THE TAP PROJECT

F. Marchesani, E. Donati – Snamprogetti, Italy
C. M. Spinelli – Eni Gas & Power, Italy
G. Mannucci, G. Demofonti – CSM, Rome, Italy
M. Cabrini, T. Pastore – Università di Bergamo, Italy

ABSTRACT

There is general consensus that the gas market will increasingly characterize the energy economy over the coming decades. International energy supply is currently considering transportation of large volumes of natural gas from remote regions to end users, over very long unprecedented distances (4 to 6000 km) across harsh environments. A competitive option of gas-to-market can be High Pressure (greater than traditional 8 to 10 MPa) and High Grade (X80, X100 or even higher) pipelines.

ENI initiated in the mid 90'ies a huge research effort on the subject and is currently performing a 3 years project, called TAP (Trasporto gas Alta Pressione), with the aim to study constructability and field performance of modern high grade line pipe in operation, as well as to define and specify new technologies for near-to-come long distance natural gas pipeline projects.

Despite the significant effort spent in recent years on the X100 issue, a series of open questions, mainly regarding integrity of high grade line pipe in operation over the envisaged life span in real environment, is still under discussion. The TAP project is aiming to fill this gap, by integrating laboratory and full scale experimental program, including the realization and simulated operation of a X100 pilot section in the CSM full scale test station, Pedasdefogu, in Sardinia island, Italy.

Operation includes typical fluctuation in pressure over a period of time, 18 months, sufficient to detect line pipe susceptibility to Environmental Assisted Cracking (EAC), accounting for different wall thicknesses/usage factors (0.72 and 0.80) as well as presence of typical defects from third party interference.

The paper introduces the TAP project, and particularly describes main aspects of the laboratory and full scale experimental campaign addressed to Environmental Assisted Cracking.

KEYWORDS

TAP, X100, High Pressure Gas Transportation, Environmental Assistance Cracking, Third Party Damage.

INTRODUCTION

It is well established in a number of independent investigations that high pressure gas pipelines, made of high grade steels, provide a gas-to-market option competitive for large volumes of gas (>15 10^9 Sm^3 per year) over long distances (>4000 km). The most important International Gas Companies have been involved, since end of 90', in research activities aimed to verify High Pressure, High Grade steel potential, and define needs to fill existing technological gap /1,2,3,4,5/.

Initial efforts were devoted to understand line pipe production capabilities, involving steel makers and checking achievable pipe steel characteristics (strength, toughness, weldability, ductility,…). Preliminary production trials proved that X100 line pipe meeting the established tensile requirements, can be made improving the traditional TMCP steel production technology. At the

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beginning of 2000, the capacity to produce adequate, for gas pipeline industry, steel for longitudinal welded UOE pipes with grade X100 /6, 7, 8/, can be considered as promising.
In parallel, a series of research were addressed to in-service performances of high grade steel pipe. Fracture propagation control drove most of the experimental activities, and scattered "Full Scale Burst Test" results pointed out that high grade pipe steels are at the upper capability borders of "self arresting pipe solution". Crack Arrestor testing are currently considered as mandatory /9, 10/. Laboratory weldability tests and first field welding trials highlighted X100 as not significantly different from traditional steel grade. This fact opened the possibility to apply well known pipeline welding processes (Automated GMAW, SMAW, FCAW), and exploiting commercially available consumables from several brands /11/.

In spite of intense research activity, a series of questions linked to construction, mechanical design, steel and welding specifications, working factors in relation to pressure containment and bending deformability, geohazards etc.., are still open. Major concern is the pipeline structural integrity, in service over the envisaged life span (min.30 years), in real environment.

The usage factors for pressure containment, as well as line pipe capacity to sustain global and local deformations, are closely linked to investment costs and reliability in operation. A series of studies confirms the major role of steel on costs, and such a new material can be adopted only when full confidence on satisfactory performance in operation, is achieved. At the same time international design guidelines currently in force did not foresee, in their development particularly with respect to material usage allowance criteria, the mechanical properties achievable for TMCP high grade line pipe steels.

Further concerns are related to the susceptibility of high grade steels to hydrogen embrittlement and environmental aggression, in case of severe local deformations or pipe wall surface damages, as those caused by third party interference, and under the sustained action of the internal pressure.

ENI, continuing a research stream dated back 1996 /1/, in 2003 started a new research project, called TAP (Trasporto Alta Pressione, High Pressure Transportation, /12/). TAP project is leaded by Snamprogetti, and is carried out in cooperation with competent divisions of ENI, Saipem, Snam Rete Gas and Enitecnologie, involving CSM as major full scale test centre and with the contribution of the University of Bergamo, Italy.

The TAP Project has been divided into five tasks, as listed herebelow:

- ✓ -***Task 1 "X100***". The aim of this task is the investigation on technical-economical-financial aspects related to "Long distance gas transportation pipeline technology", particularly with respect to international and national codes for high grade and high pressure issues for trans-national continental gas pipelines connecting remote production areas to consumption markets.
- ✓ -***Task2 "Technological Upgrading".*** The aim of this task is the collection and analysis of technological background developed worldwide, and the development of new themes (e.g. monitoring of the pipeline crossing harsh environments) coming from near-to-come project needs, to be executed by high competence groups working in ENI divisions and controlled companies, and /or strong partnership with high skilled research centers.
- ✓ -***Task3 "Feed".*** The aim of this task is to develop and prove, through front end engineering development studies along strategic routes, the engineering approach needed on one hand, to provide a robust technical solution for anticipating the satisfactory operational performance of the pipeline in realistic environments, whether mild or hostile, on the other hand to allow a realistic estimate of investment and operational costs..

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- ✓ ***-Task 4 “X80 Demonstrative”.*** The aim of this task is to verify specification, production, handling and construction aspects linked to the first adoption of EN 10208-2 L 555MB (API X80) steel pipeline section, in the Snam Rete Gas Italian pipeline network.
- ✓ ***-Task5 “X100 Pilot Section*** “. The aim of this task is to evaluate the fabrication, constructability and in service behaviour of a X100 pipeline, by building a pilot section that is put in service to test (and monitor) a realistic realization of X100 gas pipeline over the time. Specific issues that will be tested are the in service behaviour of special (and steel grade lower than X100) components (hot bends, tees, dielectric joints and other fittings), coupled to X100 line pipes and field bends. The test section includes different wall thicknesses, as main objective of the experimental activity is the definition of rationally based working factors for X100 line pipes, in relation to local steel deformability and environmental assisted fracture behaviour on damaged pipe in realistic operation condition. At the end of the simulated operation, line pipe and crack stopper capacity to arrest running shear fracture will be tested (burst test).

X100 PILOT SECTION DESCRIPTION.

