Two Step Yielding in Soft Material

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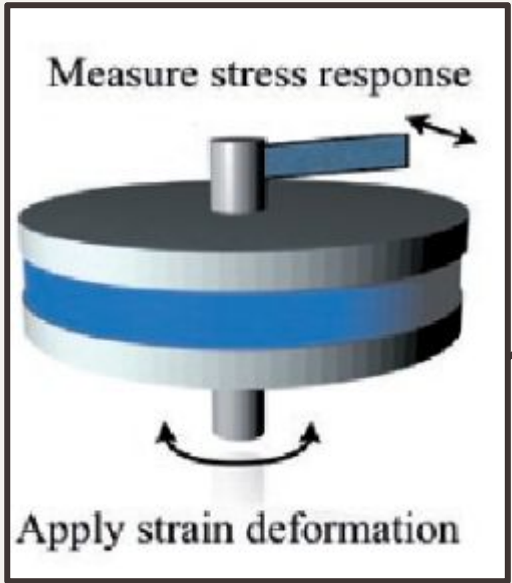
Introduction

1. Oscillatory rheology is a field of study that examines the **dynamic mechanical responses of materials** when they are **subjected to cyclic changes in shape or size**, often through techniques such as **oscillatory shear or strain**.
2. This scientific approach is key to comprehending how different materials react when exposed to varying dynamic forces, providing valuable **insights into their inherent properties and potential applications.**
3. Oscillatory rheology can be used to measure:
    - **Storage Modulus** - How much energy must be applied to distort the sample
    - **Loss modulus** - The energy lost as the material returns to its original shape after deformation
    - **Time-dependent behavior** - can be measured by varying the frequency of the applied stress or strain
4. It is extensively used in sectors such as **pharmaceuticals, food processing, polymer manufacturing, and petrochemicals**, aiding in product development and quality assurance.



Mechanistic Understanding

Factors contributing to two-step yielding:

Presence of hierarchical structures

Interactions between particles at different length scales

Stress-induced structural rearrangements

Evidence of Two-Step Yielding in different material systems:

Colloidal Gels

First yielding was linked to bond breaking and the second was due to the breaking of aggregates

Emulsions

Breaking of inter-droplet bonds at the weak points followed by a strain induced droplet reconfiguration in the densely packed microstructure

Electro and metrological fluids

First yield stress was attributed to the inter-aggregate bond rupturing and the second yield stress was associated to intra-cluster bond breakage

Glassy System

First yielding was linked to the rupturing of bonds, while the second yielding to cage breaking

Experimental Setup

Dataset Description

Input Shear Strain Function: $\Upsilon = \Upsilon_o sin(\varpi t)$

We have four Different type of Materials for the Experiment :

1. Sensodyne
2. Colgate Gel
3. Patanjali
4. Himalaya active fresh

All the different type of Toothpaste represent different type of material properties

Shear Strain	Storage Modulus	Loss Modulus
0.000104	783.83	392.35
0.000197	847.66	413.26
0.000367	1066.5	413.37

Frequency is kept constant and Amplitude is increased.

Theory

1. Oscillatory Rheology:

Oscillatory rheology is a sophisticated technique used to evaluate the temporal behavior of materials by modulating the frequency of the stress or strain applied. This approach offers a detailed understanding of the material's viscoelastic properties under different conditions.

During an oscillatory examination, a material sample is subjected to oscillating strain. The resulting reactions are meticulously analyzed to discern the material's elastic (solid-like) and viscous (liquid-like) characteristics, providing a comprehensive picture of its mechanical behavior.

Oscillatory rheology is particularly pertinent when studying materials susceptible to macroscopic or microscopic structural changes over time. This allows scientists and engineers to predict how materials will behave under specified conditions and over extended periods, facilitating the development of more reliable and durable products.

2. Elastic/Storage Modulus and Loss Modulus

1. When a material is subjected to a sinusoidal strain profile, it responds by producing a sinusoidal stress output. This characteristic response is fundamental to the process of oscillatory rheology.
2. Using specialized software, we can accurately fit the stress-strain curve and determine the amplitude and phase differences. This step is crucial for extracting precise information about the material's behavior under oscillatory conditions.
3. With the amplitude and phase differences established, it becomes possible to calculate the storage modulus (G') and the loss modulus (G"). These values provide key insights into the elastic and viscoidal aspects of the material's response, respectively.

