RHEOLOGY AND EXTRUSION OF LOW-GRADE PAPER AND SLUDGE

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ABSTRACT

This paper discusses efforts to characterize the rheological properties of pulps that include low-grade wastepapers and papermill sludges to determine their potential for extrusion and conversion into useful products. We investigated apparent changes in viscosity associated with the addition of typical inorganic paper fillers (calcium carbonate, kaolin clay, and titanium dioxide) to "clean" pulps. Addition of calcium carbonate significantly increased apparent pulp viscosity, but clay and titanium dioxide had minimal effects. When high molecular weight sodium carboxymethyl cellulose (CMC) was added to the pulps, fillers had a minimal effect on viscosity. We determined that a non-cleaned recycled magazine pulp (OMG) makes a suitable model sludge for extrusion purposes. Various levels of OMG were added to a variety of clean pulps and the pulps were extruded. As the ratio of OMG in the feed composition increased, the extrusion conditions (screw torque and die pressure) were reduced significantly, as were tensile properties.

INTRODUCTION

Paper and paper products constitute approximately 40% of the municipal solid waste in the United States. In addition to this waste, large quantities of papermill residues are disposed of in public and private landfills. At present, recyclability of this waste material is predicated on successful collection, cleaning, and deinking operations that yield fibers suitable for conventional paper and board manufacture. Recovering fiber from papers with high inorganic filler contents and other non-cellulosic components (e.g., adhesives, polymers, inks) is expensive and is often discouraged by low fiber yields and the inherent difficulties associated with sludge disposal, equipment contamination, and effluent treatment. Although the papermaking industry continues to make great strides in the recycling of wastepaper, the generation of papermill sludge continues to grow, increasing the burden of its disposal. New processes that convert low-grade wastepapers and papermill residues (sludge) directly into useful products are therefore necessary.

At the Forest Products Laboratory, we have developed an ultra-high consistency (20%-40%) pulp extrusion process to convert these materials into solid products. A key to successful extrusion is the addition of water-soluble polymers (WSP) to concentrated pulp suspensions, which markedly alters their rheological properties [1-3]. The WSP quickly hydrate and appear to bind the "free" water to the pulp, dramatically reducing the apparent viscosity of the suspension. When exposed to shear intensive mixing equipment, the suspension will easily deflocculate and disperse into a homogeneous paste. As little as 2% to 3% WSP (based on dry weight fiber) can disperse pulp suspensions with as high as 40% consistency. Reducing the apparent viscosities of ultra-high consistency suspensions would allow them to be processed with conventional extrusion equipment. In this way, engineered fiber composites with continuous complex shapes (millwork) could be produced.

In a recent study [4], we showed that pulp suspensions could be supplemented with a model sludge and processed by an extruder. Additionally, we found that torque rheometry provides a simple, rapid, and reliable test for assessing the ability of various compositions (pulp + WSP + sludge) to be processed by an extruder. Here we discuss our efforts to define the rheological properties of pulp suspensions containing various filler components found in papermill sludges and to determine their potential effects on extrusion processing and extrudate properties. The development of “model” sludges greatly facilitates the evaluation of these residues as potential raw materials for pulp-extruded products.

EXPERIMENTAL

Raw Material Preparation

Several pulps were prepared for rheological and extrusion trials by disintegration in a high consistency pulper (10% to 15%) at 50°C, dewatering in a bladder press to the desired dryness (30% solids), and crumbing in a shredder into marble-sized flocs. The following virgin and waste-based fiber sources were selected to represent a wide range of fiber properties and contaminant levels: bleached hardwood and softwood from drylap market pulp; “clean” newsprint from a stubroll; recycled newsprint (ONP), printed; recycled magazines (OMG); recycled corrugated containers (OCC); wet-strength linerboard; and “clean” copier paper. City water was used in the pulper and no attempt was made to control the pH. Calcium carbonate ($CaCO_3$), kaolin (clay), and titanium dioxide (TiO_2) were added as “fillers” to the pulps to determine their influence on apparent viscosity. A high molecular weight (-700,000) sodium carboxymethyl cellulose (CMC) with a degree of substitution of 0.88 was used as the WSP in these trials.

Several difficulties were encountered in obtaining and characterizing papermaking sludges; i.e., inconsistencies in composition, stream separation (from primary and secondary clarifiers), and the need for confidentiality. Although much useful information was obtained in the process, it was necessary to develop a model sludge that would simulate the typical characteristics of actual sludges. A highly tilled recycled magazine was selected for the model since it contained a significant filler component (-30% ash) and a high percentage of hardwood (short) fibers.

