

FOOD SCIENCE AND TECHNOLOGY

Lecture08

Lecture 08: Textural and Rheological Properties of Foods

Hi everyone, namaste. In the last class, we discussed mechanical and physical properties. Now, in this lecture, let us talk about food materials' textural and rheological properties. And we will discuss what are food rheology and the important rheological properties of fluids and solid fluids.



how to measure rheological properties and textural properties of food materials and important textural properties and their characterization techniques. So, let us discuss what is food rheology. Rheology is the science of flow and deformation of matter and describes the interrelation between force, deformation, and time. It is the study of the manner in which materials respond to applied stress and strain.



Food rheology



- **Rheology** is the science of flow and deformation of matter and describes the interrelation between force, deformation and time.
- It is the study of the manner in which materials respond to applied stress or strain.
- In rheological terms, food materials may be characterized as viscous, viscoelastic and elastic materials.
- Many of the textural properties that we perceive when we consume food are related to rheology.



Source: Fischer & Windhab (2011)

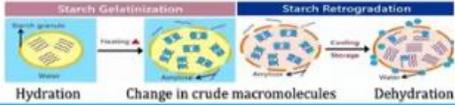
when the materials come under any stress or strain, behave. That is studied in rheology. In rheology, food materials may be characterized as viscous, viscoelastic, or elastic materials. Many of the textural properties that we perceive when we consume food are related to rheology. So, the importance of the rheological properties,

❑ Importance of rheological properties

- ❖ Rheology models summarize the physical responses (rheological parameters) under a certain deformation stress or a flow driving force

These parameters

- Reflect processability of crude, semi-processed or processed food materials.
- Determine physical stability (phase separation rate) of manufactured food products.
- Describe textural properties of food materials and reveal their sensory attributes.
- Predict how the fluid will behave in a process and in determining the energy requirement for transporting the fluid from one point to another in processing plant.

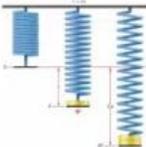


Source: www.youtube.com

summarize the physical response and rheological parameters under a certain deformation stress or a flow-driving force. And these parameters reflect the processability of crude, semi-processed, or processed food materials. Determine the physical stability that is the phase separation rate of the manufactured food products. They describe the textural properties of food materials and reveal their sensory attributes. They predict how the fluid will behave in the process and determine the energy requirement for transporting the fluid from one point to another in a processing plant, like baking process or another process. There may be, when dough is made, etcetera, starch granules and water are put in, then it may swell, there is hydration, and then when it is heated. During the cooking process or during the baking process, there is a change in the macromolecule, etcetera. Finally, in cooling, retrogradation takes place, and dehydration occurs. So, how this material is

responding during all these things and the rheology, in rheological terms, like the dough has a specific rheology. And finally, after that, during cooling, the retrogradation affects the texture, etc, and it may become hard and all those things.

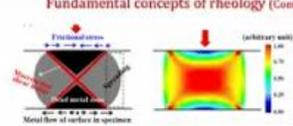
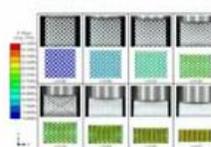
Fundamental concepts of rheology

- Viscosity** is defined as resistance of a fluid to flow. The unit of dynamic viscosity is pascal · second (Pa · s) or poise (g/cm · s). Viscosity varies with temperature and follow inverse relation.
 
- Elasticity** is the property of a material to return to its original shape after the removal of a deforming force. It measures the ability of a material to absorb energy and recover it upon unloading.
 
- Plasticity** refers to the ability of a material to undergo permanent deformation without rupture when a stress is applied and maintained. Unlike elastic materials, plastic materials do not return to their original shape after the stress is removed.
 

willentire-paaz.com
Source: www.britannica.com
(Dyaloge et al., 2023).

So, the fundamental concepts of rheology, this we can understand by discussing viscosity, elasticity, plasticity, etc. Viscosity is defined as the resistance of a fluid to flow. The unit of dynamic viscosity is Pascal second or poise, that is, $g/cm^2 \cdot s$. Viscosity varies with temperature and follows an inverse relationship. And there will be, you can see, there will be low viscous food or high viscous food. Accordingly, it will flow faster or with less speed. Elasticity is just like a spring when you pull it, it expands. So, elasticity is the property of a material when, after removing the force, it returns to its original shape. The original shape after removing a deforming force. It measures the ability of a material to absorb energy and recover it upon unloading. That is a spring, and then it is stretched. when this force is removed, it again comes back. So, it becomes elasticity. Then plasticity is another term to express rheology. Plasticity refers to the ability of a material to undergo permanent deformation without rupture when stress is applied and maintained. Unlike elastic materials, plastic materials do not return to their original shape after the stress is removed. In elastic material, they will again regain their shape, but plastic material may not regain the shape if the force is removed. Another is the force applied per unit area within the materials that arises from externally applied forces, and it is defined as the ratio of force applied to the area over which the force is distributed. The unit of stress is Pascal or Newton per square meter. Strain is the deformation or displacement of the material that results from an applied stress.

