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A Study of The Influence of Reworked Fibers on Dimensional Stability and Physical Characteristics of Paper

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A STUDY OF THE INFLUENCE OF REWORKED FIBERS ON DIMENSIONAL STABILITY AND PHYSICAL CHARACTERISTICS OF PAPER

by

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ABSTRACT

Secondary or repulped fibers, refined to the same degree in terms of freeness, exhibit different physical and optical characteristics than the same fiber in the virgin state. Paper which contains various per cent of secondary fibers have better opacity, less sensitivity to moisture and humidity, in the sense of hygroexpansivity, reduction of tendency to curl with addition of moisture to one side of the sheet, and less tensile elongation. The advantages listed above are offset to some extent by a loss in tensile strength, fold endurance and porosity.

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HISTORICAL BACKGROUND

Secondary fibers can and should play an important role in today's papermaking process. With the current emphasis on solid waste pollution and conservation of our national resources, it should be all the more reasons for the increase use of secondary fibers.

Secondary fibers come from waste paper and paper stock. "Waste Paper" is taken to mean the material as it is produced, but not necessarily in salable condition (2). The term "paper stock" has been adopted to apply to the products after it has been cleaned, sorted and baled ready for the market (2). Most paper stock is used for the deinking process. Deinking means the removal of ink and other objectionable nonfibrous materials from a slurry of paper stock. Some deinking has been done commercially since the middle of the nineteenth century in the United States and Europe. Deinking on a large scale, however, has been practiced only during the twentieth century. It is estimated that approximately half the paper and paperboard mills in the United States use some paper stock as a source of secondary fibers.

The difference between secondary wood fibers and virgin wood fibers is that the secondary fibers have been through at least one paper making cycle. It is this exposure to at least one papermaking cycle that could alter the characteristics of the fibers and the sheet properties as compared to virgin sheet properties.

According to Clause (3) as a result of heavy hydration virgin pulps become sensitive to water and susceptible to curl. Paper made from such pulp tends to be hard and harsh and have poor dimensional stability. Deinked stock has once before gone through this process and along the way has lost much of this extreme sensitivity to water.

Doane (4) has also done work on the subject of moisture sensitivity of paper made from deinked stock. He found fibers that have been previously dried one or more times do not imbibe water as readily as fibers in slush pulp coming directly from the pulp mill. This explains why more dimensionally stable paper can be made from paper stock than from slush pulp, whether or not it is deinked.

Clause (3) listed other advantages of using deinked pulp or secondary fibers than virgin pulp.

(1) It is low in cost.

(2) It imparts a high degree of opacity.

(3) Little or no beating is required.

(4) Fibers are already blended to suit many furnishes.

(5) Brightness can be better controlled than with virgin pulp.

(6) Better bonding, less fuzz.

(7) Less moisture sensitivity.

(8) Less tendency of finish paper to curl.

One of the disadvantages of deinked stock is the lowering of strength. The loss of strength is partially the result of fiber length reduction due to mechanical action and partially due to aging of the paper. Another reason is the loss of available reactive sites that were created by previous hydration and fibrillation during refining. During papermaking these sites are available for hydrogen bonding and give the sheet coherence and strength. But in deinking and bleaching these sites are exposed to oxidative forces and are lost for future rebonding.

McKee (5) did a laboratory study on the effect of beating virgin kraft at 350 CFS and repeatedly forming it into a sheet, drying and repulping it. After six repulping cycles, each time refining the pulp to the original freeness, he noted a decrease in bursting, tensile and bonding strengths and increase in tearing strength. It has been shown that the total energy in tearing a sheet of paper is composed of the work required to (a) Rupture individual fibers in tension, and (b) Pull individual fibers out of the mesh of the fiber (7). It has also been demonstrated that the work necessary to pull out fibers is greater than the work to rupture fibers (6). Thus the less strongly the fibers are bonded the fewer will be the number of fibers ruptured and greater the number of fiber pulled out. An increase in the number of fibers pulled out will reflect in a higher tearing strength.

McKee (5) concludes that the losses in tensile and bursting strength are due to weaker bonds, caused by less swelling of the fibers in water.

The characteristics of secondary fibers in paper could be quite a market for the offset printing industry. For the paper being used in offset printing is subject to various types of ink and moisture which causes the paper to become dimensionally unstable. As mentioned earlier, paper which contains secondary fibers have better opacity, less picking and fiber pulling, less sensitivity to moisture like that encountered in offset printing and therefore give less mis-register trouble from color to color. Also, there is a reduction of tendency to curl with the change in humidity or the addition of moisture to one side of the sheet.

Some of the claims made in literature for sheet characteristics of paper made from secondary fibers should be substantiated. This thesis is going to attempt that with facts and figures.

PROCEDURE

In order to simulate actual conditions of making paper from secondary fibers, the pilot fourdrinier paper machine at Western Michigan University was used. The pulp was 100% Virgin Somoa softwood pulp beaten to 350 CFS in the experimental holland beater, along with 1% rosin and 2% alum based on the weight of fibers. This pulp was made into paper at a basis weight of 45# per ream and then used as broke or secondary fibers for the following beaters: The first beater was made with 33% secondary fibers and 67% Virgin Somoa, second beater with 66% secondary fibers and 34% Virgin Somoa, third beater with 100% secondary fibers and the last one was repulped twice which is designated as 200%. Each beater consisted of 220# of pulp and beaten down to 350 CFS with 1% rosin and 2% alum added. Each beater was run on the paper machine separately and samples were collected and conditioned.

Testing of Samples

The following tests were performed on the samples collected according to the Technical Association of Pulp and Paper Industry: tear, burst, tensile, tensile stretch, fold, opacity, caliper, porosity and sensitive of stretch and shrinkage at various humidities.

DISCUSSION

The effect of various percent of secondary fibers on sheet characteristic are tabulated in Table I and II and illustrated in figures one through ten. In figure one, the apparent density is plotted on the vertical ordinate and the percent level of secondary fibers along the abscissa.

The 0% represents the apparent density of the paper made with the virgin fibers. The 33% represents the apparent density of the paper that contains 33% repulped fibers and 67% virgin fibers. The 66% represents the apparent density of paper that contains 66% repulped fibers and 34% virgin fibers. The 100% represents the apparent density of paper that contains all repulped fibers. The 200% represents the apparent density of paper that as been repulped twice. In all the illustrated figures, the abscissa represents that described as above.

Density decreases as soon as secondary fibers are introduced. At the 33% level the density decreases approximately 10% and at the 200% level approximately 9.5%. The average of all the levels is about 10% decrease. The density for a given pulp may be considered as an indirect indication of the degree of refining and hence, bonding. Since all the percent levels were carried out at the same degree of beating, measured in terms of freeness, the density results indicate a decrease in bonding either a decrease in the strength of the bonds or the number of bonds, as the percent of secondary fibers increased.

