Bridging Tribology and Microrheology of Thin Films

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Abstract:
An enhanced version of the flexure-based microgap rheometer (FMR) is described which enables rheological measurements in steady state shearing flows of bulk fluid samples of PDMS with an absolute gap separation between the shearing surfaces of 100 nm – 100 μm. Alignment of the shearing surfaces to a parallelism better then 10^{-7} rad allows us to reliably measure shear stresses at shear rates up to 10^4 s^{-1}. At low rates and for shearing gaps < 5 μm the stress response is dominated by sliding friction between the surfaces that is independent of the viscosity of the fluid and only determined by the residual particulate phase (dust particles) in the fluid. This behaviour is similar to the boundary lubrication regime in tribology. The absolute gap control of the FMR allows us to systematically investigate the flow behaviour at low degrees of confinement (gap separations 100 nm – 2 μm) that cannot be accessed with conventional (controlled normal load) tribological test protocols.

Zusammenfassung:
In diesem Artikel wird eine erweitere Version des 'flexure-based microgap rheometers' (FMR) vorgestellt, die in der Lage ist das Fließverhalten von PDMS Proben mit absoluten Scherspaltabständen von 100 nm bis 100 μm zu bestimmen. Eine parallele Ausrichtung der Scheroberflächen mit Winkelfehlern kleiner als 10^{-7} rad ermöglicht verlässliche Schergeschwindigkeiten bis zu 10^4 s^{-1}. Bei kleinen Schergeschwindigkeiten und Scherspaltabständen < 5 μm wird die Scherspannung durch Gleitreibung dominiert die unabhänging von der Viskosität des Fluids ist und nur durch partikuläre Rückstände (Staubpartikel) bestimmt wird. Dieses Verhalten ist der Grenzschichtschmierung der Tribologie ähnlich. Die absolute Kontrolle des Spaltabstandes im FMR erlaubt eine systematische Untersuchung des Fließverhaltens bei Scherspaltabständen von 100 nm – 2 μm, die mit einem konventionellen Tribometer und kontrollierter Normalkraft nicht erreicht werden können.

Résumé:
Une version améliorée du rhéomètre microgap basé sur flexion (Flexure-based Microgap Rheometer, FMR) est décrite qui permet des mesures rhéologiques des flux à l'état stationnaire en régime de cisaillement des échantillons fluides de PDMS avec une séparation du gap absolu entre les surfaces de cisaillement de 100 nm – 100 μm. L'alignement des surfaces de cisaillement avec un parallélisme mieux que 10^{-7} rad nous permet de mesurer de manière fiable des stress de cisaillement à taux de cisaillement jusqu'à 10^4 s^{-1}. Aux taux faibles et pour des gaps de cisaillement < 5 μm la réponse au stress est dominée par la friction de glissement entre les surfaces, qui est indépendante de la viscosité du fluide et uniquement déterminée par la phase particulaire résiduelle (particules de poussière) dans le fluide. Ce comportement est semblable au régime de lubrification dans la couche limite comme connu dans la tribologie. Le contrôle du gap absolu de FMR nous permet d'étudier systématiquement le comportement d'écoulement sous degrés de confinement faibles (séparations de 100 nm - 2 μm) qui ne sont pas accessibles avec les protocoles expérimentales classiques (force normale contrôlée) de la tribologie.

Key words: microrheology, thin film rheology, tribology, boundary lubrication, sliding plate rheometer, micro gap, FMR, triborheometry, PDMS

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