High strain rate behavior of thermoplastic composite materials for cryogenic hydrogen storage (H-FROST).

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The Spanish Aerospace sector is one of the best prospect industry areas for the country, currently ranked 5th and 8th in Europe and in the world, respectively; and showing enormous potential in the highly competitive air transportation market. It represents a field of engineering in which the development of lighter structures is critical. The use of composite materials like carbon fiber reinforced polymers (CFRP) is the key to reduce the aircraft weight and therefore achieving lower fuel consumption and small carbon footprint. The environmental sustainability might be enhanced transitioning towards hydrogen as combustible and a wider use of thermoplastic based CFRPs, because they offer better recyclability compared to traditional thermosets.

The integration of green propulsion and new fuel technologies (e.g., H2 storage tanks and fuel cells) along with the use of thermoplastic CFRP (TPC) will have a major impact on the fuselage design. Considering the proximity to passengers and cargo, the material behavior under extreme conditions (i.e., hydrogen at cryogenic temperature) must be known to ensure a proper mechanical performance of the main aircraft structures affected by the ancillary systems devoted to fuel storage and distribution. Laminated composites have excellent specific mechanical properties but their behavior under high strain-rates is not optimal, specially at cryogenic temperature due to expected brittleness of the polymeric matrix. New testing and certification procedures must be developed to assure that the material is capable to deal with the extreme conditions.

H-FROST is thus replying to a direct need from the aerospace industry: the lack of knowledge regarding the mechanical properties and performance of TPCs when subjected to combined high strain rates and cryogenic temperatures.

A bottom-up multiscale methodology is proposed to provide a better understanding at the microconstituent level under dynamic high strain-rates loading and at cryogenic temperature, aiming to deliver the ply behavior relying on computational micromechanics. An initial micromechanical characterization of the material will be performed to gather information to reproduce the mechanical behavior of the composite by means of numerical models based on finite elements. The constitutive models incorporate the influence of the strain rate in the material behavior to capture accurately damage initiation and propagation at cryogenic temperature, and they are fed by the mechanical properties of the composite constituents (i.e., polymeric matrix, fibers, and fiber/matrix interface). This virtual ply characterization based on reliable properties of the microconstituents provide full control of the microstructure and constituent properties, allowing microstructural optimization to be performed and the simulation of complex stress states not posible experimentally. Thanks to this bottom-up multiscale approach, the importance of micromechanical parameters such as fiber distribution, cohesive-frictional fiber/matrix interface behavior and polymer behavior can be assessed. Results from the numerical simulations will be compared and validated using the TPC dynamic characterization in transverse tension/compression and shear at cryogenic temperatures.

PhD Thesis Opportunity:

Experimental mechanical characterization and numerical analysis of thermoplastic AS4/PEEK composite material under dynamic loading and cryogenic temperature.

Host:

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Summary:

There is a clear interest of the aeronautical industry in the mechanical performance of TPC structures under static and dynamic high strain-rate loads at cryogenic temperatures. New testing and certification procedures should be developed to introduce new composite materials and manufacturing techniques able to deal with the thermal environment for cryogenic fuel applications.

In the aerospace industry, mechanical properties of composite materials are often measured for certification purposes at temperatures down to 219 K, corresponding to the typical ambient temperature during flight. Typically, under such "cold" condition, polymers exhibit a decrease in flexibility and an increase in brittleness. Additionally, at very low temperatures, the polymer may become more susceptible to cracking and breaking due to the decreased ability of the polymer chains to absorb energy. As a result, composite mechanical properties, such as tensile strength, elastic modulus, and impact resistance, are generally reduced at low temperatures, not only due to the mechanical response of the polymer but also to its ability to transfer the load to the fibers (i.e., mechanical response of the fiber/matrix interface). However, results obtained from "cold" condition cannot be extrapolated to cryogenic temperatures (T<132 K). The non-linear behavior of polymers and the strength and toughness of the chemical bond with the fibers at such low temperatures is not fully understood yet.

