

Temperature-gradient calendering of foodboard

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Temperature-gradient calendering produces smooth, glossy surfaces with less bulk reduction than conventional machine calendering.

One serious limitation of the machine-calendering operation is that it cannot change the surface properties of the paper independently of the bulk. If a smoother paper is desired, a thinner, denser paper must be tolerated. This limitation has been shown to exist for newsprint (1,2) as well as for a variety of other grades, including food board (3). Because the stiffness and compressive strength of food board decrease with decreasing bulk, it would be particularly desirable to be able to overcome this limitation and calender food board to a high finish without excessive bulk reduction.

Temperature-gradient (TG) calendering is a technique that can improve paper surface properties with less bulk reduction than with conventional calendering. This technique, which was shown to work well for newsprint (4), is illustrated in Fig. 1. The unheated paper web is calendered in a single pass through a nip between two hot calender rolls. The web touches the hot rolls only in the nip. The heat from the rolls causes the surface fibers to become more pliable, but the contact between the web and the heated rolls is so brief that the heat cannot penetrate to the middle of the sheet. Consequently, the surface fibers are permanently deformed to a greater extent than the fibers in the middle of the paper, and a better surface finish can be achieved with less bulk reduction.

In this study, sized and unsized food boards were calendered using both the TG and the conventional calendering methods. The objective of the study was to determine whether there are any benefits in applying the TG-calendering technique to food boards and other heavy paper products.

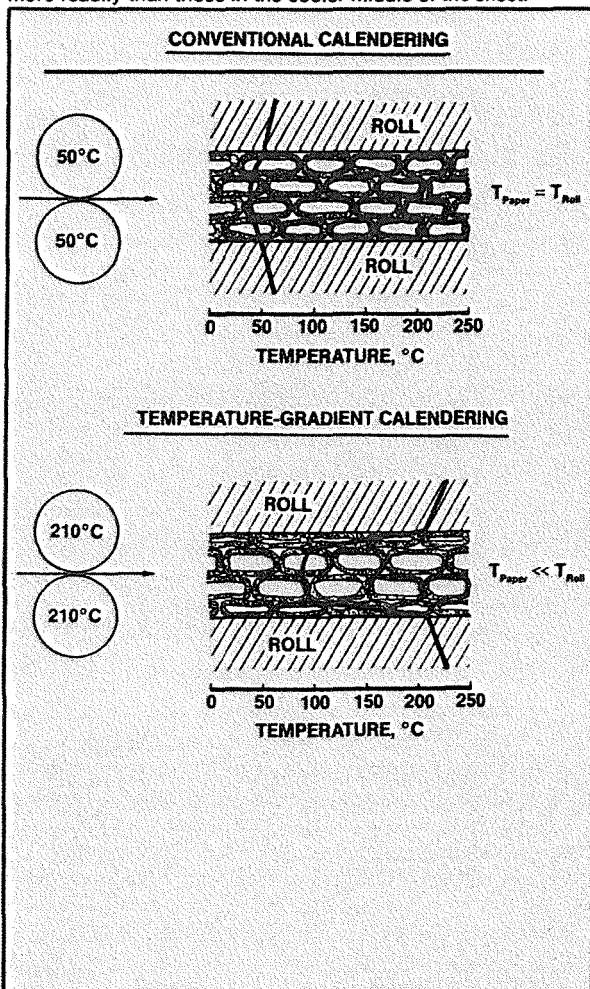
Discussion

Bulk and surface properties

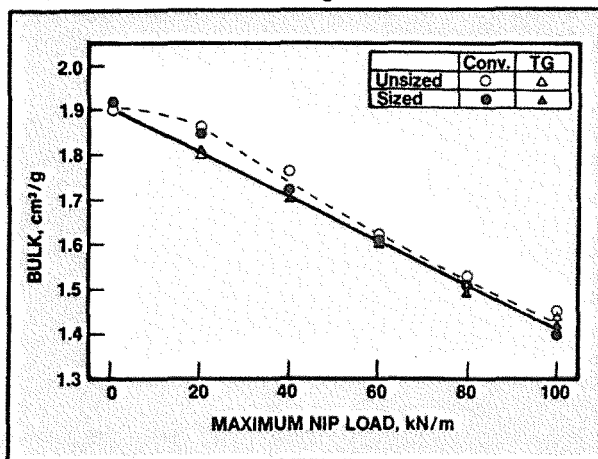
Figure 2 shows the relationship between bulk and nip load

