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The Effects of Increased Recycled Fiber on Tensile and Burst

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THE EFFECTS OF INCREASED RECYCLED FIBER ON TENSILE AND BURST

by

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ABSTRACT

The objective of this study was to determine the effect secondary fiber has on the burst and tensile of the paper sheet. There are many different physical aspects to burst and tensile and these aspects are discussed in some detail. Previous work has been performed in similar areas. The data and conclusions from that work was extremely helpful to this study. The literature search revealed several theories of the relationship between burst and tensile. The theory which this study investigates is the Carson linear relationship model.

The handsheets which were produced had varying amounts of secondary fiber. They also contained some alum and rosin to similate production requirements. The secondary fiber used in the handsheets were treated to excessive drying to produce the correct amount of hornification.

The results of the study are conclusive. The secondary fiber does effect the burst and tensile. However, it effects both of them to the same degree. The relationship between the two remains linear. When the data was used to calculate the radius of curvature, it showed more stretching of the fiber network as the percent of secondary fiber increased.

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INTRODUCTION

In this period of high inflation and decreasing productivity, the cost of producing paper products is rapidly increasing. There now appears to be a finite amount of timber available for paper and other industries because of government regulation and environmental groups. One approach to solving this problem is the recycling of paper fibers. Using secondary fibers as a partial filler with virgin stock can reduce costs significantly.

Recycling paper is a proven reality in many papermaking operations. Over one half of the paper and board mills in the United States use secondary fibers as a partial source of materials. As costs increase, secondary manufacture will become a more dominant factor in the paper industry. While the paper industry is slow to change in many aspects, it will be forced to change and adapt to recycle manufacturing methods. The paper industry is currently investing large sums of capital and effort in research and development of recycle manufacturing facilities.

There are many advantages with recycled fibers as a partial filler to virgin fibers: secondary fibers are low cost, have good opacity, need very little refining, give good brightness control, and are suitable for addition to different furnishes. There is less environmental waste associated with recycled paper as a whole. This does not mean problems do not exist with recycled furnish. There are many technological problems to be solved in the recovery of the fibers. An example of one such problem is Xerox copying paer.

Xerox paper is extremely difficult to recycle because of the nature of the inks which are used. As the financial incentives increase, this

problem and others associated with recycled papers will be overcome.

Because of the interest in secondary fibers, many studies have been proposed and initiated. However, there are still many areas which remain to be examined. An objective of this study is to examine more closely the effects of recycled-virgin mixtures on burst and tensile.

THEORETICAL DISCUSSION

This study is intended to examine tensile and burst and the effects on them resulting from increased amounts of recycled stock in the furnish. A similar study was conducted in this area by James Patton, a student at Western Michigan University. Patton examined the effects of recycling more than once, while holding the percentage of recycled fiber to virgin fiber constant.

One problem which develops is the use of handsheets as the medium for gathering much of the information. Although handsheets are of the same content as those which are produced, they may not have the same characteristics. Handsheets do not have machine direction orientation. Paper machine orientation can have a great effect on the physical properties of the sheet of paper. Handsheets are also not subject to paper machine draws or sections of continuous driers. Usually, handsheets are pressed and dried only one time. However, as a beginning step in a research project, they are usually acceptable.

Another problem,which also must be recognized, is the use of top quality fibers as the furnish to make the handsheets. These fibers have few imperfections. This is not true of the typical recycle furnish. Recycled furnish may have many contaminants which must be dealt with.

There are many physical aspects of the paper which are effected by secondary furnish. One such property is density. Density is the weight per unit volume or the specific gravity of the sheet. Density of the sheet is effected by the nature of the fiber, the amount of refining, fiber bonding, and fiber flatness. As refining of the fiber is increased, fiber length is

shortened. The fiber will flatten and produce more surface area for hydroxyl bonding. This allows the fiber mat to be compressed, producing a more dense sheet of paper. Recycled fibers tend to be shorter and flatter in nature. Thus, when recycled fibers are used, they tend to form a more dense sheet of paper and effect other physical properties.

Stress-strain properties of fiber sheets, stability of dimensions, tensile characteristics, burst characteristics, and modulus of elasticity are aspects to be considered. All of the above properties have been associated with theoretical models. It is important to realize that models are not intended to produce exact results. They are intended to guide the researcher. It may be possible in the future to develop models which will produce exact results.

Tensile testing has been of major importance since the beginning of the 1900's. Many of the first details of stress-strain relationships were published by Gibbon and Farebrother(1). Since that time, a great amount of experimentation has been performed. However, some of their basic conclusions are still relevant today. Tensile properties of the sheet are dependent on many interrelated and complex variables.

A study was performed by James Patton to examine the effects of load cycles on the paper fiber network(2). The following are some of the conclusions based on Patton's study: there are two areas which are strained, the plastic region and the elastic region. Strain in the elastic region does have recoverable tensile strength. Strain in the plastic region has almost no recovery of the tensile strength. This results in the elastic region being more extensible under subsequent loads. These tests were conducted using the three cycle load as the test basis.

