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Pipeline Integrity Maintenance and Diagnosis, with particular regard to Stress Corrosion Cracking

by Lucio Di Biase (Scientific Consultant, Milano, Italy)
Osvaldo Fumei (Solaria, Calvi, France)
Samuel.Lewis (University of Denver, 2199 Blvd Denver, CO 80208, USA)

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Pipeline Integrity Maintenance and Diagnosis, with particular regard to Stress Corrosion Cracking

Lucio Di Biase, Scientific Consultant – Italy (Past President of CEOCOR 2009 - 2015)
Osvaldo Fumei, Direttore Tecnico – Solaria – Lieu dit Croccicchia – Route d'Ajaccio 20260 Calvi – France
Samuel Lewis - University of Denver 2199 S. University Blvd Denver, CO 80208

Foreword

Oil and gas pipelines laid in the 60^{ies}-70^{ies} were usually coated by using either bituminous materials or similar (e.g. Coal Tar) or Polyethylene cold applied tapes over the ditch (e.g. Polyken); the repairs were often made by using bituminous tapes (e.g. Viapol) or cold, hand applied tapes. These types of coatings, if not properly applied, were prone to give rise to two dangerous phenomena:

- Disbondment of the coating from the metallic surface of the pipe;
- Shield effect towards the Cathodic Protection Current.

The combined effect of these two factors, when particular environmental and mechanical conditions are both present, can affect the pipeline with Stress Corrosion Cracking.
In the 90^{ies}, a particular pipeline system was quite famous for the Stress Corrosion Cracking phenomenon: the TransCanada Pipelines. On these pipelines the effect of SCC was particularly heavy due to the fact that long sections of the pipelines were affected because the mechanical stress was due the variable pressure of the transported product.
Being the stress radial, the relevant cracks were longitudinal and this also brought to worsen the integrity of the whole pipeline system, sometimes leading to the longitudinal rupture of the pipeline for lengths sometimes up to a few hundred meters.
Generally, for Oil and Gas pipelines all over Europe (and particularly in Italy) the radial stress due to the variable pressure has never been a problem; the only stress possible has always been due to external factors such as landslides or soil settlements.
As these phenomena imply longitudinal mechanical stress, the cracks are oriented horizontally.
For pipelines provided with bituminous coatings, another particular occurrence has been ascertained: the curves on these pipelines were often made by cold bending the pipe spool with a special machine (Fig. 1).

Fig. 1 – Pipeline Spool Bending Machine

For pipelines laid in mountainous areas in the year’s seventies (1960-1970) this was quite a common technique. Unfortunately, this process usually has two main inconveniences:

- The metal of these curves was cold stressed mechanically;
- The coating was usually detached from the metal (especially bituminous or coal tar coatings);
- The repairs, made usually by wrapping cold applied tapes, constituted a barrier effect to cathodic protection current.

1.1.– Studies and Researches

A large research was launched around the end of last century, also involving Universities, Research Centers, and the consultancy of one of the highest world's leading expert in this field (Prof. Redvers N. Parkins, Newcastle University, UK 1925-2004). One of the most important results of the researches carried out in collaboration with Newcastle University is shown in Fig. 2.

