How the Particle Size of Cocoa Masses Influences their Mouthfeel: Tribological Measurements

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Introduction

Tribology is the study of friction, wear, and lubrication in systems with interacting surfaces in motion. It is of great interest in food science, where it is used to understand the relationship between food structure and sensory perception.

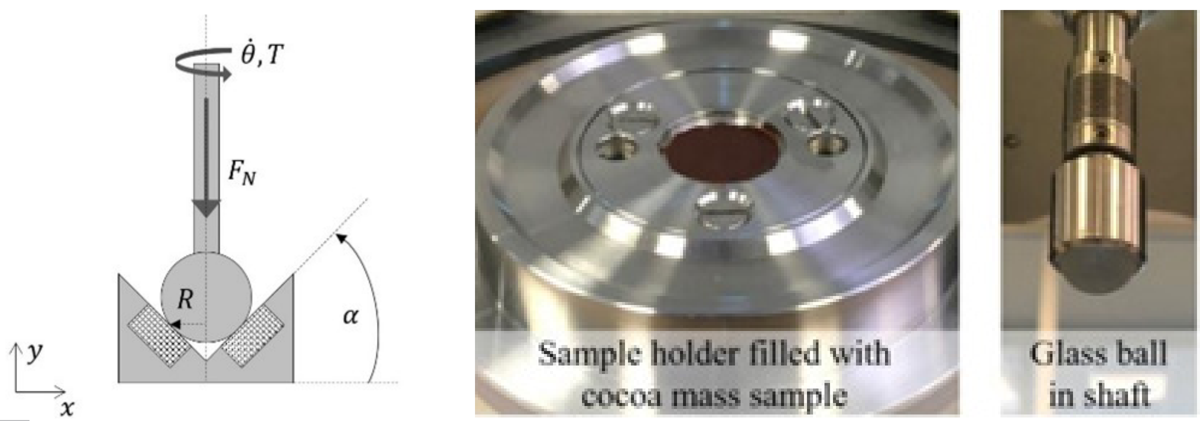
A tribological measurement is representative of the processes involved during food intake, mastication and swallowing, and thus gives insight into the mouthfeel [1]. It uses a tribosystem, such as the tongue/palate pair lubricated by food-saliva mixtures during oral processing [2]. In the following, the influence of the particle size in cocoa masses on their behavior in soft, low-pressure tribological context is investigated. More information about this application is found in [3].

Materials and Tests Conditions

Three samples were prepared from the same batch of cocoa mass to ensure the same composition. Each sample was ground on a horizontal ball mill (NETZSCH Grinding & Dispersing).

The D90 volume equivalent diameter of each sample was determined with a Mastersizer 3000 laser diffraction particle size instrument (Malvern Panalytical). The three prepared samples differed in their particle size distribution (D90): 33 µm for the coarse cocoa mass sample, 26 µm for the medium cocoa mass sample and 20 µm for the fine cocoa mass sample.

Tribological measurements were performed with a Kinexus Prime ultra+ rotational rheometer equipped with a Peltier-plate cartridge with active hood and a ball-on-three-pins tribology cell (NETZSCH Analyzing & Testing). The upper measuring geometry included a borosilicate glass ball measuring 12.7 mm in diameter, and SIL 30 silicone urethane elastomer pins (Carbon Inc.) were used as lower specimens representing the soft oral tongue-palate tribo-pair. The ball is pressed against the pins and the distance between the rotational axis and the ball-pin contact is *R*. The pins are inclined at 45° relative to the horizontal. The shaft rotates with a defined angular velocity that corresponds to the respective sliding speed at the tribo-contact (see figure 1 on the left). The torque required for this rotational movement is recorded during the tribological measurement.



1 Schematic of the measuring geometry and the tribosystem (left), sample holder with cocoa mass sample (middle), and upper geometry with glass ball (right)

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The measurements were performed at 40°C with a normal force of 1 N. The measurement program is detailed in table 1 (see also [1]).

Independently of the tribological testing, shear-viscosity curves were also performed on the three samples. They are not presented here, but can be seen in [1]. They show that at higher shear rates (> 3 s^{-1}), the shear viscosity is highest for the coarse cocoa mass sample and lowest for the fine cocoa mass.

