A Brief History of Running Crack Failures in Pipelines

Prepared for

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Some History

On November 24, 1950[1], a newly built 30-inch natural gas pipeline near King of Prussia, PA, ruptured for nearly 3,000 feet. In 1960[2], Transwestern Pipeline Co.'s gas line 58 miles northwest of Roswell N.M. suffered an 8.3-mile brittle fracture during a pneumatic pressure test. A year later a similar rupture occurred in the Mich-Wisc system in the Upper Peninsula of Michigan. It propagated 3 miles. At that time, specifying the minimum yield strength and the wall thickness were considered sufficient for designing a gas pipeline. These incidents dispelled that notion. The fractures were 100% brittle.

Following these events, a lot of noisy experiments were conducted to better understand these incidents. Many lengths of pipe were pressurized to failure; decompression velocities and fracture velocities were measured dynamically. Most of that work took place in the 1960s and early 1970s at the Battelle Institute in Columbus, OH, and were funded by the Pipeline Research Council of the American Gas Association. British Gas also conducted similar experiments.[3]

The researchers found that the brittle fracture velocity of steel was around 1500 ft/sec, but that the velocity of the gas decompression wave was around 700 ft/sec. In a compressed gas line, once a crack began to propagate, the crack would outrun the gas decompression wave, so it would not stop propagating until it reached a flange, a valve, or a crack arrestor.

The researchers also learned that if the pipe was ductile (as indicated by Charpy V-notch (CVN) impact testing), the material ahead of a propagating crack would stretch, deform and tear, slowing the crack propagation rate. The ductile fracture mechanism would enable a gas decompression wave to catch up with and move ahead of the propagating crack, causing the crack to self-arrest very quickly. The key to fracture control at that time was understood to have sufficiently ductile CVN toughness in the line pipe to avoid brittle fracture.

But in 1968, Great Lakes Gas Transmission had an 1100 ft rupture[4,5] that was 100% ductile. That wasn't supposed to happen – fracture ductility was expected to quickly arrest a propagating crack. However, investigation determined that the steel was high in sulfur and had a very low CVN ductile upper shelf energy (11 ft-lb). Industry discovered that, in addition to being ductile, the CVN upper shelf energy also has to be sufficiently high to stop running cracks.

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[1] The Washington Reporter, November 24, 1950.
[2] Oil & Gas Journal April 25, 1960 - Vol 58 No. 17
[3] Eiber, R.J., Bubenik, T.A., and Maxey, W.A., "Fracture Control Technology for Natural Gas Pipelines", Project PR-3-9113, Pipeline Research Council, Inc., Catalog L 51691, Dec. 1993. This document reviews and summarizes the preceding 30 years of research on fracture initiation and propagation, described in the numerous references cited.
[4] https://law.justia.com/cases/federal/appellate-courts/F2/506/498/322402/
[5] Eiber, R.J., "Field Failure Investigations", Paper G, A.G.A. 5th Symposium on Line Pipe Research, 1974.

Different researchers (Battelle/AGA, AISC, British Gas Council, and British Steel) linearly regressed the data and established empirical estimates of the CVN toughness that was required based on operating stress, pipe OD, and pipe wall thickness to prevent running cracks. The recommendations weren't identical, but they were generally within 10% of each other. In 1989, ASME B31.8 *Gas Transmission and Distribution Piping Systems* added a requirement that the CVN toughness of the pipe be specified as part of the pressure design of the pipe and that the upper shelf energy meet a minimum level calculated using one of the empirical relationships developed from research. The requirement to meet a minimum CVN upper shelf energy was not incorporated into ASME B31.4, *Pipeline Transportation Systems for Liquids and Slurries* since running cracks do not occur in liquids that remain liquid when the pressure is reduced.[6]

While some running cracks in failed gas pipelines originated at longitudinal welds[7], the cracks did not follow welds from one length of pipe to the next length; once a crack begins to run, it will run down the length of the pipe and across circumferential welds and into the unwelded base metal indiscriminately.[8]

Discussion

While the above history of running crack failures in pipelines is interesting, long running cracks have been limited to compressed gas pipelines. The situation with a liquid is different. As a crack progresses down the length of a pipe, the crack is driven[9] by the fluid pressure on the pipe wall just downstream of the crack tip. As noted above, if the fluid is compressible, the gas decompression wave will be slower (400 to 700 ft/sec) than the speed at which the crack propagates in the steel (1500 ft/sec.). As a result, the crack will run until it encounters something that has greater resistance to fracture propagation, such as a flange, valve, heavy-walled pipe, or high-toughness pipe. This does not happen when the fluid remains a liquid after decompression. The decompression velocity of liquids is faster than the speed at which a crack propagates in steel; for example, the decompression wave of water under pressure is 4890 ft/sec. Since the water's decompression velocity is almost a mile per second and the speed at which a crack will run in steel is only about a quarter-mile per second, the pressure in the pipe just downstream of the crack tip, which is the crack-driving

[6] Starting in 2006 B31.4 has required pipe materials to meet modest minimum CVN impact energy values in addition to being ductile at the operating temperature. The objective was to provide defect tolerance rather than control fracture propagation.

