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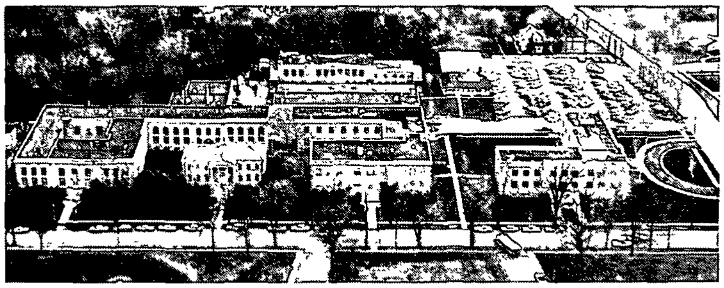

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COMPRESSIVE STRENGTH RETENTION DURING FLUTING. PART 2. IMPROVED MEDIUM STRENGTH.

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COMPRESSIVE STRENGTH RETENTION DURING FLUTING
PART 2: IMPROVED MEDIUM STRENGTH

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ABSTRACT

Previous research has shown that the compressive strength of corrugating medium is degraded in the fluting operation. In this article, attention is focused on papermaking ways to alter the properties of the medium so it can be formed with less damage and thus give more strength to the combined board. At constant basis weight, compressive strength retention is favored by high density (if associated with better fiber bonding) and a high out-of-plane to in-plane stiffness ratio (E_z/E_x). These may be achieved by using higher wet pressing pressures. Higher pressing pressures densify the medium and tend to increase E_z at a faster rate than E_x. The higher out-of-plane stiffness helps the medium resist fiber-to-fiber bond damage during fluting, and hence the medium retains more compressive strength. Densification also reduces caliper, which lowers the bending strains during fluting. As a result of the above, flat crush and ECT increase due to a better retention of strength during fluting and the higher base strength of the medium. Succeeding articles in this series will discuss other aspects of the forming operation and high speed runnability.

INTRODUCTION

In a previous article we discussed the strength losses which occur during fluting (1). Our results indicated that about 40% of the MD and 20% of the CD short span compressive strength (STFI) of the medium is lost in the fluting process. These losses are a result of the high bending strains imposed on the medium as it is fluted and by the high web tensions in the fluting labyrinth. By reducing these losses in strength, it should be possible to improve ECT and flat crush.

There are two approaches to minimizing strength losses during fluting. One approach is to make more effective use of preconditioning heat and steam. From a forming standpoint, the function of preconditioning is to temporarily alter the properties of the medium so it can be formed with less damage. Thus there is potential for improved fluting (minimizing losses) by optimizing the preconditioning heat and steam. Use of this approach will be discussed in a future article.

The second approach is to alter the properties of the base medium during its manufacture so that it can be formed with less damage. This area is the subject of this article.

Other research at The Institute of Paper Chemistry has shown that edgewise compressive strength is highly related to the elastic moduli of the sheet (2). Baum, Habeger and coworkers (3,4) have developed ultrasonic techniques for measuring the in-plane and out-of-plane elastic moduli of paper. High compressive strengths are favored by high moduli in the MD and CD directions (E_x and E_y) and by high thickness direction moduli (E_z, G_{xz}, G_{yz}). Sheet densification to increase fiber bonding is an effective way to increase all of these moduli and hence, compressive strength.

Our past work indicates that the retention of compressive strength during fluting is approximately related to the elastic stiffnesses of the sheet, basis weight and density as follows.

$$RR = 1 - (K/R)(E_x/E_z)^{1/4}\, W/\rho \qquad (1)$$

where RR = retention ratio (ratio of compressive strengths of fluted to uncorrugated medium)
E_x = MD Young's modulus
E_z = out-of-plane Young's modulus
W = basis weight
ρ = density
R = radius of curvature of the fluting rolls
K = constant

Thus in the fluting operation the retention of compressive strength should be favored by high density and a high thickness direction modulus (E_z), and adversely affected by high caliper (W/ρ) and MD modulus (E_x). This is shown in Fig. 1. Our initial research discussed here focused on wet pressing as a means for improving compressive strength retention and improved end-use properties.

