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Examples of pipe failures in Slovak transmission gas pipelines

Abstract: The paper deals with some case studies in Slovak high pressure gas pipelines. All cases were caused by an interaction effect of the weld anomalies excessive misalignment, poor workmanship or cold strain hardening, of the metallurgical aspects in pipe production liquid Cu embrittlement, irregular microstructure and by an additional bend loading earthquake, sudden pipe settlement and landslide or site bending.

Keywords: Pipeline failures, LME, SSCC, Delaminating, Cold plastic impression

Introduction

Slovakia belongs among the countries with the most dense network of high pressure transmission gas pipelines. Four lines are already passing through its territory, whereas the 5^{th} line is being completed at the moment. The oldest gas pipelines have been in service for almost four decades, and though they are inspected periodically, pipeline failures occasionally occur. This paper deals with case studies of several recent gas pipeline failures.

First international gas pipeline

The 1st international gas pipeline which was built in 1965. This line, made of the old U.S.S.R. steel (type 15 G2S) low alloyed with Si (see Table 1), is the most problematic one at present. In this line, low ductility and toughness of steel (Table 1) have met together with poor workmanship and defective corrosion protection of the pipeline.

Liquid metal embrittlement

The first case was a 1.8 m long crack running along the spiral weld of spirally welded pipe OD 720 × 8 mm (Fig.1). The initiation point was in the place where the spiral weld meets the tie strip weld. The spiral weld, which exhibits very excessive misalignment of both linear and opposite runs, is shown in Fig.2. The crack was initiated by LME (lixquid metal embrittlement) of remelted copper (Fig.3). Copper came from the abrading of copper electric contact plates applied during manufacturing of spiral welds at that time.

Table 1 Chemical composition [wt%] and mechanical properties of the 15G2S steel

C	Mn	Si	P	S	Cr	Ni	Cu	Ti
0,14-0,15	1,37-1,45	1,07-1,08	0,014	0,029	0,06	0,05	0,08	0,032
Re[MPa]		Rm[MPa]		A_5 [%]	ChV FATT (50 J·cm^{-2})		Upper shelf	
387-404		591-612		22-27	+14°C		55 J·cm^{-2}	

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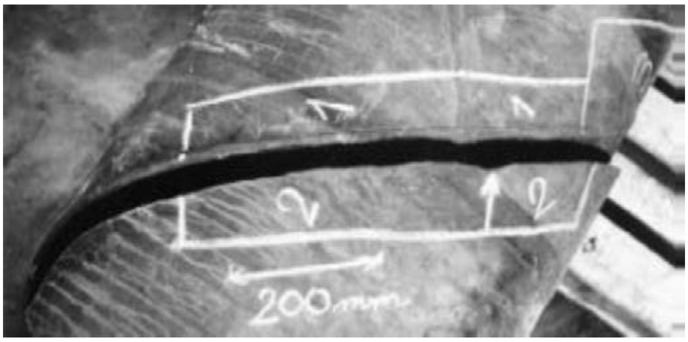

