Deformational Vorticity in Constitutive Equations for Medium Amplitude Oscillatory Shear

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The vorticity tensor is widely known to capture a fluid's rotational properties and is thought to hold valuable kinematic information about the fluid. However, this information has largely gone unused in constitutive equations due to the vorticity tensor's failure to adhere to the material objectivity requirements. Attempts have been made to incorporate vorticity into constitutive equations[1,2,3,4,5]. In prior work proposed by Wedgewood[6,7], a vorticity decomposition was introduced that was able to separate the vorticity tensor into a rigid-body rotational, non-objective part and a deformational, objective part.

This work aimed to incorporate and apply the novel kinematic variable called the objective deformational vorticity to a new constitutive equation called the *co-rigid rotational Maxwell model*. The co-rigid rotational Maxwell model was then applied to medium amplitude oscillatory shear (MAOS) flow, where the effects of the deformational vorticity were analyzed and compared against PVA-Borax hydrogel data using the third-harmonic stressed departures – e_1, v_1, e_3, and v_3 – developed by Bharadwaj and Ewoldt[8]. Additionally, analytical solutions for the prior mentioned material properties were obtained through a perturbation method that used a power series expansion in terms of rate-of-strain. Results for the proposed co-rigid rotational Maxwell model showed an improvement over the more widely known co-rotational Maxwell model. Despite the complexity of the PVA-Borax data and the difficulty to predict its material properties using a quasi-linear differential model, the deformational vorticity offered unique model capabilities that have gone otherwise unexplored. This research lays the foundations for: (1) further exploration of the deformational vorticity; (2) its implementation into new, future constitutive equations; and (3) a methodology to evaluate its effectiveness.

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