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Mechanical behaviour of austenitic stainless steel loaded in the aqueous solution of H_2SO_4 during tensile testing

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Abstract:

Introduction/purpose: Stainless steels have excellent corrosion resistance and adequate mechanical properties. However, their use in aggressively hydrogenated environments in the energy industry causes a loss of ductility. This work studied the effect of hydrogen on the mechanical behavior of the DINX15CrNiSi25.21/AISI310 austenitic stainless steel loaded in an aqueous solution of purely sulfuric acid H_2SO_4 at 1N at room temperature during tensile testing.

Methods: Experimental characterization techniques are applied to standardised machining-manufactured tensile specimens which underwent a series of heat treatments ranging from quenching at 1050°C for 35 minutes to tempering at 680°C for 30 minutes. This is accompanied by a succession of immersions of these samples by cryogenic quenching cycles at -196°C for a duration of 1 hour. The hydrogen was electrolytically loaded in a Pyrex glass cell for various loading times, ranging from 1h00 to 15h00, with a step of 2h00.

Results: The results showed a reduction in mechanical properties and plasticity. The electrochemical method confirmed the material's sensitivity to hydrogen embrittlement, calculating the embrittlement criterion EI (%). This method indicates a rapid increase in values depending on hydrogen loading times, with a maximum value of 41.60%.

Conclusion: The study highlights the negative impact of hydrogen on the mechanical properties of AISI310 stainless steel, emphasising the need for reduced hydrogen exposure in steel applications.

Key words: austenitic stainless steel, heat treatments, hydrogen pre-loaded, mechanical properties, hydrogen embrittlement (HE), faces.

Introduction

The ORSIM Oued Rhiou production unit employs the AISI310 series of austenitic stainless steel. These materials are refractory and are well-known for their categories of ferritic-austenitic steel. They contain 25% chromium and 21% nickel as additional elements. Chemical industry, petrochemicals, and energy sectors, including offshore wind turbines, highly recommend these alloys for their superior corrosion resistance due to their crystalline structure and high tensile strength, surpassing 950 MPa (Chauveau & Aubry, 2008). Working conditions in aggressive environments may require high percentages of chromium, nickel, and molybdenum to improve corrosion resistance. Several authors have conducted laboratory tests to study the electrochemical corrosion of this alloy (Chauveau & Aubry, 2008; Brass et al, 2000).

Other authors (Bach, 2018; Chêne, 2009; Brass et al, 2000) have studied the mechanical behaviour of these steels in relation to pitting corrosion, temperatures, and hydrogen embrittlement (the phenomenon of the absorption of the hydrogen molecule inside the crystal lattice) during exposure to different media, including gases, liquids, and high temperatures. Recently, several in-depth studies (Sales, 2015; Bach, 2018; Grimault et al, 2012; Lo et al, 2009; Iacoviello, 1995; Matsui et al, 1979) have been published on the mechanism of hydrogen embrittlement (H.E). These studies examine how the methods and protocols used in industrial cathodic loading conditions lead to a reduction in ductility. The studies aim to determine the appropriate medium, concentration, and pre-charging time in hours while fixing the current intensity (Hamissi et al, 2016).

This experiment aims to fully penetrate the hydrogen molecule (H_2), similar to the work of other authors (Laureys et al, 2020; Cauwels et al, 2020; Robertson et al, 2015; Kittel et al, 2013; Lynch, 2012; Depover et al, 2014), in order to make a comparison using the experimental curves obtained in tensile tests (Grimault et al, 2012; He et al, 1999; Smanio et al, 2008) at slow strain rates in the interest of looking at and analysing the performance of mechanical characteristics and ductility from the point of view of their service conditions, application, and operation.

Experimental work

Materials

Chemical composition

The chemical composition of the stainless steel duplex, type X15CrNiSi25.21/AISI310, is represented in mass percentage in Table 1.

Table 1 – Weight (%) of the AISI310 chemical composition

Fe%	C%	Cr%	Ni%	Si%	Mn%
52,201	0.057	25,23	21.08	1,712	1.013
P%	S%	NB%	Mo%	Al%	Co%
<0.0003	0.052	0.035	0.204	0.041	0.103
B%	V%	Ti%	Cu%	W%	Pb%
0.005	0.124	0.035	0.176	0.011	0.052

Tensile test specimens

The tensile specimens used in this experimental part are cylindrical (Figure 1) and obtained by machining according to DIN50125 Standard using a semi-automatic (TSA) lathe of the reference: Oerlikon—Bührle.SA, Switzerland Type: DEOa.

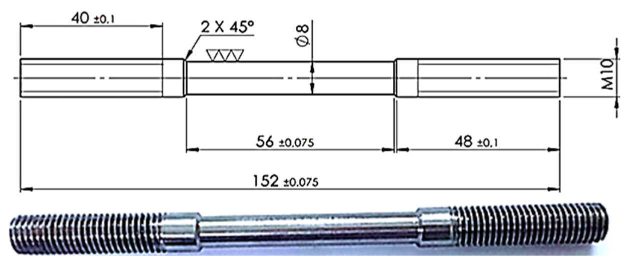


Figure 1 – Geometric shape and dimensions of the used tensile specimens

Mechanical characteristics

A mechanical tensile fracture test was carried out on a standardized reference test specimen in order to obtain the desired initial mechanical characteristics in the raw state without heat treatment (see Table 2).