Fundamental concepts of rheology (Contd..)

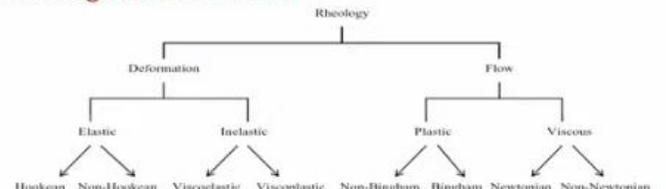
- Stress** is the force applied per unit area within materials that arises from externally applied forces. It is defined as the ratio of force applied to area over which the force is distributed. Its unit is Pa or Nm^{-2} .
 
- Strain** is the deformation or displacement of material that results from an applied stress. It is a dimensionless measure that represents the relative change in shape or size of a body in response to an external force.
 
- Shear** is the deformation forces applied on the material by two parallel posing surface rotating in opposite direction (**Shear-stress : force, shear-strain : deformation**).
 

Hwang, (2023)
Source: Bai et al., (2020)
wikilante-paar.com

It is a dimensionless measure that represents the relative change in shape or size of the body in response to an external force. Shear is the deformation force applied on a material by two forces, parallel opposing surfaces rotating in opposite directions. That is, shear stress is the force; shear strain is the deformation, etc.

Then the rheological classification of the food. If you see food rheology, there can be two types: one is the deformation in the rheology; the other may be flow. On the deformation side, the food can be elastic or inelastic. Elastic is Hookean or non-Hookean. Inelastic may be viscoelastic or viscoplastic. On the basis of their flow, there may be plastic material or viscous material. The plastic may be non-Newtonian plastic or Newtonian plastic.

Rheological classification



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graph TD
    Rheology --> Deformation
    Rheology --> Flow
    Deformation --> Elastic
    Deformation --> Inelastic
    Elastic --> Hookean
    Elastic --> Non-Hookean
    Inelastic --> Viscoelastic
    Inelastic --> Viscoplastic
    Flow --> Plastic
    Flow --> Viscous
    Plastic --> Non-Bingham
    Plastic --> Bingham
    Viscous --> Newtonian
    Viscous --> Non-Newtonian
      
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- Hookean solids and Newtonian fluids have a linear relationship between applied torque and subsequent. In other words, they have constant viscosity regardless of applied torque.
- Most foods display viscoelastic behavior. They store energy through their elastic component and dissipate energy through their viscous component.

Source: Sahin, & Sumnu, (2006)

Viscous means Newtonian fluid or non-Newtonian fluid. So, their rheological classifications of the food can be categorized into all these types of foods. Hookean solids and Newtonian fluids have a linear relationship between applied torque and subsequently. In other words, they have constant viscosity regardless of the applied torque. Most foods

display viscoelastic behaviour. They store energy through their elastic component and dissipate energy through their viscous component.

Viscous fluids

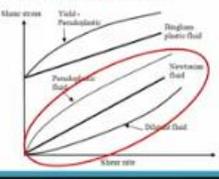
- Viscous fluids tend to deform continuously under the effect of an applied stress. They can be categorized as Newtonian or non-Newtonian fluids.

Newtonian fluids

- Fluids that follow Newton's law of viscosity are called Newtonian fluids. The slope of the shear stress vs shear rate graph, which is viscosity, is constant and independent of shear rate in Newtonian fluids.

Non-newtonian

- Fluids that do not follow Newton's law of viscosity are known as non-Newtonian fluids.
- Shear thinning or shear thickening fluids obey the power law model (Ostwald-de Waele equation).
- The slope of shear stress versus shear rate graph is not constant for non-Newtonian fluids as for different shear rates, different viscosities are observed.



