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BENEFICIAL USE OF PULP AND PAPER INDUSTRY RESIDUALS: EXTRUSION FOR THE MANUFACTURE OF BUILDING PANELS

TECHNICAL BULLETIN NO. 814

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by

C. Tim Scott
USDA Forest Service,
Forest Products Laboratory, Madison, WI

John Simonsen
Department of Forestry
Oregon State University, Corvailis, OR

Dan Klingenberg
Department of Chemical Engineering,
University of Wisconsin, Madison, WI

Stefan Zauscher
Department of Paper Science and Engineering
State University of New York, Syracuse, NY

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ABSTRACT

Pulp extrusion at ultra-high consistency (@30% solids) has been shown to be a viable process for converting used paper into solid sheets and profiles. It has been demonstrated previously that used paper pulps and "model" wastewater treatment residuals require the addition of a water-soluble polymer (WSP) to alter rheological properties such that a homogenous pulp paste can be formed and extruded. This report describes attempts to evaluate the viability of extruding three types of actual mill residuals: primary treatment residuals from deink mills; OCC rejects; and paper machine rejects. Several residuals were acquired from various mills and classified by ash content, gross contaminant level, and biological solids. Blends of residuals, old newsprint, and WSP were prepared and extruded into continuous sheets. Portions of the sheets were consolidated by press drying and then tested for physical and mechanical properties (density, fail stress, modulus of elasticity, and moisture swelling), which were compared to properties for hardboard. The results suggest that a variety of fibrous residuals can be successfully extruded to produce a material with adequate tensile strength. In addition, optimization of the process might lead to a product with improved characteristics. Because gross "contaminants" (e.g., wood chips, staples, plastics, grit, causticizing wastes) may pose difficulties for the process, however, high fiber materials that have been segregated from other wastes may be the most suitable for extrusion.

KEYWORDS

extrusion, wastewater treatment plant residuals, sludge, OCC rejects, paper machine rejects, solid wastes, recycling, beneficial use, pollution prevention, P2, alternative management, hardboard, building panels, deinking

RELATED NCASI PUBLICATIONS

Technical Bulletin No. 806 (May *2000). Beneficial use of secondary fiber rejects.*

Technical Bulletin No. 793 (September 1999). *Solid waste management practices in the U.S. paper industry - 1995.*

Technical Bulletin No. 687 (December 1994). *Alternatives for management of pulp and paper industry solid wastes: production of lightweight aggregate.*

Technical Bulletin No. 685 (October 1994). *Alternatives for management of pulp and paper industry solid wastes: production of ethanol.*

Technical Bulletin No. 655 (November 1993). *Alternative management of pulp and paper industry solid wastes.*

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BENEFICIAL USE OF PULP AND PAPER INDUSTRY RESIDUALS: EXTRUSION FOR THE MANUFACTURE OF BUILDING PANELS

1.0 INTRODUCTION

There is great interest in the beneficial use of wastewater treatment and other residuals from the pulp and paper industry and of paper that is not recovered for recycling into new paper products. The paper industry generates approximately 5.8 million tons of wastewater solids each year (NCASI 1999), some of which contain a significant amount of high quality fiber. While recycling routes about half of the used paper stream away from the landfill and/or combustor, not all grades of paper can be profitably recycled, especially those containing large amounts of fillers and contaminants.

The feasibility of extrusion to utilize used paper and wastewater treatment residuals (the latter material simulated by using a fiber source with significant filler) for the manufacture of panel and profile products, both structural and non-structural, has previously been demonstrated (Zauscher and Scott 1997; Scott and Zauscher 1997; Scott, Zauscher and Klingenberg 1999). The mechanical properties of the product depend on the type and concentration of fiber in the feed material, the dispersing agent and any other additives, and the type of extrusion process. Even materials with high filler content have been extruded successfully. Mechanical properties of the densified and dried extrudates were similar to those of wet-process hardboard.

