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The Effect of Sample Length, Fiber Length and Rate of Loading on Tensile and T.E.A.

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THE EFFECT OF SAMPLE LENGTH,
FIBER LENGTH AND RATE OF LOADING
on
TENSILE AND T.E.A.

by

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ABSTRACT

The purpose of this investigation was to study the effect of fiber length, sample length and rate of loading on tensile and TEA. The most important aspect of this study was the elimination or controlling of variables which appeared in all related studies to date. With this in mind, an experimental procedure was drawn up which would eliminate or control these variables. The original pulp was taken without any cutting, formed into handsheets, and pressed. The handsheets were then cut in order to reduce the fiber length while the handsheets were wet. Cutting of the fibers was done with a paper cutter and was followed by average fiber length determination by projection.

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HISTORICAL BACKGROUND

CHEMICAL THEORY OF BEATING

The chemical theory of beating proposed initially in 1920 by C. F. Cross and E. J. Bevan (1) suggested that during beating a fresh change takes place in the fibers as a result of their contact with a water-medium. The fibers are cut and fibrillated and at the same time the cell-wall of the fiber absorbs water, passing into a condition of a gelatinous hydrate or slime. This hydrate is presumed to be a chemcial compound of cellulose and water providing a strong adhesive which, upon drying, cements the structure together.

It has been found experimently that beaten pulp is slightly more hygroscopic than unbeaten pulp, indicating that, some hydrate is formed during the beating process. However, because there has been no definite experimental evidence as to the presence of such a hydrate, the slight excess of moisture in the beaten pulps can be satisfactorily explained by the fact that intensive beating has opened up the internal structure of the fiber, providing increased surface to absorb additional moisture. The theory that the hydrate was glue-like in character, increasing in quantity as beating proceeded, explained satisfactorily why sheet strength made from cellulose fibers also increased with beating. In fact, this chemical

theory of beating was able to explain satisfactorily almost, if not all, of the practical beating phenomena known up to that time.

It did, however, have its shortcomings as were later proved by the advocates of the physical theory of beating.

PHYSICAL THEORY OF BEATING

Strachan, in an article published in 1926 (2) severely criticized the formentioned chemical theory of beating. He insisted that the taking up of water by pulp in beating should be termed "imbibition" and not hydration. He described the water content of paper stock as follows:

1. Water of suspension, in which the fibers float.
2. Capillary water held between the fibers and in the canals and pores.
3. Colloidal water composed of (a) Water of "imbibition" absorbed by the unbeaten fiber, and (b) Water of "hydration", or an increase of water of imbibition owing to beating.

He proposed that any water retained by the fiber is retained in a physical sense only.

In his experiments he found that upon drying both beaten and unbeaten pulps under carefully controlled conditions there was no evidence of any break in the curve relating moisture content to time, and consequently no evidence of hydrate formation in the strict chemical sense.

After describing the internal structure of the cellulose fiber as we know it today, Strachan proposed that the layers of compacted fibrils, being porous, allow water to penetrate into the fiber structure causing the fiber to swell. Upon subjection to beating action these outer layers are loosened and the surface becomes fibrillated. Hence, when the sheet of paper is made the fibers of the beaten stock are soft and fibrillated and lie, and adhere together more closely than unbeaten fibers on the forming wire of the machine. Between the press rolls of the paper machine the fibers are squeezed into intimate contact according to their plasticity and degree of fibrillation.

In 1932, a Canadian investigator, W. B. Campbell (3), proposed a different view of the mechanism of bonding. This became unknown as the "Partial solubility" theory of fiber bonding. He advanced that during the formation of cellulose in nature, a precipitate is formed in the presence of water enabling the hydroxyl groups of the cellulose molecule to have attached molecule of water. As the fiber dries, the hydroxyl groups would be freed from water and their residual valences would be mutually satisfied by those adjacent cellulose molecules, thus causing the formation of secondary valence bonds. When the fibers are rewetted some of these bonds are broken and some hydroxyl groups reattach themselves to water, giving a more flexible form of structure. Campbell maintained that because of this "partial solubility" the molecules of cellulose when exposed on the surface

of the fiber by beating were on the verge of solution. Thus they were endowed with a freedom which enabled the molecules of adjacent fibers to so orient themselves that, up on drying, many of their hydroxyl groups could bond together by means of secondary valence forces.

In conjunction with Campbell's theory it is interesting to note that in 1924 two Russian investigators, Wislicenus and Gierisch (4), found that after beaking down cellulose by very fine grinding 0.05 to 0.39% of the cellulose became soluble in water, and because the amount of ash in the dissolved portion was little more than that in the original paper, it was clear that some cellulose material had dissolved. Upon investigation of the undissolved material, however, they found a marked increase in the copper number and methylene blue absorption indicating that the degree of polymerization of dissolved portion was reduced and possibly that some carboxyl groups had been formed. Thus we cannot say with absolute assurance that the material in solution was actually cellulose.

In 1933 Campbell published a theory (5) which offers a plausible explanation for the joining together of fiber elements to a degree of proximity permitting the force fields of the elements to react and bond. During the drying of the sheet, water is located in the micro-capillaries of the fibers and between fibers in the zones of close contact. According to Campbell's theory, surface tension pulls fibers and fibrils together during the drying process. Presumably

the number of such points in the paper sheet would be very large and would depend upon factors as the nature of the fiber, the type and degree of beating action, and the pressure and duration of pressure during the wet pressing period.

