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Strength Characteristics of Multi-ply and Single-ply Handsheets

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Thesis 436

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Abstract

In a multi-ply handsheet ther are three fundamental strengths. These fundamental strengths are the bonding between plies, bonding between fibers and the strength of the fibers. The strengths are interrlated and controlled by the preparation and mechanical handling of the stock.

The beating of the fibers, the consistency at which the sheet is formed, the couching pressure, and the final pressing all produce certain marked effects on the strength characteristics in a multi-ply handsheet.

In general it may be said that the strength characteristics of a given weight sheet may be increased by forming a multi-ply sheet.

It has been shown by Jeitteles (1) and Brown (2) that the strength characteristics of handsheets increase, up to a certain point, with an increasing number of plies. Brown shows with experimental data that as the plies of the handsheet increase, of a constant basis weight, the strength properties also increase. This increase continues for five to seven plies, for most tests, and then the strength test begin to decrease from the previous high values.

The reason for the increase of strength with increasing number of plies lies in the bonding between the plies and to the better formation obtained on a handsheet with the lower consistency used in making many thin plies rather than one solid sheet. The strength of the bonding between plies can be measured, and a few commercial instruments have been developed (3). Bekk (4,5) developed an instrument which measures the force required to split a sheet, when the force is applied at an angle to the sheet. Courtney and Wakefield (6) have developed an instrument that measures the force to tear plies apart.

The strength characteristies of multi-ply handsheets are effected by the pressure with which the sheets are initially forced together. The best procedure is to have the pressure lightest on couch pressing and heaviest on the final pressing. This method will give the highest ply bonding (7).

It is also known that the degree of beating and the position of the plies in relation to each other are important in the bonding between plies (8).

Tests made by Brown (2) on handsheets of the same weight and freeness (100 lbs per 1000 sq ft and 620 ml freeness) definately show the change in strength characteristics encountered when the number of plies in the sheets are varied.

Plies	Burst	Tear	Riehle	Suvant	Tensile	Stretch
1	217	9.8	50.6	153.5	59.6	5.9
2	290	9.9	58.8	147.1	73.1	6.9
3	321	9.9	56.0	146.0	84.5	7.3
4	330	10.3	54.0	145.0	85.7	6.9
5	328	10.3	60.4	141.4	82.6	7.3
6	337	10.3	56.6	142.7	83.6	7.4
7	326	10.6	57.5	147.6	82.3	6.6
9	328	10.5	56.4	137.9	83.9	6.7

The units of the several tests are; burst in points per 100 lbs per 1000 sq ft, tear in tear factor, Riehle stiffness in lbs per 100 lbs per 1000 sq ft, Suvant stiffness in units per 100 lbs per 1000 sq ft, tensile in lbs per 100 lbs per 1000 sq ft, and stretch in percent.

In a multi-ply handsheet there are three fundamental strengths. These fundamental strengths are the bonding between plies, bonding between fibers and the strength of the individual fibers. It is easily seen that these strengths are interrelated and controlled by the preparation and mechanical handling of the stock.

Beating effects

The beating effect on the three fundamental strengths is to increase the bonding between the plies and bonding between fibers with an increase in beating. However the increased beating has the effect of decreasing the strength of the individual fibers. With these strength factors reacting to beating in this manner the multi-ply sheet will increase in its general strength characteristics until the point is reached where the strength of the fibers equals the strength of the bonding between fibers and plies, after this point is reached any increase in beating will only decrease the general strength characteristics of the sheet.

It is thought that the increased beating causes a greater area of contact between the plies which is the reason for the increased strength between plies. The manner with which beating increases the bonding between plies is very similar to the manner in which beating increases the bonding between fibers.

Consistency effects

On a sheet mold lower consistencies give better sheet formation and therefore greater general strength characteristics. As more plies are made for a given weight each ply will be made at a lower consistencies and therefore increased strength characteristics will develop. This strength will increase with the number of plies until a point is reached where low-

ering the consistency will have no further effect on the formation, at this point the strength characteristics should become constant. However as the number of plies is increased a new point of weakness is developed at the boundary between plies, due to the increased difficulty of water removal, the bonding between plies will be decreased and the strength characteristics will begin to fall off.