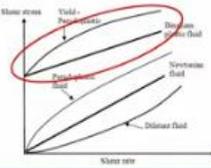
Source: Nguyen & Choi (2012)

Viscous fluids tend to deform continuously under the effect of an applied force, and they can be characterized as Newtonian fluids or non-Newtonian fluids. So, Newtonian fluids are those that follow Newton's law of viscosity. The slope of the shear stress versus shear rate graph, which is viscosity, is constant and independent of the shear rate in Newtonian fluids. You can see it will be, in the case of Newtonian fluids, constant and independent of the shear rate. Whereas non-Newtonian fluids are those which do not follow Newton's law of viscosity, Newton's law of viscosity. Shear thinning or shear thickening fluids obey the power law model, the Ostwald-de Waele equation. The slope of the shear stress versus shear rate graph is not constant here; you can see non-Newtonian fluids. The slope of the shear stress versus shear rate graph is not constant for non-Newtonian fluids. As for the different shear rates, different viscosities may be observed. Then, the plastic fluids may be Bingham plastic fluids or non-Bingham plastic fluids.

Bingham plastic fluids are the type of fluids that remain rigid when the magnitude of shear stress is smaller than the yield stress, as you can see in this graph. But they flow like a Newtonian fluid when the shear stress exceeds the yield stress. Mayonnaise, tomato paste, ketchup, etc. are examples of Bingham plastic fluids in food systems.

Plastic fluids

- ❖ **Bingham plastic fluids**
 - In these types of fluids, the fluid remains rigid when the magnitude of shear stress is smaller than the yield stress (τ_0) but flows like a Newtonian fluid when the shear stress exceeds τ_0 .
 - In food systems, mayonnaise, tomato paste, and ketchup are examples of this type of fluid.
- ❖ **Non-Bingham plastic fluids**
 - In these types of fluids, a minimum shear stress known as yield stress must be exceeded before flow begins, as in the case of Bingham plastic fluids.
 - However, the graph of shear stress versus shear rate is not linear. They are either shear thinning or shear thickening with yield stress.
 - Rice flour-based batter and molten milk chocolate are examples of the non-Bingham plastic fluids.



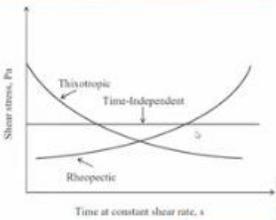

Source: Nguyen & Choi (2012)

Non-Bingham plastic foods, in this type of food, a minimum shear stress is known as yield stress, and it must be exceeded before flow begins, as in the case of Bingham plastic foods. However, the graph of shear stress versus shear rate, as you can see here in this figure, is not linear. They are either shear thinning or shear thickening with yield stress. Rice flour-based batter, and molten milk chocolates are examples of non-Bingham plastic fluids.

Then, time-dependent fluids, as you can see here in this graph, show shear stress and time at a constant shear rate. That is, when some fluids are subjected to a constant shear rate, they become thinner or thicker with time for which shear is applied. As force is removed, these fluids may retain their original shape, meaning there may be reformation, but they do not follow the same path of deformation; that is, the path of reformation may be different from that of the deformation.

Time dependent fluids

- When some fluids are subjected to a constant shear rate, they become thinner or thicker with time for which shear is applied.
- As force is removed, these fluids may retain its original shape (reformation) but do not follow the same path of deformation.
- Fluids that exhibit decreasing shear stress and apparent viscosity with respect to time at a fixed shear rate are called thixotropic fluids (shear thinning with time).
Gelatin, egg white, and shortening are examples of this type of fluid.
- In rheopectic fluids (shear thickening with time), shear stress and apparent viscosity increase with time, that is, the structure builds up as shearing continues.
This type of fluid behavior is rarely observed in food systems.




Source: Sahin, & Sumnu, (2006)

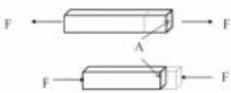
Fluids that exhibit decreasing shear stress and apparent viscosity with respect to time at a fixed shear rate are called thixotropic fluids, that is, shear thinning with time. Gelatin, egg white, and shortenings are examples of this type of fluid. In rheopectic fluids, that is, shear

thickening with time. Shear stress and apparent viscosity increase with time, and that is the structure buildup as shearing continues and this type of behavior is rarely observed in the food system structure.

Then let us talk about the deformation of material. When stress is defined as force per unit area, it is generally expressed in Pascal, that is N/m^2 , and stress can be categorized into two groups: normal stress and shear stress.

Deformation of material

Stress is defined as force per unit area. It is generally expressed in Pa (N/m^2). Stress can be categorized into two groups: **Normal stress & Shear stress.**



Normal stress (σ) is defined as the force applied perpendicular to the plane per unit area.