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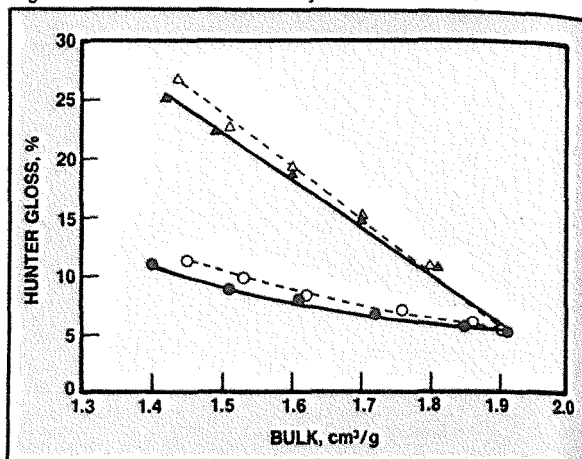
1. Roll configurations and temperature profiles through the thickness of a web as it passes through conventional and TG calender nips. For conventional calendering, the difference between the temperature of the rolls (T_{roll}) and the temperature of the paper (T_{paper}) is small, and the temperature of the sheet is nearly uniform throughout its thickness. The entire web is deformed uniformly. For TG calendering, the temperature profile in the web shows a steep gradient from the roll surface toward the center of the web. At the roll-sheet interface, the fibers are hot and are deformed more readily than those in the cooler middle of the sheet.



2. Bulk as a function of maximum nip load. At low nip loads, bulk appears to be reduced somewhat more easily with TG calendering than with conventional calendering



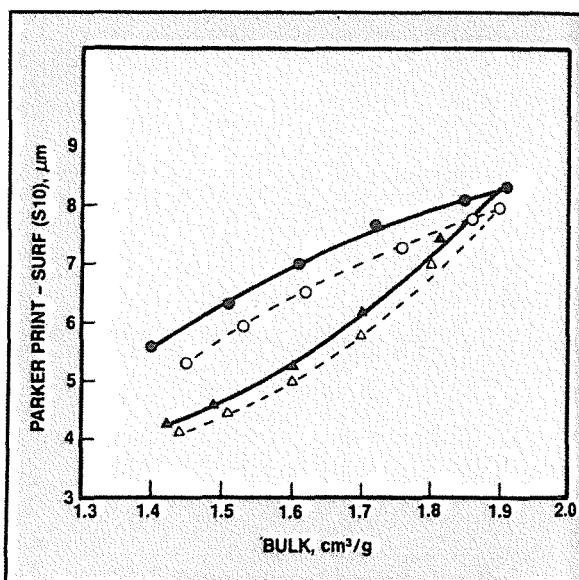
3. The effect of calendering technique on Hunter gloss. At the same bulk, Hunter gloss (75°) of TG-calendered board is much higher than that of conventionally calendered board



1. Strength properties of unsized and sized food boards calendered to a Hunter gloss of 10%

Property	Conventional calendering		TG calendering	
	Unsized	Sized	Unsized	Sized
Bulk, cm³/g	1.53	1.44	1.81	1.80
Breaking length, km				
MD	3.27	4.07	3.49	4.18
CD	2.15	2.51	2.18	2.60
Elastic modulus, km				
MD	510	538	584	622
CD	255	300	288	328
Stretch, %				
MD	1.18	1.42	0.95	1.31
CD	2.38	2.77	2.17	2.79
Compressive strength, km				
MD	1.92	2.33	2.24	2.52
CD	1.48	1.75	1.64	1.88
Taber stiffness, mN·m				
MD	23.5	27.5	32.5	45.5
CD	13.0	17.0	18.0	26.8

4. The effect of calendering technique on sheet surface smoothness. At the same bulk, the Parker Print-Surf roughness is much higher for the conventionally calendered board than for the TG-calendered board



that was obtained in this study. Note that the zero-load data points represent the uncalendered samples. The TG-calendered samples, which were calendered in a single nip, had approximately the same bulk as the samples that were conventionally calendered in several nips with the same maximum load. The only significant difference is seen at 20 kN/m and 40 kN/m maximum nip load, where the conventionally calendered samples were subjected to only one and two nips, respectively.