This effect of formation is shown by Brown (2) with handsheets made from very free (810 ml) unbleached kraft. When a seven ply sheet was made the quality of the formation was the controlling factor, the bursting strength increased to a maximum with increase in the number of plies. In testing the sheet for ply bonding, as the number of plies increased, the ply bonding decreased due to the disturbance of ply bonding in water removal. The weakest ply bonding was weaker than the fiber to fiber bonding. This gave a decrease in the strength characteristics of the handsheets.

Couching pressure effects

Couching pressure increases cause an increase in the strength characteristics of the multi-ply handsheet. The rate of increasing strength characteristics decreases as the higher couching pressures are reached. This produces a curve very similar to the curve obtained for beating effects on the strength characteristics.

The effect of couching pressure on multi-ply handsheets can be seen from the strength characteristics of six-ply unbleached kraft handsheets (770 ml freeness) as tested by Brown (2).

Couching pressure	% dry couched	Apparent density	Burst	Tear	Riehle	Suvant	Tensile
10.0	35.4	4.55	387	9.6	72.0	201	91.1
13.3	33.9	4.41	391	10.9	79.4	206	91.9
23.3	36.4	4.53	424	10.5	79.4	218	91.1
33.3	37.0	4.55	429	10.3	80.0	204	93.0
50.0	42.0	4.59	438	10.3	75.4	201	99.3
64.7	43.2	4.65	428	10.2	82.0	211	96.5
82.3	45.8	4.75	451	10.5	79.6	208	93.2
100.0	47.2	4.78	442	10.4	84.6	194	92.5
116.7	49.1	4.82	433	10.4	87.1	195	93.2
133.3	47.6	4.80	449	10.1	89.8	193	96.0
150.0	49.7	4.86	454	9.7	80.9	210	93.7

lbs per linear inch

Final pressing effect

The effect of the final pressing on strength characteristics is to increase the strength with increases in pressing force; these increases are very small and similar to the effect of a small amount of beating. Any effect that is made is only in the low ranges of final pressing force; after a certain point is reached only the smallest increases in strength is noted with increases in the final pressing force.

The effect of final pressing force on multi-ply handsheets can be seen from the strength characteristics of six-ply unbleached kraft handsheets (770 ml freeness) as tested by Brown (2).

Final pressing force	% dry pressed	Apparent density	Burst	Tear	Riehle	Tensile
0.0	35.3	3.75	346	11.3	74.1	88.3
10.0	36.5	3.89	360	10.7	69.8	88.7
13.3	36.8	3.88	355	11.8	76.6	76.8
23.3	37.0	3.90	355	11.3	76.0	77.7
33.3	40.2	4.00	358	12.3	79.5	81.9
50.0	42.8	4.06	377	10.9	78.4	85.1
64.7	45.2	4.28	386	11.4	78.1	87.7
82.3	45.4	4.35	388	10.9	83.2	88.4
100.0	46.6	4.52	390	11.4	80.4	84.4
116.7	48.3	4.48	389	10.7	80.7	89.0
133.3	47.6	4.49	398	11.1	82.4	85.9
150.0	48.3	4.53	394	11.2	82.5	94.1

lbs per linear inch

Multi-ply handsheet formation

The procedure used in making multi-ply handsheets is to make up the individual layers on the Nobel and Wood sheetmaking apparatus. These sheets are then couched from the wire to the felt by passing felt, wire, and sheet through a weighted press. The multi-ply sheet is then formed by couching one sheet upon the other until the desired number of layers is reached. Then the multi-ply sheet is given a second final pass through the press rolls. Dry the sheets at 102° - 105° C and age them at least 16 hours at 70° F and 65 % relative humidity before testing (2,9).

