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The Use of Dry Strength Additives to Improve Curling Resistance in a Sheet of Paper

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THE USE OF DRY STRENGTH ADDITIVES TO IMPROVE CURLING RESISTANCE IN A SHEET OF PAPER

BY

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ABSTRACT

The purpose of the following report was to look at the possibility of using dry strength resins to help reduce curling tendencies in a sheet of paper.

The use of dry strength additives greatly increased the strength characteristics of a sheet of paper. The increase was so great it allowed: substituting softwood fibers with hardwood fibers and/or using a higher freeness and still retain the same strength characteristics. The results of these changes would give a sheet of paper reduced curling tendencies. The changes could also result in power reductions, material savings, and/or improved formation for producing the sheet of paper.

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LITERATURE SURVEY

A survey of the literature for information on paper curl was made using the library facilities of Western Michigan University. The survey covered English articles which were available on paper curl from 1950 to the present.

When looking at curl, we must first look at the different types of curl. When we think of the curl of a sheet of paper we think of the general curvature of the sheet (1). This curvature could be a; hook, curl, or twist. The curvature could also be classified as wet curl, set curl, or just general paper curling. The curl of a sheet also has a direction of curl. All of these types of curls have to be defined so that we understand what type of curl is being discussed.

There are many causes of curl. Some are very major and some have only a minor effect on curl of a sheet. Some of the parameters that have a major effect on curl are: moisture content uniformity, drying of paper, changes in relative humidity, and fiber orientation. There are also many minor parameters that contribute to curl of a sheet of paper. Some of these are: fines orientation, additives in the sheet, mechanical stress, caliper, beating, pulp, density, ratio of elasticities, jet speed ratio, etc. These parameters listed as major and minor contributors to curl should not be stringently held in these catagories. Depending on the type of paper and its manufacturing, these parameters may be interchanged into major or minor causes of curl, or may even be canceled out altogether.

Curl: Curl is the curvature of a sheet of paper. It may appear as a gross curl around some direction in the sheet. When talking about curl, it is usually described as the degree of curvature of the sheet.of paper (2).

Hook, Curl and Twist: The terms hook, curl and twist are used to describe the general appearance of the condition of the sheet. Curl is the slight upward or downward tendency of the edges of the sheet (3). Hook is a major tendency for a sheet to curl upward or downward at the edge or edges (3). Twist is the extreme coiling of the edges or corners in the same or opposite direction. The degree of acceptability varies between grade and end use. Curl is more acciptable than twist or hook, and hook more acceptable than twist (3).

Wet Curl: Wet curl is the curl that takes place when paper is coated on one side with an aqueous solution (4). When aqueous liquids are applied to one side of the sheet, curl developes rapidly. Sometimes the degree of curl is moderate, and sometimes it is severe. The axis of the curl is in the machine direction of the sheet. It is caused because of the swelling and expansion of fibers which takes place on the wetted side of the paper.

Set Curl: When paper has remained in rolls for a period of time, the curved condition becomes set in the paper and remains after the paper is sheeted (5). This condition is more pronounced near the core. It is more likely to occur in papers which are heavier and stiffer. Set curl can be minimized by using large diameter cores, leaving the paper in roll form for the shortest possible time, and by using decurling bars or other devises as the paper is sheeted (5).

Direction of Curl: The direction of curl is defined as that side toward which the edges of the sample have curved with respect to the center of the sample (6). Wire or coated side is designated plus (+), and the felt or uncoated side is designated minus (-).

Moisture Content Uniformity: It has been stated that one of the major causes of curl is moisture distributed nonuniformly throughout the sheet (7). Dry cellulose is extremely hygroscopic, taking up moisture avidly from any source (8). The taking up of moisture causes the fibers to swell. This change is primarily in thickness with little change in length (8). Since the wire side has more of its fibers orientated in the grain direction than the felt side does, it can be expected to have a greater tendency to shrink or expand in a direction perpendicular to the grain (8). The result is a uneven degree of swelling throughout the wire side, thus a resulting curl. Curl caused by nonuniform moisture cannot be controlled by the papermaker since it involves the inherent dimensional stability of cellulose to moisture changes (7).

Change in Relative Humidity: As stated before, cellulose is very hygroscopic. When water is absorbed, swelling will occur. Swelling will cause an increase in fiber thickness as much as twenty times greater than fiber length. A greater percentage of fibers are oriented in the machine or grain direction on the wire side than on the top or felt side (9). This combination will result in an increase of area in the cross machine direction in the wire side compared to the felt side. This would result in a negative curl. Generally, papers will curl towards their felt side upon moisture absorption or exposure to high relative humidity, and towards their wire side if they dry out upon exposure to low relative humidity.(9).

Fiber Orientation: If the fibers were equally distributed in all directions throughout a sheet of paper, a major cause of curl would not exist (10). The forces resulting from shrinkage or expansion of the fibers on the two sides would then counterbalance each other and not cause the paper to curl. However, because of the mechanisms of papermaking, fibers tend to aline themselves in the machine direction. Fiber orientation also varies from one side of a paper to the other, with the wire side holding the above statement more stringently. Thus, the wire side will be most effected by shrinkage or swelling of fibers. The result will be that the total area of the wire side will be increased or decreased due to swelling or shrinkage causing a negative or positive curl.

Fines Orientation: Fines orientation effects paper curl but not to the same degree as fiber orientation. Fines are very small and do not tend to aline up in a head to tail fashion as the longer fibers do. On the felt side of a sheet of paper there is a better random distribution of fines and fibers. The net result is that swelling expands the sheet in both directions at a lesser effect. Thus, the total expansion of the sheet is minimized and so is the resulting curl (11).

Drying: As fibers give up moisture during the drying stages of papermaking, they shrink (12). It has been demonstrated that for all machine made papers, the direction of curl tends toward that side from which the moisture was last removed (12). Paper contracts continuously in all directions as it is dried, if the final paper is to be free from curl, then the total contraction between a papers two sides must be equal.

Additives: Mineral fillers, being inert to moisture, help stabilize paper and reduce its tendency to curl. The amount of fillers used can help to stabilize a sheet of paper. Literature has also shown that starch size produces a positive curl tendency (13).

