PRODUCTION AND PROPERTIES OF SOIL EROSION CONTROL MATS MADE FROM SUGARCANE BAGASSE

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ABSTRACT

The market for mats and blankets made from natural fibers is a rapidly growing segment of the erosion control industry. In south Louisiana, bagasse is a local, readily available material with properties that make it suitable for erosion control products. In the framework of work towards diversifying the sugarcane industry, a prototype of a simple continuous device to produce erosion control mats was built and tested. Rectangular mats of 1.2 m x 2.4 m (4 x 8 ft) size were produced from bagasse that had been modified by impregnation with dilute liquor of soda ash and by partial mechanical refining. The effects of the alkali treatment on the bagasse fibers were evaluated by thermo-gravimetrical analysis. The physical properties of bagasse mat samples were tested with American Society for Testing and Materials and Erosion Control Technology Council methods and compared with those reported by manufacturers of leading commercial products. The absence of netting in the bagasse products results in a lower tensile strength but should prove advantageous from the environmental impact standpoint. The availability of sufficient quantities of sugarcane bagasse and the proximity to markets should be significant factors for the competitiveness of the bagasse products in the local market.

Keywords: erosion control, soil erosion, sugarcane, sugar cane bagasse, erosion mats, agricultural fibers.

INTRODUCTION

The erosion control industry uses various types of geo-synthetics in order to mitigate the negative impact that erosion has on the environment (Berg and Suits, 1999). One of the most rapidly growing sectors within this industry is the market for erosion mats and blankets. The first rolled erosion control products were jute nettings imported from Asia but as the demand grew a wide range of products were developed with varying compositions and structures (Berg and Suits, 1999; Erosion Control Technology Council, 2005). Natural fiber products such as wood, straw and coconut predominate because of their biodegradability, moisture-holding ability and environmentally friendly image (Morgan, 2005). A comparable natural fiber available in south Louisiana is sugarcane bagasse.

In the previous program at Louisiana State University (Collier, 1997 and Thames, 1997) long rind fiber bundles were used to hand-produce one square-yard samples of erosion mats. The rind portion of the sugarcane stalk was stripped from cane billets with a cane separator, then fiberized by cooking with sodium hydroxide under pressure and steam explosion. Laboratory tests involved a comparison of the bagasse mats with commercial wood, coconut and straw products. Sugarcane mats had the highest bio-degradability, were intermediate in thickness and specific weight and had the lowest strength and light penetration among the tested products. They also burned slower and 70% of the samples self-extinguished. In cooperation with the Louisiana Transportation Research Center, a field test was organized along Interstate 10 to measure grass penetration and slope protection. While coconut mats shrank after the first rain, the sugarcane mats with no stitching maintained their integrity even during heavy rain. However, because of their lower light penetration, both products had lower germination rates than straw and wood products. Nevertheless, the overall performance was deemed to be in compliance with regulations required on state road construction projects (Collier, 1997 and Thames, 1997).

The main goal set for the present work was to develop and demonstrate a continuous and easy to scale process for production of rolled soil erosion mats using mill-run bagasse requiring minimum processing. That way the process could be implemented in a facility next to a sugar mill, thus providing economic benefit to the industry and a local source of soil erosion products. Additional objectives were determination of biodegradability and flame resistance of bagasse mats and comparison with other commercial products. Sodium carbonate rather than sodium hydroxide was to be considered the reagent of choice because of its lower cost and easier handling.

MATERIALS AND METHODS

Raw mill-run bagasse with 30 – 40% moisture was obtained from the storage pile outside one of the local mills. Attempts at forming mats from bagasse without any prior chemical treatment failed as the particles were found to be too coarse and stiff, with no cohesion once formed into a mat. Pulping bagasse with hot alkali is a well established process that frees the cellulose fibers by solubilizing some of the lignin and hemicellulose. The treatment in this work (Table 1) is an equivalent of soda pulping but carried out at milder conditions (100°C, 1% Na_2CO_3 liquor) because complete pulping is not required.

Table 1. Batch conditions for bagasse fiber preparation.

