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Fiber Orientation as a Means to Control Formation on the Ultra-Former Through Changes in the Spouting Jet to Wire Speed Ratio and Stock Consistency in the Headbox

Gerald R. Haw
Western Michigan University

"FIBER ORIENTATION AS A MEANS TO
CONTROL FORMATION ON THE ULTRA-FORMER
THROUGH CHANGES IN THE SPOUTING JET TO WIRE
SPEED RATIO AND STOCK CONSISTENCY
IN THE HEADBOX"

by

Gerald R. Haw

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ABSTRACT

The Ultra-Former is a new type of multi-ply board machine. It uses a cylinder mold without a vat and has a stock delivery system that uses a headbox similar to that found on a fourdrinier machine. The board made on the Ultra-Former has several improved qualities over the board made on the conventional type board machines. Of these several improved qualities formation is one of the most important.

Formation is important because it affects the physical properties of the finished product. One of the major physical properties affected is the tensile strength of the sheet. The tensile strength is reduced due to the higher probability of premature strain failure in areas of low fiber substance caused by poor formation.

Formation is changed through the adjustment of five key machine varibles found on the fourdrinier type headbox. The spouting jet to wire speed ratio and the consistency in the headbox are the most important of the five varibles and the easiest to control.

This project involved the controlling of formation through fiber orientation as the most important varibles, spouting jet to wire speed ratio and consistency in the headbox, are changed. The fiber orientation is deplicted by using a ratio between the machine direction (MD)

tensile and cross machine direction (CM) tensile as determined using the zero span tensile test.

The results obtained indicate strongly that fiber orientation cannot be used for a formation control because the values are too random. At high degrees of fiber orientation the formation may be good one time and low at another time. Formation tended to be more dependent upon basis weight than fiber orientation.

TABLE OF CONTENTS

LITERATURE REVIEW

Ultra-Former

The Ultra-Former is a new type of machine that was developed by the Kobayashi Corporation of Japan to make multiply board at higher speeds and better quality than the present type board machines. The machine utilizes a cylinder mold without a vat with stock flowing from a fourdrinier type headbox onto the face of a rotating cylinder. As water drains through the wire to form a web, a transfer felt carries the previously formed web forward to contact and bond to the new formed web. The felt contacts the cylinder mold for about 3/4 of its circumference, sandwiching the board between the felt and the cylinder mold. The remaining 1/4 of the cylinder mold is between the forming roll and the couch roll, and it is in this area that stock from the headbox is placed onto the rotating cylinder mold (8, 16, 30).

Formation

The formation of the board made on this machine is one of several improved quality factors found through its use. Formation in modern day terms is basically the amount or degree of uniformity of the distribution of the solid components of the sheet with specific reference to the fibers. It is usually judged by the visual appearance of the sheet when viewed by transmitted light (20). Formation is important in that this property influences many of the properties of each web which will be bonded to make the finished sheet of board. The improved formation is attributed to the fourdrinier type headbox that is easily adjusted to optimize conditions for good web uniformity (8, 7, 1).

Formation Varibles

The formation varibles are many on the Ultra-Former, the same as on the fourdrinier machine, but like the fourdrinier, the key machine controlled varibles for formation are found on the headbox. The headbox has the basic function of spreading the dilute stock evenly across the cylinder mold width and to deliver it uniformily dispersed and at a steady rate onto the mold with the minimum possible distrubance (5). Each type of headbox can be considered to have an inherent formation when all its elements are optimized. If the stock is badly flocculated and improperly delivered onto the cylinder mold, chances are good that the formation will be poor, and visa versa.

Locke (19) lists five main controllable varibles of the headbox that are important to formation.

A. The jet to wire speed ratio.

B. The headbox consistency.

C. The perforated or rectifier roll, speed, design, and position.

D. The slice geometry (e.g. angle of stock deliver).

E. The headbox liquid level.

There are other varibles also connected with the headbox but they must be assumed to be optimized through the construction of the headbox.

Some papermakers regard the relationship between the stock velocity leaving the slice and the speed of the wire as the most important factor affecting web formation. This varible is, by far, considered the most easiest controlled of the several varibles. Numerous studies that have been made using the fourdrinier type headbox on different machines indicates that when the best uniform fiber distribution is desired, the well established principle is to maintain stock velocity close to wire speed (25). The generally accepted differential is to control the stock jet velocity between 5 to 10% less than the wire speed (9, 22).