Source: Sahin, & Sumnu, (2006)

You can see here in this figure, all right. That is the tensile normal stress; it is given in the material, and compressive normal stress is also given. That is, the normal stress is defined as the force applied perpendicular to the plane of the unit area, whereas the shear stress is defined as the force applied parallel to the plane per unit area. You can see here in this figure, they can be explained. Then, the deformation of a material can be understood in terms of strain, normal strain, shear strain, etc.

Deformation of material

- Strain** is the unit change in size or shape of a material referred to its original size or shape when a force is applied.

$$\text{Strain} = \frac{\text{Extension}}{\text{Original Length}}$$

Strain, like stress, can be categorized into two groups: **Normal strain & Shear strain**

- Normal strain (ϵ)** is the change in length per unit length in the direction of the applied normal stress.

$$\epsilon = \frac{\Delta L}{L}$$

- Shear strain (γ)** is defined as the change in the angle formed between two planes that are orthogonal prior to deformation as a result of the application of stress.

$$\gamma = \tan \theta = \frac{d}{t}$$


Source: Sahin, & Sumnu, (2006)

Strain is the unit change in size or shape of a material referred to as its original size or shape when a force is applied; strain is the extension divided by the original length. Strain,

like stress, can be categorized into two groups: it may be normal strain or shear strain. Normal strain is the change in length per unit length in the direction of the applied normal stress, that is, this *normal strain* = $\frac{\Delta L}{L}$.

Then, shear strain is defined as the change in the angle formed between two planes that were orthogonal prior to deformation as a result of the application of a stress and this shear strain can be expressed as $\tan \theta = \frac{d}{t}$.

Then, elastic materials are Hookean solids. When a stress is applied to a solid, it will deform. It will deform fine lightly, but then reform to its original position after the stress is removed, and these types of foods are known as elastic foods. Materials showing elastic behaviour are known as Hookean solids.

Elastic material - Hookean solid

- When a stress is applied to a solid, it will deform finitely but then reform to its original position after the stress is removed are known as elastic solids.
- Materials showing elastic behavior are known as a Hookean solid. A Hookean solid stores all the energy necessary to deform as a potential energy, which is fully recoverable.
- The ratio of stress to strain is known as **modulus** while the ratio of strain to stress is known as **compliance**.
- Young's modulus** or Modulus of elasticity (E) is defined as the ratio of normal stress (σ) to normal tensile or compressive strain (ϵ).
- Shear modulus** or modulus of rigidity (G) is used to describe the relationship between the shear stress and shear strain.
- If the force is applied from all directions which results in a volume change, modulus is called **bulk modulus** (K).

Source: <https://ajlscientific.com>

A Hookean solid stores all the energy necessary to deform as potential energy, which is fully recoverable. The ratio of stress to strain is known as modulus, while the ratio of strain to stress is known as compliance. Young's modulus, or modulus of elasticity E, is defined as the ratio of normal stress to normal tensile or compressive strain. And here, you can see that is Young's modulus, that is here. This is $E = \frac{F/W^2}{\Delta L/L}$

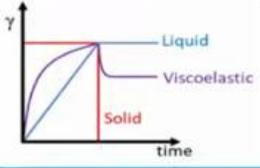
So, that is how you can find out Young's modulus. Shear modulus, or modulus of rigidity, is used to describe the relationship between shear stress and shear strain. That is, the shear modulus, that is, $\mu = \frac{F/WL}{\tan \theta} = \frac{F/WL}{\Delta L/L}$,

where W is the width, L is the length, and F is the force applied. So, by the application of force, what is the ΔL ? Then, if the force is applied from all directions, as you can see in this figure, it results in a volume change, and that modulus is called bulk modulus K. $K = \frac{F}{\Delta V/V}$.

So, you can find out using these equations: Young's modulus, shear modulus, or bulk modulus. Then, let us discuss viscoelastic material. Viscous fluids generally exhibit viscosity, while solids exhibit elasticity. Some foods show both viscous and elastic properties, which are known as viscoelastic material, that is, viscous and elastic both. These materials display time-dependent behavior.

□ Viscoelastic material

- Viscous fluids generally exhibit viscosity while solids exhibit elasticity.
- Some foods show both viscous and elastic properties which are known as viscoelastic materials.
- These materials display time-dependent behavior; they may initially deform quickly under stress and then gradually return to their original form once the stress is removed.
- Dairy cream, ice cream mix, marshmallow cream, cheese, and most gelled products are also viscoelastic foods.



- When the flow of viscoelastic material is stopped, tensile forces in the fluid cause particles to move back, called the recoil phenomenon.
- If a viscoelastic fluid is stirred by a rotating rod it tends to climb the rod, which is known as the Weissenberg effect.

