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An indentation based investigation on the characteristics of artificially aged pipeline steels

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Abstract

The decay of the mechanical properties of structural components operating in an aggressive environment can be detected by non-destructive indentation tests. The effectiveness of this approach has been verified on artificially aged pipeline steel. Indentation tests have been performed at different scales to verify the transferability of the laboratory results to the field conditions, in view of the possible development of in-situ diagnostic procedures.

Keywords: pipeline steel; material aging; mechanical characteristics; indentation

1. Introduction

The severe working conditions of gas pipelines induce material degradation with increased risk of uncontrolled brittle failure and, therefore, significant economic losses and environmental consequences. The actual safety margins of these infrastructures depend on the evolution with time of their mechanical properties, which depend on a number of factors that include the material composition, the environment conditions, the external loading (Gabetta et al., 2008; Nykyforchyn et al., 2010; Nykyforchyn et al., 2012).

The reliable and timely assessment of the material status can be facilitated by the implementation of non-destructive diagnostic procedures based on indentation tests. This fast and inexpensive experiment can be performed directly on the components, without the need of extracting material spools and working out specimens of pre-fixed

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geometry (Bolzon et al., 2012; Bolzon et al., 2015).

The sensitivity of this investigation methodology to the decay of the material properties induced by aging has been be evaluated on pipeline steels of different composition and in different states. The transferability of the laboratory results to the operative environment has been verified by performing the test at different scales.

The current state of this research is summarized in this contribution.

2. Materials

Different pipeline steels have been considered for the present investigation. In particular, samples of 17H1S (Ukrainian code, equivalent to X52) steel were cut from a pipe of 529 mm diameter and 8 mm wall thickness, others made of X60 steel were extracted from a pipe 455 mm diameter and wall thickness t = 14 mm. The different production technology of these structural components was reflected by the material microstructure, significantly finer and more homogeneous in the case of X60 steel.

Samples of both materials have been subjected to accelerated degradation processes, induced in laboratory under combined thermo-mechanical and hydrogen action. The machined specimens, shown in Fig. 1, were electrolytically pre-charged by hydrogen in an aqueous sulphur acid solution (pH2) at 20 mA/cm^2 for 95 hours; then they were mechanically stretched up to 2.8% axial strain and finally exposed to 250ºC for 1 hour. This procedure permits to simulate, on a laboratory scale, the degradation of steel during long-term exploitation. Further details have been presented by Zvirko et al. (2016).

3. Tensile tests

The investigated materials were initially characterized by means of tensile tests. The main mechanical parameters recovered from this survey are listed in Table 1. Degraded metals present a significant reduction of the overall elongation accompanied by a substantial variation of other bulk material properties like the initial yield limit and the ultimate strength. Ukrainian 17H1S steel reveals higher susceptibility to the artificial aging. All results are consistent with those recovered from former investigations (Gabetta et al., 2008; Nykyforchyn et al., 2009; Nykyforchyn et al., 2010; Fassina et al., 2012).

Fig. 1. Steel specimen broken by tensile test.

Table 1. Mechanical properties experimentally observed for studied pipeline steels in as-received and degraded states.

Steel type	Steel state	Ultimate strength [MPa]	Initial yield limit [MPa]	Reduction of area [%]	Elongation [%]
17H1S	As-received	473	304	66.1	21.1
	Degraded	467	426	46.4	10.9
X60	As-received	565	489	77.6	21.9
	Degraded	610	551	71.3	16.4

4. Indentation tests

The specimens traditionally employed for the mechanical characterization of pipeline steel are extracted from the pipe wall. The material samples are subjected to a laborious machining, which makes the approach time consuming and rather expensive. Indentation represents a faster and much cheaper testing procedure, which finds growing application for the diagnosis of metal structures. In fact, this almost non-destructive technique can be performed directly on the operating components. Results equivalent to those of traditional tensile tests can be recovered for maximum indentation force of the order of some kN (Bolzon et al., 2012; Bolzon et al., 2015). The maneuverability of the testing apparatus to be eventually operated in field conditions is however increased by reducing the load level.

The representativeness of the results of indentation tests performed at different scales has been evaluated on the considered metal samples.