– The method used for this test is mechanical fracture by traction using a Frank Karl GMBH traction machine, with a constant applied load of P_{max}= 400 kN and a slow deformation speed of ($\varepsilon = 2.7 \times 10^{-6}\ S^{-1}$),

– The elongation (A) is measured as percentage (%), according to the equation:

$A (\%) = (A-A_0)/A_0 \times 100 (\%)$.

– The aim is to obtain the mechanical properties in the initial state (raw and without thermal treatment).

Table 2 – Initial mechanical characteristics of the AISI310 austenitic stainless steel studied

Initial mechanical characteristics					
Material	σm (Air) (MPa)	σe (Air) (MPa)	σr (Air) (MPa)	Z (Air) (%)	A (Air) (%)
AISI310 Reference (Air)	750.0	720.0	542.0	68.60%	24.10%

Heat treatments (quenching, tempering)

After the manufacture of the tensile specimens, they undergo an austenization heat treatment cycle, see (Figure 2), which first consists of heating the specimens for 35 minutes at 1050°C followed by rapid quenching in water. This treatment can be followed by tempering at a temperature of 680°C for 30 minutes, then cooling in the open air (Poupeau, 1981; Sassoulas, 1997; Kenfack, 2015). Tempering makes it possible to eliminate the surface tensions developed during quenching. After these heat treatments, the material is perfectly homogeneous with a stable austenite and a relaxation of internal residual stresses, which leads to an increase in the yield strength (σe) (Grimault et al, 2012; Barralis et al, 1999).

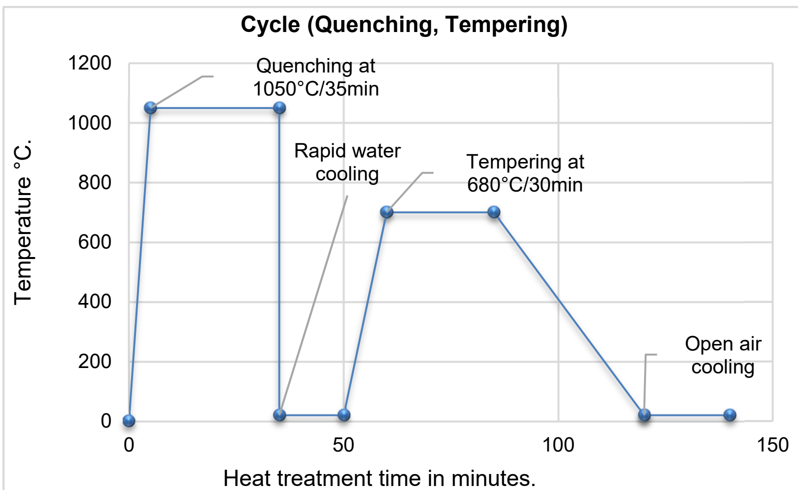


Figure 2 – Cycle of the heat treatment applied

Cryogenic heat treatment at -196°C

The next step consists of heat treating all the test specimens by cryogenic quenching at -196°C by immersion in a liquid nitrogen (N_2) bath for a holding time of 1 hour prior to heating in the open air for 40 minutes (see Figure 3).

The number of cycles is repeated in succession up to fifteen cycles (Aurélie Laureys et al, 2020; Cauwels et al, 2020; Robertson et al, 2015; Kenfack, 2015).

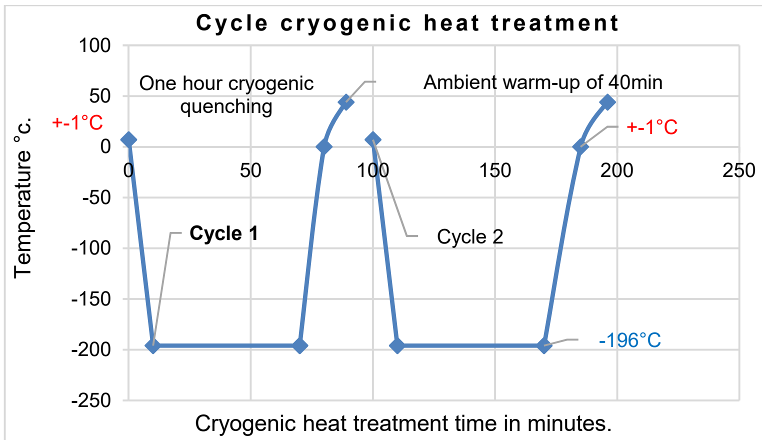


Figure 3 – Cycles of the applied cryogenic heat treatment at -196°C

Cathodic loading conditions of the test specimens

At room temperature ±20°C, the test specimens underwent cathodic loading by the aqueous solution of purely sulfuric acid H_2SO_4 at 1N (Laureys et al, 2020; Cauwels et al, 2020; Robertson et al, 2015) using a Pyrex glass enclosure (see Figure 4). Galvanostatique charge by two electrodes (cathode and anode) was carried out under the conditions adopted:

- The applied cathodic current density is fixed at 100(mA/cm^2).
- With an amperage of 1.5A, the hydrogen charging times are varied from 1 hour to 15 hours with a step of 2 hours.