This project extends the earlier work with synthetic or model treatment residuals by investigating actual residuals from several pulp and paper mills. The following objectives were proposed for this study.

- Demonstrate the manufacture via extrusion technology of useful panel products incorporating residuals from the pulp and paper industry.
- Determine the diversity of properties obtained from the residuals.
- Begin the development of an experimental foundation on which to base theoretical models for the design and manufacture of extruded products incorporating residuals from the pulp and paper industry.

2.0 ACQUISITION AND CHARACTERIZATION OF RESIDUALS

Three basic criteria were established to screen potentially useful materials. First, the residuals had to be completely “nonhazardous” both in the collected state and after processing by extrusion. Second, they could not contain any biological solids that might degrade fiber properties. Finally, they could not contain significant quantities of large contaminants (e.g., staples, paper clips, wood chips, grit, etc.). Such contaminants were considered to be potentially damaging to the extrusion equipment. The following is a list of mills willing to participate in the study, with a description of the observed characteristics of the residuals received. A summary of information on the residuals is shown in Table 2.1. Included for some of the residuals are solids and ash values from testing the received samples.

Mill A - Integrated mill for production of paperboard and printing grades, primarily from virgin fiber (kraft and groundwood). This mill has two separate wastewater treatment facilities. Treatment plant Al receives wastewater consisting of several combined effluent streams (kraft digesters, pressure screens, paper machines, etc.). The wastewater is fed to a primary clarifier, followed by aeration and secondary clarification. Solids from the primary and secondary clarifiers are combined, thickened, and dewatered in a belt press before removal to a landfill. Unfortunately, the residual solids contained significant quantities of grit and chips from the kraft digesters. They were also biologically active, rendering them unsuitable for further evaluation. Treatment plant A2 produced a residue that was strictly from groundwood production. The treatment process was similar to A1, but the fiber content of this latter residual was much more consistent (no chips). However, this residual also contained biological solids, rendering it unsuitable for further evaluation.

Mill B - Recycle mill for production of linerboard and corrugating medium, primarily from recovered paper (old corrugated containers, OCC). Several screening stages and flotation units were integrated to separate usable fiber from non-fibrous (OCC reject) materials. This mill was very selective in its choice of recycled grades for pulping, eliminating potential contaminants that would otherwise inhibit processing. Although the fiber quality appeared good, the residue contained significant quantities of contaminants including staples, foam beads, adhesives, tapes, grit, etc. Several reject streams were combined and dewatered to produce the residual. One of these streams appeared to contain a high fiber fraction with few contaminants, and a large sample of this stream was collected and saved for evaluation. This mill provided no information on the composition of these OCC rejects.

Mill C - Deink mill for coated grades containing pre-consumer and post-consumer fiber. Residuals for this project were dewatered solids from primary clarification. This material appeared to contain a high level of filler with the fibrous component being primarily short fibers. The mill reported the residuals to be at 40% solids and 32% ash. This material was used in the extrusion trials.

Mill D - Corrugating medium mill with primarily hardwood semi-chemical pulp furnish, but also some recycled kraft fiber. Both primary and secondary residuals are produced in the wastewater treatment facility and dewatered to 30% solids for disposal. However, considerable effort has been undertaken by this mill to separate residuals. The material obtained for this evaluation was a sample of paper machine rejects. An extensive evaluation of its composition was made by the mill and reviewed for this study.

Mill E - Kraft linerboard and neutral sulfite semi-chemical (NSSC) corrugating medium mill. Wastewater treatment consists of primary clarification followed by secondary aeration. Extensive confidential documentation was provided on composition. The residuals as received appeared to contain high levels of contaminants such as dregs, lime grits, and wood chips in addition to a strong odor suggestive of biological activity (even though the material was to have been sampled from the primary stream). These factors rendered the sample unsuitable for further evaluation.

Mill F - Deink mill for production of tissue and toweling. The acquired primary residuals appeared to contain high levels of filler and a significant fraction of short fibers. The sample was very similar to the material from Mill C. This residual was used in this study.