Table 2 reports the characteristic penetration depths obtained from Berkovich indentation at 500 mN maximum force. The obtained results are somewhat dispersed, as for instance visualized by the graphs drawn in Fig. 2, and a systematic trend cannot be enucleated at this load level.

Table 2. Berkovich indentation at 500 mN maximum load.

Steel type	Steel state	Maximum penetration depth, mean value [μm]			Residual penetration depth [μm]		
		fractured near crack	fractured middle position	intact	fractured near crack	fractured middle position	intact
17H1S	As-received	2.74	2.83	2.67	2.33÷2.45	2.50÷2.58	2.25÷2.45
	Degraded	2.69	2.87	2.62	2.35÷2.43	2.55÷2.63	2.31÷2.35
X60	As-received	2.62	2.60	-	2.29÷2.37	2.36÷2.40	-
	Degraded	2.59	2.64	-	2.28÷2.36	2.33÷2.53	-

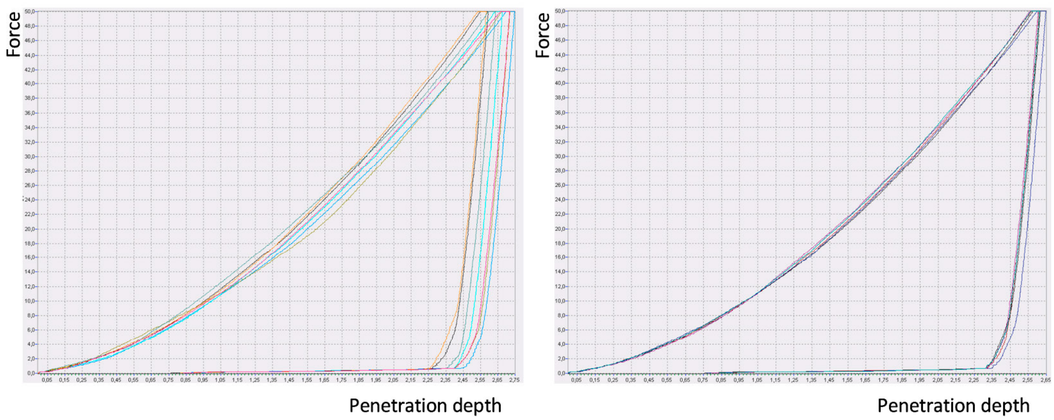

Fig. 2. Indentation curves relevant to 17H1S steel in the as-received (left) and degraded (right) states; Berkovich tip, 500 mN maximum load

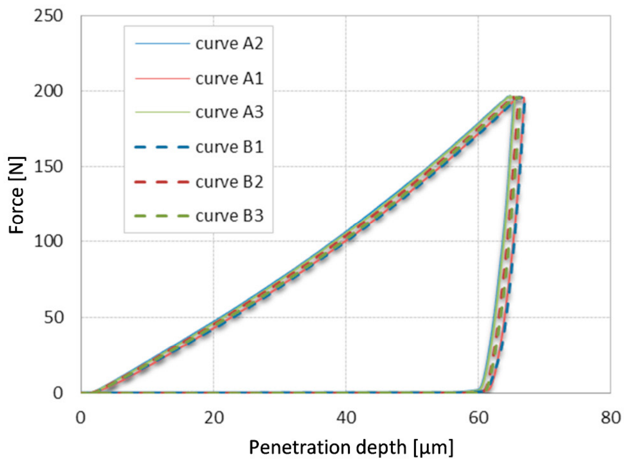

Fig. 3. Indentation curves relevant to as received and exercised X60 steel; Rockwell tip, 200 N maximum load

The output of some preliminary tests carried out on X60 steel at 200 N maximum load is visualized in Fig. 3. The graph compares the indentation curves relevant to the same material sample in the as-received and exercised states. The output is rather repetitive and a shift toward larger penetration depths is observed for the exploited material. However, the two curve sets are partially overlapping.

5. Closing remarks

The sensitivity to the decay of the mechanical properties of pipeline steels in as-received and degraded states has been be evaluated by indentation tests carried out at small and moderate load levels. The dispersion of the force-displacement curves recovered in this investigation does not permit to reach a sound conclusion. The reliability of the results can be possibly improved by the mapping of the residual imprint left on the material surface by the indenter tip. Further verification exercises will be performed in this sense in the next future.

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