This theory explains satisfactorily, why well-beaten stock compacts so easily on drying, giving a hard, dense, strong sheet.

Campbell's theory has recently been supported by Van-den-Akker (6) who in 1952 published an article dealing with this aspect of beating. He showed that if an undried test sheet were frozen and the water consequently removed by sublimation in a freezer, the resulting dry sheet was bulky, opaque and weak. This indicates the absence of any force to pull fibrils into intimate contact enabling the force fields of the fiber to react.

Cottrall (7) published photographs showing mildly beaten fibers almost completely devoid of fibrillation which still formed strong sheets of paper upon drying. He went on to minimize the importance of the external fibrillation theory and instead emphasized wet fiber pliability facilitated by the presence of hemicelluloses and internal fibrillation brought about by beating. He thus concluded that fibrillation was not alone responsible for the strength characteristics of a sheet of paper.

Thus it is evident that upon review of these above theories or investigations, with the possible exception of the cellulose hydrate theory of bonding which so far has no valid experimental basis, none

of the physical theories of bonding account satisfactorily for the high rate of strength increase always encountered during the preliminary stages of the beating cycle.

In July 1943, James d'a Clark (8) published a modified theory of beating which could well be described as a composite theory of all the above observations.

He maintained that during the chemical and mechanical treatment involved in the preparation of pulp, the primary wall of the fiber, which is permeable to, but not swolen by water, is partially cracked, rubbed loose or removed exposing the underlying surface of the fiber. In the case of wood pulps this underlying surface is the spirally wound outer layer of the secondary wall. When the fibers are almost completely covered with this primary layer, as is usual in unbeaten pulp, adjacent fibers in the wet web are prevented from adhering together on drying, thus giving poor strength characteristics.

As beating proceeds, however, this brittle primary wall is rubbed or sheared off as a result of the wetting and swelling action of the fibers. Hence the underlying outer layer of the secondary wall becomes more evenly fibrillated, which not only permits stronger surface tension effects to compact the sheet better, but also results in a greater amount of bonding surface.

When the beating action reaches a certain point, a state is reached where the increase in bonding material is offset by de-

creased fiber length and a weakening of the fibers themselves by beating. At this point the pulp reaches its maximum strength.

It seems safe to say that this composite theory of Clark's appears to account for all the observed facts known at present about the beating process. Also, it is felt that any exception to this, arising in the future, can be easily explained by modifications of this theory.

CUTTING AND FIBRILLATION

The phenomena and changes which take place when pulp is beaten and made into paper are many. This can be explained by the myriad of variables encountered in the beating process. It can be said, however, that the results of beating can be grouped for purposes of discussion into two variables according to pulp type and effect on the fibers.

As is clear, artificial cellulose fibers do not respond to beating owing to their solid structure and their characteristic inability to fibrillate. Likewise, mechanical or groundwood pulp and most semichemical pulps do not have sufficient delignification of their structure to fibrillate easily. In consequence they do not respond well to the beating action. On the other hand, chemical pulps such as kraft and sulfite, characterized by lower yields, are delignified to the degree where beating facilitates fibrillation enabling bonds to be formed between the individual fibers which in turn promotes greater strength development.

Hence, lignin removal plays a major role in the subsequent strength development of any pulp when that pulp is subjected to the stress action of a beater.

Much of the lignin associated with the cellulose fiber is found in the thin layer of the primary wall of the fiber. In chemical processing of pulp, however, the function of the cooking liquor is to dissolve the major portion of the lignin which abides on the outside of the fibers, primary wall. That is, to dissolve the lignin situated in the true middle lamella region between two fibers, thus freeing the individual fiber from its neighbor fiber. This liberation of individual fibers through chemical action is of prime importance when chemical pulps are subjected to beating.

In the case of mechanical pulps the individual fibers are not liberated from one another in the true sense of the word. Grinding represents a physical process, which by means of such mechanical actions as rubbing, tearing, and breaking in the presence of water, the wood is reduced to various sizes (9). The fibers may remain in a state of multiple "fiber bundles" or be reduced to a state even smaller then the individual fiber itself. The product is obtained as a mixture of structure of pulverized wood suspended in water.

As previously stated, the primary cell wall of the individual fiber contains a good deal of lignin not dissolved during the pulping stage. This wall may be regarded as being a sheath of non-reactive cellulose (fibrils) in its grip. In order to promote any fibrillation from the outer layer of the fiber's secondary wall,

the primary wall or constructive "gridle" of lignin and hemicellulose must first be removed. This removal is accomplished during the initial stages of the beating cycle.

The practical value of such knowledge of the cellulose fiber and its constituent structure lies in the better understanding of the beating mechanism and of the variety of influence which must be overcome during the beating action.

Broadly speaking the beating process is not effective unless carried out with water as the liquid medium. There are a few highly polar liquids which act like water but these are very few. It is essential that the liquid used be one which swells the fiber, otherwise only a cutting action will result with no fibrillation to speak of (10). Both qualities of the fiber are required to produce a satisfactory sheet of paper.

In short, using water as the carrier medium, two basic actions are accomplished during the beating cycle.(1) the fibers may be cut and (2) the fibers can be split or unravelled (11). The extent to which each of these two actions prevail will, of course, vary with the type of equipment used to prepare the pulp.

