An algebraic thixotropic elasto-viscoplastic model for describing pre-yielding and post-yielding behaviour

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ABSTRACT

Formulating an appropriate thixotropic elasto-viscoplastic constitutive equation is challenging, especially for a model describing pre-yielding material behaviour and post-yielding fluid behaviour. Very few models try to explain both behaviour simultaneously[1–3]. Oldroyd's 1946[1] formulation was one of the first models explaining it, however, assumptions of a simple linear elastic and quasi-static deformation before yielding made his model idealistic. At the same time, the quasi-static preyielding deformation assumption allows the possibility for the consideration of preyielding viscous and plastic deformation when quasi-static conditions are not fulfilled. Saramito[2] added a frictional element in Oldroyd's viscoelastic model[1] to avoid a jump in stress at the critical strain, however, his model is unable to predict initial plastic and viscous effect as pointed out by Coussot and rogers[4]. De Souza Mendes and Thompson[3] model is unable to predict true yield stress and no flow behaviour for a finite value of the parameter. Apart from the shortcomings mentioned above, their models consist of complex differential form creating difficulty for practical application. Here, we discuss the structural parameters based thixotropic elasto-viscoplastic (TEVP) constitutive model valid for both reversible (finite thixotropic time scale) and irreversible (infinite thixotropic time scale) thixotropic materials. An extensional of our earlier model[5], which is used to predict flow restart in the pipeline filled with irreversible TEVP materials. Early model was restricted to irreversible TEVP materials, only considered for predicting flow restart without discussing other aspects of the rheological behaviour of TEVP materials. Our present model, despite being a simple algebraic equation, explains both the viscosity plateau at low shear rates and the diverging zero shear rate viscosity appropriately using the same parameters but different shear histories. Furthermore, our model predicts stress overshoot during shear rate startup flow, hysteresis in shear-rate ramps, viscosity bifurcation during creeping flow, delayed yielding, sudden stepdown shear stress test results and shear banding phenomena effectively. Depending on shear histories, our model at the steady state reduces to either Bingham, Herschel Bulkley type, or Newtonian fluids model. The current framework also provides a possible physical interpretation of the Bingham model, which has been elusive despite its enormous use. Our model predicts either a no-flow start or a simple flow start for different thixotropic time scales while keeping other conditions the same, and it can also predict a delayed flow start for an appropriate structure degradation kinetic.

The results in Figure 1 show some of the important TEVP bahviour predicted by our model. Figure 1a shows stress overshoot during a constant shear rate startup flow. Figure 1b shows stress hysteresis during shear-rate up and down calculation. Whearas, figure 1c shows the stress response of the material, when a material undergoes a high shear rate for a certain period and suddenly shear rate brought to a considerably low value. These results qualitatively predict recent experimental observations of TEVP fluids.

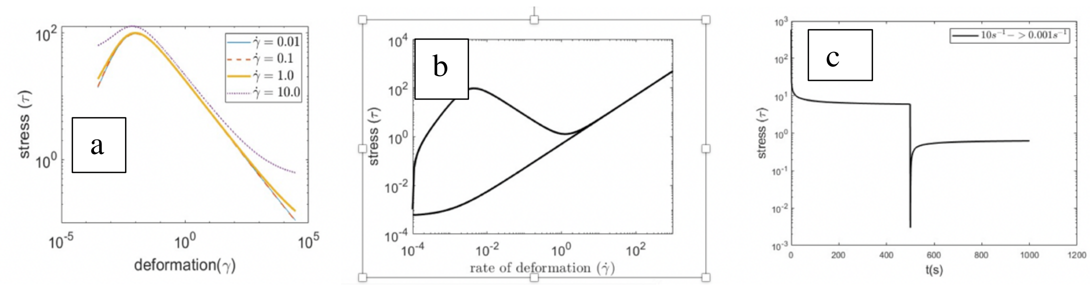

Figure 1 : . (a) shows stress overshoot during a constant shear rate startup flow, (b) shows stress hysteresis during shear up and down calculation and (c) shows the stress response during sudden shear rate down after a certain period of time.

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