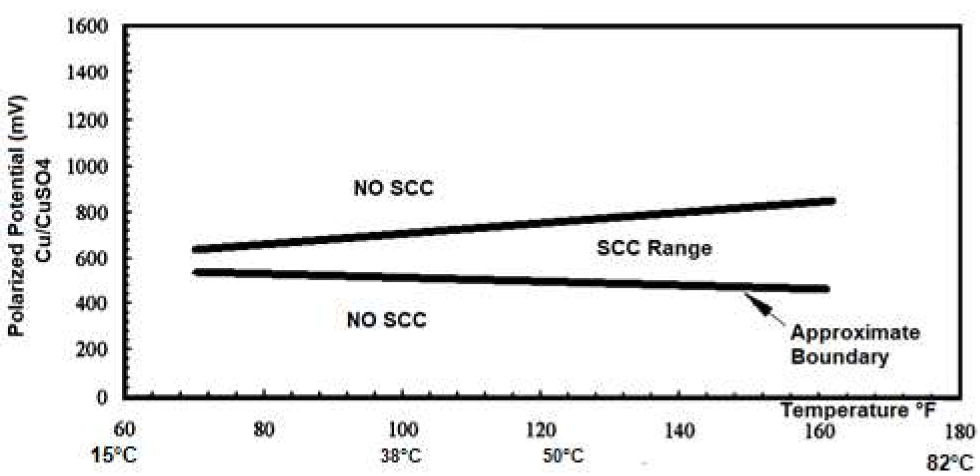

Fig. 2 – Boundaries Potential/Temperature for SCC to occur

According to various laboratory studies and field observations the following assessment and results have been achieved:

- the approximate boundaries within which Low and High pH SCC can occur have been quite well defined (Fig. 2);
- the content of CO_2 in the soil is directly responsible of the environmental conditions which can develop the SCC phenomenon;
- while in the High pH SCC the Hydrogen has no roles, in the Low pH SCC Hydrogen has a fundamental importance.

In Italy, information on previous cases of Stress Corrosion Cracking were taken throughout the whole territory. By that time, only one gas pipeline was known as being affected, some year before, by cracks due to Stress Corrosion Cracking. Some oil pipelines had been subject to HISCC (Hydrogen Induced Stress Corrosion Cracking), due to the presence of hardened pipes (manufacturing defect due to the cooling of the steel during the formation of the tube) in correspondence of faults in the coating.
In order to foresee where the Stress Corrosion Cracking Phenomenon could be in course, a large study was made by taking into consideration, among many existing pipelines, the following elements:

- Age of the pipeline;
- Coating type;
- Pipeline laid in the 60 – 70ies;
- Pipelines having a diameter up to 20” which could have been curved by using the Pipeline Spool Cold Bending Machine;
- Search of positions where these curves could present, contemporaneously with soil movements (i.e. landslides or soil subsidence).

A 16” pipeline laid in a mountainous territory was chosen as first site for this study.
A leak had occurred in 1981 on this pipe, due to some cracks found along the very downhill part of the area around 1 km length, known as being affected by a slow landslide.

The pipeline characteristics were the following:

- Pipe Diameter 16”
- Pipe Thickness: 7,92 mm
- Steel type X52

After the leak, during the repair operation when the pipeline was cut, one of its extremities was pulled back downstream by more than 20 cm, demonstrating that the mechanical stress due to the landslide was really quite strong and still present.
On the other side, a mechanical calculation was made by also considering the existing cracks, whose results were not a risk for the pipeline integrity.
As the intelligent PIG survey was already foreseen and programmed, it was decided to make this inspection as soon as possible so that a deep observation of these cracks could have been possible from the results of the intelligent PIG survey.

1.2.– Field measurements, study of pipeline book – 16” Gas Pipeline

Some Strain Gauges and Inclinometers had been installed in order to monitor the development of further movements and relevant Mechanical Stress on the same pipe during time. These measurements were taken during a very long period, with the following results:

Trend Inclinometers:	10 Mpa/y
Trend Strain Gauges	0,6 cm/y
Average Landslide Speed	24,7 mm/y

The pipe-book of this pipeline was thoroughly verified in order to localize the curves which could have been made by using the Pipeline Spool Cold Bending Machine.
A careful Coating Fault survey was performed along the entire leaning section (ca 1.000 m) by using the Direct Current Transverse Gradients Voltage Technique (DCVG).
When using this technique, the measurements along the pipeline are usually performed every 5 m; if some faults are evidenced, the Transverse Gradient Measurements are intensified to every meter on the area.

Over the same sections, further measurements were performed:
- depth of the pipeline;
- soil resistivity;
- pH measurements;
- RX soil analysis.