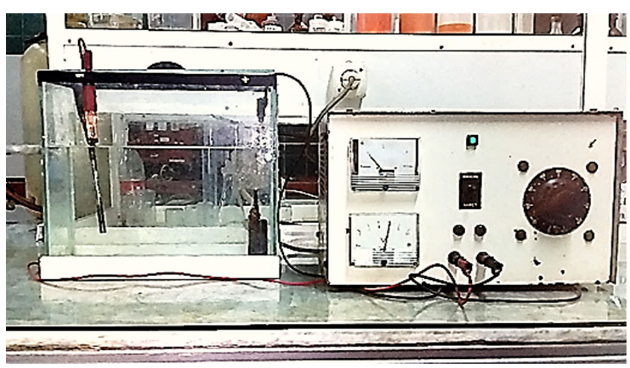
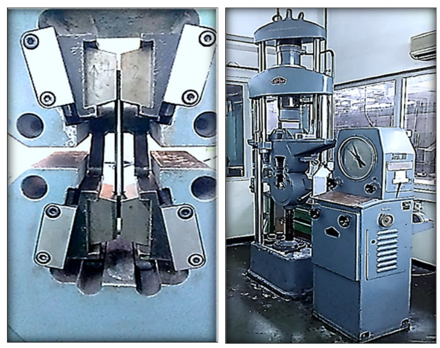


Figure 4 – Pyrex cell of cathodic loading in the aqueous solution of sulfuric acid H_2SO_4 at 1N

Mechanical fracture tensile test

After the electrolytic loading protocol (hydrogenated), all the specimens of the steel studied underwent a machine test by fracture using a reference tensile machine: Frank Karl GMBH, type: 83431 - Work Nr: 10650 (Figure 5 (a) and (b)). The fracture tests are carried out according to industrial conditions: the displacement nominal speed is ε: $2.7 x 10^{-6} S^{-1}$ (Cauwels et al, 2020) which corresponded to a constant applied load of 400kN. The mechanical results are recorded for analysis and construction of experimental curves (see Figures 6, 7 and 8).



(a) (b)

Figure 5 – (a), (b) Tensile machine Karl frank GMBH used

Table 3 shows the results of the mechanical properties following the fracture testing of all specimens before (specimen Reference) (Air) and after (specimen's hydrogenated) electrolytic pre-loading with hydrogen at room temperature ±20°C.

Table 3 – Mechanical properties of the AISI310 austenitic stainless steel after cathodic loading

Mechanical properties after hydrogenated						
N° specimen	Hydrogen Loaded in hours	$σm_{(H)}$ (MPa)	$σe_{(H)}$ (MPa)	$σr_{(H)}$ (MPa)	$Z_{(H)}$ (%)	$A_{(H)}$ (%)
N°1	1hour	552	252	465	53%	21%
N°2	3hours	538	227	375	52%	20%
N°3	5hours	526	224	355	52%	19%
N°4	7hours	523	240	375	51%	18%
N°5	9hours	535	235	372	51%	17%
N°6	11hours	526	226	354	50%	16%
N°7	13hours	516	215	340	51%	15%
N°8	15hours	508	212	374	51%	14%

Embrittlement index EI (%)

The embrittlement index (EI) is calculated in the result part and discussion by relationship (1), which compares the lengths of an uncharged reference sample (A_0) and those of the other samples that are pre-charged (A_H) electrolytically by hydrogen. The weakening index leads to a loss of plasticity which translates into a reduction in the elongation A (%).

$$EI=(A_{0(Air)}-A_{(H)}) /(A_{0(Air)}) \times 100(\%). \quad (1)$$

where

- A_0 is the elongations specimen with no charge (air),
- A_H is the elongation specimen charged in hydrogen.

Results and discussion

The results of the mechanical properties obtained are represented by experimental charts in Figures 6, 7 and 8. These charts show tensile strength, yield strength and failure strength.

The resistance of the steel results in a slight decrease in tensile strength, with a reduction of 26.40% observed at the shortest hydrogen loading time. As the loading time is extended, the tensile strength decreases further, reaching 26.67% at the longest loading time.

It was also observed that the failure strength of this type of material increased by 14.20 % during short loading times, reaching a value of 31.18 % following the hydrogen loading time until 15 hours (see Figure 6 and Table 3).