The consistency of the stock in the headbox is also very important from the standpoint of fiber flocculation. The amount of flocculation of the fibers will be dependent upon the physical properties of the fiber itself and the amount of fibers present in a liquid suspension, commonly referred to as consistency (29). The consistency of the stock, as used by the papermaker, is usually as high as possible to prevent having to handle high volumes of white water, with a given web weight, and still get the stock on the wire before fibers flock together too much.

Premature flocculation has two significant consequences in web forming (15, 28). Firstly, flocculation leads to local variations in fiber concentrations in the suspension that are reflected in the formation and, secondly, the presence and interaction of the fibers and fiber clumps causes the hydrodynamic behavior of the suspension to differ significantly from the behavior of water. The shearing action of the stock delivery system tends to distort, rupture, and disintegrate the flocs, but even at the highest shear rates fiber dispersion is not complete at paper making consistencies and fiber interaction and entanglement are still evident. At high shear rates flocculation can be regarded as a dynamic equilibrium process involving the simultaneous dispersion and formulation of floc (15, 28).

Studies by Campbell (14) and co-workers indicated that flocculation of fibers will continue to occur down to consistencies of 0.01%, at this point the fibers are isolated from each other and act independently except for occasional collisions. Formation at such low consistencies would be very good but due to the high volumes of water that must be handled, as mentioned earlier, papermaking would be impractical. Casey (5) points out that due to the dependency of fiber flocculation on consistency, on the one hand, and the impracticallity of using too low of a consistency, on the other hand, most paper making is therefore made between 0.10 and 1.0% consistency.

The controlling of the holey roll speed, design, and positioning is necessary for good formation (11, 12, 13). Changes in this varible does not readily deteriate the sheet formation as does the jet to wire speed ratio or consistency. The holey roll speed necessary is only that of a high enough R.P.M. to maintain cleanliness and deflocculation of the stock before moving through the slice onto the wire. Studies indicate that the best speed of the holey roll to achieve its function is when it is kept at a minimum R.P.M. (21). Improper speed adjustment of the holey roll will create a wake effect in the stock as it flows onto the wire. A wake effect is defined and characterized by the passage of the stock at different flow patterns and velocities through the holey roll. Wake effects appear as free surface defects in the spouting jet leaving the slice of the headbox. For best formation these defects should be controlled to a minimum velocity and parallel to the stock flow.

The slice positioning of the headbox is important to formation because it controlls the angle at which the spouting jet of stock contacts the wire. This area of formation development was studied indirectly by Nelson (24) through the use of a L/b ratio in which L equals the projection of the bottom lip of the headbox in relation to the top lip and b equals the slice opening. Nelson (14) concluded that the least critical L/b ratio for the stock jet to contact the wire was between the values of 0.7 and 2.0. More recent studies with the headbox and Nelson's (14) L/b ratio indicates that formation improves using the higher L/b ratio.

There is no information on the direct effect of the headbox level on formation. This varible's effect on formation is an indirect one. For it is the headbox level that affects the spouting jet velocity of the stock coming from the slice, consistent of the stock in the headbox and the slice opening on the headbox.

One remaining varible that affects formation and is unique only to the Ultra-Former is the formation roll. This is the roll that joins the web from the previous unit to the new web. This roll is adjustable and is said to be responsible for increased formation. The formation is affected by the size of the puddle under this roll. The turbulence in the puddle partly deflocs the surface fibers on the two contacting webs so that when dewatered again the combined web will have better fiber uniformity for increased ply-bonding tensile and formation (7).

Affect of Sheet Formation on Tensile Strength

The tensile strength properties of paper are dependent upon the combined effect of several factors as listed by Britt (2).

A. The strength of the individual fiber of the stock furnish.

B. The average length of the fiber.

C. The inherent bonding abilitv of the fiber surface, both in terms of bonded area and strength per unit of bonded area.

D. The structure and formation of the sheet.

Of the above, listed varible, the focus of interest to this project will be on "D".