Dry Strength Additives: Dry strength additives adsorb onto the fibers and increase the bonding area of their intersection with other fibers (19). This increased bonding area leads to more and stronger bonds thus giving the sheet higher strength characteristics. Therefore, the original strength characteristics can be obtained with less refining. The swelling and shrinkage of fibers, due to changes in relative humidity, increases with refining; therefore, reducing refining will aid in the reduction of curl problems (20). The use of dry strength additives can also combine the properties of higher strength with porosity, which will also help to control the sheet's stability (20).

Internal Structure: Open fibrous structure provide considerable room or inter-fiber space for movement of fibers during their expansion or contraction. Thus, soft, porous papers such as blotting and towelling seldom curl. By contrast, dense, hard papers have their fibers tightly bonded to each other, with little inter-fiber space. Expansion or shrinkage of this fibrous structure will then cause a large effect on the curl of the sheet (14).

Mechanical Stress: Set curl can develope after paper is made and stored in roll form for a period of time. The curved condition becomes set in the paper and remains after the paper is sheeted (5). Leaving the paper in roll form for the shortest possible time, by use of large cores, and by using decurling bars or other devises can help to minimize the curl problems.

Caliper: It has been noted by Spitz and Blickensderter, that curl is inversely proportional to caliper, providing that the basis weight is kept constant (15). The lower the caliper, the higher the resulting curl. The higher the caliper, the larger the free internal volume and thus the lower the resulting curl. Bulk ratio or density is the prime consideration in variations of caliper and basis weight.

Rate of Elasticities: It is shown in the literature, that the ratio of elasticities of the two sides has an effect on the curl of a sheet of paper. It is stated that curl is affected by the ratio of elasticities of the two sides but not by the average level of elasticity (16).

Beating: The amount and type of beating or refining has an effect an paper curl. Generally, increasing refining increases the fibers hydroexpansivity characteristics thus increases curl (20). The decrease in length of fibers through fibrillation produces greater dimensional instability. Refining by cutting also has some effect but only minumal compared to fibrillation.

Density: The relationship of density and curl has the same effect as the internal structure of a sheet of paper and its effect on curl. As density of the sheet of paper increases, there is less internal area available for swelling of shrinkage (14). This will result in an increase of curl to compensate for the lack of free internal volume.

Pulp: The type of pulp also has an effect on the curl of a sheet of paper. Groundwood papers are known to be relatively stable in dimensional stability, thus having minimal curl problems (17). High-yield pulps produce paper of greater dimensional stability than low-yield pulps (18). In general, sulfate pulps produce papers superior to that from sulfite pulps, in terms of lack of curl problems (17). Hardwood pulps also have greater dimensional stability than softwood pulps or rag pulps. Refined rag pulps are the poorest in dimensional stability so therefore, have the highest curling tendency (17).

EXPERIMENTAL DESIGN

From the literature survey, it was shown that there are many different causes for curl in paper. Many of these can be expected, minimized, and controlled in order to reduce curl. There is, however, means of reducing curl by adding dry strength additives which increase the sheet's strength characteristics enough so that refining can be reduced and/or a weaker and more stable fiber substituded.

This experiment, therefore, is designed to look at the feasibility of the use of dry strength additives and the adjustments needed to give increased curling resistance to a sheet of paper.

Two different types of pulps, and three different freeness levels will be used. Three different dry strength additives will be tested and their effect on various sheet properties determined.

EXPERIMENTAL INVESTIGATION

Types of Pulps: The two types of pulps used in this investigation were Esponola bleached softwood kraft and Esponola bleached hardwood kraft. Both of these pulps are northern wood pulps. It was felt that these two pulps would be a good representation of the effects of softwood fibers and hardwood fibers in a sheet of paper.

Refining Equipment: To give a better indication of industrial refining, Western Michigan University Paper Pilot Plant's refining equipment was used. A two hundred twenty pound beater was used to break the pulp sheets into free pulp. The pilot plant's Claflin refiner was used for all the refining of the pulps.

Preparation of Pulps: The sheets of pulp were added directly to the beater and time was allowed for them to completely break up. The pulp was then pumped through the Claflin refiner on a continuous cycle. The Claflin refiner was then set at 40 kilowatts.

The freeness target points were 500, 400, and 300 Canadian Standard Freeness. The Claflin refiner was opened up and freeness checks were taken at various times. When at a freeness target point a bucket full sample was taken and stored. Table 1 shows the data relating to pulp and freeness used.

TABLE 1

PULP	TARGET FREENESS (CSF)	OBTAINED FREENESS (CSF)
Esponola SWK	500	470
Esponola SWK	400	397
Esponola SWK	300	300
Esponola HWK	500	479
Esponola HWK	400	414
Esponola HWK	300	307

The pulps were treated with formaldehyde and stored in a cool place. the samples were used as soon as possible to further diminish the chance of deterioration.

Formation of Handsheets: A standard furnish was used for making the handsheets. It consisted of one percent rosin size and two percent alum based on dry fiber weight. The furnish was then treated with diluted sulphric acid to set the pH in the range of 4.5 - 5.0. A dry strength additive was then added at a specific time. The dry strength additive was added at one percent solids to an amout that equaled one-half percent dry strength additive to dry fiber weight.

Three dry strength additives were used in the handsheets. The three dry strength additives were dry strength resins from American Cyanamid. The name of the dry strength resins are Accustrength 86, 98, and 410.

The Noble and Wood handsheet equipment was used in making the handsheets. Consistency of the furnish was adjusted to make standard 2.5 gram handsheets.

Handsheets were made under twenty-four different conditions. Two pulp types, three different freeness levels, and four different types of additives (three dry strength additives and one blank).

Twelve to fifteen handsheets were made of each condition. The handsheets were wet pressed at the maximum weight. The handsheets were then dried in two passes of the cylinder drier set at 240 degrees F. Several handsheets were not dried but were set aside for the free shrinkage test.

<u>Testing of Handsheets:</u> The handsheets were tested for; free shrinkage, caliper, bulk ratio, tensile, fold, and porosity.

