CORINTH PIPEWORKS

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HYDROGEN CERTIFIED PIPES
A new era for hydrogen transportation

Hydrogen has the potential to revolutionize the way we produce, store and use energy. Pipelines are the safest and most economical option to transport hydrogen over long distances with minimal energy loss

CPW X70M HIGH GRADE HFW PIPES SUCCEED IN QUALIFICATION TESTS FOR HYDROGEN (ASME CODE)

Long term fracture toughness testing of CPW high grade / heavy gauge HFW pipes in a major European research center (RINA-CSM), verified material compliance to ASME B31.12 code and enhanced resistivity to hydrogen embrittlement.

Figure 1: *Fracture toughness specimens used in high pressure hydrogen testing*

Recent analyses demonstrate that considerable cost savings can be realized if the hydrogen pipeline can be qualified for the use of X70M steel. Compared to the use of a X52 conventional hydrogen linepipe, an X70M linepipe for hydrogen service can realize cost savings on the order of 32% [1].

Based on available standards, ASME B31.12-2019 [2] is the only available code for the design of hydrogen service linepipes. According to this code, high grade materials up to API L555/X80M can be qualified, without any design pressure penalty for design pressures up to 1500psi (103bar). The principal requirement is that the material should specifically be qualified for adequate resistance to fracture in hydrogen gas at or above the design pressure using the applicable rules of ASME BPVC, Section VIII, Division 3 [3].

Following the above provisions, CPW organized a number of ASME B31-12 fracture toughness qualification (K_{IH}) tests with pipe material from different OD x WT x Grade combinations, one of them being the 20′′ x 19.05mm X70M produced with the HFW process for a major linepipe project. All hydrogen material tests were performed in RINA-CSM S.p.A, an acknowledged European research center, specialized to evaluate material and component performance in presence of gaseous hydrogen up to 1000bar external pressure.

"Fracture toughness testing qualifies CPW L485/X70M linepipe for up to 100% H_2 service and full design pressure"

DESCRIPTION OF HYDROGEN QUALIFICATION TESTS

Fracture toughness tests in 100% hydrogen gaseous environment were performed in compliance with ASTM E1681 according to the constant displacement configuration, as required by ASME B31.12 and ASME BPVC Section VIII, Division 3. The specific testing for was performed in a sealed autoclave on an H_2 test pressure of 80bar, a typical pressure for transmission linepipes.

Typical characteristics of the tested pipe are also illustrated in **Table 1**:

Process	OD (inch)	WT (mm)	Material	YS *($R_{t0.5}$)*	TS *(R_m)*	Test Pressure	Notch position
HFW	20"	19.05	X70M,PSL2	539MPa	655MPa	80bar	Base metal, HF weld

Table 1: Properties of tested material and conditions of testing

Figure 2: *Loading of specimens in autoclave is controlled by high accuracy extensometer*

Figure 3*: High pressure autoclave in nitrogen security chamber*

The determination of the threshold stress intensity factor K_{IH} involves a specimen containing a machined notch (Figure 1). This notch is extended by fatigue cracking and the pre-cracked specimen is loaded by a constant displacement method (bolt) to a stress intensity K_{IAPP}. It should be highlighted that the pre-crack surface during loading should be prevented of contact with atmospheric oxygen and moisture in order not to inhibit hydrogen uptake, therefore application of K_{IAPP} was done in an inert atmosphere glove box. After an exposure period of 1000h (42 days) in room-temperature pressurized hydrogen gas, the specimen is examined to assess whether the initial fatigue crack did or did not grow. In case of no crack growth (≤0.25mm extension), the minimum qualified K_{IH} is 50% of K_{IAPP}. In case of crack propagation, the propagation length to arrest condition is measured and K_{IH} value is established following the procedure described in ASTM E1681.

STEEL AND PIPE PROPERTIES

The tested CPW X70M linepipe was produced with steel pre-material from ArcelorMittal Bremen steelworks. The linepipe is in full compliance with the requirements and guidelines of ASME B31.12 code for enhanced resistance to hydrogen for high grade, as presented in **Table 2**.

