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Evaluation of Local Mechanical Properties in Flexible Pipe Wires Using the Small Punch Test (SPT)

R.F. Souza[1], J.M. Pardal[1,2], S.S.M. Tavares[1,2], T.C. Chuvas[3], L.F. Guimarães[3]

1. Graduate Program in Mechanical Engineering (PGMEC), Universidade Federal Fluminense (UFF), Niterói-RJ, Brazil;
2. Graduate Program in Industrial Assembly (PMI), Universidade Federal Fluminense (UFF), Niterói-RJ, Brazil;
3. Graduate Program in Mechanical Engineering and Materials Technology (PPEMM), Centro Federal de Educação Tecnológica Celso Suckow da Fonseca (CEFET/RJ), Rio de Janeiro-RJ, Brazil.

Introduction

Offshore exploration in deep waters and in the pre-salt has consolidated the use of flexible pipes as risers and flowlines, in which resistance to axial loads is provided by the tensile armor layers, made of high-carbon steel wires [1-3]. In the presence of CO_2 and H_2S, these wires are susceptible to corrosion and sulfide stress cracking (SSC) [1,4]. As manufacturers do not disclose the thermomechanical treatments applied, mechanical properties may vary across the wire cross-section, requiring techniques capable of assessing localized regions, such as the Small Punch Test (SPT) [5-6].

Objectives

To evaluate the local mechanical properties of the tensile armor wire of a flexible pipe, made of cold-rolled Fi42C steel, by means of the SPT at three through-thickness positions, enabling a comparative estimate against the tensile values obtained in the longitudinal direction.

Methodology

Ø 8 mm discs were extracted by wire EDM from a 200 mm wire bar (profile P1), at five sequential sections and three through-thickness positions (A, B and M), totaling 15 specimens, per ASTM E3205-20 and BS EN 10371:2021 [5-6].



Figure 1 – Profile P1 after disc extraction.

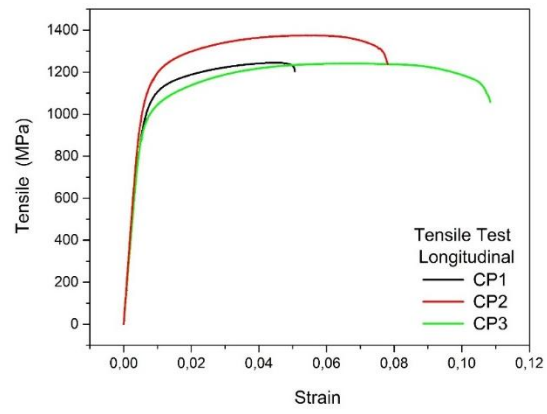
Chemical composition of profile P1 – Fi42C (wt.%)											
C	Mn	Si	P	S	Cr	Ni	Mo	Cu	Nb	Al	Fe
0.80	0.70	0.20	0.008	0.004	0.041	0.027	0.005	0.004	0.002	0.03	bal.

The discs were ground up to #1200 grit and polished with alumina to a thickness h_0 = 0.50 ± 0.005 mm, measured with a micrometer. Tests were performed at 0.2 mm/min, recording the force–displacement curve up to disc rupture. The yield strength (YS) and the ultimate tensile strength (S_u) were estimated using the empirical correlations [5,7]:

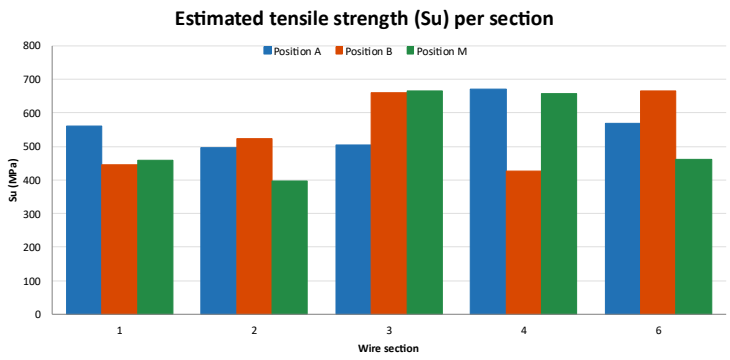
$$YS = \beta_{YS} \cdot F_e / h_0^2 \qquad S_u = \beta_{UTS} \cdot F_m / (h_0 \cdot u_m)$$

Results and Discussion

The scatter in S_u among positions within the same section reached 42% (Graph 2). The mean values per position were close (A = 561, B = 544 and M = 528 MPa), and the analysis of variance indicated no significant difference among positions (p = 0.89) or among sections (p = 0.37). The hypothesis of changes in the pearlite constituents, due to differences in cooling rate or strain hardening, still requires confirmation by microhardness testing and metallography. The S_u values obtained with the β_{UTS} from the literature [7] were below the ultimate tensile strength from the tensile test (Graph 1), indicating that the β coefficients must be calibrated for Fi42C steel.



Graph 1 – Stress × strain curves from the longitudinal tensile test of the Fi42C wire (CP1 to CP3).



Graph 2 – Tensile strength estimated by SPT, S_u (β_{UTS} = 0.277), by section and position (A, B and M).

Conclusions

The SPT enabled local evaluation of the Fi42C wire at three through-thickness positions. The scatter in S_u among positions reached 42%, with no statistically significant difference for the current number of tests. The absolute values of YS and S_u depend on β_{YS} and β_{UTS}, which will be calibrated against the tensile test of this material, along with refinement of the linearization criterion (u_A and u_B).

Additional tests, microhardness and metallography will make it possible to identify the regions most susceptible to failure, supporting the specification of wires for risers and flowlines.

References

1. American Petroleum Institute. API RP 17B: Recommended Practice for Flexible Pipe. 6th ed. Washington, 2024.
2. Souza, A. P. F. Colapso de dutos flexíveis sob pressão externa. D.Sc. Thesis – COPPE/UFRJ, Rio de Janeiro, 2002.
3. Bicudo, R. G. P. Análise de instalação de linhas flexíveis. M.Sc. Dissertation – COPPE/UFRJ, Rio de Janeiro, 2009.
4. ANSI/NACE MR0175-2021/ISO 15156:2020: Materials for use in H_2S-containing environments in oil and gas production. Houston: AMPP, 2021.
5. ASTM International. ASTM E3205-20: Standard Test Method for Small Punch Testing of Metallic Materials. West Conshohocken, 2020.
6. British Standards Institution. BS EN 10371:2021 – Metallic materials: Small punch test method. London, 2021.
7. García, T. E.; Rodríguez, C.; Belzunce, F. J.; Suárez, C. Estimation of the mechanical properties of metallic materials by means of the small punch test. Journal of Alloys and Compounds, v. 582, p. 708–717, 2014.