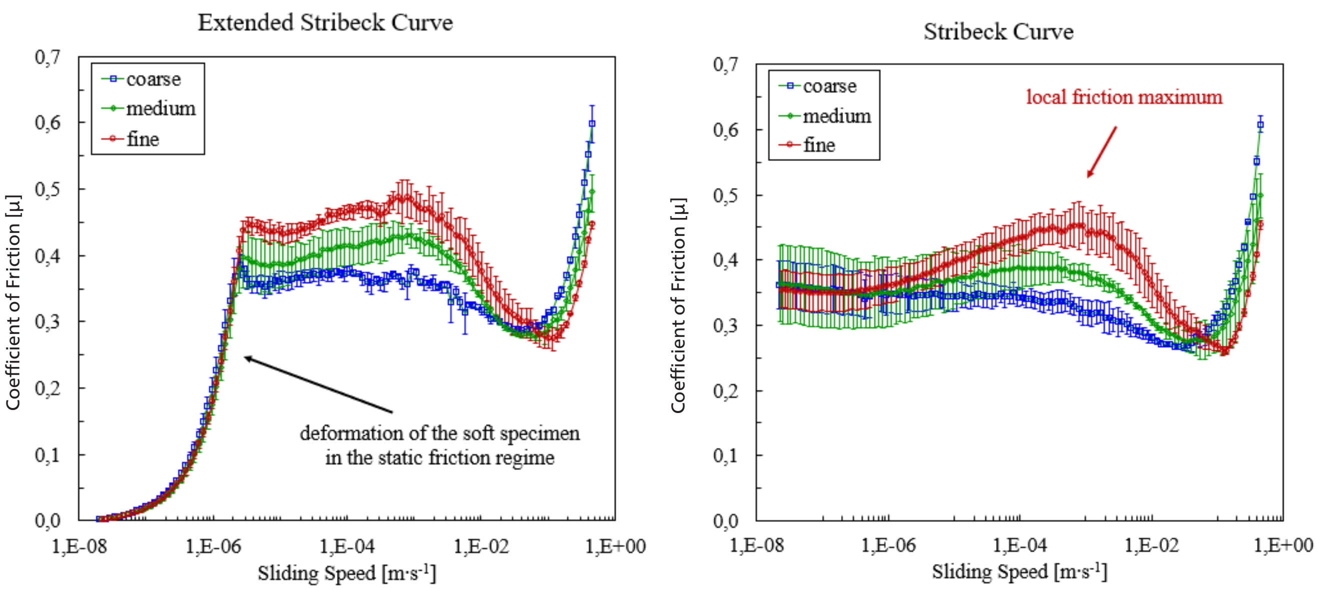
Results and Discussion

Figure 2 depicts the extended Stribeck curves and the Stribeck curves resulting from the tribological measurements on the coarse, medium and fine cocoa masses.

The increase in friction observed at the lowest sliding velocities (extended Stribeck curve) can be attributed to the deformation of the soft specimen. The curves of all three samples overlap. This suggests that this phenomenon is independent of the particle size and is instead governed by the intrinsic bulk properties of the soft specimen. A local maximum in friction can be seen for the fine cocoa mass sample in both extended Stribeck (figure 2 left) and Stribeck curves (figure 2 right). A potential reason for this behavior is the sticking of the small particles between the rotating ball and the elastomer, leading to an effective increase in surface roughness and thus in the friction.

Table 1 Parameters of the tribological measurements

	Phase	Angular Viscosity
1	Running -in	15 rad/s (10 min)
2	Holding	Relaxation (5 min)
3	Extended Stribeck curve measurement	5.10^{-6} to 100 rad/s
4	Stribeck curve measurement	100 to 5.10^{-6} rad/s



2 Extended Stribeck curves (left) and Stribeck curves (right) for the coarse, medium and fine cocoa mass samples.

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The fine cocoa mass sample exhibits the highest limiting friction (figure 3), whereas this factor is not significantly different for the coarse and the medium cocoa mass samples. After the limiting friction is exceeded, the friction of the coarse cocoa mass sample is significantly reduced. One possible explanation for this behavior is that the coarse particles are too big to enter the space between the rotating glass ball and elastomer, resulting in lower solid volume fraction of the suspension. Consequently, the friction at the tribo-contact is lower.