The pilot section of X100 pipeline has been recently constructed in the CSM full scale testing facilities at Perdasdefogu, Sardinia (Italy). The pilot section is made using X100, 48” (1220mm) OD pipes. Three major pipe mills (Europipe, JFE, Nippon Steel) have been involved; they provided X100 UOE steel pipes with different wall thickness values, which are 16.6 and 18.4mm, and different coating types (Fusion Bounded Epoxy and High Density Polyethylene). In particular the two wall thicknesses allow to get two different usage factors, 72% and 80% of the SMYS, over the 18 months of simulated operation. The line is about 800 meters long, as shown in Figure 1, and is composed by two sections to study various specific issues of the X100 pipeline.

The attention is mainly focused on the effect of the usage factor, that is the working circumferential stress mobilized to resist the internal pressure (in relation to the steel characteristic strength), both in integer pipes in presence of sweet environment and in damaged pipes in presence of normal and aggressive environment, on the safe life operability of a high pressure pipeline crossing harsh environments.

The pilot line (buried as a conventional line) will simulate real operating conditions for about 18 months, with the pressure ranging between 13.5 and 15.0 MPa. The load frequency is selected:

- ✓ -to simulated, at the end of experimental period, several years of operative service;
- ✓ -to assure a low strain rate operative condition, $< 10^{-6}\ s^{-1}$, since one of the main issue to be studied is EAC phenomena, which are strain rate dependent.

Water as pressuring medium instead of gas is used for safety reason, providing of course to prevent any internal corrosion phenomena due to the water presence.

First section (named line A as in Figure 1) is shown in Figure 2 and is built using X100 pipes, field and hot bends and tees, according to the best workmanship standard, as needed for a real long distance gas transmission pipelines. Two crack arrestors have been inserted inside the line, because at the end of the “operating period” a full scale ductile fracture propagation burst test will be performed to study the fracture propagation and arrest behavior of X100 pipes after a significant time interval in service. As main target, it is intended to qualify crack arrestor capacity after a relevant “operating period”. It is well know that this class of steel does not guarantee the fracture arrest basing upon pipe body toughness only. As a real gas pipeline, line “A” section will have a standard cathodic protection, about -850 mV vs SCE, and it will be monitored using a remote system. Figure 2 shows line A as built.

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The second section (named line B as in Figure 1) is shown in Figure 2, and is dedicated to study the influence of the environment on the long term structural resistance of damaged pipes. Third party damages affecting the steel, pipe coating rupture and failure of field joint coating, are investigated. As far as third party damages are concerned, two different kinds of mechanical damage are studied, which are gouge and dent & gouge defects (Figure 3), realized using the full scale test aggression rig of Figure 4. For large diameter-high thickness (>15.0mm) and high grade steel, the puncture/failure of the pipe is a very remote event. The delayed failure of a pipe that presents a permanent damage, not resulting in an immediate failure, can occur if coupled with the environmental action (over cathodic protection for instance) and stress rate variation (due to the internal pressure fluctuation). The same can be said for other types of damages considered, which are for instance the presence of on purpose realized coating "defected zones" upon few of the girth welds.

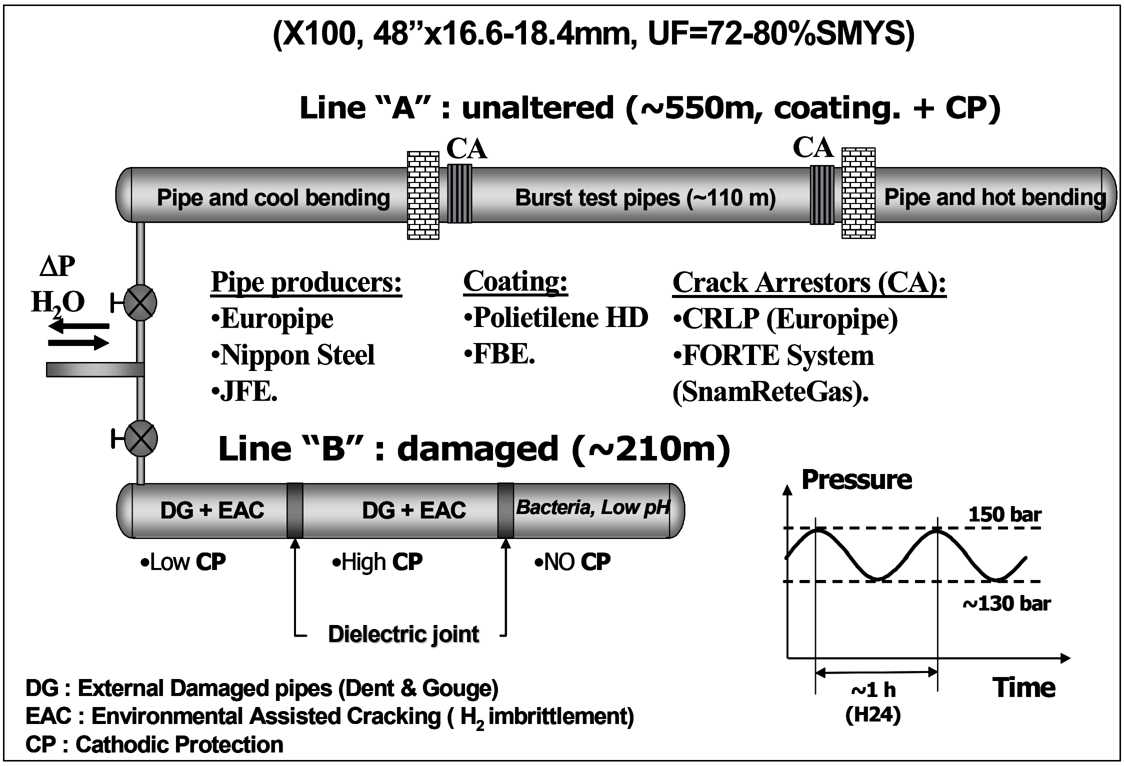

Figure 1 - X100 Pilot Section formed by two lines , "A" and "B"

It is recognized that the level of cathodic protection applied can play a not negligible role in the EAC phenomena; for this reason line B will be sectioned in three different zones by inserting dielectric joints. Three different Cathodic Protection (CP) levels are applied: standard CP level (about -850 mV), very high CP level (about -1200 ÷ -1300 mV vs. SCE) and no CP. In particular the part of line B without cathodic protection is used to study EAC phenomena (like low pH that can take place when the anti corrosion coating is detached/dis-bonded and electrically shields the steel from the cathodic protection). At the end of the test period, the line B will be sectioned in three parts and pressurized (with water) until the rupture will be achieved on each sub-section, in order to investigate the residual pressure containment resistance of such damaged pipes.

At the moment both lines A and B have been completed and are subjected to internal pressure fluctuation from 13.5 to 15.0 MPa with a frequency of about 10 cycles per day.

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Figure 2 – X100 line A (on the left) and line B (on the right) fully instrumented.

Figure 3 - Example of third part damages realized on line B coated pipes (FBE coated pipe on the left and HDPE coated pipe on the right).