The tensile test was done on a Pendulum tensile tester. The porosity test was a Sheffield porosity with a 3/4 inch diameter plate. The fold test was a MIT fold.

The free shrinkage test was done by measuring and marking fifteen centimeters on the handsheet after wet pressing. The handsheet was then allowed to dry in a constant humidity room without tension. The markings were then remeasured. The free shrinkage test reports percent shrinkage of the handsheet during drying. The free shrinkage test is about the best test for curl tendency when dealing with handsheets.

TABLE 2

PULP	CALIPER	BULK RATIO	POROSITY
SWK 300	5.8	.297	93
SWK 400	5.7	.307	122
SWK 500	5.6	.311	151
HWK 300	6.1	.285	142
HWK 400	5.7	.303	236
HWK 500	5.5	.313	351

Caliper - thousandths of an inch

Bulk Ratio - grams per cubic centimeters

Porosity - Sheffield Porosity

Freeness - 300, 400, 500

TABLE 3

A - Accustrength 86

B - Accustrength 98

C - Accustrength 410

D - Blank

PULP	FREE SHRINKAGE	TENSILE	FOLD
SWK A300	5.7	13.41	295.0
SWK B300	6.3	13.05	162.6
SWK C300	6.0	13.72	185.4
SWK D300	6.0	11.23	92.8
SWK A400	4.7	13.19	200.8
SWK B400	5.0	13.39	179.4
SWK C400	5.0	11.89	134.2
SWK D400	5.3	11.13	82.2
SWK A500	4.7	12.80	135.8
SWK B500	4.0	11.73	132.4
SWK C500	4.3	11.52	137.6
SWK D500	4.3	10.39	88.0
HWK A300	4.7	10.21	15.4
HWK B300	4.7	8.98	12.2
HWK C300	5.0	9.46	8.6
HWK D300	4.0	8.14	6.0
HWK A400	3.3	7.56	5.6
HWK B400	3.3	7.60	5.2
HWK C400	3.3	6.99	4.4
HWK D400	3.3	6.09	4.2
HWK A500	2.7	7.24	4.6
HWK B500	2.7	5.41	3.0
HWK C500	3.0	5.69	3.2
HWK D500	3.0	5.19	1.4