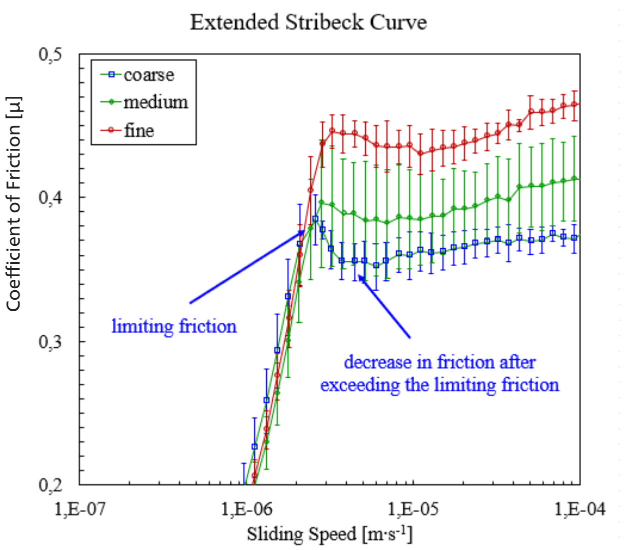
Figure 4 (Stribeck curves in the sliding speed range of the hydrodynamic regime) indicates that friction in the hydrodynamic regime is highest for the coarse cocoa mass sample and lowest for the fine cocoa mass sample. The higher the particle size, the lower the sliding speed at which the transition takes place. This accords to the higher shear viscosity of the coarse sample at higher shear rates (see [1]).

Conclusion

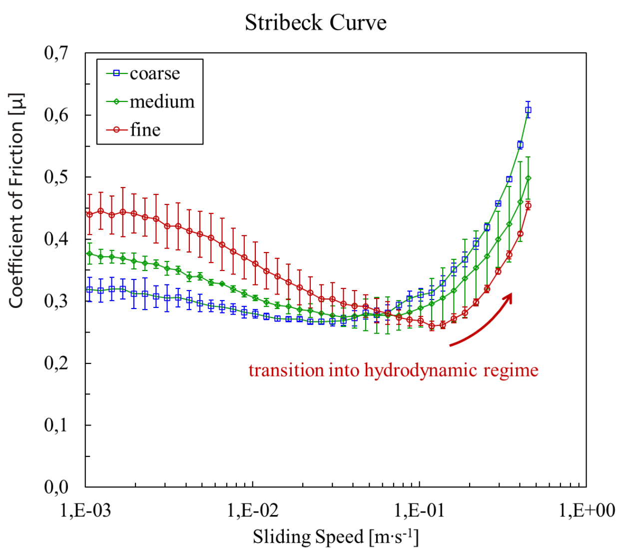
The tribological properties of three cocoa mass samples with different particle size distribution were compared. Differences in the frictional behavior were detected that can be related to different lubricating mechanisms.
Other explanations and suggested mechanisms are described in [1].

Sources

[1] In order Chen J. and Stokes J.R., Rheology and tribology: Two distinctive regimes of food texture sensation, Food Science and Technology, 2012, 25 (1), 4-12. DOI: 10.1016/j.tifs.2011.11.006.
[2] Stokes J.R, Boehm M.W., and Baier S.K., Oral processing, texture and mouthfeel: from rheology to tribology and beyond, Current Opinion in Colloid & Interface Science, 2013, 18 (4), 349-359. DOI: 10.1016/j.cocis.2013.04.010.
[3] ANNUAL TRANSACTIONS OF THE NORDIC RHEOLOGY SOCIETY, VOL. 31, 2023, Tribological Characterization of Cocoa Mass with Different Rheological Properties and Particle Size Distributions, Florian Rummel, Martina Tietz and Shona Marsh.



3 Extended Stribeck curves for sliding speeds between 10^{-7} and 10^{-4} m/s.



4 Stribeck curve showing the transition into hydrodynamic regime.

NGB · Application Note 351 · EN · 0225 · Technical specifications are subject to change.

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