Fig. 1. A crack along the spirally weld

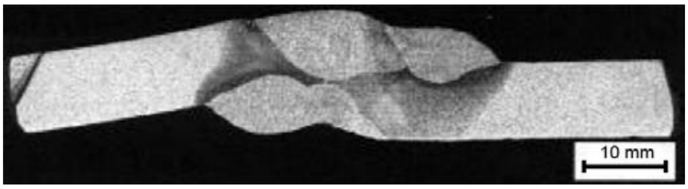

Fig. 2. Linear and opposite runs misalignment – poor workmanship

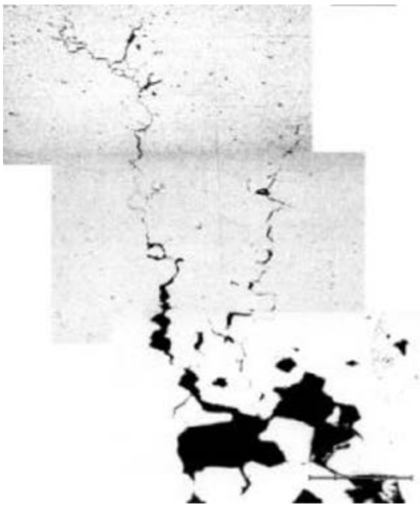

Fig. 3 Liquid metal embrittlement – Cu in the HAZ of repair weld

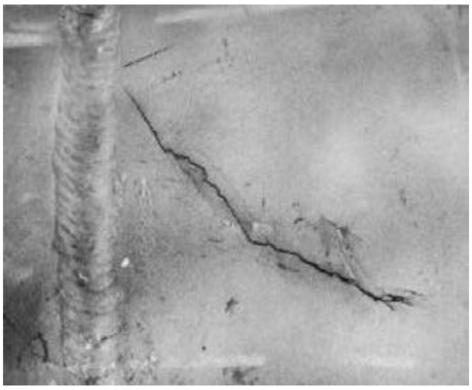

Fig. 4 Crack close to a girth weld

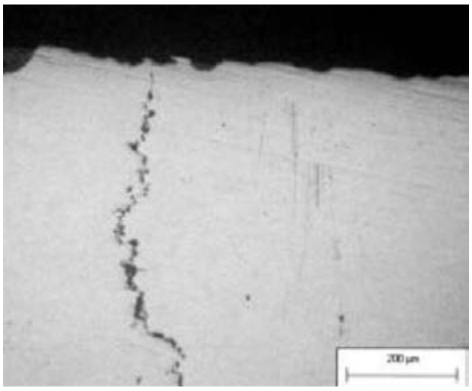

Fig. 5 SCC crack initiated in the outer surface

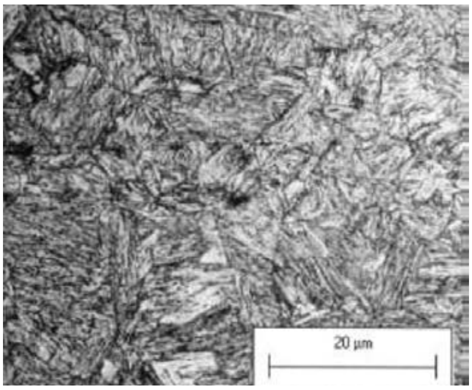

Fig. 6 Irregular microstructure at the end of a strip

Stress corrosion cracking

The next case of gas leakage was revealed on the same pipeline after a minor earthquake in East Slovakia. The 180 mm long crack occurred in the parent metal close to the girth weld (Fig.4). The crack was initiated by SSC cracks on the outer pipe surface (Fig.5) where the pipe insulation was damaged. It should be stressed that this section of line is buried in a slightly aggressive soil surrounded by a marsh. The occurrence of SSCC was supported by an irregular bainitic – martensitic microstructure of the parent metal at that place (Fig.6). It was found that the appropriate part of the pipe corresponds just to the strip end, which probably had been exposed to higher cooling rate after winding of the coil. The rest of the pipe had a regular polygonal ferritic – pearlitic microstructure. The fine fissures of SCC on the pipe surface are hardly detectable by pigging. The 15G2S steel also failed at the HIC test according to NACE TM 0284-2003, what means it is not suitable for transport of sour gas.

Overloading by additional bend moment

A cause of the excessive explosion (32 m of pipeline were torn out) was an additional bend load due to sudden landslide (Fig. 7). The crack initiated in a poor girth weld between a thicker seamless pipe (L 245 NB, t = 12 mm) and a thinner (t = 8 mm) 15G2S spirally welded pipe (Fig. 8).

Fig. 7 Breakdown of the 1st international gas pipeline (OD 720 mm)

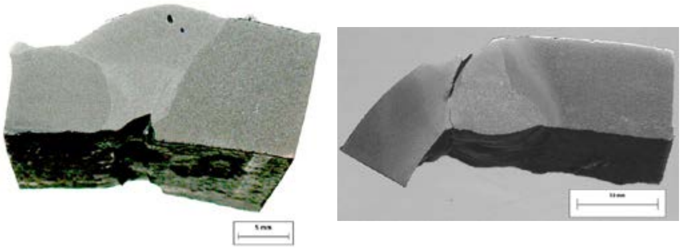

Fig. 8 Defective girth weld between seamless pipe (t=12 mm) and spirally welded pipe (t=8 mm)
a - lack of fusion, b - cold lap

Third transmission gas pipeline

Pipe steel delamination

This case deals with a very serious breakdown which happened on the third transmission gas pipeline. The OD 1220 × 13.5 mm spirally welded gas pipeline made of X – 70 grades are concerned. At the explosion, an approximately 22 m long section was torn to pieces and an extensive fire was quenched after 12 hours (Fig. 9). The concerned section of pipeline was subjected to insulation repair twice in the past. Thus, it can be supposed that bend loading was brought to the pipeline due to change in setting after burring. The crack initiated in a place where the girth weld meets the spiral weld. The metallurgical cause of cracking were expressive delaminating (partings) of the steel with typical central segregation bands (Fig.10 a and b). The starting impulse of failure was probably a sudden soil settlement as a result of snow melting at the beginning of Spring. Even modern steels made by continual casting and thermomechanical rolling are concerned, they may manifest unfavorable anisotropic properties as it happened with this steel. If we compared the impact energy results in the direction normal to strip rolling with the standardized direction normal to the pipe axis, the transition temperature T50J shifted from – 62°C to +20°C and a level of the upper shelf from 115 J down to 51 J.

