PENSTOCK EXPANSION JOINTS

PARTICULAR CASES OF CORROSION

European ICOLD Club

Penstocks, pressure shafts & pressure tunnels *workshop*

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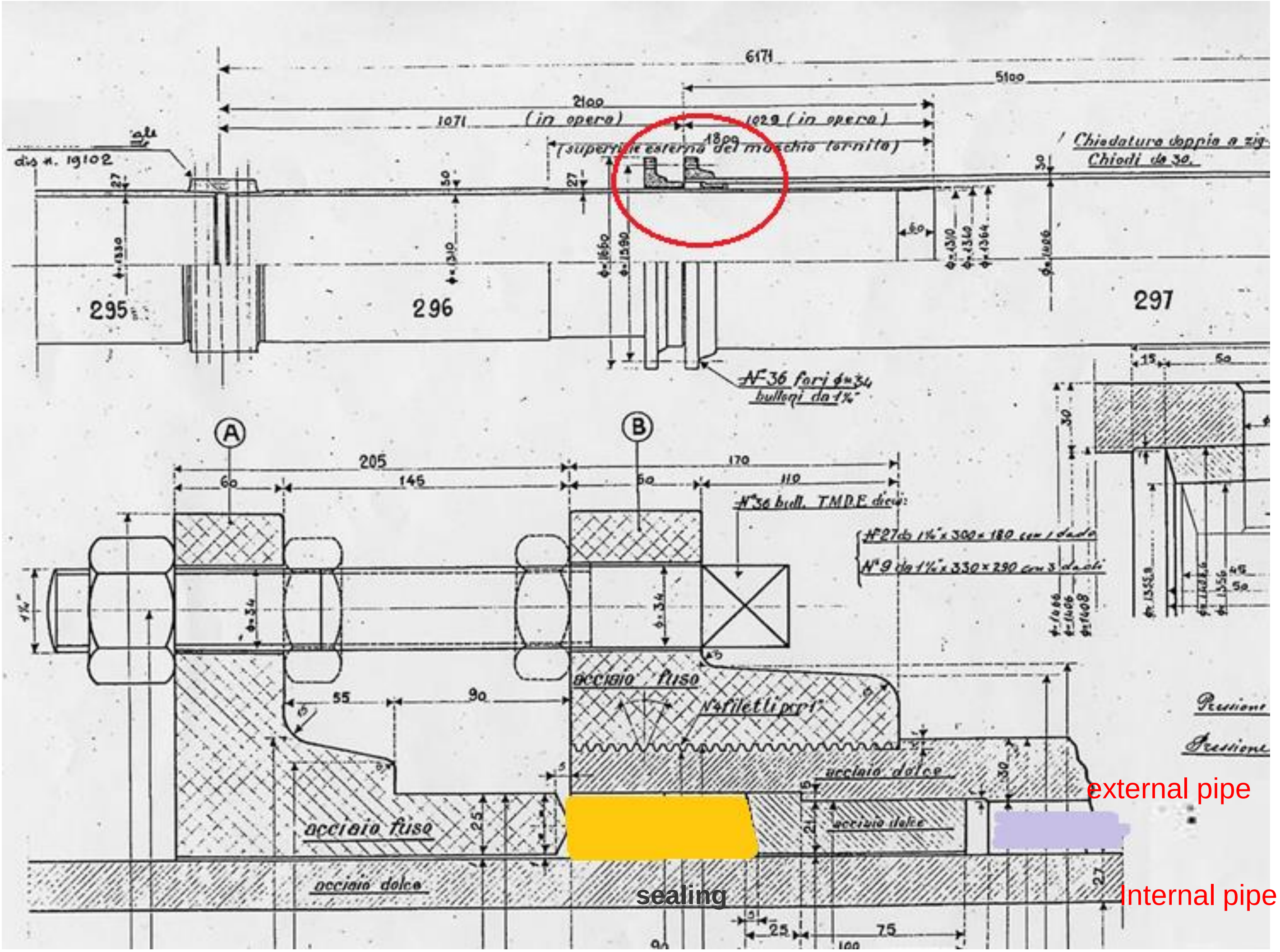
Centro Congressi FAST - Milan (Italy)

