English summary

The dynamic development of composite materials in industry is driven by the development of modern manufacturing technology and the superior properties these materials exhibit, such as high specific strength, low density, high resistance to corrosion, fatigue, and chemical environment. Moreover, the freedom of shaping geometry allows the production of new, more geometrically complex parts and objects sufficient to overstand significant load conditions with satisfactory mass.

Important examples of elements made of composite materials are wind turbine blades, drive shafts, high-pressure tanks, and even aircraft bodies. Taking into account the above-mentioned applications, it can be noticed that they are subjected to various cyclic loads. For example, the drive shaft is subjected to time-varying torsional and bending loads. These conditions significantly affect the operation of the elements and require their consideration at the design stage. The process of designing elements made of composite materials is very complex and advanced due to the anisotropy of the material. In order to ensure safety and reliability in operation, a costly experimental procedure is often required to describe the mechanical behavior of the element. This process can be optimized by mathematical description of individual phenomena that affect the strength of the designed element.

The dissertation focuses on the description of the fatigue process of a thin-walled cylindrical element made of carbon fiber reinforced polymer material (CFRP), which is subjected to axial forces and torsion. Moreover, the acting load is out of phase. This process is still not clearly described in composite materials, unlike metallic materials. Knowledge of this process will allow the fatigue life of an element to be estimated. The scientific literature provides several fatigue criteria that are used in the design of components exposed to fatigue damage. However, the available criteria do not cover all factors influencing the fatigue degradation of composite structures, such as load phase shift or mean stress. In the doctoral thesis, a fatigue criterion based on the critical plane approach was proposed. The developed fatigue criterion, based on the stress damage parameter defined for the critical plane, allows the assessment of material damage taking into account the mean stress and the phase shift of the load.

The doctoral dissertation is divided into two main stages: experimental and analytical. The first phase includes experimental work, i.e. fundamental research used for the fatigue modeling process. In this section, cylindrical CFRP specimens produced by filament winding technology are subjected to tensile, compressive, and torsional loads. The load is generated by a biaxial hydraulic testing machine equipped with special grips to ensure suitable loading conditions.

The second phase is related to modeling the fatigue process and predicting durability. Based on the developed numerical model, a stress analysis is performed to define the value of the failure parameter. The correlation of data for durability and failure parameters allowed for the description of the S-N curves, which were used to predict fatigue life. Moreover, this part of the work shows the applicability of the developed approach to other materials of the same class.

The experimental part is enriched with nondestructive (ND) methods to investigate damage mechanisms. Several failure mechanisms can occur in composite materials, such as delamination, debonding, matrix cracking, or fiber pullout. ND methods allow the

determination of defects that appear in the technological process and their development during the experiment. Computed tomography is a reliable method to assess the quality of the microstructure, among others such as defects and inclusions resulting from the technological process. Furthermore, in situ analysis using acoustic emission showed the global evolution of emerging defects and failure mechanisms during the fatigue test. In addition, a digital image correlation (DIC) device was used to measure strain during the test, providing information about defects that occur on the outer surface of the sample and the strain distribution. The data were used to verify the numerical method.

The proposed approach allows for a comprehensive filling of the existing gap in the literature regarding models predicting fatigue life, taking into account the phase shift of the load, the stress state, and its mean value.