Mill G - Kraft mill for production of hardwood and softwood market pulps. Primary clarification and secondary aeration are used to process the wastewater. The sample that was received contained numerous wood chips and also possessed a strong odor, presumably from the biological solids that were present. It was not used in this study.

Table 2.1. Selected Information on Acquired Residuals

Code	Mill Type[a]	Source	Solids (%)	Ash (%)	Used
A	Integrated kraft/GWD	Primary + secondary	--	--	no
B	Recycled paperboard	Screening of OCC	24	9.7	yes
C	Deink coated paper	Primary	40	60.3	yes
D	HWD semichem	PM[b] cleaners	35	7.3	yes
E	SWD kraft/semichem	Primary	--	--	no
F	Deink tissue & towel	Primary	38	58.3	yes
G	HWD/SWD kraft	Primary + secondary	--	--	no

[a]GWD = groundwood, HWD = hardwood, SWD = softwood.
[b]PM = paper machine.

3.0 CONTROL FURNISHES

As initially envisioned, a hardboard furnish (defibrator Aspen with 15% softwood) was to be used as the base furnish. The intent in selecting this type of furnish was to produce an extruded board that had properties comparable or superior to commercial hardboard. The residuals would then be added at 15, 30, and 45% addition levels for rheology testing and extrusion trials. As received, the hardboard furnish was very dry (55% solids) and had a high shive content and a Canadian Standard Freeness of 790 ml, properties which were thought to be typical. This furnish was further refined in an atmospheric refiner with steam injection to reduce the shives and obtain a solids content of 25%. Very little reduction in freeness was obtained (750 ml), but the shive content was noticeably reduced.

An old newsprint (ONP) furnish was prepared by pulping newspaper (without inserts) in a high consistency (15%) pulper. The resulting pulp was dewatered in a bladder press to 27% solids and shredded to marble-sized flocs. It had an ash content of 4.8%. ONP has been used in previous extrusion trials (Zauscher and Scott 1997, Scott and Zauscher 1997). It would serve here as the back-up furnish.

An old magazines (OMG) furnish was prepared by pulping high gloss magazines in the high consistency pulper. This pulp was also dewatered in the bladder press, and a solids content of 33% was obtained. The ash content of this OMG was determined to be 38.5%. OMG was used in a previous study as a model or simulated wastewater treatment residual due to its high filler content and high percentage of hardwood (short) fibers (Scott, Zauscher, and Klingenberg 1999).

4.0 EXTRUSION TRIALS

Extruders are positive displacement pumps (similar to augers) that rely on the development of very high shear stresses to disperse and mix a feedstock and then pump the composition through a die of pre-determined cross-sectional shape. In this study, a 32-mm co-rotating twin screw extruder was employed with the barrel temperature fixed at 50°C. A pulp/residuals blend of 4-kg (wet basis) mass was prepared for each extrusion trial.

One key to successful extrusion of pulps is the addition of a water-soluble polymer (WSP). The polymer must rapidly hydrate the fibers to reduce the viscosity of the pulp and promote dispersion of flocs in the feed section of the extruder. A homogeneous fiber paste is then formed that can be further dispersed in subsequent kneading zones and finally forced through a die. Previously it has been shown that very small amounts of certain WSPs (e.g., sodium-carboxymethylcellulose, abbreviated CMC) can dramatically reduce the apparent viscosity of the pulp to greatly ease extrusion (Zauscher and Scott 1997; Scott and Zauscher 1997; Scott, Zauscher, and Klingenberg 1999). If the apparent viscosity is too high, the shear forces required to disperse the flocs will be too great and the extruder will jam. On the other hand, if the apparent viscosity is too low, the polymer will only coat the surface of the floc and dispersion will not occur. Judicious application of the WSP for pulp extrusion is therefore critical.