If the strain on the fiber is great enough it will break. This phenomena is referred to as cutting and is closely related to fiber length. It is safe to say also that cutting has long been recognized as an objective of stock preparation because of its effect on sheet properties. When cutting occurs it is almost equally likely that it will be done very near the ends of the fiber rather than at or

near the exact middle of the fiber. In fact, with the production of only a small mount of cut fiber debris, it becomes much more difficult, on the average, to cut a fiber anywhere except near the end (11). Thus, our cutting process is mainly one of making the longest fibers a little shorter while diminishing the shorter fibers to a stage of mucilage.

The unravelling of the fibers is probably the objective of that aspect of stock preparation known variously as hydration and fibrillation. Upon swelling the fiber, the fibril bonds are ruptured enabling some of the torn cellulose fabric to be dislodged longitudally from its position in the fiber, appearing externally as distinct fibrils. These ruptured parts which appear as fibrils tend to be long and narrow and show a fiber-like appearance of their own. This conversion of internal service to external leads to greater possibilities of contact among the fibers and hence to greater strength. It seems, therefore, that the swelling of the fiber is required to allow fibrillation, and that fibrillation first appears after a long period of beating.

Thus, in practical beating operation both cutting and fibrillation are required in order to produce a satisfactory sheet of paper. The best that can be done is to regulate the beater roll pressure and clearance, so that the balance between cutting and fibrillation is known one way or another. It seems that for maximum strength the average fiber length should be impaired as little as possible and at the same time fiber surface be subject to a bruising or rubbing action.

It is obvious that long fibers present much more area of contact for bonding than do short fibers and hence should produce stronger paper. Short fibers or fines, however, can act to a large extent to bridge spaces between long fibers where, otherwise, contact would not have been possible. Cutting of the fibers, therefore, seems to be a thing to be avoided except insofar as the presence of fines is ncessary to obtain good formation. Thus the long-fibered portion of the pulp acts as the skeleton of a sheet, while the fines serve to fill in the intersites between the skeletal fibers thereby increasing sheet density.

STRESS-STRAIN RHEOLOGY

The phsyical and chemical theories of beating action have each been reviewed along with basic considerations dealing with the fibrillation and cutting action on the fiber.

It seems necessary now to relate these theories to the physical properties of the test sheet and to elaborate further upon the influence imposed on the sheet by fibrillation and cutting degree.

Basically, any physical strength test applied to a sheet is a measure of the stress/strain relationship of the fibers in that sheet. For example the tensile or breaking strength test applied to a sheet is a measure of the elongation of the fibers with increased stress up to a point where rupture occurs. At this point the load acting on the sheet overcomes the fiber forces opposing it, causing fiber breakage and bond slippage to occur.

It has been shown by Van den Akker and coworkers (12) that when paper was subjected to rupture stress, about 65% of the fibers involved in the rupture of the paper were actually broken. This figure will vary of course depending upon the fiber angle to the plane of strain, the degree of sheet wet pressing and on beating time. They maintain that fiber-to-fiber bonding is the most important factor in the tensile strength of ordinary paper, and that the strength of the fiber themselves is of secondary importance. Here the strength of the fibers is considered to be a greater importance than the fiber-to-fiber bonding.

It seems therefore, from the above observations, that a reasonable balance must be reached between fiber strength and fiber-to-fiber bonding in any test sheet. Clearly, the more surface area introduced on beating, the greater the possibilities regarding the internal bonding of a sheet. Yet, fiber dimension also plays a major part in the subsequent strength development of a paper sheet as it is clear that long fibers possess more inherent strength than do short fibers.

The question must then be asked, is there an optimum point which must be reached between average fiber length and fiber-to-fiber bonding in a sheet, and how critical is fiber length on the stress/strain relationship of paper?

This question was studied by A. P. Arlov and discussed at the 1957 Cambridge Symposium of Papermaking Fibers (13). He investigated

the effect of fiber length on the shape of stress/strain curves produced by various beating apparatuses. Pulp was beaten in a PFI mill, an L & W beater and a Valley beater to approximately the same breaking length after which it was fractionated in a Bauer-McNett classifier. The distribution of fiber length was measured and pulp beaten in the PFI mill was found to have the largest average fiber length. While the L & W beaten pulp had the smallest average length. He then drew normalized stress/strain curves for paper from whole pulp beaten in the three apparatus. The PFI mill pulp, having the longest fibers produced a paper whose normalized stress/strain curve was located between those of the two other beaters. Thus the curve shape is no simple function of fiber length. He goes on to say that the surface condition of the fibers is one of the main factors determining the degree of fiber-to-fiber bonding and that this factor will vary significantly between any two beating apparatus.

He does not, however, discount fiber length entirely from the stress/strain relationship of a paper sheet. He maintains that there is a contribution from fiber length regarding the shape of stress/strain curves.

In order to clarify the effect of fiber length on curve shapes, stress/strain curves were recorded for paper from the fraction of pulp collected in the four compartments of the classifier. Cyrves representing the normalized stress/strain curves from the four fractions of the beaten pulp showed that the shape parameter increased with de-

creasing fiber length. In short, it required more stress for given amount of elongation with decreasing fiber length.

EFFECT OF FIBER LENGTH ON TEA AND TENSILE

It can be said that the production of fines is a direct consequence of the beating action, the magnitude of which depends upon the extent of beating and on beater roll pressure.

