Mechanical Compaction of Nonwood Fibers for Production of High Strength Packaging papers

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Although nonwood fibers presently account for only about 6% of the total fiber used worldwide for paper making, the attention these fibers have been receiving by the paper industry has increased dramatically within the last few years. This increased attention is due to many factors, some of them being (1) a growing industry acceptance of nonwood fibers potential; (2) the projected woodpulp shortage; (3) a desire by nations or groups of nations to reduce or eliminate their dependency on long fiber imports; and (4) impressive technological strides in the pulping and processing of nonwood fibers. Before discussing in detail one of these technological advances, mechanical compaction of nonwood fibers, I would like to discuss briefly the other factors mentioned above in order to put the important technical work in proper perspective.

First, there seems to be a growing acceptance within the paper industry that being classified as a "forest products" or *wood* resources industry in this age of intense competition and shrinking profits is too confining. Many large paper companies have, by their growing use of plastics, chemicals, and other materials made it clear that they are not limited to wood as a raw material. The main theme that runs through the history of paper making is the industry's constant search for a cheaper and more abundant fiber source and despite the present overwhelming use of wood as this fiber source, the industry does have an increasing awareness of what has been called "the functional nature of natural resources." This had led to research expenditures on nonwood fibers by many industry leaders firmly based in woodpulp production.

Another important factor which will certainly increase the utilization of nonwood fibres is what is often called Economic Nationlism. Many countries are becoming more determined than ever to become self-sufficient in one of the world's most basic industries paper. The tremendous drain on a nation's economy represented by huge pulp imports is rapidly becoming intolerable and many governments are taking steps to further develop their own natural fibre resources. This pulp potential is vast, both for wood pulp and nonwood pulp when fibers such as hardwoods, eucalyptus, bamboo, bagasse. and straw are included.

All factors discussed thus far-industry acceptance, wood pulp shortage, and economic nationalism-will contribute to the growth of nonwood fiber use ; but real growth is still largely dependent upon technological progress in the collection, pulping, and processing of these fibers. Impressive progress has already been made in many areas such as improved techniques in the depithing of sugar cane bagasse that results in a higher quality pulp than previously attainable. Inadequate chemical recovery has also been a stumbling block to large-scale bagasse operations, but an indication of the future is given by a recent report from a mill in Argentina, which reportedly now has in operation a successful modern black liquor recovery system for bagasse. Developments such as these will no doubt result in greater utilization of nonwood fibers.

Mechanical compaction is another development which may lead to greater utilization of nonwood fibers because the additive nature of the process upgrades the important properties so essential for high-strength applications such as multiwall sack papers. The process then can be a tool to expand the grade range of nonwood papers. Numerous researchers, including Burgstaller and Krauss[1] and McKee and Whitsitt[2], have concluded that the most

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important strength property of such high strength papers is the "toughness" or Tensile Energy Absorption (TEA). This property is actually a measure of the sheet's ability to perform work, or stating it another way, absorb energy. From basic physics, work or energy is equal to the applied force multiplied by the distance through which the force acts. A graphical representation of TEA is shown in Figure I.

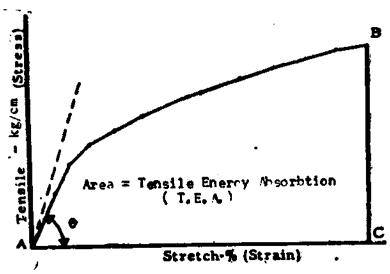


Fig. I Graphical Representation of T. E. A.

This graph is a simple stress-strain curve for a paper sample. An increasing tensile load (stress) is applied in such a way that the paper is stretched (strained) at a constant rate. This curve shows the condition of the paper sample for any load up to the breaking point. From curves of this type, a vast amount of information can be obtained about both the structure and the physical strength of the paper. Point B on the curve is the tensile breaking strength used as a specification for many types of paper. Angle θ has been found to be related to paper folding endurance and stiffness. The most important property, for this discussion, the one that has been shown to correlate best with multiwall sack performance is the *area* outlined by poitns A-B-C. This area under the stress strain curve is a direct measure of the energy absorbing capacity of the paper, and is called *Tensile Energy Absorption.* Papers made from nonwood fibers generally have low TEA values, therefore, any method to upgrade or increase this property opens a new door for utilzation of these fibers.