Rheology

A torque rheometer (bowlmixer) was used to characterize the rheological properties of pulp suspensions and compositions [2, 3]. The rheometer contained two non-intermeshing lobed cams that rotated at constant speed (simulating the mixing action of an extruder). A charge of pulp was added, along with other additives, and the torque required to maintain constant rotational speed was recorded. This measure of torque was considered the apparent viscosity of the composition. In these trials, the temperature of the rheometer housing was held at a constant 50°C. Twelve-gram charges (based on oven-dry fiber) were prepared from each pulp and from pulp blends. The CMC and filler were added either initially or after 4 min to determine their effects.

Extrusion

A 32-mm co-rotating twin screw extruder was used for all extrusion trials. This extruder has a flexible screw configuration with intermeshing screw elements that can be assembled into several conveying and kneading sections. A key to the successful extrusion of fiber flocs at ultra-high consistency is the proper assembly of conveying and kneading segments along the length of the extruder. Dispersion occurs in the kneading sections and is aided by high-compression gradients in the conveying segments prior to and after the kneading segments. The WSP (CMC) must be added to the feed composition and quickly hydrated to reduce viscosity of the composition and to aid in its dispersion. If assembled correctly, the pulp extrudate will be a completely homogeneous paste. Screw speed was a constant 200 rpm for all trials. Barrel temperature was held constant over the entire length of the extruder. Torque and exit die pressure were monitored during steady-state operation. A die was attached to the end of the extruder barrel to shape the extrudate. Several dies were designed to induce fiber alignment [4]. A slit die (4- by 105-mm) with moderate orientation (undetermined) was used in these trials. Several batches of pulps were prepared for extrusion by pre-blending them in the desired ratios, then “salting” them with dry powdered CMC. The compositions were then premixed by hand (but not kneaded) and fed into the extruder. One-meter lengths of extrudate were collected and stored for consolidation and testing.

Consolidation and Testing

For each extrusion trial, a length of extrudate was cut into 150-mm segments and press-dried between nested 150-mesh screens in a static press at 140 kPa [5]. When dry, the strips were conditioned in a controlled test environment (23°C, 50% relative humidity), removed, cut into tensile test specimens, and reconditioned for testing. Each strip was cut into five 15-mm-wide coupons. A horizontal universal test machine with a crosshead speed of 2 mm/min was used for tests of tensile properties. An extensometer was placed on the coupon to measure strain. The thickness of each coupon was also measured for calculation of fail stress and modulus of elasticity.

RESULTS

Rheology

Typical torque responses as measured in a bowlmixer rheometer are shown in Figure 1 for various pulps. As the pulp charge was added, torque increased rapidly. Significant variation in torque occurred as a result of the presence of “hard” flocs. The variation in torque was also characterized by the presence of unbound water in the bowlmixer. When a 3% charge of CMC (based on dry weight fiber) was added approximately 4 min after initiation of the test, torque dropped very sharply and the pulp quickly became a homogenous paste. A stable torque level was reached and maintained throughout the remainder of the test. Pulps with longer fibers (wet-strength linerboard) generated very high torque readings (>1000 m·g), whereas pulps with shorter fibers (bleached hardwood) generated significantly lower torque readings (-300 m·g). However, once CMC was added, the torque levels for most pulps fell below 100 m·g, the viscosity level ideally suited for pulp extrusion. The intense mixing imposed on the raw pulps by the bowlmixer rheometer can quickly degrade fiber integrity. In a 5-min bowlmixer trial with bleached softwood pulp, the weight-average fiber length distribution was reduced from 2.20 to 1.36 mm in 2 min and was further reduced to 0.67 mm in 5 min. However, in a similar trial, no reduction in fiber length was observed when CMC was added.

The effect of adding filler to clean newsprint is shown in Figure 2. Again, a pulp charge was added to the rheometer and each filler was added about 4 min afterward. A significant increase in torque was observed when a 25% charge of $CaCO_3$ was added, nearly doubling that of the raw pulp. Neither clay (25% charge) nor TiO_2 (10% charge) appeared to alter the apparent viscosity of the newsprint. Quite a different response was observed when CMC and filler were added together with the pulp. Figure 3 illustrates both the rapid hydration and dispersion of CMC in the raw pulp and the relatively short-lived peak in torque when filler was present. The final torque levels with filler were also higher than those in the absence of filler, although well within the acceptable range for pulp extrusion.