An attempt was made to characterize the rheological properties of the hardboard furnish with CMC used as the WSP. Various addition levels of CMC were evaluated, and a comparison was made with ONP (Figure 4.1). Unfortunately, CMC did not dramatically reduce the viscosity of the hardboard furnish even when added at a level of 10% on a dry-weight basis. Based on previous rheological and extrusion evaluations, it was known that the apparent viscosity must be very low (at or near a bowlmixer torque of 1 Nm) for trouble-free extrusion. Typically, 3% WSP or less should be used to obtain these torque levels. The addition of the OMG pulp to the hardboard furnish in combination with 3% CMC was found to reduce the apparent viscosity to extrudable levels (Figure 4.2). This result was in agreement with previous work in which the addition of filler had reduced the viscosity (Scott, Zauscher, and Klingenberg 1999).

Based on the rheological determinations presented in Figures 4.1 and 4.2, attempts were made to extrude the hardboard furnish with and without the wastewater treatment residual from Mill C. This residual was chosen due to its similarity to OMG. A moderately aggressive screw configuration (three kneading zones) was selected for these trials. A slit die with a 50.8-mm width and a 6.3-mm height was chosen specifically to generate only moderate backpressure in the range of 1000 to 1500 kPa. (The hardboard furnish was expected to produce excessive resistance if a narrower die were used.) Four trials were made; the first with the hardboard furnish only; and the second, third and forth with additions levels of Mill C residual at 15, 30, and 45% respectively. All four trials used 6% CMC as the WSP. The steady state screw torque and die pressures are shown in Figure 4.3.

Figure 4.3 clearly shows a dramatic reduction in apparent viscosity and extrusion process conditions when Mill C residual was added to the hardboard furnish. The blends extruded nicely at very low torques and die pressures and with good dispersion after a single pass. However, the 100% hardboard furnish did not extrude easily. In fact, a second pass was made to improve dispersion, but the die pressure doubled instead and the extrudate no longer exhibited a uniform paste-like consistency. It is suspected that there was too little interaction between the CMC and the lignin-rich hardboard fibers. This would render CMC ineffective in lubricating the fiber surfaces, leading to limited viscosity reduction and the prevention of extrusion. The hardboard furnish was abandoned altogether, since a "control" condition could not be obtained easily. ONP served as the control furnish for subsequent trials.

With ONP as the base furnish, several blends with either OMG or a mill residual were prepared for extrusion. The extrusion conditions were duplicated from the previous trials, with the exception of CMC level and die shape. For these new trials, 3% CMC was used in all cases. Additionally, a wider (100-mm) and narrower (3-mm) slit die was used. Table 4.1 lists the extruded blends with corresponding steady-state torque and die pressures for both the first and second passes through the extruder. Readily apparent is the large increase in die pressures from the previous trials that were shown in Figure 4.3. This is due in part to the more restrictive flow through the narrower die. Also, the addition of residuals increased both the screw torque and die pressure. In the case of the paper machine rejects from Mill D, the increase in die pressure was particularly large. A second pass was made to improve dispersion. Both die pressure and screw torque increased on the second pass. All extruded blends appeared well dispersed and were saved for consolidation and measurement of physical properties.

Table 4.1. Extrusion Conditions for Blends of ONP with OMG or Mill Residuals

Extruded Blend	Pass 1 Pressure (KPa)	Pass 1 Torque (Nm)	Pass 1 Mass Flow (g/s)	Pass 2 Pressure (kPa)	Pass 2 Torque (Nm)	Pass 2 Mass Flow (g/s)
100% ONP	1,100	13.6	10.2	1,310	19.0	12.4
85% ONP + 15% OMG	1,100	12.2	9.2	1,310	14.9	10.7
70% ONP + 30% OMG	1,100	14.9	12.0	1,100	13.6	--
55% ONP + 45% OMG	970	14.9	15.1	1,175	14.9	--
85% ONP + 15% Mill C	1,380	17.6	--	1,590	20.3	12.2
70% ONP + 30% Mill C	1,175	16.3	--	1,380	17.6	12.2
85% ONP + 15% Mill F	1,311	19.0	--	1,520	20.3	12.5
70% ONP + 30% Mill F	1,242	14.9	--	1,660	19.0	--
70% ONP + 30% Mill B	1,104	13.6	--	1,175	14.9	13.6
70% ONP + 30% Mill D	1,590	19.0	--	1,795	20.3	11.7