EXTERNAL DAMAGE RESISTANCE OF X100 PIPE AND ROLE OF ENVIROMENT ON DELAYED FAILURE

The external interference and related damages on pipes are main causes of failure for onshore gas pipeline in the world. The impact by an excavator can cause either a through thickness (puncture) with an immediate loss of containment or a surface defect on the pipe that, according to the defect dimensions and line pipe characteristics (geometrical and material properties), can evolve into a leak or break. A surface (i.e. part wall) defect can be classified as a dent, a gouge or a combination of the two. The dent and gouge are recognized as the most dangerous part wall defects, mainly because the deformation of the pipe wall during the impact acts as a stress concentration factor for the gouge resulting in a more severe defect than the single dent or the single gouge. In addition the spring back effect, experienced by the dent during the unloading, can cause subcritical crack growth at the gouge bottom leading to delayed (i.e. not immediate) failure, if loading conditions including variation, environmental action, secondary loads or imposed deformations, are present.

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Most of the historical research activities on the subject carried out by several Companies and Institutes (AGA, BMI, EPRG, BG, GdF, Gasunie, Mannessmann, etc.) were mainly aimed at understanding failure mechanism of mechanical damaged pipeline rather than investigating the parameters controlling the defect creation process /13, 14, 15, 16, 17, 18, 19, 20, 21/. Despite the large amount of work already performed, few data, from in-field experiences or laboratory research activities, are available for relating the excavator parameters to the defect creation process and dent and gouge defect dimensions. This is particularly true for X100 pipes, which have only recently appeared on the market.

Moreover, environmental effects on the resistance of damaged pipes is not well understood; some delayed failures were observed after third party damage on gas transmission pipelines, possibly attributed to aggravating effects of cathodic over-protection. Two key factors that seem to play a relevant role are cathodic over-protection and low frequency cyclic loads (due to internal pressure fluctuations). The failure mechanism is not completely clear so far, especially as far as very high grade steel pipe is concerned. Such high grade steels (≥X100) are in fact suspected to be more susceptible to hydrogen embrittlement than lower in grade steel pipes, and since hydrogen embrittlement is one of the more likely candidate failure mechanism for justifying the above mentioned delayed failures, the study of the resistance of X100 third party damaged pipes in presence of the combined action of environment and pressure fluctuations, is particularly important.

To fill this lack of information, an aggression test process reproducing as realistic as possible the real excavator-pipe interaction is fundamental and it can be used to assess the capability of a given pipe to successfully survive from an aggression by a given excavator class. CSM in recent years has designed and realised a specific full scale test aggression rig, named Simulator (Figure 4), together with the relevant testing methodology /22, 23, 24/. In addition a 3D laser device is used to accurately measure the damaged pipe external surface and to work out the main defect geometric characteristics. Measuring the external pipe surface before and after the test, the actual shape of the damage can be obtained as a data matrix from which further post-processing phase (as for instance FEM analysis) can be done.

In the following some preliminary full scale and laboratory experimental results obtained about the behaviour of X100 pipe material with respect to:

- third party damage resistance;
- the influence of loading variation / environmental action on delayed failure;

are reported and compared with available data on lower grade steels.:

Third Party Damage Resistance of X100 vs. Lower Grade Steel Pipes

Third party damage resistance, from both experimental and analytical point of view, was investigated for both conventional low grade gas steel linepipes and, in a more limited extension, high grade X100 pipes. A comparison between the two appears to be very interesting since it can be used for obtaining first indication about X100 pipe tendency to exhibit higher or lower susceptibility respect to this issue.

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Figure 4 - CSM’s full scale test aggression rig “Simulator” whit a FBE coated pipe ready to be damaged (TAP project)

Damaging tests of interest were performed on API X65, 36” OD x 14.9 mm wall thickness pipe and on X100 36” OD x 16.4mm wall thickness pipe. The simulated excavator was a large one, with about 33 tons of operating weight. Table 1 reports main properties of the tested pipes, while main parameters adopted during the external damage testing are reported in Table 2. Pipe samples were pressurized with 100% water for safety reason; the use of water instead of gas, looking at the very low amount of medium volume which is compressed during the impact, does not affect significantly the result. Note that both pipes, even though different in steel grade, exhibit the same diameter (36”) and were pressurized at the same usage factor (about 50%SMYS). Main results are reported in Table 3.

OD (“)	WT (mm)	Nominal steel grade	Rt0.5, round bar, transverse (MPa)	Rm, round bar, transverse (MPa)	CharpyV, full size, transverse, ambient temperature (J)
36	14.9	X65	504	589	110
36	16.4	X100	663	786	295

Table 1 – Main pipes properties

OD (“)	WT (mm)	Nominal steel grade	Excavator simulated	Tooth type	Internal pipe pressure, (bar)	Usage factor (%SMYS)
36	14.9	X65	FH 330	New	75	51
36	16.4	X100	FH 330	New	121	49

Table 2 – Main external damage tests parameters

OD (“)	WT (mm)	Nominal steel grade	Max residual dent (mm)	Max gouge depth at impact (mm)
36	14.9	X65	2.7	2.2
36	16.4	X100	0.8	1.1
			0.5	0.5

Table 3 – Main external damage tests results

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In general it can be noticed that, for a given excavator class, the X100 pipe undergoes an overall dent and gouge damage lower than a X65 one. This result is in line with the common feeling, since third party damage is first of all a sort of “macro-hardness”, and from this point of view the higher the tensile strength of the pipe (and this is the case of X100 pipe with respect to the lower steel grade pipe), the lower the damage that can be created. In spite of that good behaviour of the X100 pipe, it has to be noted that a permanent dent and gouge damage has been anyway created; this comes from considering a potential impact by a large mass (33 tons) excavator, an event that can happen during the life of a real line.

Role of Environmental Action and Loading Variation on Delayed Failure of X100 Damaged Pipe by Full Scale Test

In order both to investigate the full scale behaviour of X100 damaged pipes when subjected to soil aggressive action, (over) cathodic protection and internal pressure fluctuation, and to improve the knowledge on the phenomenon (particularly to better anticipate/manage what will happen in the X100 pilot section in Sardinia over a period of time), the X100 36”x16mm damaged pipe mentioned before has been used to perform the first long term full scale test in environment. The test was carried out at the CSM laboratory in Roma, Italy. Severe in service conditions, both in terms of stress applied (stress range due to internal pressure fluctuation: max hoop stress 100% SMYS, minimum hoop stress 72% SMYS) and environmental aggression (artificial NS4 solution with over cathodic protection at -1230 mV vs. SCE) were therefore selected.

The X100 damaged pipe sample was instrumented with strain gauges (Figure 5) for monitoring damage evaluation during the test where internal pressure fluctuation cycles were applied with a local strain rate of about $1.4 \cdot 10^{-6}$ s^{-1}. Strain gauges position were defined by means of finite element analysis of the damaged pipe starting from the result of the 3D optical device measurement as previously mentioned; mesh for the FEM analysis was directly derived from the surface scanning measurements, and this allowed to identify the areas close to the defect which are more sensible with respect to pressure fluctuation.