In a previous study of the effect of TG calendering on newsprint, Hunter gloss was found to be the property that was most affected (4). Similar results are shown in Fig. 3 for both the sized and unsized food-board samples. TG-calendered samples had a much higher gloss than the board samples that were calendered to the same bulk using conventional methods. The sized board was slightly less

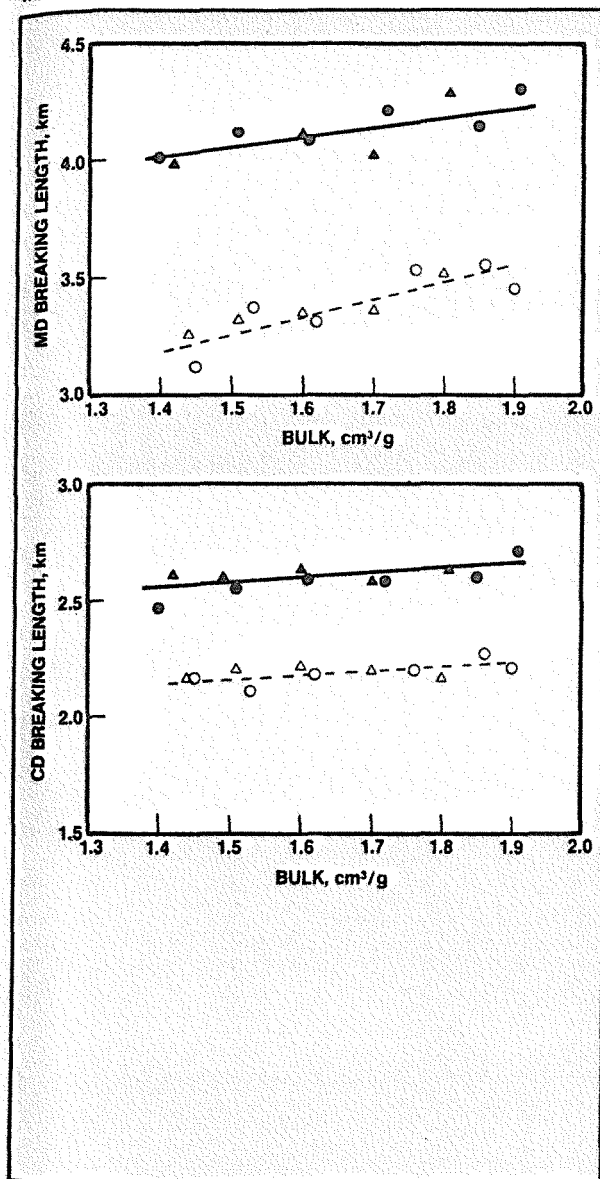
glossy than the unsized board.

The effect of calendering technique on Parker Print-Surf (S10) roughness is shown in Fig. 4. Calendering techniques had a marked effect on surface roughness. Conventionally calendered boards were found to be substantially rougher than TG-calendered boards having the same bulk. The effect is far more pronounced than it was for newsprint (4). Also, when compared at the same bulk, the sized board was consistently rougher than the unsized board. This difference was more pronounced for rougher samples and, thus, was greater for the conventionally calendered samples.

