Squeeze Flow of a Newtonian Fluid under Different Test Speeds

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***Abstract*-In this paper, the squeeze flow behavior of Newtonian fluid was investigated with a series of squeeze tack laboratory experiments. The Newtonian fluid was squeezed out radially between two parallel and circular plates. From the flow curves obtained in the squeeze tack experiments, rheological parameters such as yield stress in tension and in squeeze, have been investigated. The results indicate that the values of yield stress in squeeze and in tack of the testing material are relatively small. These values gradually decrease with increasing sample thickness. This shows that the squeezing and tacking process does not affect the testing material, glucose in this case. Although the experimental results are not much, a linear relationship can be found between tensile and squeeze stress of Newton fluid in the experiment. This is especially evident at low test speeds.**

Keywords-squeeze flow technique; glucose; yield stress; Newtonian fluid

I. INTRODUCTION

Newtonian fluid is a viscous liquid, obeying the Newton's law of internal friction, which means that the tangential stress and velocity gradient are linearly dependent on each other. The scale factor between the two is called viscosity. A Newton fluid has a constant viscosity. However, most liquids we know have changes in their viscosity and do not really fit the exact definition. In fact, almost all salts, molten polymer materials, blood, toothpaste, paint, corn starch and many other liquids are non-Newton liquids. The investigation of the behavior of these materials is very important, especially in the state of flow. In construction, to study the rheological properties of construction materials, 1-point measurement method is usually used, which is the method of measuring slump. This method has the limitation of not fully evaluating material characteristics in shear [1, 2]. There should be another method of measuring more characteristics, tracking the variation of those features over time, etc. These methods should be thoroughly investigated, first of all with Newtonian fluids.

Squeeze–tack test has been used for characterizing the squeeze flow of materials between two rigid plates. The test material was firstly squeezed to an initial set-up thickness, then it was relaxed for about 2 minutes and finally it was pulled out at a constant velocity. During the experiment, the total force was measured. Measured squeeze stress is the average value over the sample diameter at the time of calculation. During the squeeze flow experiments, the geometrical properties of two parallel rigid plates strongly affect the squeeze flow. Sliding wall phenomenon would result in a decrease of the viscous force and a profound effect on shear thickening pastes. Surface microchannels can accelerate squeezing flow of a fluid in a thin gap between parallel plates. The squeeze flow experiment of Newtonian fluids is important for understanding the characteristic of the shear thickening materials under shearing and towards more efficient applications. The squeeze-tack test can simultaneously evaluate the properties of a material under compression and tensile stress. At the same time, strong viscoelasticity can be observed during the transition. Similar to the tensile behavior, squeeze behavior should also be an important aspect to comprehend the structure evolution of a material. At the same time, shear viscosity is closely associated with the inner structure evolution. Critical shear rate of the test material strongly increases with the increasing gap in a simple shear flow. To this end, studying the shear viscosity in the squeeze mode will contribute to the understanding of the rheological properties under moving boundary. Therefore, it is necessary to investigate the squeeze flow behavior of Newtonian materials comprehensively.

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In this paper, the properties of a Newtonian material were characterized with the squeeze flow experiment. The test material was placed between two parallel rigid spheres. The typical load vs. displacement profile was determined and was used to obtain the rheological parameters of the testing material, including squeeze and tack stress. The separating velocity's values were 2mm/s, 20mm/s, and 200mm/s. The material thickness was 1mm, 2mm, 3.5mm, and 5mm. The squeeze speed was 20mm/s and 200mm/s.

II. APPARATUS

Squeeze tests have been widely used to determine the flow properties of highly viscous pastes (food, cosmetic, polymers, composites, ceramic pastes and others) [3-5], as it overcomes some of the common problems of conventional rheometry such as slip, disruption of plastic materials and the difficulty to load very thick and fiber-containing fluids in rotational devices [6]. Squeezing technique can characterize cementitious materials by compressing of a cylindrical specimen between two parallel surfaces by controlled force or displacement rate. This method has been previously used by various researchers for characterizing the rheological behavior of cement pastes [4], Herschel Bulkley fluid [6], Bingham plastic [7], etc. The typical load vs. displacement profile of a constant velocity squeeze flow experiment was determined in [8] and is used to obtain the rheological parameters of testing materials, including yield stress and viscosity. Direct measurements of yield stress are uniquely performed by stress-controlled rheometry [9, 10]. Squeeze flow tests carried out with constant displacement velocity do not allow such direct measurements [6, 11] since the material flow occurs regardless of the existence of the material's yield stress, unless the force required to overcome this value exceeds the load limit of the testing device.