A total number of 42.600 cycles was suffered by the damaged pipe before fails. A compliance variation was recorded by strain gauges in the last part of the test just before the failure. Photo of the failed sample is reported in Figure 6. It has to be noted that several additional cracks were detected close to the main one.

The examination of the facture initiation area was carried out by using the SEM analysis; the environmental action (hydrogen embrittlement) has been clearly identified over the fracture surface as depicted in Figure 7.

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Figure 5 – Dent and gouge damage on X100 pipe with indication about strain gauges and failure location (red circle), dimension in mm.

Figure 6 – View of the X100 damaged pipe after the failure

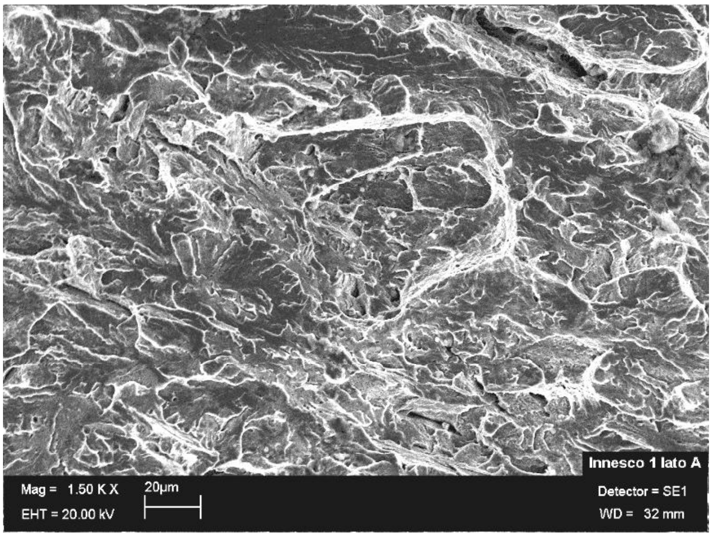

Figure 7 – SEM image of the appearance detected in the fracture area of the X100 failed pipe

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Role of EAC Resistance of X100 Materials by Slow Strain Rate Tests

In parallel with the full scale test in environment carried out by CSM, the University of Bergamo investigated the behavior of such high grade steels by an extensive laboratory testing campaign.
In particular Slow Strain Rate (SSR) tests using cylindrical tensile specimens have been carried out. Both Hydrogen Embrittlement (HE) and Near Neutral Stress Corrosion Cracking (NN-SCC) susceptibility was studied, using different solutions, the 3.5% NaCl solution and the NS4 solution proposed by Parkins for simulating soil moisture. Tests were executed at room temperature with different values of cathodic polarization (in the range –0.8 to –2 V vs SCE). The results were then compared with the behavior of traditional pipeline steels with grade in the range of X52 to X80.

The tests were performed on five X100 steels of different Steel Makers. All the steels have similar elongated banded microstructure with fine ferrite oriented along the longitudinal direction, even if different microstructures was noted between the ferrite bands.

As mentioned above the tests were carried out in 3.5 g/l of NaCl and in NS4 solutions. NS4 solution was first published by Parkins as the medium composition of the soil moisture found under disbonded coating, in areas with NN–SCC phenomena. Its composition is: 0.483 g/l NaHCO3, 0.122 g/l Kcl, 0.18 g/l CaCl2, 0.1 g/l MgSo4. The pH is 8.3, and decreases at about 6.9÷7.1 after saturation with gas mixture of nitrogen containing 0.05 atm partial pressure of CO2 /26/. The specimens were tested at the free corrosion potential, during NN-SCC test in the NS4 solution with CO2 saturation, and in the range –0.8 V to –2 V vs SCE, during HE tests under cathodic protection in aerated conditions. All the tests were performed at room temperature.

The tests were performed on cylindrical tensile specimens and with strain rates applied in the range from 10^{-3} to 10^{-7} s^{-1}. The EAC effects were assessed by using ductility measurements and fracture observations, i.e. presence of brittle areas on the fracture surface and secondary cracks. Plastic strain to failure calculated from load/elongation curves (ε_p) and Reduction in Area (RA) were normalized to the values in air tests (ε_n , RA_n).

As far as test results are concerned, it was found that at very negative potentials, the fracture surface was characterized by extensive brittle areas of crack growth. Several secondary cracks perpendicular to the tensile load were noted. Less negative potentials reduce the environmental effect although brittle propagation and secondary cracks could again be observed. The load elongation curves approach the trend of air tests as potentials increase above -0.85 V vs SCE. Under these circumstances, small secondary cracks oriented at about 45° to loading direction can only be detected in the necking zone of the specimens, with brittle propagation limited to few micrometers. Above these potentials, the behaviour becomes equal to that of the specimens tested in air. Full ductile ruptures were found (Figure 8).

Figure 9 shows qualitative trend of critical potential inducing hydrogen embrittlement for each steel as a function of strain rate. The grey area represents the field of hydrogen embrittlement insurgence for traditional ferritic/pearlitic linepipe steels. It can be noticed that the general trend observed was that lower the strain rate applied, higher the potential value found to be significant.