Let it be assumed now that in a given pulp the degree of hydration or fibrillation is approximately the same for all fibers regardless of their size. If this be so, differences between two samples of the same pulp, each having equal beating duration, will be the result of fiber length differances only. Hence, differences in average fiber length predominates when test sheet properties of this type are compared.

What is meant by the expression, "average fiber length"? A brief examination of the literature reveals that almost every authority has his own, usually unexplained, ideas on the question. For example, the average fiber length of spruce varies from 0.74 mm to 3.48 mm depending on which method was used for the length determination. This is due to the fact that there are a variety of ways to determine this average including the numerical average length of the fibers, which is much affected by the lower limit of the length of the particles considered to be "fiber", the weighted average length by length, by projected area, by volume, and by true weight.

Klemm (14) regards any fiber less than 0.10 mm as "debris", while Grund and Co-workers (15) consider this figure to be 0.30 mm.

Since the thickness of the average fiber is in the vicinity of 0.10 mm there is some reason for saying that any fiber whose length is below this figure should be regarded as "fines". This is because material shorter than this cannot sensibly be held to contribute to the fiber length, and where as this fine material has an important influence on the overall pulp quality, as will be discussed later, obviously it should be classified as a filler.

It was pointed out by Doughty (16) that density is an important factor in determining sheet strength. He proposed that density be replaced by solid fraction by volume and then went on to give a qualitative study of the tensile strength measured in a regular manner with increase in solid fraction in the test sheet, and that strength increase was due to an actual change in the surface condition (fibrillation) of the fibers, and also to those solid fraction increases dependent upon increased shrinkage, i.e. decreased fiber particle size.

Doughty later published an article in 1932 (17) showing the effect of fiber length on the tensile strength of pulp test sheets at constant solid fraction. He used a black gum pulp in his short-fibered test sheets and spruce in his long-fibered sheet and showed there was no great difference in strength among the individual pulp fractions at any given solid fraction.

He then plotted the ultimate tensile strength against the pressure on the wet sheet. Considering sheets made from both spruce and black gum, under any given pressure when wet, those from the short-fibered fraction were from 25 to more than 200 per cent stronger than those from the long-fibered fraction, depending on the exact pressure being used. This can be explained by the fact that the short-fibered pulp, pressed while wet under a given pressure, gives a sheet of higher solid fractions and therefore greater in tensile strength than one of the longer fibered pulps.

To insure that his only variable was fiber length, Clark (4), undertook a procedure in which a quantity of bleached sulfite pulp was fractionated and only the material in the long fraction was further used. Sheets made of the long-fiber fraction were cut fine with a sharp knife and the pulp reclassified into several fractions. He found that tensile strength was proportional to KL 1/2, where L is the weighed average fiber length by weight. He then went on to say in a later article (18) that by varying the density of the dry sheets, with increasing pressure on the wet test sheets, the tensile strength could be shown to increase directly with the density.

Work on glass fibers was done by O'Leary and coworkers (19) in which the influence of fines was noted on the physical properties of the test sheets produced. It was necessary to avoid completely any trace of fibrillation on the fiber. Thus, a synthetic fiber such as glass was chosen to give complete cutting when subjected to the beating action. A sample of stock fiber as prepared for the paper machine

was taken from the beater. Handsheets were made from a part of the sample, and another portion of it was run through a pulp classifier. Handsheets made from the fibers retained by the 65-mesh screen were found to have a tensile strength one-fourth that of the handsheets made from the original stock. Handsheets made from the fibers retained on the 100, 150 and 200 mesh screens mixed together were so weak that the strength could not be measured. Handsheets made from the fibers from the 65-mesh screen mixed with those from the 100, 150 and 200 mesh screens were ten times as strong as the sheets from the original stock.

It is of interest to note that neither the paper made from the long fibers (65-mesh) nor that from the combined short fibers was as strong as the paper from the original stock. The explanation of this is that when the longest fibers were used no short fibers were present to bind the long fibers together, and when the short fibers were used,, no long fibers were present to give the paper strength. With a combination of the long and short fibers, the paper was ten times as strong as the paper from the original stock because all the fines were removed. This proves to be an important factor in the manufacture of glass paper and can be applied to natural paper when fibrillation influences have been eliminated. That is, the more fines there are in the paper past an optimum point, the weaker the paper becomes. This optimum amount is necessary, however, to bind the long fibers together.

Bretcht and Klemm (4) carried out wet strength tests on groundwood at various proportions of fibers and fines, and found strength to be dependent in particularly marked fashion upon the presence of an optimum mixture. The wet strength of those sheets consisting of fibers only and that of sheets of pure fines was so small as to be impossible of measurement. The mixing of these two form components, however brought about a measurable tensile strength in the wet sheets and a maximum value was obtained at a definite proportion. He showed that with increasing content of fines the wet strength increased almost linearly, reaching a maximum with a mixture comprising approximately 50% fibers and 50% fines. With still greater proportion of fines the wet strength decreased steadily to zero with a fines content of 92%. He then goes on to say that admixture of fines to fibers at first increases the dry sheet breaking length very rapidly, the maximum value being obtained with a lower fines content than in the case of the wet tensile strength.