Such a method is the process of mechanical compaction, which works as follows: the moist web of paper, while still in plastic form, is subjected to the recoil action of an endless elastic surface. Figure 2 permits a closer examination of the working parts of equipment which consist of a nonrotating pressure member, a chromium-plated, low friction dryer cylinder which is driven, and the elastic surface, an endless rubber belt or blanket constructed so that the neutral axis of this blanket is very near the inside surface.

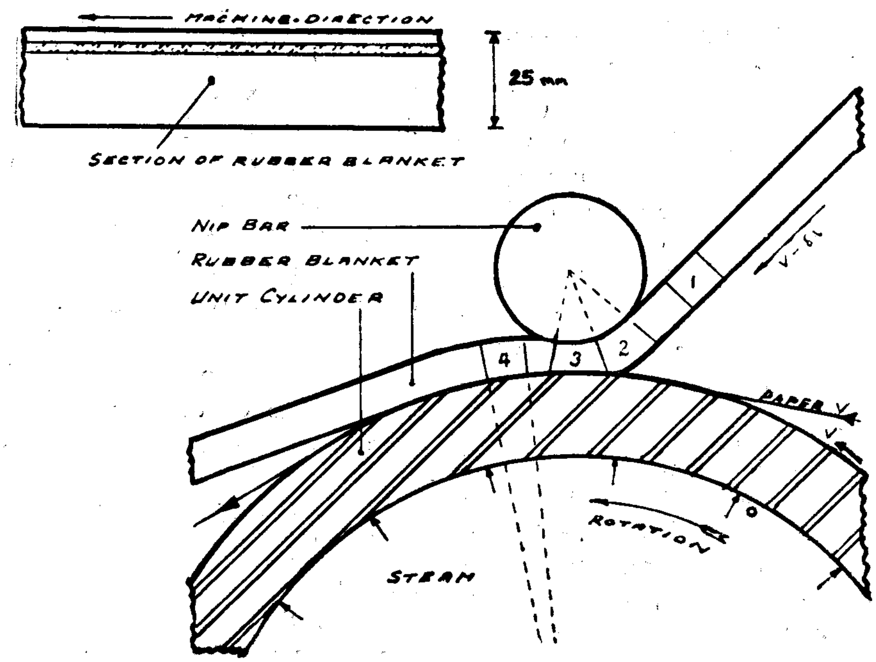


Figure 2—Blanket construction and orientation in the nip area.

With the pressure member (nip bar) loaded, the gap in the nip becomes less than the blanket thickness and the rubber then acts like water flowing through a venturi; it accelerates to an increased velocity so that the volume flowing is a constant. An examination of the blanket speeds shows that at point 1, the rubber section is plane, unstressed and travelling with a velocity of ($V-\delta V$). At point 2, the blanket reinforcing velocity is unchanged, but the outer surface of the rubber has, by virtue of wrapping the nip bar, accelerated to a velocity approaching V. The venturi effect accelerates the rubber surface still more until, at the beginning of section 3, it has attained a velocity V at the point of contact with the cylinder surface. It is at this point (the rubber surface stretched to its greatest length) that the moist paper sheet is introduced into the nip. The composite sandwich of stressed rubber, paper and cylinder pass towards the centre of the nip, after which the outer rubber surface, although still under high radial pressure, begins to recoil and primary compaction takes place. Overlapping this, a secondary compaction takes place. owing to the reverse curvature of the blanket immediately past the center line. This is apparent in section, 4, which (for the sake of clarity) has been drawn clear of the actual nip area. The rubber surface speed has now returned to its former velocity of (V–δ V).

At the time the blanket is recoiling within the latter half of the nip area, the plastic, moist sheet (even though still under a high radial pressure) is subjected to a longitudinal compressive force by the frictional effect of the blanket. This tends to induce a sheer stress within the sheet, but the highly polished chromium cylinder plus the steam film generated between the paper and the cylinder surface allow the plastic sheet to slide easily with the recoiling rubber; at the same time, the fibers are pushed and crowded together in an interlocked and rearranged form.