They may initially deform quickly under stress and then gradually return to their original form once the stress is removed. Dairy cream, ice cream mix, marshmallow cream, cheese, and most gelled products are examples of viscoelastic foods. When, as you can see here, it is a liquid, then the viscoelastic material comes like this solid material when shear stress is applied. That is when the flow of viscoelastic material is stopped.

Tensile force in the fluid causes particles to move back, and it is called the recoil phenomenon. If a viscoelastic fluid is stirred by a rotating rod, it tends to climb the rod, which is known as the Weissenberg effect. There are various ways by which we can measure the rheological properties of food materials. And here, one of the main drivers behind rheological testing of food is to determine their flow behavior, what their flow behavior and viscoelastic profiles are, and one is the rotation test.

Measurement of rheological properties

One of the main drivers behind rheological testing of foods is to determine their flow behaviors and viscoelastic profiles.

Rotational test

- Rotational tests are often used for plotting flow (viscosity) curves as a function of shear rate or shear stress; thus, these tests are applicable to both fluid and semisolid foods.
- Controlled strain modes measures the correspondent shear stresses at different preset shear rates, and used for characterizing flow behavior of materials without a yield point.
- Controlled stress mode measures shear at different preset shear stresses and is used for determining yield point (yield stress) for gelled semisolid foods.
- In both modes, the viscosities (η , Pa.s) are calculated using the equation

$$\eta = \frac{\tau}{\dot{\gamma}}$$

Where,
 τ = Shear stress (N/m²)
 $\dot{\gamma}$ = Shear rate (1/s)



Rotation tests are often used for plotting flow curves, such as viscosity curves, as a function of shear rate or shear stress, and thus, these tests are applied both to fluids as well as semi-solid fluids. The controlled strain modulus measures the corresponding shear stresses at different preset shear rates and is used to characterize the flow behavior of materials without a yield point. The controlled stress mode measures shear at different preset shear stresses

and is used to determine the yield point or yield stress for gelled semi-solid foods. In both modes, the viscosity, which is in Pascal per second (η), is calculated using the equation: $\eta = \tau / \dot{\gamma}$, where τ is the shear stress and $\dot{\gamma}$ is the shear rate. That is, viscosity is shear stress (Newton per meter squared) divided by shear rate (one per second). So, by this, you can find out the viscosity. Then there is an oscillatory test.

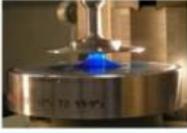
Oscillatory tests are used to measure the viscoelastic and deformation behavior of materials. Viscoelastic moduli, including the storage modulus G' (Pascal), the loss modulus G'' (Pascal), or the complex modulus G^* (Pascal). You can see here that G' , G'' , and G^* , give the viscoelastic behavior that can be calculated from the stress-strain data, which you can plot and then find out the material behavior. The storage modulus is an indication of the amount of energy stored in each cycle.

While the loss modulus is an indication of the energy dissipated in each cycle. Storage modulus represents elastic behavior, and loss modulus represents viscous behavior. This phase angle describes the extent of elastic to viscous behavior. It is usually reported as the tangent of the phase angle, that is, $\tan \delta$, which is the phase angle. So, the tangent of this elastic dominant material has a $\tan \delta$ less than 1,

whereas viscous dominant material has a tan delta more than 1. All moduli and phase angle values should be determined within the reversible elastic deformation range, also called the linear elastic range or LVR. Then, amplitude sweeps are another way by which rheological material can be found. Amplitude sweep tests apply a controlled oscillatory strain

Amplitude sweeps

- Amplitude sweep tests apply a controlled oscillatory strain or stress to a material and measure the resulting response.
- The main objective is to determine the material's linear viscoelastic region (LVR), where the material behaves elastically, and to identify the critical strain or stress at which the material starts to deform irreversibly.
- They may be conducted in **strain (a gradual increase in strain amplitude)** or **stress (a gradual increase in stress amplitude)** controlled mode and are typically conducted at moderate frequencies (0.1–10 rad s⁻¹).



- The material sample is placed between two plates of a rheometer, which precisely controls and measures the applied strain or stress, recording the response as **storage modulus (G')**, **loss modulus (G'')**, and **phase angle (δ)**.

Source: www.wse-sch.de

or stress to a material and measure the resulting response. The main objective is to determine the material's linear viscoelastic region where the material behaves elastically. To identify the critical strain or stress at which the material starts to deform irreversibly. They may be considered in strain, that is, a gradual increase in strain amplitude or stress, a gradual increase in stress amplitude and control mode and are typically conducted at moderate frequency, that is, minus 0.1 to 10 radians per second.