The effect of formation on the standard tensile strength test can be linked to a paper chain, in which the high fiber substance parts represent the strong links and the low fiber substance parts represent the weak links. When such a paper chain is strained to failure, as with any type of chain, failure occurs always at the weakest link. The standard tensile strength measurement, reflects as it does, the strength of the weakest link, in a group of links, therefore, it is biased towards the strength of the low fiber substance areas and has a value less than the average paper strength in the test strip. The average of the paper can only be gotten by averaging all the fibers or at least of a random number of the fibers (28). The better the formation of a sheet the higher will be the tensile strength of the sheet and visa versa.

Fiber Orientation Effect on Formation

The test speciments used for a tensile strength measurement are relatively large compared to the size of the fiber substance spots, thusly it can easily be recognized that very small test speciments should minimize the variation in fiber substance, to give a maximum in tensile strength measurement on each sample. When such a small sample is used to minimize fiber non-uniformity the tensile test becomes essentially a test of an individual fibers strength (29). The test results would then become dependent only on the number of fibers involved in the test, assuming that the differential between strengths of all the individual fibers is relatively small. Such a test for determining the individual fiber's strength and minimizing the fiber substance area variations in the sheet is the zero span tensile test.

The tensile strength of an individual fiber as determined through the zero span tensile test, cannot be considered accurate without the consideration of fiber bonding and fiber curl. Kallmes (18) states that if a ratio is used between the machine direction (M.D.) tensile and cross machine direction (C.M.) tensile, using zero span tensile, the effects of bonding and fiber curl can be minimized thereby leaving only the variation due to the number of fibers involved in the test. The number of fibers that will be involved in the tensile test will be determined by the degree of fiber orientation in the sheets. The degree of fiber orientation is the greater predomance of fibers that are aligned in one direction than in another in the web of paper.

When a handsheet is made there is no fiber orientation because there are no forming gradients as found on a machine, therefore, when zero span tensile measurements are made the ratio of one direction to another is unity or very close to it (28). The fiber orientation in machine made paper is more than in the handsheets because of forming gradients, and the tensile ratio is significantly greater than unity with fiber orientation highest in the M.D. The machine made paper is usually never "square" as is the handsheet paper.

Work done by Pruss (26) on the effect of fiber orientation on sheet properties, observed that the only strength properties really affected by fiber orientation was tensile. The tensile was increased in the machine direction and the MD/CM ratio was always greater than unity. A very interesting result that concerns this study was that the more fiber orientation that occured the better was the sheet formation. Pruss (26) stated that it was very hard to make a handsheet with good formation without fiber orientation. Other work done by Finger and Majewaski (10) indicated that formation is better with some fiber orientation than with no fiber orientation as found in handsheet paper or "square" paper.

Paper with good formation can usually be made on a machine easier than on a handsheet mold with no forming gradients.

CONCLUSIONS

The Ultra-Former is the best type of multiply board machine sold today. It produces a board at higher speeds and higher quality than the convention type board machines.

Of the several improved qualities found with the board made on the Ultra-Former, formation is one. The improved formation is generally attributed to the fourdrinier type headbox used to deliver the stock onto the cylinder mold. This type of headbox is readily adjustable to quickly optimize board quality.

Of the several varibles that can be adjusted within the headbox, the jet to wire speed ratio and consistency of the stock in the headbox are the most important.

Formation does affect the tensile strength properties of paper. The better the formation the higher is the tensile strength of the paper.

A zero span tensile measurement will give the relative strength of the individual fiber and the tensile value will vary due to the number of fibers included in the test. A zero span tensile ratio thus will give an indication of the degree of fiber orientation. By using a ratio the effects of fiber bonding and fiber curl are minimized.

Formation is affected by the degree of fiber orientation. The higher the fiber orientation, generally the better the formation.

Objective

This project will be run on the Ultra-Former, varing the main controllable headbox varibles, that being the jet to wire speed ratio and the consistency in the headbox. Paper samples from the machine will then be tested for degree of fiber orientation using a zero span test ratio. The goal of the project is to determine whether formation on the Ultra-Former can be controlled by using the zero span tensile ratio and its relationship to fiber orientation.