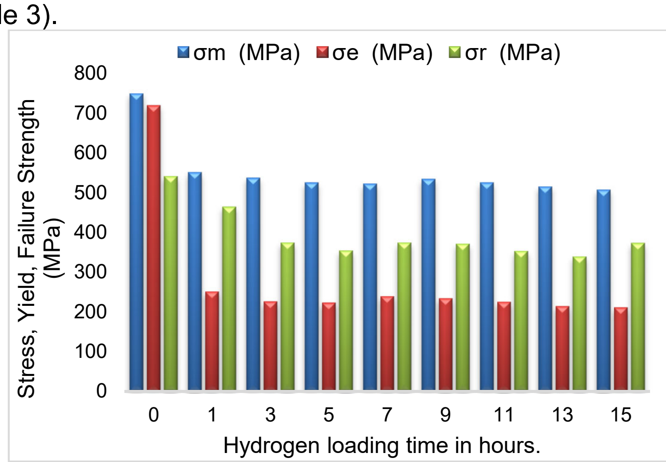


Figure 6 – Effect of the hydrogen loading time on the stress, the failure, and the yield strength in MPa of the AISI310 austenitic stainless steel

Variation of plasticity A, Z (%)

Figure 7 represents the variation of the plasticity characteristics of the X15CrNiSi25.21/AISI310 steel influenced by hydrogen loading, which causes slight reductions in these Z (%) restrictions compared to the reference from $Z_{(Air)}$: 68.60 % to $Z_{(H)}$: 53.0 % to reach a stable value of $Z_{(H)}$: 51.0 % throughout the level of hydrogen pre-charging times in hours (Table 3).

Losses of its plasticity are explained by a progressive decrease in elongations A (%) in percentage compared to the reference, from $A_{(Air)}$: 24.10 (%) to $A_{(H)}$: 21.0 (%) until reaching a minimum value of its plasticity of $A_{(H)}$: 14.0 % (see Table 3). These results are similar to the work by (Hamissi et al, 2016) which shows losses of plasticity translating into a gradual reduction at the lengths A %, under the industrial conditions adopted (simulated medium, loading time in hours, high concentration)

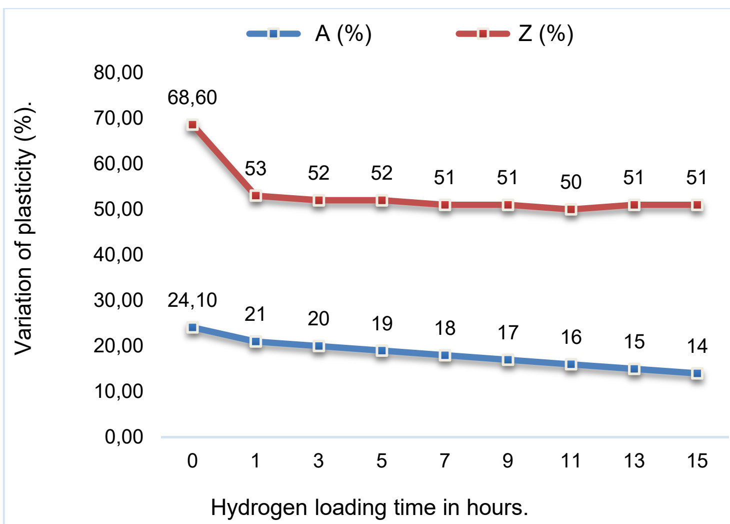


Figure 7 – Effect of the hydrogen loading time on the variation of plasticity in (%) of the AISI310austenitic stainless steel

Yield strength σe (MPa)

Figure 8 shows a progressive reduction in the yield strength (σe) of the material studied compared to the reference under the usual atmosphere of $\sigma e_{(Air)}$: 720.0 (MPa), to that under a high concentration of hydrogen $\sigma e_{(H)}$: 252.0 (MPa). The yield strength passes through a minimum value after the loading level of 15hours, $\sigma e_{(H)}$: 212.0 (MPa), due to high solubility of bound hydrogen to industrial conditions: high current density, charging time in hours and significant mechanical stress. It allows the absorption of a significant quantity of hydrogen, which causes the embrittlement of the material. The phenomenon of hydrogen embrittlement (H.E) was studied by several authors (Brass et al, 2000). In the same direction, one can note a plastic deformation of the useful part of the specimen exerted by the applied tensile stress (Lo et al, 2009), which leads to the conclusion that this type of steel has a fragile behavior with a reduction in ductility and its yield strength by producing an internal cracking structure, see Figure 10 (a) and (b).

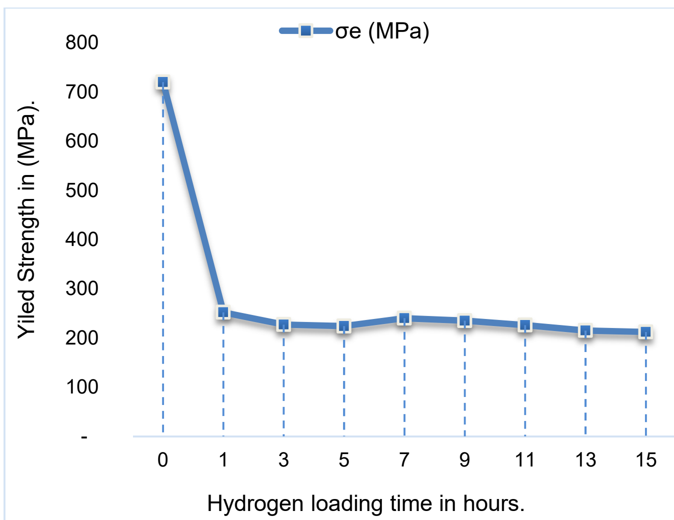


Figure 8 – Effect of the hydrogen loading time on the yield strength (σe) in (MPa) of the AISI310 austenitic stainless steel

Hardness HRV (N/mm^2)

Table 4 presents the results of the evolution hardness which changes the level of loading time in hours. It was noticed that the reference specimen presents the greatest value in $HRV_{(Air)}$ of the order 246.0 (N/mm^2) in relation to the other test specimens which are pre-loaded during ifferent hydrogen cathodic charging times of the order $HRV_{(H)}$ of 175.0 (N/mm^2), where the hardness HRV passing through a minimum HRV hardness is of the order $HRV_{(H)}$: 140.0 (N/mm^2).