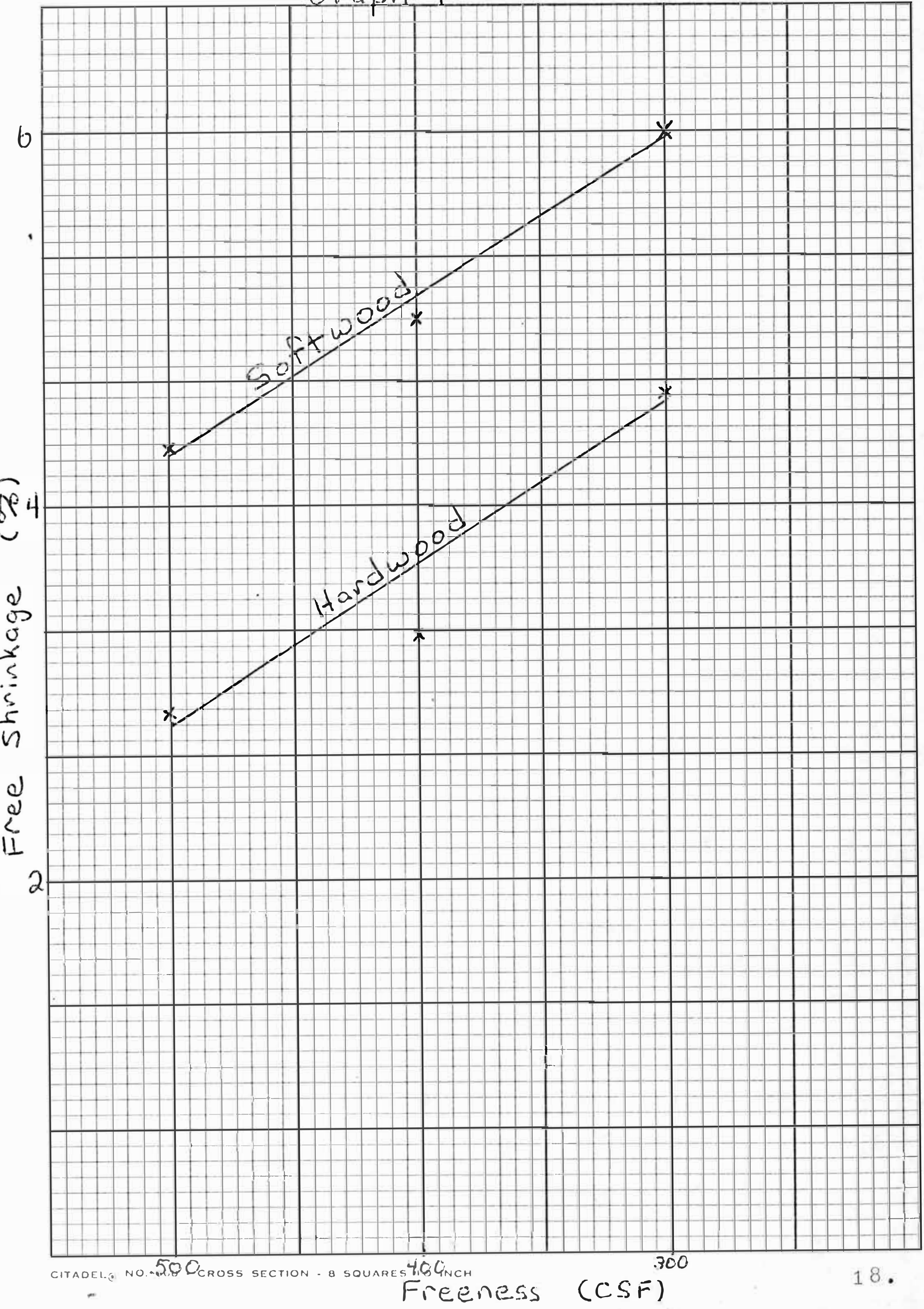
Freeness 300, 400, and 500

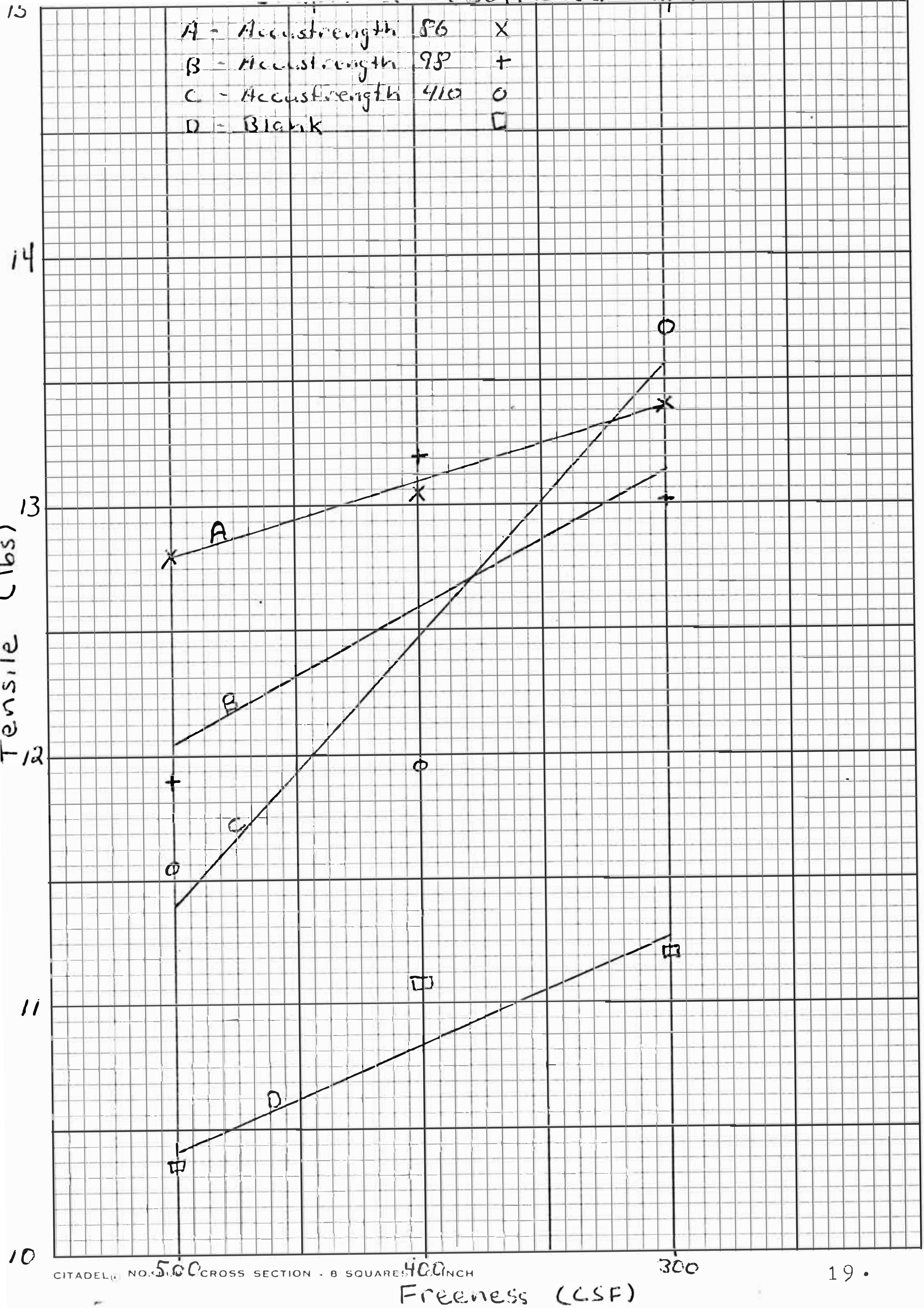
Free Shrinkage - % free shrinkage

Tensile - pounds