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3. LOAS Analysis of Two-step Yielding(large amplitude oscillatory shear test)

1. Large Amplitude Oscillatory Shear (LAOS) is a powerful technique for probing the nonlinear rheological behavior of materials, including those that exhibit two-step yielding. By applying a sinusoidal strain with increasing amplitude, LAOS allows for the extraction of higher-order harmonics of the stress response, providing more detailed information about the underlying structural rearrangements that occur during yielding.
2. LAOS can provide information about the timescales and mechanisms of both steps of the yielding process.
3. LAOS parameters such as Lissajous plots, Fourier transforms, Chebyshev polynomials, and decomposition into harmonic and anharmonic stresses can be used to quantify the nonlinear rheological behavior.

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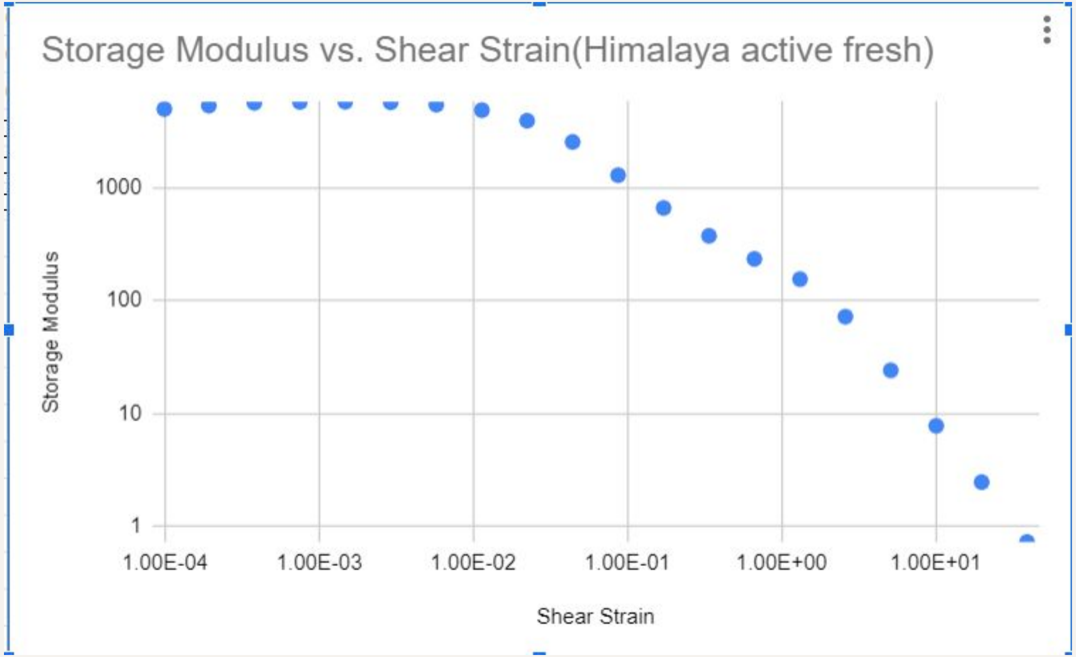
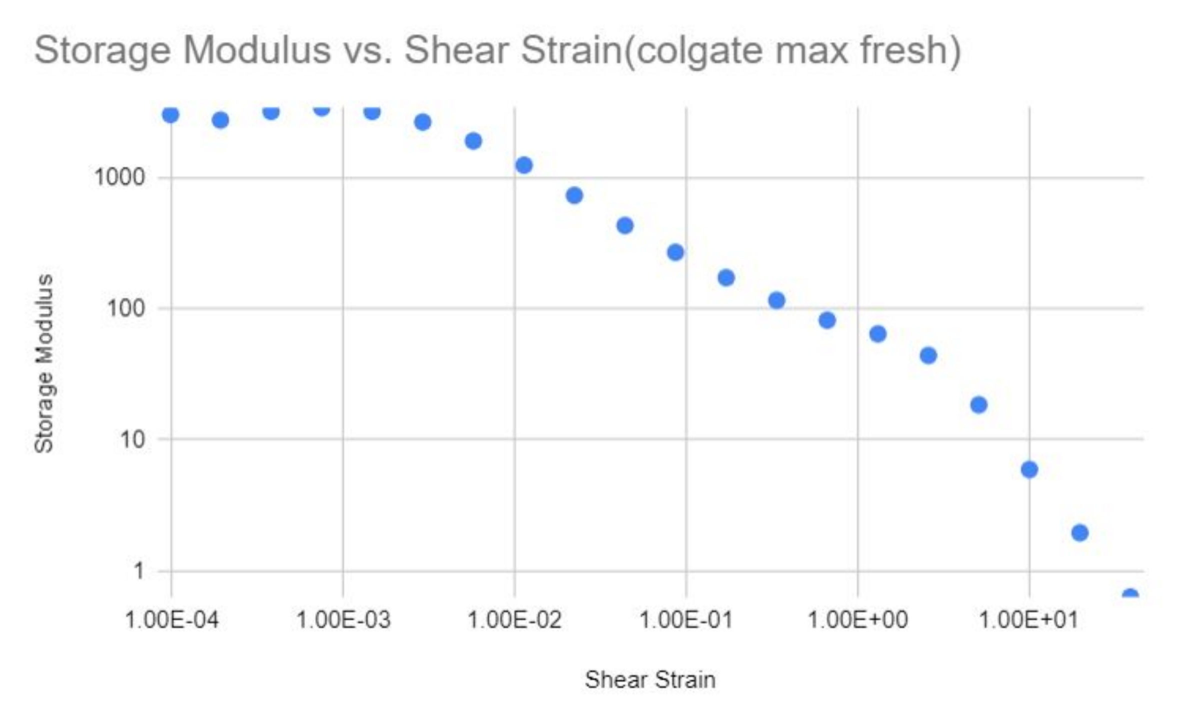
Results-1



