Analysis of Chocolate Using Tribo-Rheometry and its Correlation to Mouth-Feel

Keywords: tribology, tribo-rheometry, chocolate, mouth-feel, structure-rheology relationship

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ABSTRACT

Many resources in the food science industry are directed at understanding properties of food products such as texture and mouthfeel before, during, and after the consumption of food and beverages. These properties play a large role in consumer selection and acceptability, directly impacting the success of new formulations. Unfortunately, many of these sensory properties are difficult to characterize. Numerous studies have been shown to correlate some properties, such as firmness, fattiness, and creaminess with bulk rheological properties and recently, studies have begun to focus on thin-film tribological properties and their correlation to mouth-feel properties.

INTRODUCTION

Tribology is defined as the study of friction, wear, and lubrication between two interacting surfaces in relative motion. Oral processing, or the progression of food and beverage consumption within the mouth, includes a myriad of "interacting surfaces in relative motion". Within the mouth alone, these surface interactions include: teeth-teeth, tongue-teeth, tongue-palate, tongue-food, and many more. As such, it is believed that the science of oral processing is heavily related to tribology.

Naturally occurring and processed foods are structurally ordered from the nanoscale to the macroscopic scale. Each phase contributes to the overall perceived texture and mouthfeel during consumption, which directly correlates with consumer acceptability. The food industry has been pushed to truly understand the role each structure plays in texture and mouthfeel.

Rheology testing focuses on a fixed gap, whereas tribology testing focuses on a fixed load and the thin-film characteristics between two surfaces in contact with one another. Rheologically characterizing food products is only half of the story and tribological testing should be considered to paint a better picture of the consumption process in the mouth when food or beverages are devoured. Tribology complements rheology, providing information on solid-solid interactions that adds insight to the bulk fluid measurements of rheology. Tribology is especially concerned with quantifying the coefficient of friction as a function of sliding speed and load force, under dry or lubricated conditions. Tribology can be used to analyze friction properties of substrates within the mouth and food surfaces and then further correlated with consumer perception and mouthfeel.

EXPERIMENTAL

Commercially available white chocolate, milk chocolate, and 100% cocoa chocolate formulations, were used in this study. All testing was performed using a combined motor and transducer rheometer. Viscosity and yield stress testing was carried out using a 40 mm, 2 degree cone and plate geometry. Steady state flow measurements were performed at a temperature of 37°C. The coefficient of friction was measured using the tribo-rheometry accessory configured with the ball on three plates geometry. Surfaces consisted of a stainless steel sphere and stainless steel plates covered with Transpore™ tape, which was used to mimic a textured surface, such as the tongue.

The chocolate was melted externally using a heated water bath before loading onto the rheometer. The coefficient of friction was measured using standard flow sweep tests at sliding speeds up to 50 mm/s under a 3 N load force at 37°C.

RESULTS AND DISCUSSION

Yield Stress and Viscosity

Steady state flow measurements of all three chocolate samples were performed to analyze the viscosity behavior as a function of shear rate, shown in Figure 1. The white chocolate sample was shown to have a higher viscosity than all other samples, while the 100% cocoa chocolate sample showed the lowest viscosity at shear rates between 1 and 10 1/s. Yield stress and infinite rate viscosity values were measured by fitting all viscosity profiles with the Casson model. The Casson model is mathematically represented by equation 1 where σ represents the shear stress, σ_y represents the yield stress, k represents the fitting parameter known as consistency, and $\dot{\gamma}$ represents the shear rate. This model has been used to accurately model the behavior of molten chocolate.

$$\sqrt{\sigma} = \sqrt{\sigma_y} + \sqrt{k\dot{\gamma}} \qquad (1)$$

The infinite rate viscosity and yield stress values for all three samples can be found in Table 1.

Table 1. Casson model fitting results for three chocolate samples.

