Strength Evaluation of Cellulose Nanofiber Materials by Sequential Digital Image Correlation

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Development of lunar habitation modules is actively underway for future lunar exploration [1]. In the early stages of construction, building materials must be transported from Earth; therefore, lightweight materials and deployable structures are of particular interest. In this study, cellulose nanofiber (CNF) materials were investigated as candidate structural materials due to their low density, high strength [2], and water-induced flexibility, which enables folding and deployment. However, lunar environments are characterized by intense ultraviolet (UV) radiation and extreme temperature fluctuations, which may significantly degrade material performance. In particular, the influence of UV irradiation on the mechanical properties and durability of CNF has not yet been sufficiently clarified. Therefore, this study first aims to evaluate the effects of UV exposure on the mechanical properties and failure behavior of CNF materials under simulated lunar conditions. In addition, since CNF materials are expected to be used in deployable structures, they are subjected to repeated folding and unfolding processes. Such mechanical loading may also affect their structural integrity. Therefore, the influence of folding conditions, including folding angle, on the mechanical properties of CNF is also investigated. To evaluate these effects, tensile tests were conducted, and deformation behavior was analyzed using sequential digital image correlation (DIC). Video images captured during the tests were divided into consecutive frames, and DIC analysis was applied to quantify time-resolved deformation and strain fields. This approach enabled visualization of localized deformation and the progression of damage leading to failure. CNF specimens were first exposed to UV irradiation, and their mechanical properties, including tensile strength and elastic modulus, were evaluated before and after exposure. Subsequently, the relationship between folding angle and strength was examined. Furthermore, microstructural observations of surfaces and cross-sections were conducted using scanning electron microscopy (SEM) to characterize internal damage. The results revealed the effects of UV irradiation and folding conditions on the mechanical properties of CNF. In addition, sequential DIC analysis provided detailed insights into strain localization and failure processes. These findings contribute to evaluating the applicability of CNF materials for deployable structures in lunar environments.

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