INSTITUTO DE PESQUISAS TECNOLÓGICAS

COMUNICAÇÃO TÉCNICA

Nº 179341

Fragilização por hidrogênio em pipelines

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Fragilização por hidrogênio em pipelines

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Motivação

- Necessidade de transmissão de gás hidrogênio por longas distâncias
- Risco associado: fragilização

With the emergence of the new hydrogen economy and infrastructure, it is believed that piping and pipeline systems will need to be operated at pressures with possible cyclic pressure loading in excess of our current operating regimes. It is expected that hydrogen piping systems will have to be operated up to 100 MPa (15,000 psig), transport pipelines will operate up to 20 MPa (3,000 psig), and both piping and pipeline systems will be operating at or below 150°C (300°F). In doing so, the metallic pipe materials in use today could be placed in an operating environment for which we currently have little or no data on their mechanical properties and behavior in a dry hydrogen environment.

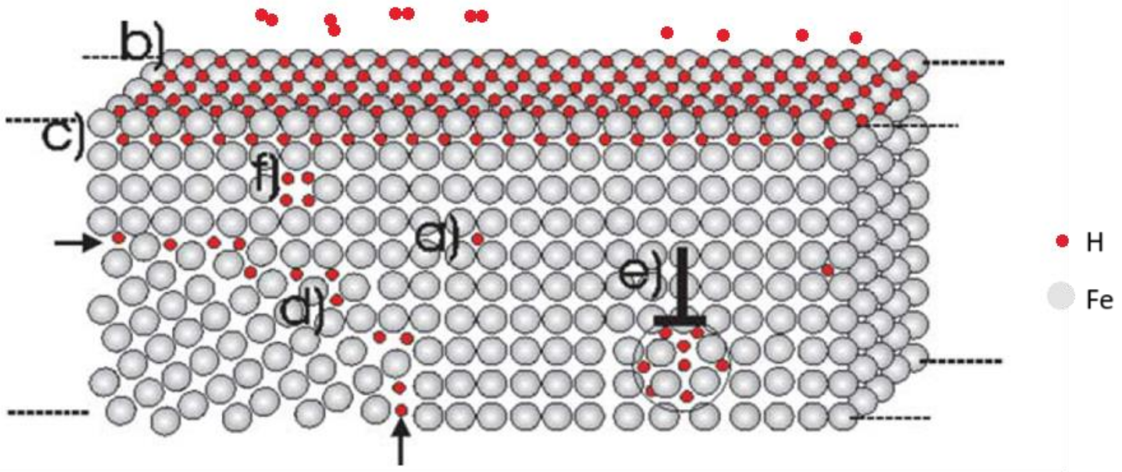
ASME B31.12

Danos por hidrogênio

- **Fragilização por hidrogênio (*hydrogen embrittlement* – HE)**
- **Trincamento devido à precipitação de hidrogênio (*hydrogen-induced cracking* – HIC)**
- ***Blistering***
- Ataque por hidrogênio em alta temperatura (*high temperature hydrogen attack* – HTHA)
- Trincamento devido à precipitação de hidretos

Danos por hidrogênio

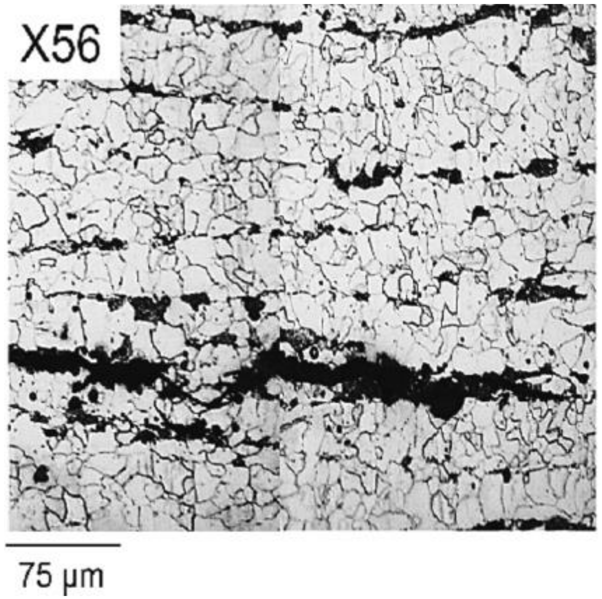
- **Fragilização (*hydrogen embrittlement* – HE)**
  - Queda de ductilidade e tenacidade devido à presença de hidrogênio dissolvido, H (até 5 ppm)
  - Alteração do mecanismo de fratura
  - ↑Resistência do material ↑Susceptibilidade
  - Reversível

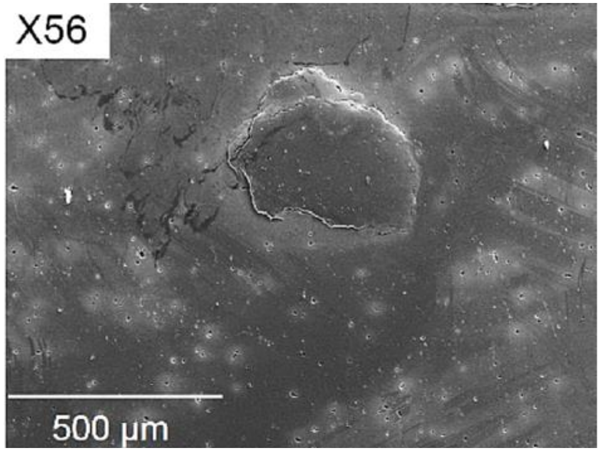


Fonte: adaptado de https://doi.org/10.1146/annurev.matsci.36.090804.094451

Danos por hidrogênio

- **Trincamento devido à precipitação de hidrogênio (*hydrogen-induced cracking* – HIC)**
- **Blistering**
  - Manifestações do mesmo dano; propagação de trinca pela precipitação de hidrogênio molecular
  - Irreversível





Fonte: https://doi.org/10.1016/j.engfailanal.2023.107650.

Códigos/guias para pipelines transportando hidrogênio

ASME B31.12-2019
(Revision of ASME B31.12-2014)

Hydrogen Piping and Pipelines

ASME Code for Pressure Piping, B31

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

Table IX-5A
Carbon Steel Pipeline Materials Performance Factor, H_f

Specified Min. Strength, ksi		System Design Pressure, psig						
Tensile	Yield	≤1,000	2,000	2,200	2,400	2,600	2,800	3,000
66 and under	≤52	1.0	1.0	0.954	0.910	0.880	0.840	0.780
Over 66 through 75	≤60	0.874	0.874	0.834	0.796	0.770	0.734	0.682
Over 75 through 82	≤70	0.776	0.776	0.742	0.706	0.684	0.652	0.606
Over 82 through 90	≤80	0.694	0.694	0.662	0.632	0.610	0.584	0.542

GENERAL NOTES:
(a) Tables IX-5A, IX-5B, and IX-5C are for use in designing carbon steel, low, and intermediate alloy piping and pipeline systems that will have a design temperature within the hydrogen embrittlement range of the selected material [recommended lowest service temperature up to 300°F (150°C)]. If the system design temperature is out of this range, use the design allowable stresses from Table IX-1A for piping or the specified minimum yield strength for pipelines from Table IX-1B.
(b) Table IX-5A was developed for pipeline systems and as such the design factors are based on the specified minimum yield strength of the material ranges shown.
(c) Design factors may be calculated by interpolation between pressures shown in the tables.
(d) For materials not covered by Tables IX-5A, IX-5B, and IX-5C, use the allowable stresses in Table IX-1A.