Parameter	Value
Water	200 L
Na_2CO_3	2 kg
Raw bagasse for treatment	15 kg
Treatment time	90 min
Temperature	100 °C

Mill-run bagasse may contain incompletely shredded cane rind (Figures 1 and 3) that would interfere with mat formation. The large pieces were removed with a 2.5 cm mesh screen. The mild alkali treatment only softens the fibers and it was found that partial mechanical refining of at least a portion of the alkali treated bagasse was beneficial to improve mat cohesion. A single pass of one third of the alkali treated bagasse through a 20 cm diameter Bauer Brothers single disk refiner with a 0.05 cm plate gap was found sufficient. The partially refined fibers were then mixed with the non-refined bagasse and used to form the mat (Figure 2). The partial refining not only reduces the fiber width but also releases some bagasse pith that contributes to the cohesion of the fibers once formed into the mat.

Figure 1. Rind pieces in mill-run bagasse (scale in inches).

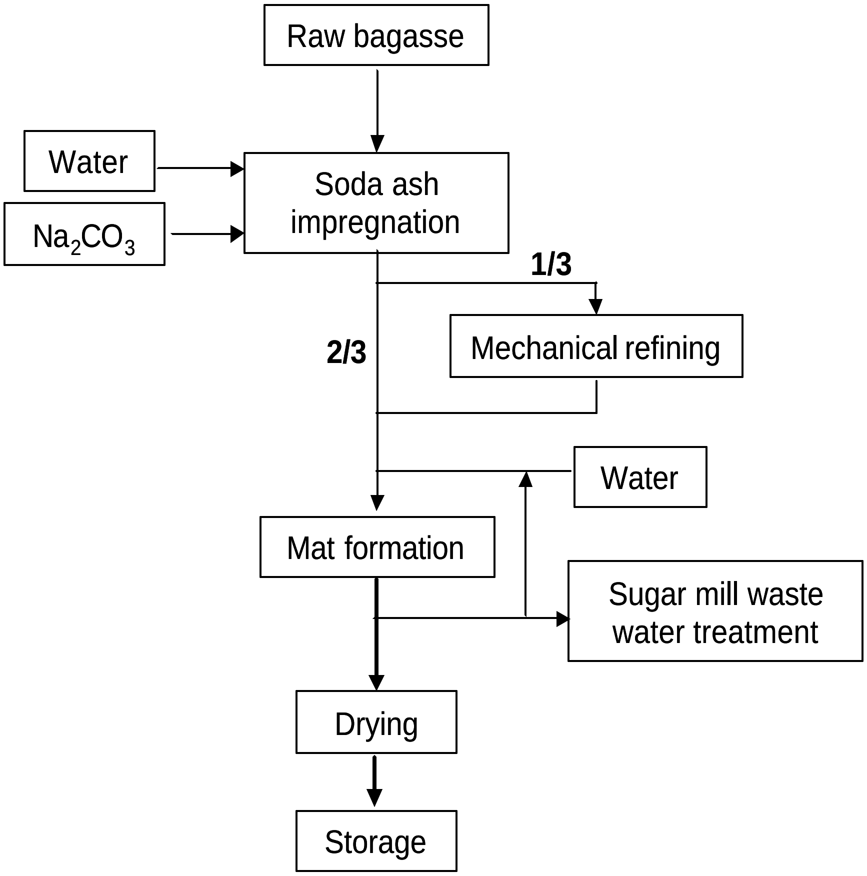

Figure 2. Block diagram of the bagasse mat production process.

The large rind pieces in bagasse come from incomplete shredding of the cane prior to juice extraction. The extent of the mechanical and possibly even the chemical treatment could therefore be adjusted depending on the actual quality of the bagasse that is being processed. Comparison of bagasse samples from three different mills (Figure 3) shows better fiber uniformity in the samples from Texas and Florida.

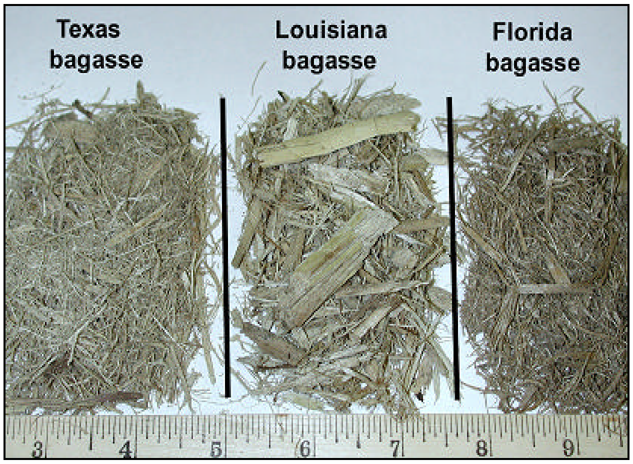

Figure 3. Comparison of bagasse samples from three different mills (scale in inches).

