PULP EXTRUSION AT ULTRA-HIGH CONSISTENCIES

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ABSTRACT

A new process for producing continuous lignocellulosic fiber products is currently under development at the USDA Forest Service, Forest Products Laboratory. The goal of this exploratory research is to utilize conventional pulping techniques to process recovered papers with high filler contents, retain fiber integrity, and produce an engineered extruded product This process involves the extension of wet crumb pulp (primarily derived from recovered paper) at consistencies of 20% to 40% with small amounts of water-soluble polymers added as hydromodifiers. The water-soluble polymers appear to have two important theological functions in the extrusion process: (a) they bind water to the fiber and (b) they add lubricity to the pulp. A torque rheometer was used to measure the apparent viscosity of various pulp suspensions with water-soluble polymers. The added polymers reduce viscosity dramatically and enhance fiber dispersion. Polymer addition levels ranging from 1% to 3% by weight dry fiber were evaluated. Selected pulp/polymer compositions were then processed by a twin screw extruder. A slit die was designed to produce a thin sheet that could be press-dried and cut into coupons for measurement of tensile properties. Fiber orientation appeared to be random, and tensile properties were nearly equivalent in the flow and cross-flow directions. For most extruded compositions, fail stress and modulus of elasticity ranged from 10 to 20 MPa and 3 to 5 GPa respectively. These results indicate that pulp extrusion at ultra-high consistencies is possible and poses a viable alternative to the disposal of highly filled moved papers and papermill sludges.

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INTRODUCTION

Paper and paper products constitute approximately 40% of the municipal solid waste in the United States. 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. Although the supply of wastepaper is large, great strides have been made in its utilization. However, recovering fiber from papers with high filler contents and other non-cellulosic components is expensive and is often discouraged by low fiber yields and the inherent difficulties associated with sludge disposal and effluent treatment. Although we have become more proficient at recycling these grades, the generation of papemill sludge has continued to grow and we are faced with the burden of disposal. New processes that convert low quality recovered paper and papermill sludges into useful products are therefore necessary. Processing of these materials, however, is difficult. At low and medium consistencies (1%-15%), conventional paper and board manufacture is generally not possible because of extremely slow drainage. Severe flocculation and nonhomogeneous flow characteristics impede processing at high (15%-20%) and ultra-high (>20%) consistencies.

With the objective of developing innovative process technology to utilize recovered paper and papermill sludges, we initiated an exploratory study to evaluate the feasibility of processing these materials by extrusion. Other studies at the Forest Products Laboratory (FPL) had demonstrated the potential of processing relatively clean recovered paper into melt-blend thermoplastic composites by extrusion (1). However, melt-blend processing requires the use of oven-dry (OD) fiber. Unfortunately, dry fiberization reduces fiber length and integrity (2), thereby reducing the role of the fiber component to that of a filler in the composite. Our goal is to preserve fiber integrity by utilizing conventional wet pulping techniques and then process the pulp at ultra-high consistencies by extrusion. This approach would allow the production of engineered fiber composites with continuous complex profiles, where fiber orientation could be controlled and advantage could be taken of the incredible strength of cellulose fibers.

EXPERIMENTAL

Rheology

A torque rheometer (Brabender Plasti-Corder with bowlmixer) was used to characterize the rheological properties of pulps. This instrument functions much like an eggbeater. Two lobed cams (non-intermeshing) rotate at constant speed inside a double-barrel chamber, simulating the conditions presumed to exist within an extruder. When material is added to the chamber, the torque necessary to maintain constant rotational speed is recorded. This measurement can be interpreted as the apparent viscosity of the material. The torque rheometer is usually used to measure changes in the viscosity of thermoplastic polymers as a function of temperature and shear rate (3). For our purposes, the rheometer was used to observe the effect of extreme shear mixing on crumb pulps at ultra-high consistency and to examine any rheological changes caused by the addition of a water-soluble polymer (WSP). Initially, a charge of crumb pulp (12 g OD fiber) is loaded into the bowlmixer. After about 1 to 2 min, a steady-state torque reading is obtained. A WSP is then added as a dry granulate and a drop in torque and stable reading are generally observed. In a typical rheometer run, torque is recorded as a function of time at fixed run conditions (pulp at 70% moisture content, 60 rpm, 50°C). All crumb pulps were prepaid from post-consumer recovered paper (newsprint (ONP), magazines (OMG), and copier paper) by disintegrating in a high consistency pulper (15%), dewatering to the desired moisture content (typically 70%), and crumbing in a shredder.