It was found that the observed tensile strength depends upon the rate at which the specimen is loaded, the tensile strength increasing as the rate of loading increases. The variation in the observed tensile strength with rate of loading requires some standardization of the testing method of results obtained with various instruments. Carson (2) has suggested that the rate of loading rather than the speed of the stressing jaw be specified i.e. that the specification consist of a statement that the load shall in-

crease at so many pounds per second rather than that the speed of the stressing jaw shall be so many inches per minute. The choice of the proper rate of loading is a difficult one to make. Thin and weak papers must be tested at a rate of loading so low that the application of the load does not remotely resemble an impact. A rate of loading satisfactory for these thin papers is so low that the time of test for strong papers becomes undesirably large. They worked with six different papers and change in rate of loading and different jaw speed. The sample length was constant. At the end they found

a definite increase in tensile strength with the increase of rate of loading.

From the theoratical view point, it is to be expected that the observed tensile strength will decrease as the specimen length is increased. The dependence of the tensile strength on specimen length has been studied by a number of investigators. Oliver (5) listed 5 and 18 cm length of three papers. Houston (6) tested five lengths (50, 90, 100, 150 and 180 mm) in each of the two principal directions of the sheet for each of 10 papers using four widths (1/4, 1/2, 3/4 and 1 inch). Harrison (20) tested 100 and 180 mm lengths of two kraft papers. Oliver and Houston found the tensile strength to decrease with an increase of specimen length. Harrison found a decrease for one paper and increase for the other. The tests for each length of specimen were carried out at a rate of loading of one pound per second, except for those specimens which has a tensile strength of less then five pounds for which a rate of loading of

less then one pound per second was used. The relationship between change in tensile strength and specimen length is not sufficiently regular to warrant the calculation of a correction factor by which the tensile strength observed at any specimen length may be reduced to corresponding values for another specimen length.

Since the change in tensile strength with specimen length is related to the frequency of occurrence of weak spots in the specimen, it might be expected that papers of good and poor formation would behave quite differently.

EXPERIMENTAL DESIGN

For the elimination of bleaching in the raw fiber stock and to provide initial fibers of length, the samples were taken from an unbleached softwood kraft and conditioned at constant temperature and humidity.

The sample pulp was torn into approximately one inch square pieces and soaked in water for about 4 to 5 hours. The pulp and water mixture was made up to 15 to 20 liters with water at room temperature and then the pulp was disintegrated at 1.5% consistency for about 5 to 10 minutes in Atlas stirrer. This disintegrated pulp was placed in ball mill and refined to get just fibrillation. This milling process was done in two liter batches. Pulp was milled until the tear test reached its highest peak. Now this pulp was ready for making handsheets.

Handsheets were made on a Noble & Wood Machine (whole amount of pulp) by using this fibrillated pulp. Canadian standard freeness test was done on all different sets of work. A few slides were made from the original pulp for the measurement of fiber length. This measurement was done by slide projection method. Some of the handsheets were dried and placed in humidity room to be tested. The rest of the pressed handsheets were not dried, but cut into small strips when they were wet because the main aim was to get the fiber cutting. All these strips were soaked in water for about 4 to 5 hours and then disintegrated. Slides were made from the pulp for measuring the fiber length.

This work, making handsheets, saving some for testing, cutting into strips, soaked into the strips and making handsheets. Every time CSf was measured to see the cutting.

For testing the handsheets, all sheets were placed in humidity room according to TAPPI standard conditions. Tensile and TEA were run according to TAPPI standard T404 - ts 66 and TAPPI suggested method T494-464 respectively. For testing the effect of load and sample size, changes were made on Instron Tensile Tester.

DISCUSSION

In order to check the effectiveness of the fiber cutting, fiber slides were made and fiber length was measured. To get an indication of cutting, Canadian Standard freeness was measured but there was not any observed effect on freeness, maybe because of the loss of fines during sheetmaking. For this investigation it was necessary that the fibers be cut cleanly and without any damage. Flattening of the frayed ends would effect the results of this investigation.

It can be readily seen in Figures 1 to 8 that cutting has an effect on fiber length. From Figures 1 to 4 fiber length distribution is not very good and the reason for this is that the strips were cut into a larger size (one inch squares). Figures 5 to 8 show good distribution of fiber length this time because strips were cut into 1/2 inch squares. This shows the effect of cutting technique.

Figures 9 and 10 show the effect of fiber length on tensile and TEA. It can be seen that cutting means fiber length has more effect on TEA then tensile. Results in this investigation show that as the length of fibers decreases, tensile and TEA increases. The fibrillation was given by Ball-Mill, if the fibrillation is enough this investigation should give higher values but the results are not high may be because of less fibrillation.

From this investigation it can be said, the fiber length has effect on tensile and TEA with little amount of fibrillation. The results are increasing by 40% in tensile and 70% in TEA. Obviously fiber-to-fiber bonding is the prime importance in the tensile strength of the paper. Fiber length and the strength seem to be secondary thing when compared with other investigations.