After several preliminary designs, a 1.2 m (4 ft) wide mat production prototype was designed and built (Figure 4). The bagasse that was added manually into the tank (1) is kept in suspension by the flow of water (11) and mechanical mixers (2). The water flow rate (11) was adjusted such as to supply an even overflow (3) of the bagasse slurry onto the moving mesh (4). For the belt (4), a vinyl-coated polyester fabric with a 1.5 mm mesh size was found suitable to allow rapid drainage of water while retaining all the fibers. Two PVC rollers (5) compress and squeeze some of the excess moisture out of the mat. The rubber coated roller (6) was driven by a variable speed motor (8). The excess water flows through the mesh into a collection tank (9) and can be recycled into the process. The wet fibers have little cohesion. Therefore, another, support mesh (7) which is identical to the first one was used to support the wet mat as it is being removed off the moving belt and transferred to dry. The thickness of the mat is affected by the rate at which fibers are added in the feed tank, the water flow rate, and the belt speed. The operating parameters listed in Table 2 were found to give good and reproducible performance.

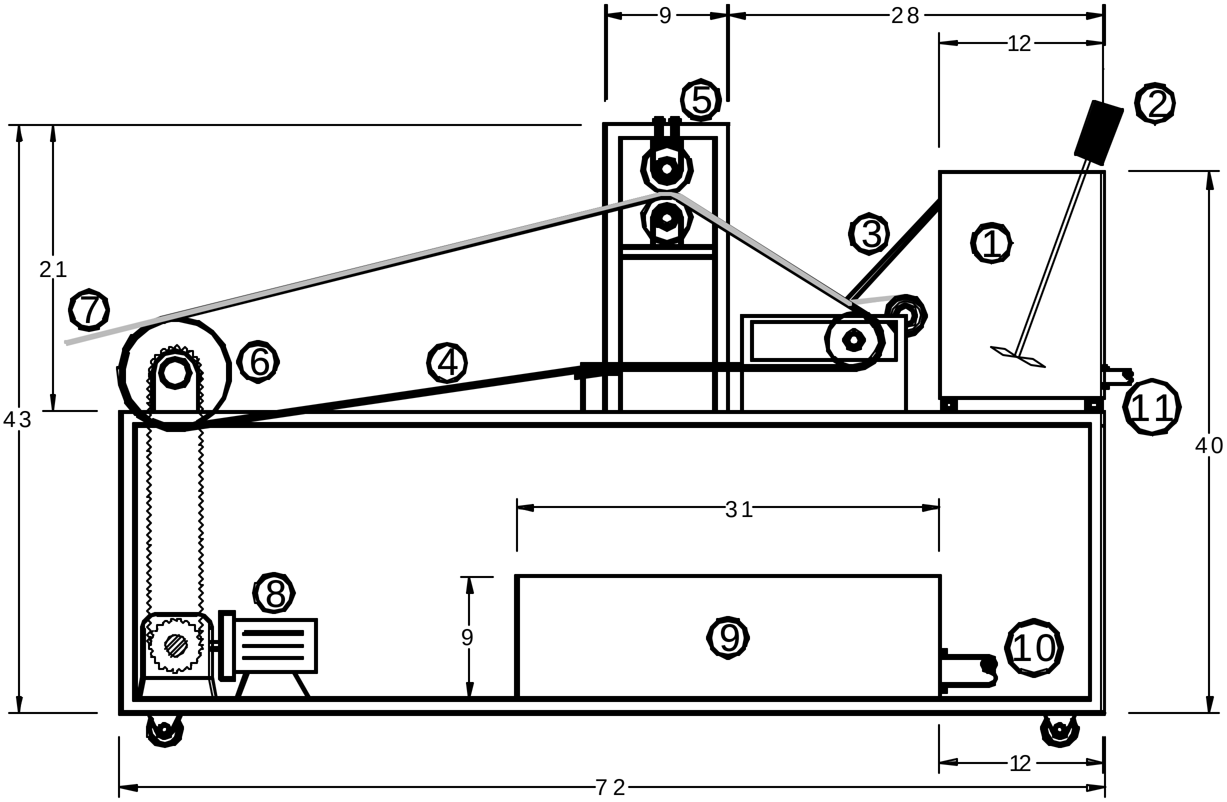

Figure 4. Schematic of the main components and dimensions of the mat formation prototype machine (scale in inches).

