Nonmonotonic flow curves and shear banding in granular flows

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Dense granular packings, both dry and suspended in liquid, are among the most abundant materials on earth. They are relevant to manifold geophysical phenomena, e.g., landslides and debris flows, and to industrial processes such as paste extrusion. Understanding their deformation and flow properties is thus of major practical importance. It is also of fundamental interest in statistical physics, fluid mechanics and rheology. Here we use particle simulations to map comprehensively the shear rheology of dry and wet granular matter comprising particles of finite stiffness, in both fixed pressure and fixed volume protocols. At fixed pressure we find nonmonotonic constitutive curves that are shear thinning, whereas at fixed volume we find nonmonotonic constitutive curves that are shear thickening. We show that the presence of one nonmonotonicity does not imply the other. Instead, there exists a signature in the volume fraction measured under fixed pressure that, when present, ensures nonmonotonic constitutive curves at fixed volume. In the context of dry granular flow we show that gradient and vorticity bands arise under fixed pressure and volume respectively,
as implied by the constitutive curves. For wet systems our results are consistent with a recent experimental observation of shear thinning at fixed pressure. Reconciling these rich banding dynamics with a detailed mechanistic description accounting also for non-locality and boundary effects remains an open challenge.

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