[7] Ruptures more frequently originated at corrosion defects or mechanical damage in the pipe body.

[8] The attempt to limit the length of a seam fracture to a single pipe length led to the common practice of offsetting the alignment of longitudinal submerged arc-welded seams from joint to joint by placing them alternately at the 2- and 10-o'clock positions. However, the same practice was typically not followed with ERW seams because the seams could be difficult to observe visually if they are well trimmed. Today the practice is unnecessary since seams in modern line pipe often have strength and toughness properties as good as or better than the base metal.

[9] Pipeline Fracture Control Concepts for Norwegian Offshore Carbon Dioxide Capture and Storage, Gaute Gruben , Kenneth Macdonald , Svend T. Munkejord , Hans L. Skarsvåg and Stephane Dumoulin1Proceedings of the 2020 13th International Pipeline Conference IPC2020 September 28-30, 2020

force, will drop so rapidly that the crack will just stop, leaving a short fish mouth rupture. That was the case on a burst test that one of the authors performed on NPS 24 standard weight pipe in 1992[10]. Before failing at 2250 psi, that pipe grew from 24 to 27 inches in diameter and the 3/8 inch wall thickness was reduced to 3/16 in at the point of fracture.

Anytime the fluid remains liquid when pressure is suddenly released (and the material is ductile at the operating temperature), the pipeline forms a fish mouth and the crack will grow no further in length than the diameter of the pipe, even if the longitudinal welds joining two pieces of pipe are perfectly aligned with each other.[11]

The Special Case of Spiral Welded Pipe

As noted above, running crack failures occur down the axis of a pipeline, not across circumferential welds; they do not follow weld seams. All of the failures of pipelines containing gas traveled down the length of the pipe, not in the circumferential direction. This happens because the stress due to pressure in the hoop direction (i.e., across a longitudinal weld) is twice as high as the stress across a circumferential weld. When it comes to spiral welded pipe[12], there is no weld down the length of the pipe. Rather, the weld is mostly circumferential. Fractures propagate primarily perpendicular to the maximum stress in a pipe, which is usually the hoop stress. If a flawed spiral weld cracks, the stress across the flaw will always be low; in the worst case, the weld will leak before it forms a fish mouth. Moreover, a flaw in a spiral weld must be much longer (along the weld) than in a longitudinal seam to fail at the hoop stress. These fundamental relationships were established theoretically and in testing of angled defects and spiral welded line pipe sponsored by the natural gas industry.[13,14,15] In spiral welded pipe, there is no weld that is subjected to the full stress due to pressure that welds in longitudinally welded pipe experience. In spiral welded pipe, it is the material that is subjected to the full stress due to pressure, not the spiral weld.

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[10] See "How Good Do Piping System Welds Really Need to Be?" at https://sperkoengineering.com. Be sure to watch the video using the link just below the article link.

[11] Note that some early vintage ERW seams manufactured prior to the practice of post-weld heat treatment of the seam could exhibit very low CVN absorbed impact energy. When such seams ruptured, the low-toughness fracture could extend the full length of the pipe joint even when the fluid is a liquid. Either multiple initiation points developed ahead of the fracture, or the entire seam was effectively an origin. But it would quickly arrest when it entered the upstream and downstream pipe lengths. Starting in 1967, API 5L and 5LX required PWHT of ERW seams though many pipe manufacturers were practicing PWHT of ERW seams several years prior to that.

[12] Also referred to as helical seam pipe.

[13] Maxey, W.A., "Fracture Initiation Control Concepts", Paper I, A.G.A 6th Symposium on Line Pipe Research, 1979.

[14] Maxey, W.A., "Flaw Behavior in Spiral Welded Pipe", Paper 12, A.G.A 7th Symposium on Line Pipe Research, 1986.

[15] Kramer, G.S., Wilkowski, G. and Maxey, W., "Fracture Initiation Behavior of Spiral Welded Pipe Under Pressure and Longitudinal Loads", A.G.A. Report, L 51514, NG-18 Report 154, January 1987.

Summary

As noted above, a fracture in a water line will always be a fish mouth of very limited length even if the longitudinal seam welds in two lengths of pipe are perfectly aligned with each other. When the pipe is spiral welded to another spiral welded pipe, there is even less reason to be concerned about the alignment of the spiral welds. The requirement for spiral welds to be offset from each other by a length equal to five times the material thickness serves no purpose.

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