Tensile energy absorption(TEA) in a sheet resulting from tensile stretch is composed of two parts: the energy required to rupture individual fibers, and the energy required to pull individual fibers from the fiber network. Experimentation has shown that the energy required to rupture the sheet is smaller than the energy necessary to pull individual fibers from the sheet(3). Increasing refining reduces the TEA value. This results from more fibers rupturing than being pulled out.

Secondary fibers do not have as much strength as virgin fibers. This is explained by several phenomenon: the reduced length of the fiber due to previous refining, the need to rewet the fibers, and damage to the fiber.

The form of the stress-strain relationship for paper is a function of the rate of straining(4). The faster the rate of straining, the more linear the stress-strain curve. This can be related to the phenomenon known as creep. Many of the early studies proved invalid because they did not properly account for the effects of increased rates of straining. It is desirable to use a motor driven tensile tester to obtain uniform rates of loading.

The paper sample should have a uniform length. Short samples result in a higher tensile than long samples. The lower tensile in the long samples is usually the result of imperfections. The longer the samples, the more likely imperfections will exist. The standard TAPPI length is 180 millimeters. An error of ten millimeters can be allowed, however, this can result in a one percent error(5).

There are many theories for tensile charactersitics. The most common theory is the fiber-to-fiber bonding effect. This theory applies to the plastic region of the stress-strain curve. Straining in the plastic region

causes fiber-to-fiber bonds to collapse(6). The stress is then applied over fewer fibers and bonds resulting in ultimate sheet failure.

Refining has a definite effect on the tensile and burst strength of the paper. A study by McKee(7) on the effects of refining indicates that refining increases the strength of the sheet to a maximum. After the maximum is reached, there is a marked decline in the strength of the sheet.

Bonded area is very important to the strength properties of the sheet. A study by Manuel Perez in 1970, attempted to develop a mathematical model to describe the stress-strain relationship with respect to bonding. The model was developed. In doing so, it was shown that the fiber bond failure was much more complex than previously believed(8).

The length of the fiber and the distribution are factors effecting the physical properties. Small variations in the fiber length can effect tensile results significantly. Tensile strength is proportional to the square root of the fiber length divided by the weight of the fiber(9). The longer the fiber, the higher the tensile strength until a maximum is reached. The shorter fibers and fines are also important because they fill the voids between the fibers, increasing fiber network bonding.

The physical strength of the fiber determines greatly the strength of the sheet. The strength of the sheet can be no greater than the cumulative strength of the fibers. A study, by J. A. Van Den Akker(10) in 1958, was performed to determine if fiber bonds were breaking or if the fibers themselves were shearing. Van Den Akker concluded that a majority of the time the fibers were rupturing. However, several other aspects of the study supported the contention that fiber-to-fiber bonding is more critical to the strength of the sheet.

Much of the testing which has been performed in recent years indi-

cates that bonding is the key feature to the strength of the sheet. Zero span tensile tests have been performed to determine the strength loss which can be attributed to the fiber. A zero span tensile tester is a device which measure the strength of the fiber. The jaws of the tester have no seperation. Individual groups of fibers are clamped between the two jaws. The result is an average of all of the fibers clamped. Some problems have developed in determining the average number of fibers clamped between the jaws. A theory was developed by Van Den Akker(10) to predict the nember of fibers which will be in the span.

The Pulmac Zero Span Tensile Tester has been developed by the Pulmac Instruments Limited of Montreal, Canada. This instrument has the ability to measure several basic strength properties with zero span. The data from the device is interms of breaking length verses span. At zero span, there is no data. However, with careful interpolation a value for zero span can be obtained(11).

The mechanism for zero span also considers the friction and slippage of the fibers between the jaws. A model was developed and interpreted into the mathematical equation which follows:

$$Z=2uwLC$$

C= clamping pressure
wL= area of the surface on which the friction can act
u= operational coefficient of friction
Z= friction load

The failure of the fiber with regard to the friction slippage depends on the amount of fiber extended under the clamp jaw. Several other equations have been developed to explain other aspects of the testing device. Overall, they allow all of the factors to be expressed as a single value denoted as

residual span. Residual span is used as a correction factor to obtain the true value for zero span.

Another analysis which can be used to obtain zero span is an equation developed by Van Den Akker(12). Zero span can be calculated from the breaking tensile. The equation which follows allows this conversion:

$$T_{po} = .375\ t_f$$

t_f = tensile of the fiber at breaking point

T_{po} = zero span tensile

*both must be expressed in the same units

The value is an approximation and can be used in simple analysis. This should only be used when reliability is not critical to the analysis. The ratio of the zero span values produce gives some estimation of the amount of bonding.

Burst is a common test used in many mills to determine the general strength of the paper. Burst is the pressure required to rupture paper which is clamped between two clamps, each of which has a hole 1.20 inches in diameter. As with the tensile, it is important to keep the rate of loading constant. Test values may vary depending on several factors: air in the hydraulic system, clamping pressure, diaphram and orifice machining, and non-correct calibration. These factors tend to cancel each other out, and generally, the results are reproducable.