EXPERIMENT PROCEDURE

Machine Operation Section

The study was conducted using the 30" Ultra-Former unit found in the pilot plant of the Paper Science and Engineering Department at Western Michigan University. The machine is similar to the commercial machines except for its smaller web width and that it can only make single ply paper since there is only one unit.

The machine was run at five different speeds between 200 and 280 fpm, while varying the consistency of the stock from .64% to 1.20%, going onto the wire. The headbox liquid level, the slice position, and the holey roll speed were held constant through the trial. The headbox level was maintained at 3" which gave a theoretical spouting jet velocity of 239.4 fpm going onto the wire. The vertical lip of the slice was set at 0.5" open, with the lower horizontal lip of the slice protruding 24 mm past the vertical lip. This arrangement gave an l/b ratio of 1.89 which is within the "safe" limits described by Nelson (24) (.7 l/b 2.0) in which the sensitivity to change is lowest. The holey roll speed was permanently set at 27.5 rpm.

Press Section

The press section of the machine has a 40" roto belt vacuum unit and three rubber presses, varying in hardness. The only parts of the press section used in the study was the roto belt vacuum unit and the last press.

At no time was the web pressed without being against a felt.

Pulp and Sampling of Pulp

The pulp used was a 50/50 blend of hardwood and softwood refined to a CSF of 400. The pulp had no additives in it. Pulp samples for consistency checks were taken from the headbox during each run. The samples were stored until tested.

Paper Sample Collection

The paper samples were collected wet from the machine and dryed in between sheets of pulp. Weight was put on the sheets of pulp during drying to prevent shrinkage of the sample. The samples, after drying were conditioned according to Tappi Standard 220-M60 for 24 hours before testing.

Testing

The consistency of samples collected from the headbox were checked by weighing out "X" grams of sample, then evaporating in an oven until dry.

The basis weight of the sheet samples were determined by weighing "X" square feet of the sample then converting this weight into #/1000 ft.^{2}.

The zero span tensile test was done following Tappi Standard 481-Su60 using the instron for both machine direction (MD) and cross machine direction (CM). A ratio was then calculated using the MD and CM tensile values obtained.

The formation of the samples was determined using a Thwing-Albert Formation Tester. This instrument works by scanning an 8" diameter sample of paper rotating at 1500 rpm with a beam of light, and that which is transmitted through the paper is picked up by a photo cell. The photo cell being the type which changes its resistance with the amount of light striking it. The more light striking the cell, the lower is its resistance and the higher is the electron flow (e.g. current) through the cell. The electron flow is then amplified and calibrated to a readout meter which gives the overall formation as a % of some standard. The changes in the amount of light picked up by the photo cell is due to the change in the small scale sheet uniformity.

Observations

Under the machine conditions set up at the start of the trial the consistency range was limited between a low of .50% and a high of 1.30%. At the low consistency samples could not be obtained because there was insufficient wet strength in the sheet to hold it together while handling. At the high consistency there was crushing of the web at the last press, totally destroying the web.

The jet of stock spouting from the headbox had a large amount of ripples and turbulence which lessened as the wire speed increased. The ripples and turbulence in the jet seemed to be due to the high rpm of the holey roll, it was beating air into the stock and creating a large amount of turbulence while still in the headbox. The ripples and turbulence, caused some streaking at the low wire speeds.

DISCUSSION OF DATA

The basis weight of the sheet samples decreased with increasing speed, because the total volume of stock flowing onto the wire remained constant at each consistency setting. The average change in weight from the lowest speed to the highest speed was about 6#/1000 ft.^{2} (Table II-C).

The change in fiber orientation, as deplicted by the MD/CM tensile ratio, increased very slightly with changes in speed at a given consistency setting. This was not expected because of the supposed combing effect of the wire when its speed goes above the theoretical speed of spouting jet coming from the slice. The theoretical speed for the liquid head of 3" was 239.4 fpm, this speed was exceeded by 40 fpm on the wire. At 40 fpm above the theoretical speed no great amount of fiber orientation was noted (Table II-A). Greater fiber orientation changes due to the wire combing probably couldn't be detected because the weight of the paper was to great, splitting the sheet and testing only the wire side may have indicated more fiber orientation.