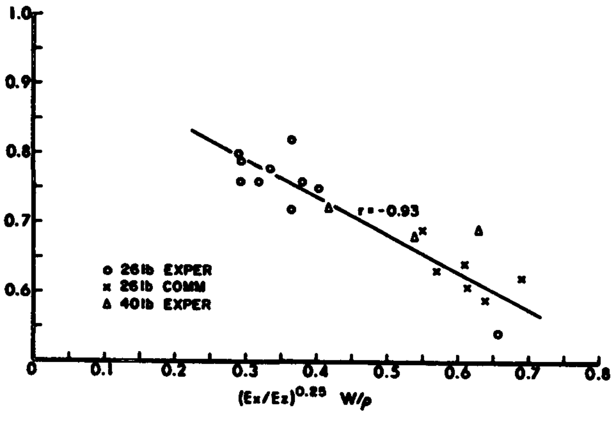

Fig. 1 Retention of compressive strength during fluting depends on elastic stiffnesses, (E_x/E_z), basis weight (W) and density (ρ).

Fluting Performance of Densified Mediums

We made oriented sheets on a Formette Dynamique from a 75% semichemical/25% softwood furnish over a range of densities from about 500 to 1100 kg/m^3, based on IPC soft platen caliper tests (5). To obtain an initial evaluation of corrugating performance, the 26 and 40 lb/1000 ft^2 experimental sheets were spliced into a commercial "carrier" medium, and made into single-faced boards at a speed of about 200 fpm.

All of the experimental and the commercial mediums used as controls corrugated with no difficulties at the low speed used. No bonding problems were encountered; the single face pin adhesion test values were satisfactory for all the mediums.

Figure 2 shows that increasing sheet density increases the retention ratio of compressive strength for both the 26 and 40 lb/1000 ft^2 experimental mediums, as compared to a commercial 26 lb/1000 ft^2 medium. The improvements in retention were less for the 40 lb/1000 ft^2 mediums than for the lighter material because of the greater thicknesses of the 40 lb/1000 ft^2 sheets.

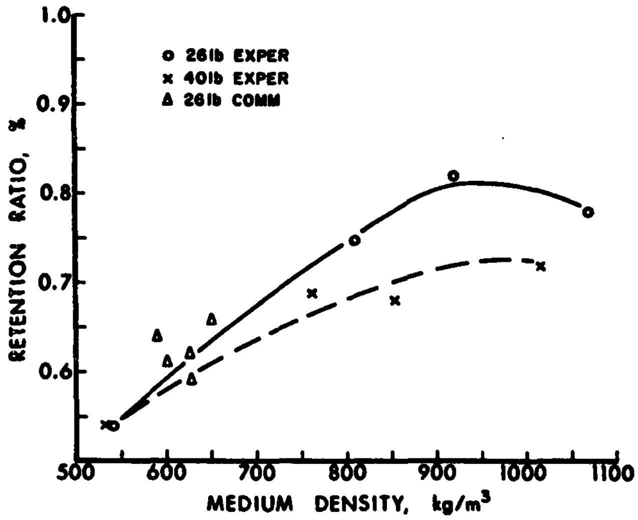

Fig. 2 Effect of density on retention of compressive strength during fluting.

Densification improves most strength properties, thus flat crush strength also increased substantially as density increased, as shown in Fig. 3. At the higher densities the flat crush strengths are greater than those obtained with most commercial mediums. These improvements in flat crush can be attributed to both better retention during fluting as well as the higher MD compressive strengths of the densified sheets.

Compression tests on the combined board show that increasing the medium density markedly increases CD ECT (Fig. 4) as a result of the higher CD compressive strength of the medium.