The material sample is placed between two plates, as you can see here. A rheometer precisely controls and measures the applied strain or stress and, therefore, records the response as storage modulus, loss modulus, and phase angle. The frequency shifts. Frequency shift tests involve applying an oscillatory frequency ramp to a sample.

While keeping the strain and temperature constant. This test measures how the material's viscoelastic properties change with different frequencies of deformation. The primary goal is to evaluate the material's behavior at different time scales. Providing insights into the internal structure and stability. The material sample is placed between two plates of a rheometer.

Frequency sweeps

- Frequency sweep test involves applying an oscillating frequency ramp to a sample while keeping the strain and temperature constant.
- This test measures how the material's viscoelastic properties change with different frequencies of deformation.
- The primary goal is to evaluate the material's behavior at different time scales, providing insights into its internal structure and stability.
- The material sample is placed between two plates of a rheometer. The rheometer applies a constant strain while varying the frequency of oscillation, all at a fixed temperature.
- The rheometer records the storage modulus (G'), loss modulus (G''), and phase angle (δ) at each frequency.
- These parameters help characterize the elastic and viscous behavior of the material over different time scale.

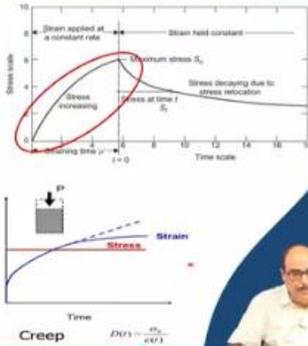


The rheometer applies a constant strain. While varying the frequency of oscillation at a fixed temperature. The rheometer records the storage modulus, loss modulus, and phase angle at each frequency. These parameters help characterize the elastic and viscous behavior of the material over different time scales. Then, the creep relaxation test.

A creep test measures the slow continuous deformation. That is, the creep of a material under a constant load or stress over an extended period. It is used to evaluate the material's ability to withstand long-term stress. And to predict its behavior, that is, you see stress is increasing here. So, coming to that is, standing time, the time scale and this size stress scale.

Creep-relaxation test

- A creep test measures the slow, continuous deformation (creep) of a material under a constant load or stress over an extended period.
- It is used to evaluate a material's ability to withstand long-term stress and to predict its behavior.
- Creep testing reveals three distinct stages of deformation: primary (decreasing creep rate), secondary (steady-state creep), and tertiary (accelerating creep leading to material failure).
- Materials are tested for creep to ensure their reliability in long-term applications, especially in packaging materials and some food material.



Creep $D(t) = \frac{\epsilon(t)}{\sigma_0}$

Source: Joyner, (2019)

Then, creep testing reveals three distinct stages of deformation. That is, the primary, that is, decreasing creep test. Then, secondary, steady-state creep test, and tertiary. That is, accelerating creep, leading to finally material failure. the materials are tested for creep to ensure their reliability in long-term applications.

Especially in packaging materials, other types of food materials, etc. So, you can see here strain stress and creep $D t$ is equal to 0 divided by $T e t$, you can find out this creep. Then, the stress relaxation test. The stress relaxation test you can see here. It measures how a material, after being subjected to a constant strain, that deformation decreases

Stress-relaxation test

- The stress-relaxation test measures how a material, after being subjected to a constant strain (deformation), decreases its stress over time as the material adjusts to the applied strain.
- Biological tissue undergoes breakdown in response to stress with increasing strain.
- Stress-relaxation tests are widely used in industries such as food, and packaging, to evaluate time-dependent properties.
- The results from the stress-relaxation test help in designing materials that need to maintain shape or structure under prolonged loads.
- It can also provide insights into the durability and long-term performance of materials.

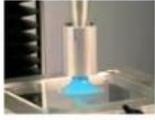
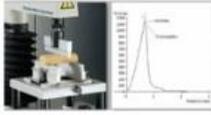
Source: Joyner, (2019)

its stress over time as the material adjusts to the applied strain. Biological tissues undergo breakdown in response to stress while increasing strain. Stress relaxation tests are widely used in industries such as food and packaging to evaluate time-dependent properties. The results from the stress relaxation test help in designing materials

that need to maintain shape or structure under prolonged loads. It can also provide insight into the duration, durability, and long-term performance of the materials, and the $relaxation = \frac{\sigma(t)}{E_0}$. So, that can be used to find out either the creep or relaxation. Then we talk about the textural properties of the food material that the texture of the is a physical and chemical interaction in the mouth and can be directly correlated to the food rheology. The texture of food is closely related to its physical structure and mechanical properties and it directly affects the acceptability of the food to the consumer. So, the importance of the food texture is That explains a food's structural characteristics.