Figure 5. The mat formation process: bagasse fibers are added manually into the feed tank and the bagasse slurry overflows onto the moving mesh belt forming the mat.

Table 2. Mat formation operating parameters.

Parameter	Value
Tank volume	170 L
Belt length	3 m
Belt speed	0.24 – 0.60 m/min
Water flow	100 – 200 L/min
Time to form one 2.5 m long mat	~12 min

Figure 6. A partially rolled and dried bagasse mat.

After formation, the 2 to 3 m long mats were air-dried while supported by the mesh (Figure 6). Once dry, the mats could be peeled off the support and rolled. During the mat formation on the moving mesh, fiber stratification takes place. The finer pith particles penetrate through the longer fibers but are mostly retained by the support mesh. Therefore, the mats tend to have a two-layered structure (Figure 7) with most of the pith at the bottom of the mat and the larger fibers at the top. The bottom pith layer contributes to the cohesion and strength of the mat.

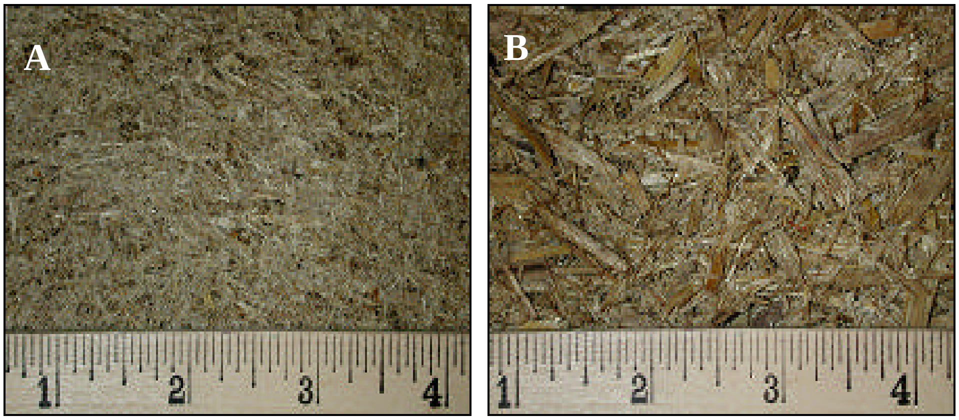

Figure 7. The bottom of the mat (A) with most of the pith and the top (B) composed mostly of coarse fibers (scale in inches).

RESULTS AND DISSCUTIONS

Evaluation of the effects of alkaline treatment on bagasse fibers

Thermo-gravimetric analysis (TGA) was used to evaluate effects of the chemical treatment on bagasse fibers. Two samples were used for comparison: raw (untreated) bagasse fibers and the fibers recovered from finished mats. The air-dried samples were ground with a Wiley mill with a 0.5 mm screen and the undersize fractions analyzed with a Mettler Toledo TGA/SDTA851^e analyzer. Samples of 10 to 20 mg were heated from 40°C to 700°C at 10°C/min, then kept isothermal for 10 min under N_2 and then ashed for 10 min under air at the same temperature. For reference, relatively pure samples of cellulose (Avicell from FMC BioPolymer), lignin (Granit, SA) and hemicellulose (oat spelts xylan from Sigma Chemical) were also analyzed. Hemicellulose is the least thermally stable of the three with the onset of decomposition at 279°C (Table 3). In comparison, the onset of decomposition for cellulose is at 319°C.

Table 3. The onset, weight loss, char and ash values for the pure compounds and treated and untreated bagasse samples.

Compound	Onset of decomposition	Weight loss at 400°C	Char	Ash
	°C	----------------------	% ----------------------	
Cellulose	319	78	11	0.5
Hemicellulose	279	63	24	6.9
Lignin	296	36	31	1.3
Untreated bagasse	282 – 291	58 – 60	28-30	13 – 16
Treated Bagasse	292 – 294	64 – 66	20-23	3 – 6

The lignin decomposes over a wide temperature range, between 200°C to about 500 °C. These observations are broadly in line with the values reported in the literature (Chen et al., 2005; Orfao et al., 1999; Raveendran et al., 1996; Haiping et al., 2006), but the exact values are affected by the temperature gradient, the source and purity of the compounds, and other experimental factors.