GIUSEPPE DONGHI

1° CASE

Expansion joint



Joint design

The powerplant is equipped by 2 penstocks 900 m long
Diameter 1.6 to 1.3 m
Thickness from 8 to 27mm
2x6 expansion joints

At the end of year 2008 During periodic NDT test we found great thickness variability on the joints external pipe, not so easy to explain.

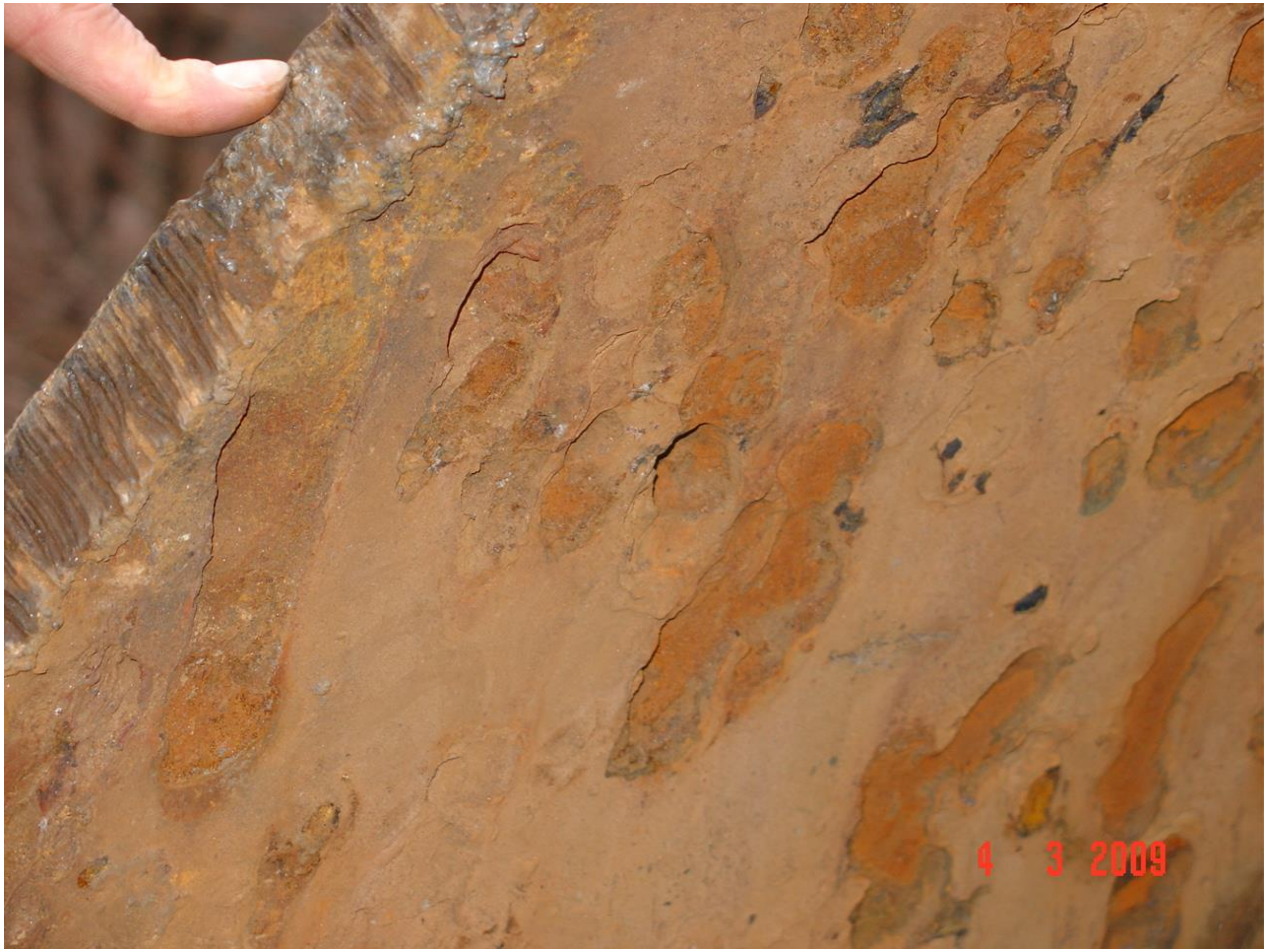
We took the decision to replace them.