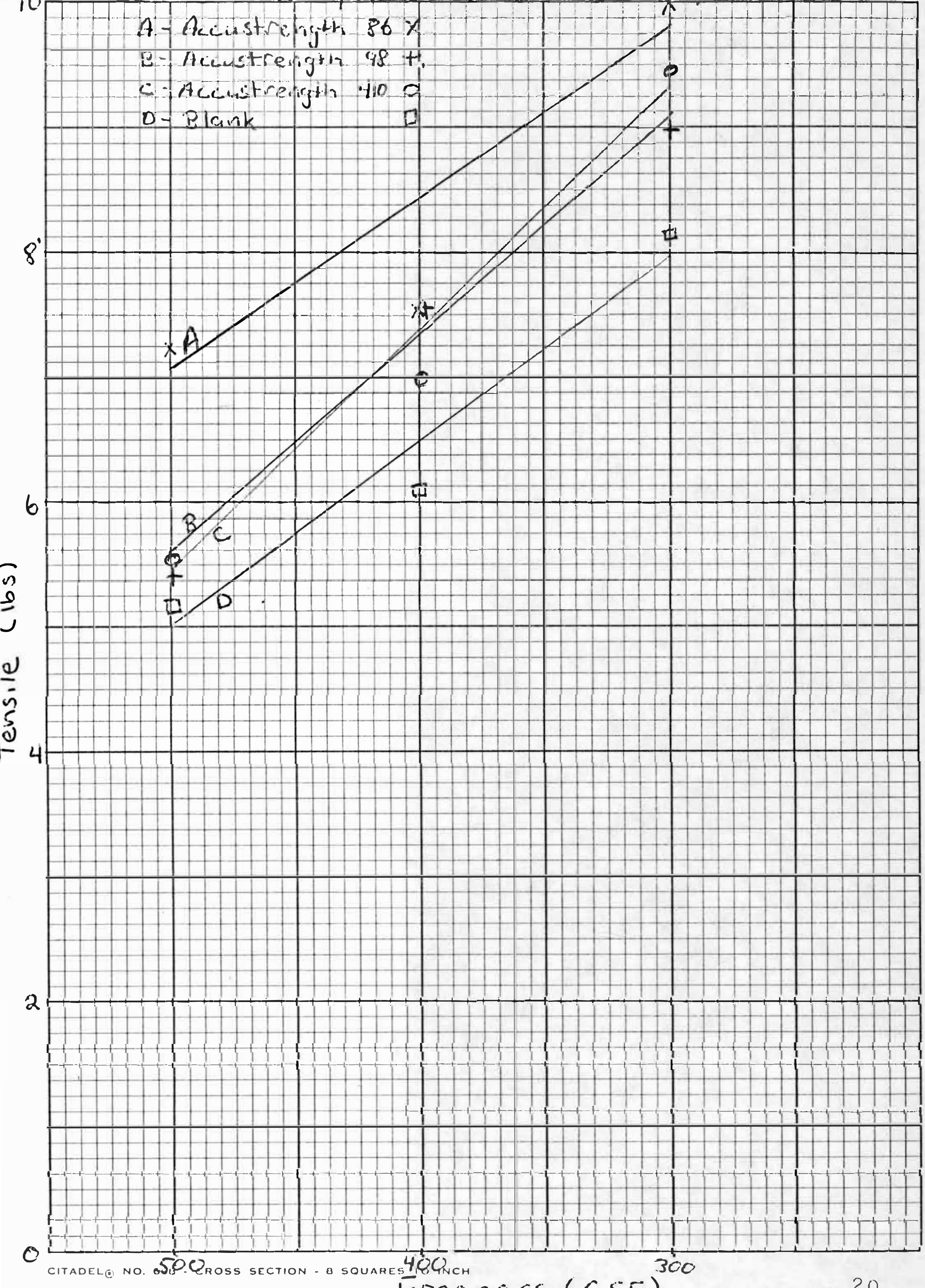
Fold - number of folds

Graph 1

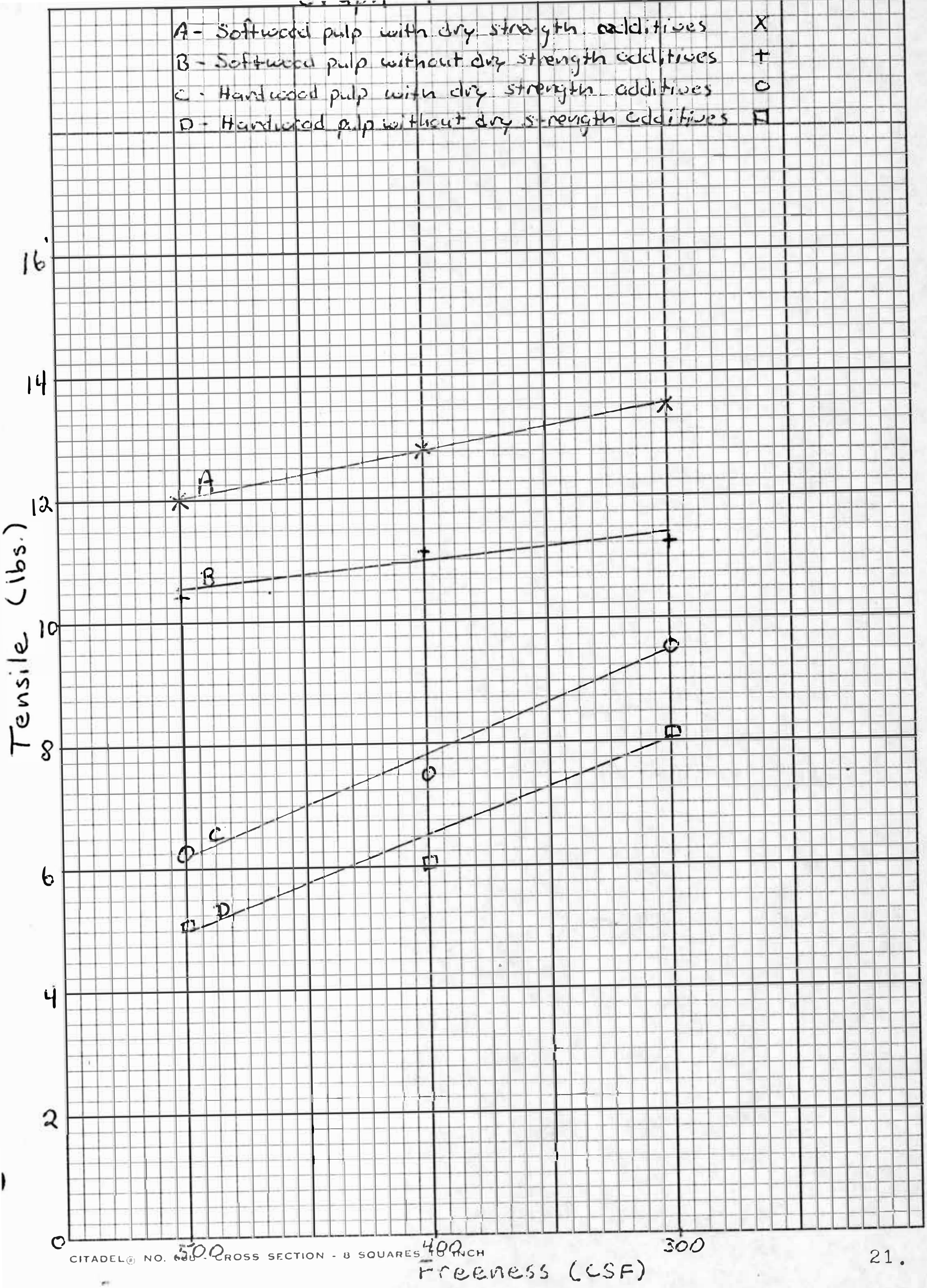

6
4
2
Free Shrinkage (%)
Softwood
Hardwood
500
400
300
Freeness (CSF)