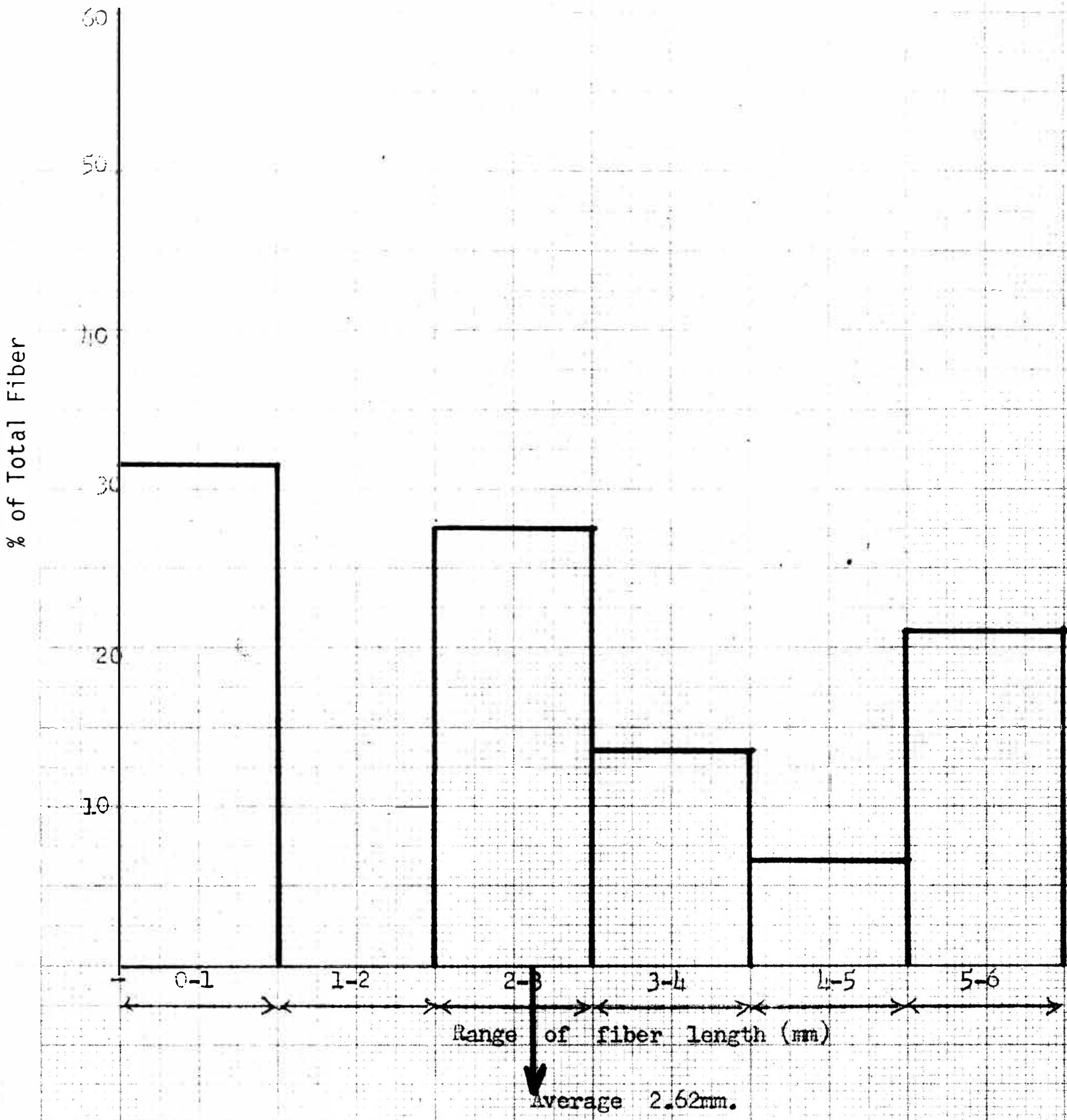
As the number of cuttings increases the amount of the fines within the sheet increases and the fibers becomes shorter, so the bonding between the fibers within the sheet increases. This might increase the strength of the sheet. In this investigation that might be the one factor which influences the results.

It can be seen from the Figures 11 and 12 that as the sample length increases, tensile and TEA both decreases. This relation depends on the area of the sample. The different curves in these two Figures, show the increase in results of tensile and TEA by going from longer fibers to shorter fibers.

The change in tensile strength with the sample length may be related to the frequency of occurrence of weak spots in the sample. This is one reason, in TAPPI Standard for measuring the tensile strength of paper has standard length and width of the sample because the ratio length to width is important in measuring tensile strength. This might be the reason for the decrease in tensile strength results as the length of the sample increases.

