# Energy Dissipation and Rheological Characterisation of Sand-Clay Mixtures

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**Abstract: Geophysical flows-such as floods, mudflows, and debris flows- display increasingly complex rheological behaviour as solid fraction rises, greatly impacting hazard assessment and mitigation. While prior research concentrated on monotonic shearing of two-phase flows, the detailed mechanisms governing energy dissipation during shear deformation remain unclear This study systematically explores rheological transitions in sand-clay-water mixtures subjected to oscillatory shear using parallel plate rheometer, quantifying elastic, viscous and plastic energy contributions. The results demonstrate that rising clay content promotes a transition from elastic to viscous stress dominance and enhances shear-thinning behaviour.**

**Keywords:** ***Rheology, Energy dissipation, Geophysical flows.***

## Introduction

Debris flow material consists of a wide range of particle sizes, from clay-sized fines to boulders a few metres in diameter (Iverson, 1997). This heterogeneity presents substantial challenges for characterising shear response, leading to simplified approaches that model flow-like landslides as two-phase flows.

Recent developments include a generalised drag model for solid-fluid mixtures that more realistically quantifies energy dissipation during inter-phase interaction, eliminates singularities and incorporates material composition, flow dynamics, and mass flux for diverse dissipation modes (Pudasaini, 2020). A detailed understanding of viscous and elastic responses in sand-clay systems could be achieved by rheological testing with oscillatory shear as explained in Mezger (2020).

Ettehadi et al. (2020) investigated the energy dissipation mechanisms in clay-water suspensions under oscillatory shear using a rotational rheometer. Their results indicated that energy dissipation increases with clay content, with a corresponding increase in the viscous contribution. This suggests that the presence of clay particles enhances the mechanisms of viscous dissipation within the suspension. In addition to the viscous effects, the influence of yield strength on energy dissipation via irreversible plastic deformation should be given due consideration as this is one of the dominant mechanisms of frictional energy loss in geomaterials.

This study investigates the influence of sand content in clay-water mixtures on energy dissipation during oscillatory shear testing in a rotational rheometer employing parallel plate geometry. A series of rheometric tests is conducted to characterise the elastic, viscous and plastic components of stress. Subsequently, corresponding energy dissipation is derived from these stress responses utilising a theoretical model.

## Test Plan and Procedures

Oscillatory rheometer tests were performed in a commercial rheometer using parallel plate geometry, with a radius diameter of 25 mm and a sample thickness of 3 mm (Figure 1). Adhesive tape with sand was used on the plates to ensure no-slip boundary conditions. Amplitude sweep tests were conducted at 1Hz frequency and seven strain amplitudes. Sand-clay mixtures with varying clay content were prepared to examine the effects of fines on energy dissipation. Special attention was given to water content control due to its importance for rheological properties. The test plan used in this study is summarised in Table 1.

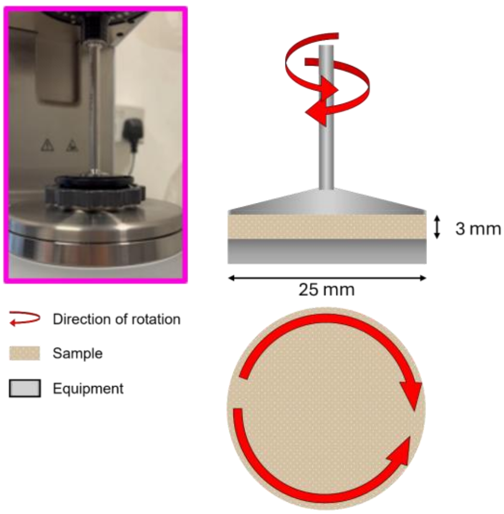


*Figure 1, Instrument with schematics of test setup and test material.*

*Table 1, Test plan.*

| Test ID | Fluid | | Sand content (%) |
|---|---|---|---|
| | Clay content (%) | Water content (%) | |
| C5 | 5 | 95 | |
| C10 | 10 | 90 | 36 |
| C20 | 20 | 80 | |

## Results

For the sand mixed with 5% clay-water mixture, the storage modulus decreases from $10^5$ Pa to $10^{-1}$ Pa as the strain amplitude increases from $10^{-3}$% to $10^3$%. The storage and loss moduli cross over between 1 % to 10 % strain, with elastic effects dominating at very low strains. Beyond the crossover, viscous effects become dominant, leading to viscous response at large strains. Similar trends appear for 10% and 20% clay mixtures, with higher clay content causing higher dominance of plastic contribution to energy dissipation, evidenced by a sharper drop in storage modulus at higher strain amplitudes.

These results show that as clay content is increased from 5% to 20%, the shearing behaviour of sand and clay-water mixture in the small shear strain range ($\gamma_o < 10^{-1}$%) starts to exhibit a linear viscoelastic region where the deformation is closer to that of a solid material. This behaviour likely stems from the increase in yield strength of the clay-water mixture with increasing clay-content (Ng et al., 2024). At large shearing strains ($\gamma_o > 10$%), the material starts to behave like fluid as the elastic contribution rapidly reduces with commensurate development of flow structures where clay particles likely parallel to the shearing direction.

The result can be clearer by using the shear stress versus shear strain relationship (Bhatta, 2025). Shear stress versus strain plots for sand with 20% clay-water mixture at a strain amplitude of 0.01% reveal elastic-dominance with minor plastic and viscous components. As the strain amplitude increases, plastic strain accumulates, reducing elastic stress and increasing plastic and viscous stress contribution. These changes are reflected in the geometry of stress-strain loops, which are used to quantify energy dissipation components.

## Conclusions

Oscillatory shearing tests were conducted on sand-clay-water mixtures to quantify changes in the shear moduli to understand rheological characteristics and energy dissipation behaviours of two-phase flows. The degradation rates of the storage modulus were much more pronounced compared to the loss modulus after the strain increased to the range of $10^{-1}$ % to 1%, marking a transition from an elastic-dominated regime to a viscous-dominated regime. The deduced stress-strain plots can be utilised to quantify the proportional changes in elastic, viscous and plastic stress contributions to the mechanical response at different strain amplitudes, as well as oscillation frequency.

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