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Parallel-plate Geometry Correction for Transient Rheometric Experiments

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Abstract:
It is well known that the shear and shear rate are not uniform in the azimuthal flow within the gap between parallel concentric disks – perhaps the most versatile among the geometries used in rheometry. This flow inhomogeneity represents a disadvantage, because the data analysis becomes intricate. Typically the stress is calculated at the rim with the assumption that it varies linearly with the radial coordinate, and then a correction is applied. This correction may be very large, depending on the nature of the sample, type of test, and range of parameters. While for steady-state shear flow different methods for correcting the stress are available, for transient flows they are rather scarce and in some cases unavailable. In this work we analyze in detail the stress correction for the main rheometric experiments, and discuss when it is needed. To this end, we performed different tests with a commercial hair gel and a polyacrylamide solution. For oscillatory flows, a simple equation to correct the stress amplitude is obtained in terms of the amplitudes of the torque and shear rate.

Key words:
rheometry, parallel-plate geometry, stress correction

1 INTRODUCTION

The parallel-plate geometry is widely used in rheometry for a great variety of materials, such as polymer melts, suspensions, dispersions and emulsions. One of its advantages over the cone and plate or the concentric cylinder geometries is the ease of varying the gap, which is crucial in the case of systems containing a disperse phase such as particles, droplets or bubbles. The gap must be much larger than the particle size (at least ten times), otherwise the continuous medium hypothesis always adopted in the rheometer theories is violated. Thus, for multiphase systems, this requirement rules out the employment of the cone-and-plate geometry and restricts the range of applications of narrow-gap concentric cylinders. Another advantage of the parallel-plate geometry is a wider range of shear rate, which can be changed by varying the plate diameter, gap, and angular velocity. In addition, when measuring viscoplastic materials it is recommended that all surfaces in contact with the sample be roughened, so as to avoid the occurrence of apparent wall slip [1, 2]. Surface roughening, either by covering it with grit sandpaper, by sandblasting or by profiling (e.g. cross-hatched surfaces), is easily done with parallel plates.

However, in contrast to the cone-and-plate or the narrow-gap concentric cylinder geometries – for which the deformation γ and shear rate $\dot{\gamma}$ are uniform or nearly uniform throughout the sample – in the case of the parallel-plate geometry both of these kinematic quantities vary linearly with the radial coordinate r:

$$\gamma = \frac{\theta r}{H} \; and \; \dot{\gamma} = \frac{\Omega r}{H} \tag{1}$$

where H is the gap between the plates, θ is the angular displacement, and $\Omega = \dot{\theta}$ is the angular velocity. Flow inhomogeneity is inconsequential[1] when the shear stress σ also varies linearly with r (e.g. for Newtonian fluids, $\sigma = \mu\dot{\gamma}$, and Hookean solids, $\sigma = G\gamma$). In this case we can write the shear stress in the form $\sigma = Cr$, where

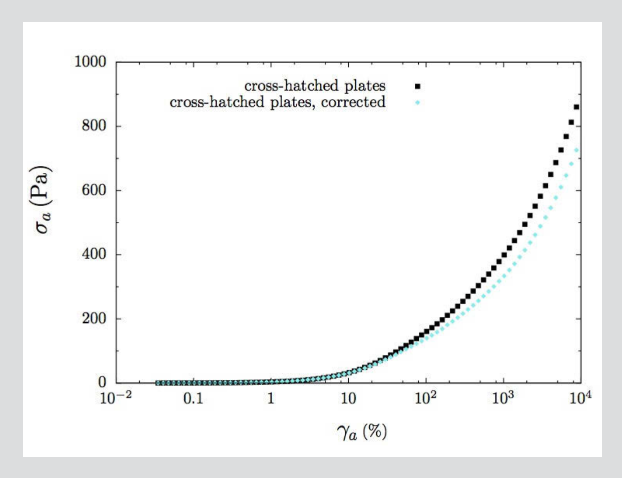

Figure 10: Strain sweep results for the hair gel: Stress amplitude versus strain amplitude.

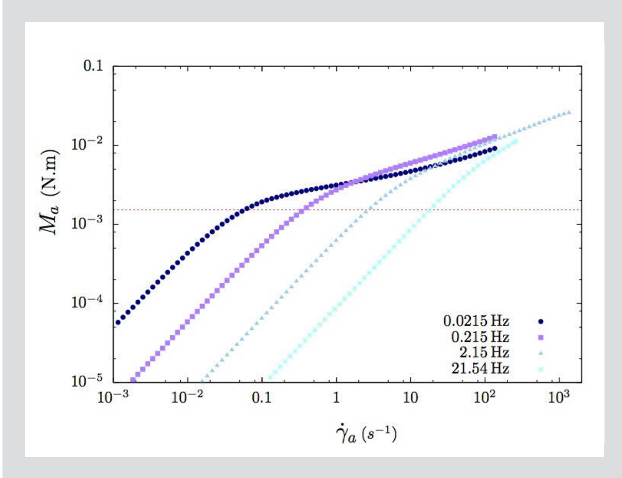

Figure 11: Strain sweep tests with hair gel at different frequencies: Torque amplitude as a function of the shear rate amplitude. The horizontal red dotted line indicates the torque that corresponds to the yield stress σ =62.5 Pa.

cept is directly related to the fact that the material microstructure resists to higher shear stresses if they are applied cyclically rather than steadily (i.e. at a fixed value) because the microstructure breakup needs continuous exposure to a stress above the yield stress during some minimum length of time. The higher the frequency, the higher the maximum stress to which it resists. As the frequency tends to zero, this maximum shear stress approaches the yield stress. The effective stress at the bend conditions is equal to the yield stress for all frequencies, while the applied stress amplitude at the bend increases with the frequency. These trends are clearly illustrated in Figure 11, and imply that the shear stress correction due to flow inhomogeneity is only relevant and is certainly quite important for LAOS tests, which are typically performed at low frequencies.

4 CONCLUDING REMARKS

In this paper we present an experimental study of the effect of flow inhomogeneity on the shear stress in rheological tests that employ the parallel-plate geometry, with especial emphasis on oscillatory flows. To this end, we performed different kinds of tests using both a shear-thinning, viscoelastic liquid and an elasto-viscoplastic gel. The general conditions under which the need for a correction arises were discussed in detail. It was illustrated that the correction needed on the shear stress may be as high as 49%, depending on the material, stress range, and type of test. It is shown that the parallel-plate geometry can be used without corrections to perform creep tests when the sole objective is to measure the yield stress. A correction for the stress amplitude in oscillatory tests is proposed, and some illustrative results showed that it accurately corrects the data for the flow inhomogeneity of the parallel-plate geometry, supporting the adoption of the simplifying assumption that the local stresses are all in phase with the torque. In contrast to other corrections found in the literature, the one proposed here does not depend on an assumed constitutive model. It was also illustrated that the stress correction is not needed in SAOS experiments, but is especially important in LAOS tests.

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FOOTNOTE

[1] Except that the shear-rate gradient may induce shear dispersion, causing the dispersed phase to migrate radially towards the center. This effect may cause important measurement errors, depending on the characteristics of the system and of the test itself.

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