The resultant web can be simply defined as a non-creped paper with substantially parallel faces, having no bodily folds and being characterized by high stretch and high TEA. Visually, the sheet has the same appearance as regular paper, but is slightly less stiff.

Fig. 3 illustrates the set-up for the rubber blanket and the fundamental parts of the unit. The nip bar does not rotate and is water lubricated by two sprays inside the blanket.

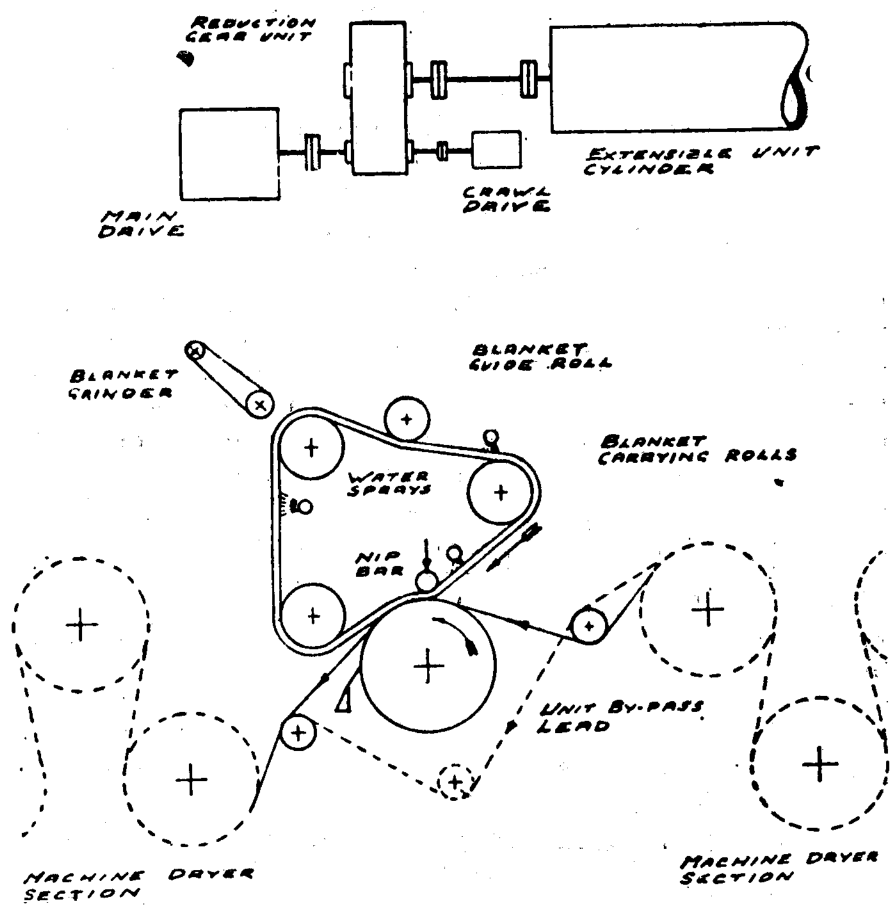


Figure 3—Digrammatic arrangement of blanket extensible unit.

A thrid spray covering the outside of the blanket cools the blanket surface during paper breaks and is automatic in operation. The unit is installed within the dryer sections of the paper machine at a point that the paper is normally in the range 33–38 per cent wet and usually occupies the space vacated by four drying cylinders. The unit drive is simple. consisting of an electric motor (or differential gearbox in the case of a mechanical drive), a reduction gearbox and then straight on to the unit cylinder end. A very small electric auxiliary drive is built into the reduction gearbox for crawling the extensible unit for blanket maintenance. The total required horsepower is equal to that of a simple wet press. The papermachine drive is then arranged so that the sections after the extensible unit can be independently slowed down in speed equal to the compaction imparted to the paper. Machine-direction stretch levels of 20 per cent have been easily obtained, but, for commercial requirements, the units are designed for a maximum of 18 per cent machine-direction stretch at the reel.