In 2009 Edison replaced all the original expansion joints of the penstocks.

After the demolition of the old joints, it appeared:

Joint internal pipe

Joint external pipe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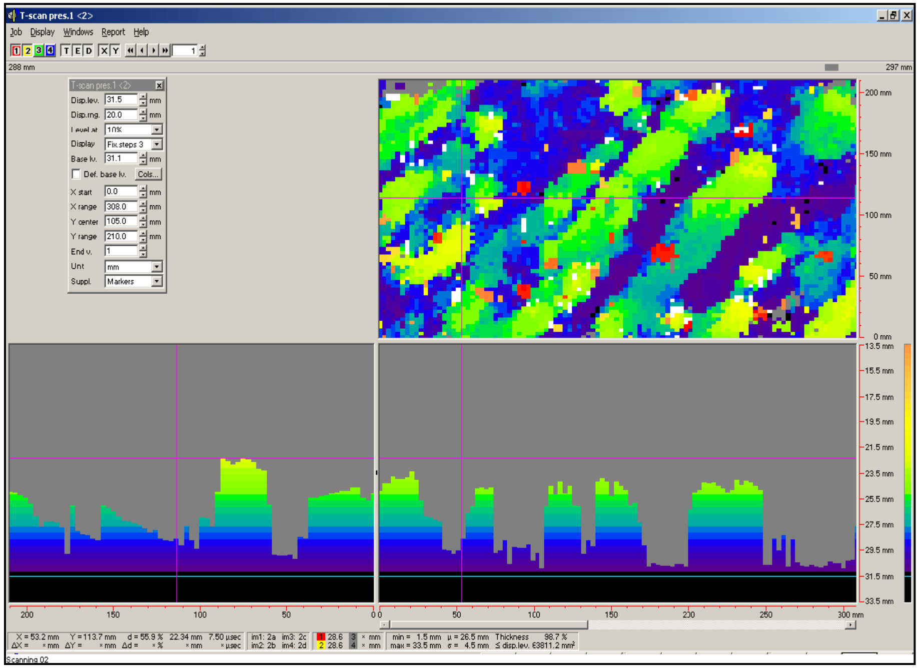
Sample for corrosion test

Joint external pipe corrosion



C-Scan imagine of the sheet by Phased-Array

LABORATORY TEST

- Chemical analysis
- Mechanical test
- Micrography
- Analysis by electronic X-ray micro probe
- Electronic scanning microscope
- X-ray difractometer

Result

- Wet corrosion with presence of organic material

Orientation of corrosion «stripes»

To be noted:

- The corrosion stripes orientation was vertical
- The corrosion stripes were only on the left side of the external pipes
- The left side of penstocks is sunny exposed
- Probably the left side temperature rises during powerhouse stops

2° CASE

The hydro power plant is equipped by 6 Francis units fed by 6 penstocks installed in 1914, internal diameter 2700 mm, about 100 meters long, with an inclination of about 26°.

The penstocks are riveted both in the longitudinal direction (double riveting) and in transverse direction (single riveting), the sheet has constant nominal thickness of 7 mm.