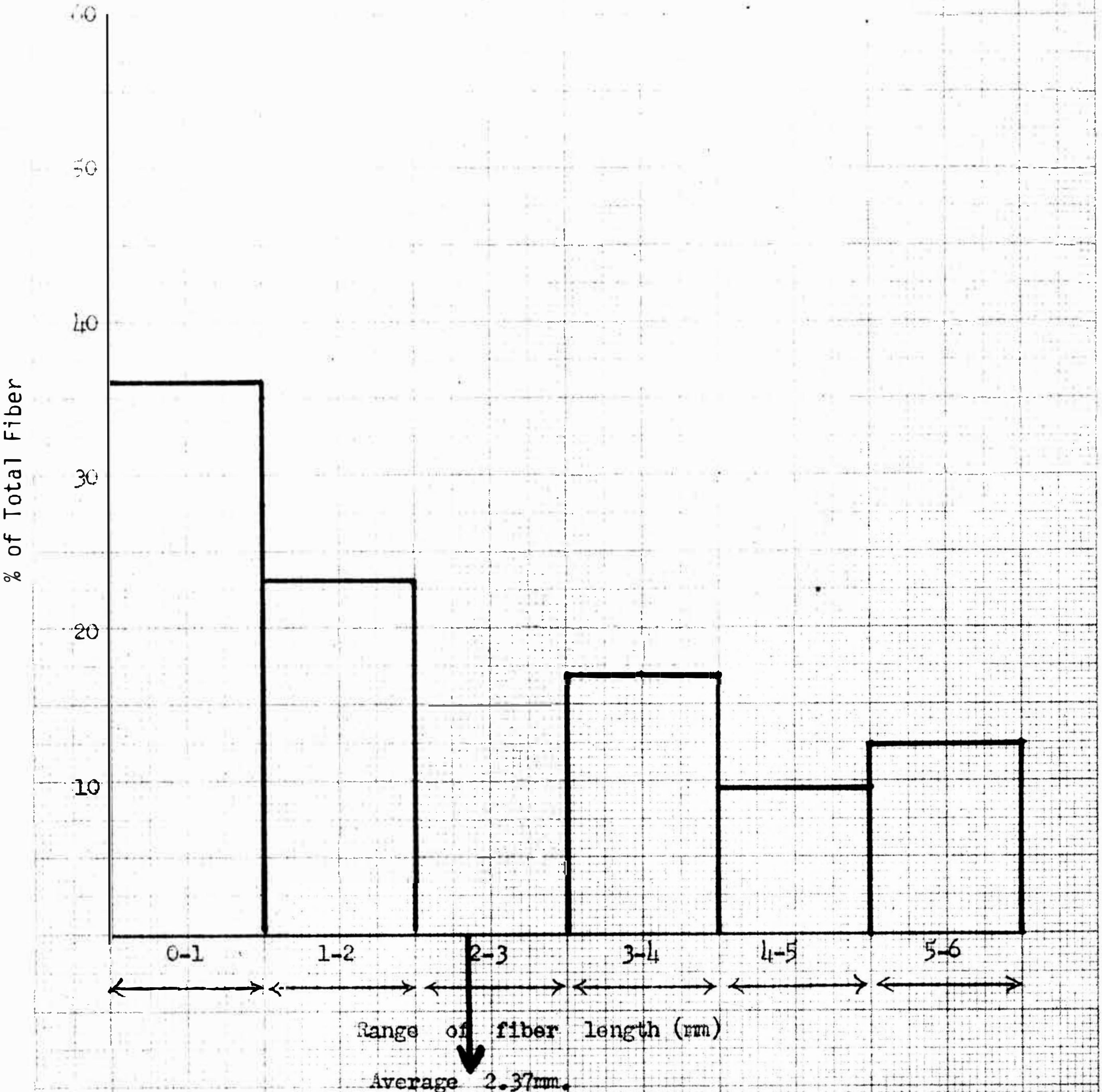
For finding the effect of rate of loading, results were taken and graphs were plotted as shown in Figures 13 and 14. Figure 14, shows very flat curves as there is not too much effect of rate of loading on tensile while it has some effect on TEA increases.