Classe de resistência máxima recomendada: X52

EIGA

HYDROGEN PIPELINE SYSTEMS

IGC Doc 121/14

Revision of Doc 121/04

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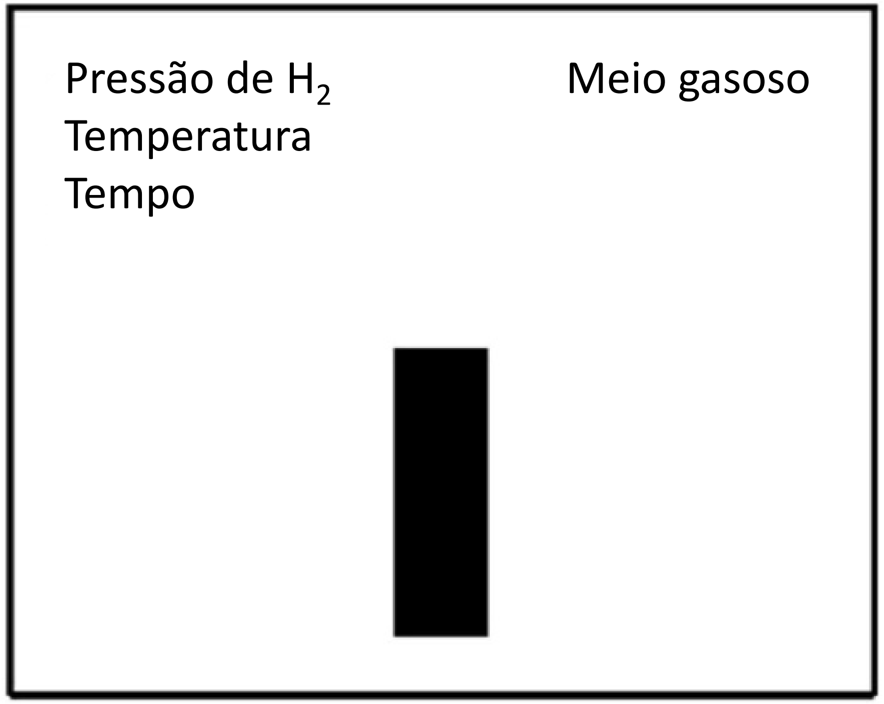
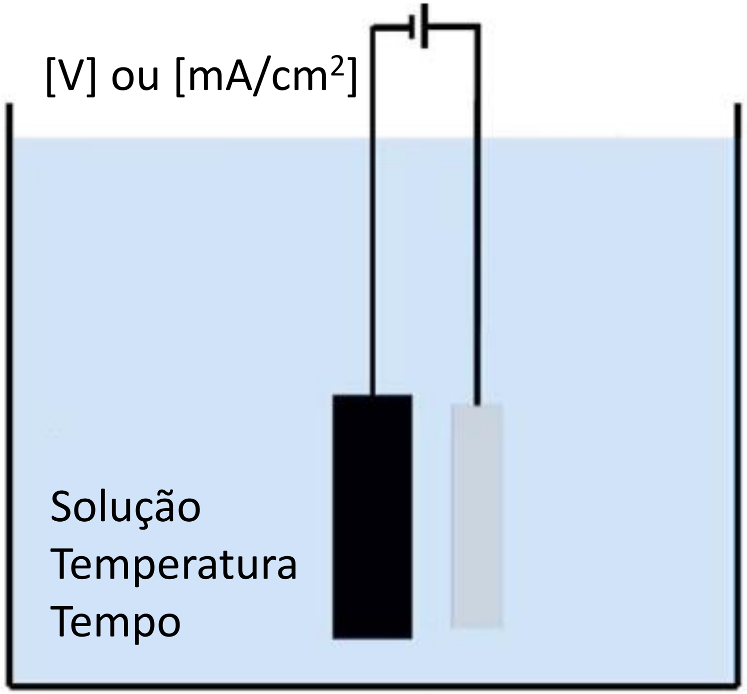
Literatura