Extrusion

Twin screw extruders (TSEs) are positive displacement pumps (similar to augers) that rely on the development of very high shear stresses to disperse and mix a feedstock composition and pump it through a die of predetermined cross-sectional shape. Unlike melt-blend extrusion, processing can be carried out well below 100°C and at much lower torques and die pressures. Material mixing and dispersion can be easily achieved with proper screw configuration. Fiber damage suffered during extrusion is minimal (4), and special dies can be designed to produce desired profiles and to induce fiber orientation.

A 32-mm co-rotating TSE was used for all extrusion trials. This extruder has a flexible screw configuration with intermeshing screw elements that can be assembled into kneading and conveying segments. A key to successful pulp extrusion is an understanding of the mixing and dispersion of fiber flocs at high consistencies. Dispersive mixing occurs predominately in regions where shearing action is present and can be enhanced by employing kneading elements. Mixing and dispersion can be tailored to accommodate pulps and additives by judicious arrangement of the transport and kneading elements. If assembled correctly, the pulp extrudate will be completely homogeneous. A die is attached to the end of the extruder barrel to shape the extrudate. A 20-mm rod die was designed to induce fiber alignment in the extrudate. Additionally, a 4- by 105-mm slit die was designed to produce strips for consolidation and testing. Various pulp compositions were extruded at selected run conditions (constant temperature, 50°C and constant speed, 300 rpm). In addtion, all bleached hardwood (HRDWD) and softwood (SFTWD) wet-laps were shredded and extruded. Screw torque and exit die pressure were monitored during steady-state operation. Several l-m strips were collected and bagged for each extruded pulp composition and stored in a cold room for further processing and testing.

Consolidation and Testing

The slit die was used to produce thin strips that could be consolidated by press-drying in a static press at 140 kPa and 150°C for 6 min. Four 105- by 125-mm segments were pressed for each pulp. Each segment was cut into 5- to 15-mm-wide coupons for tensile tests. Coupons were cut in both the flow and cross-flow directions to determine orientation effects. A clip gage extensometer was placed on the coupons to measure strain. A cross-head speed of 2 mm/min was used for all tests. The thickness of each coupon was also measured for calculating fail stress and modulus of elasticity (MOE).

RESULTS

The addition of WSP to a concentrated pulp suspension appears to have a remarkable effect on the theological properties of pulp suspensions (4,5). Figures 1 and 2 show typical rheometer torque measurements for two high molecular weight WSPs, polyethlyeneoxide (PEO) and sodium carboxymethylcellulose (CMC). These figures demonstrate the dramatic drop in torque associated with the addition of only a small amount of WSP to a pulp suspension. Once added, the WSP is quickly dispersed and the suspension becomes a paste, flowing easily at a much lower and more stable torque level Figure 3 shows the immediate dispersion of WSP when CMC was added to ONP before the test. Steady-state torque levels for CMC concentrations up to 3% for various pulp compositions are shown in Figure 4; for these compositions, the torque levels stabilized around 2%. Steady-state torque levels at 30°C to 90°C for ONP with 0% and 3% CMC are shown in Figure 5. Temperature clearly had a strong influence on theological properties.

We developed a screw configuration suitable for pulp extrusion that gave excellent dispersion and throughput for most pulp compositions evaluated. Figure 6 shows screw torque as a function of exit die pressure for various pulp compositions. When the rod die was used, die pressures rarely exceeded 300 kPa. The slit die restricted pulp flow considerably, resulting in much higher die pressures.

The processing temperature selected for these trials was not high enough to vaporize the water in suspension. Therefore, it was necessary to consolidate the extrudate in a post-extrusion press-drying operation. Tensile tests on coupons of the pressed extrudates indicated a strong relationship between the development of strength (fail stress) and stiffness (MOE) (Fig. 7). For most compositions, fail stress ranged from 10 to 20 MPa and MOE from 3 to 5 GPa. For the OMG + 1% CMC composition, however, poor dispersion and unbound water were observed. For compositions tested in both the flow and cross-flow directions, there was very little difference in tensile properties, suggesting random fiber orientation. Without WSP, it was not possible to extrude the wet crumb pulp. Screw torque quickly became excessive and the trials were aborted. However, with only a small amount of CMC (2%-3%), the pulps extruded easily.