The derivative thermo-gravimetric (DTG) profiles of hemicellulose and cellulose (Figure 8) display distinct maxima at 308 and 360°C. The DTG curves (Figure 9) of the treated and untreated bagasse samples show peaks from the loss of residual moisture at below 100°C and cellulose decomposition at 360-370°C. The shoulder at about 300°C on the untreated sample curve corresponds to decomposition of hemicellulose but is absent in the curve of treated bagasse.

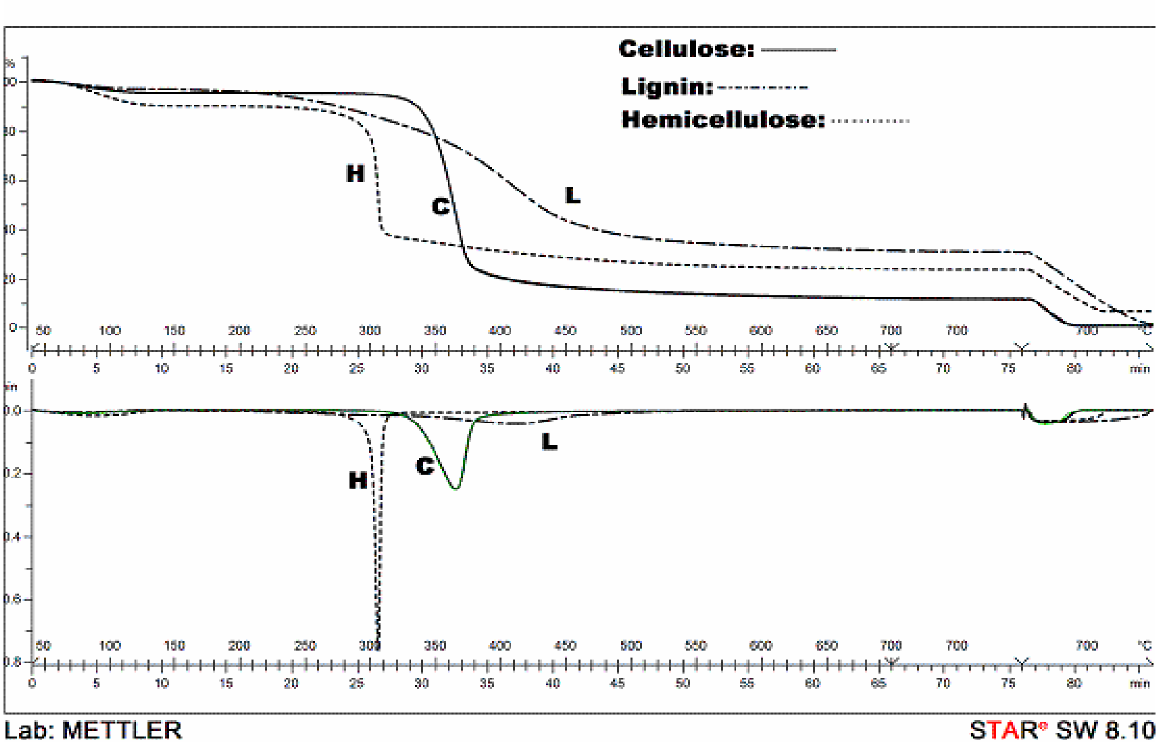

Figure 8. Comparison for the TGA curves (top) and DTG curves (bottom) for cellulose, lignin and hemicellulose.