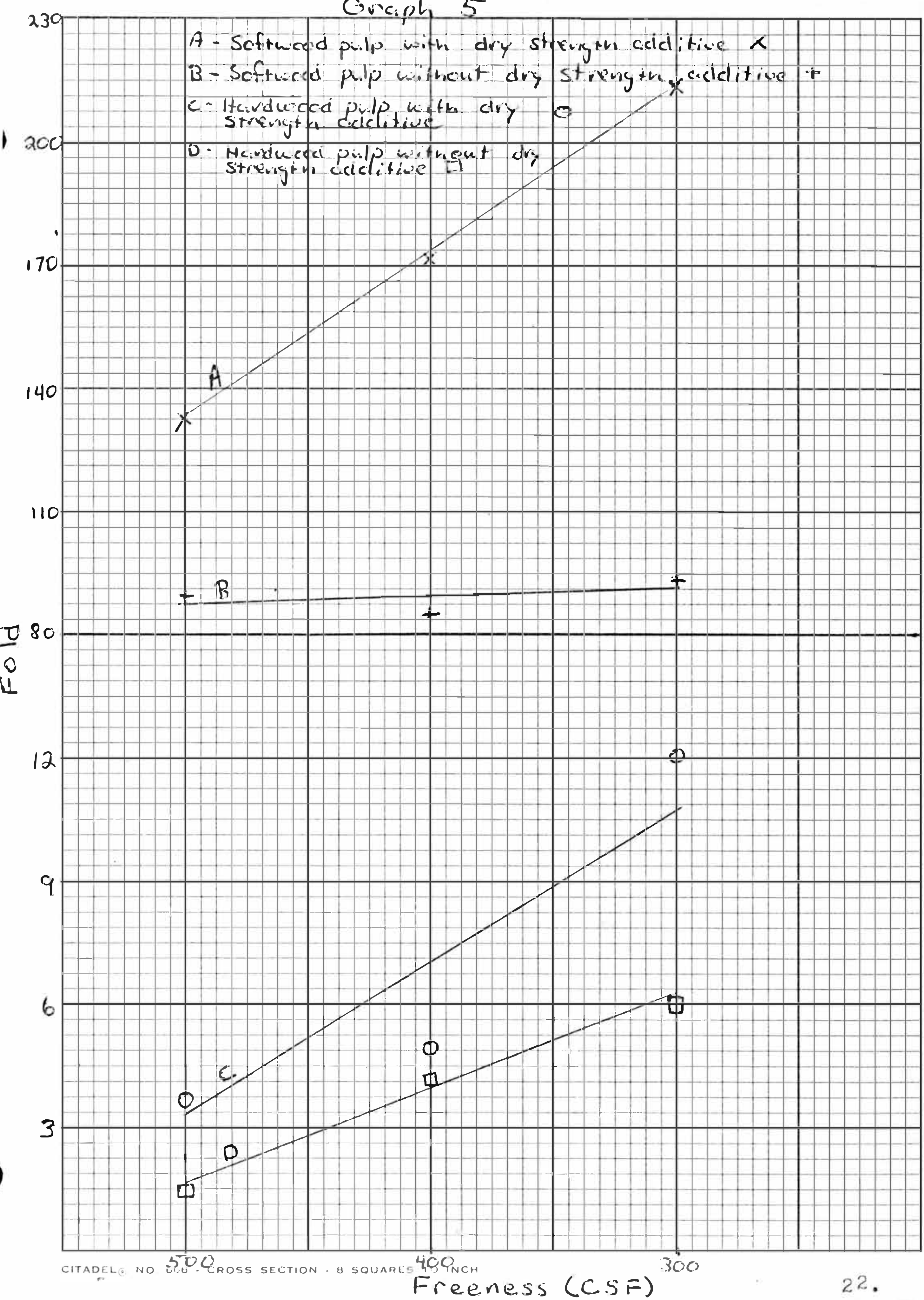
A - Accustrength 86 X
B - Accustrength 98 +
C - Accustrength 410 o
D - Blank □
15
14
13
12
11
10
Tensile (lbs)
A
B
C
D
500
400
300
Freeness (CSF)



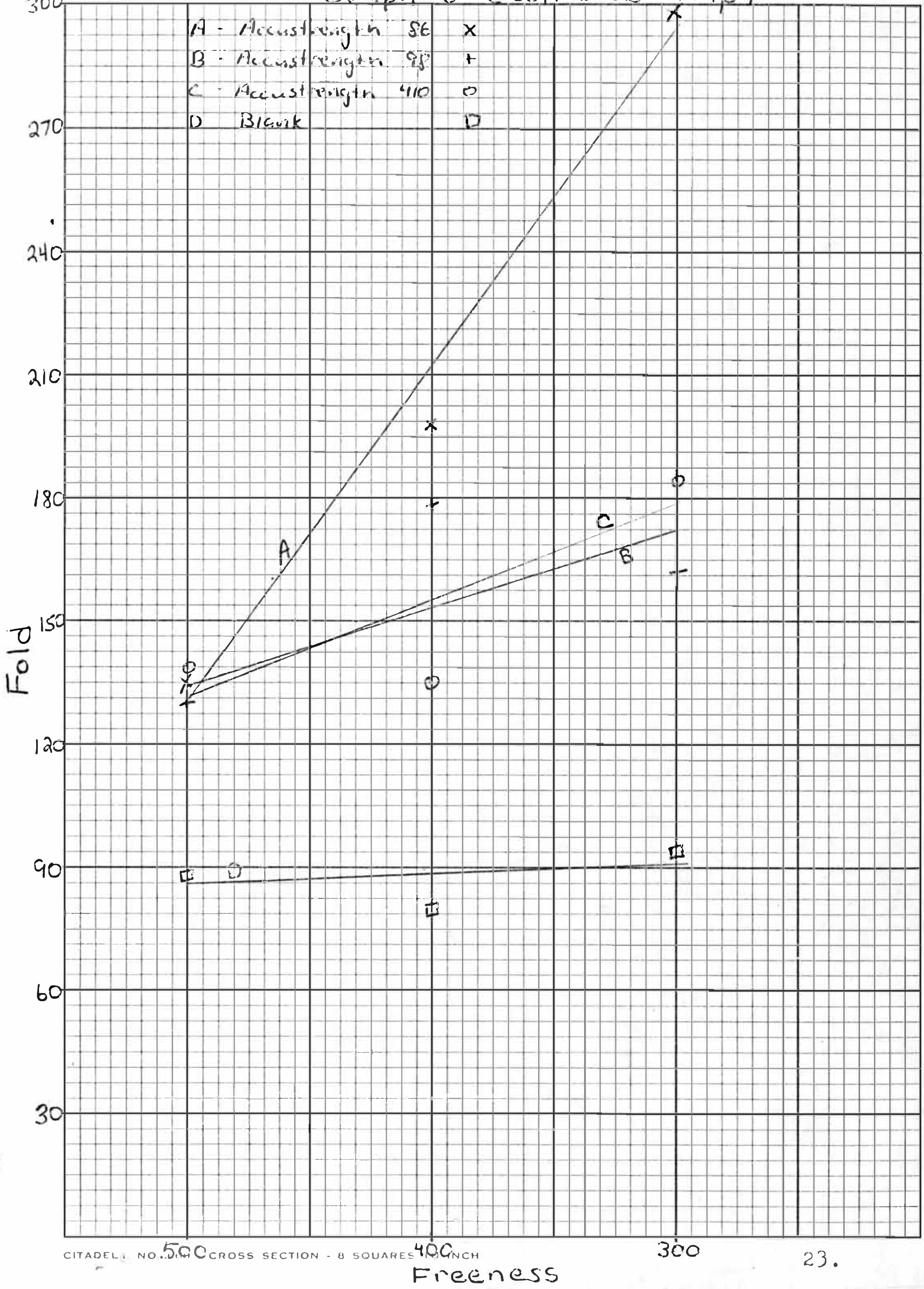
CITADEL® NO. 6?? - CROSS SECTION - 8 SQUARES TO INCH