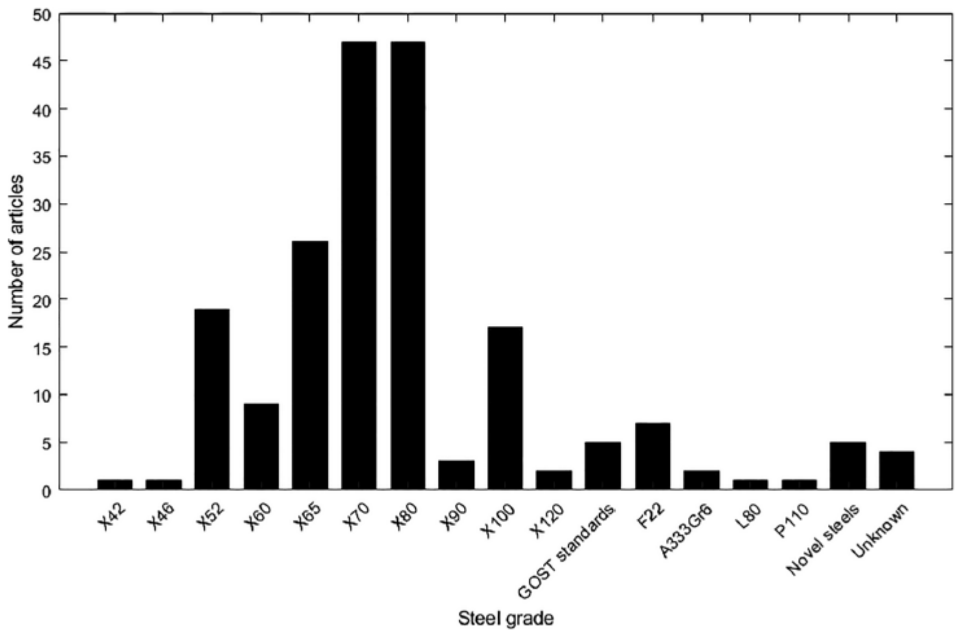


Carregamento gasoso



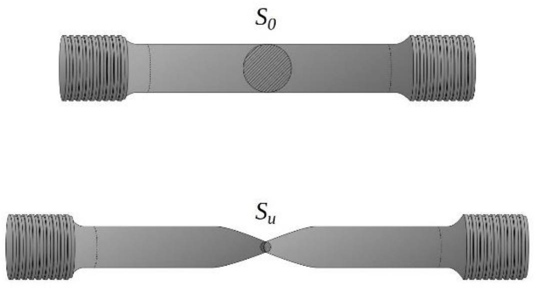
Carregamento catódico

Literatura

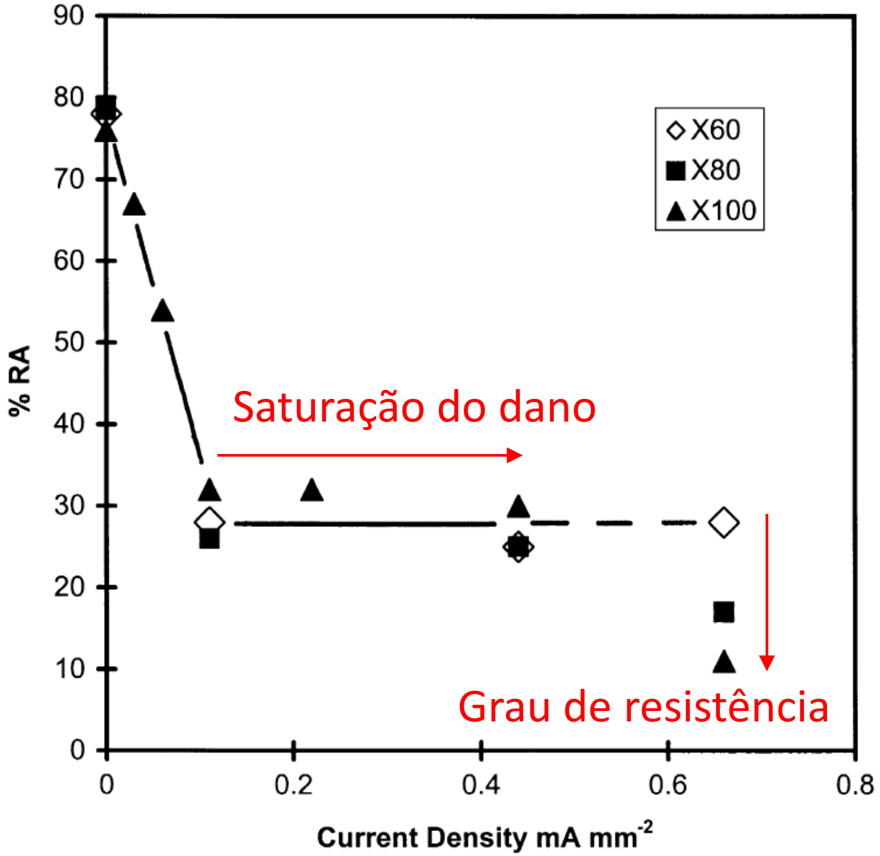


Fonte: https://doi.org/10.1515/corrrev-2022-0052

Type	Experiment	Standards	Number of studies
Tensile	Slow strain rate tensile (SSRT)	ASTM G142, ASTM G129	30
	Small punch (SP)	ASTM E3205	2
	Tensile test	ASTM G142, ASTM E8	28
Permeation	Devanathan-Stachurski method	ASTM G148	34
Fatigue	Beam specimen		2
	Compact tension (CT)	ASTM E647	19
	Edge notched tension		2
	Eccentrically loaded single-edge notched tension (ESET)		3
	Spiral notch torsion test (SNTT)		1
	Wedge open loading (WOL)	ISO 7539	1
Fracture toughness	Modified wedge open loading (MWOL)		1
	Circumferentially notched tension (CRT)	ASTM G142	9
	Compact tension (CT)	ASTM E647	2
	Hollow circumferentially notched tension		1
	Three point bending (TPB)/Single-edge notched bending (SENB)	ASTM E1820	7
	Single-edge notch tension (SENT)		5
Impact	Charpy pendulum impact test	ASTM E23	7
Distribution	Hydrogen microprint technique		2
SCC	Hydrogen-induced cracking	NACE TM0284	24
	U-bend test	ASTM G30	1
Electrochemical corrosion	Electrochemical impedance spectroscopy (EIS)	ASTM G106	11
	Potentiodynamic polarisation	ASTM G61	18
	Scanning vibrating electron technique (SVET)		2
Hydrogen content	Thermal desorption spectroscopy (TDS)		6
	Displacement methods		10
	Hydrogen analyser		2
	Hot extraction method		2
	Potentiometer discharging		4
Other	Disc pressure test		2



Literatura



Steel	Current density mA mm^{-2}	% Reduction in area
X60	**0**	**78**
X60	0.11	28
X60	0.44	25
X60	0.66	28
X80	**0**	**78**
X80	0.11	26
X80	0.44	25
X80	0.66	17
X100	**0**	**76**
X100	0.03	67
X100	0.06	54
X100	0.11	32
X100	0.22	32
X100	0.44	30
X100	0.66	11
X100[a]	0.66	77

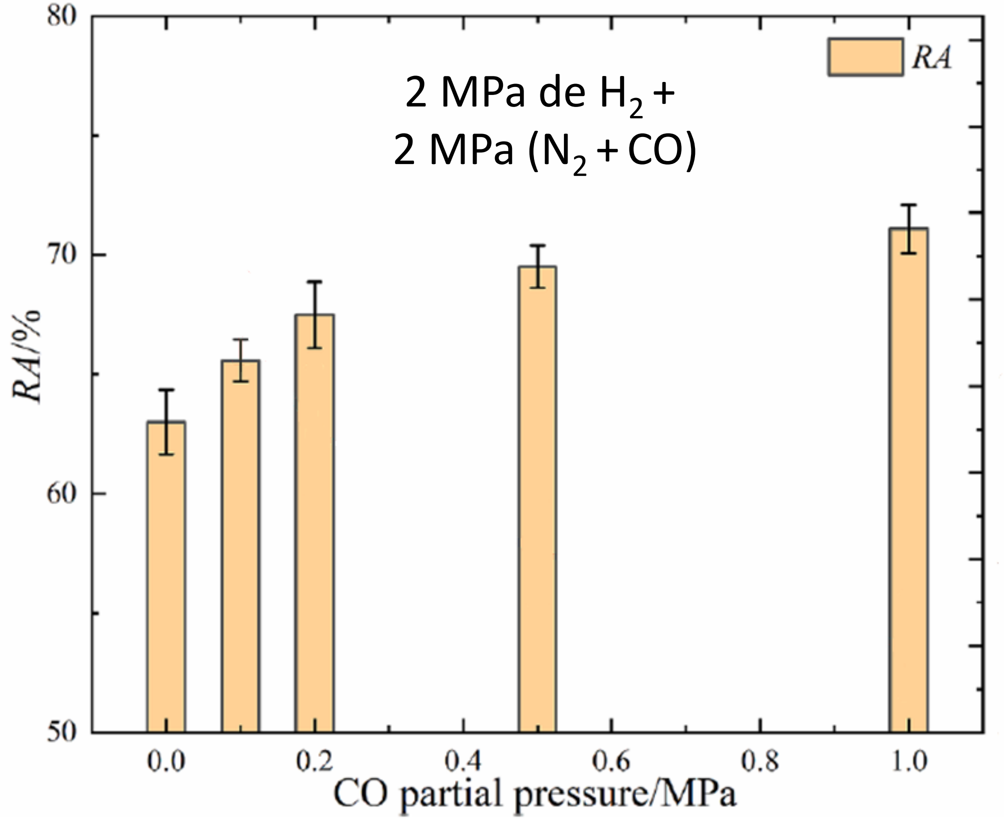
[a] Left one week in air at room temperature before straining.