Reproducibility

The reproducibility of test results is very good with this method of sheet formation as is shown by Brown (2) when taking the average percentage deviation from the mean on sets of five, two-ply handsheets of unbleached sulphite.

burst	plus or minus		4.1 %
tear	"	"	4.3 %
Riehle	"	"	6.6 %
tensile	"	"	4.5 %
stretch	"	"	12.5 %
Suvant	"	"	3.0 %

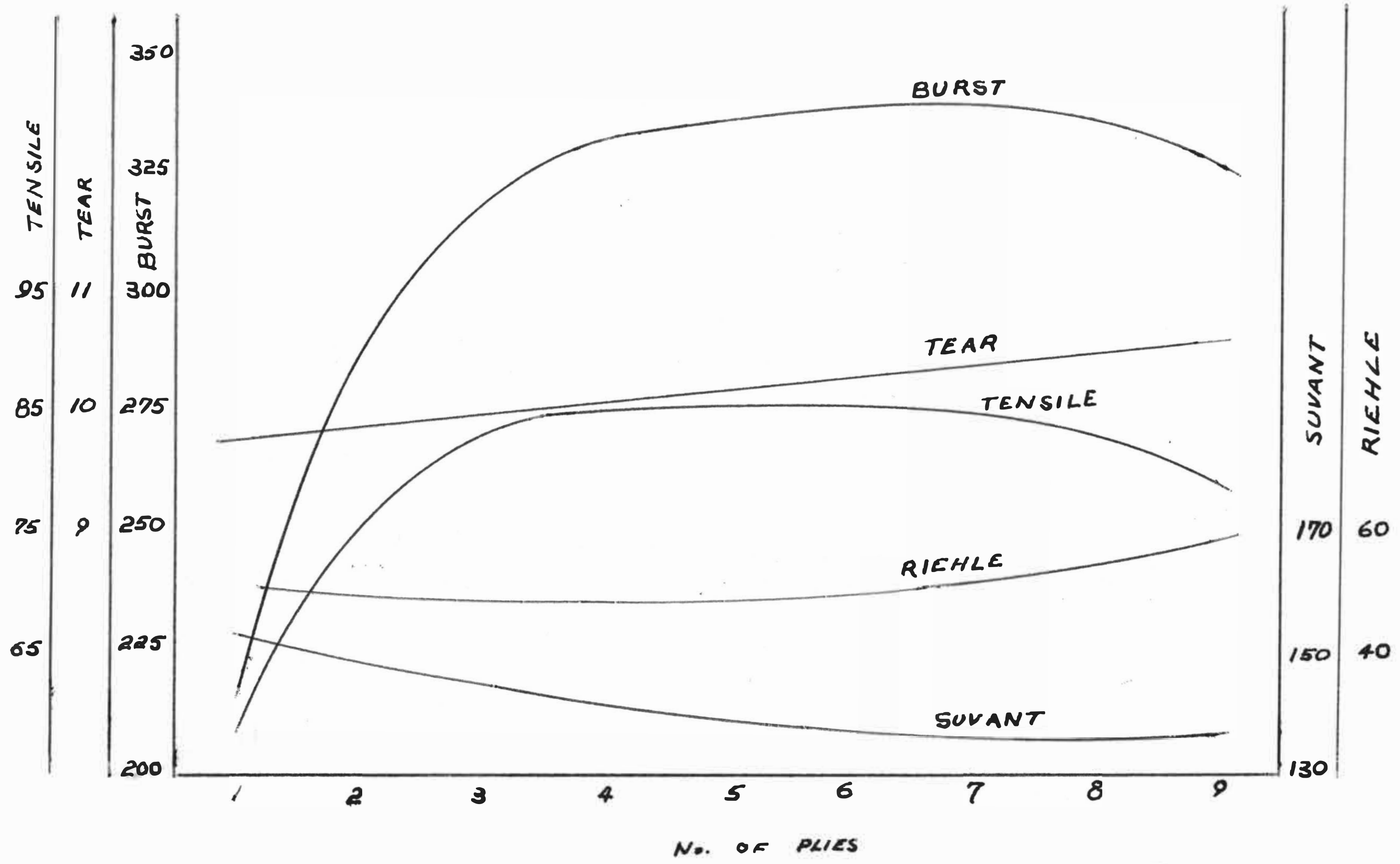
The handsheets should always possess the same properties if made under the same conditions. Those handsheets made under different conditions must be different, and all handsheets must have a constant relation to machine made papers (2).