	Yield Stress (Pa)	Infinite Rate Viscosity (Pa.s)
White Chocolate	27.3	3.9
Semi-sweet Chocolate	15.9	3.1
100% Cacao Chocolate	3.4	3.4

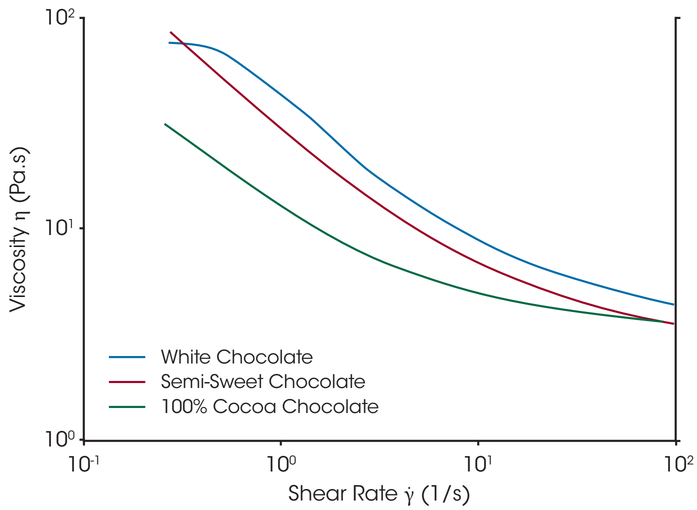

Figure 1. Viscosity profiles as a function of shear rate for white chocolate, semi-sweet chocolate, and 100% cocoa chocolate.

Despite the difference in formulation, all three samples exhibit similar infinite rate viscosity values. Infinite rate viscosity would most closely describe fluid behavior related to the process of swallowing. However, sensory panels described the mouthfeel to be different for all three samples. In this respect, another approach other than bulk rheology may provide further insight and quantitative results.

Coefficient of Friction: Effect of Cocoa Content

The coefficient of friction was measured using the tribo-rheometry accessory and ball on three plates configuration. Approximately 1 mL of sample was deposited onto the three plates. The upper ball and three plates were brought into contact and a load force of 3 N was applied. The sliding speed between the two surfaces was increased while the coefficient of friction was measured in the presence of individual chocolate samples, shown in Figure 2. Despite all samples having similar infinite rate viscosities, the coefficient of friction is shown to be drastically different. The white chocolate sample is shown to have a higher coefficient of friction than all other samples up to a sliding speed of 50 mm/s. A greater coefficient of friction may be attributed to elevated fat content and higher concentration of emulsifiers in white chocolate compared to the other products. The information gained by comparing the coefficient of friction for all three samples can be used to cross-reference with existing sensory panel information, and provide internal benchmarking information.

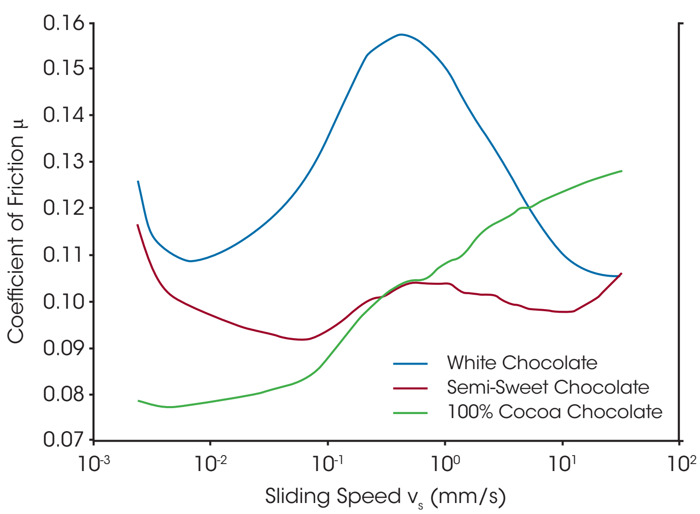

Figure 2. The coefficient of friction as a function of sliding speed was measured for three chocolate samples using the ball on three plates tribo-rheometry accessory configuration.

CONCLUSIONS

The tribo-rheometry accessory can be utilized to measure the coefficient of friction as a function of sliding speed. Information gained through tribology testing can be used to complement the bulk fluid behavior gained through typical rheological testing. This concept has been demonstrated using white, semi-sweet, and 100% cocoa chocolate samples. Rheological measurements indicated all samples had similar infinite shear viscosities. However, greater differences in samples were exemplified using the tribo-rheometry accessory. Quantification of the coefficient of friction could be correlated with mouthfeel properties and sensory perception.

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