Reversibilidade do dano

Fonte: https://doi.org/10.1016/j.corsci.2006.02.011

Literatura

API X52



Fonte: adaptado de https://doi.org/10.1016/j.engfailanal.2024.108111.

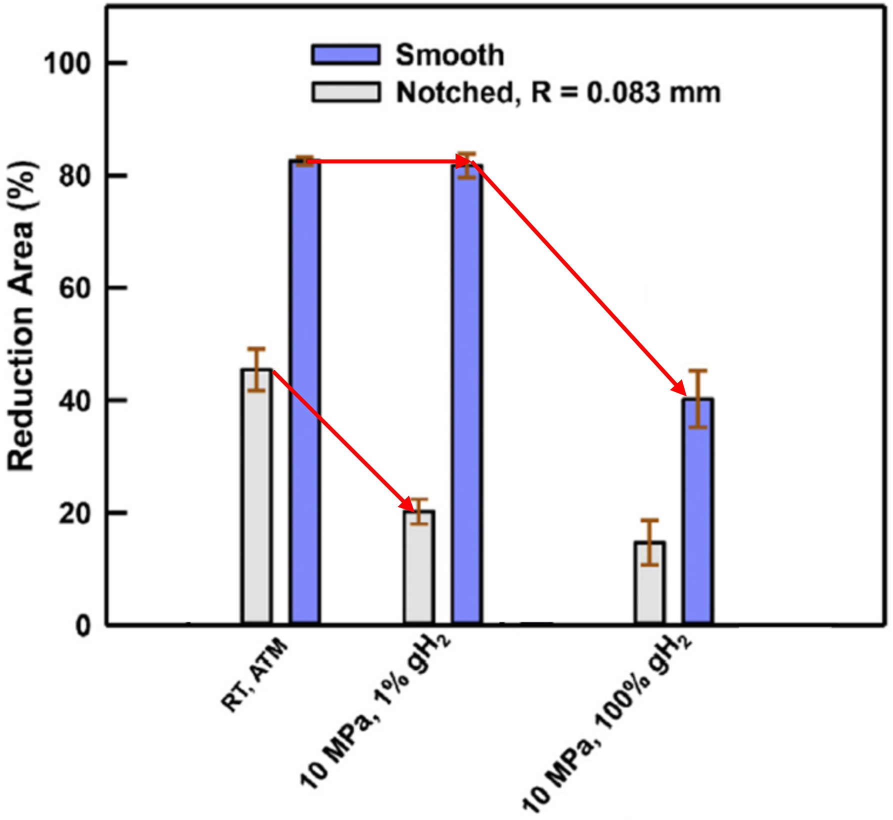
Adsorção preferencial de CO na superfície do aço “atrapalha” ingresso de H.

O_2 e SO_2 também atuam nesse sentido enquanto H_2S favorece o dano.
CO_2: resultados variados.
CH_4 e N_2: sem efeito.
[1-3]

[1] Gallon, N. HYDROGEN PIPELINES – DESIGN AND MATERIAL CHALLENGES AND MITIGATIONS.
[2] https://doi.org/10.1016/j.engfailanal.2024.108111.
[3] https://doi.org/10.1533/9780857093899.3.526

Literatura

API X70
Misturas de CH_4 e H_2

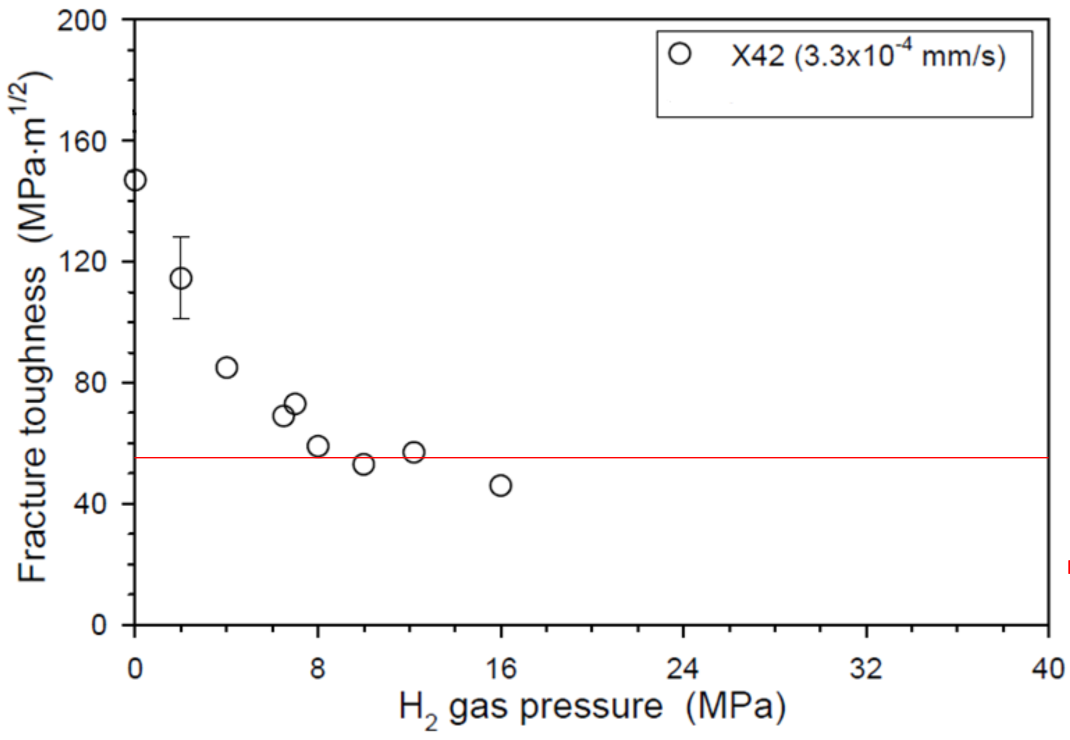


Smooth

Notched

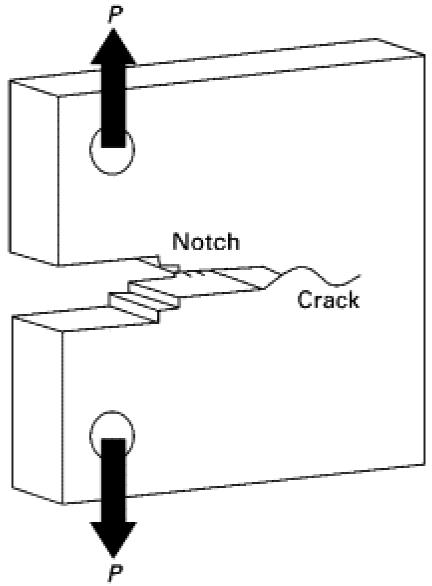
Fonte: https://doi.org/10.1016/j.ijhydene.2019.11.013.