The effect of varying the use of secondary fibers on bursting strength and tearing strength is shown in figure two. The bursting strength decreased as soon as secondary fibers were introduced. At the 33% level the bursting strength dropped about 19% and kept close to that level.

Tearing strength exhibits the opposite trend to that shown in density in that the tearing strength increased in both machine direction and cross machine direction with the increase use of secondary fibers. In machine direction the tearing strength increases to approximately 10.5% and then levels off. In cross machine direction it increases as high as 12.8% at the 66% level and then drops almost back to its original level at the 200% level.

It has been shown as mentioned earlier that the total energy in tearing a sheet of paper is composed of the work required to (a) Rupture individual fibers in tension, and (b) Pull individual fibers out of the mesh of the fiber. It has also been demonstrated that the work necessary to pull out fibers is greater than the work to rupture fibers. Thus the less strongly the fibers are bonded the fewer will be the number of fibers ruptured and greater the number of fibers pulled out. An increase in the number of fibers pulled out will reflect in a higher tearing strength. This can also be explained by the apparent density and presumably bonding decreases with the introduction of secondary fibers and hence tearing strength would be likely to increase.

The effect of secondary fibers on tension characteristics are shown in figure three and four. Both tensile strength and stretch decreased in both machine direction and cross machine direction with increasing amount of secondary fibers. After adding up to 100% secondary fibers and repulping twice the tensile in machine direction and cross machine direction averaged a decrease of 10.0% and 10.6% respectively and the stretch in machine and cross direction decreased 22.4% and 25.7% respectively.

The effect of secondary fibers on MIT fold endurance is shown in figure five. The fold endurance decreased rather rapidly in both machine and cross machine direction with the increased amount of secondary fibers added. To be exact, it decreased 44.1% in machine direction and 50.0% in cross machine direction. The fold endurance characteristics of a sheet of paper is generally considered to be a function of fiber length, degree of bonding, strain characteristics, etc. The present results indicate that those properties on which fold depends are developed to a lesser extent with the introduction of secondary fibers.

The relationship between porosity, measured in terms of the Gurley densometer, and the varies levels of secondary fibers is shown in figure six. The curve indicates that the general trend is for the porosity values to decrease with the increase amount of secondary fiber. This indicates that the sheet compaction decreases with increasing amount of secondary fiber and thus offer less resistance to the passage of air. The porosity trend is in keeping with the apparent density results.

The effect of secondary fibers on opacity is shown in figure seven. The opacity increased approximately 4.7% from 0% to 200% level. The secondary fibers tend to give a better formation and a more level and uniform sheet, leaving less open spacing thus giving a better opacity.

The relationship between curl and various levels of secondary fiber is shown in figure eight. The curl as measured by the Carlson curl tester, decreased approximately 54.6% as soon as secondary fibers were introduced. As a result of heavy hydration virgin fibers become sensitive to water and susceptible to curl. Secondary fibers have already gone through the papermaking process and along the way has lost much of its extreme sensitivity to water, thus curl to a lesser degree.

Table II and figures nine and ten illustrate the dimensional stability of secondary fibers in machine and cross machine direction, at an average increase humidity of 39.6% and at an average decrease humidity of 52.7%. At all percent levels of secondary fibers the percent stretch and percent shrinkage decrease. These results comply with the fact that secondary fibers are less sensitive to moisture and humidity then virgin fibers. This is evident by comparing 0% level results and 100% level results in Table II.

TABLE I

	0%	33%	Difference %	66%	Difference %	100%	Difference %	200%	Difference %
Basis Weight g/m air dried	68.8	68.4		71.0		67.2		68.0	
Caliper, microns	98.7	109.	+10.5	110.	+11.5	110.	+11.5	108.	+ 9.42
Apparent density	.697	.627	-10.0	.646	- 7.30	.609	-12.6	.631	- 9.50
Bursting strength factor	16.8	13.6	-19.0	14.0	-16.7	13.2	-21.4	14.2	-15.5
Tensile breaking length, M.D.	4,600	4,470	- 2.82	4,480	- 2.60	3,670	-20.2	3,950	-14.1
Tensile breaking length, C.D.	2,240	1,950	-12.9	2,030	- 9.37	1,930	-13.8	2,100	- 6.25
Stretch, % M.D.	1.90	1.60	-15.8	1.50	-21.0	1.20	-36.8	1.60	-15.8
Stretch, % C.D.	4.30	3.70	-13.9	3.90	- 9.30	3.60	-16.3	3.30	-23.3
Tear strength factor, M.D.	79.8	84.8	+ 6.26	89.3	+11.9	87.6	+ 9.77	88.3	+10.6
Tear strength factor, C.D.	94.9	105.	+10.6	107.	+12.8	100.	+ 5.37	95.9	+ 1.05
MIT fold, M.D.	34.0	21.0	-38.2	26.0	-23.5	16.0	-52.9	13.0	-61.8
MIT fold, C.D.	20.0	11.0	-45.0	12.0	-40.0	8.00	-60.0	9.00	-55.0
Porosity	49.0	21.0	-57.1	28.0	-42.9	23.0	-53.1	36.0	-26.5
Opacity	73.6	75.9	+ 3.12	76.8	+ 4.34	77.2	+ 4.89	78.3	+ 6.38
Curl, arbitrary units	8.60	3.60	-58.1	4.60	-46.5	3.60	-58.1	3.80	-55.8

NOTE: Machine Direction (M.D.)
Cross Machine Direction (C.D.)

TABLE II

EXPANSIMETER RESULTS

Machine Direction	0%	33%	Difference %	66%	Difference %	100%	Difference %	200%	Difference %
% Stretch	.315	.211	-33.0	.195	-38.1	.042	-86.7	.268	-14.9
% Shrinkage	.795	.498	-37.4	.522	-34.3	.436	-45.2	.461	-42.0
Cross Machine Direction									
% Stretch	2.71	2.06	-23.9	2.17	-19.9	1.83	-32.5	2.03	-25.1
% Shrinkage	2.70	1.89	-30.0	2.03	-24.8	1.88	-30.4	2.24	-17.0