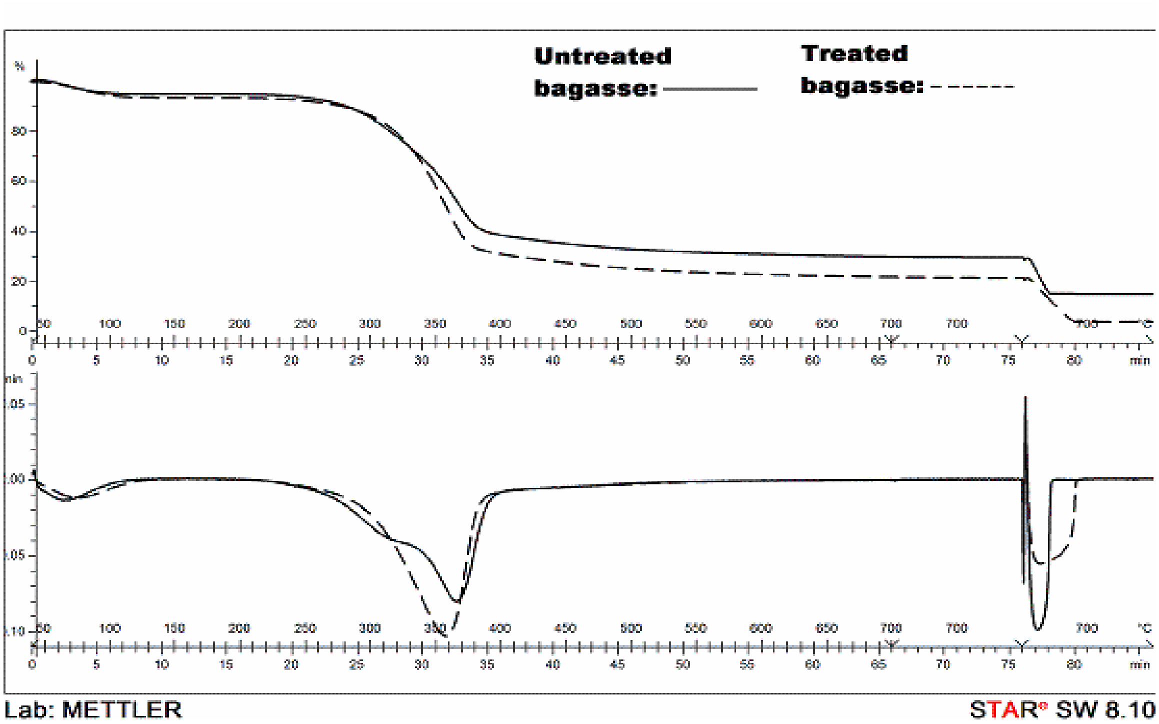

Figure 9. Comparison of the TGA curves (top) and DTG curves (bottom) of treated and untreated bagasse samples.

This is an evidence of at least a partial removal of hemicellulose in the alkali treatment. The rate of cellulose decomposition is higher in the treated than untreated sample. This is probably related to the disruption of the cellulose network by a partial removal of hemicellulose and lignin during the alkali treatment. Because of the broad range of purified lignin decomposition (Figure 8), lignin decomposition peaks are not apparent in either treated or untreated bagasse curves. However, the higher yield of char (Table 3) from the untreated material in comparison with the treated one is an evidence of some lignin removal in the alkali treatment. This is consistent with reports (Chen et al., 2005; Orfao et al., 1999) that higher lignin content material yielded higher amount of pyrolysis char and also with the char yields obtained from the three pure compounds (Table 3) in this work. The apparent peaks in the DTG curves in Figures 8 and 9 at 700°C are artifacts from switching between nitrogen and air atmosphere.

In plant tissues, lignin and hemicellulose are known to be a part of the cellulose network contributing to the strength and stiffness of the fibers. The alkali treatment used in this work, i.e. boiling with 1% sodium carbonate for 1½ hours, proved suitable for their partial removal; as a result, the cellulose fibers are rendered sufficiently flexible and can be formed into cohesive mats. In a separate experiment, the solubility of the pure lignin sample in a 1% sodium carbonate liquor was determined to be about 8.5 g/L.

Evaluation of the physical properties of the erosion control products

The bagasse mats were tested in accordance with the ASTM and ECTC (Erosion Control Technology Council) methods and the specifications compared (Tables 4 and 5) with those of four leading commercial products as reported by their manufacturers or measured in this work.

Table 4. Details of the four commercial erosion mats used for comparison with the bagasse products.

Name	Description	Manufacturer
S 150	Straw, double PP net	North American Green
C 125	Coconut, double PP net	North American Green
Curlex I	Curled wood fibers, double PP net	American Excelsior Co.
Curlex high-velocity	Curled wood fibers, double high-velocity PP net	American Excelsior Co.

Thickness of the bagasse mats can, of course, be varied, but was chosen such as to be comparable with the commercial products. The specific mass of the bagasse mats is higher than the S150 and C125 products, but comparable with the Curlex materials. Because of the higher density and porosity of the bagasse fibers, the water absorption is much higher. The swelling is about the same as reported for straw (S150) and coconut (C125) mats and less than reported for the Curlex wood products.

