PhD fellowship
(3 years from October 2021)

PolyAmide resistance to damage cumulation from high-pressure hydrogen cycling and fatigue loading

Consideration of hydrogen as an alternate energy carrier for ensuring cleaner means of mobility necessitates the design of reliable infrastructure for the transport, storage and dispensing of gaseous hydrogen. In order to make the sector a credible alternative, an immediate goal is to deploy networks of refueling hydrogen stations along with the increase of vehicles. In this emerging context, the need for cost reduction and optimized design of reliable components is a huge challenge for materials used in hydrogen devices. Feedback about high-pressure hydrogen-exposed polymers is lacking. Better understand of their interaction with hydrogen, among which deformation and damage mechanisms, is crucial to formulate polymers combining good mechanical and permeation properties and to develop modeling tools to design durable and safe infrastructures.

This PhD, part of a project funded by ANR, focuses on hoses for refueling stations, and more precisely on damage processes activated in thermoplastic parts of these structures. The work will be conducted in PolyAmide 11 (PA11), an interesting semi-crystalline thermoplastic for hoses in hydrogen stations. The PhD will be prepared at Institut Pprime but in close collaboration with Hydrogenius laboratory (University of Kyushu, Japan), and will benefit from the feedback of Arkema (France and Japan) about industrial service conditions and specifications.

On one hand, decompression failure is known to affect polymers exposed to high-pressure gases, due to the expansion of gas during pressure release. In semi-crystalline thermoplastics, it results in nano-/micro-voiding and cracks. Due to repeated refueling of vehicles, hoses undergo repeated decompression cycles, with possible cumulated damage, but the phenomenon has not been really addressed in hydrogen. Cumulative laws and consequences on mechanical and permeation properties has been rarely addressed so far. On the other hand, mechanical loading is known to nucleate damage in semi-crystalline thermoplastics, especially under triaxial conditions. Due to repeated hoop stresses or bending, fatigue loadings may enhance cumulated damage in hoses. Therefore, both types of loadings are bound to act as microstructure change and damage sources, which may affect themselves the mechanical resistance and the permeability of hoses.

The most original scientific challenge here is to address simultaneously fatigue and repeated pressure cycles as co-existing sources of microstructure changes and damage, and to better understand their cross-dependent influence on residual mechanical properties and permeability. A second originality of the project is the unusual pressure range for now (90 MPa), currently under consideration to extend operating conditions and made accessible by Hydrogenius facilities.

Fatigue and pressure cycling will be studied separately first, in the virgin material. Each series of tests will be interrupted after a selection of numbers of cycles. Then, the two damage sources will be variably combined: successively, as alternated blocks and simultaneously. The two latter cases are expected to exacerbate coupling effects between sources.

After each loading history, cumulated microstructure changes and damage mechanisms (by SAXS, WAXS, DSC, density, SEM, tomography) and their consequences on the residual mechanical properties will be investigated. The aim is to highlight how far damage sources activate similar microstructure changes and damage mechanisms or not, with similar consequences on residual mechanical properties or not, and similar dependence on the number of cycles. Damage and/or microstructure indicators will be processed and globally analysed to formulate unified cumulative laws bound to be inserted into modelling. Integration into existing models or criteria could be tested in a last prospective part of the project. The effect of single or combined damage sources on permeability, which is a key part of specifications for hoses, will be investigated in a selected number of critical cases, motivated by the above conclusions.

Candidate

Talented and enthusiastic candidates with a MSc degree in Polymer Science, Materials Science or Mechanical Engineering are encouraged to apply. They must be motivated by experimental research in the field of mechanics and structure-properties relationships in polymers, rigorous and well-organized to manage this project involving multiple partners. Since the work will mix several physical and mechanical approaches, they should have a strong interest in multidisciplinary research, a deep scientific curiosity and possess a drive to learn new methods and concepts. Good communication skills are absolutely needed in oral and written English .

About the consortium

Institut Pprime (Poitiers, France) and Hydrogenius laboratory (Kyushu, Japan) are two major academic actors of the field of physical and mechanical experiments under high-pressure hydrogen in polymers. They have been collaborating for 10 years.

Institut Pprime conducts experimental, theoretical and numerical researches about diffuso-mechanical couplings and decompression failure at the micro and macro scales, among which high-pressure mechanical tests.

Hydrogenius leads researches about physics and chemistry of hydrogen-polymer systems, with strong expertise in physical characterization of diffusion and failure mechanisms from several techniques.

Arkema is a worldwide supplier of specialty polymers. PA11 is one of the lead products. For 40 years, the Cerdato research center (France) has been developing this polymer series to respond to market developments, among which new energies..

Application

The PhD student will be employed for 3 years by ISAE-ENSMA (net salary 1430€/month). Application documents (in PDF format) must include a letter of motivation, a detailed curriculum vitae, and transcripts of BSc and MSc grades. Contact information of potential referees will be appreciated.

Supervisor of the PhD : Sylvie Castagnet (sylvie.castagnet@ensma.fr).