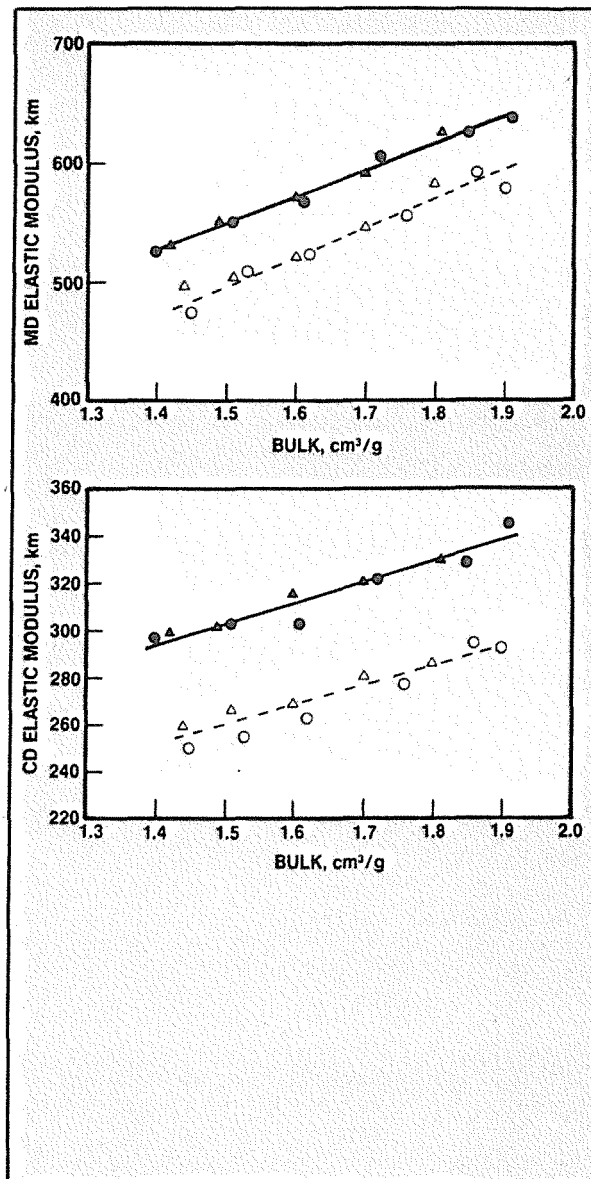
Strength properties

Results for the various strength properties, both in the machine direction (MD) and the cross direction (CD), are shown in Figs. 5-9 as a function of bulk. All strength

5. Tensile breaking length in the MD and CD as a function of sheet bulk changed by calendering. Note that the results in Figs. 5-9 indicate that the choice of calendering technique has no systematic, significant effect on sheet strength



6. Tensile elastic modulus in MD and CD as a function of sheet bulk



properties decreased with the bulk reduction obtained on calendering, with the exception of stretch-to-rupture, which increased. The CD breaking length, however, for both the sized and unsized board apparently suffered little reduction. When compared at the same bulk, no significant difference was observed between the strength properties of the conventionally calendered and the TG-calendered boards. Thus, the change in the strength properties with calendering is independent of the two calendering methods used in this study.

The increase in MD and CD stretch-to-rupture upon calendering was found to be contrary to previous observations made with newsprint calendered under similar conditions. The newsprint's stretch decreased with increased calendering (4). De Montmorency (5), on the other hand, reported substantial increases in CD stretch for laboratory-

and mill-calendered newsprint, but he found no change in MD stretch.

The observed drop in the strength properties of food board with calendering is consistent with observations made earlier by one of the authors (6), who studied the effect of conventional calendering on the strength properties of 180-g/m² laboratory-made sheets of various initial bulks. It was also found that the tensile strength of sheets increased slightly with initial bulk reduction at low nip loads and then decreased as bulk was reduced further. Similar increases in tensile strength with initial calendering have also been reported by Mackin *et al.* (7) for sack kraft paper. In the present study, such a trend was noticed only with the unsized board.

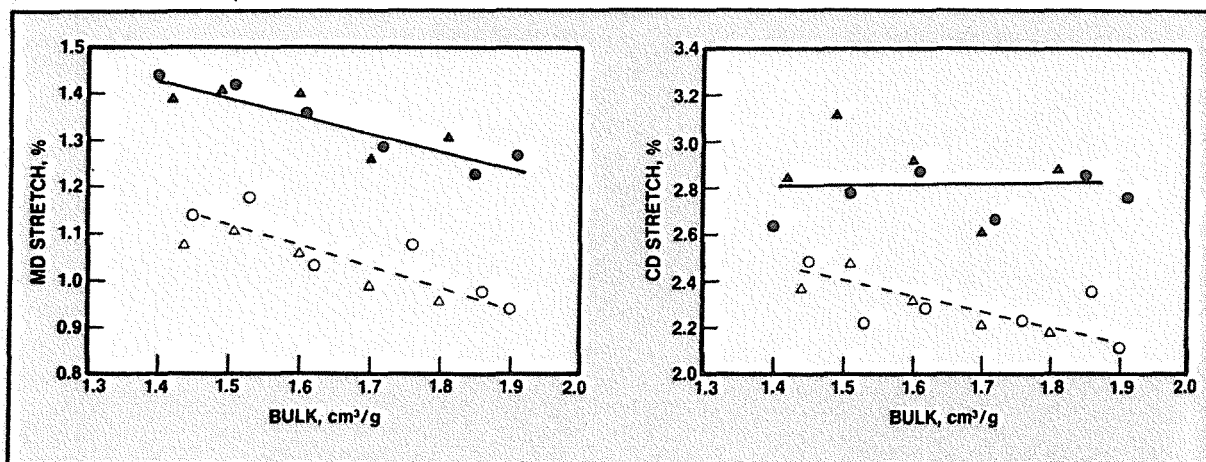
The strength loss during calendering can represent a substantial cost factor in the manufacture of food board.