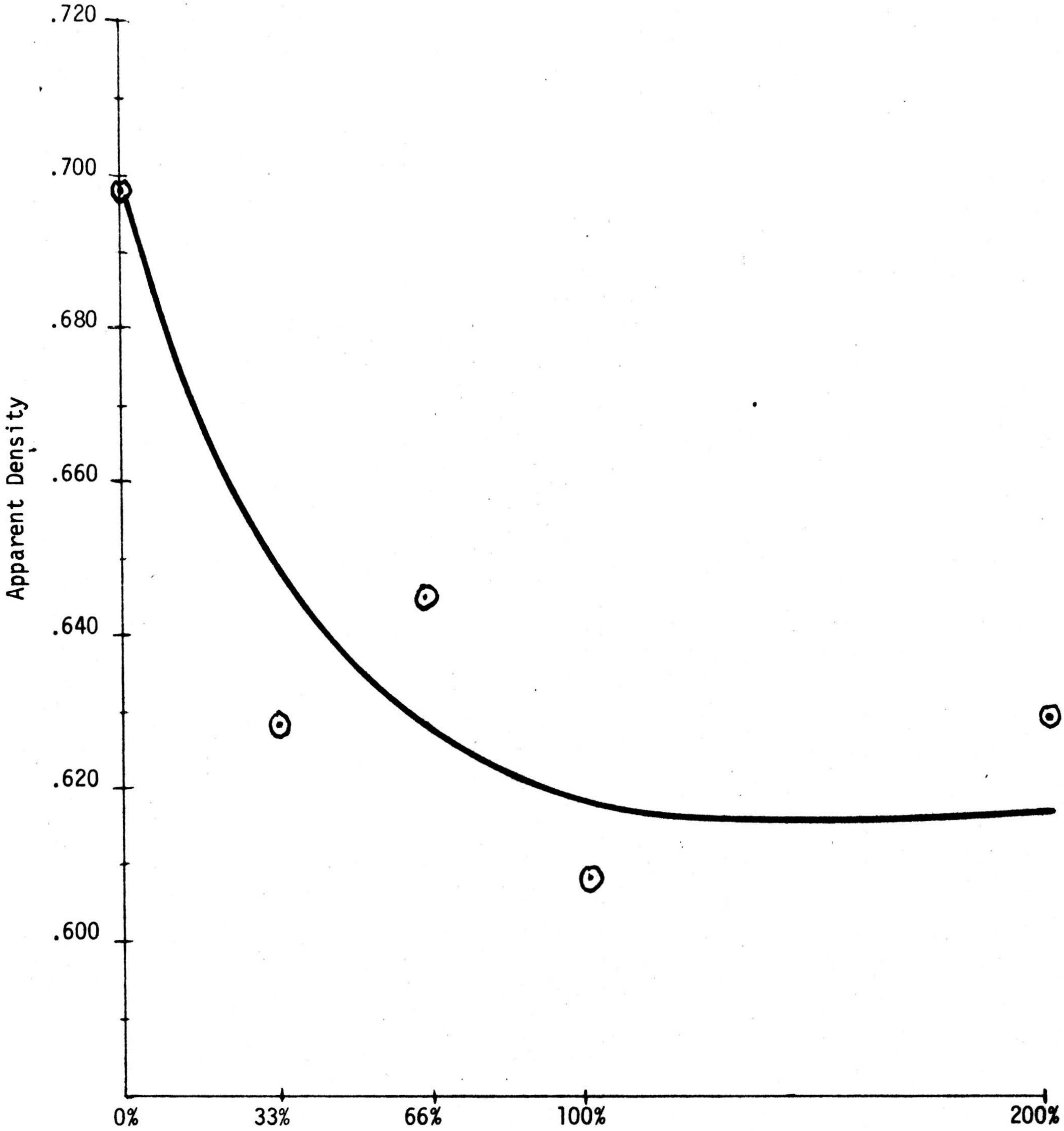
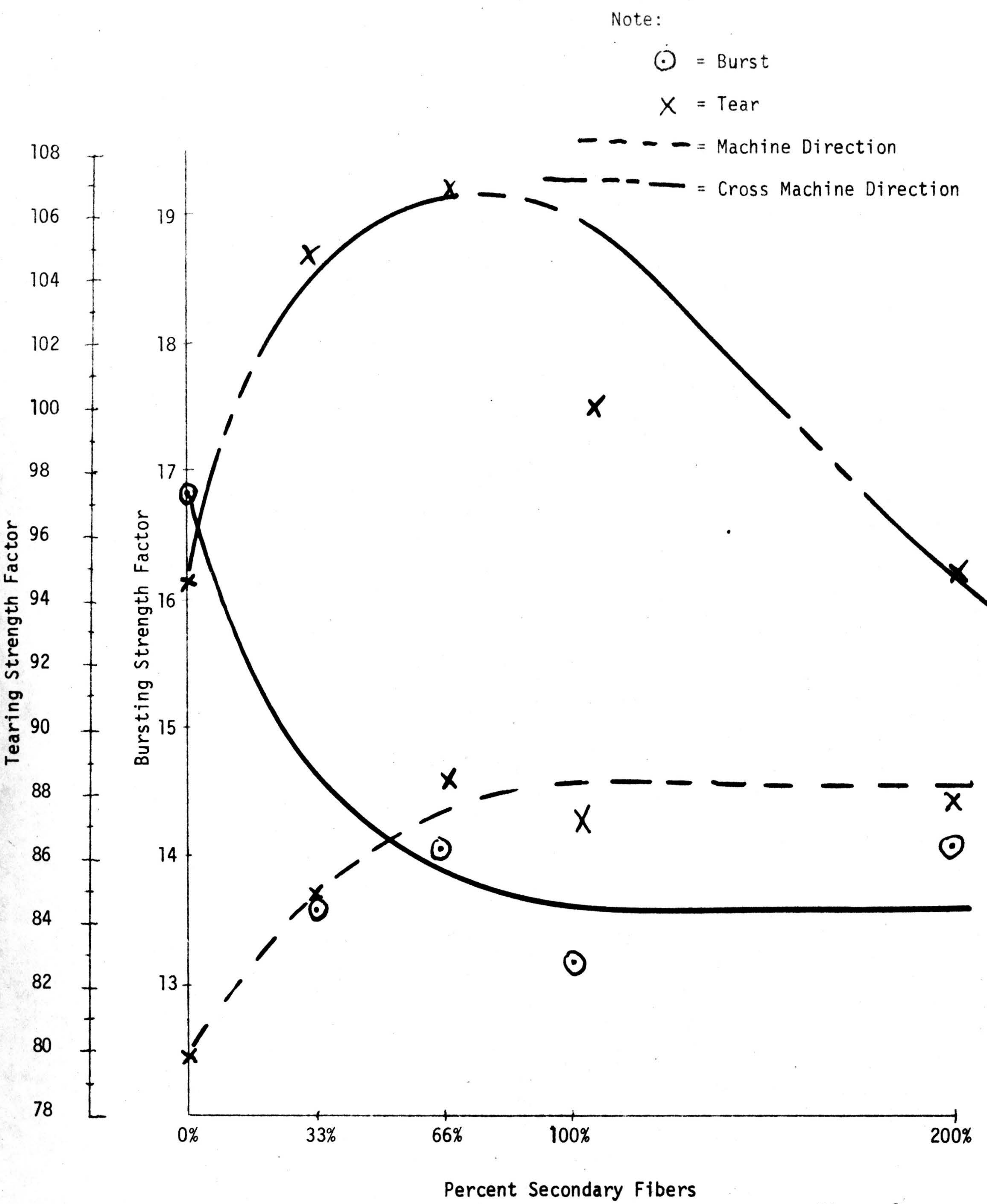