The unit does not limit the speed of operation and it is still the papermachine that determines the maximum speed. At the present time, extensible sack kraft is being commercially produced at 1800 ft/min and the largest extensible unit in the world is in production in Finland on a machine of 281 in wire width and a design speed of 2500 ft/min.

Commercial installations have for a number of years now used the process to produce high-quality premium-priced packaging papers, but even from the first, some operations have utilized the benefits gained from compaction by increasing the proportion of hardwoods, broke, waste, etc. in the furnish and still producing an acceptable sheet.

Table 1 gives comparative values of regular and extensible krafts; it can be seen that, with the chosen stretch level of about 9 per cent, T. E. A. is increased four times with a corresponding increase in the cross direction. Tear values are always improved, usually by approximately 5 percent in the machine-direction and 15 per cent in the cross-direction. Air permeability is little changed; in any case, unlike a crepe sheet, this value can be altered by refining changes in the same way as with a regular sheet.

TABLE 1

Comparative Physical Test Results on Regular and Extensible Papers

Property	Sheet Direction	North American Paper (1) Regular	North American Paper (1) Extensible	European Paper (2) Regular	European Paper (2) Extensible
Basis weight, g/m^2	—	81	81	80	80
Caliper, in	—	0.0051	0.0049	—	—
Tensile strength, lb/in	Machine	32.3	23.2	34.3	28.8
	Cross	20.0	18.7	22.5	18.5
Stretch, per cent	Machine	1.9	9.6	3.2	10 8
	Cross	4.2	5.6	6.0	7.3
T.E.A., ft lb/ft^2	Machine	4.2	16.8	10.8	32.4
	Cross	7.2	8.4	17.7	16.4
Tearing strength.g	Machine	130	136	—	—
	Cross	150	172	—	—
Air permeability, sec/100 cm^3	—	7	9	—	—
Air permeability, cm^3/min	—	—	—	260	240

(1) Tested at 50 per cent rh (2) Tested at 65 per cent rh

The European results illustrate the additive properties of the process for a high strength base sheet. This is true also for a weaker sheet and the system has proved to be particularly effective for upgrading an inferior furnish. Fig. 4 and 5 illustrate for both regular and extensible papers the effect of a change in furnish from 100 per cent kraft to 100 per cent short fibres–in this case, hardwood. Because the process is mechanical, stretch is independent of furnish and, even with a completely short-fibred sheet, the T.E.A. figure can easily be twice as high as the control, whereas the tear values remain the same even with the addition of up to 50–60 per cent short fibres.

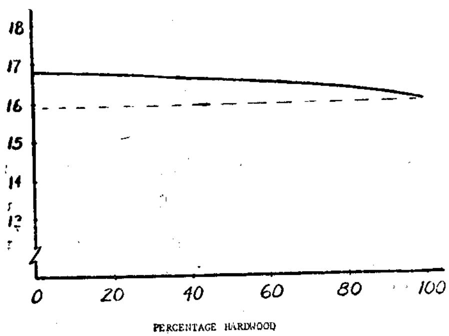
Bagasse was one of the first nonwood fibers to be upgraded by compaction in a commercial operation. Table 2 compares the quality of a regular sheet, made from 100% long-fibered kraft pulp to a sheet with 55% bagasse made on the same machine but compacted. The important point to note is that in the case of TEA and tear, the compacted bagasse sheet is superior to the uncompacted long-fibered wood sheet. Results such as these have led to the current commercial production of more than 150 metric tons per day of compacted multiwall sack paper with a bagasse content around 60%.

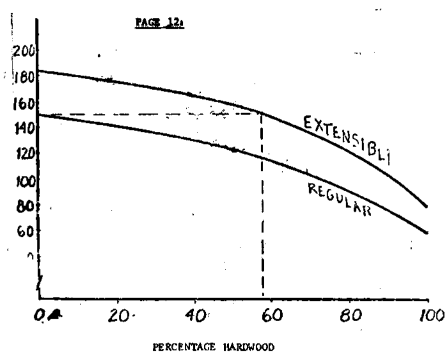
Labortory compaction studies have been made to investigate the effect of mechanical compaction on other webs containing nonwood fibers such as bamboo aud straw.