Increasing medium density monotonically increases CD STFI compressive strength; however, CD ring crush passes through a maximum at a density of 750-800 kg/m^3 (Fig. 5). Thus the shortspan compressive strength results were more indicative of combined board ECT performance. A similar situation prevails when MD STFI and MD ring crush results are compared with the combined board flat crush results (6). Seth (7) also has shown that ring crush passes thru a maximum as wet pressing is increased.

Higher wet pressing pressures also produce substantial increases in the tensile strength of the medium (Fig. 6). The higher tensile strengths should allow higher corrugating speeds before flute fracture occurs because the medium will be better able to tolerate the high tensile stresses imposed during fluting.

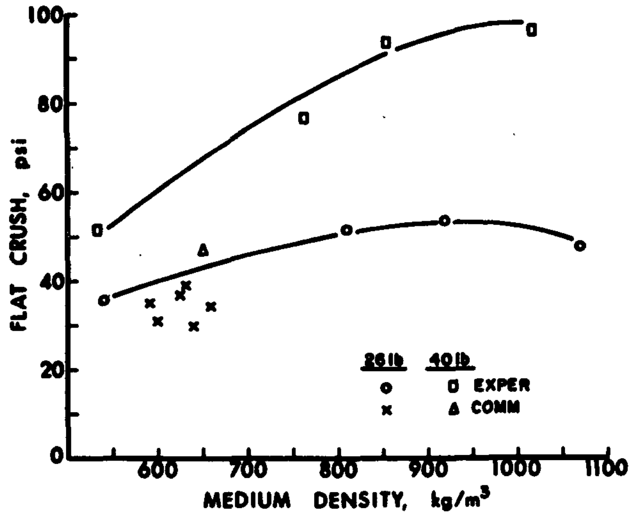

Fig. 3 Increasing medium density improves flat crush.

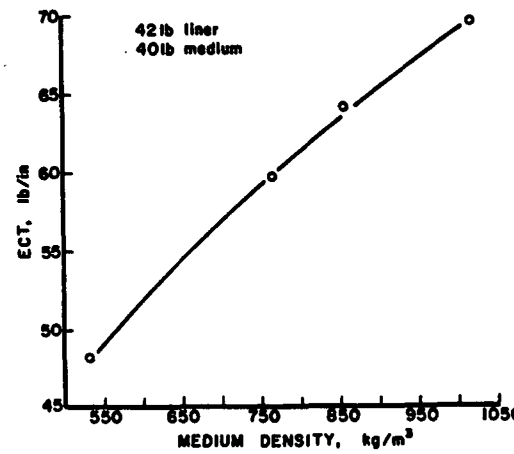

Fig. 4 Increasing medium density improves ECT strength.

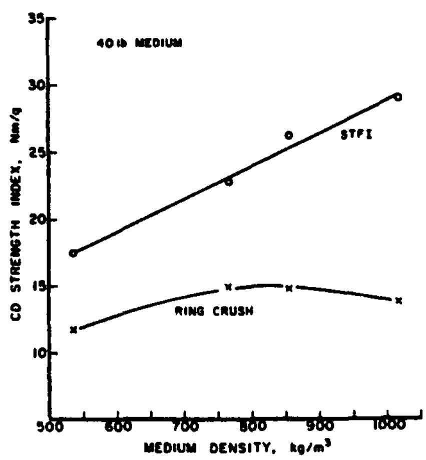

Fig. 5 CD short span compressive strength and ring crush results vs. medium density.