OLD EXPANSION JOINTS

At top of each penstock was installed an expansion joint consisting essentially of circular sectors of sheet riveted together in radial and circumferential directions and connected to the penstock by means of L-shaped corners.

The penstock steel (manufactured in 1914), from chemical and metallurgical investigations carried out in the past, is comparable to the Fe37 Gr.B steel type, corresponding to the current S235JR steel. The steel is therefore weldable.

OLD EXPANSION JOINTS

The main geometric features of the old joints were:

- pipe diameter: ~ 2700 mm;
- outer diameter: ~ 3900 mm;
- axial span (including the L-shapes corners riveted to the pipeline): ~ 320 mm.

OLD EXPANSION JOINTS

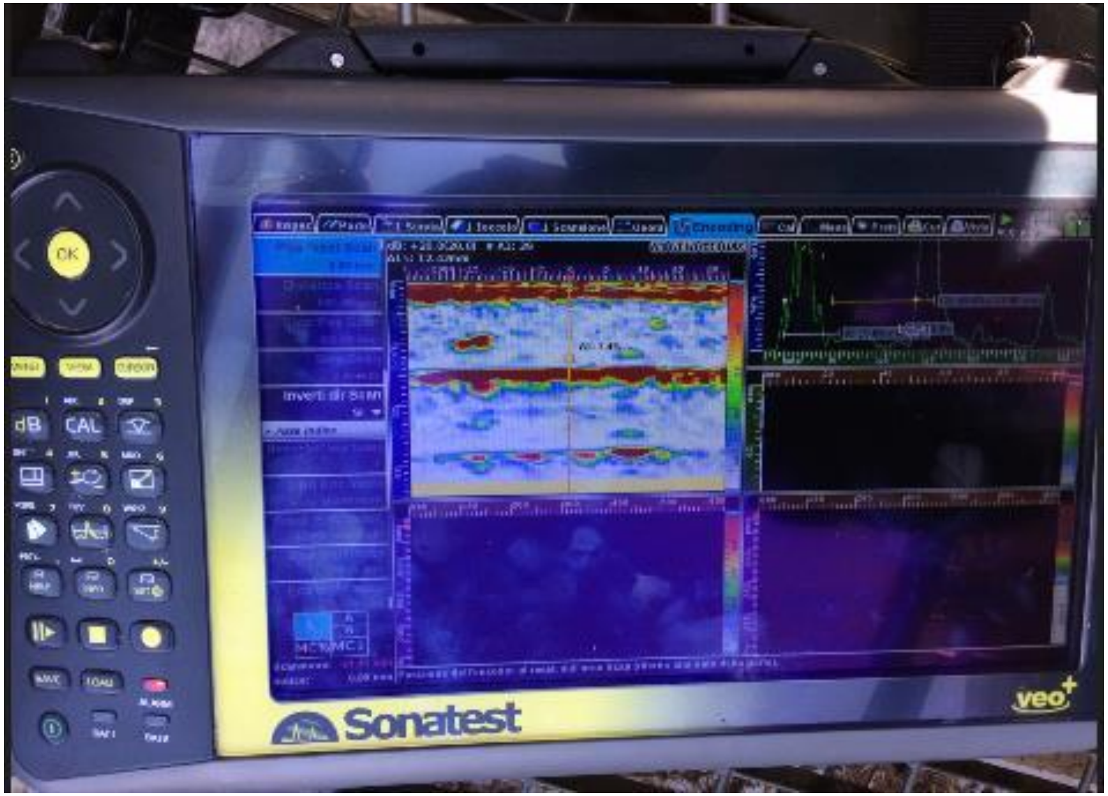
Visual periodically inspection and NDT investigations pointed out internal severe corrosion.

NON DESTRUCTIVE TEST - EQUIPMENT

To map pipes and joints internal corrosion, the "Phased Array" ultrasonic technique was used, mounted on a roller, coupled to the steel sheet by water. The automatic UT scan of the sheet was carried out pulling the roller probe by an electric "trolley" equipped with magnetic wheels.

