Multiscale Investigation of Tribological Interactions at the Rubber/Ice Interface

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Abstract

According to the U.S. Department of Transportation, 24 percent of annual car accidents are attributed to snow or ice on roads, encompassing both minor and severe collisions. Additionally, the International Union for Conservation of Nature reported that tires accounted for 28 percent of microplastic pollution in oceans as of 2017, making them the second-largest source of such pollutants.
This study addresses two critical challenges - enhancing road safety on icy surfaces and mitigating environmental pollution - by investigating the interfacial friction response of ice/rubber contacts under a broad range of environmental conditions. Experiments were conducted at temperatures as low as -28∘C and sliding velocities ranging from 50 μm/s to 1 m/s. Rubber samples, provided by Michelin, varied in composition, surface topography, and mechanical properties. The ice used in the experiments was homogeneous, transparent, and prepared through a controlled machining and thermalization process.

A novel in-situ contact area measurement methodology was developed to capture the static and dynamic behavior of the ice-rubber interface during mechanical loading, unloading, and sliding. By combining in-situ visualization of contact areas with friction force analysis, the study elucidated the complex interplay between adhesion, viscoelastic, and thermal effects in governing frictional behavior. These mechanisms were examined as functions of sliding velocity and temperature, providing insights into the dynamics of the ice-rubber interface in real-time.
Building on the foundational work of Schallamach and later developments by Chernyak and Leonov, a friction model was proposed to account for molecular-level interactions. This model incorporates the time-temperature dependence of the formation and rupture of molecular junctions at the rubber-ice interface, offering a comprehensive framework for understanding and predicting frictional performance under diverse conditions.

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