Literatura



55 $MPa\sqrt{m}$

Valor mínimo requerido por um critério da ASME B31.12



Fonte: San Marchi, C. and Somerday, B.P. Sandia Report SAND2012-7321, Technical Reference for Hydrogen Compatibility of Materials. Alburquerque, NM : Sandia National Laboratories, 2012.

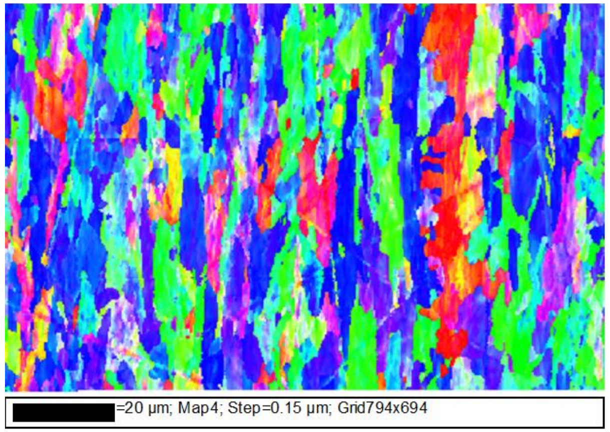
Literatura

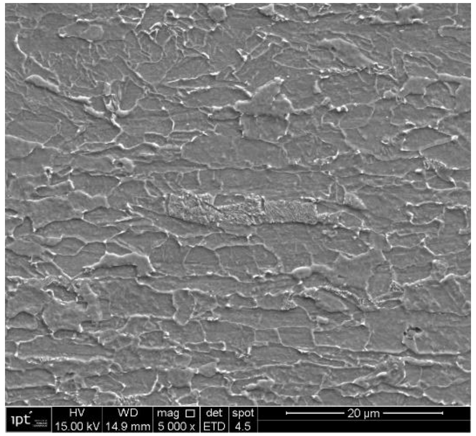
Necessidade de estudos focados em:

- Soldas e zonas afetadas pelo calor [1]
- Criar uma base de dados confiável, explorando altas pressões de hidrogênio (100 MPa), especialmente para tenacidade à fratura e fadiga [2,3]

[1] https://doi.org/10.1515/corrrev-2022-0052
[2] https://doi.org/10.1016/j.engfailanal.2024.108917
[3] https://doi.org/10.1533/9780857093899.3.526

No IPT





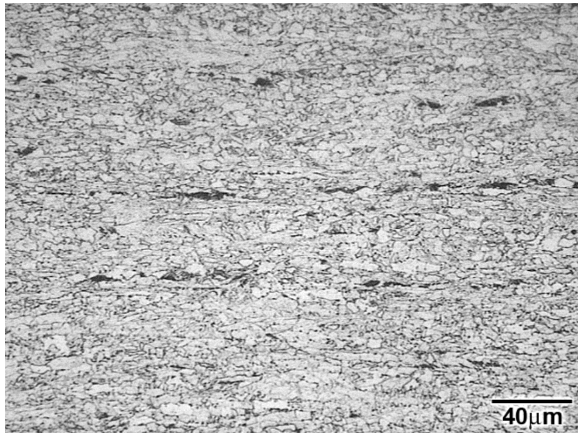


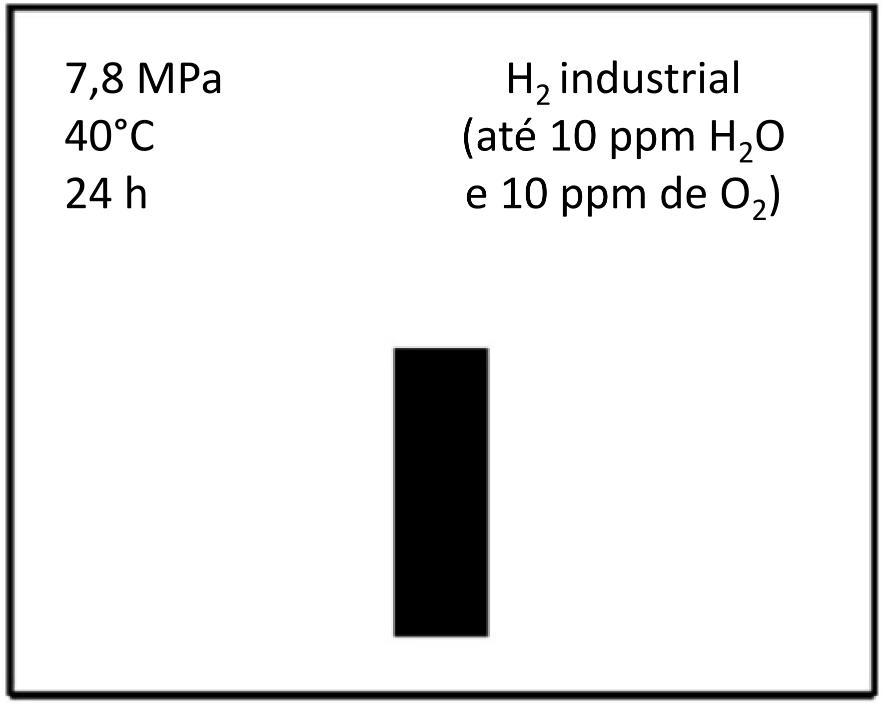
Tabela 01- Determinação elementares via SPARK OES (% massa)

Item	Identificação	Replicatas	C	S	Al	Si	P	Ti	V	Cr	Mn	Co	Ni	Cu
476/24	API X65	1	0,092	0,0080	0,035	0,233	0,0218	0,027	0,045	0,014	1,575	0,003	0,007	0,012
		2	0,085	0,0085	0,035	0,227	0,0216	0,028	0,045	0,012	1,567	0,003	0,007	0,012
		3	0,082	0,0085	0,032	0,227	0,0214	0,027	0,044	0,012	1,555	0,003	0,007	0,012
		Média	0,086	0,0083	0,034	0,229	0,0216	0,027	0,045	0,013	1,566	0,003	0,007	0,012
		Incerteza*	0,012	0,0007	0,004	0,008	0,0005	0,002	0,001	0,003	0,025	0,000	0,001	0,001