It explains the changes in physical properties of food during processing. and cooking processes, during manufacturing and cooking processes. It improves food quality and unique characteristics and explores the relationship between sensory analysis and instrumental measurements. So, important textural properties are adhesiveness, hardness, cohesiveness, springiness, chewiness, gumminess.

❑ Important textural properties

- ❖ **Adhesiveness**
Force required to remove the material that adhere to a specific surface (e.g. lips, palate, teeth). 
- ❖ **Hardness**
Force required to deform the product to given distance, i.e. force to compress between molars, bite through with incisors, compress between tongue and palate. 
- ❖ **Cohesiveness**
Degree to which the sample deforms before rupturing when biting with molars.  

Source: www.stablenmicrosystems.com

So, adhesiveness means the force required to remove the material that adheres to a specific surface, like a palate, teeth, or lips, etc, when we eat the food and put it in the mouth tube. So, it adheres. So, the force required to remove it is known as adhesiveness. Then, hardness is measured by a texture analyzer, etc. You can see in this graph, the force required to deform the product to a given distance, that is, the force to compress between molars or bite through with incisors, compressors are between the tongue and the plate that is put, that is how much, even suppose you are eating a food. So, with the teeth, etc, they are working on it and breaking it. So, how much force, and this similar limitation in texture measurement, we can apply the force and see how much force is required to break that material, which is called hardness. Then, cohesiveness is the degree to which the sample deforms before rupturing when biting with molars. That is before it completely ruptures, how it deforms, that is known as cohesiveness. The material is very cohesive; that is how it behaves. Then, springiness. Springiness is the degree to which the product returns to its original size or shape after partial compression. That is without failure between the tongue and the plate of the teeth. That is springiness. That is the degree to which the product returns to its original size and shape.

Then, chewiness. Chewiness is the number of chews. That is at one chew per second. It is needed to masticate the sample to a consistency suitable for swallowing. And similarly, the gumminess. The energy required to disintegrate a semi-solid food to a state ready for swallowing. So, these are the different characteristics: textural profile, textural characteristics of the food. So, for the characterization of the texture, obviously, there are various methods used. Food texture can be evaluated by sensory methods or by instrumental methods. Instrumental methods are less expensive and less time-consuming as compared to sensory methods. So, in the compression method or snapping bending method, in the compression method, there is a compression or deformation test

❑ Texture characterization

- Food texture can be evaluated by sensory or instrumental methods.
- Instrumental methods are less expensive and less time consuming as compared to sensory methods.

❖ Compression

- Compression (deformation) test measures the **distance** that a food is **compressed under a standard compression force** or the **force required to compress a food a standard distance**.
- According to the AACC method, bread firmness can be determined by using compression principle.

❖ Snapping-bending

- This test measures the **force** required to **bend or snap brittle foods** such as biscuits or crackers.
- The three-point bending test is the most commonly used snapping-bending test.
- The upper part of test piece is compressed and the lower part is elongated during bending.



measuring the distance that a food is compressed under a standard compression force or the force required to compress a food a standard distance. According to the AACC method, bread firmness can be determined by using compression principles. Then, snapping bending: This test measures the force required to bend or snap brittle foods such as biscuits, crackers, and so on. The three-point bending test is the most commonly used snapping bending test.

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The upper part of the test piece is compressed, and the lower part is elongated during bending. Cutting shear. A Kramer shear is used to determine the texture of fruits and vegetables. Shear blades are forced through the material until they pass through the bars at the bottom of the sample. The force on the ram holding the blades is measured over time and correlated to the firmness of the product. Then, the puncture test measures the force required to push

❖ **Cutting shear**

- The Kramer shear is used to determine the texture of fruits and vegetables.
- Shear blades are forced through the material until they pass through the bars in the bottom of the sample container.
- Force on the ram holding the blades is measured over time and correlated to the firmness of the product.