CONCLUSIONS

Our research shows that wet-processed pulps can be extruded at ultra-high consistencies with the addition of small amounts of certain water-soluble polymers (WSPs). Without WSP, torque levels are extremely high and unstable. When WSP is added to the pulp suspension, it quickly hydrates and disperses, converting the suspension into an homogeneous paste. This transformation is associated with a corresponding drop in torque. For the two high molecular weight WSPs evaluated, a threshold of 2% added WSP (based on dry fiber weight) appeared to produce the torque levels necessary for extrusion. Twin screw extruders were found to be well suited for processing pulp/WSP compositions. For the slit die, fiber orientation appeared to be random; tensile properties ranged from 10 to 20 MPa for fail stress and 3 to 5 GPa for MOE for most compositions tested. We anticipate that ultra-high consistency extrusion of pulp compositions may have application in the production of millwork-type products.

Perhaps the most important aspect of this research is the potential use of recovered papers with high filler contents and papermill sludges in extruded products. We have shown that pulps containing high filler contents are easily extruded. For instance, the 100% OMG was pulped at 15% consistency and was neither cleaned nor completely disintegrated when used, yet it extruded easily at low torques and die pressures for both the rod and slit dies. This finding may have significant environmental consequence. It suggests that paper-based materials, which are now considered waste, can be processed at ultra-high consistencies by extrusion. Continued research is focused on developing a fundamental understanding of the theological properties of fiber-polymer compositions and their relationship to extrusion processing conditions. Die design for fiber orientation as well as post-extrusion treatments for development of properties are also under investigation.

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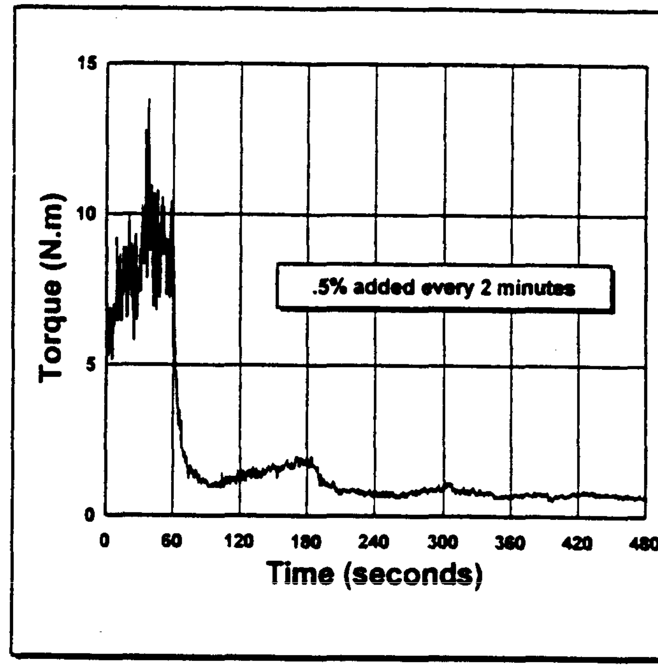

Fig. 1. Apparent viscosity of ONP as measured by torque rheometer; 0.5% PEO (MW = 7,000,000) was added at 60 s.

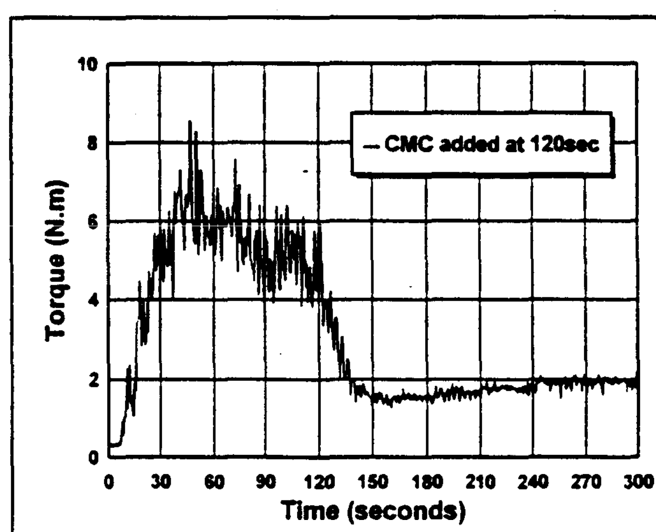

Fig. 2. Apparent viscosity of ONP as measured by torque rheometer; 3% CMC (MW = 800,000) was added at 120 s.