.720
.700
.680
.660
.640
.620
.600
Apparent Density
0%
33%
66%
100%
200%
Percent Secondary Fibers

Figure 1



Note:
⊙ = Burst
X = Tear
= Machine Direction
= Cross Machine Direction
Tearing Strength Factor
108
106
104
102
100
98
96
94
92
90
88
86
84
82
80
78
Bursting Strength Factor
19
18
17
16
15
14
13
0%
33%
66%
100%
200%
Percent Secondary Fibers

Figure 2

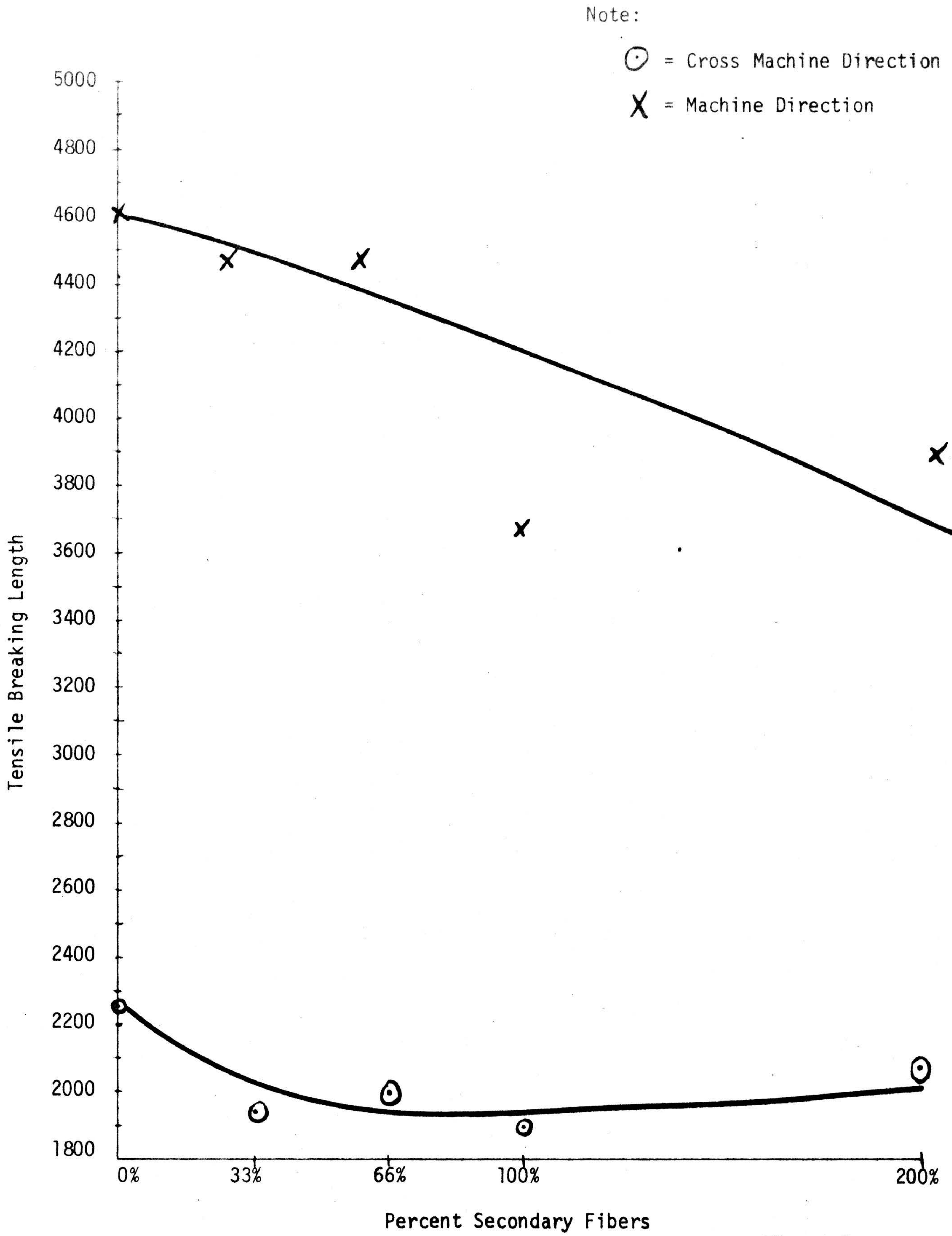

Note:
⊙ = Cross Machine Direction
X = Machine Direction
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
Tensile Breaking Length
0%
33%
66%
100%
200%
Percent Secondary Fibers

