, has been used as a pipeline material in western Canadian oilfields for more than 40 years. In the early years it was installed in lower pressure production flowlines and oilfield produced water disposal pipelines, usually to provide a corrosion resistant material alternative to carbon steel pipe where high levels of corrosive produced salt water were transported. RCP pipe in the earlier years of use was typically individual length jointed pipe or so-called “stick pipe,” as spoolable flexible pipe products as currently used by industry were not manufactured at the time.

Today RCP is commonly installed in similar upstream oilfield pipeline services however much higher pressure rated composite pipe products are available in both individual/stick jointed lengths as well as flexible pipe products. The flexible pipe products are manufactured and delivered in long continuous pipe lengths that are placed onto transportable pipe reels.

RCP products are included in CSA Z662-2007², Canada’s oil and gas industry pipeline code and included in other industry standards published by standards writing bodies such as ASTM International, International Organization for Standardization (ISO), and the American Petroleum Institute (API).

In April 2007, at the Banff Pipeline Workshop performance statistics were presented in a workshop that indicated the failure frequency for reinforced composite pipelines was relatively high for oilfield pipelines on a leak per pipeline length basis compared to carbon steel pipelines. The causes of failures were considered to be generally preventable and thought to be quite often due to designing and installing RCP pipelines using familiar steel pipeline methods that for some aspects of design and installation are generally unsuitable for reinforced composite pipelines, given the different mechanical properties of RCP when compared to steel pipe.³

During the Banff presentation referenced, the following issues were presented and then discussed in the workshop regarding failures of RCP and other non-metallic material pipelines:

1. The failures appear to be increasing due to “construction” related causes;
2. The failures are not typically related to material design or material quality; and
3. The root causes of failures often relate to the use of poor installation procedures, improper or lack of field supervision and a perceived lack of time during construction that leads to hasty and sometimes inappropriate decisions.

Figure 1 provides a summary of reinforced composite pipeline failures in Alberta by cause in 2007. The data reveals that some of the more common and reoccurring stated causes of failures are the following in no particular order:

1. Damage resulting from installation practices;
2. Corrosion failure of associated steel pipe risers, or fittings that were included in the installation;
3. Damage by others, 3rd party damage;
4. Mechanical failures of valves or fittings; and
5. Miscellaneous/pipe failure

An outcome of the discussions at the Banff workshop was to form an industry based task group that would undertake to develop and prepare an industry available document that would attempt to gather

and provide the best management practices used by the oil and gas production industry for design and installation of RCP pipelines for typical oilfield production applications.

To facilitate and sponsor this activity, the Canadian Association of Petroleum Producers (CAPP) through the Pipeline Technical Committee provided facilities and staff for organizing task group meetings, preparation of a document outline and the eventual writing and publishing of the document.

Therefore, the main intention of the document was to address the following:

- Differences between conventional steel pipe and reinforced composite pipe
- Lessons learned and recommended best practices as gathered from Canadian industry experiences
- Provide high level and practical background information to assist pipeline designers, installers, and end users who have limited experience with reinforced composite pipelines.

COMMON CAUSES OF FAILURE

Common Incident Causes/Potential Solutions

Installation Related: Installation related damage that leads to pipe failures can take many forms. Most often installation damage is not intentional but results from trying to install reinforced composite pipelines in a similar fashion, with similar techniques and installers as used for steel pipelines. The reinforced composite pipe installation requirements are generally not that much different from good installation practices for steel pipelines where due care and handling should also be taken, however with reinforced composite pipe, the material is far less forgiving than steel to installation related issues such as inadequate soil support, inappropriate anchoring methods, pipe impact and improper backfilling practices.

In some cases installation damage may cause a leak to occur very quickly and be located during the construction pressure test. In some other cases construction initiated damage may take a much longer time to further develop and eventually cause a failure during operation. An example would be pipe abrasion due to a sharp rock buried next to the pipe, it may take several years of rubbing against the composite pipe to eventually cause a failure to occur.

Pipe impact damage can also occur due to dropping of lumps of frozen backfill or large rocks over the pipe during backfilling.