The Nobel and Wood sheetmaking apparatus is used because of the very close approximation of strength characteristics to those of machine produced papers. In a test on handsheets made on the Nobel and Wood compared with the same stock run on a six cylinder machine making 85 lb kraft lined chipboard, the following results were obtained (2).

Test	Handmade	Machinemade
weight	88.7	85
caliper	29.0	28.5
burst	179.0	161.0
tear	9.7	6.4 *
MIT fold	664.0	240.0 **
Riehle	40.7	49.6 **
tensile	53.6	56.8 **
tear split	18.4	34.4
perpendicular bonding	21.4	32.8

* In machine direction only
** Average machine and cross directions

EFFECT OF THE No. OF PLIES ON STRENGTH OF UNBLEACHED SULPHITE



Purpose

The purpose of this experimental work, is to find how the number of plies effect the strength characteristics of a hand-sheet, of a given basis weight.

Apparatus

The stock prparation equipment consisted of soaking pails, drill press with adgitating rod, and the Valley laboratory beater.

The apparatus used for the sheet formation was the Nobel and Wood sheetmaking apparatus. This apparatus was used because of its adaptability to the formation of multi-ply sheets and its ease in duplication of sheets of a given weight.

All test sheets formed were conditioned and tested in the constant humidity and temperature room at Western Michigan College. All test apparatus as specified by TAPPI standards was used.

Stock Preparation

Kalamazoo Vegetable Parchment unbleached kraft was used in all experimental work.

The weighed pulp was first torn into small squares and soaked over night, at room temperature. The soaked pulp was then agitated on the drill press at 600 r.p.m., for 20 minutes, using the same agitating rod and drill press each time. The temperature of the pulp was then adjusted to 25° C. and the pulp was allowed to circulate in the laboratory beater without

weights on the bed plate. The weights were then put on the bed plate and the pulp beaten for six minutes. This beating time gave a relatively low mullen, near maximum tear, and a free stock.

Sheet Formation

The sheets were formed on the Nobel and Wood sheetmaking apparatus. The single ply sheets were formed according to standard practice as suggested by the manufactor.

The multi-ply sheets were formed by sandwiching several individually formed sheets under the press (top weights on press removed), when as many plies as are desired are sandwiched under the press with the light pressing, a final hard pressing is given each sheet (all weights on the press). The multi-ply sheet was then dried on the rotary steam drier.

Sheets were formed with from on to four plies and in three different weights; 13.5, 27.0, and 40.5 pounds per thousand square feet.

Sheet Testing

All standard tests on the sheets were conducted according to TAPPI standard methods. The tests performed were; weight (T 410 m-45), caliper (T 411 m-44) tear (T 414 m-49), mullen (T 403 m-47), tensile (T 404 m-50), density (T 411 m-44), stiffness (Smith-Taber), and ply bonding.

The ply bonding test used, was the maximum force required

to separate two plies with a right angle pull over a strip of paper 15 mm wide and 2.5 inches long. This test was performed on the tissue tensile tester, with the force measured in ounces.

The sheets were conditioned, at least over night, in the constant humidity and temperature room before the test were conducted. All the tests were conducted in the conditioned room.

Average Results

Standard Basis Weight * — was actual wt. checked?
(13.5 lbs - 1000 sq. ft.)

Plies	Caliper	Density	Tensile	Tear	Burst	Ply Bonding	Stiffness
1	.0059	7960	6.09	117	20.3	- --	2.0
2	.0060	7820	9.80	113	25.7	1.17	2.0
3	.0060	7810	8.52	121	20.3	1.34	2.6
4	.0057	8220	7.35	125	21.9	1.38	1.1

Double Standard Basis Weight *
(27.0 lbs - 1000 sq. ft.)

