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ON THE RELATIONSHIP BETWEEN MICROSTRUCTURE, MECHANICAL PROPERTIES AND HYDROGEN EMBRITTLEMENT OF PIPE STEELS

Abstract. The medium carbon casing pipe steels for oil and gas wells with fine grain bainitic microstructure and with coarse microstructure of ferrite-pearlite were tested. The steel with higher strength and with more dispersed microstructure was less susceptible to hydrogen embrittlement than the another one. The finite element method of load simulation of the specimens with crack was used for assessment of the embrittlement of the studied steels.

Casing pipe steels are operated under simultaneous effect of corrosive and hydrogenating environments and mechanical loading. There is currently tendency to use steels with higher strength but they could be more sensitive to an influence of aggressive environments. Moreover, pipe steels produced by different manufactures and met the requirements to strength and plasticity can have different microstructure [1–3], since there is no requirement for initial microstructure in the standards. The study was aimed to assess the mechanical behaviour and hydrogen embrittlement of two casing pipe steels depending on their microstructure from the point of view their serviceability in oil and gas oilfield.

Two medium carbon steels of casing pipes with fine grain bainitic microstructure (mass. %: 0.35 C; 1.22 Mn; 0.26 Si; 0.135 Cr; 0.01 S; 0.020 P; 0.129 Cu; Fe – balance) and with coarse microstructure of ferrite-pearlite (mass. %: 0.53 C; 0.72 Mn; 0.25 Si; 0.046 Cr; 0.03 S; 0.023 P; 0.024 Cu; Fe – balance) were studied. Basic mechanical properties of the investigated steels, namely, yield strength σ_Y. ultimate strength σ_{UTS}, elongation δ, and reduction in area (*RA*), and impact strength *KCV* were determined. Susceptibility of the investigated steels to hydrogen embrittlement was studied by tension of specimens in air after electrolytically hydrogen pre-charging and assessed by changes in plasticity of steels due to pre-charging. To estimate the embrittlement of steels, calculations using finite element method were used, taking into account the true stress-strain relationships [4].

Tensile mechanical properties of the investigated casing pipe steels with different microstructure before and after their hydrogen charging are presented in Table 1. It should be noted that the 0.53 C steel with lower strength and with coarse-grained microstructure was characterized by lower plasticity compared to another steel with the fine grain bainitic microstructure. The impact strength values *KCV* of the investigated steels also show the remarkable difference between them. The fracture surface for the 0.53 C steel with lower value of brittle fracture resistance was characterised by the signs of cleavage fracture mechanism predominantly.

Table 1. Mechanical properties of casing pipe steels before (in the numerator) та after (in the denominator) their hydrogen charging.

Steel	σ_Y [MPa]	σ_{UTS} [MPa]	δ_H [%]	RA_H [%]	KCV [J/cm^2]
0.35 C	654/652	787/773	25.3/17.2	72.9/61.6	16.2/-
0.53 C	391/383	710/715	19.0/9.6	42.6/24.3	2.2

The 0.53 C steel with lower strength was characterized also by higher susceptibility to hydrogen embrittlement compared with that of the 0.35 C steel with higher strength and higher initial characteristics of plasticity.

The usage of the numerical modelling of specimen with crack allows us to calculate stress and strain distributions in front of the crack tip and to evaluate the crack growth resistance of the material. Finally, it was obtained (Fig. 1) that for the 0.53 C steel with lower strength the distribution of the stress triaxiality factor reaches higher values and the maximum value is closer to the crack tip (Fig. 1a) than that for another one. For the 0.53 C steel the level of effective plastic deformation before the crack tip is lower than that for the higher strength 0.35 C steel (Fig. 1b), which is also a feature of its lower fracture toughness.

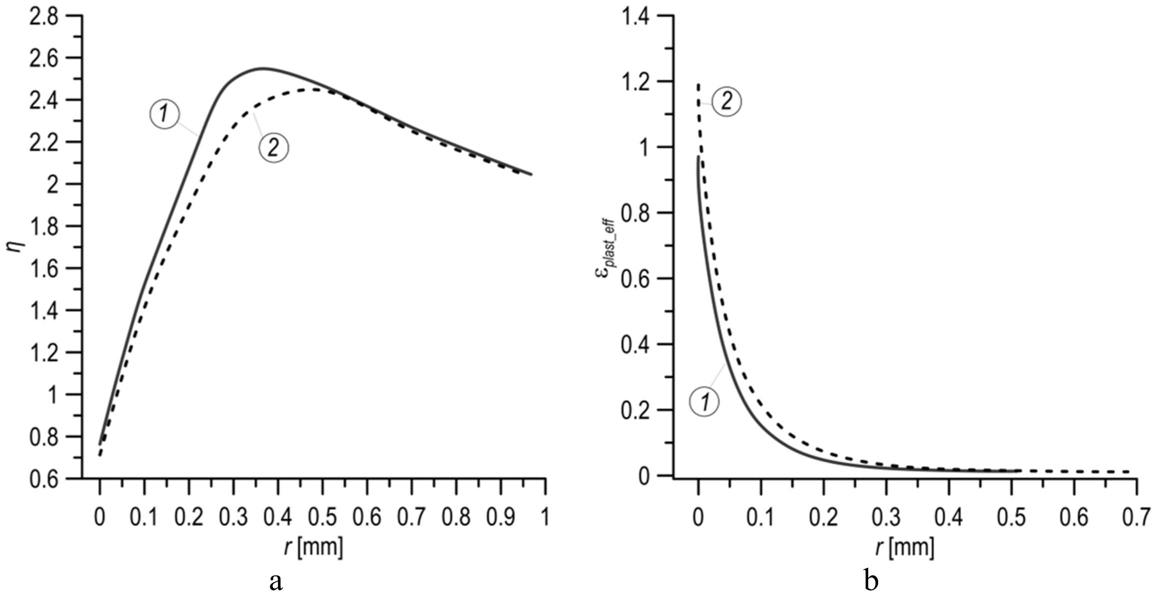

Fig. 1. The stress triaxiality factor (a) and the effective plastic strain (b) distributions for 0.53 C steel (*1*) and 0.35 C steel (*2*).

Thus, the presented results of experimental tests and numerical simulations clearly prove higher strength characteristics and also crack development resistance for the steel with fine grain bainitic microstructure compared to that with coarse microstructure of ferrite-pearlite. Usage of casing pipes made of the 0.53 C steel with coarse-grained ferrite/pearlite microstructure in corrosive and hydrogenating environments in oil and gas wells should be limited due to their high susceptibility to hydrogen embrittlement.

References.

1. Stress corrosion cracking behavior of high strength casing steel in working fluids / X. Guo, T. Shi, Z. Zhang, B. Ma // J. Nat. Gas Sci. Eng. – 2016. – 29. – P. 134–140.
2. Microstructure evolution of the semi-macro segregation induced banded structure in high strength oil tubes during quenching and tempering treatments / B. Li, M. Luo, Z. Yang, et al. // Materials. – 2019. – 12. – 3310.
3. Influence of the structural features of steels of casing pipes on their mechanical properties and hydrogen brittleness / O. I. Zvirko, O. T. Tsyrulnyk, I. Dzioba, et al. // Mater. Sci. – 2021. – 56(6). – P. 748–754.
4. Dzioba I., Lipiec S. Fracture mechanisms of S355 steel—experimental research, FEM simulation and SEM observation // Materials. – 2019. – 12. – P. 1–17.