A primary damage mechanism is lack of underground pipe support. For example, where the end areas of pipelines during construction may be over-excavated it results in large areas of relatively unstable soil when it is placed back around the pipeline. If the soil support to the pipe is not adequate or uniform, it can result in damage to reinforced composite pipes due to differential pipe settling and the development of excessive axial or shear stresses in the pipe body or at connections. RCP pipe is generally much more sensitive to this mechanism of damage than steel pipe.

Related to the pipe support issue, where a reinforced composite pipeline riser is connected to above ground steel headers or wellsite piping, it is imperative that the aboveground steel piping be supported independently of the composite pipeline risers. It is not recommended to provide anchoring or support to an above ground steel piping system through anchors or supports placed on or below a reinforced composite pipe riser.

For spoolable pipe risers, an underground structural steel support to support the spoolable pipe riser is often used but this type of support structure is not intended to support above ground steel piping.

Another area of concern for stick pipe is pipe joint integrity. Pipe joints are made from either threaded mechanical connections on smaller diameter stick pipe or adhesive bonded bell and spigot on larger diameter pipe. Currently there is no technology capable of conducting reliable non-destructive examination (NDE) of these joints before placing them into service. Therefore reliance on the qualifications and competencies of joining personnel, strict adherence to the qualified joining procedure and use of specified joining equipment is required and is a key success factor. This is a challenging area to manage for pipeline construction projects, especially for installers whose pipeline installation experience is based primarily on steel pipelines.

Similarly, spoolable pipe products each have different joining coupler designs that are mainly mechanical in nature and rely on strict adherence to installation procedures and qualified joining personnel. In some cases manufacturers allow field installations of their proprietary connections by certified construction contractors. In these cases the manufacturer should train and approve installers of their couplers. This approach may also present challenges to the end user to manage joint quality and determine who is qualified to make these connections.

With spoolable pipes a great deal of care should be taken to not over torque the pipe body during placement especially during wintertime construction when the inner liner material is stiffer and less ductile. Over-torque of the pipe can result in cracks developing in the outer reinforcement structure that may go undetected and then further degrade in service and lead to pipe failure.

With spoolable pipe, kinking can occur during installation and requires careful unreeling and vigilance during construction. In some cases during winter construction where heat is applied to the pipe reel, over heating or non-uniform heating on the reel may occur and may result in kinking during unreeling as the pipe could become more pliable in some hotter areas but remain stiffer in colder areas of the reel.

Where spoolable pipes or reinforced composite pipes are installed through an existing steel carrier pipe as a liner, support of the spoolable pipe where it enters and exits that steel pipe is of primary importance. The steel carrier pipe will normally behave as a solid and settled area of ground that has not seen soil movement for many years since construction. However the area where the composite pipe exits is subject to new and varying soil settling that often may lead to a failure right at the entry/exit areas of the carrier pipe. Furthermore, for longer pull sections through existing carrier pipe, any intermediate bellhole excavation locations that connect two adjacent pull sections are areas where differential soil settling could cause excessive shear stress to develop in the spoolable pipeline.

The need for internal and external corrosion protection for metallic joining couplers used for spoolable pipes should also be provided based on the corrosiveness of the service fluid and general soil conditions. Application of protective coating and cathodic protection must also be considered.

Internal Corrosion Of Steel Risers: In some reinforced composite pipeline installations the use of a carbon steel riser pipe is preferred. The use of steel pipe is usually to provide increased strength or damage resistance, or fire resistance for the exposed riser pipe section.

Since reinforced composite pipelines are quite often installed in highly corrosive service fluid, internal corrosion of the steel riser pipe should be considered a threat and be mitigated.

Most often this is accomplished by use of internal plastic coatings that are shop-applied before hand and the internally coated riser is then shipped to the construction site equipped with flanged ends suitable for connection to the reinforced composite pipeline. In some cases specialty coated and welded insert fittings are used to fabricate risers using coated pipe sections.

A couple of factors to consider for use of plastic coatings with risers are the diameter and design of the riser. The use of NPS 2" diameter pipe is not recommended since generally this is too small to internally coat successfully.

The use of an appropriate internal coating product combined with a quality application by an experienced coating applicator is highly recommended. There are several pipe internal coating applicators available that specialize in this type of coating application and should be utilized for riser coatings. Also industrial coating manufacturers should be consulted for their recommendations for suitable internal coating materials and applicators. A key factor is using a coating with adequate temperature and chemical resistance. Epoxy based coatings are most often specified in typical thickness range of 300-400 microns (12-16 mils).