In the present work, the testing material is firstly compressed/squeezed between two parallel surfaces until a predefined thickness, followed by a relaxation period of 1.5min, and is finally separated with a predefined tack velocity (Figure 1). A typical curve of squeeze-tack can be seen in Figure 2 in [12], in which three periods can be observed, including compression, relaxation and traction.

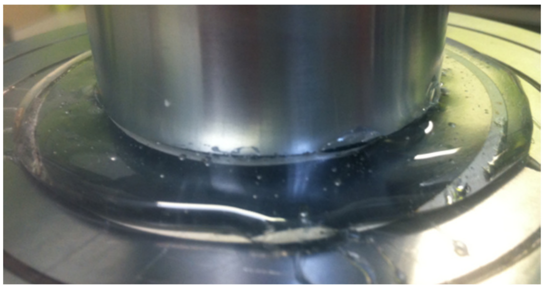

Fig. 1. A squeezing - tack experiment in process.

It is possible to conduct indirect yield stress determination by the extrapolation of the flow curves in the squeeze stage of the experiment. The yield stress is calculated by dividing the maximum force recorded by the area at that time. The formula is as follows:

$$\sigma_s = \frac{F_s^{\max}}{A_s} \quad (1)$$

where A_s is the average area of the testing sample at the moment that the recorded load is max:

$$A_s = \frac{V}{h'} = \frac{\pi R^2 h}{h'} \quad (2)$$

and h is the predefine thickness of the test mortar, R is the radius of the sample and h' is the mortar's thickness at the moment of the maximum squeeze force.

Similar calculations with the yield stress at tensile stage can be performed in order to investigate the variation of the material's resistance in tack measurement.

III. RESULTS AND DISCUSSION

A controlled stress experiment was performed in order to plot the relationship between shear rate and shear stress. The results in Figure 2 indicate that the test material is Newtonian.

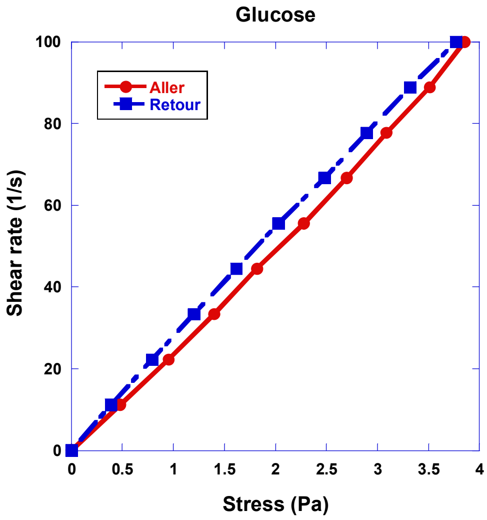

Fig. 2. Flow curves of the experimental results determine that the testing material is Newtonian.

The recorded squeeze forces obtained in the squeeze step are shown in Figure 3. Each subfigure corresponds to a different initial material thickness (1mm, 2mm, 3.5mm, and 5mm). During the squeeze phase, the test material was squeezed to the previous set-up thickness and the normal forces were recorded as a function of displacement/time. The squeeze stress was then calculated. From the obtained graphs, it is possible to evaluate the role of the sample thickness to the rheological properties of the material by displaying the force relational graphs over time on the same general chart. From each of the graphs in Figure 3, the maximum tensile force value, corresponding to the yield tensile stress, will be calculated using (1).

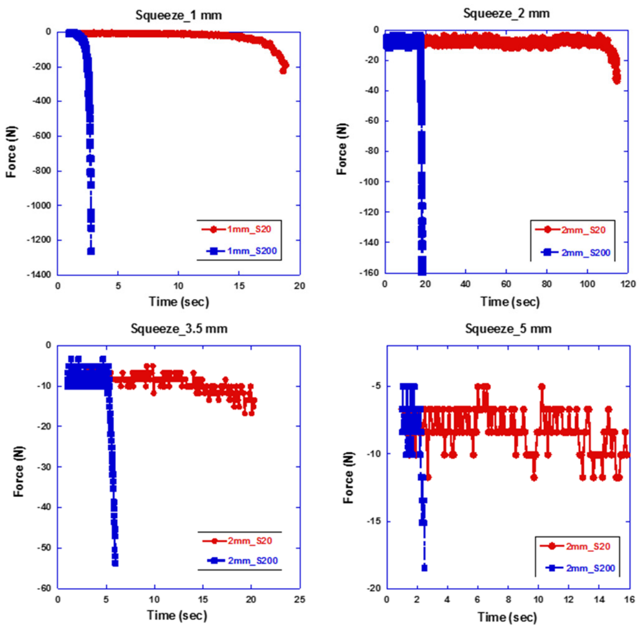

Fig. 3. The squeeze force obtained in the squeeze experiments.

