Fatigue behavior and life assessment of CFRP structures under global non-proportional multi-axial loading conditions

Popular Science abstract

The growing demand in the composite materials market is caused by continuously developed manufacturing processes. This demand is led due to the prominent properties, which these materials show, such as high specific strength, low density, high resistance to corrosion, fatigue, and chemical environment. Moreover, the design flexibility allows producing newly complicated geometrical parts and objects applying modern hybrid materials. It is worth mentioning a few examples such as wind turbine blades, transmission shafts, high-pressure vessels, or plane airframes. It assumed that these applications are subjected to various cyclic loads. A good example is the transmission shaft, which is subjected to torsion and bending loadings. These conditions significantly influence the operation service of the objects. Because of the development of composite materials in structural engineering, a detailed design process that provides safety and reliability in service is required.

This research focuses on the characterization of fatigue behavior. The specific layered material is under investigation, carbon fiber reinforced polymer (CFRP) subjected to axial force and torsion, which is phase shifted. Knowledge of this behavior allows assessing the fatigue life based on the energy approach. So far, no unambiguous mathematical description of the behavior of this type of material has been identified in the literature, taking into account the mean stress and disproportionality of loads. In this project, the redeveloped fatigue criteria based on the energy approach will be provided to assess the lifetime taking into account the investigated parameters. The undertaken research direction will allow for a better understanding of the phenomena of degradation and failure of composite materials in a complex state of stress.

The methodology of the project can be divided into the experiment and analytical phases. The first phase includes experimental labor, that is, a preliminary study for fatigue life assessment. In this part, the cylindrical CFRP structures manufactured using the filament winding method will be subjected to tension/torsion loading conditions. The servo-hydraulic test system equipped with special grips provides adequate loading conditions. The second phase would be connected with fatigue behavior assessment. The validation of fatigue hypotheses available in the literature is examined and an attempt to develop an own fatigue criterion having regard to the examined parameters will be examined, which will assess the fatigue life of the structure.

The experimental part will be enriched with nondestructive (ND) methods to examine the failure mechanisms. In composite materials, several failure mechanisms may occur, for instance, delamination, debonding, matrix cracking, or fiber pull-out. The ND methods allow determining the defects that appear due to the technological process and developing them during the experiment. Ex-situ computed tomography is a reliable method to determine pores and inclusions that are in the wake of the technological process. Furthermore, in–situ analysis shows the evolution of appearing defects and failure mechanisms during the fatigue test. Additionally, to measure strain during the test, the digital image correlation (DIC) device will be used. It will also provide information about defects occurring on the external surface of the sample.

As a result of the work carried out, new cognitive knowledge will be created that will fit into the development of the disciplines: mechanical engineering, or more precisely: experimental and computational mechanics as well as modeling issues in mechanics.