Desired microstructure of polygonal and acicular ferrite
♦ TMCP made steel is recommended
♦ Phosphorus content ≤ 0.015% wt.
♦ Carbon content ≤ 0.07% wt.
♦ Carbon Equivalent (Pcm) ≤ 0.17% wt.
♦ Maximum UTS 110ksi (758MPa)
♦ Nb micro alloyed steel

Table 2: *Requirements and guidelines for hydrogen resistant API 5L steel material from ASME B31.12*

Respective chemical analysis and distribution of tensile properties are presented in Table 3 and Figures 2-4.

C	Si	Mn	P	S	Cr	Mo	Ni	Al
0,05	0,31	1,67	0,010	0,0004	0,02	0,013	0,25	0,034
Cu	**Nb**	**Ti**	**V**	**Ca**	**B**	**N**	**P_{cm}**	**IIW**
0,007	0,054	0,015	0,001	0,0024	0,0001	0,004	0,15	0,35

Table 3: *Chemical analysis of X70M steel tested (% wt.)*

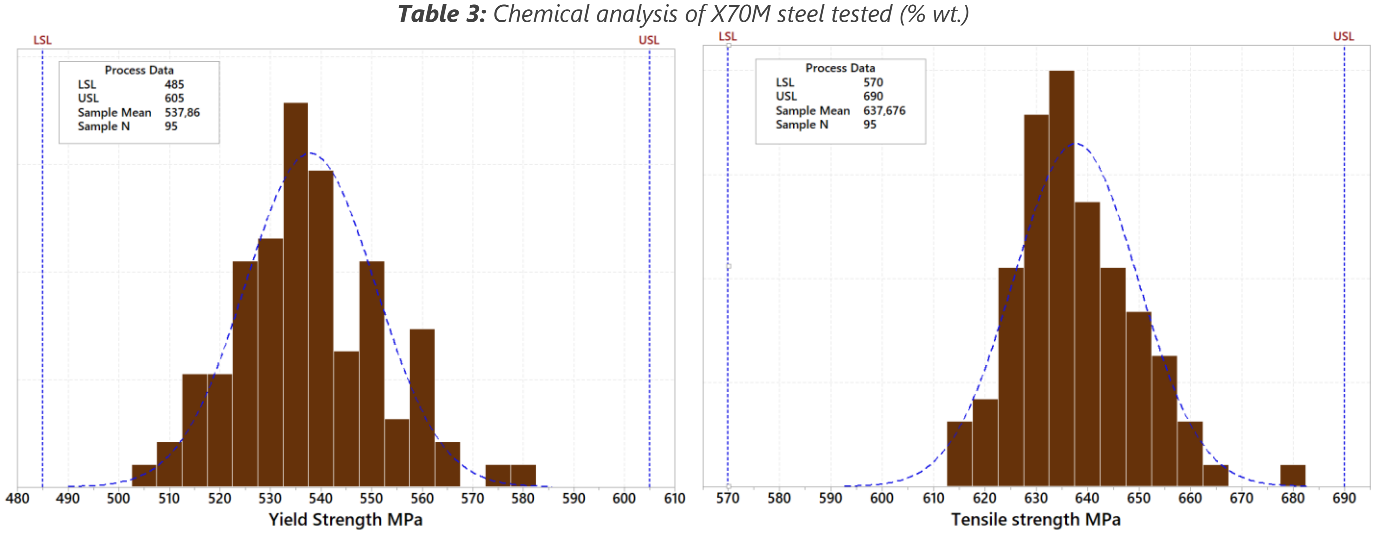
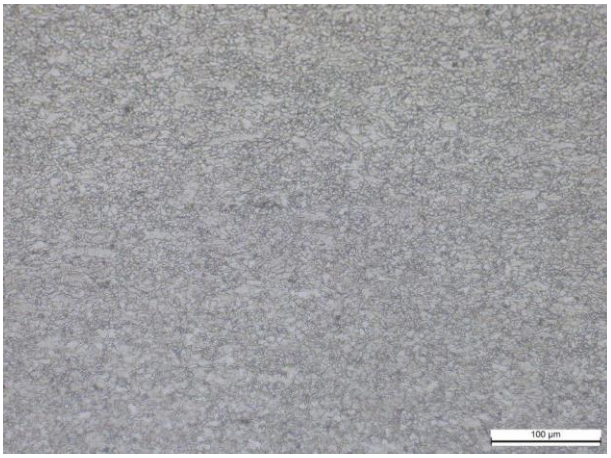


Figure 4: *Typical distribution of YS, TS properties for X70M steel*

Figure 5 presents micrographs of X70M pipe on parent material and weld seam presenting a fine polygonal ferrite microstructure, free of banding, in alignment with the recommended microstructure of ASME B31.12.