II. Calendering conditions and bulk surface properties of unsized and sized food board

Sample no.*	Roll temperature, °C	Nip load, kN/m	Speed, m/min	Bulk, cm ³ /g	Basis weight, g/m ²	Thickness, mm	Hunter gloss, %	Parker Print-Surf, µm	
								S10	S20
U-0	...	...	...	1.90	362	686	5.4	7.94	7.36
U-1	50	20	200	1.86	363	675	6.0	7.79	7.16
U-2	50	20 40	200	1.76	358	632	7.1	7.28	6.60
U-3	50	20 40 60	200	1.62	360	583	8.3	6.54	5.86
U-4	50	20 40 60 80	200	1.53	362	553	9.8	5.95	5.23
U-5	50	20 40 60 80 100	200	1.45	360	522	11.2	5.31	4.72
U-6	211	20	200	1.80	359	646	10.8	7.00	6.30
U-7	211	40	200	1.70	359	612	15.1	5.80	5.14
U-8	209	60	200	1.60	364	581	19.2	5.00	4.54
U-9	209	80	200	1.51	359	543	22.7	4.46	4.06
U-10	207	100	200	1.44	362	523	26.8	4.17	3.72
S-0	...	...	...	1.91	375	716	5.2	8.32	7.84
S-1	50	20	200	1.85	378	698	5.8	8.10	7.62
S-2	50	20 40	200	1.72	378	652	6.8	7.66	7.09
S-3	50	20 40 60	200	1.61	381	613	8.1	7.03	6.33
S-4	50	20 40 60 80	200	1.51	377	569	9.5	6.32	5.53
S-5	50	20 40 60 80 100	200	1.40	375	527	11.0	5.60	4.84
S-6	211	20	200	1.81	376	682	10.6	7.45	6.66
S-7	211	40	200	1.70	377	641	14.8	6.19	5.26
S-8	209	60	200	1.60	377	602	18.6	5.29	4.60
S-9	209	80	200	1.49	377	561	22.4	4.60	4.03
S-10	207	100	200	1.42	374	532	25.1	4.24	3.60

*U = unsized samples; S = sized samples.

7. Tensile stretch-to-rupture in the MD and CD as a function of sheet bulk



When using the conventional machine-calendering technique, the bulk reduction is a necessary consequence of improved surface properties. TG calendering offers an alternative whereby the desired surface properties can be achieved with substantially less strength loss.

If, for example, a board with a Hunter gloss value of 10% was required, the unsized and sized boards would have to be calendered by conventional means to bulks of 1.53 cm³/g and 1.44 cm³/g, respectively (Fig. 3). The same gloss can be

achieved by TG calendering to bulks of 1.81 cm³/g and 1.80 cm³/g, respectively, thereby retaining greater strength in the sheet. Table I shows the relative effects of the two calendering techniques on strength for sized and unsized boards calendered to a Hunter gloss of 10%.

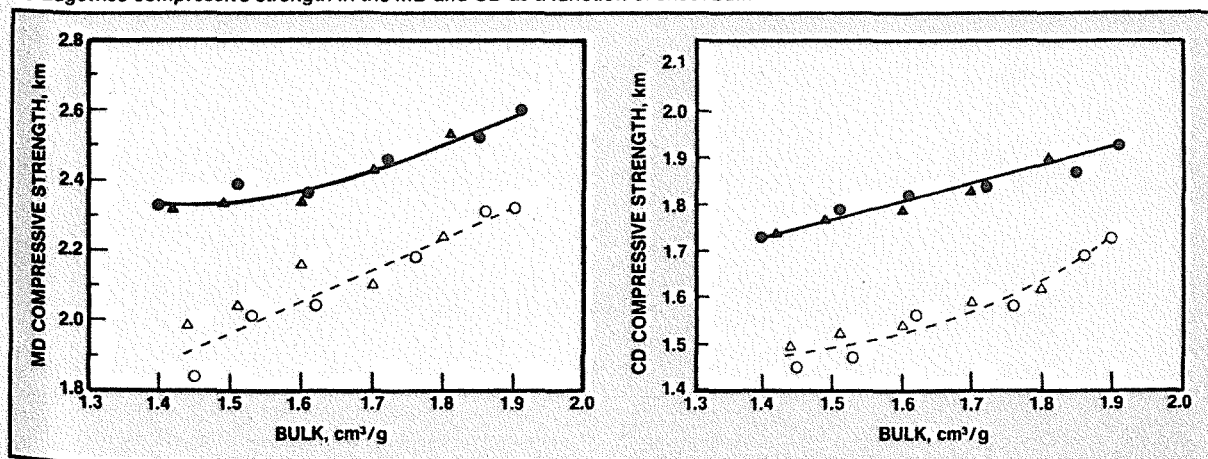
TG calendering also offers the potential for furnish savings, since strength properties can be maintained at a lower basis weight for a given surface finish.