Extrusion

Several blends of OCC and OMG with various amounts of CMC and filler were extruded at selected temperatures, ranging from 30°C to 70°C. Extrusion process conditions (screw torques and die pressures) for these trials are shown in Figure 4. Surprisingly, there was a linear relationship between torque and die pressure for all compositions evaluated. This linearity seems to be defined by screw configuration and die design rather than by compositional factors. Several trends, however, emerge from Figure 4: screw torque and die pressure increased with increasing long fiber fraction, decreased with increased clay content, and decreased with increasing temperature. These trends were evident in other extrusion trials with various pulp compositions [2]. Clearly, substantial amounts of filler in the feedstock composition can be extruded with good dispersion. However, the low “green” strength of the extrudate made it difficult to handle and consolidate for tensile tests.

In general, we found that pulp compositions containing OCC extruded easily but were not completely dispersed, having a mottled appearance. The material not collected for consolidation and testing was recycled back through the extruder. Dispersion improved with each consecutive pass. Again, screw configuration and the generation of backpressure by die selection strongly influenced dispersion.

Consolidation and Testing

Several pulp compositions were consolidated by press drying and tested for tensile properties. Unfortunately, the compositions with high filler contents were too liquid to consolidate, flowing excessively in the press. Also, the highly filled compositions tended to plug the screen pack, reducing heat transfer and preventing vapor release. The addition of a long fiber fraction seemed to restrain this lateral flow and allowed consolidation and drying to occur. Figure 5 shows average tensile properties of selected OMG/OCC blends extruded at 70°C. Two trends, common to all tested compositions, are apparent in this chart: both fail stress and modulus of elasticity increased with increasing long fiber fraction and with each consecutive pass through the extruder.

CONCLUSIONS

The apparent viscosity of various "clean" pulps, as measured by a bowlmixer rheometer, appears to be a function of fiber length. Viscosity ranged from 300 m·g for bleached hardwood to 1,300 m·g for wet-strength linerboard. Addition of calcium carbonate to newsprint significantly increased apparent viscosity, and clay and titanium dioxide had only minimal effects. When carboxymethyl cellulose (CMC) was added, however, apparent viscosity was reduced dramatically, obviating the effect of fillers. For this reason, a water-soluble polymer (in this case, CMC) is a required ingredient in the feedstock composition for extrusion.

As a result of difficulties encountered in obtaining and characterizing actual papermill sludges, OMG was selected as a model sludge because of its high filler content and hardwood (short) fiber base. Several blends of OMG and OCC were extruded successfully. Screw torques and die pressures increased with an increase in the long fiber fraction of the feedstock composition. Increased filler levels resulted in very low screw torques and die pressures. However, green strength of the extrudate was poor, and it was too difficult to process the extrudate further. Consolidation by press drying was effective for most blends. Extrudate tensile properties for several OMG/OCC blends depended on the long fiber fraction. Fail stress and modulus of elasticity exceeded 30 MPa and 7.5 GPa, respectively, for the 75% OCC+25% OMG blend.

A new study is underway to collect a variety of papermill residues and to characterize their rheological properties, These sludges will be added to a standard hardboard furnish and extruded.