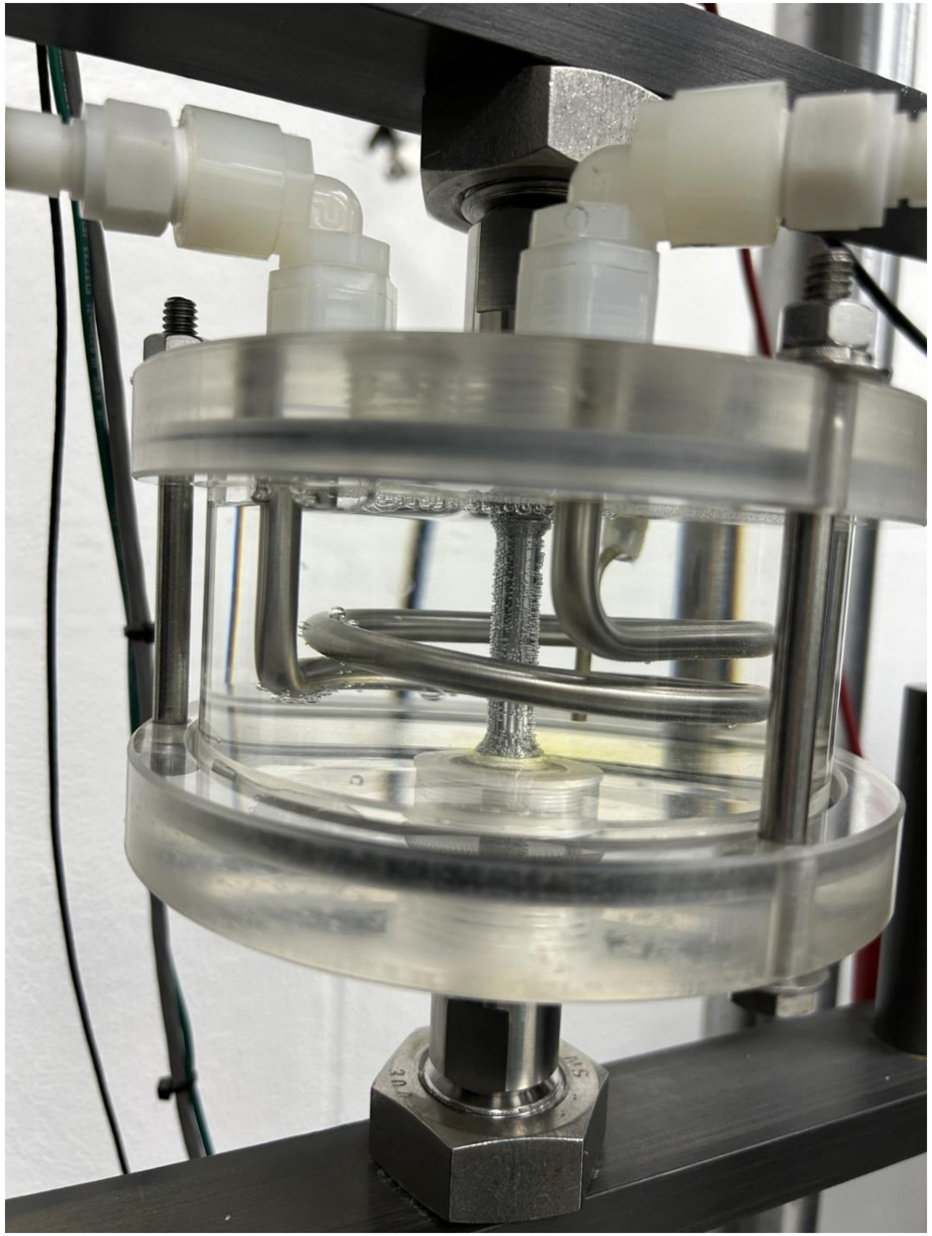
**A incerteza associada refere-se ao intervalo de confiança de 95%, utilizando a distribuição t de Student para n= 3*

Aço API X65M

No IPT



Carregamento gasoso



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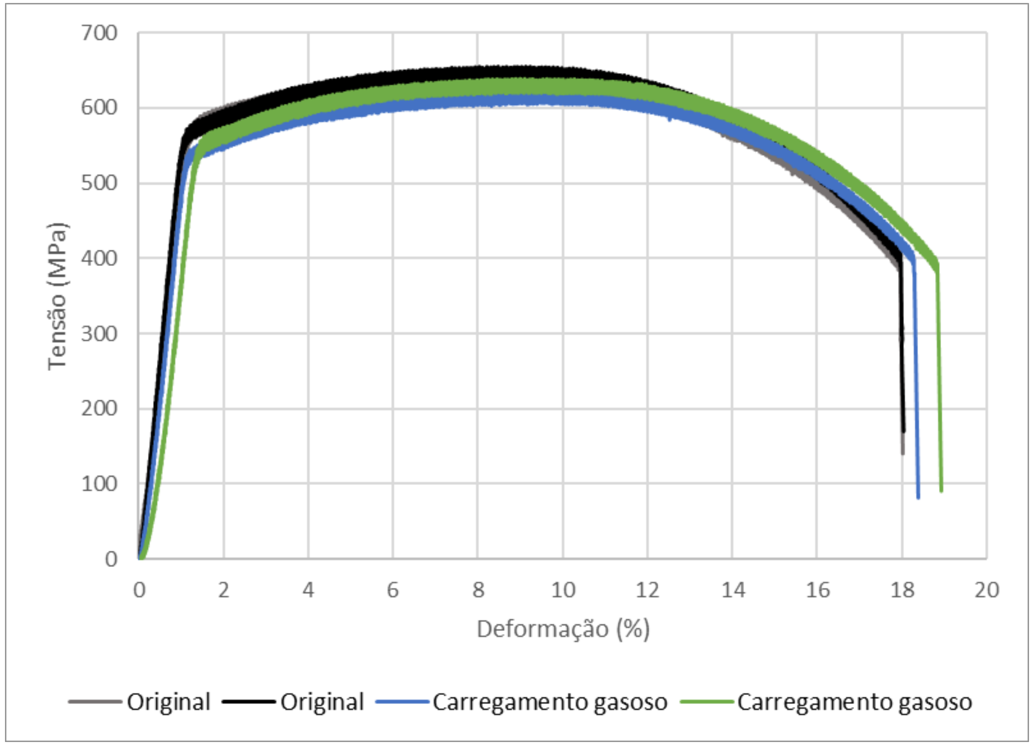
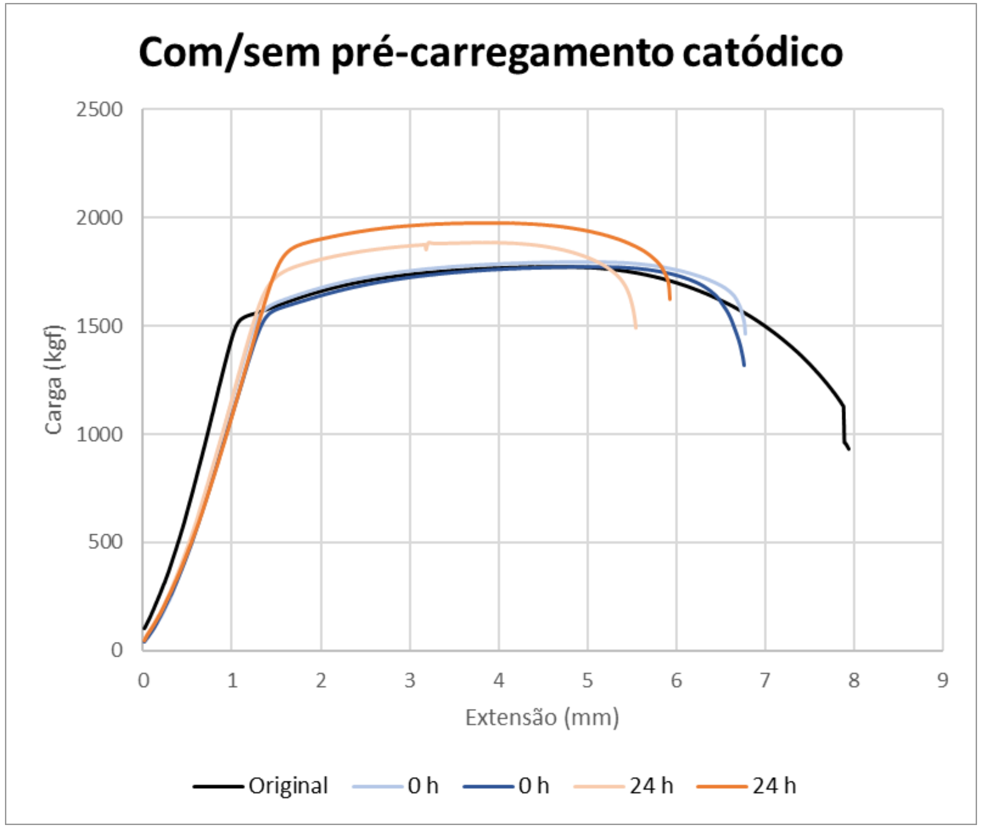


