Development of a Biaxial Loading Device for Advanced Fibrous Materials (Identifying the Thermomechanical Behavior Laws of Viscoelastic-Plastic Materials with Complex Structures)

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Abstract

This study introduces the development of an advanced biaxial testing device designed to characterize and model the thermomechanical behavior of complex fibrous materials, specifically those exhibiting viscoelastic-plastic properties under dynamic and cyclic loading. Given the expanding application of fiber-based composites across industries like aerospace, automotive, defense, and energy, understanding their fatigue and hysteretic behaviors is essential for predicting performance and longevity. The designed testing system aims to address this need by providing a controlled, high-precision environment to simulate and analyze the behavior of fibrous materials under biaxial stress conditions, an approach that replicates real-world operational scenarios more accurately than traditional uniaxial tests.

The core of the system is a biaxial thermomechanical testing setup that combines dual-axis loading with high-frequency modulation. Each axis operates independently and can apply up to 4000 daN in modulation at frequencies of up to 20 Hz, supporting high-stress applications. The testing device is equipped with an array of sensors, including four strain gauges per axis, allowing for continuous monitoring of the mechanical response of the sample. This system generates up to 36 parameters per cycle, enabling detailed real-time data collection on stress, strain, and force distribution. Such precise measurement is critical in capturing the nonlinear and anisotropic responses of fibrous structures and in determining their mechanical and thermal behavior under cyclic loads.

In addition to mechanical measurements, the device integrates a synchronized 2D optical correlation system and an infrared (IR) thermography setup to capture both deformation fields and thermal variations. The 2D optical correlation system provides high-resolution surface displacement data, enabling tracking of in-plane and out-of-plane deformations across the sample. IR thermography captures temperature changes induced by stress variations, leveraging the thermomechanical coupling principle to map local heat generation-a key indicator of material fatigue and microstructural transformation under stress. By correlating thermal and deformation data, this setup allows for a comprehensive understanding of the spatial and temporal evolution of mechanical behavior across fibrous structures.

This research also develops a computational framework to analyze and interpret the acquired

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data. The data are synthesized to establish predictive behavior models for these materials, focusing on their viscoelastic and viscoelastic responses. This modeling supports the identification of fatigue parameters and mechanical degradation pathways, crucial for estimating service life in applications such as hydrogen transport systems, where weight optimization and durability are critical.