

Tensile Characterization of Modern and Ancient Egyptian Yarns: Insights from X-ray Microtomography and Finite-Element Analysis

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Abstract

This study aims to investigate and compare the mechanical properties of modern and ancient Egyptian yarns (MEY and AEY) using advanced techniques. Utilizing X-ray microtomography, detailed 3D images of the internal structure and morphology of yarns are obtained. These scans are then utilized to construct 3D finite-element models, enabling simulation and analysis of mechanical behavior under tensile loading conditions. Understanding the mechanical properties of ancient Egyptian flax fibers is crucial for envisioning modern flax fibers as competitive substitutes for synthetic materials in the composite industry. AEY dating back to 2140-1976 BC and MEY cultivated in Egypt (Malika variety) in 2023 were examined. Analysis of AEY strength yields vital insights into material composition, manufacturing processes, and durability. Notably, 3D imaging elucidates ancient Egyptian techniques in yarn creation, revealing details such as kink-bands and porosity [1]. Furthermore, these images shed light on yarn degradation over time.

The primary objective was to discern how stress is distributed in MEY and AEY during tensile loading. The axial stress values reached up to 350 MPa for MEY, while for AEY, the axial stress peaked at 80 MPa. Notably, the considered model is linear and elastic, lacking a damage criterion. The Representative Volume Element (RVE) approach was utilized in the study for managing yarn heterogeneity. The computed apparent modulus of MEY was 19 GPa, but it varied from 32 GPa to 21 GPa for RVE models. In contrast, the apparent modulus for AEY was 5 GPa, and for RVE models, it ranged from 2 GPa to 9 GPa. Due to the yarn's non-uniformity, significant stress heterogeneity was observed. By comparing MEY and AEY, it was observed that the inter-fiber airiness was higher in AEY. Furthermore, the contribution of bundles under tensile loading was lower in AEY due to the discontinuity of fiber bundles. This discontinuity is linked to the degradation of fibers and middle lamella in AEY. The findings offer insight on the effects of ancient fiber degradation on tensile strength and stress distribution, leading to a denser knowledge of the mechanical behavior of both MEY and AEY.

Keywords: X-ray microtomography, representative volume element method, flax yarns

References

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