Figure 4 represents the evolution of tack forces versus time obtained when *h*=1mm and *h*=3.5mm. The indicator S corresponds to the squeeze speed and T to the tack speed, so S20 T20 means that the squeeze speed is 20mm/s and the tack speed is 20mm/s, etc.

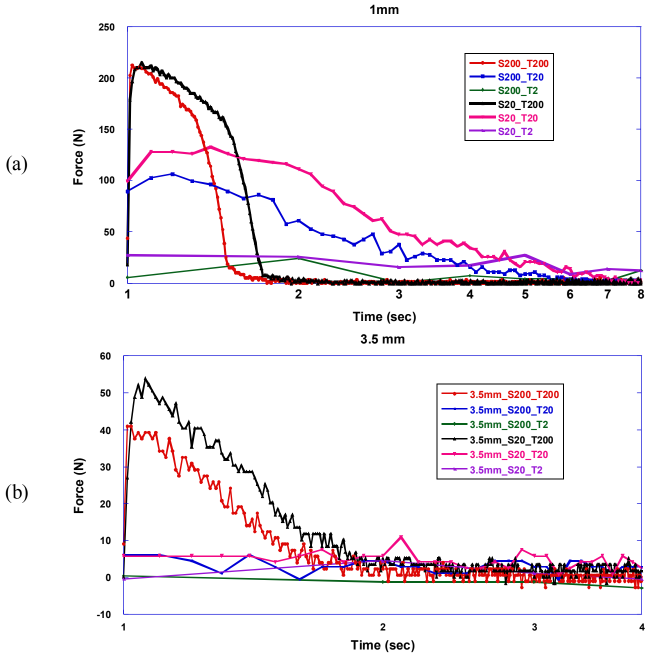

Fig. 4. Flow curves obtained in the squeeze experiments.

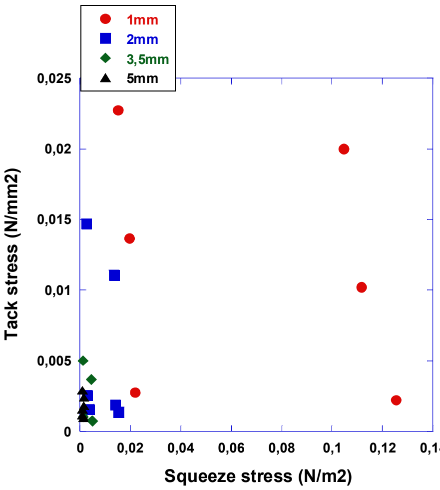

Fig. 5. The relations between tack stress and squeeze stress.

As can be easily seen in Figure 4, the greater the drag speed, the greater the drag force. For example, with a 1mm sample thickness, the top two curves are obtained when pulling is conducted at a speed of 200mm/s, followed by two curves obtained when pulling is conducted at 20mm/s and finally at 2mm/s. The greater the drag speed, the faster the drag force reaches its maximum and the curve obtained after crossing the maximum point will become steeper. From these curves it is possible to determine many rheological characteristic values of materials such as yield stress, viscosity, etc. However, in the current research, only the stress of test materials in squeeze step and those in tack are investigated. Figure 5 represents the relationship between tack stress and squeeze stress of glucose. It is possible to see distinct areas on the graph, corresponding to the different material thickness values. The more the sample thickness increases, the more this area is closer to the origin. This shows that at a large thickness of the specimen, the yield stresses when pulled and when pressed are very small. When the specimen thickness is smaller (i.e. 1mm and 2mm), in order to squeeze the specimen to a given thickness or to pull the specimen, a much larger force is required to overcome the drag. This result can be explained by the arrangement of material particles when pulled or pressed at low speed.

When considering the relationship between the two types of stresses when fixing pressing speed (Figure 5), at the same tensile speed, the relationship between compressive stress and tensile stress is linear when the tensile speed is low. In contrast, when the tensile speed is large (200mm/s), the slope of the straight line changes, decreasing gradually as the sample thickness is reduced.