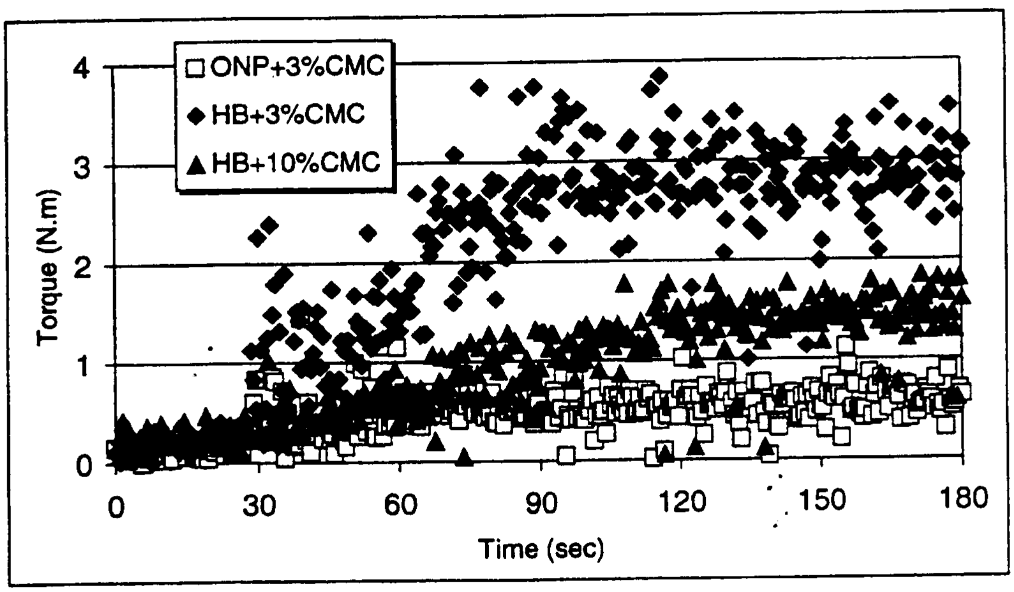

Figure 4.1. Apparent Viscosity (torque vs. time) of Hardboard and ONP Pulps with CMC as Measured with a Bowlmixer Rheometer.

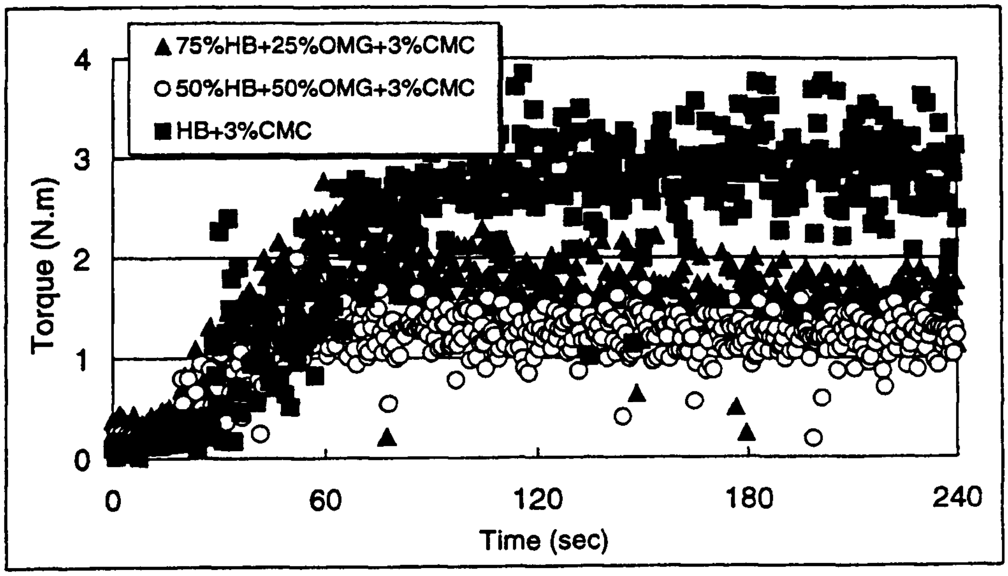

Figure 4.2. Apparent Viscosity of Hardboard and OMG Blends with 3% CMC.