Steel pipe risers to be internally coated should also be designed with suitable flanges or fittings that provide internal access for both weld area grinding and the coating application. Where internal weld beads are left rough or if weld splatter exists at the welds, than the coating may likely fail prematurely at these points. Where access for weld grinding in pipe spools is not practical, the use of alternate welding processes, such as MIG, that develop a smoother internal weld bead should be considered. NACE SP0178⁴ provides information on preparation of welds surfaces for internal coating application.

Diameter differences between reinforced composite piping and the riser piping (particularly when the riser piping diameter is smaller) should be evaluated in the coating selection step regarding the erosion resistance properties of the coating. Where possible, gradual diameter changes should be used, as more aggressive changes may lead to pre-mature coating failure (i.e. NPS 4 piping reduced down to a 2" valve assembly). Furthermore, flanged connections versus welded connections should be considered for the ease of coating smaller pipe sections and grinding weld areas for surface preparation. Cost is a factor to be considered since flanged connections are normally more expensive than welded connections.

The field application of internal coatings is not normally recommended due to inability to adequately clean the steel pipe and apply uniform coatings under typically adverse field conditions. Therefore, steel pipe riser internal coating applications should be performed in a specialized coatings application shop.

It is also common to install reinforced composite pipe risers and to transition to steel pipe just above ground level with a flange. This is discussed in more detail in the design and installation sections of this guide.

In some cases corrosion resistant alloy (CRA) piping such as stainless steel alloys have been used for risers, however an appropriate alloy material should be carefully selected that is suitable for the service fluid. The alloy selection and connecting method between the alloy riser piping and the reinforced composite pipe should be discussed with the reinforced composite pipe manufacturer.

External Corrosion of Steel Risers: External corrosion of steel risers is also identified as a cause of failure. Where steel risers are employed in conjunction with reinforced composite pipelines than suitable external coatings such as liquid epoxy, shrink sleeves or tape wraps should be applied that are rated for the service temperature. To supplement the protective coating, spot cathodic protection is also installed, usually with a sacrificial anode.

Third Party Damage: Damage by third parties is identified as a cause of service failures for reinforced composite pipelines. In some cases this is a result of a lack of knowledge regarding the accurate location of underground pipelines or not following industry recognized ground disturbance procedures.

It is important and a CSA Z662 pipeline code requirement, that all reinforced composite pipelines be installed with a suitable tracer wire to allow accurate use of pipeline location equipment. In older oil fields there can be pipelines that are installed but do not have a tracer wire installed. In those cases careful analysis and caution should be exercised, using information such as drawings or installation files to best determine pipe location. Again proper ground disturbance that avoids use of mechanical excavation near buried facilities can help to minimize this risk.

Above ground pipeline markers are also required and recommended to help increase awareness of underground pipelines and to help locate pipelines.

In cases where the location is not accurately known there may be no choice but to perform careful hand or hydro-vacuum excavation to locate the pipeline. Use of steel probes pushed through the soil to locate pipe should be avoided since these can damage reinforced composite pipe if driven into the pipe wall excessively. If no alternative exists, probes should have blunted ends.

DESIGN ASPECTS

Success with reinforced composite pipelines usually involves aspects of design that go beyond a simple review of pipe pressure rating to include the following:

- Selection a suitable pipe product,
- Assessment of soil conditions to ensure provision of adequate pipe support and prevent pipe damage,
- Riser material and design configuration,
- Metallic coupler material selection, and,
- Selection, qualification, and use of a competent pipeline installation contractor.

Throughout the design process it is recommended to involve the pipe manufacturer to provide technical assistance and provide input based on their experiences with their products from similar pipeline installations.

Some of the key design parameters also include determining an accurate service fluid composition, operating pressure range including the amplitude and frequency of pressure cycles, operating temperatures, upset operating conditions, pump operation conditions including pump start/stopping effects and pump pulsation control.