An equation has been developed by Carson which relates burst to tensile. The equation is as follows (13):

$$PR=2T$$

P= burst pressure
R= radius of curvature
T= tensile strength

The equation developed by Carson contains three variables; tensile, burst, and radius of curvature. The equation presents a linear relationship between tensile and burst assuming R is constant. The value of R should be a constant an can be estimated. R should approximate 40-45% of the diameter of the hole in the mullen clamp. The R value may vary 10-15% and still have a valid linear relationship between tensile and burst.

A paper was presented at Western Michigan University at the 20th Annual Pulp and Paper Conference on April 31,1976. The paper was presented by David R. Lee of the Bergstrom Paper Company(14). Experimentation had been performed to determine the properties of secondary fiber verses virgin fiber. Handsheets were made using Valley beaters and standard forming devices.

The burst for the deinked stock had a higher value than the hardwood, but a much lower value than the burst for the softwood samples. The deinked stock had a higher tensile at zero minutes of beating compared to the hardwood or the softwood. As the beating time was increased, the softwood pulp showed superior tensile. The deinked stock tensile was still superior to the hardwood.

The report also contained an analysis of the quality of the paper produced with the deinked stock. Lee claimed that it was possible to produce a sheet of paper using recycled and virgin fibers which was superior to a 100% virgin sheet. Brightness and other sheet properties were similar to those of a virgin sheet. There were some problems with a 100% deinked sheet: contaminants, dirt specks, and slow drainage. However, with careful control, an acceptable sheet can be manufactured.

One concern of this study is the effect of the secondary fibers on the relationship between burst and tensile. As mentioned previously, there are mathematical relationships between tensile and burst. Tensile and burst curves when plotted against refining are parallel(15). A basic hypothesis of this study is that the secondary fiber will effect the tensile and burst, but will effect them similarly and that the linear relationship between them will apply.

EXPERIMENTAL PROCEDURE

For this research, it is essential to keep the quality of the handsheets the same. Handsheets will be produced which have different concentrations of secondary fiber. They should have the same amount of refining to produce produce strength results which can be compared. To obtain this result, The freenesses of each set of handsheets are the same. The following paragraphs will describe in detail the procedures which were used to produce and test the handsheets, and to analize the data which was obtained from the testing.

Canadian softwood bleached kraft was used to produce the handsheets. The softwood was beaten in the Valley beaters to a freeness of 320-340. Two percent alum and one percent rosin was added. The percentages were based on the dry weight of the fibers. This pulp was then made into handsheets weighing between two to five grams. These handsheets were run through the drier drum, which was at a temperature of 250°C, five times. These handsheets were then ready to be used as secondary fiber.

200 gram samples were then refined in the Valley beaters to a freeness of 400-425. The 200 gram samples contained one percent rosin and two percent alum. The sample consisted of secondary fiber and virgin fiber. The percentage of secondary fiber varied from 10% to 80%. This pulp was then made into handsheets which weighed between 2.40g to 2.60g. Twenty samples at each concentration were made.

The handsheets were then tested for tensile. The Instron tensile testor was used. It was calibrated using the two kilogram weight. The full scale setting was 20 kilograms and the crosshead speed of the clamp was two centimeters per second. The handsheets were also tested for burst

using a Mullen tester with a orifice diameter of 1.20 inches. While the tensile testes were being run the integrater was also in use. This produced the values which were calculated into the tensile energy absorption values.

The results from the tests were then graphed individually and collectively. Averages and standard deviations were obtained. A statistical analysis was performed to determine the reliability of the relationship between the burst and tensile.

DATA DISCUSSION

All of the data has been arranged in tables and graphs. Table I contains burst, tensile, and tensile energy absorption. The standard deviations are also included in Table I. The standard deviations were calculated using the standard equation:

$$S=\sqrt{\frac{(\sum X-x)^2}{n-1}}$$

Table II contains the calculated R values which are produced when the tensile and burst values are substituted into the Carson equation. The standard deviation for the radius of curvature for each percentage concentration is not calculated. Figure 6 contains the radius of curvature values plotted against the percent secondary fiber.

Figures 1,2, and 3 contain tensile, burst, and tensile energy absorption plotted against percentage secondary fiber. Figure 4 is a combination of tensile and burst verses percentage secondary fiber. The linear relationship is obtained from the plot in Figure 5. This is a plot of tensile verses burst.