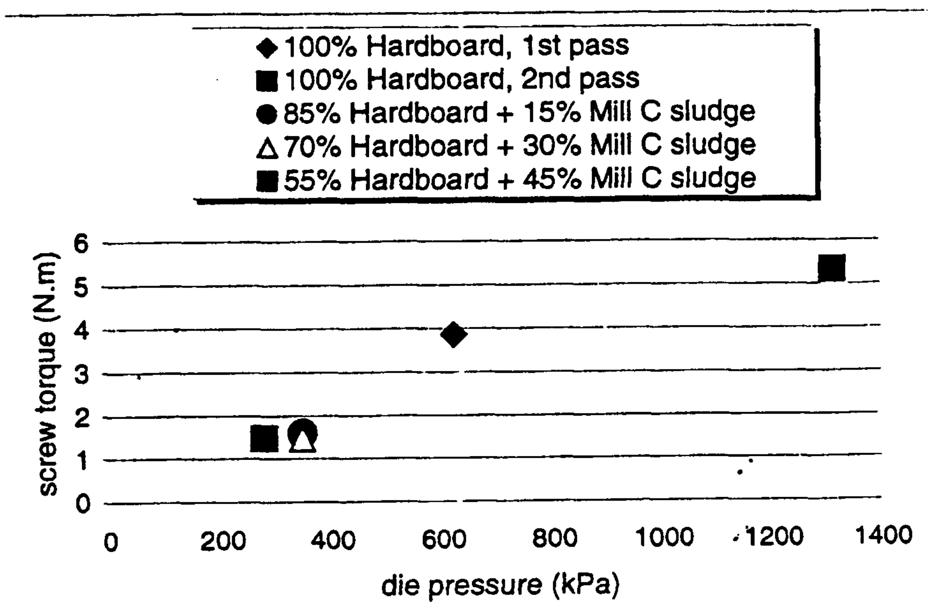

Figure 4.3. Extrusion Conditions for Trials with Hardboard Residual Blends and 6% CMC.

5.0 CONSOLIDATION OF EXTRUDATES

Several strips 25 cm in length were collected at the die for each blend extruded. Since the extruder was run relatively cold, essentially no moisture was lost in the process. Therefore, a "press-drying" technique was employed to consolidate the strips (Setterhohn 1979). A hydraulic hot press with a nitrogen accumulator was set up to apply a constant pressure to the strip as it dried. A 10-cm long segment was placed between a nesting of screens (100 mesh) and pressed at 150°C until dry. Five of these segments were pressed per blend. Three segments were pressed at 70 kPa and one was pressed at 350 kPa. A fifth segment was instrumented with three thermocouples to determine the drying time at 70 kPa. When the temperature was observed to reach 140°C, the segment was considered dry. Drying times for the various blends ranged from 275 to 400 seconds.

The press-drying technique described above is similar to that used to densify and dry hardboard. It quickly became evident however, that the extremely high pressures, typically between 3,500 and 7,000 kPa, used in hardboard consolidation protocols (Suchsland and Woodson 1987) could not be achieved. Even at 350 kPa, there was excessive "squeeze-out" of the pressed segment. Although density increased substantially between 70 and 350 kPa, the targeted density (that of high-density hardboard) was not reached. It is suspected the large reduction in viscosity imparted by the addition of the WSP created the squeeze-out phenomenon. The presence of mineral filler and possibly of unknown WSP in the residuals also may have contributed to the phenomenon.