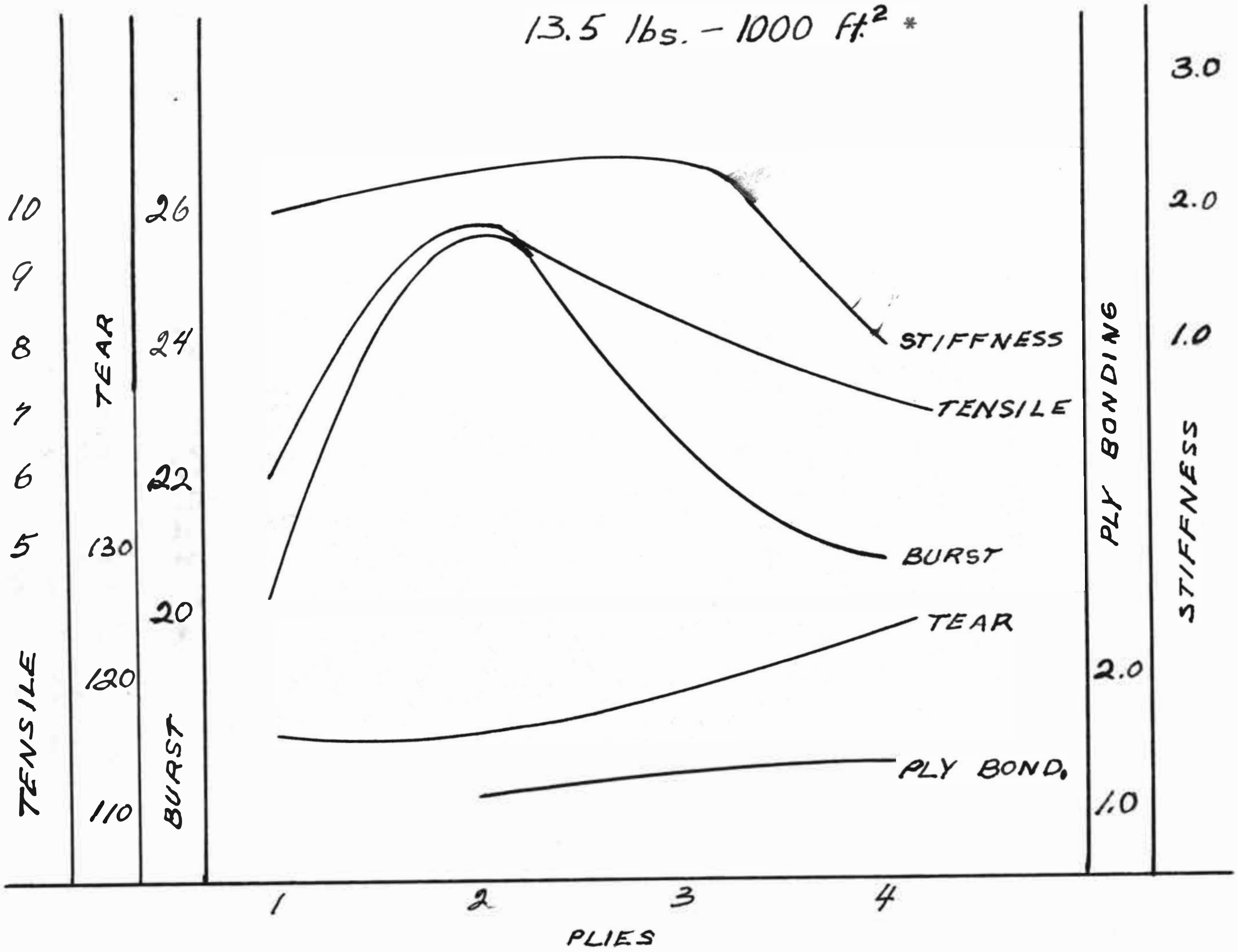
Plies	Caliper	Density	Tensile	Tear	Burst	Ply Bonding	Stiffness
1	.0103	9360	15.8	273	52.9	- --	6.8
2	.0103	9350	23.9	296	75.6	1.42	10.2
3	.0089	10390	19.7	290	60.5	2.42	7.5
4	.0089	10410	19.5	275	59.5	2.22	12.3