The change in fiber orientation due to change in the consistency at a given speed, was quite significant. An increase of 30% or more in fiber orientation was noted by increasing the consistency from .64% to 1.20%. This was probably due to the floccing together of the stock before leaving the headbox and thusly being aligned by the flow through the slice and along the lower horizontal lip of the slice rather than the combing effect of the wire.

Fiber orientation under both situations seems to be more dependent upon the amount of fiber present in the stock than the speed of the wire.

This is readily seen in the situation where the consistency increases while holding the speed constant (Table I-A).

Under the set of conditions set up for the trial there does'nt seem to be any good relationship between fiber orientation and formation. Under one set of conditions, increasing speed at a constant consistency, the fiber orientation did increase and the formation improved, while under the other conditions, increasing consistency at a constant speed, the fiber orientation also increased but the formation became very poor (Table II-A, B). The formation in each speed consistency grouping changed more predictibly from changes in basis weight than fiber orientation. The formation always improved with a lowering of the basis weight, dispite the degree of fiber orientation. In fact, looking at Graph I, (Formation vs. Consistency) the rate of change of formation with consistency was the greatest at the .64% and .82% consistency levels, where the basis weight was the lowest and some of the lowest fiber orientation values were noted. Overall one test speciment may have had a high degree of fiber orientation and good formation while another may have had still a higher degree of fiber orientation but very poor formation. The fiber orientation values are too random to show any strong correlation between it and formation.

EXPERIMENT CONCLUSIONS

There is a significant increase in fiber orientation when changing from one consistency to another at a constant speed.

Formation in this study tends to be more dependent upon basis weight than fiber orientation.

The relationship between fiber orientation and formation is not sufficient enough, so that fiber orientation can be used as a means to control formation on the Ultra-Former.

TABLE I

Result at .64% Consistency

Speed	Tensile MD (kg)	Tensile CM (kg)	MD/CM	Basis Weight #/1000 Ft.^{2}
200	7.402	6.172	1.198	17.00
220	6.182	4.885	1.266	15.64
240	5.473	5.160	1.061	15.11
260	4.216	3.907	1.079	14.38
280	5.432	4.740	1.146	12.75

Result at .84% Consistency

200	12.34	9.171	1.345	23.86
220	11.93	9.696	1.230	21.47
240	11.48	8.963	1.281	19.53
260	5.747	4.130	1.392	16.54
280	5.958	3.979	1.497	13.61

Result at 1.06% Consistency

200	16.51	10.79	1.532	29.57
220	15.33	9.727	1.576	26.50
240	13.83	9.250	1.497	24.98
260	12.15	8.846	1.374	22.28
280	12.70	7.418	1.612	20.88

Result at 1.20% Consistency

200	18.97	12.40	1.530	31.44
220	17.56	10.67	1.645	29.20
240	14.53	8.469	1.616	27.34
260	13.54	8.029	1.686	24.95
280				

TABLE II-A

Fiber Orientation

(MD/CM Ratio)

Speed/Consistency	.64%	.84%	1.06%	1.20%
200	1.198	1.345	1.532	1.530
220	1.266	1.230	1.576	1.645
240	1.061	1.281	1.497	1.616
260	1.079	1.392	1.374	1.686
280	1.146	1.497	1.612	

TABLE II-B

Fiber Orientation

(% of Standard)