Percentage Secondary	Basis Weight*	Burst (psi)	Standard Deviation	Tensile (kg/cm)	Standard Deviation	Tensile Energy Absorption	Standard Deviation
10%	37.62	54.74	4.54	12.52	1.36	865.83	140.43
20%	37.47	60.60	3.94	14.28	1.20	1013.70	232.13
30%	37.62	60.60	5.88	15.19	.96	1095.85	147.87
40%	37.47	62.18	3.94	15.43	1.00	1150.88	95.88
50%	37.32	52.42	3.48	13.87	.96	983.63	266.60
60%	37.77	43.25	2.38	11.76	1.34	884.43	137.33
70%	37.77	44.46	4.99	11.88	1.17	815.30	134.66
80%	37.47	37.86	3.51	10.30	.96	628.90	128.96

Standard deviation average burst = 4.13

Standard deviation average tensile= 1.12

Standard deviation average TEA = 157.48

*based apon a ream of 500 sheats of size 24 x 36 inches

Table I

Burst, Tensile and Tensile Energy Absorption

Table II

Carson Burst and Tensile Equation

$$PR=2T$$

P= burst pressure

R= radius of curvature

T= tensile strength

Percentage Secondary	R Value
10%	.45
20%	.47
30%	.50
40%	.49
50%	.52
60%	.54
70%	.53
80%	.54

Figure 1

Burst verses Percent Secondary Fiber

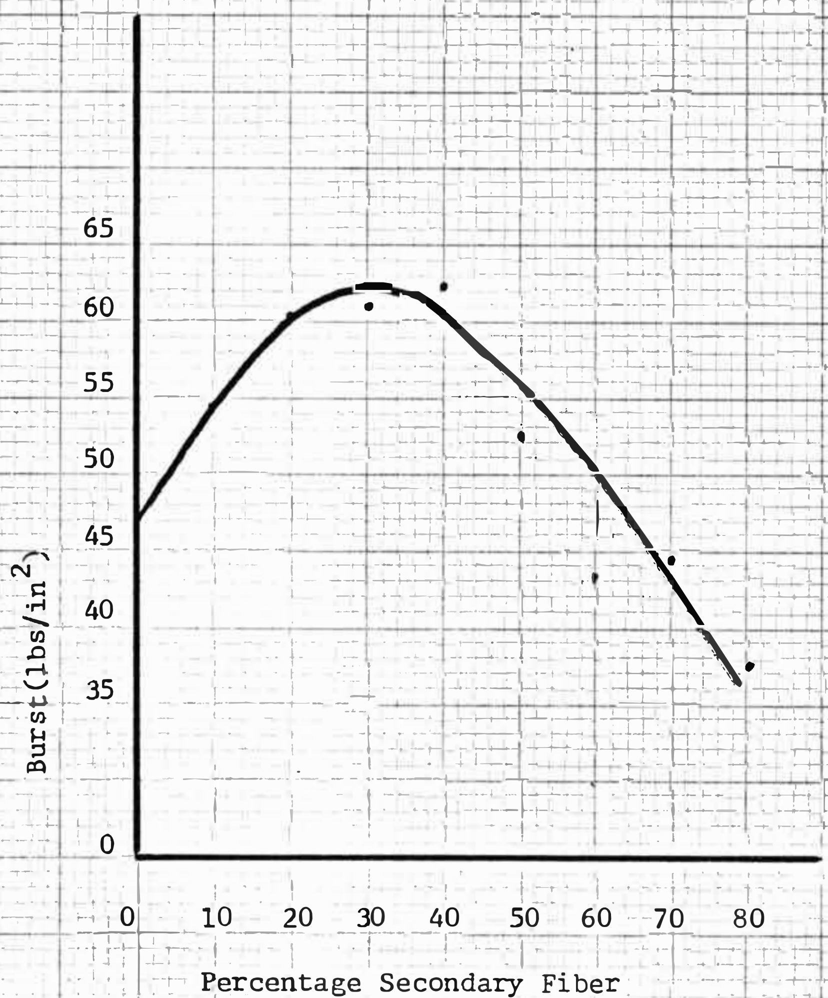
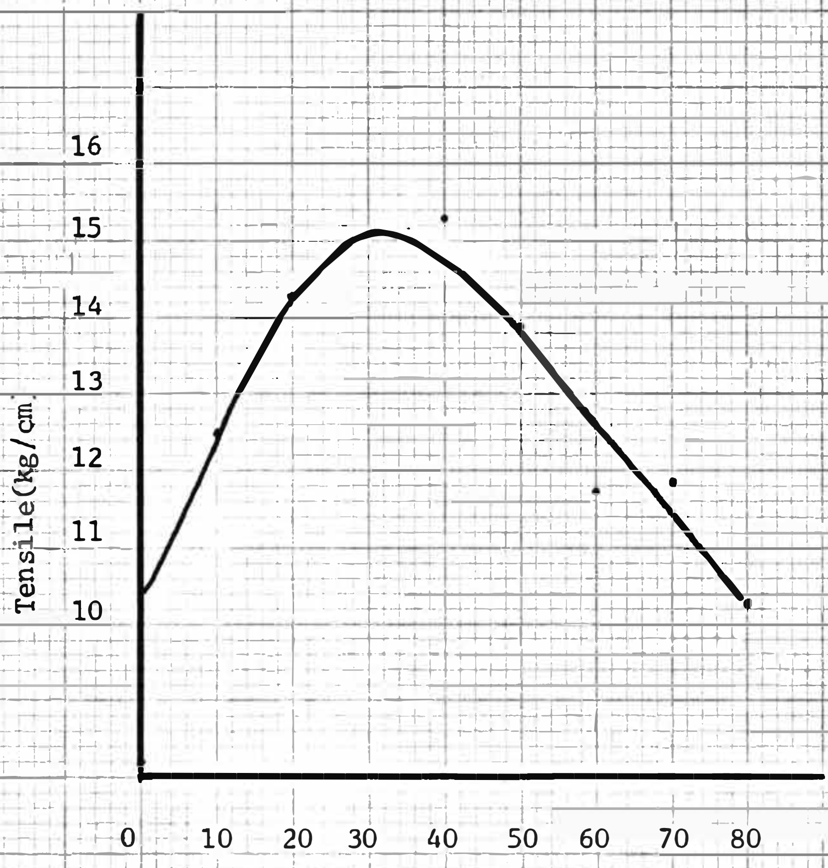