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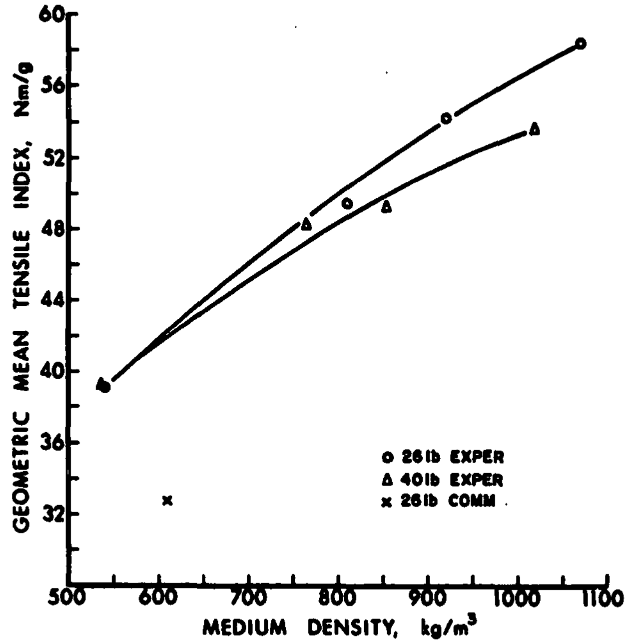

Fig. 6 Increased wet pressing increases tensile strength.

The specific in-plane and out-of-plane elastic stiffnesses also increased with increasing density as shown in Fig. 7. As noted earlier, compressive strength is dependent on the product of $E_x^{3/4}E_z^{1/4}$ or $E_y^{3/4}E_z^{1/4}$ for the MD or CD directions, respectively (2). Because densification increases all three stiffnesses, it would be expected that compressive strength would increase as illustrated in Fig. 5 for the short span STFI compressive strength results.

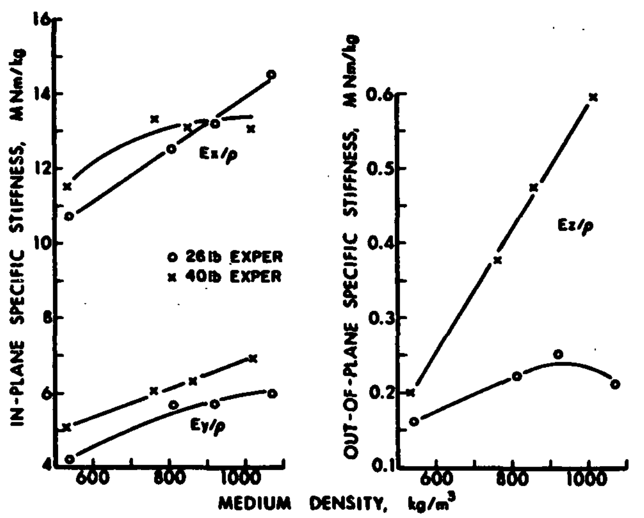

Fig. 7 Effect of density on elastic stiffnesses.

Runnability

Work was carried out to determine whether densification of the medium would adversely affect high speed runnability, including flute fracture, high-lows, and bonding. Because of their greater strength, densified mediums should be better able to resist fracture, but densification could reduce porosity and water receptivity, which would affect high speed bonding.

Oriented medium sheets were made at several densities achieved by wet pressing. The sheets were made with typical MD/CD orientation of about 2/1, using a 75% semichemical plus 25% softwood furnish. Two pressing/drying techniques were employed, namely:

(1) Blotter pressed and dried. One side of sheet was in contact with blotters, while the other side was in contact with a belted rotary press-dryer drum.

(2) Felt pressed and dried. One side of sheet was in contact with a linerboard press felt, with the other side in contact with the belted rotary press-dryer drum.

The blotter and felt-pressed sheets exhibit different compressive strengths at the same density as shown in Fig. 8. The same trend has been observed in other work in progress. This demonstrates that pressing conditions (such as the felt structure) also can affect compressive strength. The elastic stiffnesses of the sheets are affected in a similar way by these drying techniques, as shown in Fig. 9. While the felt-pressed sheets gave lower compressive strengths and stiffnesses, they exhibited higher tensile strengths at the same density, see Fig. 10.