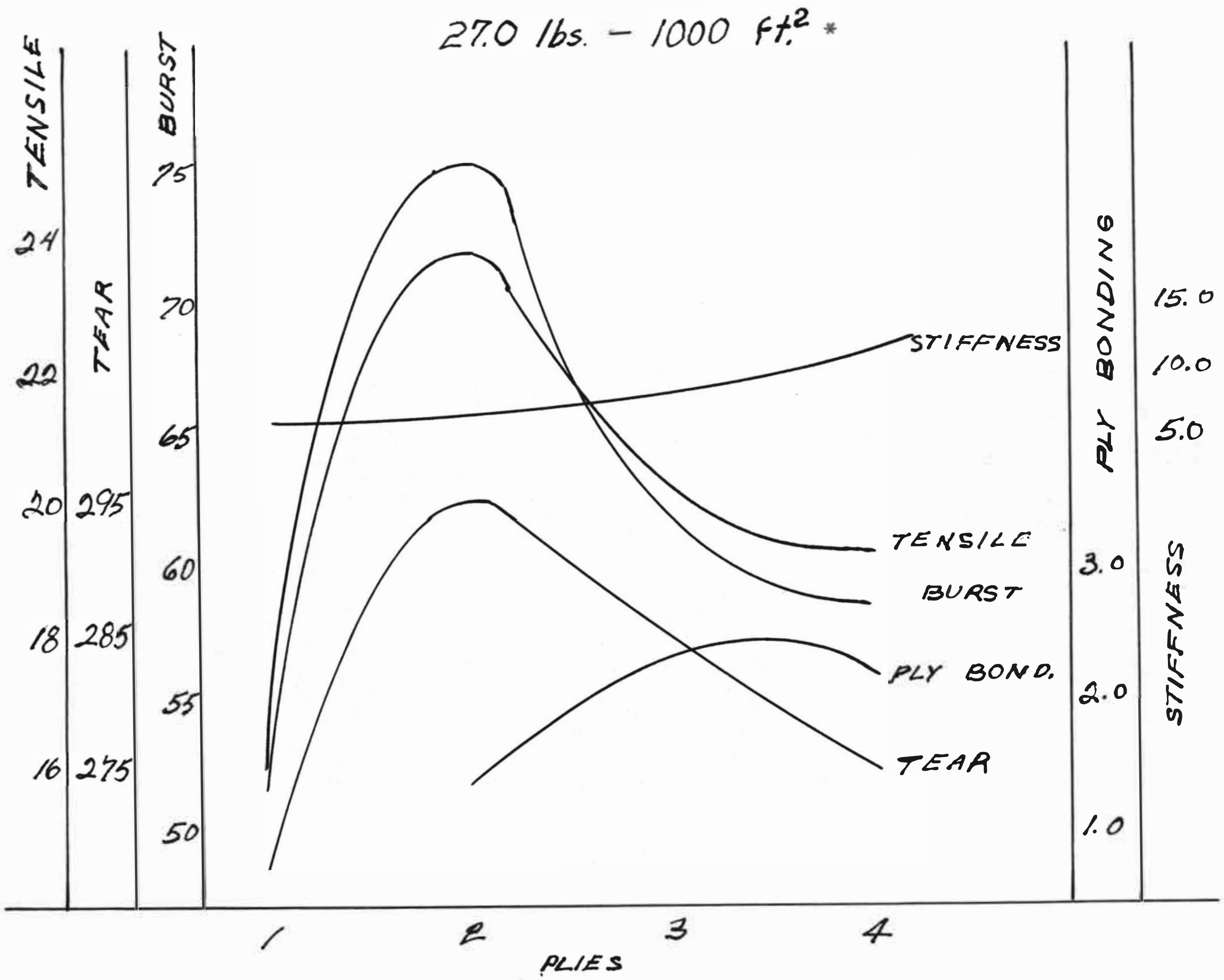
Triple Standard Basis Weight *
(40.5 lbs - 1000 sq. ft.)