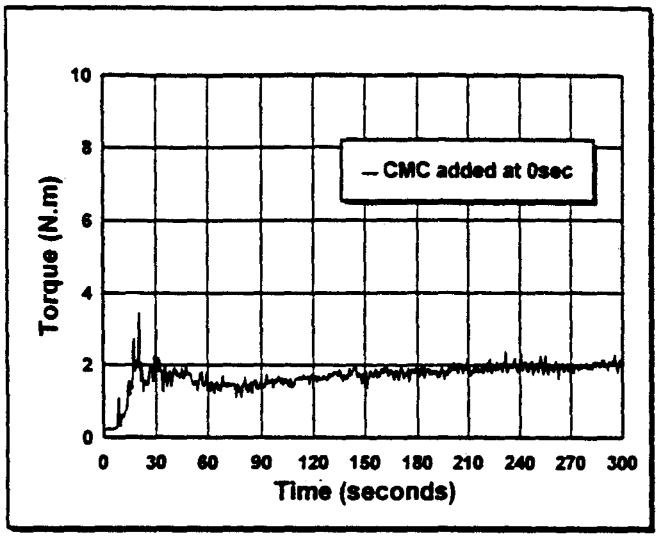

Fig. 3. Apparent viscosity of ONP as measure by torque rheometer; 3% CMC (MW = 800,000) was added before the test.

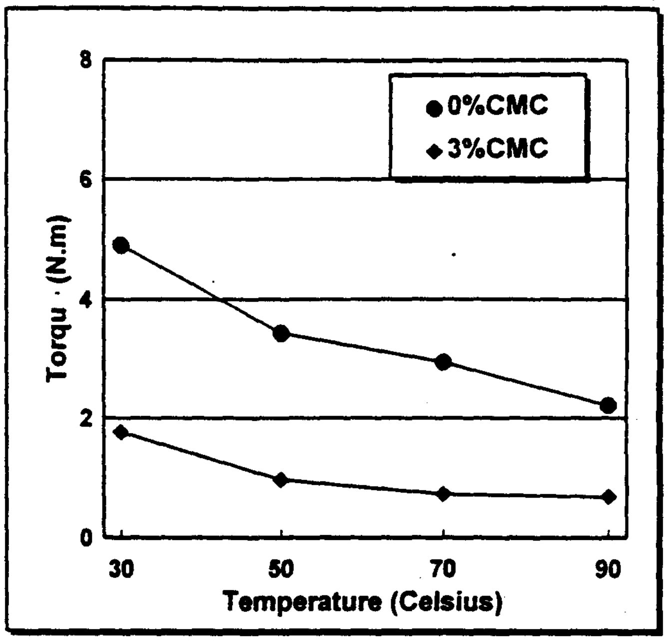

Fig. 5. Apparent viscosity of ONP with 3% CMC as a function of temperature.

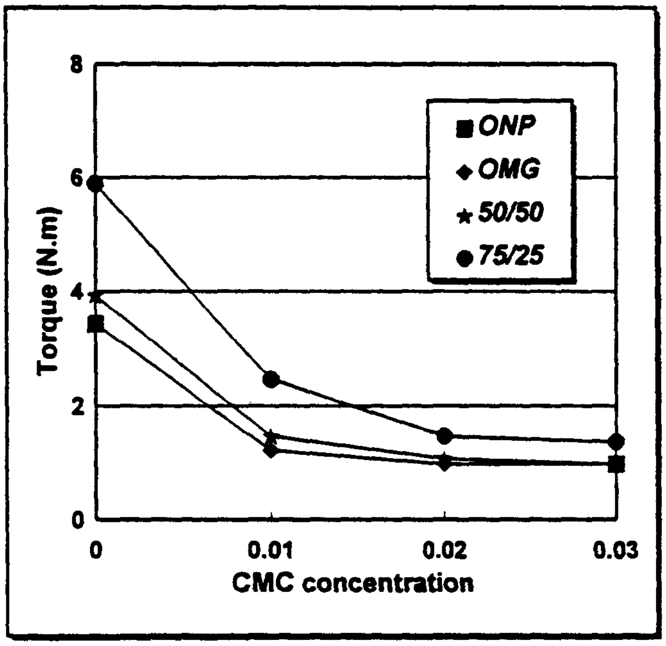

Fig. 4. Apparent viscosity of ONP, OMG, and two blends as a function of CMC concentration.