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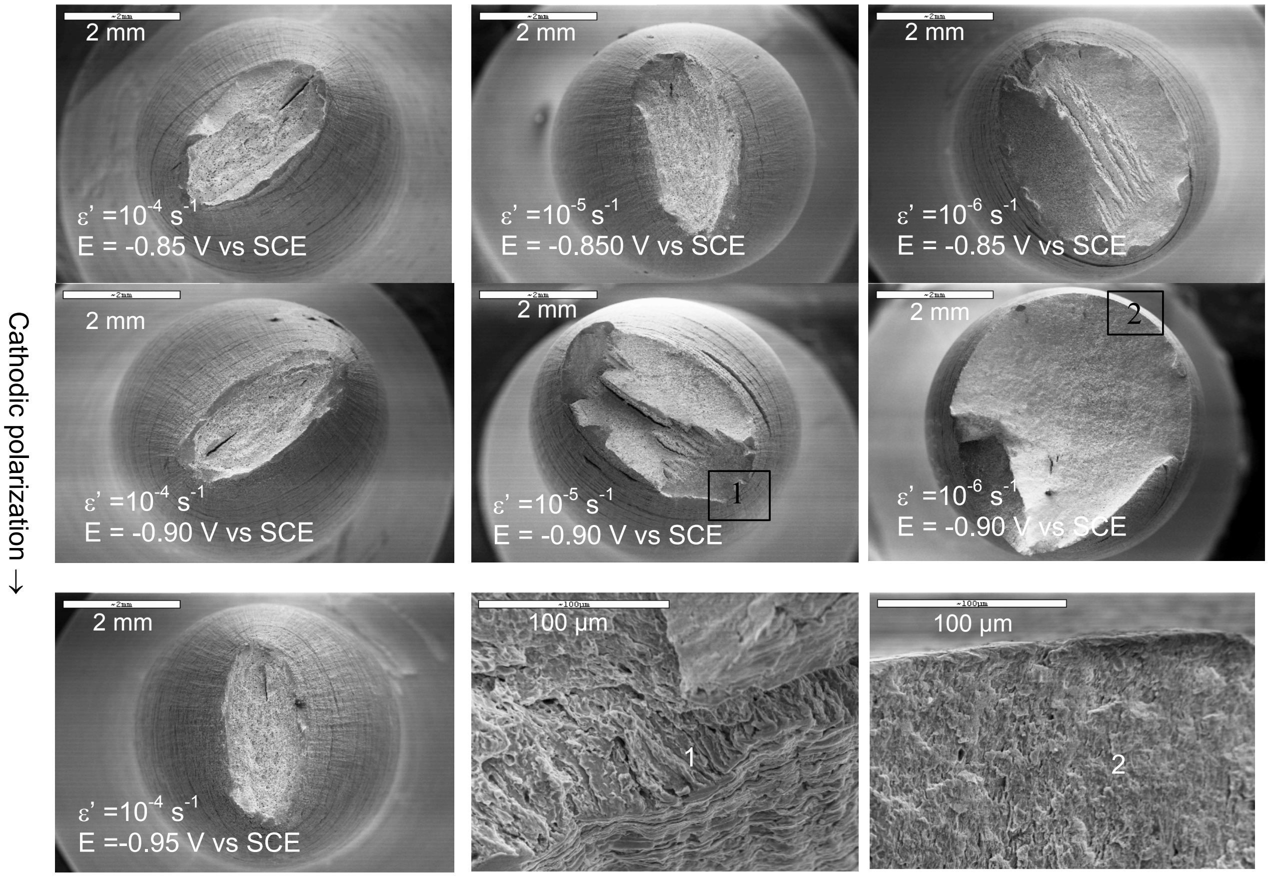

Figure 8 - SEM images of specimens of Steel B after SSR tests in NS4 solution at different potentials and strain rates

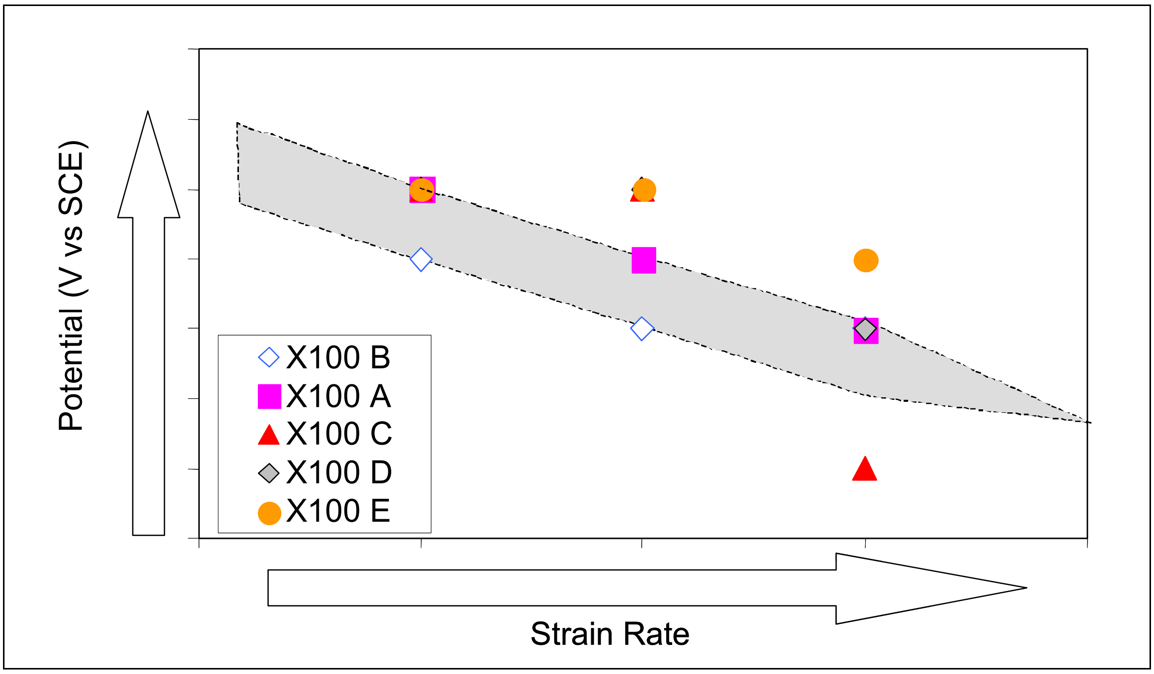

Figure 9 – Qualitative trend of critical potential to have hydrogen embrittlement phenomena as a function of strain rate for the examined X100 steels

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The comparison between the X100 steels and the traditional pipeline steels can be made using the normalised reduction of area at fixed potential and strain rate, see for instance Figure 10 where at –1.05 V vs SCE the normalised reduction of area was found to be similar for both the low grade and the X100 steels examined.

The decreasing of the normalised reduction if area resulted to be independent from the mechanical properties of the steels: some X100 steels show values of the normalised reduction of area similar or higher than some X65 or X80 steels. The main effect on the hydrogen embrittlement resistance can be attributed to the microstructure of the steel /27, 28/. The traditional types, with Yield Strength ranging from 420 to 470 MPa, have banded ferrite/pearlite microstructures. Controlled rolling increases Yield Strength and toughness by producing fine ferrite grains. Accelerated cooling after controlled rolling produces a further reduction of ferrite grain dimension and modifies microstructure by promoting bainitic and martensitic transformations. The pearlite located between ferrite bands is progressively replaced by acicular ferrite with carbides, bainite and tempered martensite as cooling rate increases. The content of pearlite, bainite and martensite varies for the considered steel and over the thickness (Figure 11).

Hard microstructures increase the yield strength of the steels, and it is expected that increases the hydrogen embrittlement susceptibility. On the other the accelerated cooling reduces banded microstructures, giving homogeneous fine microstructures which are less susceptible to HE, promoting numerous hydrogen traps uniformly distributed inside metal. Consequently, hydrogen is dispersed into metal after its ingress, without any major concentration in weak areas. Hydrogen diffusivities in steel with acicular ferrite, bainite and martensite may be lower than 50% of diffusivity in a traditional hot rolled ferrite pearlite steel. Furthermore an isotropic behavior was observed whereas diffusivity was mainly affected by direction with respect to the ferrite pearlite bands /29/.