Possible fluid hammer conditions and their effects should also be assessed during design. In general fluid hammer should be prevented or minimized through use of slow acting valves and equipping pump motors with variable frequency drivers. Associated operating conditions such as the effects of pigging, hot-oiling, additive chemicals, and well stimulation chemicals should be understood and included in the design analysis. Discussion with the pipe manufacturer's technical staff can provide guidelines and is strongly recommended.

In general pigging should be avoided, as it may damage the internal surfaces of the pipe or corrosion coating, but if required selection of a suitable pig style that will not harm the pipe is required. Hot oiling for paraffin control, if necessary, must be done in a manner to not exceed the pipe's maximum temperature and pressure ratings.

The effects of additive chemicals such as sulphur solvents or acidic well stimulation chemicals may prove harmful to the pipe material and must be carefully considered. In cases where the chemical exposure period is very short duration, the harmful affects of chemicals may be reduced.

As well the pipeline terrain conditions should be understood and include a review of general soils stability, existence of muskeg sections, water crossings, general rock conditions, and overall soil characteristics, as a minimum.

In terms of appropriate soil conditions for reinforced composite pipelines, industry standards such as ASTM D 3839⁵, AWWA M45⁶ and ASME B31.3⁷ provide guidance on RCP pipe design. ISO 14692-Part 3⁸ provides general design guidance for reinforced composite piping systems. Also pipe manufacturer's technical manuals include information on required soil conditions, compaction, and other design information.

Table 1, based on information taken from ASTM D3839, shows examples of the constrained soil modulus values for different soil stiffness classifications that are compacted to 90% standard proctor density. The range of resultant modulus values is indicative of the capability of the soils to support pipe within the pipeline trench.

Unlike steel pipe, stick composite pipe is anisotropic, therefore its mechanical properties, such as tensile strength or modulus of elasticity are directionally orientated. This is mainly a result of the fibre reinforcement winding orientation. Therefore stick composite pipe will have different modulus of elasticity for hoop and axial orientations with the pipe having much higher hoop strength than axial strength. This means that axial loads must be carefully considered during the design stage.

DISCUSSION

In general the design and installation of reinforced composite pipe must be undertaken using appropriate methods and by experienced personnel to reduce premature failures.

Unlike steel pipe where manufacturers typically are not directly involved with end applications such as pipelines, reinforced composite pipe manufacturers normally have engineering and technical staff that are able to provide applications guidance for their products use, both in the early design stages of projects and also through installation with training and site quality monitoring.

Particular attention must be paid to pipeline trench soil stability and at over-excavated sites where risers or pipe transition fittings are located. Special design and installation considerations are necessary to provide acceptable soil stability.

During operation, highly cyclic operating pressures can lead to premature degradation of reinforced composite pipes and this aspect must be considered during design stage and also monitored during operation.

No specific definition exists for highly cyclic operating pressure and requires judgement to be applied that considers both the amplitude and frequency of cyclic operating pressures. Several instances of failure are reported to have occurred where cyclic pressures generated by positive displacement water injection pump start/stop cycles have resulted in high amplitude pressure cycles occurring several times per day.

The pipe manufacturer is best able to provide guidance on the effects of cyclic pressure and must be consulted regarding the operating conditions and a suitable cyclic design factor applied if required.

CONCLUSIONS

Based on the review conducted by the industry and documented in the CAPP composites document the following conclusions are drawn regarding failures of reinforced composite pipelines:

1. Failures of reinforced composite pipelines are often a result of inadequate design and installation practices that do not address all key aspects and provide provisions to compensate for the unique mechanical properties of reinforced composite pipe materials.
2. The use of steel pipe risers on reinforced composite pipelines requires that suitable corrosion control measures be provided for the life of the steel piping portions.
3. Closer communication and cooperation at the design and installation stages between industry users and the technical resources offered by composite pipe manufacturers is required.
4. The oil and gas production pipeline industry should ensure that suitable training and experience is obtained by their construction staff, including supervisory and inspection staff, prior to taking on projects involving reinforced composite pipelines.
5. For all projects an awareness and understanding of the prevalent soil conditions in the pipeline trench is required at the design stage to ensure provision of measures to provide soil stability and adequate support for the pipeline. This is especially important at over excavated sites typically at pipeline termination points where pipeline risers are located.
6. The new best management practices document to be published by CAPP should be a valuable resource to the upstream oil and gas pipeline industry and is intended to broaden the awareness of the general requirements for design and installation of reinforced composite pipelines.