	Original	Carregamento gasoso
LE 0,2% (MPa)	568 ± 6	538 ± 11
LR (MPa)	647 ± 11	631 ± 12
Alongamento (%)	18 ± 0	19 ± 0
Redução de área (%)	71 ± 2	66 ± 1

Sem diferenças para nível de confiança de 95%

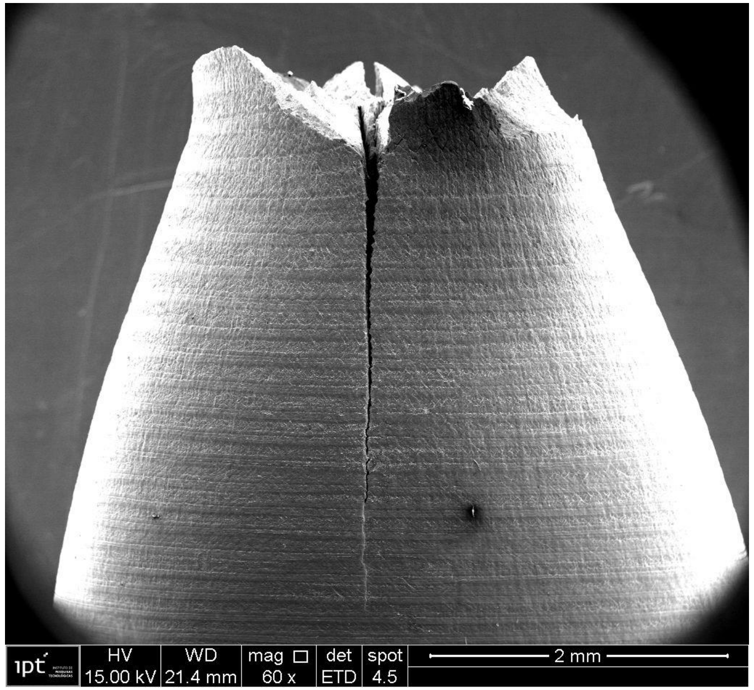
No IPT



	Original	O h	24 h
LR (kgf)	1776	1787 ± 15	1929 ± 64
Extensão (mm)	8	7 ± 0	6 ± 0
Redução de área (%)	74	34 ± 2	24 ± 4

Sem diferenças para nível de confiança de 95%

No IPT



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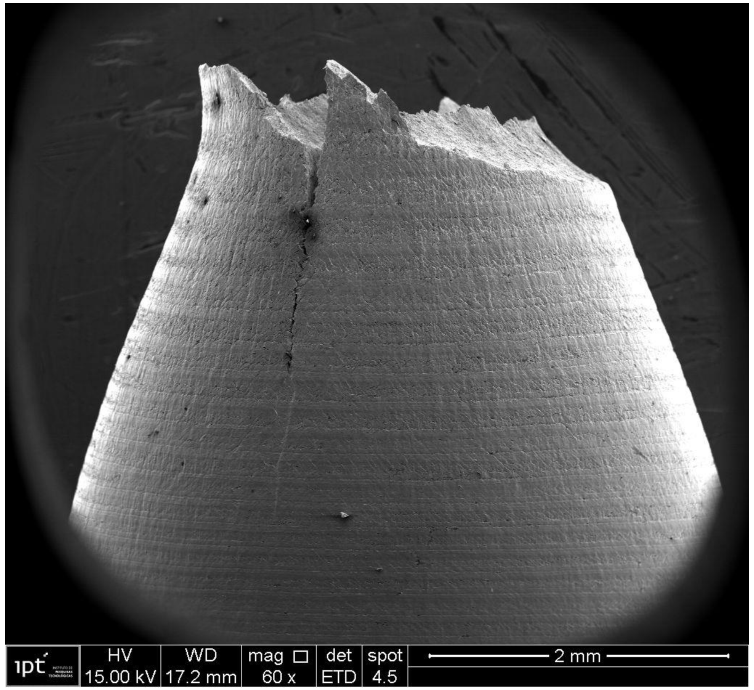