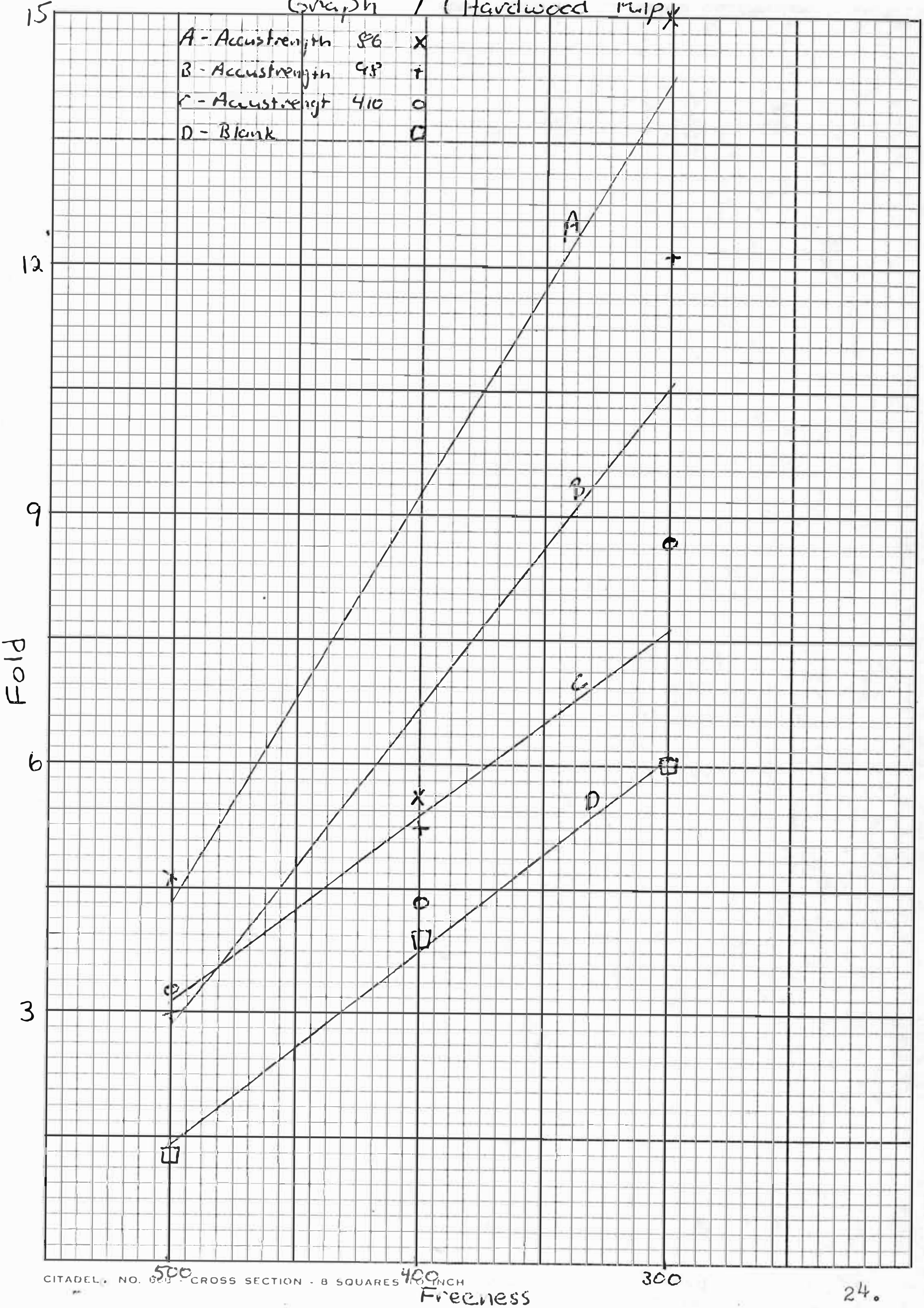


A - Softwood pulp with dry strength additives X
B - Softwood pulp without dry strength additives +
C - Hardwood pulp with dry strength additives O
D - Hardwood pulp without dry strength additives □
A
B
C
D
16
14
12
10
8
6
4
2
0
Tensile (lbs.)
500
400
300
Freeness (CSF)
CITADEL® NO. 680 - CROSS SECTION - 8 SQUARES TO INCH


Graph 5
A - Softwood pulp with dry strength additive X
B - Softwood pulp without dry strength additive +
C - Hardwood pulp with dry strength additive O
D - Hardwood pulp without dry strength additive □
A
B
C
D
230
200
170
140
110
80
12
9
6
3
Fold
500
400
300
Freeness (CSF)
CITADEL NO. - CROSS SECTION - 8 SQUARES TO INCH

Graph 6 (Softwood Pulp)





CITADEL. NO. 800 - CROSS SECTION - 8 SQUARES TO INCH

DISCUSSION OF EXPERIMENTAL RESULTS

In order to facilitate the interpretation of the experimental results several graphs and tables have been prepared.