The bagasse mats have a relatively low smolder resistance. Unlike the straw and coconut mats that have a loose structure and wide spaces between fibers, bagasse mats are more compact with the smoldering ring of up to 10 cm. The Curlex blankets for which manufacturer's data was not available were also tested. The smoldering ring had a maximum of only 1.5 cm. Although smolder resistance is reported by the manufacturer, one sample of the S150 straw mat was also tested and found to smolder as well.

Table 5. Product specifications

Property	S150	C125	Curlex I	Curlex High-velocity	Bagasse mats	Test
Thickness (mm)	8.13[1]	8.91[1]	9.14[2]	13.72[2]	7.5 -10[3]	ASTM D 6525
Specific mass (g/m^2)	257[1]	271[1]	407[2]	841[2]	550-850[3]	ASTM D6475
Water absorption (%)	327[1]	110[1]	253[2]	194[2]	807-1090[3]	ECTC (modified ASTM D 1117)
Swell (%)	15[1]	13[1]	49[2]	48[2]	14-36[3]	ECTC
Smolder resistance	YES[1]	YES[1]	NO[3]	NO[3]	NO[3]	ECTC
Tensile strength (kN/m)	2.27[1]	3.12[1]	1.4[2]	3.36[2]	0.10[3]* 0.18[3]**	ASTM D 5035

[1] - product data sheet (North American Green, 2004); [2] - product data sheet (American Excelsior Company, 2006); [3] - measured in this work

* - sample oriented with most fibers perpendicular to the load direction

** - sample oriented with most fibers parallel with the load direction

The higher tensile strength of the commercial products stems from the polypropylene nets imbedded in the product. For instance, the tensile strength of the polypropylene mesh alone isolated from a commercial sample of S150 was 0.18 kN/m or 80% of the reported value (North American Green, 2004) for the complete erosion mat. In the case of the bagasse mats, the strength is solely from fiber entanglement and adhesion. Because of how the wet-laid process was designed, the fibers are oriented mostly perpendicular to the direction of belt movement and the tensile strength is somewhat higher along the preferred orientation of the fibers. The polypropylene nets that hold the fibers together are described by the manufacturers as photodegradable but their life span may be long enough to present ecological problems. There have been reports of birds and other small wildlife animals trapped in the nets in their attempt to nest in the blankets (Prunty et al., 1998). Obviously, nets could also be imbedded in bagasse mats to increase their strength; but, at present, their absence is considered to be an environmental and economic advantage.

ECONOMIC CONSIDERATIONS

Erosion control manufacturing is a growing industry supplying markets with a variety of products (Berg and Suits, 1999). Erosion control blankets for temporary soil protection in road construction projects, for levee protection and similar applications range from \$0.4/m^2 (straw and wood based) to \$2/m^2 for polypropylene and up to \$3/m^2 for imported coconut fiber products (Peña, 2005 per. comm.). The reported weight of 300 g/m^2 for straw and 500 g/m^2 for coconut is equivalent to about \$1.3/kg to \$6/kg respectively. Taking the lowest estimate of \$1.3/kg for the prospective bagasse products would translate to a value of about \$0.6/kg or \$600/t of mill-run bagasse with 50% moisture; thus, making it potentially an attractive product for the sugarcane industry.

The annual local Louisiana market alone is estimated at \$10 to \$20 million, or 5,000 to 10,000 tons of erosion control fabrics (taking an estimate of \$2/kg of fabric). With a yield of 33%, based on mill-run bagasse, this would require 15,000 to 30,000 tons or about a five to ten day production of bagasse in an average Louisiana sugar mill. Such a relatively small amount should be available at any mill with only minor improvements in the mill's steam economy.

CONCLUSIONS

A simple continuous wet-laid process for production of sugarcane bagasse erosion mats has been developed and demonstrated. The physical properties of the bagasse mat samples were tested according to ASTM and ECTC procedures and compared with those of four commercial products. The bagasse mats have comparable specific mass, thickness, and swelling, but lower tensile strength because no polypropylene netting is used and water absorption capacity is higher. The absence of plastic netting is considered an advantage from the standpoint of environmental impact and the production cost. The relatively small volume of bagasse that would be required to satisfy the local erosion control market should be readily available at the sugar mill site, providing a new business opportunity for the sugar industry.

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