Percolation behavior of cobalt-nanowire-based magnetorheological fluids

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Conventional magnetorheological (MR) fluids are composed of micron-sized ferromagnetic spherical particles suspended in a hydrocarbon or silicone carrier fluid.[1] By applying an external magnetic field (H), the initially viscous liquid/particle suspension converts to a semi-solid, with an achievable field-induced yield stress of $\sim 100\,kPa$.[2] Upon application of the H-field, the particles acquire a magnetic polarization and attract one another, developing chain-like structures that join to form fibrils parallel to H . This allows for numerous applications such as variable dampers, brakes, and clutches that exploit the continuously controllable, field-dependent yield stress.[3]

The field-dependent shear strength of MR fluids depends on the size, composition, morphology, and volume fraction of the particles (p).[4] Increasing p increases the achievable yield strength, but also increases the off-state viscosity.[5] As H is increased, the shear strength of the fluid increases and then plateaus, as magnetic saturation is reached. In our work with iron-nanowire-based MR fluids, we observed a complete absence of settling and a significant enhancement of yield-stress for volume fractions as low as $p = 0.06$.[5]

To investigate further the unique rheological behavior of nanowire-based MR fluids, we generated cobalt nanowires ($330\,nm$ diam. $\times 8.0 - 12\,\mu m$) via template-based electro-deposition using commercially available, anodized alumina membranes as templates.[5] For MR fluids synthesized with these wires, we systematically varied p and measured the dynamic yield stress at different H-fields. In doing so, we observe a percolation transition in the yield stress and find the behavior near the critical volume fraction (p_c) to depend on H (FIG 1)[6].

Using a standard continuum percolation model, we fit the data using two critical exponents. For $p > p_c$, we find the elastic exponent (f) to be independent of H , having a value near $f = 1.3$, suggesting that these on-state MR-fluids exhibit two-dimensional (2D) behavior,[7] possibly due to the preferred spatial direction for fibril formation. For $p < p_c$, the superelastic exponent (c) decreases with increasing H and is smaller than that seen in 2D or 3D networks. We find p_c to increase with H , likely due to the increased alignment of the nanowires with the applied H-field.[8] Future experiments that vary the nanowire aspect ratio, use other materials (e.g., iron and nickel), and employ quasistatic, rather than dynamic measurements, should help separate these issues from the underlying physical mechanisms.

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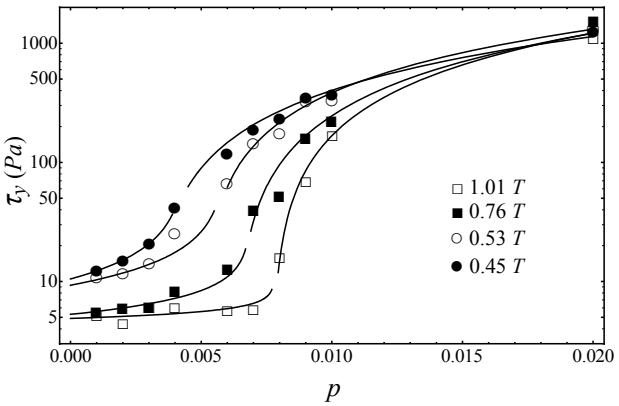

FIG. 1. Apparent yield stress (τ_y) of on-state, cobalt-nanowire MR fluids as a function of p for varying H (indicated in legend). For the sake of detail, we show the data and fit up to $p = 0.02$; both actually extend out to $p = 0.06$.

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