Shear and Elongational Rheology of Gypsum Slurries

Suman Sinha-Ray[1], Raman Srikar[1], C.C. Lee[2], A. Li[2], Alexander L. Yarin[1,3]

[1] Department of Mechanical and Industrial Engineering, University of Illinois at Chicago, 842 West Taylor Street, Chicago, IL 60607-7022, USA
[2] USG Corp., Research & Technology Center, 700 N US Highway 45, Libertyville, IL 60048, USA
[3] Center for Smart Interfaces, Technische Universität Darmstadt, Petersenstrasse 32, 64287 Darmstadt, Germany

*Corresponding author: ayarin@uic.edu
Fax: x1.312.413.0447

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Abstract:
Concentrated gypsum slurries used for wallboard production are studied using shear and elongational rheometers. It is shown that the rheological behavior of different slurry compositions can be sufficiently accurately described in the framework of the Ostwald–de Waele power law, which reproduces both shear and elongational experimemtal data with sufficiently close values of the consistency and flow behavior indexes for each slurry composition studied.

Zusammenfassung:
In dieser Arbeit wurden konzentrierte Gipsschlämme für die Produktion von Wandbauplatten mit Hilfe scher- und dehnrheologischer Messungen untersucht. Es wird gezeigt, dass die rheologischen Eigenschaften für verschiedene Schlammzusammensetzungen ausreichend genau mit Hilfe des Ostwald-Waele Potenzgesetzes beschrieben werden können, das sowohl die experimentellen Daten in Scherung als auch in Dehnung mit ausreichend hoher Präzision für den Konsistenz- und den Fließverhaltensindex für alle Schlammzusammensetzungen erfassen kann.

Résumé:
Des boues concentrées de gypse utilisées pour la production de panneaux muraux ont été étudiées à l'aide de rhéomètres extensionels et rotationnels. Nous démontrons que le comportement rhéologique des différentes compositions de boue peut être suffisamment et précisément décrit dans le cadre du modèle Ostwald-de Waele à loi de puissance, qui reproduit les données expérimentales avec des valeurs suffisamment proches des index de consistance et de comportement d'écoulement pour chaque composition de boue étudiée.

Key words: gypsum slurry, shear rheology, elongational rheology, power-law fluid, flow curve, capillary thread thinning

1 INTRODUCTION

Gypsum is a naturally occurring mineral, which is also referred to as calcium sulfate dihydrate. Gypsum in the form of stucco, when mixed with water at sufficient concentrations, constitutes concentrated slurries. Such slurries represent themselves a key element of gypsum processing in industry to wet-form gypsum products, e. g. wallboards. In addition, gypsum slurries solidify due to rapid hydration of gypsum and evaporation of water. Rheology of gypsum slurries is an uncharted area and is tremendously important for gypsum processing. Generally speaking, gypsum slurries belong to a wide class which can loosely be termed as muddy materials, materials with a complex internal structure or construction materials. Complicated rheological behavior of such materials is currently in focus [1–10].

In the present work the term gypsum is applied to β-hemihydrate form of synthetic gypsum obtained by the desulfurization of flue gases at coal fired power plants. The term stucco used below is understood as a shorter term applied to this form of gypsum, namely, $CaSO_4 \cdot (1/2)H_2O$. Rehydration of stucco in water proceeds according to the following reaction [11]

$$CaSO_4 \cdot (1/2)H_2O + (3/2)H_2O \rightarrow CaSO_4 \cdot 2H_2O + Q \qquad (1)$$

in which β-hemihydrate transforms into dihydrate [$CaSO_4 \cdot 2H_2O$] by binding more water, whereas its molecular weight increases from 145.15 Da to 172.17 Da. The reaction is exothermic with the heat release Q = 111.9 - 173.3 J/g. The Reaction (1) is not only chemical but also structural. In

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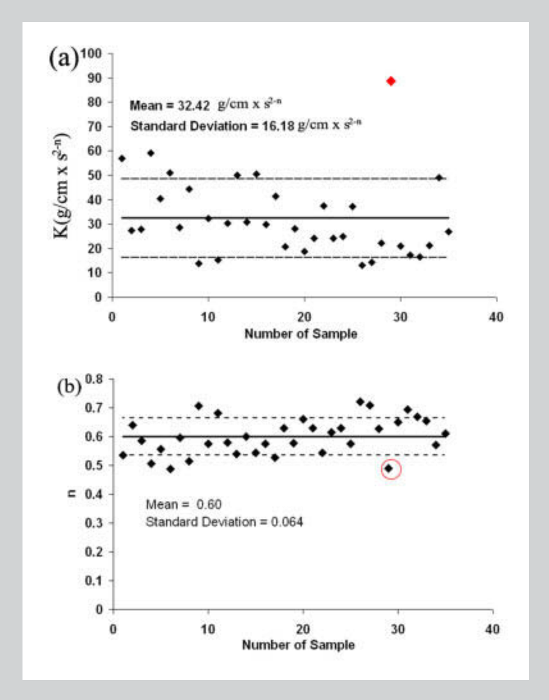