Table 4 – Evolution hardness HRV of the AISI310 austenitic stainless steel after cathodic loading

Hydrogen loading in hours	Values of hardness HRV(30) (N/mm^2)
Reference0 (Air)	246.00
1 hour	175.00
3 hours	170.00
5 hours	160.00
7 hours	160.00
9 hours	170.00
11 hours	150.00
13 hours	165.00
15 hours	140.00

Embrittlement index EI (%)

Table 5 shows the results of the embrittlement index (EI, in %) of this specimen, obtained by the cathodic method. This index corresponds to the loss of mechanical properties, in particular plasticity, and is deduced from the measured elongations.

The samples preloaded with hydrogen, $A_{(H)}$, were compared with a non-hydrogenated reference specimen, $A_{0(Air)}$. No additional loading was carried out after the mechanical tensile tests. The values of the embrittlement index are calculated according to formula (1) (Lo et al, 2009; Brass et al, 2000).

From formula (1), it was concluded that the hydrogen embrittlement index (EI, in %) values are irreversible (see Table 5).

The results show a significant increase in EI, from 0.0% for the $A_{0(Air)}$ reference to 12.50% for the $A_{(H)}$ samples after a hydrogen loading time of up to 15hours. This rapid increase continues, reaching an embrittlement index EI(H) of 41.60%, validated by the work of M. Cauwels (Cauwels et al, 2020)

Table 5 – Embrittlement Index EI (%) of the AISI310 austenitic stainless steel

Hydrogen loading in hours	Values of the Embrittlement Index EI (%)
Reference0 (Air)	0.00%
1 hour	12.50%
3 hours	16.60%
5 hours	20.80%
7 hours	25.10%
9 hours	29.10%
11 hours	33.30%
13 hours	37.50%
15 hours	41.60%

Specimen states faces

Other experimental work by the authors (Smanio et al, 2008; Laureys et al, 2020; Kittel et al, 2013) was based on observations. The cracking of the test specimen types of the useful part subjected to fracture by tensile testing was observed in order to distinguish and validate the type of cracking which is linked to the zones of localized fractures (1) and (2). For further details, please refer to Figures 9 and 10.

The experimental study enables a comparison of the two examples of faces of the reference test specimens (Reference 0) of the useful part in the raw state and before the heat treatment. In Figure 9, face 1 (a) and face 2 (b) illustrate the aspects of specimen N°8 which underwent all the heat treatment applied, being electrolytically charged for 15 hours. A mechanical fracture tensile test was then carried out on the specimen at slow nominal speed, as illustrated in Figure 10, face 1 (a) and face 2 (b).

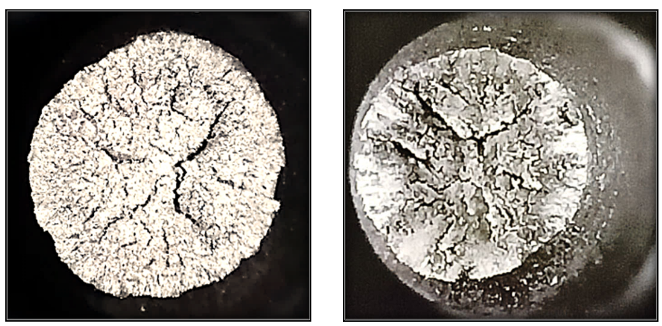
Face 1 (a) Face 2 (b)

Figure 9 – Faces of the specimen raw states (a): raw state Face 1; (b): raw state Face 2 of the AISI310 austenitic stainless steel

Figures 10 (a) and 10 (b) show the evolution of two brittle fracture surfaces of a specimen loaded with hydrogen for 15 hours. These figures easily identify cracks after the mechanical tensile test, which generally results in a reduction in ductility and the capacity to support cyclic loads. This reduction is associated with the cleavage of the weakened (α) ferrite (Philibert et al, 2013) and the ductile fracture of austenite (γ).

Internal cracks are typically observed at both ends of this tensile test specimen; these are continuous cracks propagating over the entire fractured zone within the grain boundaries (Laureys et al, 2020; Lo et al, 2009) of the ferrite phase (inter-granular cracking) (Brass et al, 2000). The crack is broken at an angle of 90° with the axis of the applied stress load (Kittel et al, 2013; Smanio et al, 2008).

Hydrogen promotes trans-granular cracking of the ferrite phase, including the indices of micro-cracks in the austenitic phase, which is validated by a previous study (Lo et al, 2009).