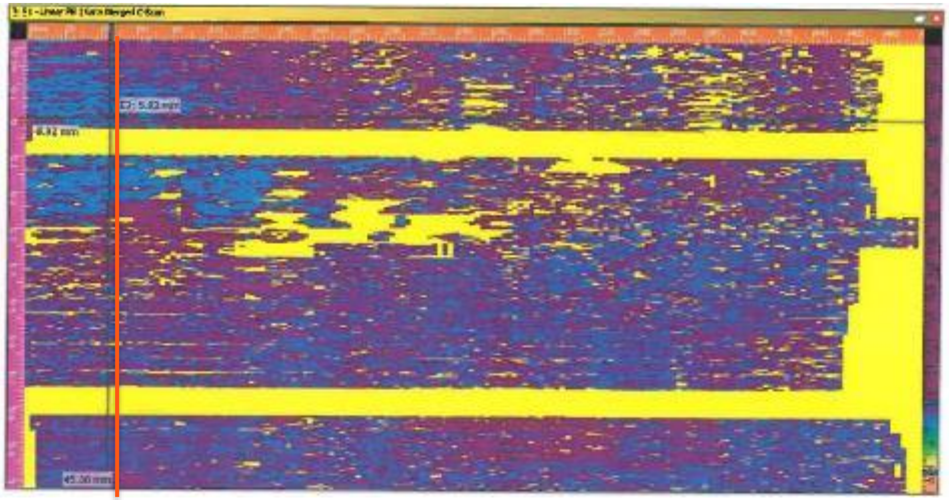
NON DESTRUCTIVE TEST - EQUIPMENT

The portable control unit, can show on the screen and store UT scans of the sheet by means of C-Scan representation (i.e. on the sheet plane), B-Scan (i.e. in section), and A-Scan (reflection point). An encoder mounted on the probe allows the volumetric representation of the sheet.

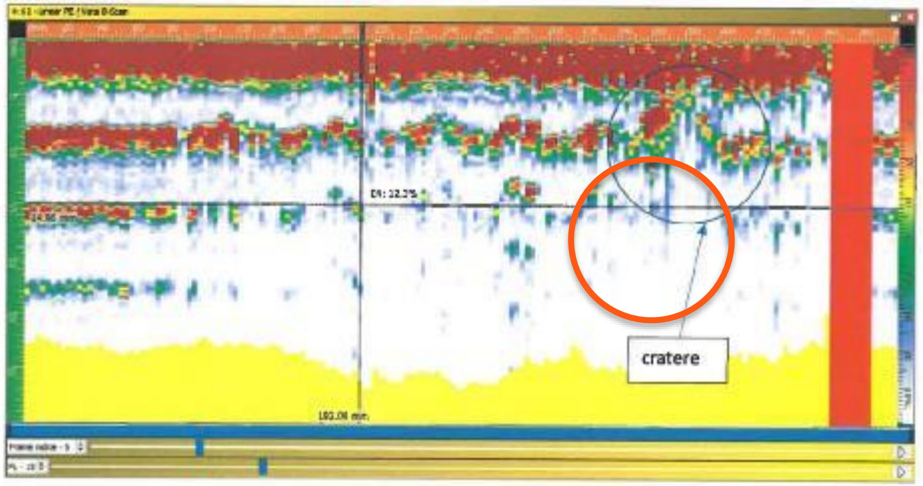


NDT RESULT

The Phased Array investigation showed that joints were subject to internal pit corrosion with minimum thicknesses of about 2.5 mm (7 mm nominal).



C-Scan representation of a portion of the steel sheet (in yellow the areas of non-coupling of the probe on the sheet because of surface irregularities)



B-Scan representation of the selected sheet section, with highlighted a corrosion pit

OLD JOINTS DISASSEMBLY

Edison replaced all the original expansion joints of the penstocks with new corrugated stainless steel joints. After the demolition of the old joints, the pit internal corrosion was confirmed.