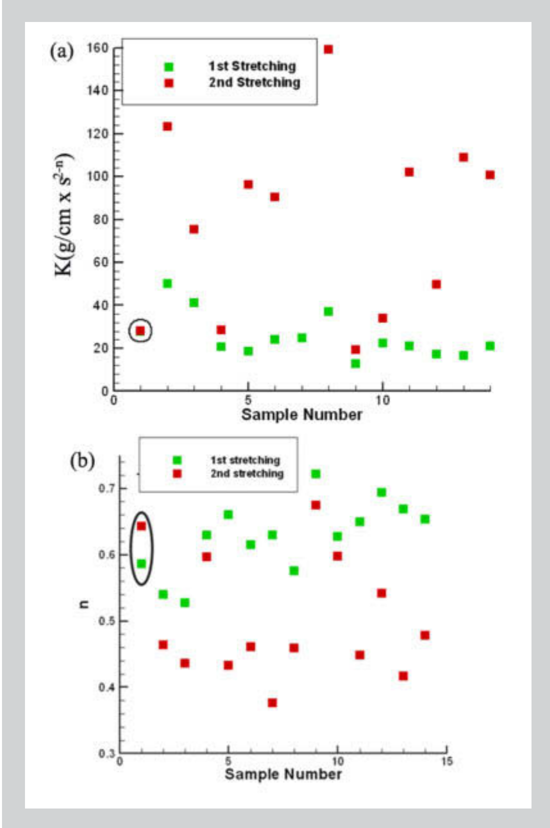

Figure 8 (left): (a) Values of K, and (b) values of n found for all 34 successful experiments on the 1st stretching (slurry 75 WSR-composition 11). The solid lines correspond to the averaged values, the dotted lines to the standard deviations.

Figure 9: (a) Values of K and (b) values of n found in the 14 successful 2nd stretching experiments with the same droplet (the data for the 1st stretching is also shown for comparison, 75 WSR-composition 11). Except one case (the encircled data points) the value of n decreased and the value of K increased in the 2nd stretching compared to the first one.

ments were found for the 3rd stretching of the same droplet.

One of the 34 successful experiments on the 1st stretching is shown in Figure 7. The theory, Equation 8 was fitted to the experimental data using the least square method and the corresponding values of the rheological parameters are shown in Figure 8. Using the measured value of the surface tension of slurry (110.81 mN/m), the value of the consistency index K is found out to be 48.07 g/cms^{2-n}, while n = 0.57. Values of K and n for the other successful experiments of this series are combined in Figure 8. The average values of n and K are $n = 0.6 \pm 0.064$ and $K = 32.42 \pm 16.18$ g/cms^{2-n}. The large standard deviation in the value of K can be attributed to variability in slurry mixing and non-uniformity of slurries, which are ultimately related to irregular shapes and sizes of the stucco particles (Figure 1), as well as some inevitable variation in size of the initial droplets used in the elongational tests. In Figure 8a the red point corresponds to the value of K, to which corresponds the encircled value of n in Figure 8b. For this data point, the 1st stretching of slurry droplet was done in 60 s. after the moment when water was added to stucco at the stage of slurry preparation, whereas for all the other data points-only in 52 – 55 s. This was done on purpose, to evaluate the effect of slurry setting on the results. The comparison of the red data point with the other data points shows that slurry setting results in increasing the consistency index K and decreasing the value of n- both trends in the direction of a more pronounced pseudoplasticity. When the values of the rheological parameters n and K presented in Figure 8 (n = 0.6 ± 0.064 and K = 32.42 ± 16.18 g/cms^{2-n} for elongation of 75 WSR-composition 11) are compared to the values obtained in shear experiments (Table 2: n = 0.55 and K = 51.61 g/cms^{2-n} for shear of 75 WSR-composition 11), it can be seen that the values of n are rather close, whereas there is a difference in the values of K. This might be due to an inaccuracy in the value of the surface tension coefficient used to process the data of the elongational experiments.

The rheological parameter values evaluated from the 14 successful 2nd stretching experiments are plotted in Figure 9. The data in Figure 9 show a clear tendency of the value of n to decrease and the value of K to increase for the 2nd stretching of the same droplet compared to the 1st one. This shows a clear tendency toward the enhancement of pseudoplasticity of slurry due to water evaporation and hydration chemical reactions, similarly to the finding related to different delay times in the 1st stretching experiment discussed before.

4 CONCLUSIONS

Using the shear and elongational viscometry, it is shown that concentrated gypsum slurries can be roughly characterized as materials following the tensorial Ostwald–de Waele (power law) constitutive equation. The other known examples of materials which follow the tensorial power law constitutive equation in both shear and elongation with roughly the same values of the rheological parameters (the consistency index K and flow behavior index n) also include suspensions of needle-like γ-Fe_2O_3 particles in oil and gelled propellant simulants [13, 18]. However, the fami-

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ly of such materials is not wide. Indeed, the power law model is frequently used to fit the shear data but very rarely efforts are directed to simultaneous elongational testing, which in many cases would disprove applicability of the tensorial model, as for example, in the case of polymer solutions and melts. In the present work the tensorial power-law rheological behavior was established for gypsum slurries with different water content and compositions. In particular, the values of the rheological parameters *n* and *K* found in elongation of slurry with water-to-stucco ratio of 75 (composition 11) were: $n = 0.6 \pm 0.064$ and $K = 32.42 \pm 16.18$ g/cm s^{2-n}, whereas for shear of the same slurry it was found that $n = 0.55$ and $K = 51.61$ g/cms^{2-n}, which is sufficiently close.

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