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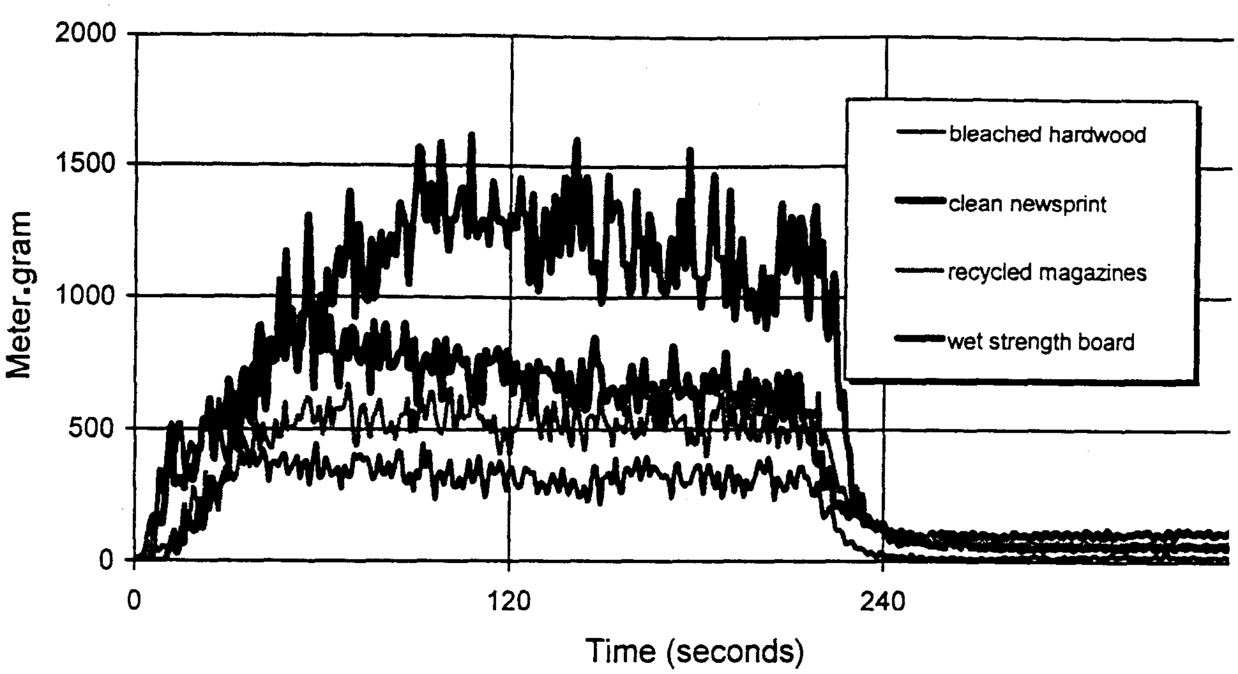

Figure 1. Torque response of various raw pulps measured by bowlmixer rheometer. Addition of 3% CMC at 240 s caused a drop in torque and reduced viscosity.

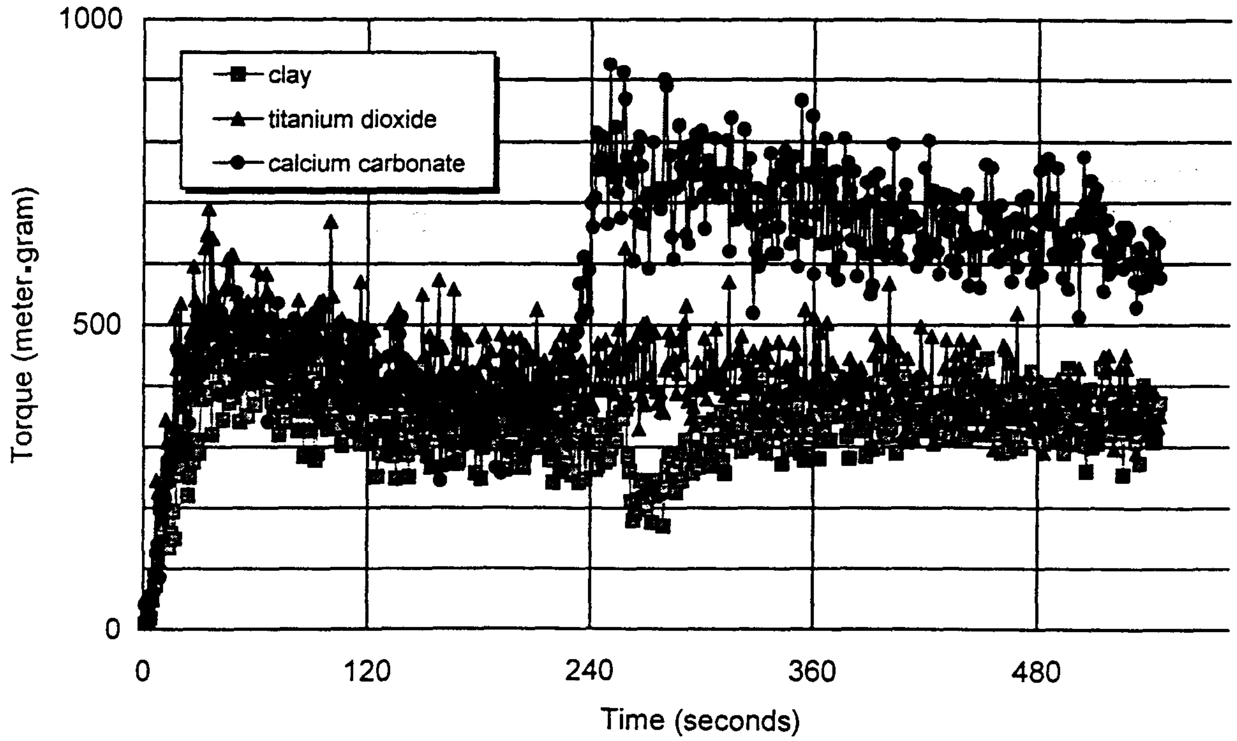

Figure 2. Torque response of newsprint pulp as measured by bowlmixer rheometer with addition of various fillers at 240 s.