TABLE 2

Comparative Values of Compacted Paper Containing 55% Bagasse and Uncompacted Paper Containing 100% Pine

Property	Sheet Direction	Compacted	Uncompacted
Basis weight, g/m^2	—	100	100
T.E. A. cm–kg/100 cm^2	Machine	21.3	7.9
	Cross	6.4	4.9
Stretch, per cent	Machine	9.7	2.0
	Cross	3 0	2.6
Tensile strength, kg/15mm	Machine	6.3	10.6
	Cross	4.5	4.6
Tearing strength, g	Machine	108	102
	Cross	142	128
Furnish		55% bagasse 45% pine	100% pine





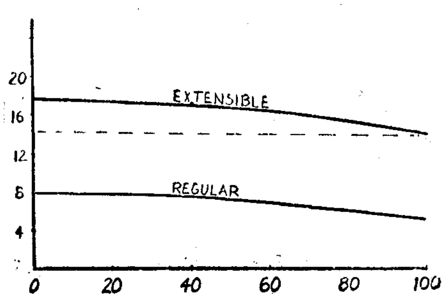


Fig. 4 Percentage Hardwood

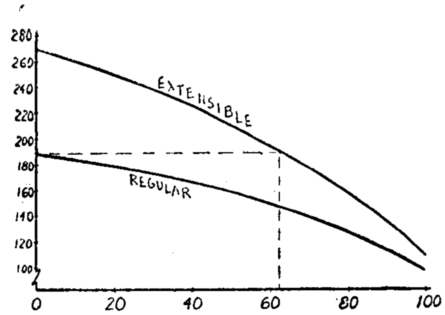


Fig 5 Percentage Hardwood

For the bamboo study, the species Dendrocalamus Strictus was obtained from the Dangs and Vyara Districts of Gujarat State in India. Data on the pulping conditions and pulp quality is presented as Table 3.

TABLE 3 Details of Bamboo Pulp for Compaction Study

Raw Material :	Bamboo
Species :	*Dendrocalamus Stricuts*
Forest :	Dangs and Vyara Districts of Gujarat State, India.
Quality of pulp :	Unbleached Kraft.
Process :	Sulphate.

Cooking Conditions :

Chemicals :	12–13% as Na_2O on B. D. Chips.
Chip to liqu r :	1: 2.8
Time to temp :	2½ hrs.
Temperature ;	150–155°C
Time at temperature :	2 hrs.
'K' No. :	25–27

Lab Evaluation Report :

1. Initial Freeness (CSF) :	700
2. Final Freeness (CSF) :	260
3. Burst Factor :	36.7
4. Tear Factor :	66.7
5 Breaking Length (m) :	6,160
6. Double Folds :	37
7. Bulk (cm^3/g) :	1.58
8. Beating time (mts) :	170
9 Knit Counts (3 g/6 mts) :	39

Fibre Classification (%) :

+20 mesh	+50 mesh	+60 mesh	+125 mesh	–125 mesh
56.2	73.9	80.1	84.3	15.7

Regular and compacted papers were produced from 100% bamboo pulp after beating in a 25 pound (11.4 kg.) Valley Beater at 3% consistency to 48 seconds Williams Standard Freeness. The papers were produced on a 12 inch (30.5 cm) wide experimental paper machine. For comparison, sheets were also produced using 100% North American long-fibred pulp; and for further study, sheets were produced using mixtures of the two furnishes. Half of all the papers made were mechanically compacted, and then control and compacted samples were conditioned and tested. The results are illustrated in Figures 6 to 10 and then summarized in Table 4. These figures show the following :

1. The increase in the important property TEA (Figure 6) as a result of compaction ranged from 140–330% more than the TEA of the uncompacted sheet. The TEA of the compacted sheet with 100% bamboo is almost 40% more than the uncompacted sheet with 100% kraft long fiber.

