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Direct Comparison between Rotational and Extrusion Rheometers

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The use of cone and plate rotational rheology to characterize the flow properties of concentrated dispersion and extrusion methods to determine the rheological properties of pastes have become established rheometric techniques. Direct comparison between the results obtained from the two techniques has not previously been demonstrated. In this article the results of such a comparison using established experimental methods and associated analysis are reported. It is found that for most samples investigated the difference in the calculated values of shear stress at a shear rate of 5/s is ≤10%. Data for a series of slurries, composed of various solid fractions of lime waste, are reported over a shear rate of 0-10/s. The computed results for two techniques are shown to be, within the experimental error, identical over this shear rate range.

Keywords: *rheology, extrusion, flow, stresses, mechanical properties*

1. Introduction

Rheology is the science of studying the flow and deformation of materials rooted in the laws of elasticity and viscosity proposed by Hooke and Newton in the late 17th Century. Flow behavior can be conveniently separated into three components: Shear and extensional flows which are characterized by the corresponding viscosities and Elastic behavior which is characterized by measurement of modulus or swell ratios. Proper characterization of flow behavior is likely to require sophisticated and versatile instrumentation. To fully characterize a material, instrumentation is required which has the capability of extracting these parameters over a range of temperatures and shear/extension rates. Modern laboratory rheological test apparatus can be divided into two broad categories of rotational rheometers and capillary extrusion rheometers.

Extrusion (capillary and orifice) is a well established methodology which is adopted in the processing of relatively soft solids. This technique and the associated analysis were developed for the processing of polymer melts and solutions, but the same principle has been used in ceramics and food processing as well as in the allied industries[1-8]. Extrusion is used in the ceramic industry for the manufacturing of different shapes ranging from very simple geometries such as clay bricks to very complicated articles such as ceramic honey comb matrices used in a car exhaust system to control the exhaust emissions[9]. Extrusion is also used in the metal industry for production of articles such as wires and rods. Various analytical treatments which have been adopted, based upon metal plasticity approaches using extrusion, may be found in the literature[10-12]. These theories have been modified so that they may be applied to ceramic pastes[2, 13]. The main modification is the introduction of a velocity dependent flow stress term into the equation for the computation of the extrusion pressure. The capillary extrusion flow experiment has also been used to measure the boundary slip velocity between the capillary wall and the flowing material[2, 14]. The rheological properties of complex fluids are greatly influenced by the interface between the wall of rigid equipment and the material. The boundary condition has a significant effect upon the experimental results obtained. During shear, the energy is transmitted from the rigid walls of operating equipment to the bulk of material. Knowledge of boundary conditions between the walls and the material is necessary in order to deconvolute the true rheological characteristics of the material under investigation. In addition, during the course of the imposed deformation and flow, the boundary between the material and the wall develops its own characteristics.

A more conventional means of determining the rheology of such materials, although it can not be used for very high volume fraction plastic fluids, is the rotational cone and plate rheometer system. One of the advantages of using these instruments is that the shear rate is nominally independent of the position of the fluid within the shear zone, provided the cone angle is very small (≤5°)[15]. Rotational rheometers are the preferred choice when the requirement is to obtain information concerning the molecular structure and how this affects processing characteristics. In particular, the ability to easily extract information about the average molecular weight and molecular weight distribution via measurement of the viscoelastic properties makes the rotational rheometer a powerful tool. The capillary rheometer extends the shear rate range attainable in the laboratory beyond that available in a rotational instrument and allows the flow properties to be measured under typical processing conditions.

Although the capillary extrusion and the cone and plate rheometers have been extensively used independently, direct comparison of the results provided by these two techniques is rarely undertaken. One of the reasons for this may be due to the fact that the capillary extrusion method is normally used for relatively concentrated suspension/pastes while the cone and plate technique is adopted for relatively less concentrated suspensions. Generally, a given system is not amenable to an evaluation by using of both techniques within similar compositional ranges. The material used in this study is shown to be appropriate for the study by both techniques thus allowing a direct comparison of the results obtained by the both techniques.

The capillary extrusion and cone and plate rheometers have different flow geometries. Despite the different geometries involved in capillary and cone and plate rheometers, a comparison of the data is possible, since the data may, in principle be reduced to similar material response parameters. In both cases certain assumptions

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