SYNERGETIC MODEL OF FRICTIONAL SOFTENING OF ICE SURFACE LAYER

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Ice and snow friction is of great importance in life, sports, nature, and industry [1, 2]. The kinetics of ice friction is determined by such processes as adhesion, surface and pressure melting, frictional heating, creep, and fracture [3]. The question whether temperature or yield stress of ice plays the crucial role at friction is still a subject of some debate. The study [4] for the first time concludes that the reason for reduced friction is a water film, produced on the ice surface due to frictional heating. Several investigators have extensively developed this idea, since understanding of liquid film formation conditions is necessary for practical applications. According to [5], the pre-melting layer is formed with fluctuating domains of liquid water and solid ice that resembles the defect structure.

We show the ice surface softening during friction as a result of the spontaneous appearance of shear strain caused by external supercritical heating. This transformation is described by the Kelvin-Voigt equation for viscoelastic medium, the relaxation equations of Landau-Khalatnikov-type and for heat conductivity. The study reveals that the above-named equations formally coincide with the synergetic Lorenz system, where the order parameter is reduced to shear strain, stress acts as the conjugate field, and temperature plays the role of the control parameter. The underlying assumption of our approach is that ice softening during friction is ensured by self-organization both of stress and strain shear components, on the one hand, and the temperature, on the other [6]. The relationship between stress and strain is well-known, with the Kelvin-Voigt model describing its simplest case. The temperature effect is caused by critical increase in the shear modulus with decrease in the temperature: modulus is equal to zero in the water, and it has non-zero value in the ice. The derived governed equations consider the above mentioned circumstances. The study of realization conditions of ice surface softening is presented according to the mechanism of continuous second-order transition. The interaction of mentioned factors results in setting in the steady state at supercritical value of thermal energy imposed in the surface layer, where the shear strain can take anomalous large values. The critical heating rate is proportional to the relaxed value of the ice shear modulus and inversely proportional to its typical value. The lubrication ice friction regime is discussed here, i.e., the model applicable to dry ice friction when the temperature is too low for ice to melt. Using the adiabatic approximation, the stationary values of basic quantities are derived. The examination of dependence of the relaxed shear modulus on strain explains the ice surface softening according to the discontinuous first-order transition mechanism. Such behavior is observed experimentally [3].

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