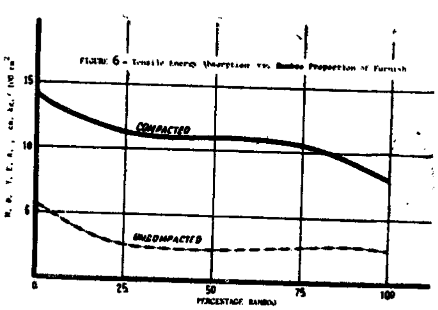


Fig 6

2. The machine direction stretch (Figure 7) was, as expected, increased dramatically by compaction, regardless of furnish.

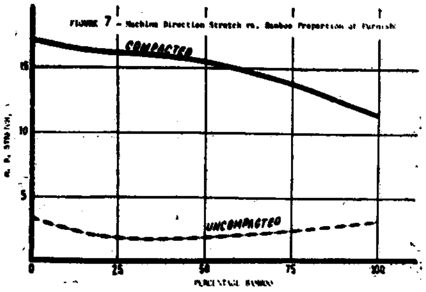
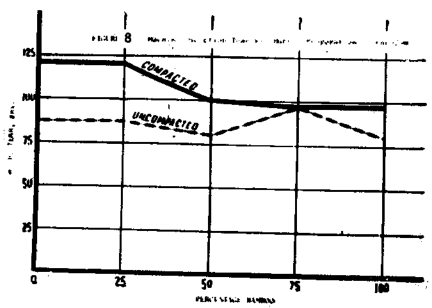


Fig. 7

3. Figures 8 and 9 illustrate the higher tear values obtained when the sheets were compacted, and they also show a modest decrease in tear with the compacted sheets when the bamboo portion of the furnish was increased.



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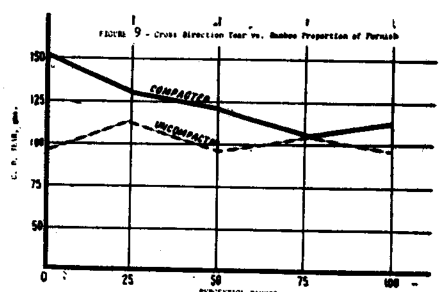

Fig. 9

4. Figure 10 illustrates that the compacted sheets suffered a reduction of tensile strength and that this percentage loss remains practically constant as the bamboo portion of the furnish increases.

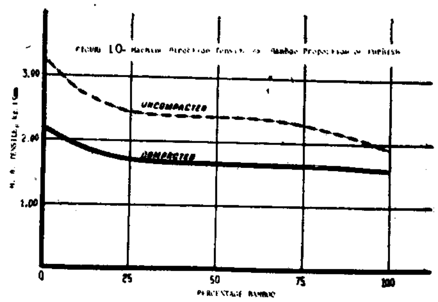

Fig. 10

Results such as these indicate that mechanical compaction treatment of bamboo papers significantly upgrades certain important strength properties.

Straw pulps have been utillzed in paper making for many years and at least 11 countries now have continuous straw digesters. Although straw fibers are short, the strength properties are quite good. Laboratory compaction work was carried out using straw obtained from Greece. As with the bamboo study, the straw pulp was mixed in varying proportions with long fibered kraft pulp. Both pulps were beaten independently in a Valley Beater at 3% consistency. The straw required only two minutes beating time to obtain a Williams Freeness of 74 seconds. The pine was beaten 30 minutes to obtain an average freeness of 29 seconds Williams Freeness. Once again, half of all papers produced were compacted and then all sheets were conditioned and tested. This data which has been corrected to a basis weight of 100 grams/meter^2 is presented as Figures 11 to 14 and can be summarised as follows :

