ID contributo: **12** Tipo: **Presentazione orale**

Frictional resistance for a rigid cylinder rolling over a viscoelastic adhesive halfplane

venerdì 5 settembre 2025 11:30 (15 minuti)

Rolling and sliding of an adhesive cylinder over a viscoelastic soft polymeric substrate is of primary importance in tribology. In particular, despite nearly a century of basic laboratory experiments and theories, rubber friction is still a debated topic not well understood. On the other hand, the seminal experiments by Grosch [1] demonstrated a relation between friction and the viscoelastic properties of the polymer, and the major result was the collapse of several experimental friction curves into a single master curve by using the WLF transform [2], which is an empirical equation, but a consequence of time–temperature Boltzmann's superposition principle. The shape of the curve friction coefficient with respect to the sliding speed was dependent on the condition of the surface, i.e. for the smooth wavy glass, the friction curve was symmetrical and showed a single peak which was attributed to adhesion, while for a rough substrate the friction curve was asymmetric. For the normal contact of a cylinder the Maugis λ parameter plays a crucial role in determining the contact interactions nevertheless, at the best of the authors knowledge, there is no study which has attempted to clarify the role of λ for sliding or rolling contacts. Moreover, being λ a scale dependent parameter, assessing its influence on the friction curve would be fundamental to better understand how frictional resistance is generated in multiscale contacts with several implications in every-day applications. We have considered the case of a rigid cylinder of radius R steady sliding at velocity V over a frictionless adhesive viscoelastic halfplane. The contact problem was solved by using the boundary element method, which fundamental solution is that of a constant pressure element sliding over a viscoelastic substrate. In the adhesiveless problem it has been shown that the friction coefficient $^* = R/a_0$ (a_0 is the contact semi-width in the Hertz theory) depends only on the ratio glassy to rubbery Young modulus E_∞/E_0 and on the velocity V. The friction coefficient curves obtained numerically show a bell-shape and the friction is maximized at intermediate velocities where viscoelastic dissipation happens. Finally, we investigated the convergence of the maximum friction coefficient with the material parameter $k = E_0/E_\infty$ (the latter investigation for λ = 3) and the results show that the maximum friction coefficient vanishes for k = 1, which corresponds to the elastic limit, then sharply increases, and converges for k ⊠ 10^{-3}, which suggests for typical elastomers which show k 10^{-3}, the friction coefficient may indeed be independent on the ratio E_0/E_∞. For the rolling contact problem, we made some comparisons with the experiments of Barquins [5,6] proved that due to van der Waals attractive forces and the difference in work of fracture in opening and closing crack in viscoelastic solid, a rigid cylinder could roll on an inclined rubber plane with a friction force which depends as a power law of velocity, but which was approximately equal for negative or positive normal force. Further in other sets of experiments with Charmet [6], he found that contact area increased with velocity quite strongly and that rolling was possible under negative loads even 50 times higher than the static pull-off force. The dependence of friction force on speed is found to be linear at very low speeds, a power law at intermediate speeds which depends on the material, then decaying at large speeds, while experiments found only the power law regime. We therefore obtain qualitative agreement with experiments, but fail to obtain quantitative agreement, partly because to the simplified material model.

[1] Grosch, K. A. ”The relation between the friction and visco-elastic properties of rubber.”Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences 274, no. 1356 (1963): 21-39.
[2] Williams, Malcolm L., Robert F. Landel, and John D. Ferry. ”The temperature dependence of relaxation mechanisms in amorphous polymers and other glass-forming liquids.”Journal of the American Chemical society 77, no. 14 (1955): 3701-3707.
[3] Wu, J. J. (2009). Adhesive contact between a cylinder and a half-space. Journal of Physics D: Applied Physics, 42(15), 155302.
[4] Afferrante, L., & Carbone, G. (2016). The ultratough peeling of elastic tapes from viscoelastic substrates. Journal of the Mechanics and Physics of Solids, 96, 223-234.
[5] Barquins M. (1988) Adherence and Rolling Kinetics of a Rigid Cylinder in Contact with a Natural Rubber Surface, The Journal of Adhesion, 26:1, 1-12, DOI: 10.1080/00218468808071271

[6] Charmet, J. C., & Barquins, M. (1996). Adhesive contact and rolling of a rigid cylinder under the pull of gravity on the underside of a smooth-surfaced sheet of rubber. International journal of adhesion and adhesives, 16(4), 249-254.

Autori principali: PAPANGELO, Antonio (Politecnico di Bari); Prof. CIAVARELLA, Michele; Sig. NAZARI, Roohollah

Relatore: PAPANGELO, Antonio (Politecnico di Bari)

Classifica Sessioni: Progettazione Meccanica

Classificazione della track: Progettazione Meccanica