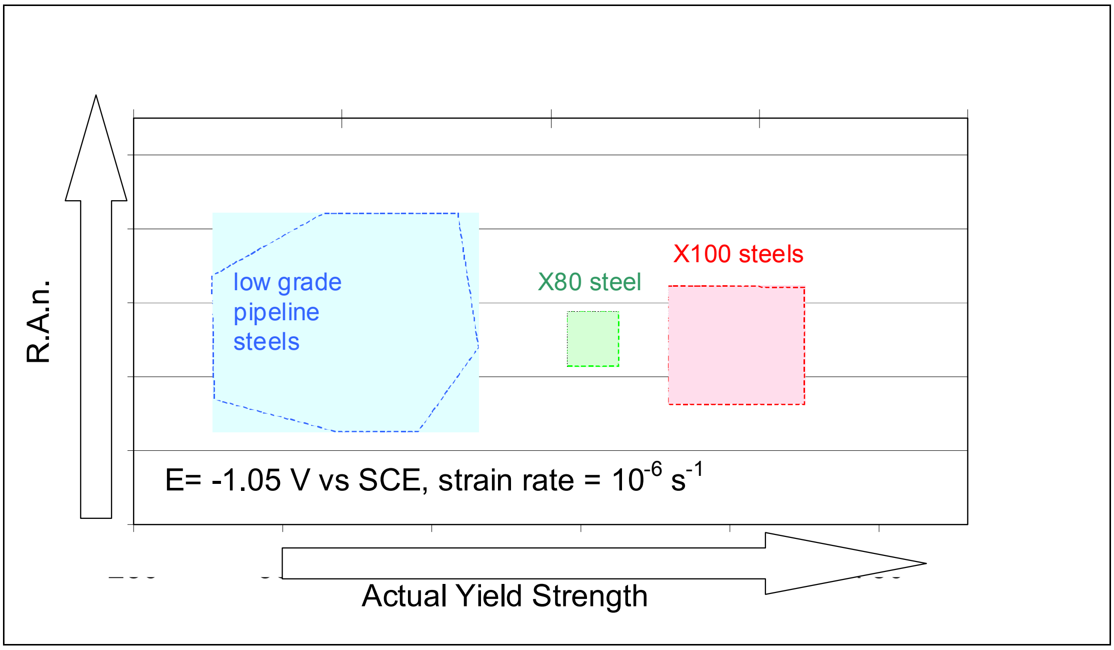

Figure 10 – Qualitative trend of normalised reduction of area of the specimens after the SSR tests at –1.05 V vs SCE and the same strain rate as a function of the Actual Yield Strength

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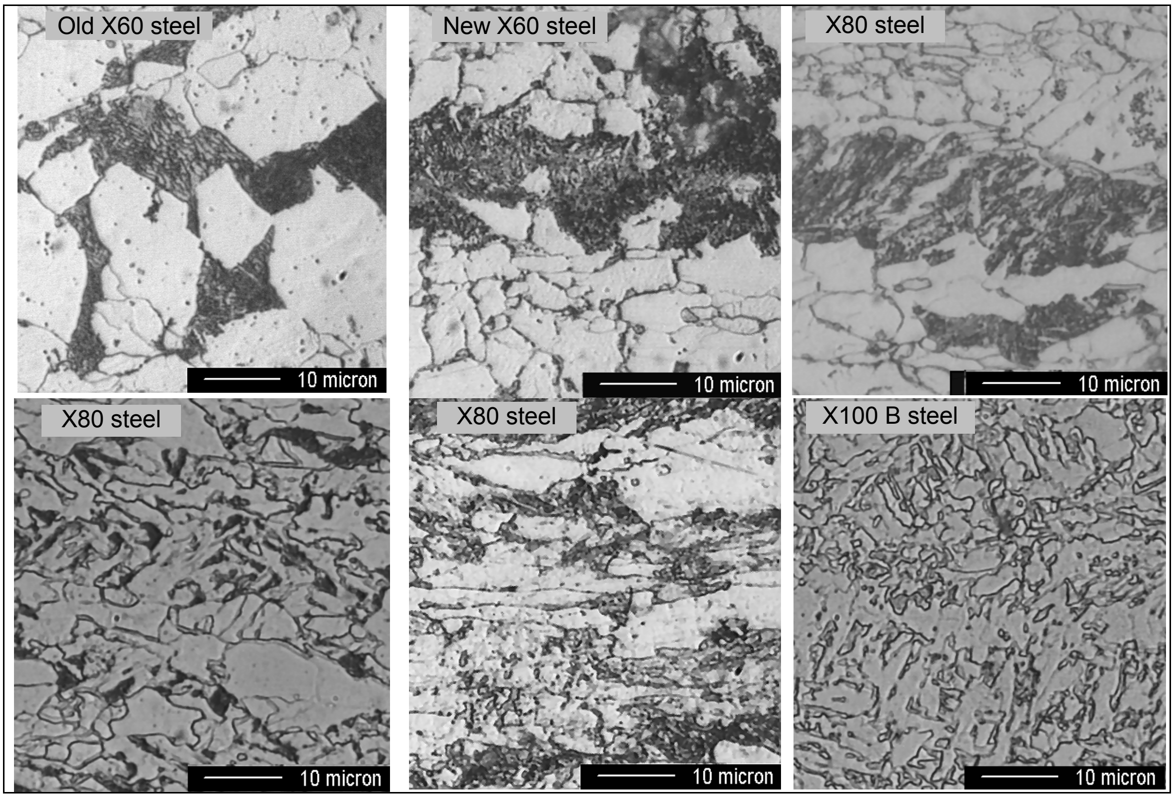

Figure 11 - Examples of microstructure of hot and controlled rolling steels. Optical micrograph. 4% Nital.

The researches conducted on NN-SCC indicate that the cracks propagation mechanisms is hydrogen embrittlement /30, 31, 31/. The possibility to have reduction of hydrogen ions at neutral pH values is due to the formation of a complex iron carbonate scale on the metal surface that promotes localised corrosion. Inside the localised attacks the local pH decreases, increasing the hydrogen ions concentration. The iron carbonate acts as catalyser for the hydrogen reduction, and facilities the diffusion of the hydrogen atoms into the metal lattice. The hydrogen atoms concentrate in the plastically strained zones and promote the initiation of brittle cracks. The NN-SCC cracks are preferentially initiated from localised attacks. It is possible to enhance the NN-SCC phenomena by means of electrochemical pre-corrosion of the specimens, as shown in Figure 13.

Being the NN-SCC mechanism recognised as an hydrogen embrittlement one, it is expected that the behaviour of the X100 steels in this environment should be similar to those observed in cathodic protection. The Normalised Reduction of Area obtained for the X100 steels in NN-SCC environments are compared with those of the low grade pipeline steels in Figure 12. The presented results are still preliminary, but it seem that some X100 steels have a behaviour similar to the low grade steels, but for other X100 cases the susceptibility to the NN-SCC increases as the actual Yield strength increases.

