Development of an Analytical Mechanical Model of Staple Fibre Yarns from fibre tensile and friction properties

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Abstract

Fiber-based materials are ubiquitous in both daily life and industry, appearing in applications such as clothing, insulation, civil engineering, and composite materials. The study and modeling of the mechanical behavior of yarns-structured assemblies of fibers or filaments-has been a foundational research area in the textile field since the pioneering work on staple fiber yarn by Gégauff in 1907 (1). Between 1940 and 1980, extensive theoretical research established a mathematical formalism and analytical models to describe structural characteristics that influence yarn behavior. Mechanical studies of staple fiber yarns provide insights into the deformation and rupture phenomena of yarns composed of synthetic or natural fibers, aiding in the determination of manufacturing process parameters. Several models exist to predict the rupture forces of yarns with high twist (2-3); however, the mechanical behavior of intermediate and low twist yarns is more complex, as it requires understanding the frictional interactions between fibers within a yarn. The proposed model addresses these interactions using the Euler-Eytelwein model, with lateral force transmission through the yarn based on Love's theory of elasticity for a rod bent into a helical form (4).

An experimental study is conducted on synthetic fibers and yarns, selected for their clean and uniform structure that aligns well with the model's geometrical assumptions-ideal for an initial experimental approach. Tensile properties are obtained by using the Automatic Single-Fibre Test System FAVIMAT+ to measure the linear density of individual aramid fibers and capture their complete stress-strain profiles during tensile testing. Friction characteristics are obtained from a specific method (5). Pertinent tensile and friction criteria are chosen supplying essential mechanical parameters for model input. Yarn samples are tested using an Instron tensile testing machine with specialized clamps to impose and measure specific twist levels, ensuring controlled torsional conditions throughout testing. Tensile tests on yarns across varying twist levels are conducted to facilitate direct comparison with the model, assessing its accuracy in predicting the mechanical response of the yarn under different torsion conditions. Following this initial study with synthetic fibers, future work

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will compare results with natural fibers, such as flax. Although the model may require adjustments to account for the variability of natural fiber properties, this step will enable a broader validation of the model across different fiber types.

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