The Mechanics of Fire Ants

Mechanics of Soft Matter
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Outline

• Introduction to Fire Ants
• The Mechanical Behavior of Fire Ants
  • Floating Rafts
    • Cohesion
    • Surface Tension
  • Continuums of Fire Ants
    • Rheological Tests
    • Creep Tests

Fire ants self-assemble into waterproof rafts to survive floods
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Mechanics of fire ant aggregations
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Courtesy of Mlot, et al. [1]
Introduction: Ants as a Soft Matter Material

- Mesoscopic Building Blocks: Fire Ants
- Aggregations Occur;
  - When Ants are Placed in Water
  - In Other Controlled Environments
    - E.g., Confinement

Fire ants cluster together to form a continuous medium [2].

The medium behaves like both a fluid and a solid, depending on the time scale and load conditions. (b)-(d) Ants exhibit solid-like, elastic response (short timescale).
(e)-(g) Ants exhibit fluid-like, viscous response (long timescale).
Ant Aggregations: Bond Types

- Types of ant bonds are formed using mandibles, tarsal claws, and adhesive pads
- Max Tensile Force $620 \pm 100$ dyn Leg-Leg connection $195 \pm 7$ dyn Leg-Body tensile force $69 \pm 52$ dyn

A) Aggregation of ants acting as a raft. B) Fire ant using mandibles to attach. C) Fire ants using tarsal hooks to attach. [1]

Cohesion & Surface Tension

- **Cohesion**
  - Aggregations exhibit finite Young’s modulus and yield strength
  - Ringelmann Effect: Yield stress does not scale linearly with cross-sectional area: ants in group work 50% less than alone

- **Density**
  - Packing fraction, ants control spacing ($\rho_{raft} = 0.2 \text{ g/mL}$)

- **Surface Tension**
  - Wetting
  - Surface Tension of raft: $10^3 \text{ dyn/cm}$ (10x surface tension of $\text{H}_2\text{O}$)

- **Viscosity**
  - Have viscosity of $10^4 \text{ P}$ (similar that of high-viscosity Si oil)
Fire Ants’ Fluid-like Behavior: Rheology [2]

\[ \eta \approx (\rho_{sp} - \rho)gr^2/u \]

- Stress plateaus at 70 Pa
  - Attributed to force-dependent detachment rate

- Shear-thinning observed
  - \( \Delta \eta \Rightarrow \) viscosity is adjusted by ants to maintain stress

Viscosity data is compiled using different techniques. Top: photo of falling sphere viscometry set-up. Bottom: graphic of rheometry setup. [2]
Fire Ants’ Fluid-like Behavior: Creep

• Creep measures time evolution of strain under constant stress.
  • Various constant stresses applied
• Regions of linear strain-time relation (i.e. constant strain rate) observed.
• At low stress, regions of low strain observed
  • Means ants are storing elastic energy instead of flowing

Creep behavior (i.e. strain vs. stress) of fire ant aggregations at various applied stresses. (a) 40 Pa, (b) 70 Pa, (c) 100 Pa and (d) 200 Pa. [2]
Fire Ants’ Viscoelastic Behavior: Frequency Sweep

- Oscillatory Strain: $\gamma(t) = \gamma_0 \sin(\omega t)$
- Measure lag in stress response to find;
- Elastic (or Storage) Modulus, $G'$
- Dissipation (or Loss) Modulus, $G''$
  - $G' \approx G'' \sim \omega^{0.39}$ for ants
  - => dynamic relaxation time that is a function of frequency
- Ants maintain similar energy dissipation and storage values at all $\omega$ => $k_d = f(\dot{\gamma})$

(a) $\gamma(t)$ and $\sigma(t)$. (b) $G'$ and $G''$ plotted for various amplitudes of strain. (c) $G'$ and $G''$ plotted for a range of $\omega$ at 4 different live aggregation densities. (d) $G'$ and $G''$ versus $\omega$ for Maxwell model (note: intersection => single relaxation time). (e) $G'$ and $G''$ plotted for a range of $\omega$ at 3 different dead aggregation densities ($G' > G''$ => dead ants are always elastic)
Conclusion

Fire Ant Aggregations: a Soft Matter Material that Exhibit;

1. Hydrophobicity, cohesion, and surface tension
2. Elastic Properties at Short Timescales & High Densities
3. Shear-thinning, Fluid-like Properties at Long Timescales
4. Viscoelastic properties (i.e. Both Energy Storage & Dissipation) with a force-dependent relaxation rate

All attributed to their ability to detach and reattach into lower stress configurations at a force-dependent rate.