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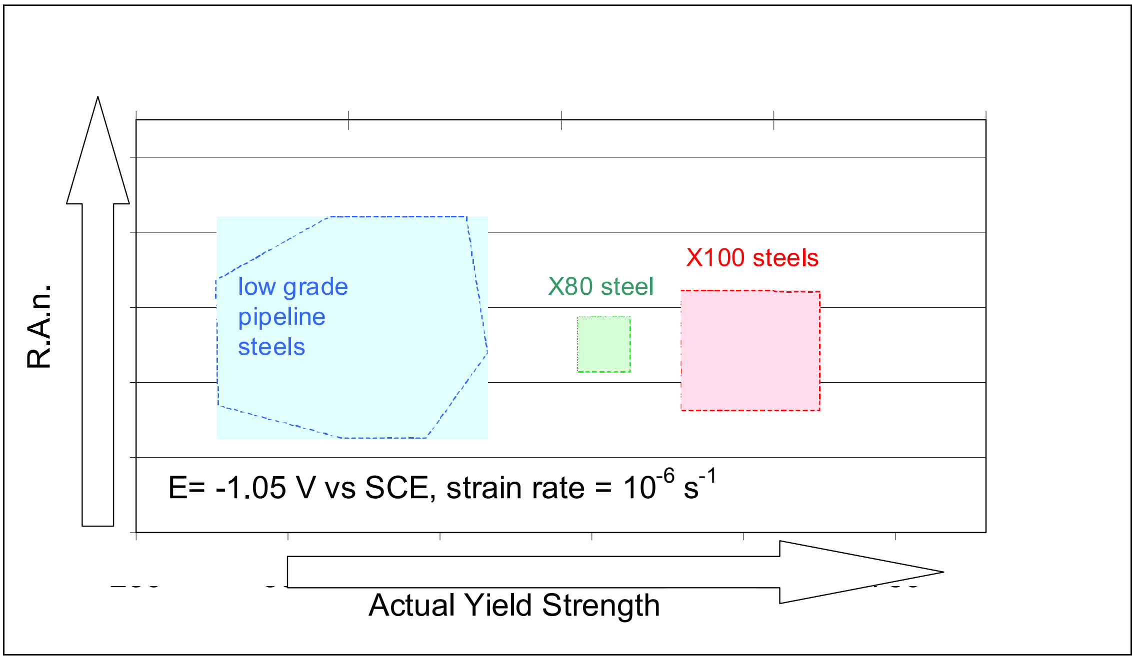
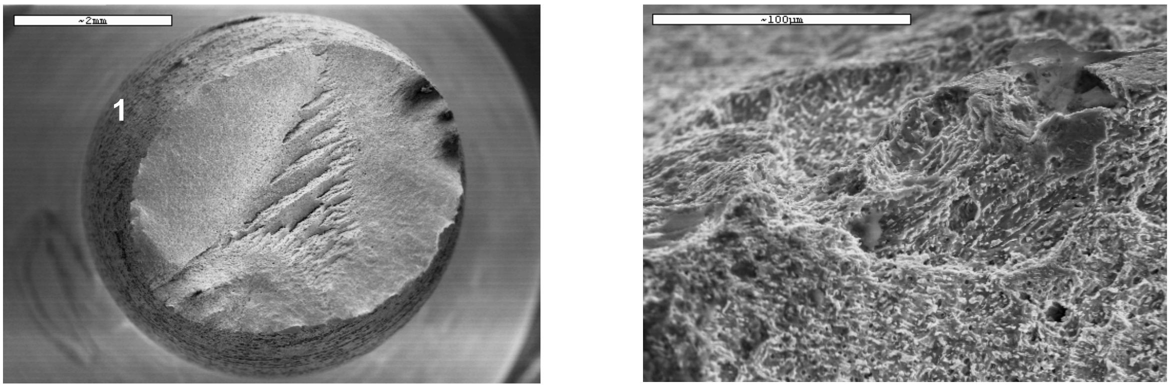


Figure 12 - Effect of Normalised Reduction of Area of the specimens after the SSR tests in NN-SCC environment



a) b)

Figure 13 - SEM image of the electrochemically pre-corroded specimen of X100 B steel after the SSR test in NN-SCC environment; a) macro image; b) close up (1000 ×) of the point 1 in a)

CONCLUSIONS

Majors recognize that, in order to successfully face the technical challenges of safe use of X100 steel for future long distance, high pressure gas transmission pipelines, the demonstrative construction and operation of a provisioning X100 pilot section pipeline, including on purpose damaged pipes properly monitored, and coupled with extensive parallel laboratory experimental work, is necessary.

In the TAP project, this approach was adopted, building a pilot section about 800m long, where the the performance of X100 line pipe over time is studied, including the Environmental Assisted Cracking (EAC) phenomena under severe conditions (third party damage, internal pressure fluctuation, over cathodic protection etc..).

According to the know how on the subject gained in recent research projects, first full scale experience on X100 steel pipe revealed that the behaviour of such high grade material under third party damaging interference, appears as promising in the sense that no critical defect could be caused even considering a large mass excavator impacting the pipe. Damages are limited in size

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when compared with similar damages caused by the same class of excavator on a conventional grade API X65 steel pipe, and they are not able to cause the immediate failure of the X100 pipe.

Despite of that good behaviour, a permanent dent and gouge damage has been created on X100 pipe, and such a defect, if not properly repaired, can lead to a delayed failure of the X100 line especially if additional loading conditions (like those due to environmental action, cycling loading, etc.) are acting at the same time, as demonstrated by the unique EAC full scale test carried out on an X100 third part damaged pipe so far, where a hydrogen embrittlement related failure was observed after a certain number of cycles in correspondence of high stress range applied.

As for the laboratory activity, this is mainly related to the concern about the potentially higher EAC susceptibility (mainly Hydrogen Embrittlement under cathodic protection (HE) and Near Neutral Stress Corrosion Cracking (NN-SCC)) of the X100 steels with respect to the lower grade materials, since it is generally accepted that susceptibility usually increases with mechanical properties of the steel. X100 susceptibility to environmental cracking was assessed during slow strain rate tests at potentials and strain rates which were in the critical ranges of the traditional low strength steels.

The laboratory SSR test results obtained so far are promising: the risk of hydrogen stress cracking related to the use of X100 steels is verified as minor; a performance similar to that of traditional pipeline steels with lower yield strength, have been experienced. To make the comparison with the full scale behaviour of a damaged pipe subjected to internal pressure fluctuation, significant with respect to actual performance, laboratory tests are taking into account the initial presence of a surface damage (like the dent and gouge one, where there is the combined presence of plastic deformation and metal loss with local material alteration/cracks) and the loading variation over the time. This phase of the laboratory testing programme is currently ongoing, and first results are expected to be available soon.

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REFERENCES

1 L. Barsanti, R. Bruschi and E. Donati, From X80 to X100: Know-How Reached by ENI Group on High Strength Steel, Proceedings of Application & Evaluation of High-Grade Linepipes in Hostile Environments, Yokohama, Japan, November 2002.

2 A. Glover, D. Horsley and D. Dorling, Application and Installation of grade 690 (X100) Linepipe, Proceedings of 14th Biennial Joint Technical Meeting on Pipeline Research, Berlin, Germany, May 2003.