Figure 3

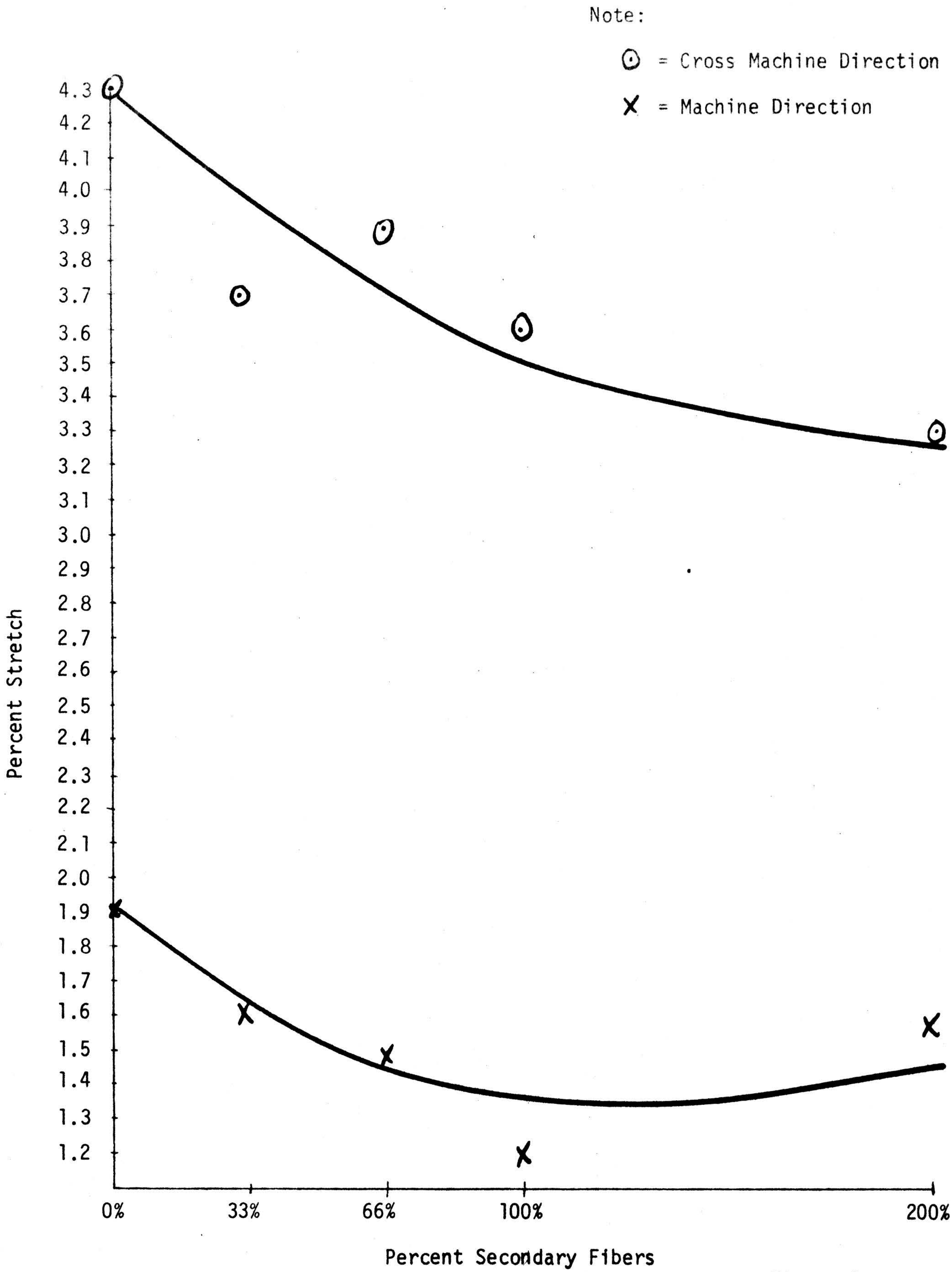

Note:
⊙ = Cross Machine Direction
X = Machine Direction
Percent Stretch
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
0%
33%
66%
100%
200%
Percent Secondary Fibers

Figure 4

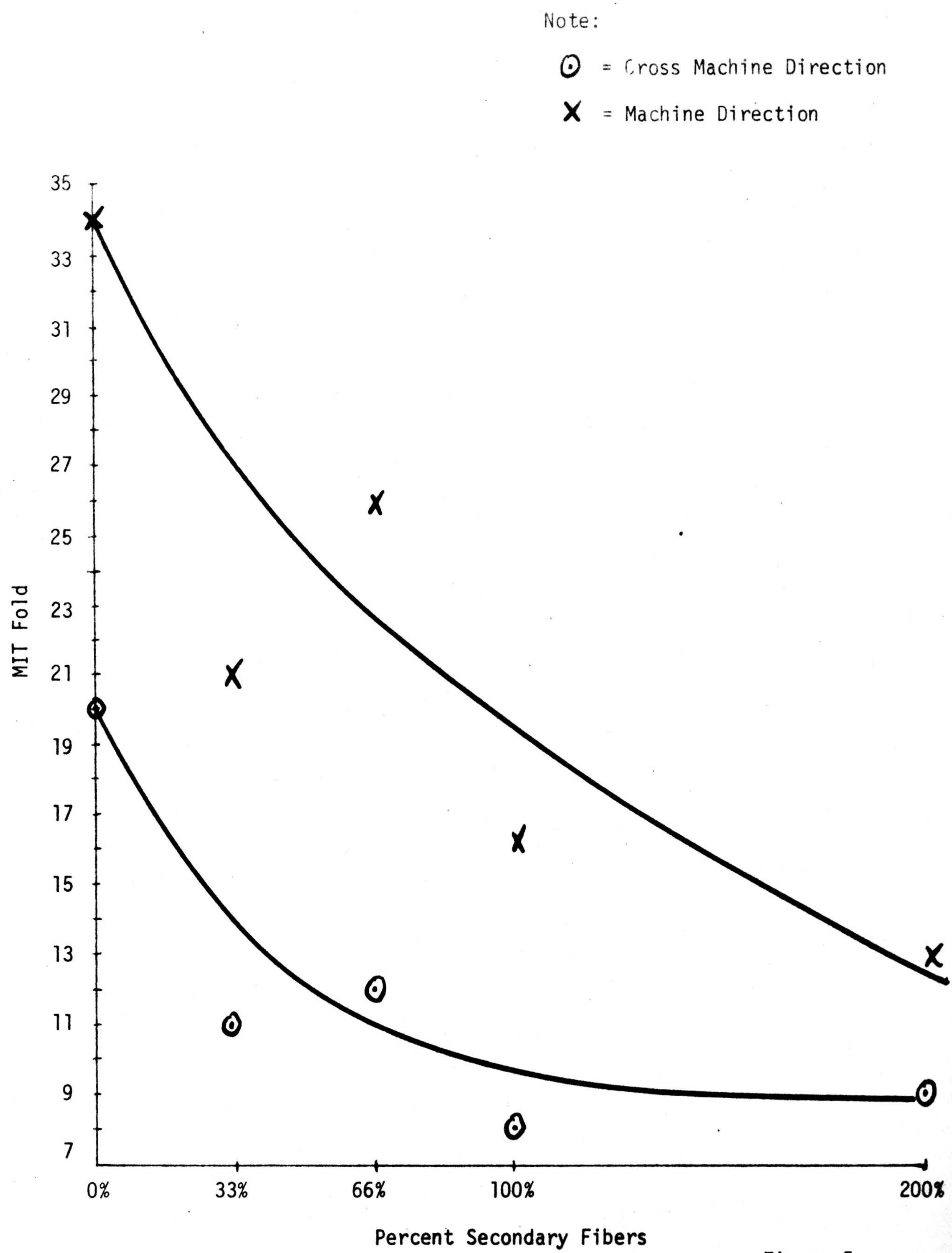
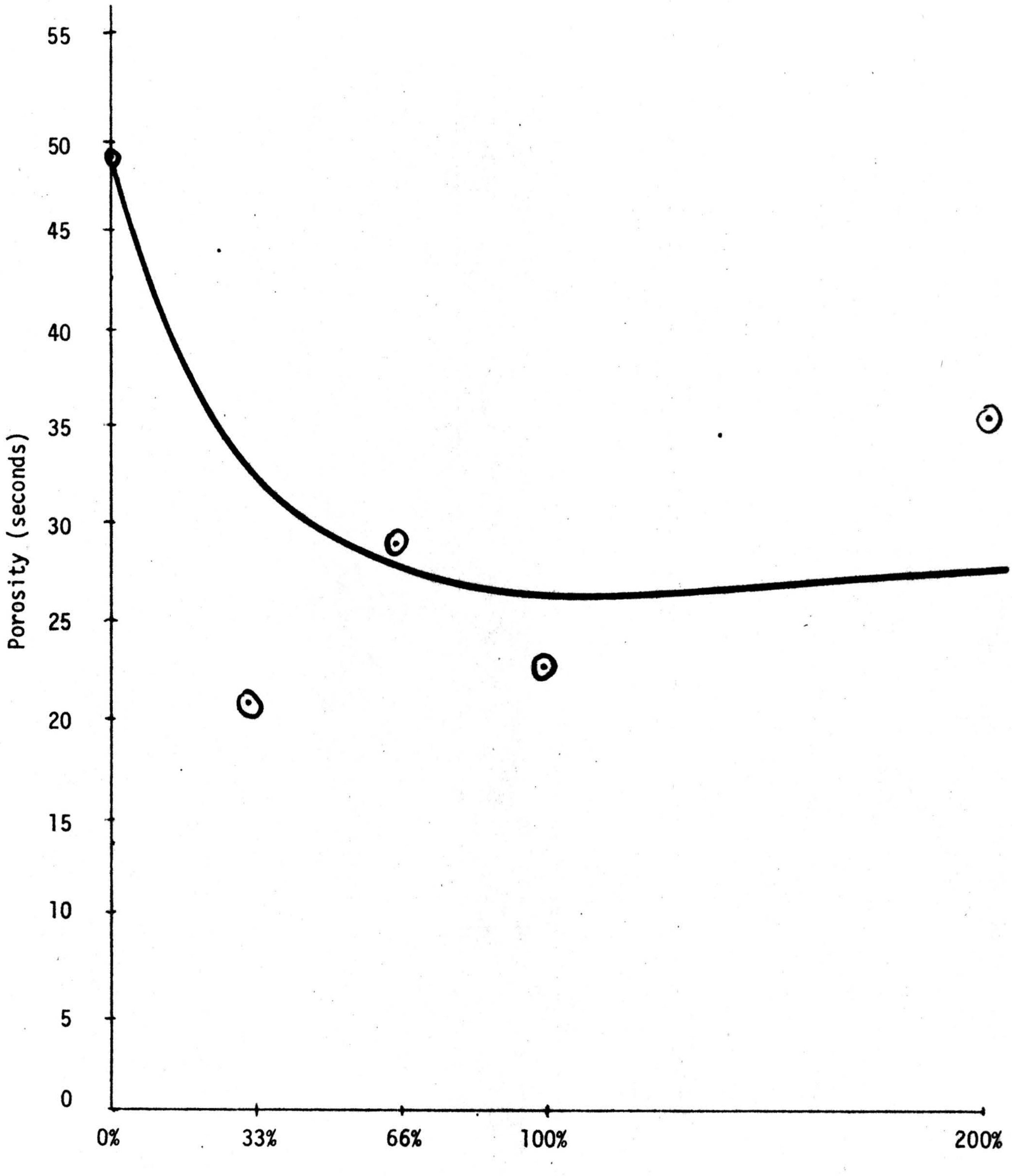