Table 2 gives the test averages of caliper, bulk ratio, and porosity. The results are for the hand-sheets with and without dry strength resins added. This was done because there was little variation between the different types of handsheets.

Table 3 shows the test averages for free shrinkage, tensile, and fold for every condition. Notice that there is little variation of free shrinkage values at each freeness point. The relationships of free shrinkage, tensile, and fold with respect to freeness are graphed.

Graph 1 shows the relationship of percent free shrinkage with refining or freeness, for each pulp. Since free shrinkage is an excellent indication of curling tendency, this graph is a good indication of how refining and type of pulp effect curling tendency of a sheet. The graph shows that softwood fibers have a much greater free shrinkage values than do hardwood fibers. The graph also shows that increasing refining increases free shrinkage. The results of these findings show that softwood fibers have a greater curling tendency than do hardwood fibers. The results also show that as freeness goes down the curling tendency is greater.

Graphs 2 and 3 plot tensile strength of the handsheets against freeness. Plotted are each condition, blank or dry strength additive, for both hardwood and softwood handsheets. The graphs clearly show an increase in tensile strength with the addition of a dry strength additive. The percent increase ranges from 10.9% to 23.2% increased tensile strength for softwood handsheets and from 4.2% to 39.5% increased tensile strength for hardwood handsheets. On the average, the addition of a dry strength additive increases the tensile strength by 16.7% for softwood handsheets and 18.8% for hardwood handsheets. There doesn't seem to be a great difference in tensile strength within the different dry strength additive handsheets. Graph 4 shows the tensile strength on the average for handsheet with a dry strength additive and for the blank handsheets with repect to freeness.

Graphs 6 and 7 relate folding endurance of every condition with repect to freeness for both softwood and hardwood handsheets. The graphs clearly indicates an increase of folding endurance with the addition of a dry strength additive. The range of increased folding endurance is 50.5% to 218% for softwood handsheets and 5% to 188% for hardwood handsheets. On the average the addition of a dry strength additive increases folding endurance by 97.8% for softwood handsheets and by 93.0% for hardwood handsheets. Like the tensile strength, folding endurance doesn't vary much within the different dry strength additive handsheets. Graph 5 averages the dry strength additives handsheets together and compares that value with the fold value of the handsheets with no dry strength additives.

CONCLUSIONS

This experiment has shown that the addition of dry strength additives appreciably increase tensile strength and folding endurance of a sheet of paper. Since we assumed that the free shrinkage test is an indication of curling tendency, the experiment has also shown that curling tendencies increase hith decreasing freenesses. Softwood fibers have a greater curling tendency than hardwood fibers, was also a conclusion from this investagation.

The addition of dry strength additives would allow the sheet of paper to be made at higher freenesses and still retain the same strength characteristics. The addition of dry strength additives would also allow the replacement of hardwood fibers with softwood fibers and still retain the same strength characteristics.

These types of changes could result in; power reduction, material cost savings, improved formation. The power reduction could be seen in less refining with the addition of dry strength additives and retaining the same strength characteristics. Material cost savings could be made by replacing softwood fibers with hardwood fibers and retain the same strength characteristics by adding dry strength resins. Usually hardwood fibers cost 3/4 less than softwood fibers. This replacement could also improve formation of the sheet of paper.

This report enables a manufactor of a sheet of paper with high curling tendencies, to look at the use of dry strength additives as a possible solution to some curling tendencies in his sheet of paper.

BIBLIOGRAPHY

1. The Dictionary of Paper, Third Edition, American Paper and Pulp Association, copyright 1965

2. Byers, William, Graphic Art Monthly 27, no. 10:156, 158, 160, 162, 164, 168 (Oct. 1955)

3. Erspamer, August S. and Rice, William D., Paper Mill News 73, no. 28: 76-78, 88 (July 15, 1950)

4. Bureau, W. H., Graphic Art Monthly 29, no 9:62,64 (Sept. 1957)

5. Bureau, W. H., Graphic Art Monthly 47, no 7:62-65 (July 1975)

6. Cretors, Fred, Watervaliet Paper Company Internal Correspondence, May 5, 1976

7. Zeitlin, Frank, Tappi 47 no 7:170A, July 1964

8. Gallay, Wilfred, Tappi 56 no 11:54-63 Nov. 1973

9. VanDen Akker, J. A., Wink, W. A., Bobb, F. C., Tappi Vol 42, no 4:340-344, April 1959

10. Bolam, Franci, The Formation and Structure of Paper, pages 452-459

11. Nordman, Lars S., Tappi Vol 41 no 1:23-30 Jan 1958

12. Glynn, P., Jones, H. W. H., Gallay, W., Pulp Paper Mag. of Canada, 62(1) Jan 1961

13. Goldner, Paul, Tappi Vol 47 no 7:168-169 July 1964

14. Anderson, O. E., Tappi Vol 47 no 7:168 July 1964

15. Spitz, D. A., Blickensderter, P. S., Tappi Vol 46 no 11:676-680, Nov. 1963

16. Beeman, L., Watervaliet Paper Company Internal Correspondence, Aug 2, 1976

17. Gallay, Wilfred, Tappi Vol 56 no 12:90-95 Dec 1973

18. Rance, H. F., Tappi 37 (12):640 1954

19. Allied Colloids, "Dry Strength Resin," page 2, 1975

20. MacDonald, Ronald G., Papermaking and Paperboard Making, pages 58-59