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Rib Design of Fiber-Reinforced Polymer Reinforcement Bars and Study on Stick-Slip Friction at the Concrete Interface

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ABSTRACT

With the rapid advancement of global infrastructure development and the deepening of sustainable development principles, fiber-reinforced polymer (FRP) reinforcement bars have emerged as an innovative alternative to traditional steel reinforcement due to their lightweight, high-strength, corrosion resistance, and fatigue-resistant properties. However, the practical engineering application of FRP bars in concrete structures still faces critical challenges in optimizing the interfacial bond performance between the reinforcement and concrete. This study addresses the scientific bottleneck in rib height design for FRP bars by systematically investigating the evolution mechanism of fiber strain during the rib-forming process through theoretical analysis and finite element numerical simulations.

In this work, a fiber strain analysis model was first established based on fiber damage mechanism analysis, and an approximate analytical solution for the critical rib height was derived. A numerical model incorporating finite bending stiffness was further developed via finite element methods to validate the theoretical model, revealing the nonlinear transition characteristics of fiber strain with increasing rib depth. The results indicate that the fiber strain distribution is significantly influenced by the coupled effects of rib depth and fiber diameter, exhibiting a transition mechanism from bending-dominated to tensile-dominated regimes. By quantifying the relationship between strain distribution and the bending-to-tensile energy ratio, a dimensionless parameter β was introduced, and a three-dimensional $\beta(h^*, d^*)$ map was constructed, providing a quantitative basis for the synergistic optimization of rib depth and fiber diameter in engineering design.

Furthermore, to quantify the impact of rib height on the bond strength of reinforcement bars in concrete, an analytical relationship between rib height and pull-out force was derived by integrating contact mechanics and the classical Prandtl-Tomlinson model, which was subsequently validated through finite element modeling. This modified Prandtl-Tomlinson model effectively explains, for the first time, the unique friction-weakening stick-slip phenomenon during bar pull-out from concrete, offering further theoretical support for the quantitative design of rib height. This study not only provides scientific guidance for FRP rib design but also lays a foundation for the paradigm shift in composite interface design from empirical-driven to model-driven approaches, holding significant theoretical and engineering application value.

KEYWORDS

Fiber-reinforced polymer (FRP) reinforcement bars; interfacial bond performance; Rib design; stick-slip friction

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