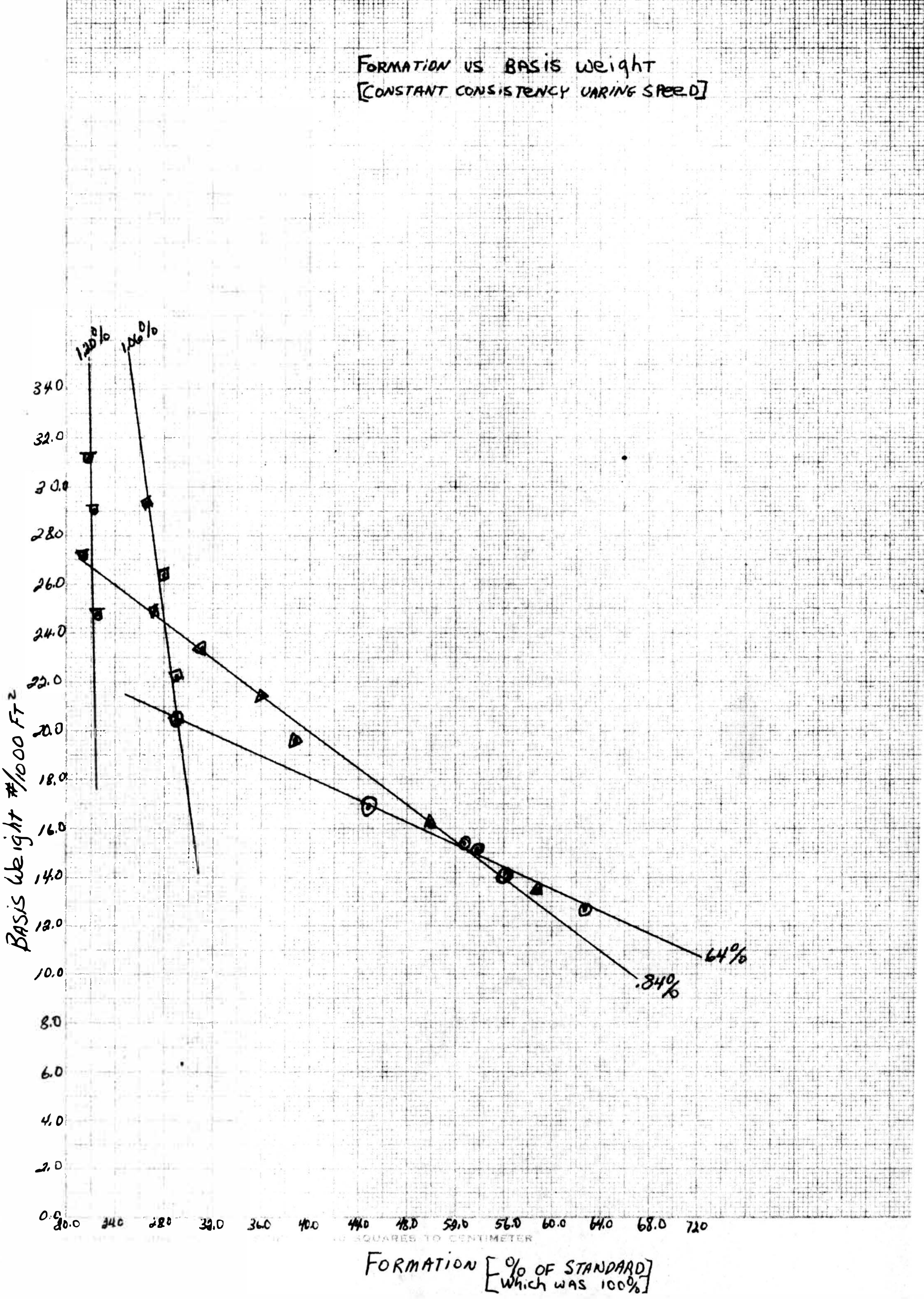
Speed/Consistency	.64%	.84%	1.06%	1.20%
200	45.2	31.7	25.6	21.7
220	54.1	36.3	28.1	22.0
240	53.2	38.7	27.4	21.3
260	54.6	49.0	29.4	22.6
280	63.0	59.1	29.0	