Note:
⊙ = Cross Machine Direction
X = Machine Direction
35
33
31
29
27
25
23
21
19
17
15
13
11
9
7
MIT Fold
0%
33%
66%
100%
200%
Percent Secondary Fibers

Figure 5



55
50
45
40
35
30
25
20
15
10
5
0
Porosity (seconds)
0%
33%
66%
100%
200%
Percent Secondary Fibers

Figure 6

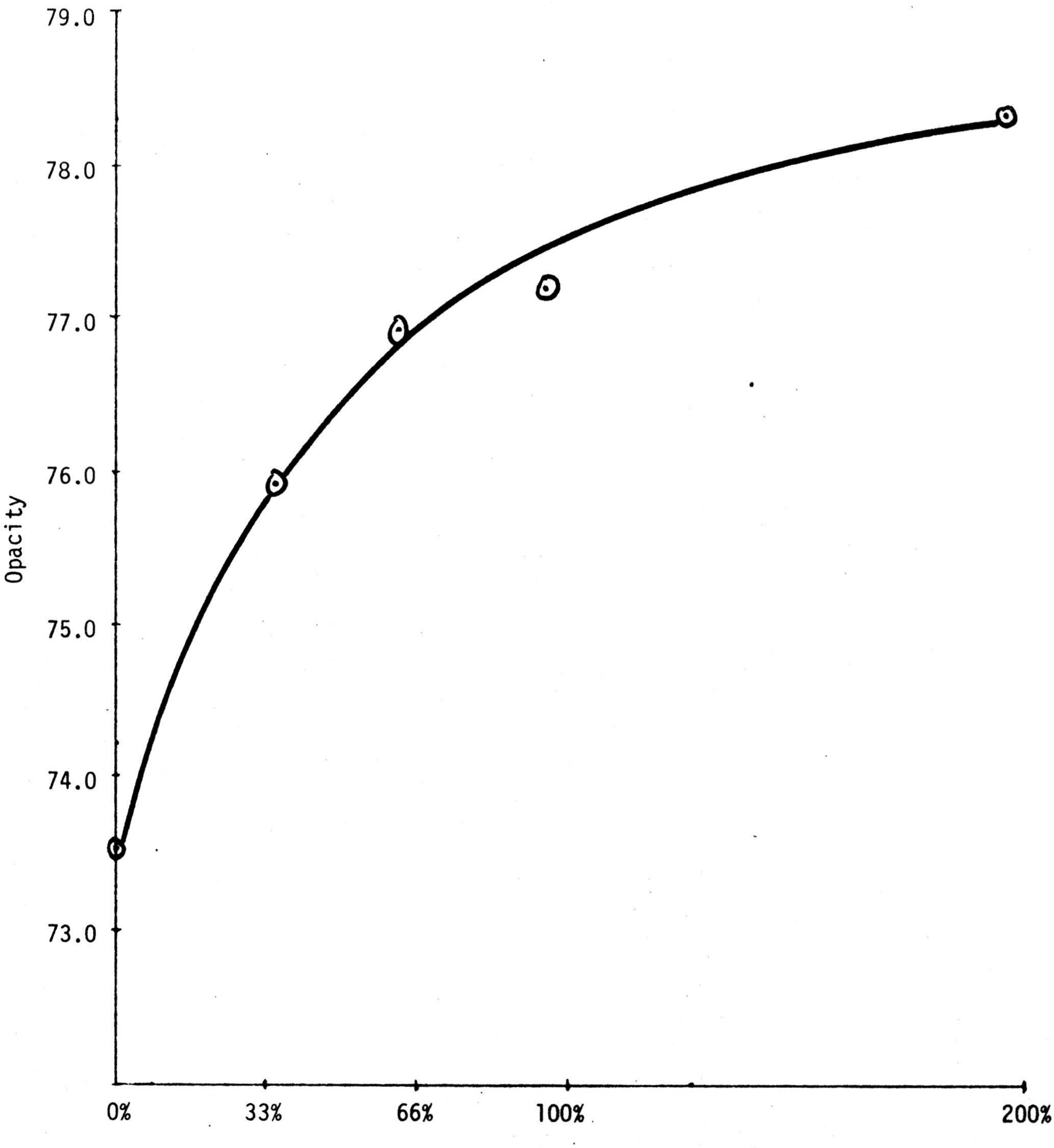

79.0
78.0
77.0
76.0
75.0
74.0
73.0
Opacity
0%
33%
66%
100%
200%
Percent Secondary Fibers