Territory characteristics were thoroughly studied and the effect of the landslide was easily demonstrated by various observation of the soil such as:
- The shape of some trees, the particular conditions of a farm house;
- The presence of water containing CO_2 (sparkling water);
- By observing the data of the pipeline book, some curves were localized, which had been realized by using the Cold Bending Machine;
- The fault location survey evidenced that in correspondence of these curves, the coating was damaged, sometimes quite heavily.

1.3. – Excavations and results

Following the results of the investigations, 5 excavations were performed along the leaning territory, starting from the top of the hill which represented the most stressed section, opening a total of 18 pipeline spools (the length of a pipe spool is usually 10 m).

- The visual inspection showed that the original coal tar coating was broken during the bending of the pipeline spool and a cold applied tape was wrapped around the pipe to repair the damaged coating, by forming a rolled layer of polyethylene, without any bonding with the metal (Fig. 3).

This fact determined the following conditions:
- The coating was not bonded to the metal of the pipeline;
- The CP current was unable to reach the metal due to the shield effect;
- The environment was rich of CO_2, thus reaching the pH for developing the typical
- cracks due to Low pH (or near neutral) SCC (pH 6 – 7).

At 55 m downstream the start of the survey, a group of circumferential cracks have been found. A total amount of 25 groups of cracks has been found and some others isolated along the various spools. The worst crack was 22 cm length, with a depth of max 2 mm, measured with an ultrasound scanner.

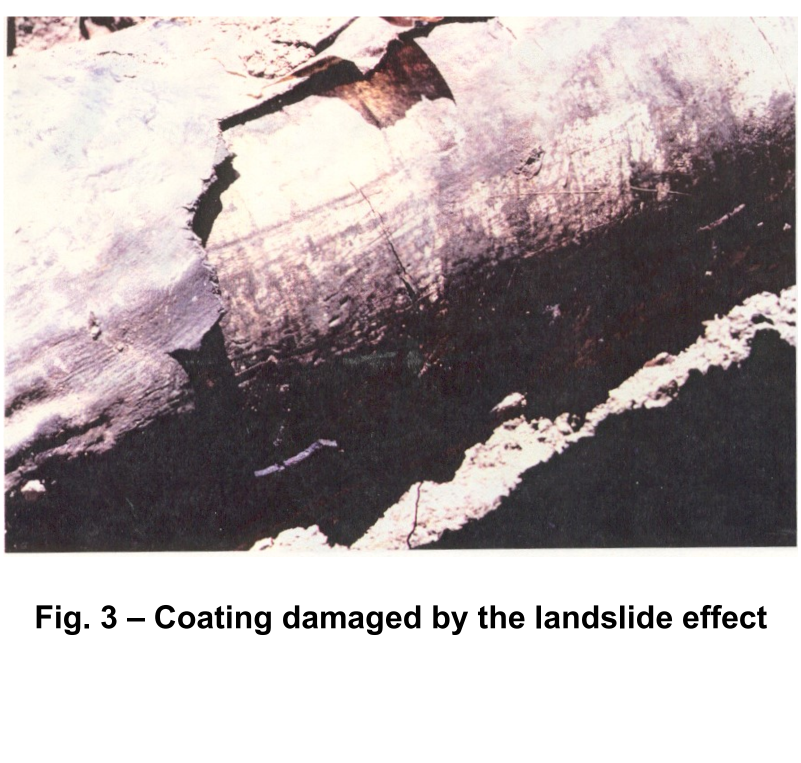

Fig. 3 – Coating damaged by the landslide effect

1.4. – Comparison with intelligent Pig survey

A comparison was made between the results of the data obtained from a magnetic flux leakage PIG (Intelligent PIG) in correspondence of the cracks on the pipe. It was observed that:

- The very small signals determined by the existing cracks were automatically excluded through the existing software, thus completely eliminating the possibility of detecting their presence;
- Upon our request, the PIG Company provided the “raw” data; when analyzing these data (not filtered), the position of the cracks corresponded perfectly to the ones really found by the PIG, but the signals were very weak;
- The cracks were too small and not yet through the complete wall thickness, so that the lack of metal was really very small, as always happens in SCC cases;
- In correspondence of the cracks the signal was very sharp, and could localize them very precisely. But, even today, due to the fact that per default the minor defects are excluded from the results, intelligent PIG is not able to localize this type of cracks. Also, if the Raw Data are observed, it is quite difficult to distinguish the small signals due to the Cracks from the very crowded background noise.

