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Toward co-design of surface textures and Non-Newtonian fluids for decreased friction in lubricated viscous sliding

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We show experimentally in laminar flow that using surface textures and polymer additives together can reduce friction more than each acting independently. Motivated by this, we describe and solve a range of constitutive models, from simple to complex, that can be used for posing optimization problems for co-designing the fluid rheology and the surface texture to achieve optimal friction reduction. We have previously developed and validated a flow solver for Newtonian fluids against careful experiments at small gaps using a tribo-rheometer setup [1]. This model was then used to find optimal, generalized surface topography for surface texturing, resulting in spiral-like valleys across the disc domain [2]. To include Non-Newtonian effects, we consider a range of models with varying fidelity, from a systematic expansion about Newtonian behavior (second order fluid expansion with the 3-D flow theorem of Giesekus) up to fully nonlinear models (Giesekus) with the full 3-D Cauchy momentum equation. We describe our computational implementation of these models and present optimization results in the context of trade-offs: simpler models apply more generally for different material formulations, but for limited deformation conditions (limited range of the Pipkin map), whereas fully nonlinear models apply up to large Weissenberg and Deborah numbers, but cannot apply for all types of rheologically-complex material formulations. This represents a general challenge to design and optimization of non-Newtonian behavior.

References

[1] J. K. Schuh, Y. H. Lee, J. T. Allison, and R. H. Ewoldt, "Design-driven modeling of surface-textured full-film lubricated sliding; validation and rationale of non-standard thrust observations," *Tribology Letters*, vol. 65, 2017.

[2] Y. H. Lee, J. K. Schuh, R. H. Ewoldt, and J. T. Allison, "Enhancing full-film lubrication performance via arbitrary surface texture design," *Journal of Mechanical Design*, vol. 139, no. 5, pp. 053401-1-13, 2017.