6.0 PROPERTIES OF CONSOLIDATED EXTRUDATES

After the segments were press-dried, they were cut into coupons 15-mm wide for tensile testing. The strips were cut only in the flow direction; each segment yielded six test coupons. All coupons were allowed to equilibrate in a conditioned room at 23°C and 50% RH before testing. The thickness, length, and weight of each coupon were measured and entered into the data acquisition system. A universal test machine was employed to maintain a constant elongation rate of 3 mm/min as load and strain were acquired. Density, fail stress and modulus of elasticity (MOE) were calculated and tabulated. Values for these parameters are listed in Table 6.1 as are minimum values typical for standard and tempered hardboard. The effect of consolidation pressure on extrudate properties can be seen clearly. Values for the extrudates generally are below those for hardboard, but in some cases the differences are not great. In particular, tensile properties of the blend with OCC rejects from Mill B pressed at 350 kPa are very close to those of standard hardboard. Figure 6.1 illustrates the distribution of MOE and fail stress values.

Thickness swell was also measured for those compositions press dried at 70 kPa. Selected coupons were allowed to soak in water for 24 hours. They were then removed and the thickness was measured. Values are shown in Table 6.1. Of particular interest is the reduced swelling as more filler is present in the product. The wastewater treatment residuals from Mills C and F had significant amounts of filler materials (high ash) and low thickness swell. Conversely, the OCC rejects from Mills B and the paper machine rejects from Mill D had low amounts of filler (low ash) and relatively high thickness swell.

Table 6.1. Physical and Mechanical Properties of Consolidated Extrudate Blends

	Pressed at 150°C, 70 kPa				Pressed at 150°C, 350 kPa		
Extruded Blend	Density (g/cc)	Fail Stress (MPa)	MOE (GPa)	Swelling (%)	Density (g/cc)	Fail Stress (Mpa)	MOE (GPa)
100% ONP	0.58	18.5	3.14	73	0.62	25.2	3.96
85% ONP + 15% OMG	0.61	18.5	3.41	71	0.62	19.4	3.07
70% ONP + 30% OMG	0.66	17.8	3.60	64	0.72	25.1	4.45
55% ONP + 45% OMG	0.62	14.4	2.97	58	0.73	19.8	3.92
85% ONP + 15% Mill C	0.64	16.7	3.19	41	0.73	20.1	3.83
70% ONP + 30% Mill C	0.64	13.2	3.08	41	0.82	18.9	4.19
85% ONP + 15% Mill F	0.58	9.8	2.26	43	0.82	19	3.86
70% ONP + 30% Mill F	0.61	6.2	1.85	42	0.80	10.4	2.84
70% ONP + 30% Mill B	0.63	19.6	3.70	81	0.68	24.4	4.31
70% ONP + 30% Mill D	0.65	17.4	3.14	84	0.70	21.9	3.77
Hardboard[a]							
Tempered	0.95	31.7	5.10	--	--	--	--
Standard	0.88	25.5	4.30	--	--	--	--

[a]Suchsland and Woodson 1987.