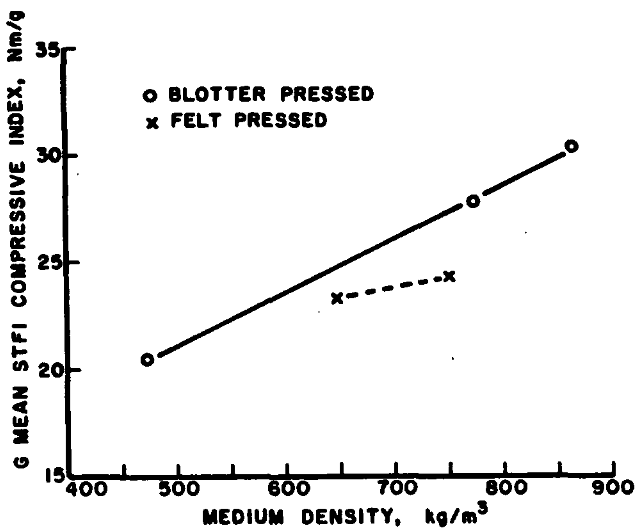

Fig. 8 Effect of densification on geometric mean compressive strength for different pressing/drying conditions.

The air porosity of the sheet decreases, as shown in Fig. 11, as pressing pressures are increased. Commercial mediums, however, exhibit a wide range of porosities. For example, the three commercial mediums used for controls in this study gave Bendtsen porosities ranging from about 350 to 1300 mL/min. Experience indicates that mediums having quite different porosities can be successfully bonded at normal corrugating speeds, although some adjustments in the adhesive or the preheaters and steam showers may be necessary.

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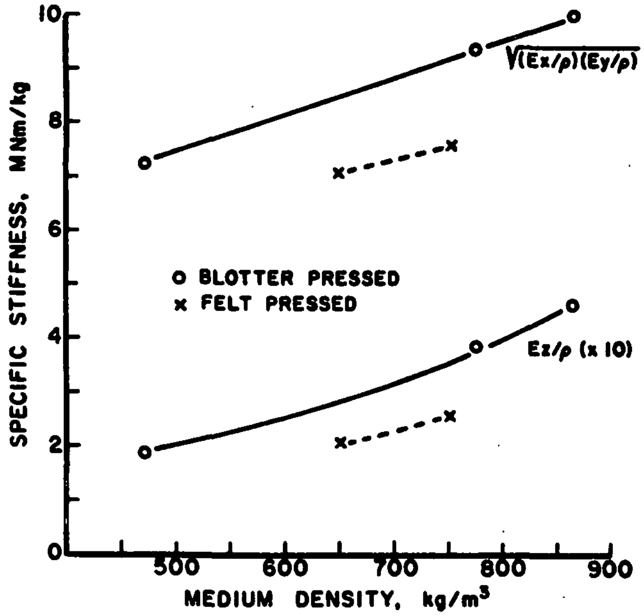

Fig. 9 Effect of densification on specific elastic stiffnesses for different pressing/drying conditions.

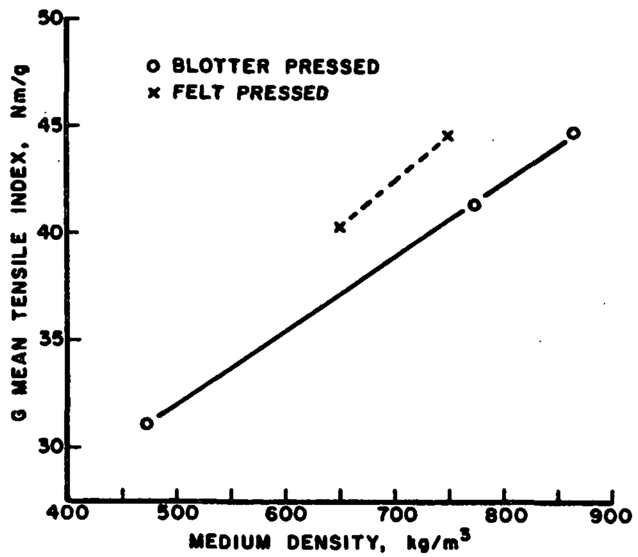

Fig. 10 Effect of densification on tensile strength for different pressing/drying conditions.