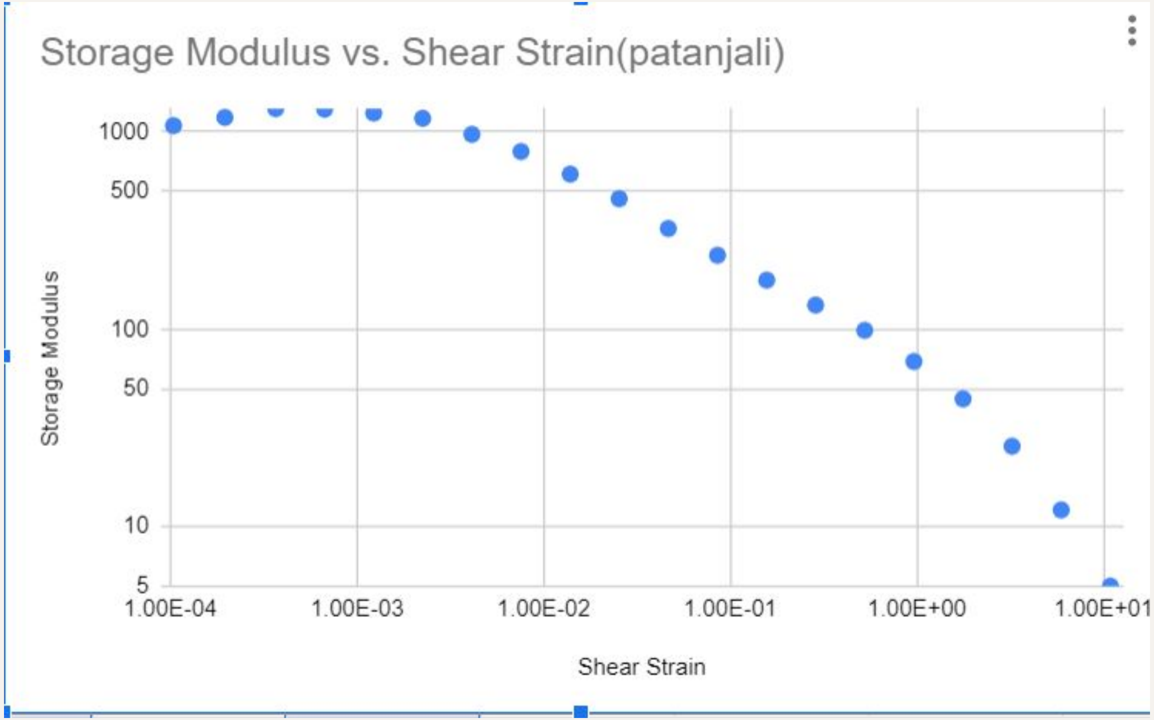
Storage Modulus vs. Shear Strain(Himalaya active fresh)
Storage Modulus
1000
100
10
1
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
Shear Strain