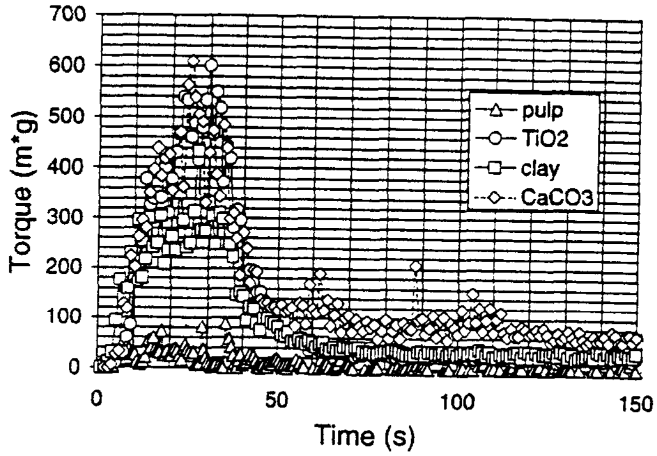

Figure 3. Torque response of newsprint pulp as measured by bowlmixer rheometer with addition of CMC and filler at 0 s.

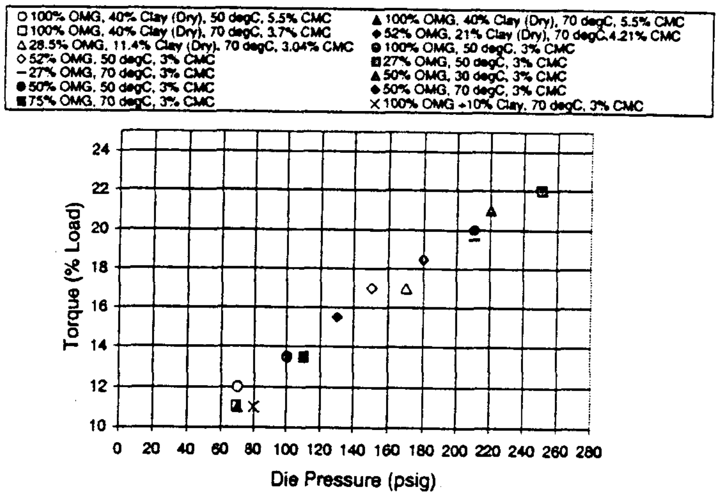

Figure 4. Extrusion conditions for selected blends of OMG and OCC with various levels of filler and CMC.

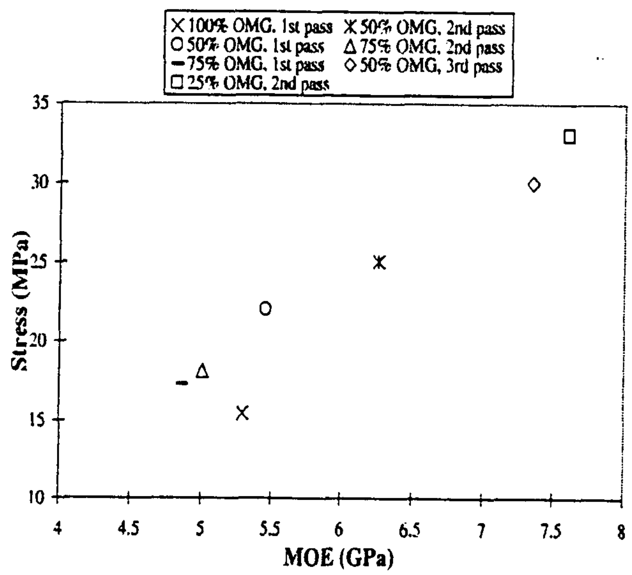

Figure 5. Tensile properties of extruded and consolidated pulps. Each point represents average of five test coupons. Only the OMG fraction is shown in the legend.

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