Face 1 (a) *Face 2 (b)*

Figure 10 – Specimen faces (a): face1, (b): face 2 - fractured specimen (propagation of cracking after hydrogenation at 15hours of sulfuric acid H_2SO_4 at 1N of the AISI310 austenitic stainless steel

Conclusion

The objective of this study was to characterise experimentally the influence of electrolytic hydrogen on the mechanical characteristics of AISI310 austenitic stainless steel. The remarks that can be made from this study are given as follows:

- The variation in tensile strength, yield strength, and failure strength of austenitic stainless steel decreases significantly with the increase in the duration of hydrogen loading, with reductions of 32.26%, 70.55%, and 30.99%, respectively. This can be explained by the fact that hydrogen diffusing into the steel's atomic lattice in the form of (H^+) weakens the metallic bond, reducing resistance until the material breaks.

- The structure of steel plays a very important role in the diffusion of hydrogen. The variation in mechanical resistance between the initial, untreated material and the hydrogen-charged material demonstrates this. This variation in resistance is pronounced by the variation in the hydrogen charging time as well as the temperature.
- The phenomenon of hydrogen embrittlement is more pronounced under high concentrations of hydrogen produced by industrial polarization conditions (charging time in hours, high current density, high acid concentration); this is because the martensitic pseudo-transformation makes the material harder and therefore more fragile.
- The mechanical tensile tests, which are related to the damage index EI (%), show that the absorbed hydrogen causes the elongation to decrease at break and creates a difference in elongation between the specimens that are loaded and those that are not loaded. High loading times produce a maximum value of the embrittlement index equal to EI=41.60(%).
- AISI310 stainless steel experiences strength reduction and embrittlement with increased hydrogen exposure, requiring minimized exposure, alternative material selection, and design considerations for hydrogen environments. Engineers should make informed decisions for safety and longevity of structures when using AISI310 stainless steel.

Symbols and abbreviations
σm: tensile strength (MPa)
σe: yield strength in (MPa).
σr: failure strength in (MPa).
A: elongations in (%).
Z: restriction in (%).
HRV (30): Vickers hardness in (N/mm^2).
ε: Nominal speed in (S^{-1}).
γ: Austenitic.
α: Ferritic.
EI: Embrittlement indice in (%).
A_0: Elongations specimen not charged, (Reference not charged (air).
A_H: Elongations specimen charged in hydrogen. (Specimen charged).

References

Bach, A.-C. 2018. *Etude du piégeage de l'hydrogène dans un acier inoxydable austénitique dans le cadre de la corrosion sous contrainte assistée par l'irradiation*. PhD thesis. Paris: Université PSL (Paris Sciences & Lettres) [online]. Available at: https://theses.fr/2018PSLEM044 [Accessed: 20 March 2024].

Barralis, J., Castex, L. & Maeder, G. 1999. Précontraintes et traitements superficiels. *Techniques de L'Ingénieur - Traitements des métaux*, art.ref:M1180v2, December 10. Available at: https://doi.org/10.51257/a-v2-m1180.

Brass, A.-M., Chêne, J. & Coudreuse, L. 2000. Fragilisation des aciers par l'hydrogène : étude et prévention. *Techniques de L'Ingénieur - Corrosion Vieillissement,* art.ref:M175v2, June 10. Available at: https://doi.org/10.51257/a-v2-m175.

Cauwels, M., Claeys, L., Depover, T. & Verbeken, K. 2020. The hydrogen embrittlement sensitivity of duplex stainless steel with different phase fractions evaluated by in-situ mechanical testing. *Frattura ed Integrità Strutturale*, 14(51), pp.449-458. Available at: https://doi.org/10.3221/IGF-ESIS.51.33.

Chauveau, E. & Aubry, D. 2008. Les aciers inoxydables austéno-ferritiques en fils et barres et leur utilisation dans l'industrie de l'eau. *Techniques Sciences Méthodes*, 6, pp.65-72. Available at: https://doi.org/10.1051/tsm/200806065.

Chêne, J. 2009. L'hydrogène dans les matériaux métalliques en relation avec les interactions plasticité-environnement. In: Viguier, B. (Ed.) *PlastOx 2007 - Mécanismes et Mécanique des Interactions Plasticité - Environnement*, Argelès-sur-Mer, France, pp.131-145, May 19-25. Available at: https://doi.org/10.1051/ptox/2009010.

Depover, T., Pérez Escobar, D., Wallaert, E., Zermout, Z. & Verbeken, K. 2014. Effect of hydrogen charging on the mechanical properties of advanced high strength steels. *International Journal of Hydrogen Energy*, 39(9), pp.4647-4656. Available at: https://doi.org/10.1016/j.ijhydene.2013.12.190.

Grimault, B., Chauveau, E., Gaillet, L., Drissi-Habti, M., Chaussadent, T. & Mantel, M. 2012. Comportement d'aciers inoxydables à hautes caractéristiques mécaniques vis-à-vis de la corrosion par piqûre et de la fragilisation par hydrogène. *Matériaux & Techniques*, 100(2), pp.113-125. Available at: https://doi.org/10.1051/mattech/2012008.