The water drop values for the blotter-pressed sheets increased with density, as expected. At the same density, however, the felt-pressed sheets gave lower water drop values, showing that pressing and drying conditions can affect the water receptivity of medium. In general, however, the experimental sheets had water receptivities in the same range as the commercial controls.

All of the mediums corrugated without fracture at speeds up to 650 fpm (Table 1), except that the lowest density sheets exhibited minor fractures in the 400 to 650 fpm range. This was probably due to their lower strength and relatively high caliper, which would increase the bending strain during fluting.

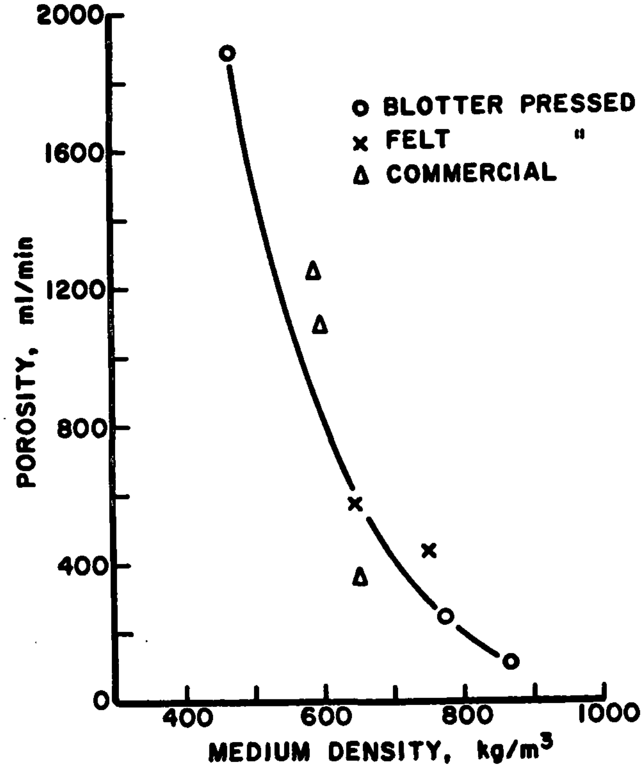

Fig. 11 Effect of densification on porosity.

Table 1. Corrugating results.

	Speed fpm	Low Dens. (185)	Med. Dens. (186)	High Dens. (182)	Felt Pressed[a] Med. Press.[a] (63)	Felt Pressed[a] High Press.[a] (77)	Commercial Controls 6171	Commercial Controls 6208	Commercial Controls 6209
Fracture[b]	400	SlF	No F	No F	No F	No F	No F	No F	No F
	550	SlF	No F	No F	No F	No F	No F	No F	No F
	650	SlF	No F	No F	No F	No F	No F	No F	No F
Pin adhesion lb/ft	400	26.2	37.0	36.5	--	--	38.5	36.0	36.5
	550	28.1	33.1	31.8	--	--	33.0	32.4	31.1
	650	20.1	22.8	--	--	--	18.5	24.8	23.5
High-low,% >4 mil	400	1.0	11.4	6.2	0	4.2	3.6	12.5	15.6
	550	0	7.8	17.2	0	6.2	15.6	--	20.8
	650	1.0	1.0	--	6.2	8.3	11.5	14.6	16.6
% >3 mil	400	6.2	20.8	15.6	2.1	14.6	12.2	27.1	35.4
	550	3.1	15.4	28.9	10.4	22.9	30.2	11.4	27.1
	650	4.2	4.2	--	10.4	27.1	34.0	27.1	35.5
ECT, lb/in.	400	33.1	40.1	41.7	--	--	39.2	36.6	36.2
	550	34.2	40.0	43.0	--	--	36.8	36.6	35.2
	650	33.1	41.6	--	--	--	36.8	34.7	33.5
	Av.	33.5	40.6	42.4	--	--	37.6	36.0	35.3
Flat crush, psi	400	38.1	56.1	59.2	36.5	40.6	34.5	34.8	30.5
	550	39.7	57.1	57.2	35.4	40.1	35.2	36.2	30.8
	650	37.7	57.3	--	38.2	40.2	34.1	35.4	30.9
	Av.	38.5	56.8	58.5	36.7	40.3	34.6	35.5	30.7

[a] Low and high felt pressed sheets, fabricated at a later time with new 42-lb liner roll.
[b] SlF = slight fracture; No F = no fracture.