Figure 7

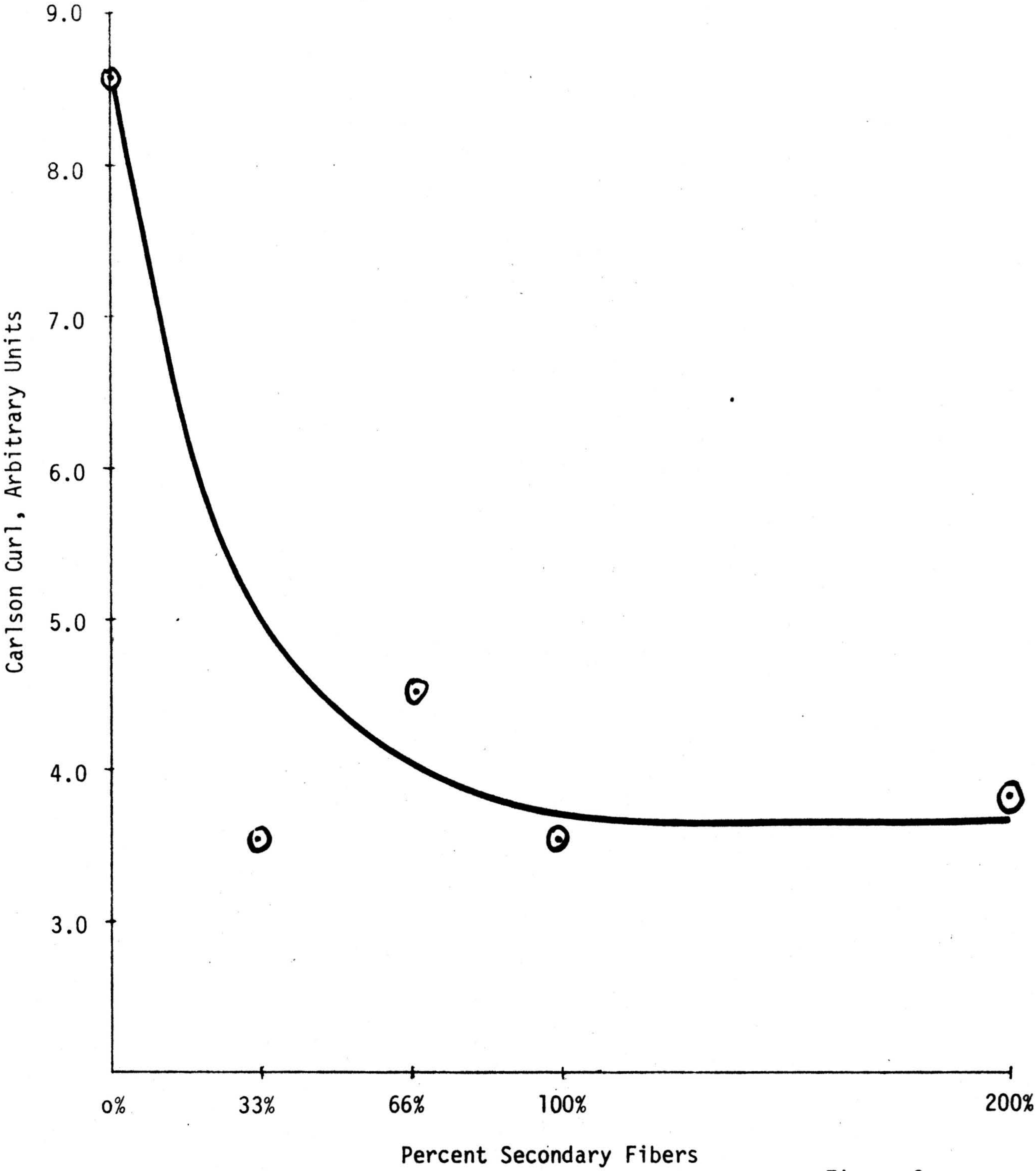

9.0
8.0
7.0
6.0
5.0
4.0
3.0
Carlson Curl, Arbitrary Units
0%
33%
66%
100%
200%
Percent Secondary Fibers