Plies	Caliper	Density	Tensile	Tear	Burst	Ply Bonding	Stiffness
1	.0133	10570	26.0	388	78.1	- --	25
2	.0129	10880	34.4	528	101.8	1.23	23
3	.0124	11310	34.6	425	130.8	3.12	29
4	.0120	11700	37.2	396	136.4	2.70	21

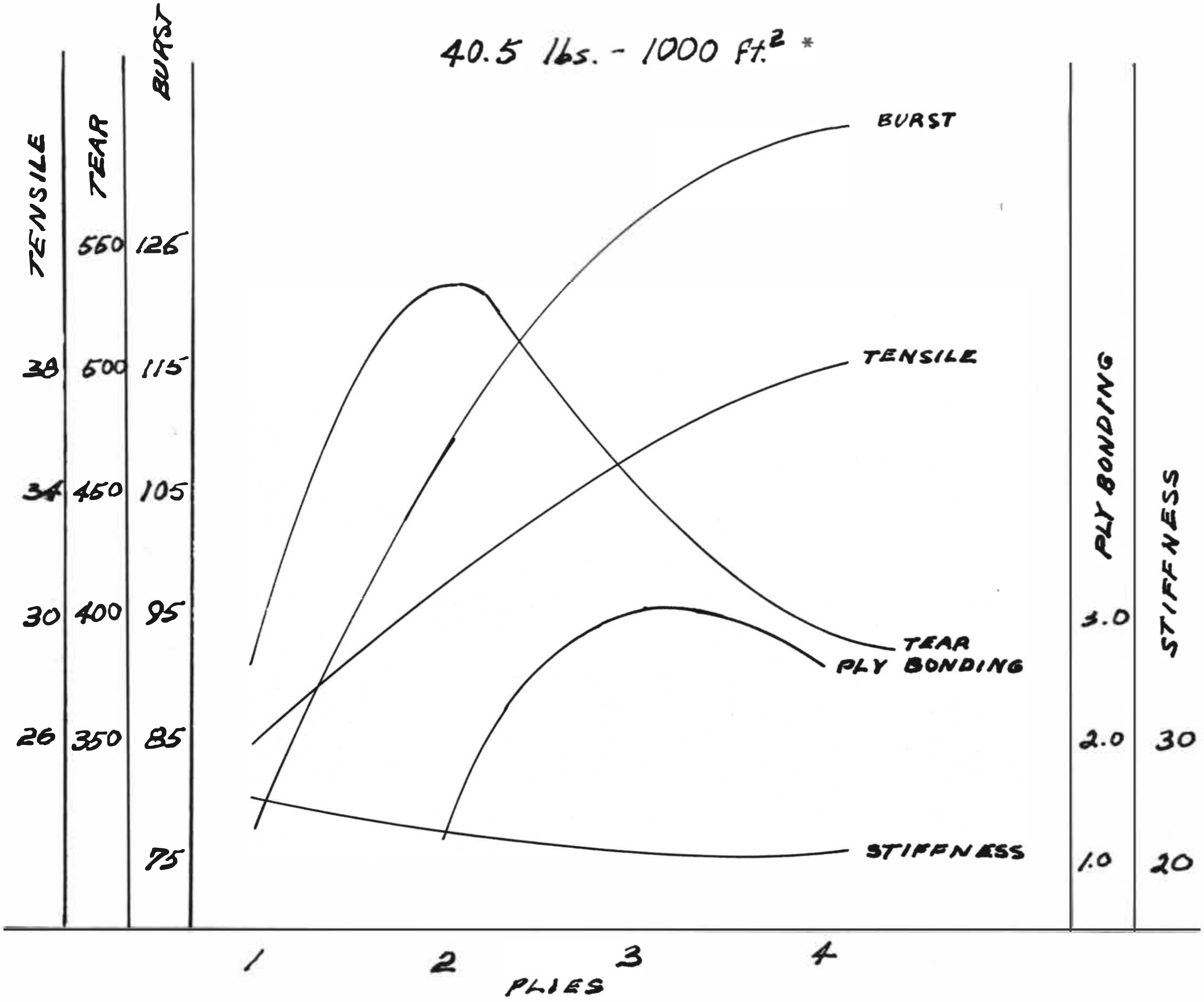
* The units of the tests are; caliper in inches, density in grams per meter^2 per micreon, tensile in kilograms per 15 mm width, tear force in grams to tear a single sheet, burst in pounds per square inch, stiffness in Smith-Taber stiffness units, and ply bonding in force in ounces per 15 mm width and 2.5 inches in length.