NEW JOINT

New joint

OTHER CORROSION POINT

- The pipe is partially embedded in concrete.
- Since the sheet is colder than the surrounding environment, the moisture in the air condenses on the pipe surface and flows towards the point of embedding concrete.
- The inspection of the pipe was made from the inside and it was seen that the contact line of embedding concrete was corroded.
- Consequently remedial works were put in place.

Final considerations

- As we have seen, joints or other hidden parts can present corrosion problems;
- Generally speaking, however, the pipes, except in particular cases, are in good conditions.
- The penstocks seen in 2nd case were installed over 110 years ago, they probably had a bituminous internal coating, we know that this internal coating has not been present for over 50 years.
- The first case penstock has been in service for almost 90 years.
- The corrosion occurred on the joints: these are particular places because sediments stagnate in the cavity.
- They are also areas where it is very difficult to proceed with sandblasting and painting.

3°case

The penstock, built in the 1920s, have a longitudinal «welding» made by hammering the two edges of the sheet after heating by «water gas» at T> 1100 ° C

pipe section – «welded» joint by water gas

During NDT test a crack was identified on the MK160 pipe which has the following main features:

-working pressure : 40 bar

-internal diameter : 410 mm

-nominal thickness: 11mm

crack length 59 mm

depth 8.4 mm

For safety, the pipe MK160 was removed and then used for tests

A series of mechanical and metallographic investigations were conducted on the removed pipe, with the aim of determining the residual strength of the component affected by that crack, in order to acquire elements for safety evaluation in similar cases.