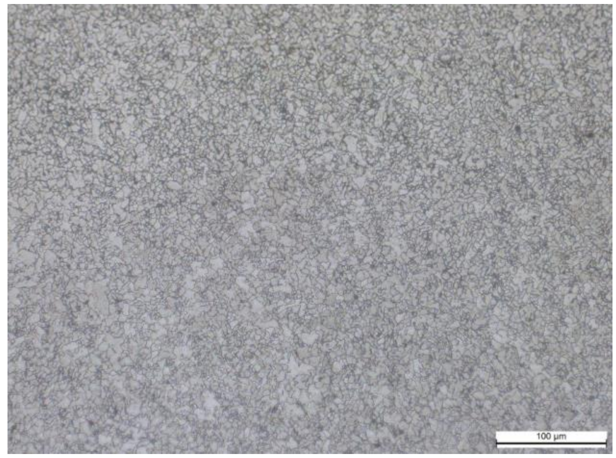


Figure 5: *Micrographs of X70M pipe on PM (left) and weld seam (right). Etching: Nital 2%*

TEST RESULTS

After the specified test period (1000h) the specimens were removed from the test chamber and unloaded. In order to mark any advance of hydrogen-assisted cracking, the specimens were heat tinted and subsequently broken in liquid nitrogen. No visual trace of crack extension from the fatigue pre-crack front could be detected.

The fractured specimens were also post examined by Scanning Electron Microscopy and the absence of any crack extension due to hydrogen was again verified. As presented in Table 3, the obtained fracture toughness results clearly surpass the qualification criteria of ASME B31.12 Option B ($K_{IH} \geq 55 MPa \cdot \sqrt{m}$), as well as fulfill ASME code design flaw tolerance criteria. Based on the code, the material can be qualified as suitable for hydrogen service.

Figure 6*: Fracture toughness specimens after exposure*

Position	Applied stress intensity factor (K_{IAPP})	Subcritical crack growth after exposure	Qualified stress intensity factor (K_{IH}) $55\ \mathrm{MPa} \cdot \sqrt{\mathrm{m}}$ minimum
HFW weld	$118\ \mathrm{MPa} \cdot \sqrt{\mathrm{m}}$	None (<0.25mm)	$>59\mathrm{MPa} \cdot \sqrt{\mathrm{m}}$
Parent metal	$118\ \mathrm{MPa} \cdot \sqrt{\mathrm{m}}$	None (<0.25mm)	$>59\mathrm{MPa} \cdot \sqrt{\mathrm{m}}$

Table 4: *K_{IH} results for H_2-service qualification of X70M pipe*

CONCLUSIONS

The certification of pipes for the transportation of pure gaseous hydrogen or H_2/NG gas mixtures without additional design pressure limitations can be realized if the pipe material's fracture resistance properties are qualified under design "Option B" of code ASME B31.12. The respective qualification tests require the long-term exposure of artificially pre-cracked specimens under high pressure 100% H_2 conditions.

Following the above qualification scheme, Corinth Pipeworks organized a series of relevant tests for High Frequency welded pipe in grade X70M. All tests were accomplished in RINA-CSM S.p.A. an acknowledged external research institute, highly experienced in hydrogen testing and fracture mechanics.

According to the obtained test results, both weld and base metal specimens demonstrated high resistance against hydrogen-assisted crack growth and the measured values for the K_{1H} fracture toughness property clearly surpassed the ASME B31.12 criteria for Design Option B.