Figure 2

Tensile verses Percentage Secondary Fiber



Squares to the Centimeter

Figure 3

Tensile Energy Absorption verses Percentage Secondary Fiber

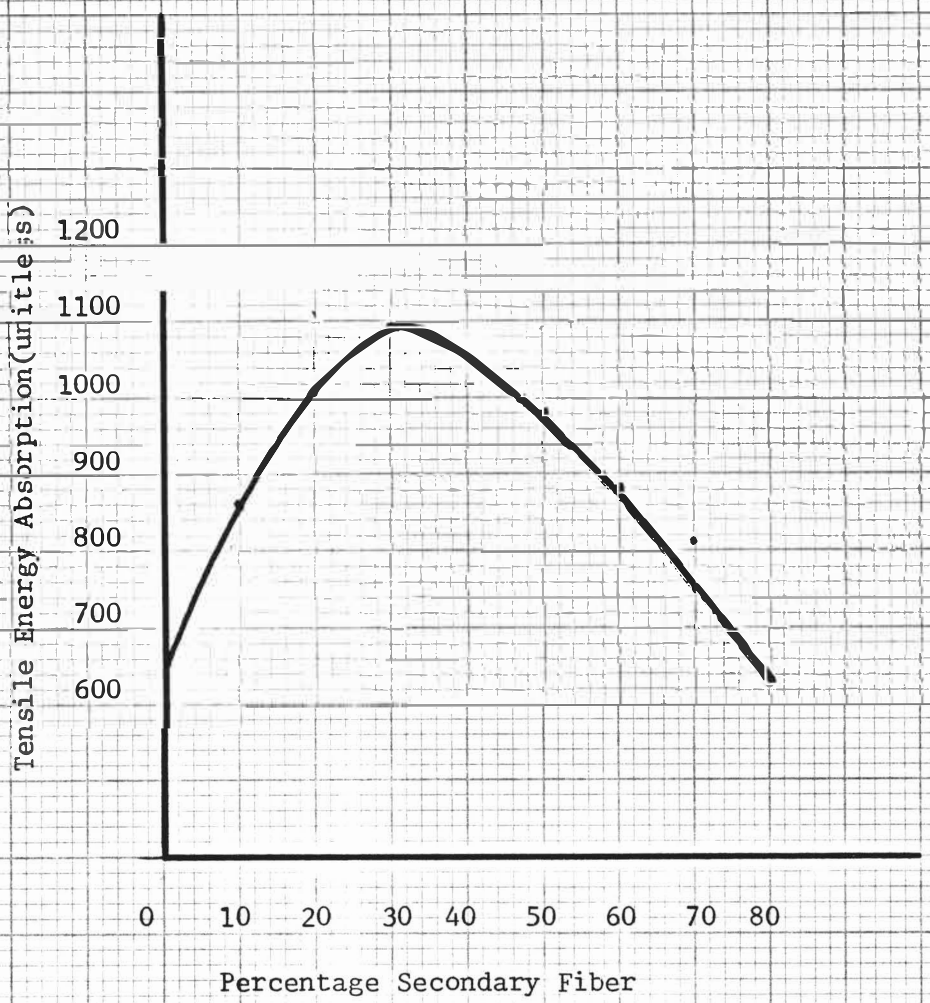


Figure 4

Burst and Tensile verses Percentage Secondary Fiber

