Extension of Spread-Slump Formulae for Yield Stress Evaluation

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Abstract:
This paper provides a new model to evaluate the yield stress of suspensions, slurries or pastes, based on the release of a finite volume of material onto a horizontal surface. Considering the height (h) and the radius (R) of the sample at the flow stoppage, two asymptotic regimes, where h > R or h < R, lead to different analytical models that allow the determination of yield stress. Experimental observations show typical sample shape at stoppage between slump (h > R) and spread (h < R). Based on these observations, we have developed a new analytical model to evaluate accurately the yield stress of materials in this intermediate regime. The validity of this model was evaluated from data obtained using various Carbopol® dispersions. The yield stress measured with the proposed model was compared with the yield stress evaluated from shear flow curves obtained with roughened plate/plate geometry fitted to the Herschel-Bulkley model. Results show the relevance of the proposed model which that can be applied in the range between models used for the two asymptotic regimes.

Zusammenfassung:
Diese Veröffentlichung stellt ein neues Modell zur Bestimmung der Fließgrenze von Suspensionen, Schlämmen und Pasten aus Daten der Ausbreitungsmessungen vor. Basierend auf der Höhe h und Radius R der Probe am Ende der Ausbreitungsmessung existieren für zwei asymptotischen Bereiche, h > R und h < R, jeweils analytische Lösungen zur Berechnung der Fließgrenze. Experimentelle Beobachtungen zeigen zwei typische Haufenformen zwischen Ausbreitung (h < R) und teilweise kollabiertem Zylinder (h > R). Basierend aus diesen Beobachtungen ist ein neues analytisches Modell für den Übergangsbereich entwickelt worden. Die Validierung des Modells wurde mit verschiedenen Carbopol® Suspensionen durchgeführt. Die so ermittelte Fließgrenze wurde dann mit der aus Fließkurven gemessenen und ans Herschel-Bulkley Modell angepassten Fließgrenze verglichen. Die Ergebnisse zeigen, dass das vorgeschlagene Model gut für den Übergangsbereich zwischen den beiden asymptotischen Bereichen verwendet werden kann.

Résumé:
Cet article présente un nouveau modèle d’évaluation du seuil de mise en écoulement pour des fluides complexes tel que des suspensions, pâtes ou coulis. Nous proposons d’évaluer le seuil par un essai d’écoulement libre du matériau sur une surface plane. Actuellement, deux principaux régimes d’écoulement amenant à deux solutions distinctes sont considérés en prenant en compte la hauteur h et le rayon R du matériau à l’arrêt (h > R ou h < R). Nous avons observé un régime intermédiaire d’écoulement, entre le régime d’affaissement (slump), caractérisée par h > R et le régime d’étalement (spread) où h < R. De ce fait, nous proposons un modèle analytique conduisant à une solution unique pour évaluer le seuil de mise en écoulement. Le modèle est validé en comparant les résultats obtenus sur différents gels de Carbopol®. Les seuils évalués par étalement sont comparés aux seuils de mise en écoulement évalués en adaptant le modèle d’Herschel-Bulkley sur les courbes d’écoulement obtenus avec un rhéomètre équipé d’une géométrie plan-plan rugueuse. Les résultats du modèle sont très pertinents, assurant une continuité de l’interprétation entre les deux régimes asymptotiques.

Key words: yield stress, slump test, intermediate regime, spread flow, rheology

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$$b=\left[\frac{8\pi}{15}(R-R_o)^{\frac{5}{2}}+\frac{4\pi}{3}R_o(R-R_o)^{\frac{3}{2}}+\pi R_o^2(R-R_o)^{\frac{1}{2}}\right]\sqrt{\frac{2}{\rho g}} \tag{28}$$

$$c=-V_o \tag{29}$$

4.5 MODEL VALIDATION

As shown in Figure 7 and mentioned above, the yield stress values of the suspensions vary between 5 and 100 Pa depending on the water content of the Carbopol® suspension. These values are compared with the yield stress values obtained from the spreading measurement and calculated with Equation (26), as set out in Figure 7. For comparison purpose, the solution of the asymptotic spread regime (Equation 17) and slump regime (Equation 10) are also reported in Figure 7.

In the yield stress range of 18 to 100 Pa, we observe a lower prediction of the yield stress with our model, which provided a better correlation with the values of yield stress evaluated from the shear flow data. Therefore, in the regime between slump and spread, the proposed model, which takes into account the original shape at the end of the flow, ensures a precise prediction of the yield stress. Below yield stress values of 18 Pa, the material is mainly in spread regime and the hat's height is low. Consequently, Roussel's model [8] (Equation 17) is well adapted to predicting yield stress. For yield stress value close to 100 Pa, it is noted that our model yields a value close to the solution of Equation 10, which corresponds to the elongational regime [8]. Above 100 Pa, the release of the suspensions tends towards a slump flow. It is worth noting that a change of mould geometry can affect the limits of the yield stress range linked to intermediate flow currently obtained.

5 CONCLUSION

It has been noted that a yield stress material flowing on a horizontal plane surface is not necessarily characteristic of a spread regime ($R > h$) or a slump regime ($R < h$) and can lead to an intermediate flow range between these two asymptotic regimes. Consequently, a new analytical model was developed to allow the determination of yield stress in this intermediate regime. The validity of the proposed model was assessed using Carbopol® dispersions. For the mould geometry used and in the yield stress range 20 to 100 Pa, the developed model for an intermediate flow leads to a reliable prediction of yield stress when compared to shear flow data.

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