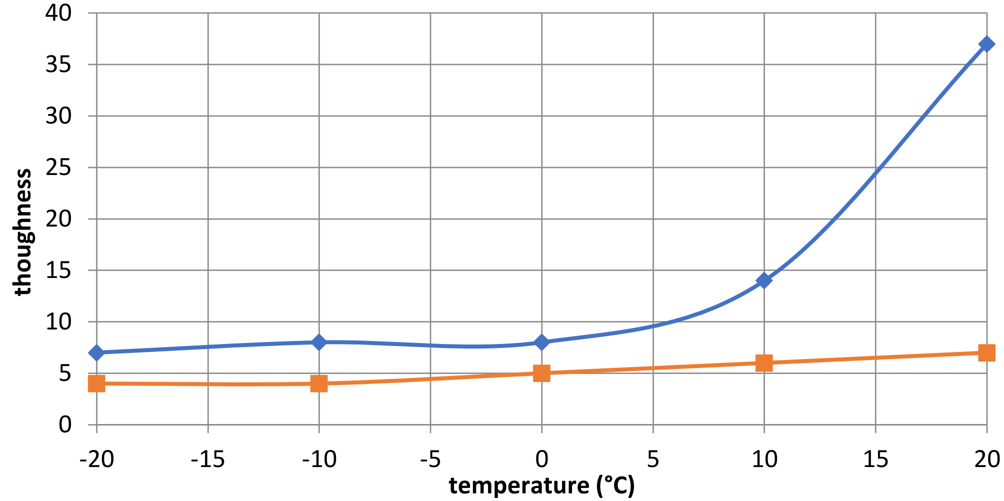
MECHANICAL TESTS AND MICROGRAPHIES

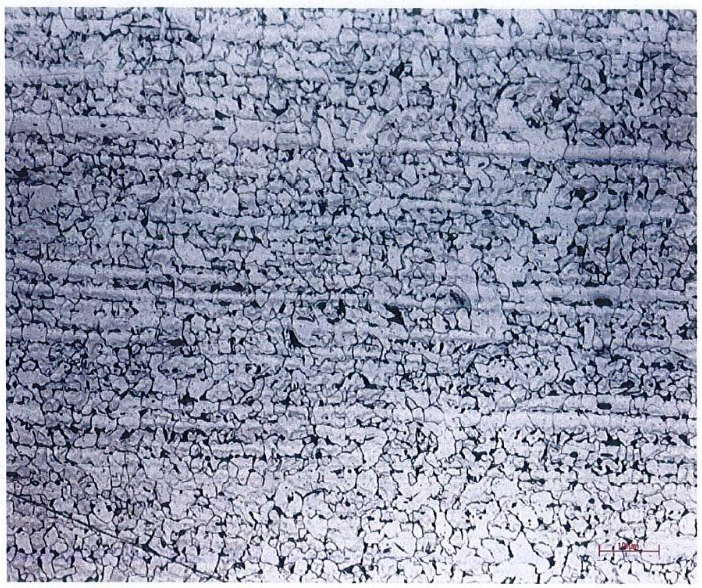
Tensile tests were carried out on the sheet and on the “welding”, the steel is similar to S275 EN 10025-2

The tensile stress in correspondence of the “welding” (385 N/mm^2) is slightly lower than the sheet (420 N/mm^2).

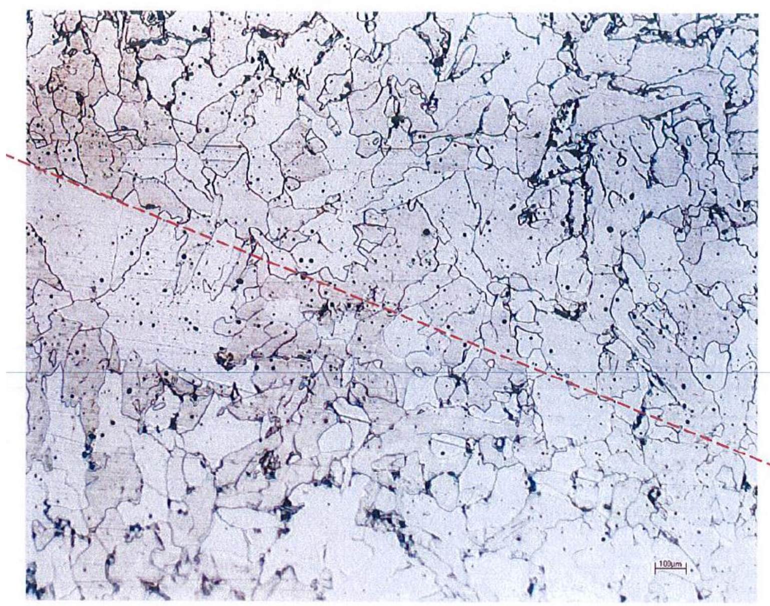
The toughness tests have shown that steel has good ductility at 20°C but drops at 0 ° C.

The specimens of the “welding” were instead fragile at any temperature, the average toughness was only 6 J. This is due to the size of the grain, confirmed by the micrographies.





Micrography sheet



Micrography «welded joint»

HYDRAULIC TEST

We subjected the pipe to hydraulic test, in the workshop, till the unstable propagation of the existing crack.

The internal pressure causing the mechanical failure was 100 bar.