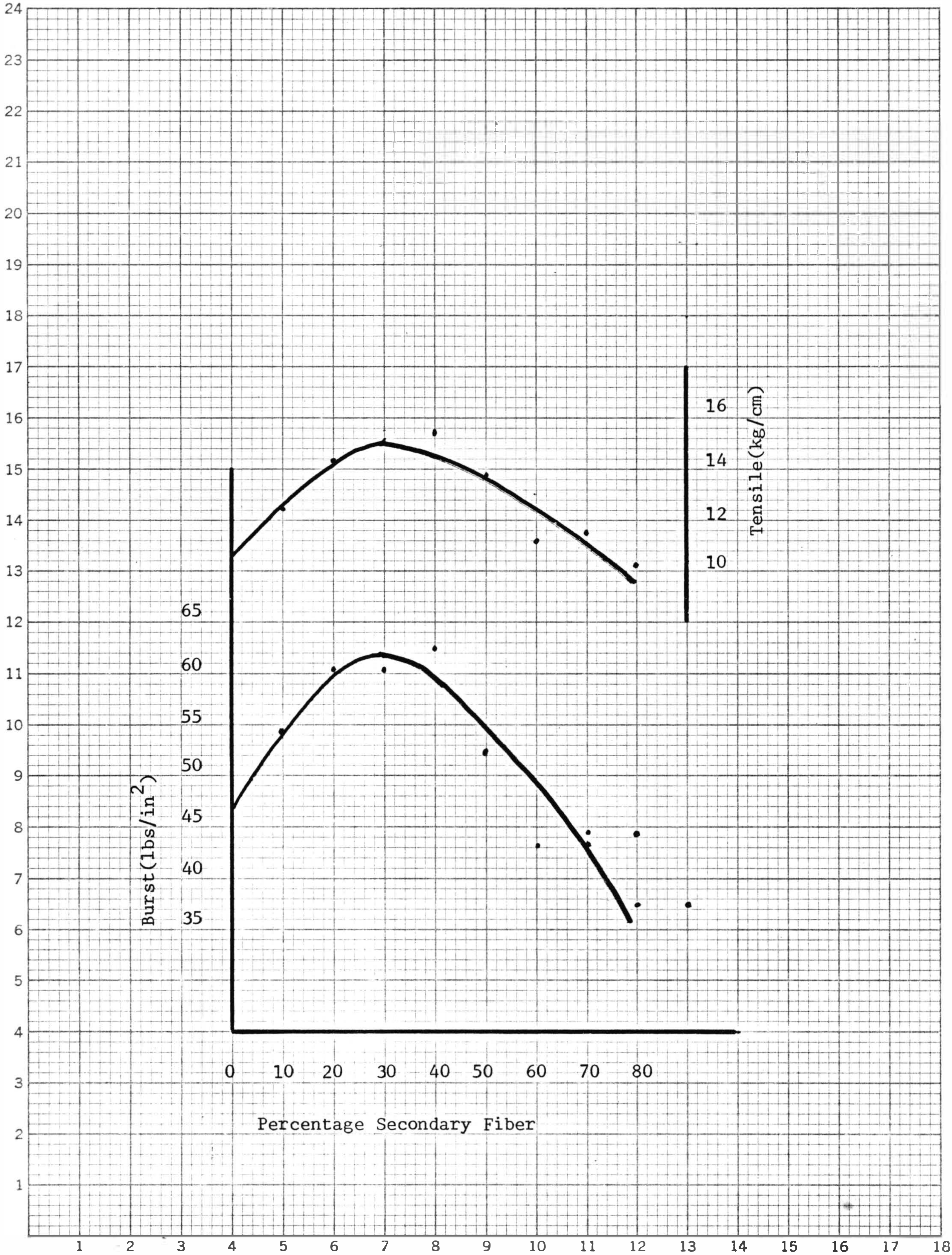


Figure 5

Tensile verses Burst

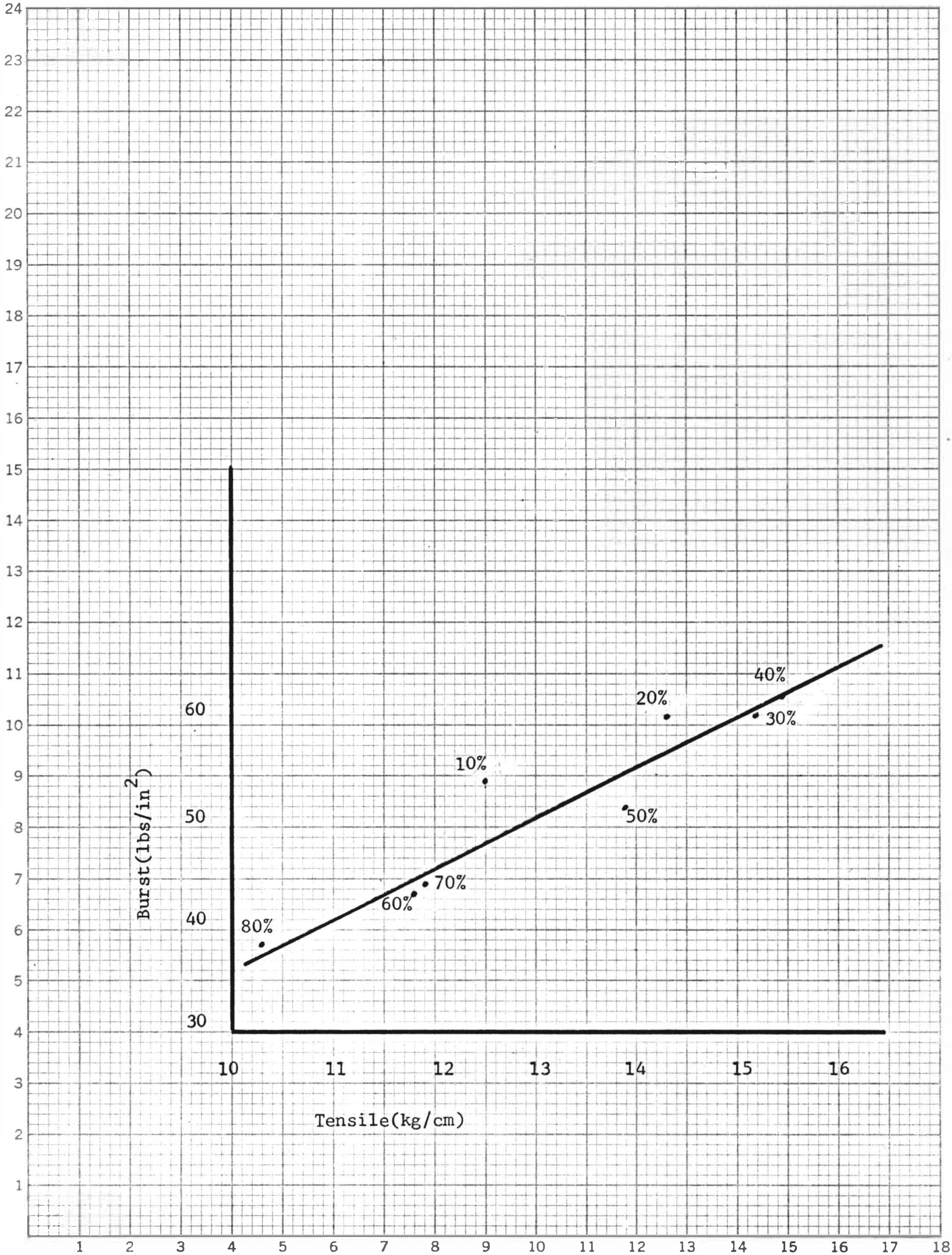
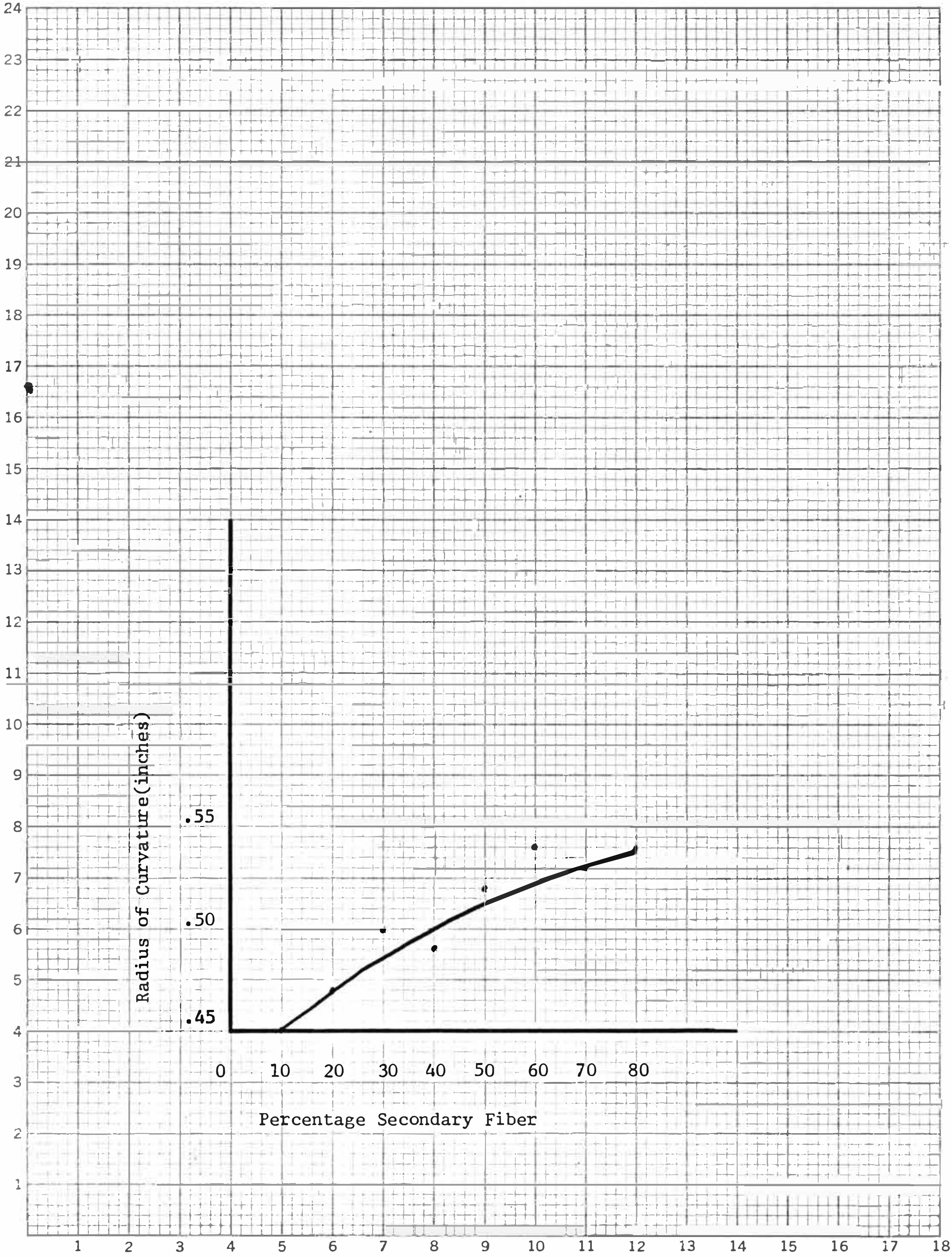