TABLE II-C

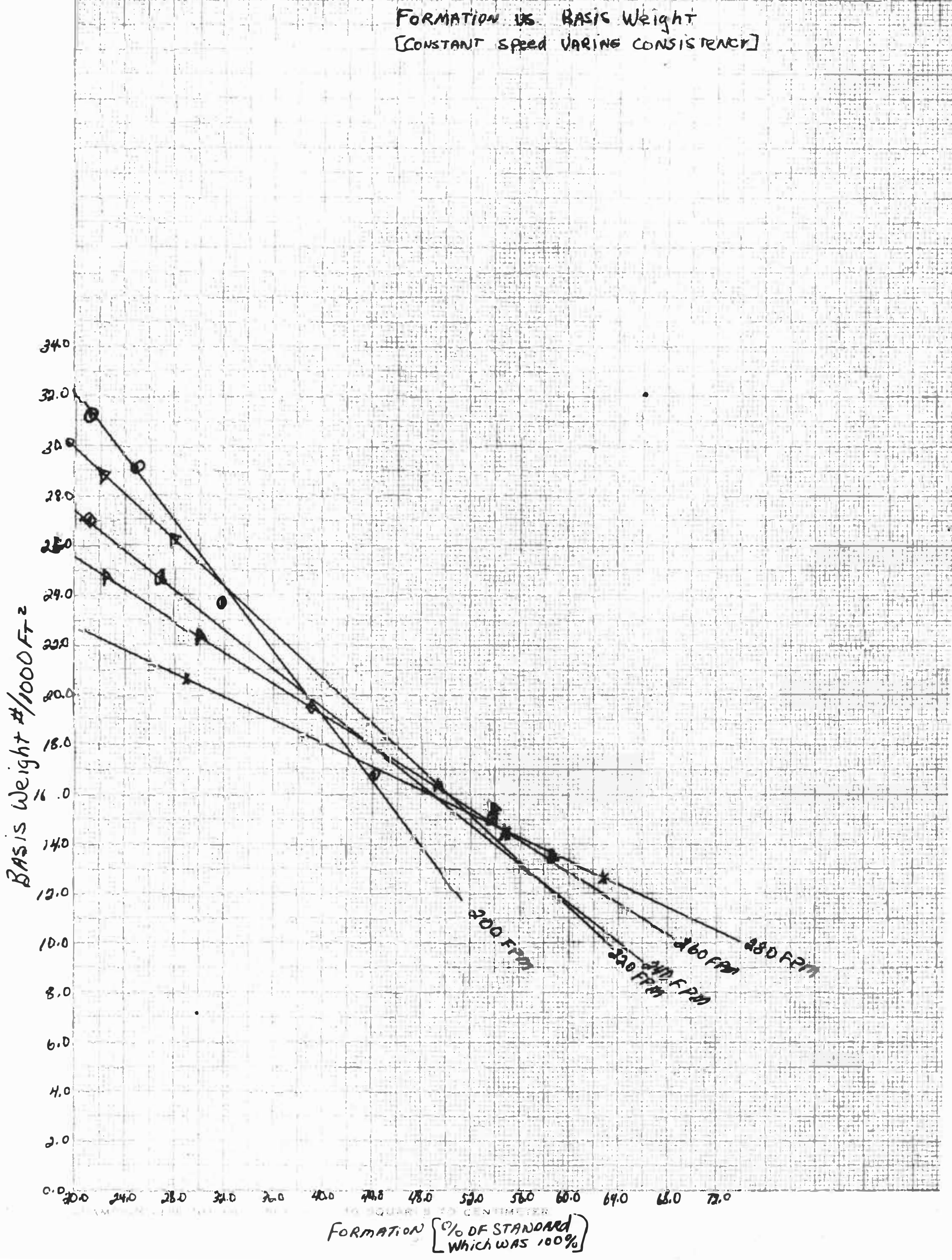
Basis Weight

Speed/Consistency	.64%	.84%	1.06%	1.20%
200	17.00	23.86	29.57	31.44
220	15.64	21.47	26.50	29.20
240	15.11	19.53	24.98	27.34
260	14.38	16.54	22.28	24.95
280	12.75	13.61	20.88	

GRAPH I


FORMATION VS BASIS WEIGHT
[CONSTANT CONSISTENCY VARING SPEED]
120%
106%
64%
.84%
34.0
32.0
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
20.0
24.0
28.0
32.0
36.0
40.0
44.0
48.0
52.0
56.0
60.0
64.0
68.0
72.0
SQUARES TO CENTIMETER
Basis Weight #/1000 FT²
FORMATION [% OF STANDARD]
[Which WAS 100%]

GRAPH II


FORMATION vs BASIS WEIGHT
[CONSTANT SPEED VARING CONSISTENCY]
BASIS WEIGHT #/1000 FT²
FORMATION [% OF STANDARD WHICH WAS 100%]
200 FPM
220 FPM
240 FPM
260 FPM
280 FPM
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
32.0
34.0
24.0
28.0
32.0
36.0
40.0
44.0
48.0
52.0
56.0
60.0
64.0
68.0
72.0

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