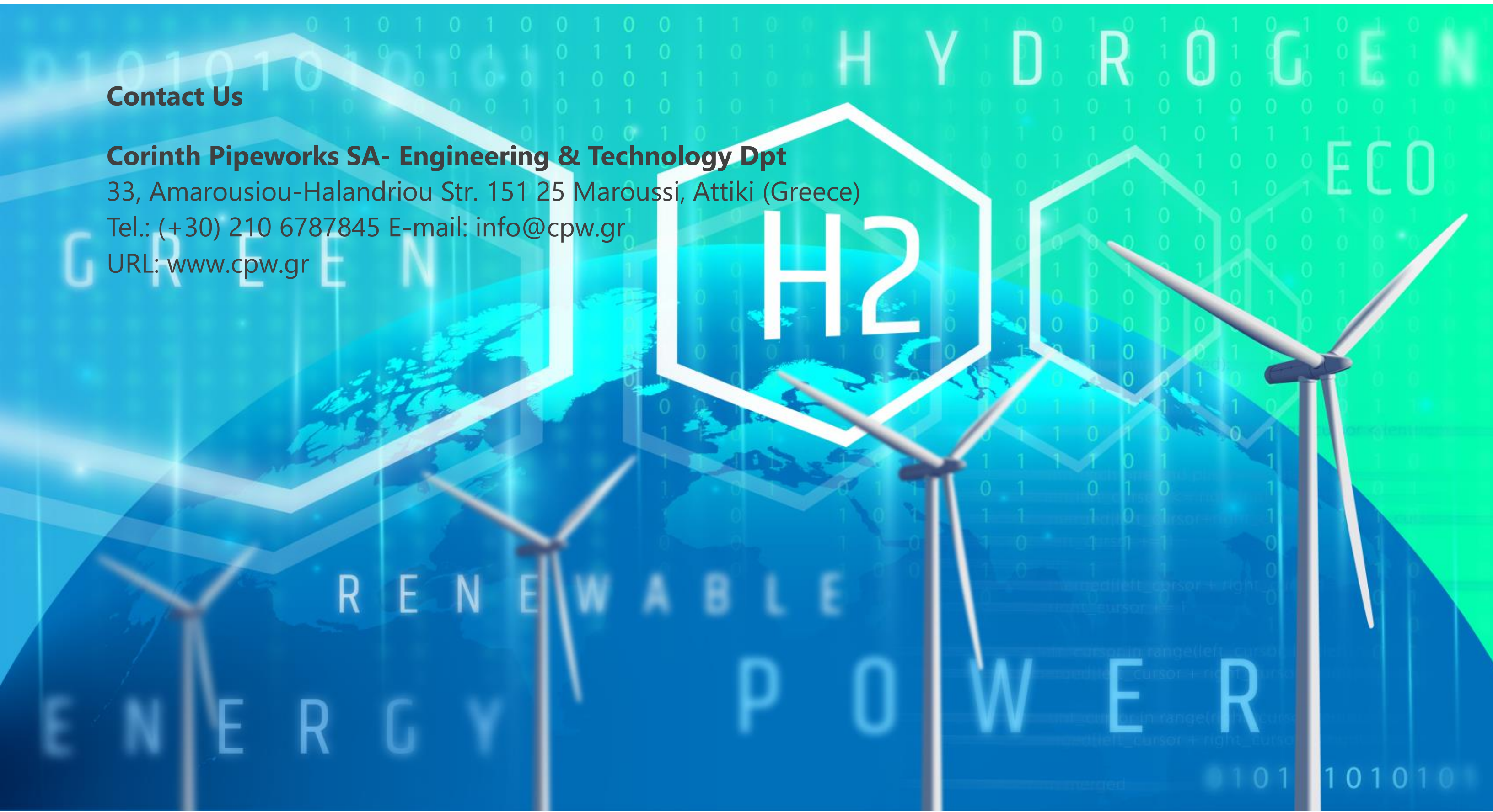
REFERENCES

[1] J. R. Fekete et al "Economic impact of applying high grade steels in hydrogen gas pipelines, Intl Journal of Hydrogen Energy 40 (2015) 10547-10558

[2] ASME B31.12-2019, Hydrogen Piping and Pipelines.

[3] ASME Boiler and Pressure Vessel Code, Section VIII, Rules for Construction of Pressure Vessels, Division 3, Alternative Rules for Construction of High Pressure Vessels.

[4] ASTM E1681-03 (2013), Standard Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials.



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