TABLE 4

Physical Tests of Uncompacted and Control Sheets VS. % Bamboo

% Kraft Pine	% Bamboo	TENSILE (kg/15 mm) Compacted	Control	ELONGATION (%) Compacted	Control	T. E. A., (cm kg/100 cm², Compacted	Control	INTERNAL M. D. Compacted	Control	TEAR (gms) C. D. Compacted	Control
100	0	2.20 ±0.19	3.35 ±0.13	17.1 ±0.8	3.6 ±0.6	14.0 ±1.0	5.7 ±0.9	120	88	152	96
75	25	1.72 ±0 08	2 44 ±0.05	16.2 ±1.0	2.0 ±0.2	11.2 ±0.6	2.7 ±0.5	120	88	128	112
50	50	1.66 ±0.05	2.39 ±0.16	15.4 ±0.6	1.9 ±0.5	10.9 ±0.4	2.5 ±0.3	100	80	120	96
25	75	1.63 ±0.11	2.25 ±0.11	13.7 ±1.1	2.4 ±0.8	10.6 ±0.9	2.8 ±0.6	96	96	104	104
0	100	1.53 ±0.08	1.85 ±0.08	11.3 ±0.7	2.9 ±0.2	7.8 ±0.6	2.5 ±0.3	96	80	112	96

NOTE : All values average of five tests from center of web.
Tear values are averaged during test so that no measure or variation is available.
All values reported are corrected to 83.0 gms/m² basis weight.
Basis weight variation was from 82.0 gms/m² to 84.8 gms/m² on uncompacted sheets.
Cross direction tensile, stretch, and TEA tests are not reported because of edge effects of the narrow machine.

1. There seems to be no real relationship between sheet composition and the tensile strength, stretch or TEA (fiigures 11—13).

2. The increase in TEA, as a result of compaction, averaged about 300%. (Figure 11).

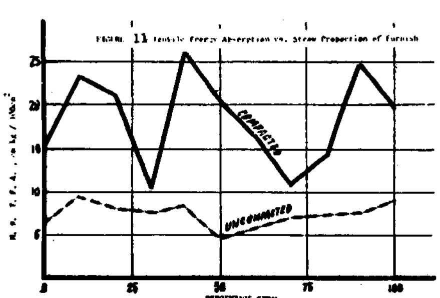

Fig 11

3. The loss in tensile strength as a result of compaction averaged about 25% (Figure 12).

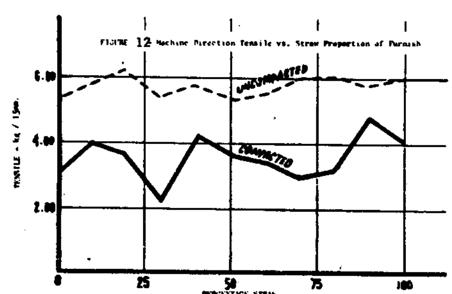

Fig. 12

4. The machine direction stretch of the compacted papers ranged from around 4 to 7 times as great as the stretch of the uncompacted papers (Figure 13).

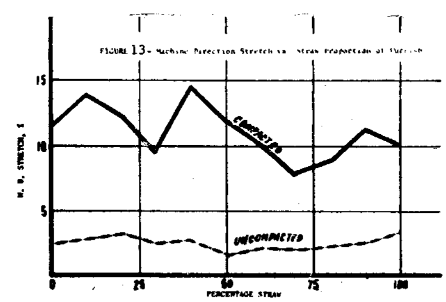

Fig. 13

5. Edge tear tests showed a definite correlation with sheet composition, both for compacted and uncompacted samples. In both cases, the edge tear values decreased as the percentage of straw increased (Figure 14). These results also illustrate the dram-

atic increase in edge tear values as a result of sheet compaction, and show that a compacted 100% straw sheet has comparable edge tear with an uncompacted sheet containing around 70% kraft pine.

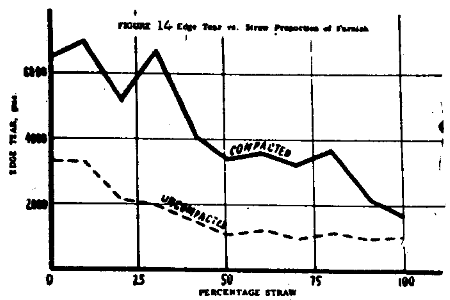

Fig. 14

Commercial production of straw based extensible paper for multiwall sacks is scheduled to commence about mid 1973. The commercial compaction of bagasse papers and the laboratory compaction of bamboo and straw papers indicate that the physical effects of the mechanical compaction process on many different types of papers can be predicted with a fair degree of accuracy. The additive and the mechanical nature of the process enable significant strength increases to be achieved on virtually any type of paper. It is clear that the ability of this process to easily control some of the vital properties of paper from nonwood fibers will be an important consideration in developing the tremendous potential these fibers represent.