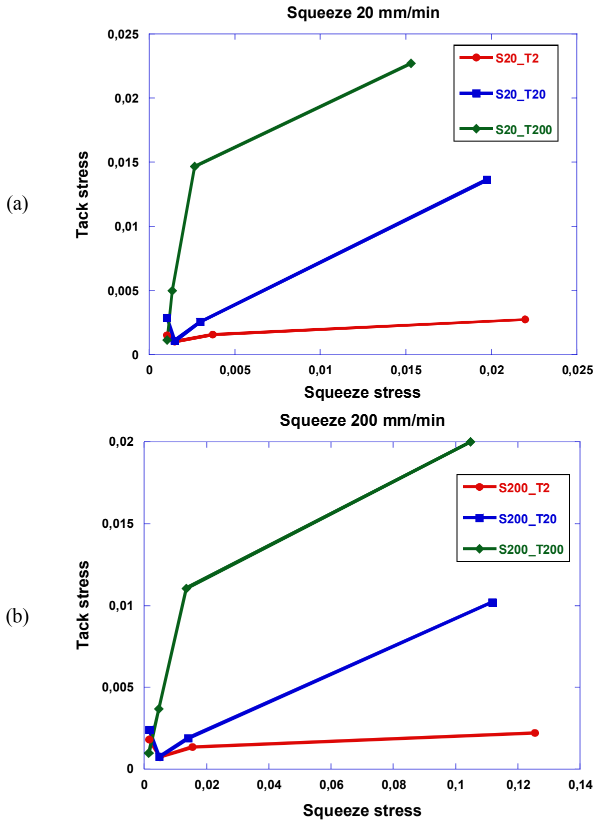

Fig. 6. Tack stress versus squeeze stress at different squeeze speeds.

IV. CONCLUSIONS

The squeeze flow is a simple and effective method for the rheological characterization of materials in a wide range of consistencies, providing important information regarding the rheological behavior of materials in practical applications. From the flow curves obtained in the squeeze tack experiments, the rheological parameters, including yield stress in tension and in squeeze, have been investigated. The results indicate that the yield stresses of the testing material are relatively small. These values gradually decrease with increasing sample thickness. This shows that the squeezing and tacking process does not affect the testing material, in this case glucose.

Although the experimental results are far from been characterized as complete, a linear relationship can be found between the tensile and the compressive stress of a Newton fluid in the experiment.This is especially evident at low test speeds.

REFERENCES

[1] P. Banfill, "Use of the ViscoCorder to study the rheology of fresh mortar," *Magazine of Concrete Research - MAG CONCR RES*, vol. 42, no. 153, pp. 213–221, Jan. 1990, doi: 10.1680/macr.1990.42.153.213.

[2] P. V. Tien, "Influence of re-dispersible powder on the properties of mortars," *Journal of Materials and Engineering Structures*, vol. 1, no. 1, pp. 2–10, 2014.

[3] J. Engmann, C. Servais, and A. S. Burbidge, "Squeeze flow theory and applications to rheometry: A review," *Journal of Non-Newtonian Fluid Mechanics*, vol. 132, no. 1, pp. 1–27, Dec. 2005, doi: 10.1016/j.jnnfm.2005.08.007.

[4] O. Campanella and M. Peleg, "Squeezing Flow Viscosimetry of Peanut Butter," *Journal of Food Science*, vol. 52, no. 1, pp. 180–184, Aug. 2006, doi: 10.1111/j.1365-2621.1987.tb14000.x.

[5] B. H. Min, L. Erwin, and H. M. Jennings, "Rheological behaviour of fresh cement paste as measured by squeeze flow," *Journal of Materials Science*, vol. 29, no. 5, pp. 1374–1381, Mar. 1994, doi: 10.1007/BF00975091.

[6] K. Kardjilova, V. Vozarova, and M. Valah, "Influence of Temperature on Energetic and Rheological Characteristics of PLANTOHYD Bio Lubricants – a Study in the Laboratory," *Engineering, Technology & Applied Science Research*, vol. 3, no. 3, pp. 424–428, Jun. 2013.

[7] J. D. Sherwood and D. Durban, "Squeeze-flow of a Herschel–Bulkley fluid," *Journal of Non-Newtonian Fluid Mechanics*, vol. 77, no. 1, pp. 115–121, May 1998, doi: 10.1016/S0377-0257(97)00099-2.

[8] F. A. Cardoso *et al.*, "Experimental Developments of the Squeeze Flow Test for Mortars," in *Rheology and Processing of Construction Materials*, Cham, 2020, pp. 182–190, doi: 10.1007/978-3-030-22566-7_22.

[9] B. Belahcene, A. Mansri, and A. Benmoussat, "Investigation on the Rheological Behavior of Multigrade Oil under the Effect of Organic and Inorganic Impurities," *Engineering, Technology & Applied Science Research*, vol. 4, no. 6, pp. 711–713, Dec. 2014.

[10] G. H. Meeten, "Yield stress of structured fluids measured by squeeze flow," *Rheologica Acta*, vol. 39, no. 4, pp. 399–408, Aug. 2000, doi: 10.1007/s003970000071.

[11] T. Phan and D. D. Nguyen, "Influence of Squeezing Rate on Yield Stress and Viscosity of Fresh Mortar," *Engineering,* Technology *and Applied Science Research*, vol. 10, no. 4, pp. 5921–5924, Aug. 2020

[12] V. T. Phan, "Evaluation of Some Rheological Properties of Xanthan Gum," *Engineering, Technology and Applied Science Research*, vol. 10, no. 5, pp. 6172-6175, Oct. 2020.