Figure 6

Radius of Curvature verses Percentage Secondary Fiber



DISCUSSION

The basic objective of this research project was to determine the relationship between burst and tensile as the percentage of secondary fiber was increased. There is a need for more information in this area because of the increased use of recycled fibers as a source of materials in papermaking. Previous work in this area has not been sufficient. Many individuals have proposed theories in this area. These theories have been helpful in guiding this investigation.

As previously mentioned, the different handsheet samples were to have had the same amount of refining. The amount of refining was to be determined by the Canadian Standard Freeness. It was originally intended to produce a sample which contained 90% secondary fiber. However, it proved impossible to produce a sample with the correct freeness level.

The effect of the changing percentage of secondary fiber on burst and tensile is shown in Table I. As Figure 4 clearly shows, there is a definite relationship between burst and tensile. The relationship is linear. The linearity between burst and tensile is also shown in Figure 5. Statistical analysis of the data also verifies the linear relationship between burst and tensile. There is a standard correlation coefficient equation for determining if a linear relationship exists. The equation is as follows:

$$r = \frac{S_{xy}}{\sqrt{S_{xx} S_{yy}}}$$

$$S_{yy} = \sum y_{ij}^2 - \frac{(\sum \sum y_{ij})^2}{12}$$

$$S_{xx} = \sum n_i x_i^2 - \frac{(\sum n_i x_i)^2}{12}$$

$$S_{xy} = \sum \sum x_i y_{ij} - \frac{(\sum n_i x_i)(\sum y_i)}{12}$$

S_{xx} = sum of squares error

S_{yy} = sum of squares total

S_{xy} = sum of squares regression

The closer the r value is to 1 the more linear the relationship(16). The value of r for the data produced is .818. This indicates a very good linear relationship.

Graphical and statistical methods have proven the relationship between burst and tensile to be linear. By substituting the data values into the Carson equation, the radius of curvature values can be calculated. Table II contains the calculated R values. As the percentage of secondary fiber increased, the radius of curvature also increased. This suggests that the fiber network is stretching more as the percent secondary fiber is increased. This is possible because the shorter fibers produce less bonding allowing the fibers to slide past one another more easily.

The general results of the curves in Figures 1 and 2 were also as theory predicts. In the 10,20,30% region, the burst and tensile increase. This is caused by the short fibers filling in the voids and increasing the bonding, which, increases the sheet strength. As the percentage of secondary fiber increases further, the shortness of the fibers overcomes the increased bonding and the strength of the sheet decreases.

The tensile energy absorption also reacts as theory predicts. At

the 10,20,30% levels, there is increased bonding. Thus, more energy is needed to pull the fibers from the sheet. As the shortness begins to predominate, the strain is placed on fewer fibers. More rupturing occurs and lower TEA results.

In the theoretical discussion, zero span tensile was discussed. It was originally intended to obtain zero span results. These results were then going to be subtracted from the burst and tensile results to produce actual bonding strength. It was not possible to convert fiber strength into kg/cm. Therefore a useful comparison could not be made. Therefore, the zero span tensile was not performed.

In 1971, a thesis was performed by Martin Smith. Smith's thesis had the same objective as this thesis. Four points were used: 0,33,66, 100% secondary fiber. Smith's paper was produced on the pilot machine at Western Michigan University. Smith's results were consistent with the results obtained from this experiment. This substantiates the hypothesis that the handsheets are acceptable as a experimental medium(17).

RECOMMENDATIONS

There are several areas of this study which can be expanded to gain further information. Paper should be produced on the pilot machine using the same percentages which were used with the Noble-Wood produced handsheets. Different species of pulp should be used, hardwoods, southern softwoods, etc... The secondary fiber should vary by species and should not be the same as the species of virgin fiber. Some contaminants should be added to the secondary fiber to produce a more production realistic situation.

There should be further investigation with the Carson equation. A refining freeness curve should be performed. The burst and tensile should be measured along the curve. This would examine the aspect of refining on the radius of curvature. It would also demonstrate the effect refining has on burst and tensile and the relationship between them.

All of the above suggestions if implemented would produce more data apon which new theories could be developed. Papermakers need this new knowledge as the amount of recycled produced paper is increased.

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