Figure 8

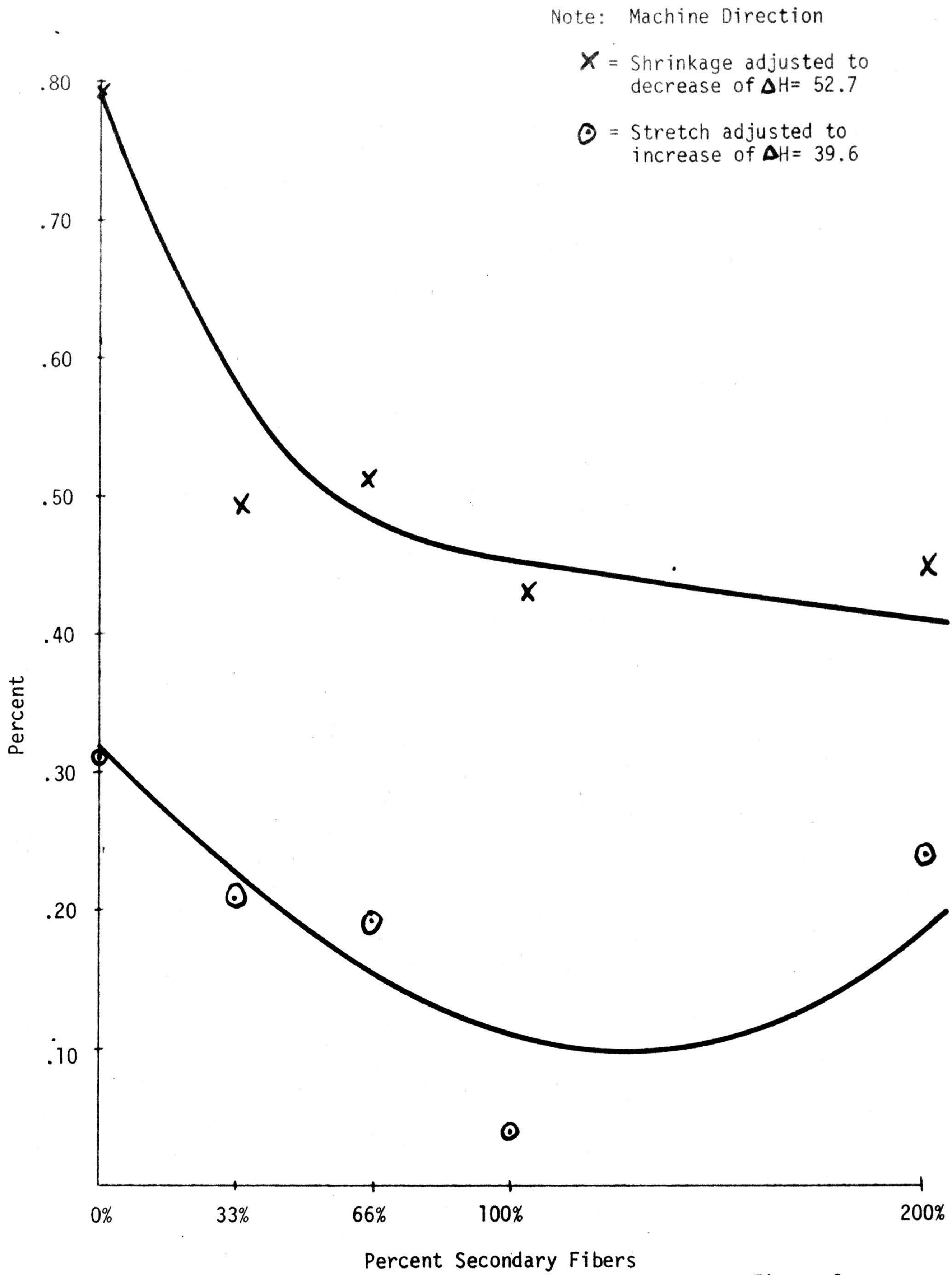
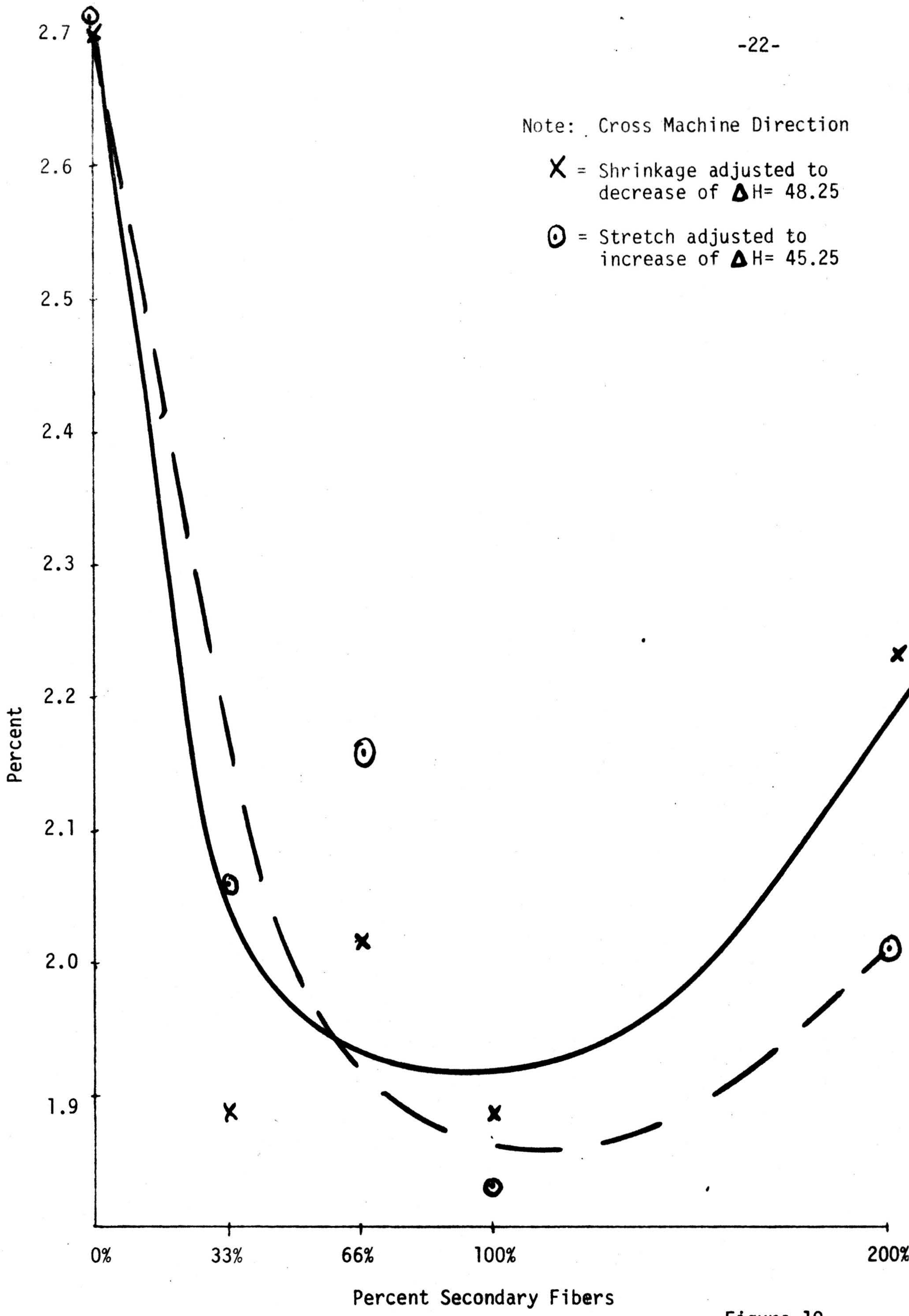

Note: Machine Direction
X = Shrinkage adjusted to decrease of ΔH= 52.7
⊙ = Stretch adjusted to increase of ΔH= 39.6
.80
.70
.60
.50
.40
.30
.20
.10
Percent
0%
33%
66%
100%
200%
Percent Secondary Fibers

Figure 9



Note: Cross Machine Direction
X = Shrinkage adjusted to decrease of ΔH= 48.25
⊙ = Stretch adjusted to increase of ΔH= 45.25
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
Percent
0%
33%
66%
100%
200%
Percent Secondary Fibers

Figure 10

CONCLUSION

The characteristics of secondary fibers in paper have desirable features for use by the offset printing industry. Paper which contains secondary fibers have better opacity, less sensitivity to moisture and humidity, in the sense of hygroexpansivity, reduction of tendency to curl with addition of moisture to one side of the sheet, and less tensile stretch. Secondary fibers are much more dimensionally stable than virgin fibers. For this dimensional stability,tensile strength, burst, fold, and porosity is sacrificed. Thus it depends on the paper specification if secondary fibers are to be used in the furnish. The only problem left is to find an economical way to sort and collect secondary fibers for the recycling process. With the plastics, rubber glues and wet strengths, this sorting and collecting of secondary fibers has become an economical problem. Current emphasis on solid waste pollution and conservation of our national resources demands a solution to these problems.

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