*Data for the graph and units of the tests on page 11





*Data for the graph and units of the tests on page 11



*Data for the graph and units of the tests on page 11

In the graphical illustration of the obtained results, it is easy to see that the two ply sheet seems to have the strongest strength characteristics, of the two lightest weight sheets formed. This seems to indicate that in sheets of very light weight, a definite increase in the strength characteristics can be obtained by forming a two ply sheet. The formation of more than a two ply sheet in the lower weight ranges will not increase the strength characteristics above that maximum value reached with the two ply sheet.

The 40.5 pound sheet did not show a drop in burst and tensile strength, as did the two lighter sheets upon increasing the number of plies above two.

This weight sheet continued to give higher burst and tensile with increasing plies. It is easily seen from the graph of this basis weight, that as four plies are made the burst and tensile have started to level off. Without further testing, with increasing number of plies, it would be impossible to know if the four ply sheet has the maximum strength characterisitcs.

Conclusions

The literature survey and the experimental data show that for a given basis weight the strength characteristics of a sheet may be increased by forming a multi-ply sheet. However, the number of plies required to give the maximum strength properties depends upon the weight of the sheet being formed.

Sheets being made on the Nobel and Wood sheetmaking apparatus at the standard basis weight will posses higher strength

properties if made in two plies. Sheets being made on the Nobel and Wood sheetmaking apparatus of three or four times the standard basis weight will require four or more plies to give maximum strength characteristics.

Summary

The literature and experimental work on the strength characteristics of multi-ply handsheets indicates that as the number of plies increase, for a given basis weight, the strength characteristics will also increase. This increase will continue until a sheet contains a certain number of plies. At this point a maximum in strength properties will be reached. A greater number of plies will not increase the strength, the strength characteristics will remain constant and then decrease from the maximum.

The reason for the strength increase may be the better formation obtained with the lower consistency used, when making several thin plies rather than one thick ply. However, after a certain number of plies, depending on the weight of the sheet, better formation due to lower consistencies does not exist and the strength tests remain approximately constant or decrease because of weakening ply bonding.

The effect of different kinds of stocks and different freenesses in the individual plies should be very interesting to a student interested in multi-ply sheets.

End

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Literature Cited

1. Jeitteles, Eberhard, Wochbl. Papierfabr 64:755-756 (1933)
2. Brown, Duncan A, Tech Assoc. Papers 23, 143-154 (1940)
3. Abrams, Allen, Paper Trade J. 91, No. 4:56 (July 24, 1930)
   Tech Assoc. Papers 13:38-39 (1930)
4. Bekk, Julius, Zellstoff u. Papier 14:501-502 (1934)
5. Bekk, Julius, Paper-Maker 89:TS 88-93, (1935)
6. Courtney, R. P., and Wakefield, H. F., Ind. Eng Chem, Anal Ed. 6:470-473 (1934)
7. Doughty, R. H., and Baird, P. K., Paper Trade J. 97, No. 10:38-39 (Sept. 7, 1933)
8. Brax, A. J., Pappers-Trävarutid Finland 18:334-336, 338, 340 (1936)
9. Coghill, James, Paper Trade J. 102, No. 9:27-44 (Feb. 27, 1936)