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TABLE 1:

EXAMPLES OF CONSTRAINED MODULUS OF SOILS WITH VARIED GRAIN SIZES (ASTM D3839)

Soil Stiffness Classification	Density, % SPD	Constrained Soil Modulus, MPa at 2 m	Suitable Placement Zones Pipeline Trench
SC-2	90	10.3	Over-excavated Foundation; Unstable trench bottom replacement; Embedment zone
SC-3	90	5.1	Over-excavated foundation; Embedment; Restricted for high water condition
SC-4	90	2.2	Embedment zone only; Restricted for high water condition

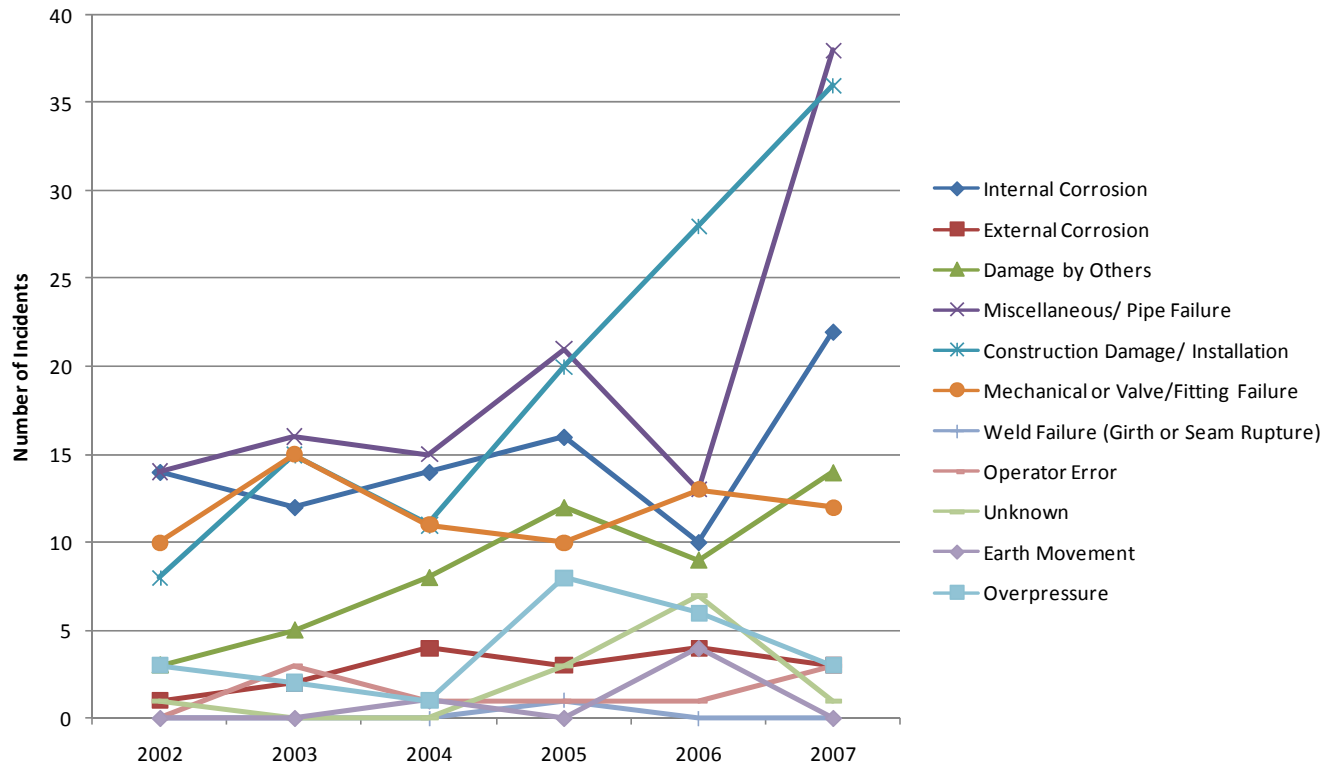


FIGURE 1- Composite Pipeline Failure Causes

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