Results-2



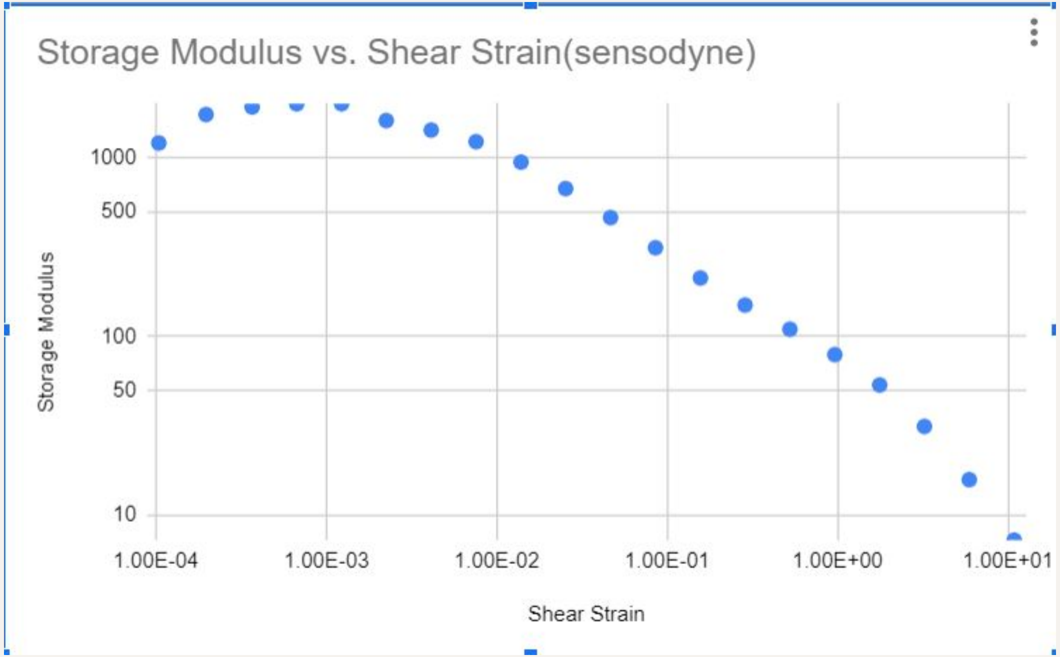
Storage Modulus vs. Shear Strain(colgate max fresh)
Storage Modulus
1000
100
10
1
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
Shear Strain

Results-3



Storage Modulus vs. Shear Strain(patanjali)
Storage Modulus
1000
500
100
50
10
5
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
Shear Strain

Results-4



Storage Modulus vs. Shear Strain(sensodyne)
Storage Modulus
1000
500
100
50
10
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
Shear Strain

Challenges in modeling two-step yielding:

Complexity of microstructure and interactions

It involves multiple microstructural processes such as dislocation multiplication,cross-slip and dislocation rearrangement which are highly interconnected.

Lack of comprehensive models

Existing model focuses only on one stage. Models which focuses on first yield point might overlook strain hardening. Models which focuses on second yield point may overlook initial yield point.

Limitations of simulation methods

For example, molecular simulations(MD) are limited to small system sizes and short timescales so it’s hard to capture long-range interactions whereas Finite element(FE) simulations can handel large systems and longer timescales but are computation expensive.

LEARNING OUTCOMES:

- Two-step yielding can observed in **colloidal gels, attractive glasses, emulsions, suspensions, and pastes**.

- The two-step yielding behavior can be characterized by two distinct yield points or thresholds.

- The first yield point is known as the "**pre-yield**". It occurs at a lower shear stress and at this point initial breakdown of structural bonds or rearrangement of particles occurs within the material.

- The second yield point is known as the "**main yield**,". It occurs when there is larger increase in shear stress and marks the onset of more pronounced flow and deformation.
- The second yield point is associated with **strain softening(**Strain softening is the degradation of material strength as strain increases**)** or **shear thickening(**viscosity increases with shear rate**)**.

SOURCES OF ERROR:

1. Instrumentation and measurement precision:

The quality and precision of the testing equipment used to measure the mechanical properties of toothpaste can influence the accuracy of the results.

2. Temperature and storage conditions:

Toothpaste properties can be sensitive to temperature and storage conditions

3. Aging and shelf life:

Toothpaste properties can change over time due to aging,

Contaminants and impurities:

Any contaminants or impurities in the toothpaste can affect its mechanical properties.

APPLICATIONS :

Cosmetics and personal care products

Food products

3D printing inks

Medical applications

Conclusion:-

- **Reason for two-step yielding in glassy fluids:-**
  - The initial yielding occurs due to softening or breaking of bonds when subjected to stress
  - This occurs after when more stress is applied leading to cage breaking occurs and material undergoes substantial deformation

- **Reason for two-step yielding in colloidal fluids:-**
  - Primary yielding occurs due to structural changes or reorganization due to breaking of bonds. This change is often reversible and the material retain its state when stress is removed
  - Second yielding occurs when the stress exceeds a certain threshold leading to breaking of individual agglomerates or irreversible flow

Thanks!