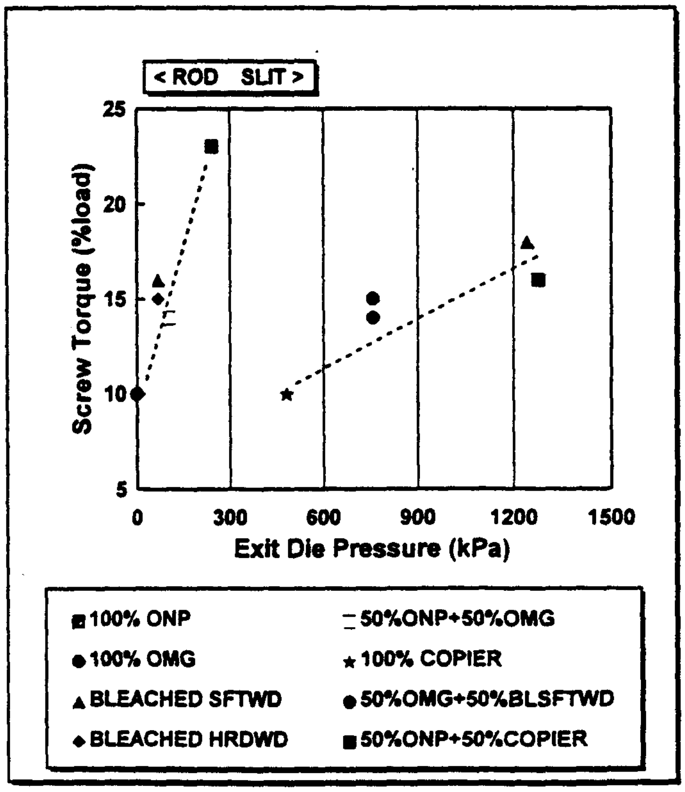

Fig. 6. Screw torque as a function of exit die pressure for extrusion trials on various pulps and pulp blends.

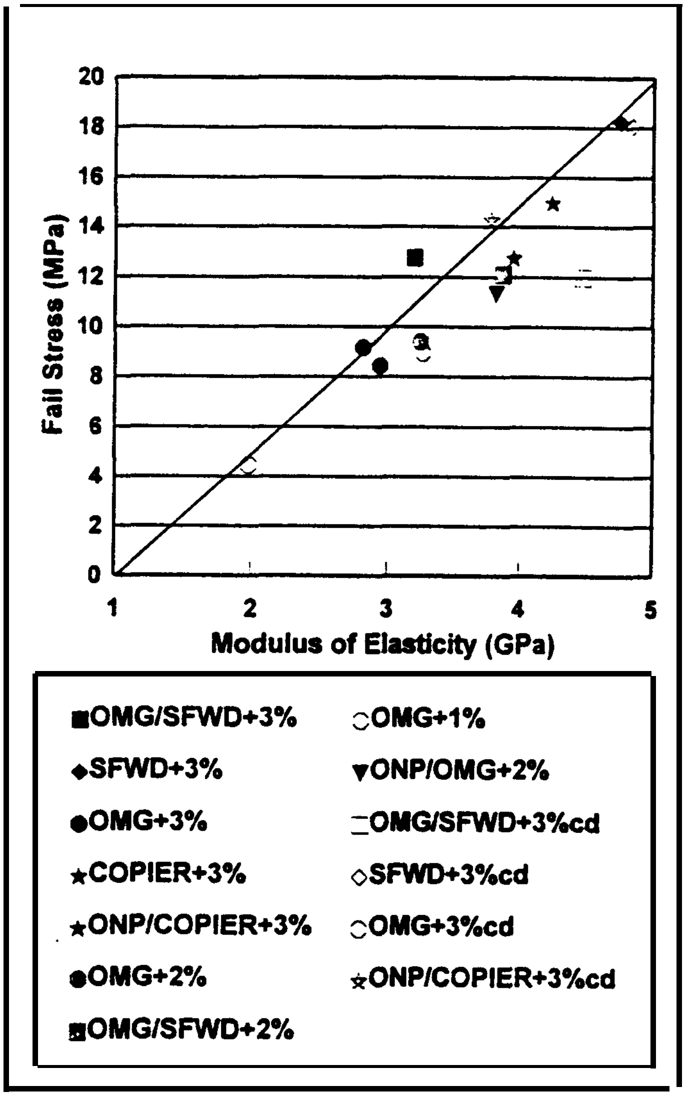

Fig. 7. Fail stress and modulus of elasticity of coupons of various extruded and press-dried pulp compositions.

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