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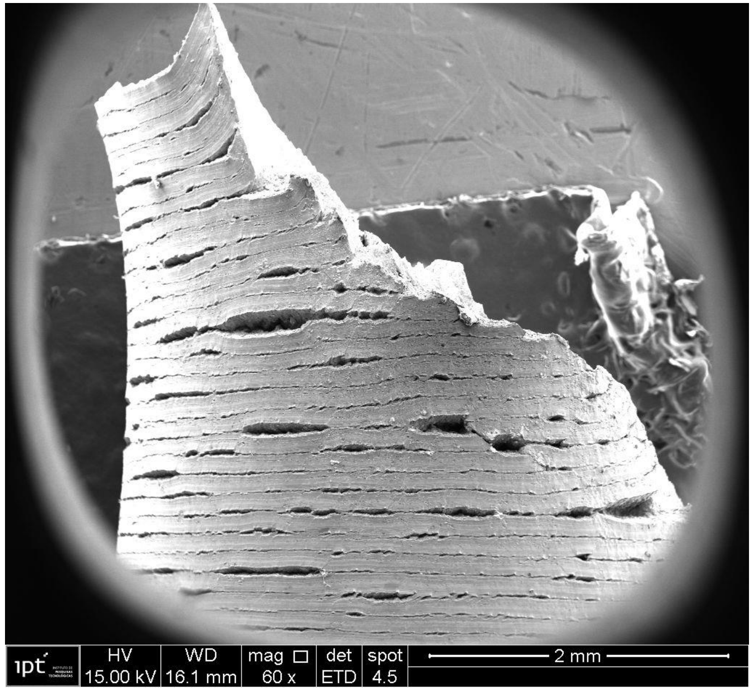
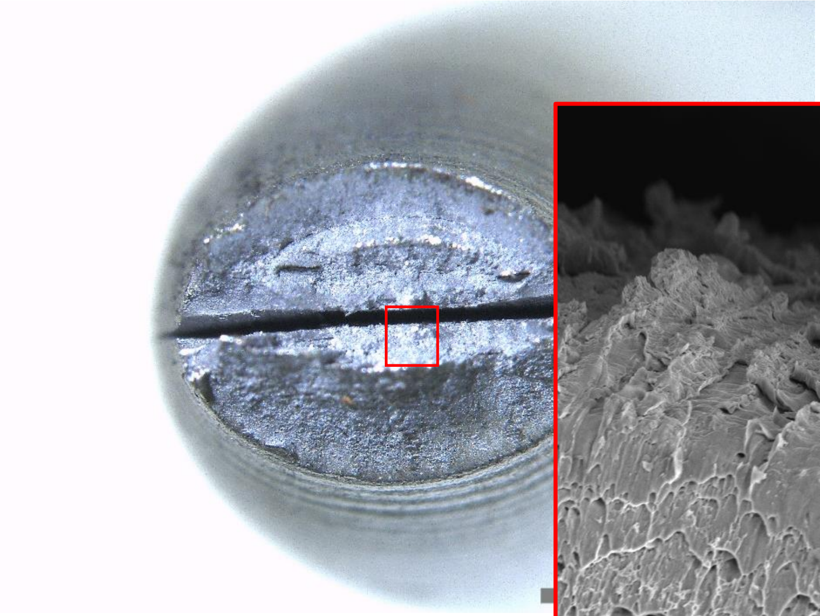


Carregamento catódico (0 h pré-carregamento)

No IPT



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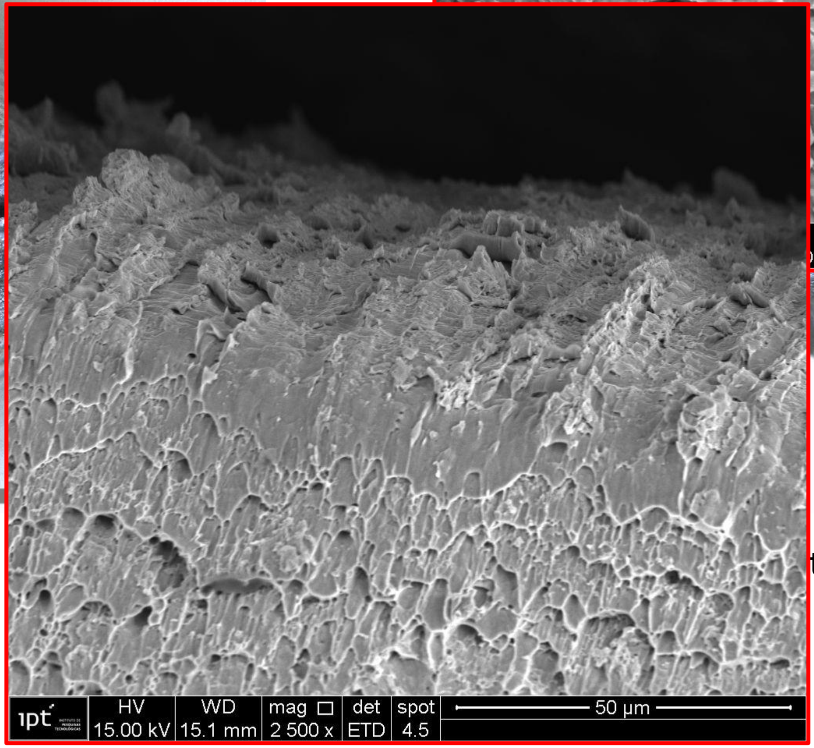

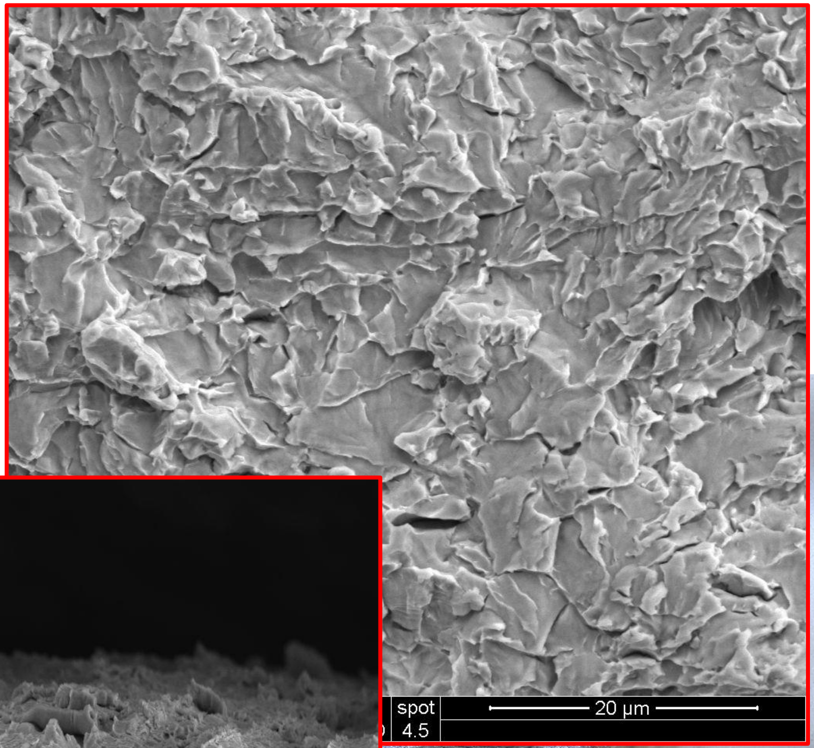

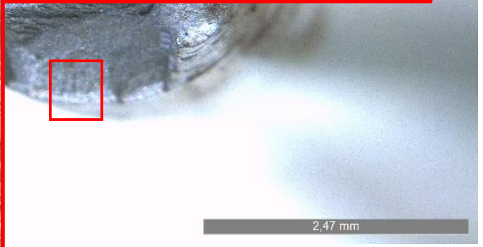

tódico (0 h pré-carregamento)

Obrigada!

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