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Micro and macro mechanical analysis of gas pipeline steels

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Abstract

The actual safety margins of gas pipelines depend on a number of factors that include the mechanical characteristics of the material. The evolution with time of the metal properties can be evaluated by mechanical tests performed at different scales, seeking for the best compromise between the simplicity of the experimental setup to be potentially employed in situ and the reliability of the results. Possible alternatives are comparatively assessed on pipeline steels of different compositions and in different states.

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Keywords: pipeline steel; diagnostic analysis; non-destructive techniques

1. Introduction

Pipelines of gas transportation networks are exposed to aggressive chemical media and to demanding working conditions. The actual safety margins of these infrastructures depend on a number of factors that include the gas pressure, the external actions, the environment characteristics and the material properties, which evolve with time. Aging increases the risk of fracture and the possibility of significant economic losses and severe environmental consequences (Gabetta et al., 2008; Fassina et al., 2012).

Failure prevention is usually performed by continuous monitoring activities implemented during pipeline operation. Visual inspections and ultrasonic measurements help detecting the formation and propagation of localized damages. In-bulk degradation is evidenced instead by the mechanical testing of material samples extracted from the pipe wall.

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The experiments are usually carried out according to standardized procedures, which are rather expensive and time consuming (Nykyforchyn et al., 2010). However, the diagnostic analysis of metal structures can rely on alternative, faster and cheaper non-destructive approaches. In particular, mechanical characterization methodologies based on indentation techniques can be considered in this context (Bolzon et al., 2015).

Indentation tests can be performed at different scales, seeking for the best compromise between the maneuverability of the equipment and the reliability of the experimental results. This approach permits to transfer the laboratory procedures to the field conditions, in order to develop effective structural diagnosis methods based on in-situ measurements.

Alternatives testing protocols have been comparatively assessed on pipeline steels of diverse grade and composition and in different states: as received, mechanically hardened, thermally treated and chemically degraded (Zvirko et al., 2016). This contribution summarizes the main results of this on-going research activity.

2. Materials and degradation processes

Low-alloyed 17H1S (Ukrainian code, equivalent to X52) and X60 pipeline steels have been considered for the present investigation. Material samples were extracted from real pipes. Microstructural characterization was performed by Zvirko et al. (2016), evidencing the different material texture visualized by the micrographs in Fig. 1.

Some samples were subjected to electrolytical hydrogen pre-charge in aqueous sulphuric acid solution (pH2) at 20 mA/cm^2 for 95 hours, followed by the thermo-mechanical treatment (aging) consisting of mechanical loading up to 2.8% axial strain and exposure to 250ºC for 1 hour. The process simulates, on a laboratory scale, the effects of long-term exploitation. In particular, the preliminary electrolytic hydrogenation of the specimens before mechanical loading simulates the operational conditions in those situations where the moisture present in the transported gas condenses on the internal surface of the pipe and produces corrosion. Corrosion serves as a source of hydrogen (Tsyrulnyk et al., 2008), which is absorbed by the metal and causes pipe wall hydrogenation. In such circumstances, the degradation of the metal is influenced by the mutual action of the stress state and of the hydrogen absorbed by the steel from the internal surface of the pipe. The role of hydrogen in the degradation process consists, in the first turn, in an acceleration of the damaging processes occurring in the metal.

The current density applied for the preliminary electrolytical hydrogen charging of the steel was not high enough to induce damaging during this process performed in laboratory conditions. However, further mechanical loading of the hydrogenated metal can lead to material degradation on the nano or microscale, similar to what occurs during long-term operation of pipeline steels (Nykyforchyn et al., 2010). Damages induced in X52 steel in service for more than 30 years are for instance visualized in Fig. 2.

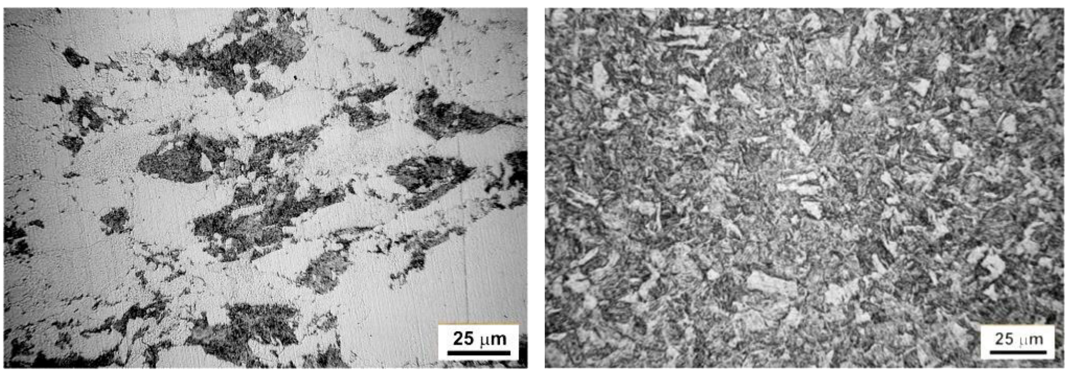

Fig. 1. 17H1S and X60 microstructure