Figure 12 indicates that the experimental blotter-pressed mediums exhibited high-low levels which were about the same or less than the commercial controls. High-lows were defined as the percentage of flute height differences exceeding 4 mils. They were measured using a SELCOM laser displacement gage. Thus, densification does not appear to increase the proclivity to form high-lows. It is believed this is due to the lower thickness and better fiber-to-fiber bonding achieved by wet pressing.

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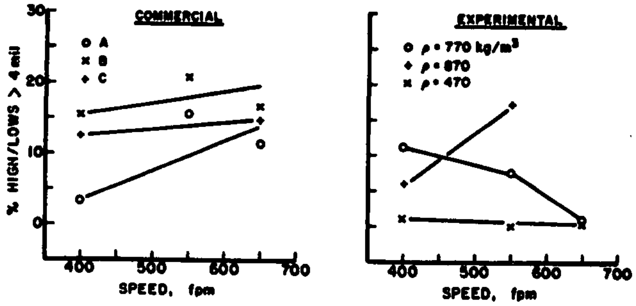

Fig. 12 High/low results on commercial and densified mediums. (A, B, and C are three 26-lb commercial mediums used as controls and corrugated at the same time as the experimental medium).

In Fig. 13 the single-face adhesion results for the densified blotter-pressed mediums are compared to the commercial controls. In general, the densified sheets exhibit about the same pin adhesion strengths as the commercial mediums at the same corrugator speeds. In both cases the adhesion strengths decrease with increasing speed, consistent with other results from our pilot corrugator.

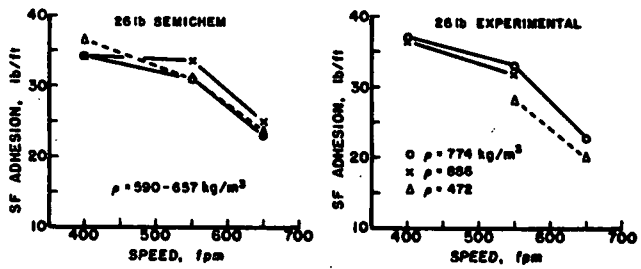

Fig. 13 Comparison of single-face adhesion results on commercial and experimental densified mediums.

Summarizing, these results indicate that densification of medium can be beneficial to high speed runnability. If necessary, adhesive formulations could be changed to optimize adhesion. It would still be possible to adjust the water receptivity of the medium with surfactants as is commonly done today.

CONCLUSIONS

This work explored ways to minimize the strength losses that occur during fluting (1). This would enhance ECT and flat crush strength in combined board. The results show

1. Densification of medium by increasing the wet pressing pressure makes substantial increases in flat crush and the ECT strength of combined board made from the medium. These improvements are due to the retention of compressive strength during fluting and the higher compressive strengths and elastic stiffnesses obtained from densification.

2. The retention of compressive strength during fluting is favored by lower weight to density ratios (caliper) and by a higher out-of-plane stiffness (E_z/ρ) relative to the in-plane stiffness (E_x/ρ).

3. The high density mediums gave single-face bonding levels in the corrugator which were comparable to those obtained with commercial mediums. High-low flute formation levels were also comparable for the experimental and commercial mediums. While these results are not necessarily conclusive because of the small sheet sizes and narrow width of the pilot corrugator, they do indicate that commercial corrugating should be feasible. If necessary, adjustments in surface receptivity or starch formulation could be made.

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