Fig. 9 Situation after explosion

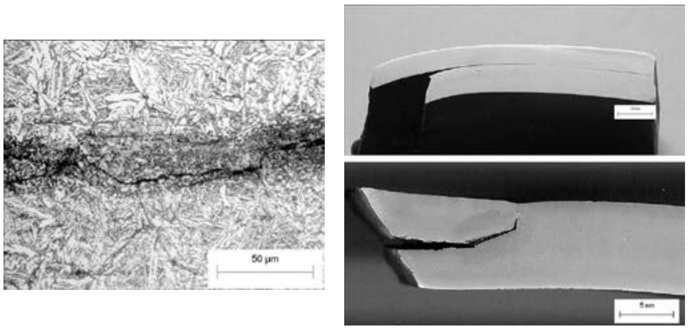

Fig. 10. a: Delamination of pipe wall in the HAZ;
b: Delamination of the BM

Fourth transmission gas pipeline

Cold strain hardening

The last case of failure did not happen during the pipeline service. It appeared at construction (laying) of the 4th transmission line OD 1420 × 18.6 mm spirally welded pipes made of X-70 steel grade.

During bending of pipes on site, a few pipes cracked along the spiral welds. The cracks of a length of up to 1 m always appeared in the same distance (~ 11.5 m) from the pipe end (Fig.11). The crack occurrence corresponded to an appearance of a cold impression on the outer spiral weld reinforcement (Fig.12 and 13). It was found that such an impression was formed due to incorrectly installed supporting steel rollers in the furnace used during pipe insulation. In this furnace, the pipes are flame heated up to 300°C prior to PE insulation, where they rotate (about 70 revolutions) on the rollers. In certain periods of manufacture, some pairs of rollers were taken out for repair, and therefore the pipe weight (about 12 tons) was only supported by the remaining pair (in 11.5 m distance). Since all pipe inspection is performed prior to pipe insulation, the impression could not be detected.

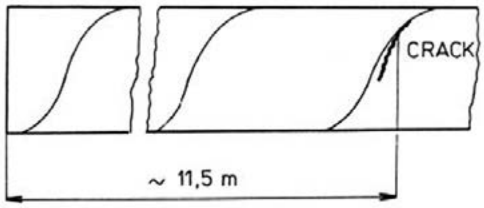

Fig. 11 Sketch of the fractured pipe

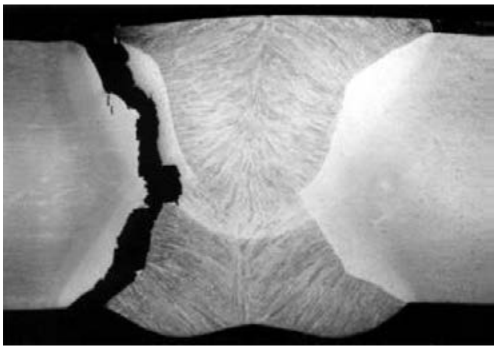
Fig. 12 Fracture of the spiral weld

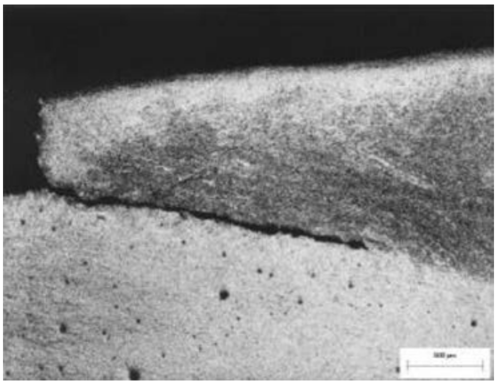
Fig. 13 Overlapping due to an impression

If such cold strain hardening of the weld reinforcement was located on the drawn side of the bend, the pipe cracked. This finding resulted in repeated ultrasonic inspection of all bent pipes manufactured in that period. The problem was, that the concerned pipes were already distributed in a section of about 150 km long, which were already buried under the soil. The 24 defective pipes were detected by UT, and of them, half were repairable and a half had to be replaced.

Conclusions

Slovak transmission gas pipelines are periodically inspected by pigging and inadmissible defects are preferably repaired onto in-service or unrepairable ones are cut out. Even that in the oldest lines some weld anomalies like high misalignment and metallurgical irregularities such as hard microstructure, steel delamination or LME embrittlement may have occurred. Such irregularities which are hardly detected at inspection may have an interaction effect to the additional bend loading (earthquake, soil settlement or sudden landslip) and may sometimes result in serious breakdown. That is why the most critical landslip areas are precisely monitored at present. So far, the 1st international transmission gas pipeline had no problem with transport of fairly clean Russian gas, but the situation may change when gas from the new resources (Egypt, Iraq…) will start to flow via a perspective Nabucco pipeline.