Then, the Intelligent PIG (Magnetic Flux Leakage PIG) by that time was not able to detect this type of cracks, as it is today.

1.5. – Results of Laboratory Tests

The results of laboratory tests were the fracture surface appearance observed in pipes taken from service was reproduced suggested that, if special attention is focused on the mechanical factors rather than the chemical parameters, the term ***low pH stress corrosion cracking***, normally used to define this cracking phenomenon, is inappropriate and can be misleading. If greater attention is paid to the strain rate and loading parameters, low pH in buried pipelines can be reproduced in laboratory tests (with no major influence of the solution pH) and the phenomenon can be better described. Through a comparison with data that describe in literature the behaviour of landslides, the hypothesis that crack growth occurs only during short intervals, followed by long periods where only generalised corrosion takes place, can be proposed. This is consistent with the features observed on the fracture surfaces of pipelines that failed in service.

1.6. – Proposed Protocol

According to the results of our field studies, laboratory tests and researches on the subject of Low pH Stress Corrosion Cracking, the following protocol has been proposed for a complete characterization of the phenomenon in the real field.
As a first approach, the pipelines laid in the 60 - 70^{ies}, coated with bituminous or cold applied tapes should be searched among those where SCC phenomenon could mainly occur. A thorough observation of the Pipeline Book is to be made in order to carefully localize in the real field, the presence of pipe spools at mayor risk (mechanical stress, disbonded coatings). Then, the following observations and measurements are suggested:

- localise the sections where the higher mechanical stress is supposed to be (results of strain gauges measurements if existing, hydro-geological and geo-physical observations, verify the presence of cold bends, the presence of landslides - soil settlement and similar);
- localise sections where the coating is bound to be disbonded (type of coating, clayey soils, spool curved by Cold Bend Machine and repaired by using cold applied tapes);
- perform precise electrical surveys along these sites (e.g. by using the Transverse Voltage Gradients Technique every 1 or 2 metres);
- make digs laterally on the pipeline ditch down to the pipe depth so that possible presence of water can be observed;
- perform measurement of soil resistivity at different depths;

- take water and soil samples for XRD analyses in the laboratory;
- measurement of water pH (portable pH-meter or paper pH meter with high resolution);
- determination of CO_2 content (by using selective portable CO_2 meters);
- determine the content of total bicarbonate (HCO_3) in the water; determine the chlorides content;
- determine the sulphates content;
- determine the content of ions (Ca, Mg) wherever possible, directly in the field.

1.7 – Conclusions

The occurrence of SCC is possible when various concurrent factors are contemporaneously present:

- Environmental conditions;
- Lack of cathodic protection (usually due to disbondment of the coating);
- Mechanical stress.

Higher Susceptibility to Low or Near Neutral SCC (in order of importance):

- type and level of mechanical stress;
- coating type (in relation to the disbonding);
- presence of water table at the pipe level (even when discontinuous);
- pH value of water table (range of 5,5 – 7);
- higher content of CO_2 and bicarbonate (HCO_3^-) in the water;
- clayey soils;
- higher chlorides concentration in the water;
- lower concentration of alkali-soil (Ca, Mg);
- lower concentration of sulphates in the water;
- higher soil resistivity.

The Temperature does not influence the occurrence of Low or Near Neutral SCC.
Usually, the higher susceptible soils are those normally classified as “low aggressive soils”.
According to the results evidenced in the paper, a thorough examination of all the above said parameters will allow to choose sections where samples excavations could be made so that a further examination is possible directly on the pipeline in order to localize possible existing cracks.