Hamissi, C., Lakhdari, A.A., Aboura, A. & Seddak, M. 2016. Hydrogénation Des Vis En Acier 35b2 Lors Du Décapage Acide. *Revue des matériaux et énergies renouvelables*, 1(1), pp.1-7. Available at: https://www.asjp.cerist.dz/en/article/67672 [Accessed: 10 July 2024].

He, J., Han, G., Fukuyama, S. & Yokogawa, K. 1999. Tensile behaviour of duplex stainless steel at low temperatures. *Materials Science and Technology*, 15(8), pp.909-920. Available at: https://doi.org/10.1179/026708399101506715.

Iacoviello, F. 1995. V - Fragilisation par l'hydrogène de l'acier inoxydable duplex Z2CND2205 chargé en hydrogène à 200°C. *Matériaux & Techniques*, 83, pp.48-50. Available at: https://doi.org/10.1051/mattech/199583120048s.

Kenfack, C. 2015. Guide hors production operateur traitement thermique. *Academia* [online]. Available at: https://www.academia.edu/33201915/Guide_hors_production_operateur_traitement_thermique [Accessed: 10 July 2024].

Kittel, J., Ropital, F., Grosjean, F., Sutter, E.M.M. & Tribollet, B. 2013. Corrosion mechanisms in aqueous solutions containing dissolved H2S. Part 1: Characterisation of H2S reduction on a 316L rotating disc electrode. *Corrosion Science*, 66, pp.324-329. Available at: https://doi.org/10.1016/j.corsci.2012.09.036.

Laureys, A., Pinson, M., Claeys, L., Deseranno, T., Depover, T. & Verbeken, K. 2020. Initiation of hydrogen induced cracks at secondary phase particles. *Frattura ed Integrità Strutturale*, 14(52), pp.113-127. Available at: https://doi.org/10.3221/IGF-ESIS.52.10.

Lo, K.H., Shek, C.H. & Lai, J.K.L. 2009. Recent developments in stainless steels. *Materials Science and Engineering: R: Reports*, 65(4–6), pp.39-104. Available at: https://doi.org/10.1016/j.mser.2009.03.001.

Lynch, S. 2012. Hydrogen embrittlement phenomena and mechanisms. *Corrosion Reviews*, 30(3-4), pp.105-123. Available at: https://doi.org/10.1515/corrrev-2012-0502.

Matsui, H., Kimura, H. & Moriya, S. 1979. The effect of hydrogen on the mechanical properties of high purity iron I. Softening and hardening of high purity iron by hydrogen charging during tensile deformation. *Materials Science and Engineering*, 40(2), pp.207-216. Available at: https://doi.org/10.1016/0025-5416(79)90191-5.

Philibert, J., Vignes, A., Bréchet, Y. & Combrade, P. 2013. *Métallurgie. Du minerai au matériau*, *2e édition*. Paris: Dunod [online]. Available at: https://www.dunod.com/sites/default/files/atoms/files/9782100597543/Feuilletage.pdf. ISBN: 978-2-10-059754-3.

Poupeau, P. 1981. Traitements thermiques des métaux et alliages. *Techniques de L'Ingénieur - Traitements des métaux*, art.ref:M1105v1, January 10. Available at: https://doi.org/10.51257/a-v1-m1105.

Robertson, I.M., Sofronis, P., Nagao, A., Martin, M.L., Wang, S., Gross, D.W. & Nygren, K.E. 2015. Hydrogen Embrittlement Understood. *Metallurgical and Materials Transactions A*, 46(6), pp.2323-2341. Available at: https://doi.org/10.1007/s11661-015-2836-1.

Sales, D.G. 2015. *Etude des mécanismes d'endommagement d'aciers martensitiques associés au SSC (Sulphide Stress Cracking)*. PhD thesis. University of Rochelle [online]. Available at: https://theses.fr/2015LAROS041 [Accessed: 20 March 2024].

Sassoulas, H. 1997. Traitements thermiques des aciers inoxydables. *Techniques de L'Ingénieur - Traitements des métaux*, art.ref:M1155v2, March 10. Available at: https://doi.org/10.51257/a-v2-m1155.

Smanio, V., Fregonese, M., Kittel, J., Cassagne, T., Ropital, F. & Normand, B. 2008. Wet Hydrogen Sulfide Cracking Monitoring by Acoustic Emission. In: *Eurocorr 2008*, Edinburgh, UK, September [online]. Available at: https://ifp.hal.science/hal-02475510 [Accessed: 20 March 2024].

Comportamiento mecánico del acero inoxidable austenítico cargado en la solución acuosa de H_2SO_4 durante ensayos de tracción

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CAMPO: materiales
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Resumen:

Introducción/objetivo: Los aceros inoxidables tienen una excelente resistencia a la corrosión y adecuadas propiedades mecánicas. Sin embargo, su uso en ambientes agresivamente hidrogenados en la industria energética provoca una pérdida de ductilidad. Este trabajo estudió el efecto del hidrógeno sobre el comportamiento mecánico del acero inoxidable austenítico DINX15CrNiSi25.21/AISI310 cargado en una solución acuosa de ácido puramente sulfúrico H_2SO_4 a 1N a temperatura ambiente durante ensayos de tracción.