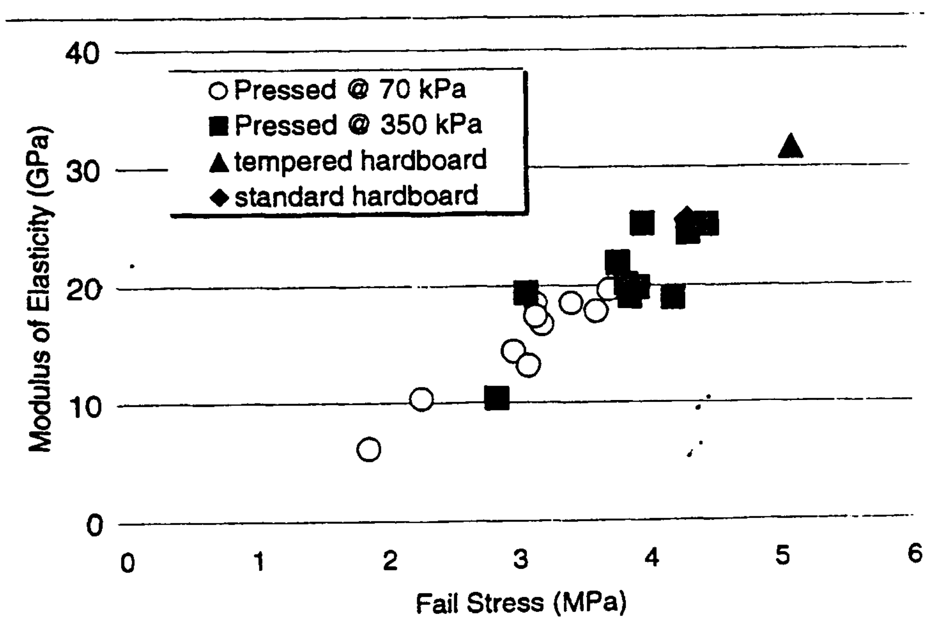

Figure 6.1. Modulus of Elasticity vs. Tensile Fail Stress for Extrudates and Hardboard.

7.0 SUMMARY AND CONCLUSIONS

Previous trials with various grades of used paper suggested that the extrusion process could tolerate just about any fiber-based furnish, even with high filler levels. However, as this study has shown, characterization of actual mill residuals for extrusion is not trivial, and each residual is essentially unique to the process(es) from which it was derived. An unexpected barrier was the inability to use the hardboard furnish as the base pulp. Too much water-soluble polymer (CMC) was required to reduce the viscosity of the furnish, and extrusion was extremely difficult. Therefore, that material was abandoned and replaced by ONP.

Four residuals (samples of wastewater primary solids from two deink mills, one sample of OCC rejects, and one sample of paper machine rejects) were employed in extrusion trials. The two wastewater treatment residuals had high ash contents and appeared similar to OMG. The OCC rejects had a high fiber content, but also contained minute levels of contaminants (staples, stickies, and foam beads). The paper machine rejects appeared to be very uniform and contained a high percentage of fiber shives.

All four residuals extruded easily in various compositions with ONP and 3% CMC. Screw torques and die pressures were low and not much higher than those of the ONP/OMG "control" blends. All extruded compositions were consolidated by press drying and tested for tensile strength and thickness swell. Although densification was limited due to viscous flow under pressure, the tensile properties of the blend with OCC rejects (pressed at 350 kPa) approached those of standard hardboard.

Two of the residuals that were initially considered for study contained biological (secondary) solids but otherwise contained high fiber and no large contaminants. If the biological solids could be easily removed or deactivated, they would not pose any potential biological hazard (potential for mold growth) nor degrade fiber properties, and the residuals probably could be extruded. Also, other wastewater treatment residuals that were heavily "contaminated" still had significant fractions of fiber. These contaminants (e.g., metal, grit, and wood chips) could damage the extruder. The challenge in such a case lies in extracting that fiber from the rest of the material. Mills typically combine all of their effluent streams prior to wastewater treatment. If the streams that contain the most useable fiber could be diverted and recovered, then the solids from them should be viable for pulp extrusion.

The results of this study are encouraging, particularly considering that the processes employed were not optimized. For example, other WSPs might greatly improve the mechanical properties of residual-containing panels by permitting greater consolidation pressures. The first two objectives listed in the introduction were achieved. The third was partially achieved. The data presented here add to the experimental foundation of extrusion technology. It is believed that there are fibrous mill residuals that can be incorporated into extruded products and thus diverted from disposal. However, the results of the experiments reported here indicate the characteristics that are successful for one residual may not hold true with a different residual, or with a different base furnish. Thus, each application requires careful study to successfully develop an extruded product. While this is not surprising, it greatly complicates the development of theoretical models mat might allow for the rapid transfer of this technology to industry.

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