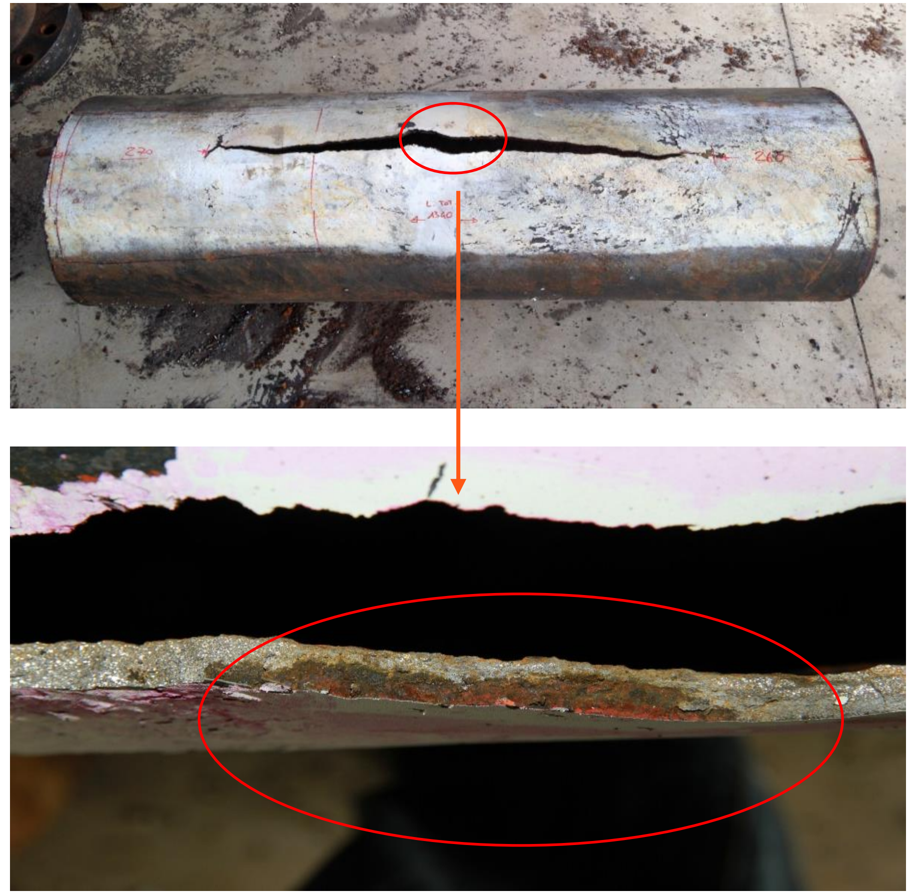
100 bar, 5 seconds before failure, the crack has not yet grown

100 bar, 1 second before failure, the crack begins to open

100 bar, pipe burst due to unstable crack propagation

Filmato alla pressione di 100 bar

Crack after failure



The visual inspection of the fracture pointed out the oxidized edge of the crack; this allowed to confirm the maximum crack depth, about 8 mm on 11 mm of sheet thickness, measured by ultrasonic method.

position of the crack in the cross section

THEORETICAL CALCULATION ACCORDING TO THE PRINCIPLES OF FRACTURE MECHANICS

- Yeld stress of the pipeline: Rsn = 260 N / mm2 (from mechanical tests on the sheet);
- σ piping in operation = 90 N / mm2 (operating pressure +20% to take into account water hammer during transients);
- safety factor (K) = 3 (= 260/90);
- fracture toughness of the material (KIC) = ~ 1900 $Nmm^{-3/2}$ estimated from the 6 J thoughness of the "weld" joint.
- Considering the crack dimensions (max depth 8.5 mm, length 60 mm and sheet thickness 11 mm), according to the principles of fracture mechanics : the maximum stress, beyond which occurs unstable crack propagation, is about 190 N/mm^2
- This means a reduction of the safety coefficient (K) from 3 to about 2.1

  (= 190/90) due to the crack ;
- The stress of 190 N/mm2 corresponds to internal pressure of 100 bar, close to the pressure which caused the unstable growth of crack during the hydraulic test.

CONCLUSIONS

The mechanical tests carried out on the pipe MK 160 showed the fragility of this kind of longitudinal "welds" at any operating temperature.

By the toughness of the "welded joint", using the fracture mechanics criterion, the reduction of the safety factor due to the crack was estimated.

The safety factor K is reduced from about 3 to about 2.1.

The results of the investigations led to the decision to extend NDT to the 100% of the "water gas weldings".

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THANKS FOR YOUR ATTENTION