Métodos: Se aplican técnicas de caracterización experimental a probetas de tracción fabricadas mediante mecanizado estandarizado que se sometieron a una serie de tratamientos térmicos que van desde templado a 1050°C durante 35 minutos hasta revenido a 680°C durante 30 minutos. Esto va acompañado de una sucesión de inmersiones de estas muestras mediante ciclos de enfriamiento criogénico a -196°C durante una duración de 1 hora. El hidrógeno se cargó electrolíticamente en una celda de vidrio Pyrex durante varios tiempos de carga, que oscilaron entre 1h00 y 15h00, con un paso de 2h00.

Resultados: Los resultados mostraron una reducción en las propiedades mecánicas y la plasticidad. El método electroquímico confirmó la sensibilidad del material a la fragilización por hidrógeno, calculando el *criterio de fragilización El (%). Este método indica un rápido aumento de los valores en función de los tiempos de carga de hidrógeno, con un valor máximo del 41,60%.*

Conclusión: El estudio destaca el impacto negativo del hidrógeno en las propiedades mecánicas del acero inoxidable AISI310, enfatizando la necesidad de reducir la exposición al hidrógeno en las aplicaciones de acero.

Palabras claves: acero inoxidable austenítico, tratamientos térmicos, precarga de hidrógeno, propiedades mecánicas, fragilización por hidrógeno (HE), caras.

Механическое поведение аустенитной нержавеющей стали, погруженной в водный раствор H_2SO_4, при испытании на растяжение

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РУБРИКА ГРНТИ: 81.09.00 Материаловедение
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Нержавеющие стали обладают превосходной коррозионной стойкостью и соответствующими механическими свойствами. Однако их использование в агрессивно гидрированных средах в энергетической промышленности приводит к потере пластичности. В данной статье изучалось влияние водорода на механические свойства аустенитной нержавеющей стали DINX15CrNiSi25.21/AISI310, погруженной в водный раствор чистой серной кислоты H_2SO_4 при 1N при комнатной температуре во время испытания на растяжение.

Методы: Экспериментальные методы определения характеристик применялись на стандартных образцах в испытании на растяжение. Образцы, изготовленные механической обработкой, подвергались ряду термообработок, начиная от закалки при температуре 1050°C в течение 35 минут и заканчивая отпуском при температуре 680°C в течение 30 *минут. Испытание сопровождалось последовательным погружением образцов по циклам в криогенной закалки при температуре -196°C продолжительностью 60 минут. Получение водорода производилось электролизом в емкости из термостойкого стекла в течение различного времени загрузки, варьирующегося от одного до пятнадцати часов с двухчасовым интервалом.*

Результаты: Результаты показали снижение механических свойств и пластичности. Электрохимический метод подтвердил чувствительность материала к водородному охрупчиванию, рассчитав критерий охрупчивания EI (%). Данный метод показывает быстрый рост значений в зависимости от времени загрузки водорода с максимальным значением 41,60%.

Вывод: В исследовании выявлено негативное влияние водорода на механические свойства нержавеющей стали AISI310, что подчеркивает необходимость снижения воздействия водорода при производстве стали.

Ключевые слова: аустенитная нержавеющая сталь, термообработка, предварительная загрузка водорода, механические свойства, водородное охрупчивание (HE), поперечные сечения в месте повреждения.

Механичко понашање аустенитног нерђајућег челика изложеног воденом раствору H_2SO_4 при испитивању затезањем

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КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Нерђајући челици имају одличну отпорност на корозију и одговарајућа механичка својства. Међутим, њихова употреба у агресивним хидрогенизованим срединама у индустрији енергетике доводи до губитка дуктилности. У овом раду проучава се ефекат *водоника на механичко понашање аустенитног нерђајућег челика DINX15CrNiSi25.21/AISI310, оптерећеног у воденом раствору чисте сумпорне киселине (H_2SO_4) при 1N на собној температури током испитивања на затезање.*

Методе: Експерименталне технике карактеризације примењене су на стандардизоване затезне епрувете добијене машинском обрадом и подвргнуте серији термичких обрада – од каљења на 1050°C током 35 минута до отпуштања на 680°C током 30 минута. То је праћено низом потапања епрувета током циклуса криогеног каљења на -196°C у трајању од 60 минута. Водоник је оптерећен електролитички у стакленој посуди од пирекса за различита времена оптерећења, од једног сата до 15 сати, с кораком од 2 сата.

Резултати: Резултати су показали редукована механичка својства и пластичност. Електрохемијски метод је потврдио осетљивост материјала на водоничну кртост, израчунавањем критеријума кртости EI (%). Овај метод указује на брзи раст вредности зависно од времена оптерећења водоником, при чему је максимална вредност 41,60%.

Закључак: У раду се наглашава негативан утицај водоника на механичка својства нерђајућег челика AISI310, при чему се истиче да је при употреби челика потребно смањити његову изложеност водонику.

Кључне речи: аустенитни нерђајући челик, термичка обрада, претходно оптерећење водоником, механичка својства, водонична кртост (HE), попречни пресеци на месту лома.

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