EVALUATION OF TECHNIQUES FOR MEASURING THE YIELD STRESS OF A MAGNETORHEOLOGICAL FLUID

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ABSTRACT:
The yield stress of a magnetorheological fluid was measured as a function of magnetic flux density using different techniques. The yield stress values were determined by extrapolating the experimental shear stress-shear rate data to zero shear rate with the help of Bingham and Herschel-Bulkley models, and by using stress ramp and dynamic oscillatory tests. To obtain the rheological data, the rotational rheometer equipped with a magnetic field generator and a plate-and-plate measuring geometry was used. The different methods produced yield stress values which were in reasonable agreement with each other.

ZUSAMMENFASSUNG:
Die Fließgrenze einer magnetorheologischen Flüssigkeit wurde als Funktion der magnetischen Flussdichte mittels verschiedener Techniken gemessen. Die Werte der Fließgrenze wurden aus einer Extrapolation der experimentellen Schubspannungs- und Scherratendaten auf den Nullpunkt der Scherrate bestimmt. Für die Extrapolation wurden die Modelle nach Bingham und Herschley-Bulkley angewendet. Weiterhin wurden Messungen mit einer Spannungsrampe und dynamisch oszillatorische Tests durchgeführt. Um die rheologischen Daten messen zu können, wurde ein Rotationsrheometer mit einem Magnetfeldgenerator und einem Platte-Platte-Messsystem eingesetzt. Die unterschiedlichen Methoden liefern Werte für die Fließgrenze, die untereinander vergleichbar sind.

RÉSUMÉ:
La contrainte seuil d'un fluide magnétorhéologique a été mesurée en fonction de la densité de flux magnétique en utilisant différentes techniques. Les valeurs de contrainte seuil ont été mesurées en extrapolant les données contrainte de cisaillement-vitesse de cisaillement jusqu'à une vitesse nulle, à l'aide des modèles de Bingham et de Herschel-Bulkley, et en utilisant des rampes de contrainte ainsi que des tests dynamiques en oscillation. Afin d'obtenir les données rhéologiques, on a utilisé le rhéomètre rotationnel équipé d'un générateur de champ magnétique et d'une géométrie plan-plan. Les différentes méthodes produisent des valeurs de contrainte seuil qui sont en harmonie les unes avec les autres.

KEY WORDS: magnetorheological fluid, yield stress, rotational rheometer

1 INTRODUCTION

Magnetorheological (MR) fluids are suspensions of magnetizable particles in a carrier liquid such as mineral, silicone or synthetic oil. When exposed to an external magnetic field these materials show sudden, significant and reversible rheological property changes. Upon the application of a magnetic field the suspended particles interact with each other and aggregate into chain-like structures aligned in the field direction, which gives rise to an increase in the suspension viscosity and the appearance of a yield stress. The yield stress, which indicates the threshold stress to break down the structure and initiate flow, is one of the key properties of the MR fluid. With increasing magnetic flux density, the yield stress of the fluid increases until the saturation magnetization of the particles is reached. Detailed discussions on the mechanisms, rheology and potential applications of MR fluids are available in recent review articles [1–3].

Although the existence of a true yield stress in fluids has been questioned [4, 5], it is generally recognized that a variety of fluids exhibit a limiting stress below which appreciable flow does not occur. A number of techniques have been

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other through the whole flux density range. The values obtained by the dynamic oscillatory testing are at the same level with others at low flux densities, but become higher when the flux density increases. It is worth noting that the stress ramp test gave the lowest values of all, which is in accordance with the results of Ulicny et al. [17].

All measurements were made for at least two samples to get some information about the reliability and reproducibility of the measurements. In general, it turned out that the scatter associated with the measurements decreases with increasing magnetic flux density regardless of the test method. It is evident, however, that no definite judgments can be made on the merits of different techniques studied here. Yet, particularly at higher magnetic flux densities the extrapolation of the steady flow curve appears to be a rather straightforward and reliable way to determine the yield stress of the MR fluid. At low magnetic flux densities the scatter with this method is quite large (more than ± 10 %), but decreases clearly with increasing magnetic flux density. The stress ramp technique, on the other hand, exhibits the lowest scatter (less than ± 5%), but the yield stress results tend to be dependent on the ramp rate at least within the experimental parameter range used here. A similar drawback is encountered with the dynamic oscillatory testing, that is, the yield stress values attained are frequency dependent. The scatter with this type of experiment was between ± 5 - 15 % depending on the applied magnetic flux density.

In the present work, the interpretation of the rheological data was based on the assumption that the no-slip condition prevails at the fluid-plate interfaces of the rheometer. It is, however, well known that slip may occur particularly for complex fluids like suspensions and emulsions. It is possible to detect the presence of slip with the plate-and-plate measuring geometry by varying the gap between the plates. If slip occurs, the measured shear stress at a fixed nominal shear rate appears to decrease with decreasing gap. To examine this matter, a couple of steady shearing experiments were also conducted with gaps less than 1 mm. A point worth noting here is that for a given coil current the magnetic flux density within the sample increases with decreasing gap, as demonstrated by Mazlan et al. [31]. Thus, in order to allow for a meaningful evaluation of slip the input current needs to be adjusted to give a comparable flux density for each gap. Within the experimental uncertainty, the data measured with different gaps coincided with each other implying the absence of slip.

4 CONCLUSIONS

The characterization of the field-dependent yield stress is essential for the development of MR fluid technology. Using the rotational rheometer with a magnetic field generator and a plate-and-plate configuration, we compared a variety of techniques for determining the yield stress of a commercial MR fluid as a function of magnetic flux density. The yield stress values were determined using steady shear, stress ramp and dynamic oscillatory measurements. Comparison of the results showed relatively good agreement between the methods.

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