3 C. W. Petersen, et al.; Improving Long Distance Gas Transmission Economics : X120 Development Overview, Proceedings of 4th International Conference on Pipeline Technology, Ostend, Belgium, May 2004.

4 A. Glover, D. Horsley, D. Dorling and J. Takehara, Construction and Installation of X100 Pipelines, Proceedings of IPC 2004 International Pipeline Conference October 4 - 8, 2004, Calgary, Alberta, Canada.

5 I. Takeuchi, et al., Prospect of High Grade Steel Pipes for Gas Pipelines, Proceedings of Application & Evaluation of High-Grade Linepipes in Hostile Environments, Yokohama, Japan, November 2002.

6 I. Asahi et al., Development and Properties of Ultra-High Strength UOE Linepipe, Proceedings of IPC 2004 International Pipeline Conference October 4 - 8, 2004, Calgary, Alberta, Canada.

7 H. G. Hillenbrand and C. Kalwa, Production and Service Behavior of High Strength Large Diameter Pipes, Proceedings of Application & Evaluation of High-Grade Linepipes in Hostile Environments, Yokohama, Japan, November 2002.

8 H. G. Hillenbrand, A. Liessem, K. Biermann, C.J. Heckmann and V. Schwinn, Development of High Strength Material and Pipe Production Technology for Grade X120 Line Pipe, Proceedings of IPC 2004 International Pipeline Conference October 4 - 8, 2004, Calgary, Alberta, Canada.

HOME

9 G. Demofonti, G. Mannucci, H.G. Hillenbrand and D. Harris, Evaluation of the Suitability of X100 Steel Pipes for High Pressure Gas Transportation Pipelines by Full Scale Tests, Proceedings of IPC 2004 International Pipeline Conference October 4 - 8, 2004, Calgary, Alberta, Canada.

10 M. Di Biagio, A. Fonzo and F. Marchesani, Crack Arrestor Design by Finite Element Analysis for High Grade Gas Transportation Pipeline Under Extreme Operating Conditions, Proceeding of PRCI-EPRG-APIA 15th Biennial Joint Technical Meeting On Pipeline Research, Orlando, Florida, USA 16-18 May 2005.

11 L. Di Vito, M. Hudson, G. Demofonti, B. Andrews and S. Slater, X100 - Girth welding, joint properties and Defect tolerance, Paper presented at this Conference.

12 C.M. Spinelli and F. Marchesani, Tap Project, Proceedings of IPC 2004 October 2004, Canada

13 W.A. Maxey, Defect Behavior-1: Analysis Made of Outside-Force Damage to Pipelines, Oil & Gas Journal, 18 May 1987, pp. 33-42.

14 W.A. Maxey, Defect Behavior-2: Outside-Force Damage to Pipe Analyzed, Oil & Gas Journal, 25 May 1987, pp. 74-76.

15 W.A. Maxey, Defect Behavior-Conclusion: Serviceability of Damaged Line Pipe Rated, Oil & Gas Journal, 15 June 1987, pp. 41-50.

16 P. Hopkins, J. Corder and P. Corbin, The Resistance of Gas Transmission Pipelines to Mechanical Damage, Paper VIII-3, International Conference on Pipeline Reliability, Calgary, Canada, June 1992.

17 D.G. Jones, The Significance of Mechanical Damage in Pipelines, 3R International, 21, Jahrgang, Heft, 7, July 1982.

18 J. Spiekhout, A.M. Gresnigt, C Koning and H. Wildschut, Calculation Models for the Evaluation of the Resistance Against Mechanical Damage of Pipelines, 3R International, 25, pp 198-203, 4 April 1986.

19 M. Zarea et al., The Pipe Aggression Rig: A Comprehensive Means for Studying Pipe Resistance to Third Party Damage, Paper TSO-05, Proceedings of IGRC98 California, USA, 0-11 November 1998,

20 R. Champavere et al., Excavators Modelling for the Evaluation of Their Maximum Static and Dynamic Damage Capacities, Paper TSP-19, Proceedings of IGRC98 California, USA, 0-11 November 1998,

21 R. J. Bood et al., EPRG Methods for Assessing the Tolerance and Resistance of Pipelines to External Damage – Part 1+2, 3R International, 10-11/1999, P. 739-744, 12/1999, P. 806-811.

22 G. Mannucci, M. Guagnelli, O. Vittori and C.M. Spinelli, An Experimental Approach to Evaluate the Resistance of Gas Pipeline to Dent and Gouge Damage by an Excavator, Proceedings of 4th International Pipeline Conference IPC02, Calgary, Alberta, Canada, September 29-October 3, 2002.

23 G. Malatesta, G. Mannucci, G. Demofonti and L. Barsanti, An Experimental and Analytic Approach for Predicting the Formation of Dent and Gouge Damage on Gas Pipeline by an Excavator, Proceedings of 4th International Conference on Pipeline Technology, Ostend, Belgium, May 2004.

24 G. Mannucci, A. Lucci, G. Malatesta and C.M. Spinelli, Resistance Of X100 High Pressure Gas Transportation Pipelines With Respect To Third Part Damage, Proceedings of IGRC04, November 2004 Canada.

25 L. Barsanti, R. Bruschi and E. Donati, “Modern Pipeline Technology Secures Natural Gas Transportation over Long Distances and Harsh Environments”, Pipe Dreamer’s Conference, 7-8- Novembre 2002, Pacifico Yokohama, Japan.

26 R.N.Parkins, NG-18 Report No.191, American Gas Association, August 1990.

27 M. Cabrini, L. Migliardi, T. Pastore and C. Spinelli, Synergic Effect Of Cathodic Potential And Strain Rate On Hydrogen Embrittlement Of Different Microstructure Carbon Steels, H-CDI: Hydrogen – Corrosion Deformation Interaction, Jackson Lake Lodge, Wyoming, (2001), pp.16-21.

28 M. Cabrini, T. Pastore, L. Barsanti and C.M. Spinelli, “Effect of microstructure on the behaviour of HSLA steels to hydrogen embrittlement under cathodic protection”, Second International Conference on Environmental-Induced Cracking of Metals EICM04, September 19-23, 2004, The Banff Centre, Banff, Canda.

29 M. Cabrini, O. Cogliati and S. Maffi, La metallurgia italiana, N. 3 (2003) pp.13-20

30 E. Sinigaglia and M. Cabrini, “Electrochemical and stress corrosion cracking behaviour of micro-alloyed steels in Co2/HCO-3 environment”, Proceedings of “NACE CORROSION/97”, National Association of Corrosion Engineers, Houston, 1997, Paper 202.

31 R.N. Parkins, W.K. Blanchard Jr. and B.S. Delanty, Corrosion 50, 5(1994): p.394.

32 R.N. Parkins and B.S. Delanty, “The initiation and early stages of growth of SCC cracks in pipeline steel exposed to a dilute, near neutral pH solution”, 9th Symposium on Pipeline Research, Houston,1996.

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