III. Strength properties of unsized and sized food board

Sample No.*	Bulk, cm ³ /g	Tensile properties						Edgewise compressive strength, km		Taber stiffness, mN·m	
		Breaking length, km		Elastic modulus, km		Stretch, %		MD	CD	MD	CD
		MD	CD	MD	CD	MD	CD				
U-0	1.90	3.46	2.21	579	293	0.94	2.11	2.32	1.73	39.0	18.7
U-1	1.86	3.56	2.27	593	295	0.98	2.35	2.31	1.69	36.1	18.2
U-2	1.76	3.54	2.20	556	277	1.08	2.23	2.18	1.58	27.7	15.8
U-3	1.62	3.32	2.18	523	263	1.04	2.28	2.04	1.56	24.8	14.5
U-4	1.53	3.37	2.12	508	255	1.18	2.22	2.01	1.47	22.7	12.9
U-5	1.45	3.13	2.17	473	250	1.14	2.48	1.84	1.45	18.9	11.0
U-6	1.80	3.53	2.17	584	287	0.96	2.18	2.24	1.62	31.9	17.4
U-7	1.70	3.36	2.20	547	280	0.99	2.21	2.10	1.59	30.0	17.1
U-8	1.60	3.35	2.23	522	269	1.06	2.32	2.16	1.54	27.1	14.6
U-9	1.51	3.33	2.20	505	267	1.11	2.47	2.04	1.52	22.7	13.4
U-10	1.44	3.27	2.17	497	260	1.08	2.37	1.99	1.50	19.2	11.7
S-0	1.91	4.31	2.70	639	345	1.27	2.76	2.60	1.93	44.6	27.5
S-1	1.85	4.15	2.60	626	329	1.23	2.85	2.52	1.87	45.7	26.6
S-2	1.72	4.21	2.58	606	322	1.29	2.66	2.46	1.84	39.3	23.9
S-3	1.61	4.09	2.59	568	303	1.36	2.87	2.37	1.82	33.9	20.5
S-4	1.51	4.12	2.55	550	303	1.42	2.78	2.39	1.79	30.3	18.8
S-5	1.40	4.02	2.47	525	297	1.44	2.63	2.33	1.73	24.9	16.2
S-6	1.81	4.29	2.63	627	330	1.31	2.88	2.53	1.90	45.9	26.9
S-7	1.70	4.03	2.58	592	321	1.26	2.61	2.43	1.83	40.8	24.1
S-8	1.60	4.12	2.64	571	316	1.40	2.92	2.34	1.79	35.1	21.7
S-9	1.49	4.18	2.60	551	302	1.41	3.12	2.34	1.77	34.7	20.0
S-10	1.42	3.98	2.61	531	299	1.39	2.84	2.32	1.74	29.5	17.3

*U = unsized samples; S = sized samples.

8. Edgewise compressive strength in the MD and CD as a function of sheet bulk



Conclusions

The effects of two calendering techniques—TG calendering and conventional machine calendering—on the surface and strength properties of unsized and sized food boards were investigated. The results show that TG calendering can produce the same bulk in a single nip as is produced by conventional machine calendering in several nips. When calendered to the same bulk, the TG-calendered board

showed a much higher Hunter gloss and a lower Parker Print-Surf roughness than the conventionally calendered board. Most strength properties were adversely affected by the bulk reduction that occurs during calendering, regardless of the technique used. However, for similar improvements in gloss and smoothness, the loss in sheet strength is much less with TG calendering than with conventional calendering. Thus, the major advantage of the TG technique over conventional machine calendering

is that a smooth, glossy surface can be produced with less bulk reduction and thus less strength loss. This can lead to potential furnish savings.