In commericial use, the application of extensible paper has entered the majority of fields for which toughness, resistance to impact, puncture and tear are required and thi hass led to the production of extensible bag and sack papers, wet strength and saturating grades, plastic and foil laminates, laminated kraft liner, cable papers, insulation board and pressure-sesitive tape stock. Because of its conventional appearance, the paper accepts coatings and print economically with good definition and with its extensibility, the paper is further enhanced by the natural extensibility, of many coatings previously lost on regular paper.

In 1955, Burgstaller and Krauss[2] demonstrated that a paper's T.E.A. value could be used to predict its performance when used in a multiwall sack, thus the advent of extensible paper has resulted in a considerable use for sack manufacture, which increases yearly. Briefly, extensible multi-wall sacks will contain less paper than with a regular construction, thus showing a subs-

TABLE 5—Multi-Wall Sack Constructions in Regular and Extensible Kraft Paper

Weight of filled sack	Product filing the sack	Original construction* regular paper	Total basis weight, g/m²	New construction* extensible paper	Total basis weight, g/m²	Saving per cent
110 lb	Saltpetre	1/75PE 3/75 1/75PE	375	1/90PE 1/90 1/90PE	270	28
—	Refuse sack	2/80	160	2/75	150	6
				or 1/120WS	120	25
110 lb	Cement	3/80	240	2/90	180	25
10 lb	Cement for			or 2/100	200	17
	export	4/80	320	3/90	270	16
				or 3/80	240	25
110 lb	Iron powder	6/80	480	4/90	360	25
110 lb	Sugar	4/80	320	3/90	270	16
75 lb	Phthalic anhydride flake	4/88	352	2/80 1/80 WS	240	32
50 lb	Polystyrene pellets	1/88 PE4/88	440	2/88 1/88PE1/88WS	342	29
50 lb	Polystyrene pellets for export	1/88PE 4/88 2/80	600	3/88 1/88PE1/88WS	440	27
110 lb	Cement for export	5/75	375	3/90	270	28

*Construction details give plies with their basis weight in g/m², the inside plies being listed first.

PE=Polythene-coated WS=Wet strength

tantial financial saving and at the same time, outclassing the regular sack in performance. A recent report by Mckee and Whitsitt[3] demonstrates the substantial improvement in sack drop test figures with increase in machine-direction stretch; it also shows the paper's superiority with change in relative humidity, an important factor with hot packing such as cement. Table 5 shows European sack constructions and paper savings; Table 6 illustrates some actual drop test results to illustrate the improved performance coupled with the paper saving.

TABLE 6

Drop test results for regular and extensible kraft Multi-Wall sacks.

Weight of filled sack	Product filling the sack	Original construction* regular paper	New construction* extensible paper	Paper saving, per cent	Flat drop of 4ft	
					Original	Extensible
94 lb	Cement	2/65 2/81	3/81	17	3.8	11
94 lb	Mortar	4/65	2/65 1/81	19	3.0	5.7
51 lb	Animal feed	2/65 1/81	2/98	8	9.0	18
80 lb	Fertilizer	1/145 AL 2/65 1/81	1/162 AL 1/65 1/81	14	4.0	8

* Construction details give plies with their basis weights in g/m², the inside plies being listed first

Conducted under standard labaratory conditions of

50 percent rh, 73° F AL=Asphalt-laminated

From the results presented it should be clear that machanical compaction can be a useful tool to increase the use of hard wood or nonwood fibers in papers requiring high strength properties. With questions already being raised concerning long fiber availability in the future, it is important for producers of such papers to be aware of all available alternatives, and it is hoped that the studies presented here will add to the knowledge in this field.

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