❖ **Puncture**

- Puncture test measures the force required to push the probe into the food and expressed as firmness or hardness of the product.
- Puncture force is proportional to both area and perimeter of the probe and compression and shear properties of food.
- The relationship is shown by Bourne (1966) as $F = K_c A + K_s P + C$

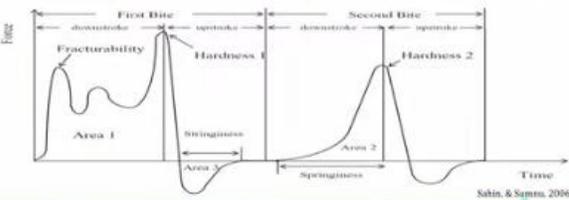
Where, F is the puncture force, K_c is the compression coefficient of food, K_s is the shear coefficient of food, A is the probe area, P is the probe perimeter, and C is a constant.



the probe into the food, and it is expressed as the firmness or hardness of the product. Puncture force is proportional to both the area and perimeter of the probe and the compression and shear properties of the food. So, the relationship between this is shown by 1996, that is $F = K_c A + K_s P + C$, where F is the puncture force, K_c is the compression coefficient of the food, K_s is the shear coefficient of the food, A is the probe area, P is the probe perimeter, and C is a constant. Then, a texture profile analysis, TPA, compresses a bite-sized piece of food, usually one cubic centimeter, twice to simulate the chewing action of the teeth inside the TPA instrument. Since the instrument compresses the sample twice,

Texture profile analysis

- Texture profile analysis (TPA) **compresses a bite-sized piece of food** (usually 1 cm cube) **twice to simulate the chewing action** of the teeth.
- **Since the instrument compresses the sample twice, two positive and two negative curves are obtained.**
- **Peak forces and areas under the curves** are used to determine various textural properties of food.



Sahin, & Sumnu, 2006



two positive and two negative curves are obtained, as you can see here. The peak force and areas under the curves are used to determine the various textural properties of the food. You can see here in this figure, this is the first bite, and this is the second bite. In both the first bite, downstroke and upstroke, as well as in the second bite and then it goes like this, and there are different areas that are area 1, area 2, area 3, then it gives structural ability, it is hardness, this is the springiness area 3, this is the springiness area 2, then hardness 2, time, strength. So, these are various, like, for example, you can see structural ability. That

is brittleness, which is defined as the force at the first significant break in the first positive area.

Texture profile analysis (Contd...)

- **Fracturability (brittleness)** is defined as the force at the first significant break in the first positive bite area.
- **Hardness** is defined as the peak force during the first compression cycle.
- **Cohesiveness** is the ratio of the second positive bite area to the first positive bite area.
- **Adhesiveness** is the negative force area for the first bite representing the work required to pull the plunger away from the food.
- **Springiness (elasticity)** is defined as the height to which the food recovers during the time that elapses between the end of the first bite and start of the second bite.
- **Gumminess** is the product of hardness and cohesiveness. In sensory terms, it is the energy required to disintegrate a semisolid food so that it is ready for swallowing.
- **Chewiness** is the product of gumminess and springiness. In sensory terms, it is known as the energy required for chewing a solid food until it is ready for swallowing.

That is the fracturability. Hardness is defined as the peak force during the first compression cycle. Cohesiveness is the ratio of the second positive bite area to the first positive bite area. Adhesiveness is the negative force. Area for the first bite representing the force required to pull the plunger away from the same food.

Springiness, that is elasticity, is defined as the height. springiness that is the height to which the food recovers during the time that elapses between the end of the first bite and the start of the second bite. Gumminess is the product of hardness and cohesiveness. In sensory terms, it is the energy required to disintegrate a semi-solid food that is ready for swallowing, and chewiness is the product of gumminess and springiness. In sensory terms, it is known as the energy required for chewing a solid food until it is ready for swallowing. So, these are the different What is how the using texture while analysis TPA analysis you can measure this; there are various structural properties.

So, now, I will summarize this lecture: Rheology is the science of flow and deformation of matter and the food materials. They may be, in rheological terms, characterized as viscous, viscoelastic, and elastic materials. And most of the food displays viscoelastic behaviors, and the texture of the food in its physical and chemical interaction in the mouth can be directly correlated to the food rheology. Texture profile analysis compresses a bite-sized piece of food twice to simulate

Summary

- Rheology is the science of flow and deformation of matter
- In rheological terms, food materials may be characterized as viscous, viscoelastic and elastic materials.
- Most foods display viscoelastic behavior. They store energy through their elastic component and dissipate energy through their viscous component.
- Texture of the food is its physical and chemical interaction in the mouth and can directly correlate to food rheology.
- Texture profile analysis (TPA) compresses a bite-sized piece of food twice to simulate the chewing action of the teeth.



the chewing action of the teeth, and from this TPA analysis, we determine different properties of the food. Food textural analysis of the textural characteristics of the food that is, how it behaves inside the mouth or what is the force required to tear it, swallow it, and what is its adhesiveness, gumminess, chewiness.

So, these are the references for this lecture.

Then finally, thank you very much for your patient hearing. Thank you.