Furthermore, the ability to withstand high strain-rate dynamic loads is an important design criterion for many structures in aerospace, automotive, marine, and civil engineering applications. In this regard, mechanical response of CFRP can change when subjected to high strain rates [1] [2] [3], mainly due to the presence of the polymeric matrix. More research is needed to fully understand its behavior under such extreme environments. Almost no previous research has been performed to study the behavior of TPC carbon laminates at high strain-rates and cryogenic temperatures. It is only possible to find very few works regarding thermo-set laminates under low temperatures and dynamic loads [4] [5] [6] [7] [8].

Specific objectives:

- **Increase the knowledge in the behavior of thermoplastic matrix subjected to dynamic loading at cryogenic temperatures** and understand its role in the overall behavior of the composite ply. To this end, novel tests will be done, providing the strain rate dependency of the thermoplastic matrix at different strain rates and cryogenic temperature.
- **Develop a methodology to obtain fiber/matrix interface strength at different strain rates and cryogenic temperatures** and understand its role in the overall behavior of the composite ply under such conditions.
- **Develop novel testing methods to obtain the multiaxial response of composite materials** at different **strain rates and cryogenic** temperatures, aimed to develop new standards for the certification of new materials to be used in the next generation hydrogen-fueled aircrafts.
- **Develop efficient numerical models able to provide the mechanical response of the TPC subjected to dynamic loading at cryogenic temperatures** for transverse tension/compression and shear load combinations, reproducing the failure mechanisms experimentally observed and providing accurate failure envelopes aimed to improve state-of the art failure criteria (e.g., Hashin, Puck, LaRC).

Scientific/Technical impact:

Vulnerability to impact has become an important issue from a regulatory perspective and aeronautical safety. Both the American and European regulatory certification requirements (FAR and JAR, respectively) include specific cases for preventing severe failure caused by an impact. The combination of dynamic loading and cryogenic temperature represents an open question that must be solved if composite materials must be certified to be used in new propulsion technologies based on H2 (e.g., storage tanks and aircraft structures potentially exposed to cryogenic environment and dynamic events).

The aerospace sector is not just willing to develop lighter, less fuel-intensive vehicles emitting less greenhouse gases but to integrate new materials to increase the recyclability of the structural parts. In this regard, the use of thermoplastic reinforced composites like the one chosen in the present work represents a good opportunity compared to traditional thermoset-based composites.

The research team maintains a steady transfer activity with companies from various industrial sectors, at a national and international level, such as: **AIRBUS**, AERNNOVA, AIRBORNE, OXEON, CHOMARAT, FOKKER, APPLUS-IDIADA, EMBRAER, among others. All of them are interested in the improvement of the mechanical properties of composite materials and their optimal structural use. As an example, the European aeronautic company **Airbus** announced recently that it is developing a new combustion engine fueled by hydrogen in preparation for entry-into-service of a zero-emission aircraft by 2035, in line with its ZEROe project. Therefore, it is expected that Airbus will be aggressively researching hydrogen fuel technologies in the short-term.

What we look for:

We are seeking a highly motivated and enthusiastic candidate with background in continuum/experimental mechanics eager to be part of an exciting new research project.

Research stays:

One or several national and/or international research stays will be planned at the beginning of the PhD to complete some of the specific tasks in the research planning.

Training activities:

The candidate will be enrolled in a PhD programme of the Universidad Carlos III de Madrid which includes several technical and/or soft skills courses. In addition, the student will attend international conferences and other specific technical courses that could enrich his/her technical skills.

What we offer:

A 4 year fully-funded position for a PhD student in the LSDG group, in the Continuum Mechanics and Structural Analysis at UC3M. You will join an active and dynamic research team. The position include Spanish social security and health care benefits.

Qualifications:

- A master's degree in aerospace engineering, mechanical engineering, engineering mechanics, or related fields is preferred.
- Candidates with experience in the following areas will be given priority: (i) solid mechanics; (ii) experimental mechanics; (iii) composite materials; (iv) Dynamic behavior of materials; (vi) applied mathematics; (vii) finite element simulations and programming in a higher-level language (Python, including Numpy package).

Professional and/or research experience:

Candidates with research and/or technical experience will be a plus, but not mandatory.

Letter of motivation & references:

A letter of motivation stating the reasons why we should hire you should be provided. A recommendation letter from a teacher (master's degree) or senior researcher/engineer (professional background) shall be considered positively.

References:

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