PhD proposal at CEA-Grenoble (LITEN/LCA)
and research center SMS – UMR CNRS 5307 (Mines St-Etienne)

Fatigue behavior of low alloy steels in pressurized natural gas containing hydrogen

Context of the study

In the context of future developments, 'GRTgaz' examines the possibility of hydrogen introduction in its natural gas grid. In order to guarantee the grid security, it is necessary to investigate the effect of hydrogenated natural gas on the behavior of pipelines steels, in particular under cyclic charges. The LITEN/LCA laboratory of CEA/GRENOBLE is engaged in a common study with 'GRTgas', aiming to evaluate the behavior of steels used for pipeline manufacturing in mixtures of natural gas (NG) and H_2 in order to improve the lifetime predictability of components in the field conditions. The experimental strategy is to investigate the low cycle fatigue behavior of steels and to determine crack propagation characteristics in gaseous NG/H_2 mixtures under various pressure. The Materials Science and Engineering (SMS) research center of Mines Saint-Etienne is associated with the LITEN/LCA laboratory in this project, in particular concerning the understanding of interactions between hydrogen and cyclic plasticity as well as the mechanisms of hydrogen embrittlement (HE) in this family of low alloy steels. The expected output of the study is a more precise estimation of the maximal hydrogen concentration admissible in 'GRTgaz' networks.

Research program

The core of the research program is an extensive characterization of fatigue behavior of low alloy steels in gaseous NG+%H_2 environments with different hydrogen contents. In the first step, the macro-scale fatigue crack propagation will be studied using conventional tests on standardized pre-cracked CT samples. The tests will be carried out under plane strain loading conditions and the results will be analyzed on the base of LEFM, including the effect of hydrogen concentration on Paris' law coefficients and the crack propagation threshold (ΔK_{th}). In parallel, the effect of hydrogen on fracture mode will be qualitatively investigated. The results will then be compared with those obtained in similar tests performed in air. In the second part, low cycle fatigue (LCF) experiments will be applied for a detailed study of crack initiation and propagation mechanisms. First of all, the localization of plastic deformation at the surface in the reference conditions (air) will be studied. Cyclic hardening laws will be determined from tests realized at different applied plastic strain amplitudes. Local plasticity will be analysed using slip band intersections with the sample surface. The repartition of plastic activity (preceding short crack initiation) between ferritic and pearlitic zones of the microstructure will give indications about the crystallographic and morphologic aspects of the first stage of fatigue damage, i.e. the crack initiation. The analytic tools to be used are SEM-FEG, EBSD and AFM. In the following step, the effect of gaseous hydrogen on fatigue damage mechanisms will be investigated. LCF tests will be carried out in NG+%H_2 environments, the same as those used in crack propagation experiments. In parallel with LCF tests to failure, interrupted tests at fixed fraction of the fatigue life will be carried out aiming to establish the effect of hydrogen embrittlement on the damage scenario. 3D microscopy, SEM-FEG, EBSD and FIB-TEM will be exploited to evaluate the effect of hydrogen on the evolution of dislocation networks with the number of cycles. The results will be analyzed and discussed on the basis of existing models and mechanisms. Emphasis will be put on hydrogen-plasticity interactions, including possible effect of vacancies. To better understand diffusion and trapping of hydrogen, gas permeation and TDS experiments on samples with different dislocation structures and vacancy concentrations will be carried out. The final objective will be to integrate the conclusions of the study with internal procedures used by 'GRTgaz', concerning the defect analyses in the environments concerned. For this reason, training periods in GRTgaz research center (RICE) will be scheduled in order to get familiar with internal procedures of defect analysis.

Profile

The candidate must be interested in the investigation of physical mechanisms of material damage. Basic background on material science, mechanics and environmentally assisted damage of metallic materials is required.

Laboratoires and application details

- Laboratoire Composants et Assemblages, Liten, CEA/Grenoble
  Liten/DTBH/LCA, CEA Grenoble, 17 rue des Martyrs, 38054 Grenoble Cedex 9

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Ecole doctorale

ED 488 - Ecole Doctorale Sciences, Ingénierie, Santé (SIS) Saint Etienne

Duration

Full-time PhD position (36 months) starting September 2020