Experimental

The sized and unsized food-board samples were made from 100% bleached kraft pulp, containing a mixture of approximately 80% hardwood and 20% softwood fibers. The basis weight of the unsized board was 361 g/m² and that of the sized board was 377 g/m². The difference in basis weight is attributable to the size application. The samples were prepared on a commercial machine with the calender stack lifted. Hence they were effectively uncalendered. The coating, a pigmented starch consisting of two parts pigment to one part starch, was applied in a size press.

Single sheets (457 mm × 305 mm) were conditioned at 23°C and 50% relative humidity for 24 h and then calendered in the Institute's laboratory calender (8) at a speed of 200 m/min under the following conditions.

Conventional calendering. The samples were calendered in successive passes through a single nip loaded to 20, 40, 60, 80, and 100 kN/m. The calender rolls were heated to 50°C, and the food board entered the first nip at 23°C. In subsequent passes, the board was still warm from previous passes, and thus at a temperature between 23°C and 50°C. After each nip, samples were retained for testing.

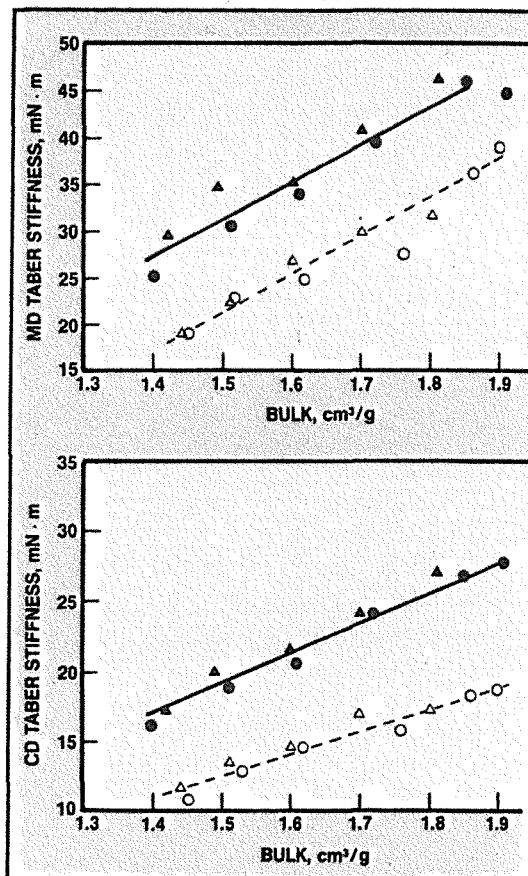
TG calendering. The samples were calendered in one pass through a single nip with the rolls heated to 210°C and with nip loads of 20, 40, 60, 80, and 100 kN/m. In each case, the board entered the nip at 23°C.

Basis weight, thickness, and 75° Hunter gloss were measured immediately after calendering. The samples were then stored in polyethylene bags for 24 h before the Parker Print-Surf roughness was measured. Gloss and roughness were measured on the top side of the board only. The Parker Print-Surf roughness was measured with a soft backing, with two levels of pressure on the land area (1000 kPa for S10 and 2000 kPa for S20). The gloss was measured both in the MD and in the CD and reported as an average of the two. The bulk and surface properties and the calendering conditions are provided in Table II.

The strength tests were performed at 23°C and 50% relative humidity following several days of conditioning. The tensile strength, elastic modulus, and stretch-to-rupture were calculated from load-elongation curves obtained on 100-mm × 15-mm specimens with a floor-model Instron universal testing instrument. The elongation rate was 10 mm/min. The edgewise compressive strength was measured on the STFI short-span tester (6).

The tensile strength, elastic modulus, and compressive strength, which were calculated by dividing the load per unit specimen width by the basis weight of the sheet, are expressed as a length. It is the stress that is borne only by the solid fraction of the sheet. The results for the tensile properties were based on ten measurements on each sample. Results for compressive strength were based on twenty measurements made on each sample. Taber stiffness measurements were obtained from four different samples for each calendering condition according to the standard Appita method. The values were read directly from the instrument with no weights attached to the pendulum. Results of the strength tests are presented in Table III.

9. Taber stiffness in the MD and CD as a function of sheet bulk.



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