% of Total fibers vs. Range of fiber length - Set.1

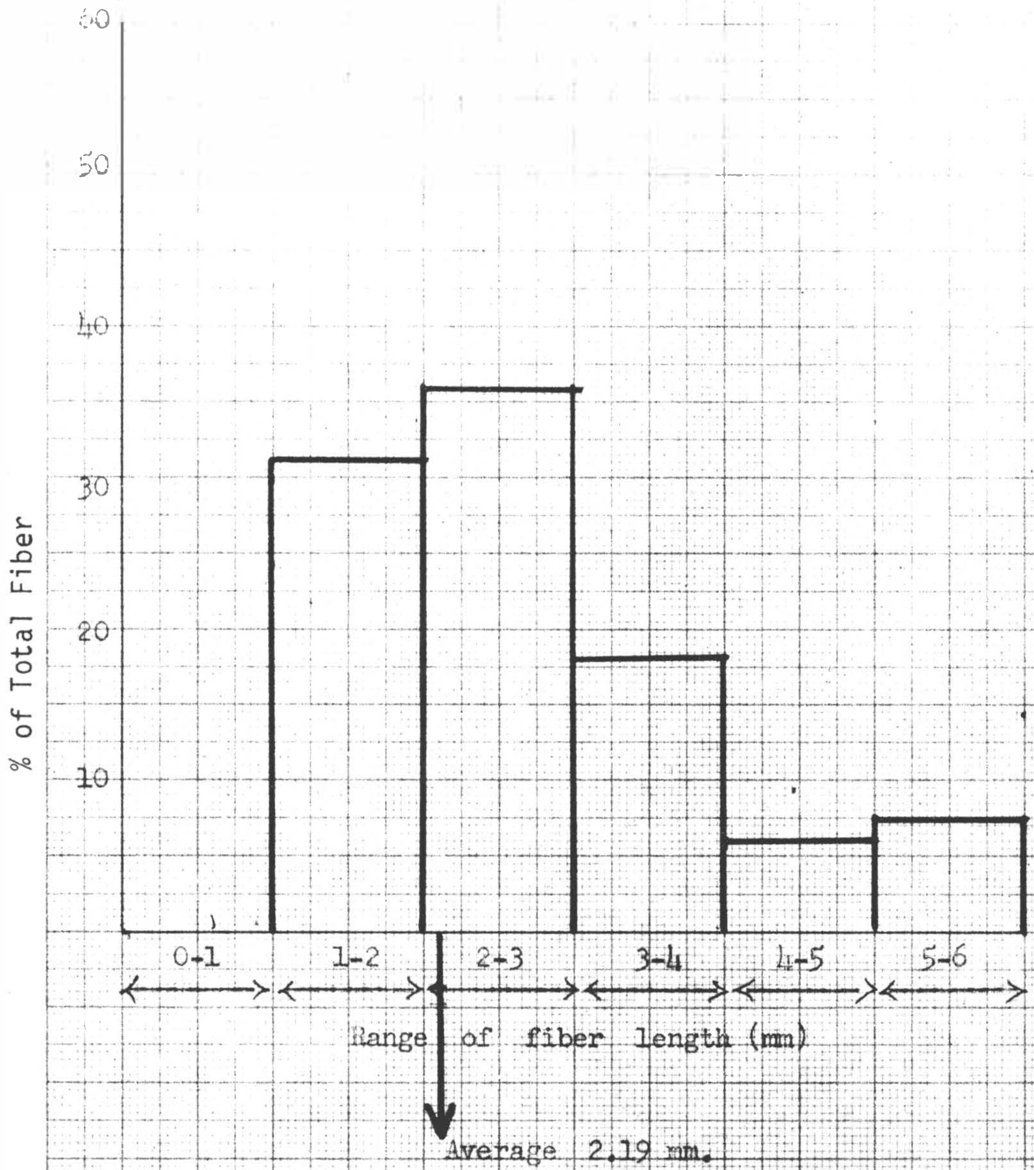


% of Total fibers vs. Range of fiber length

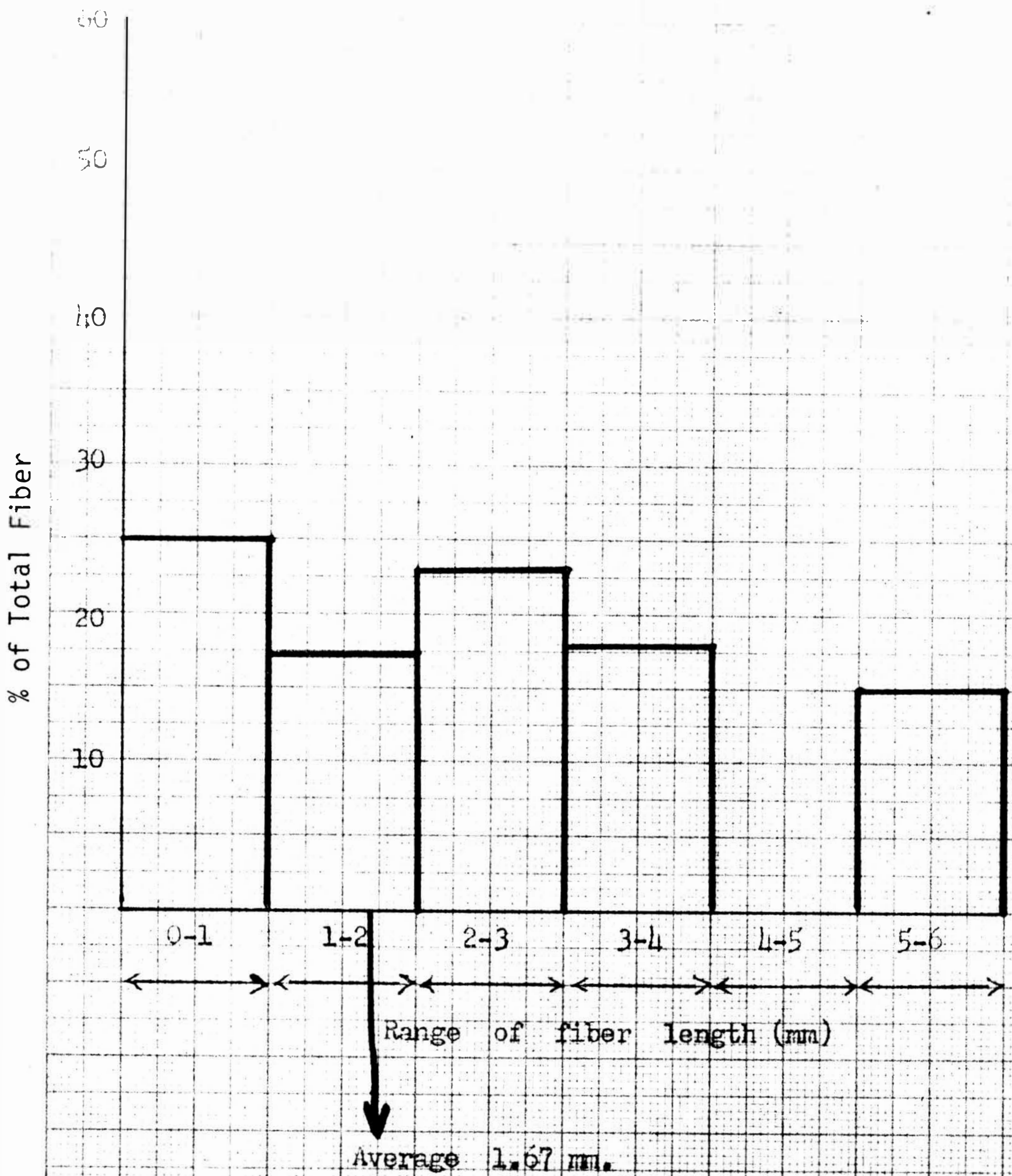
Set - 2



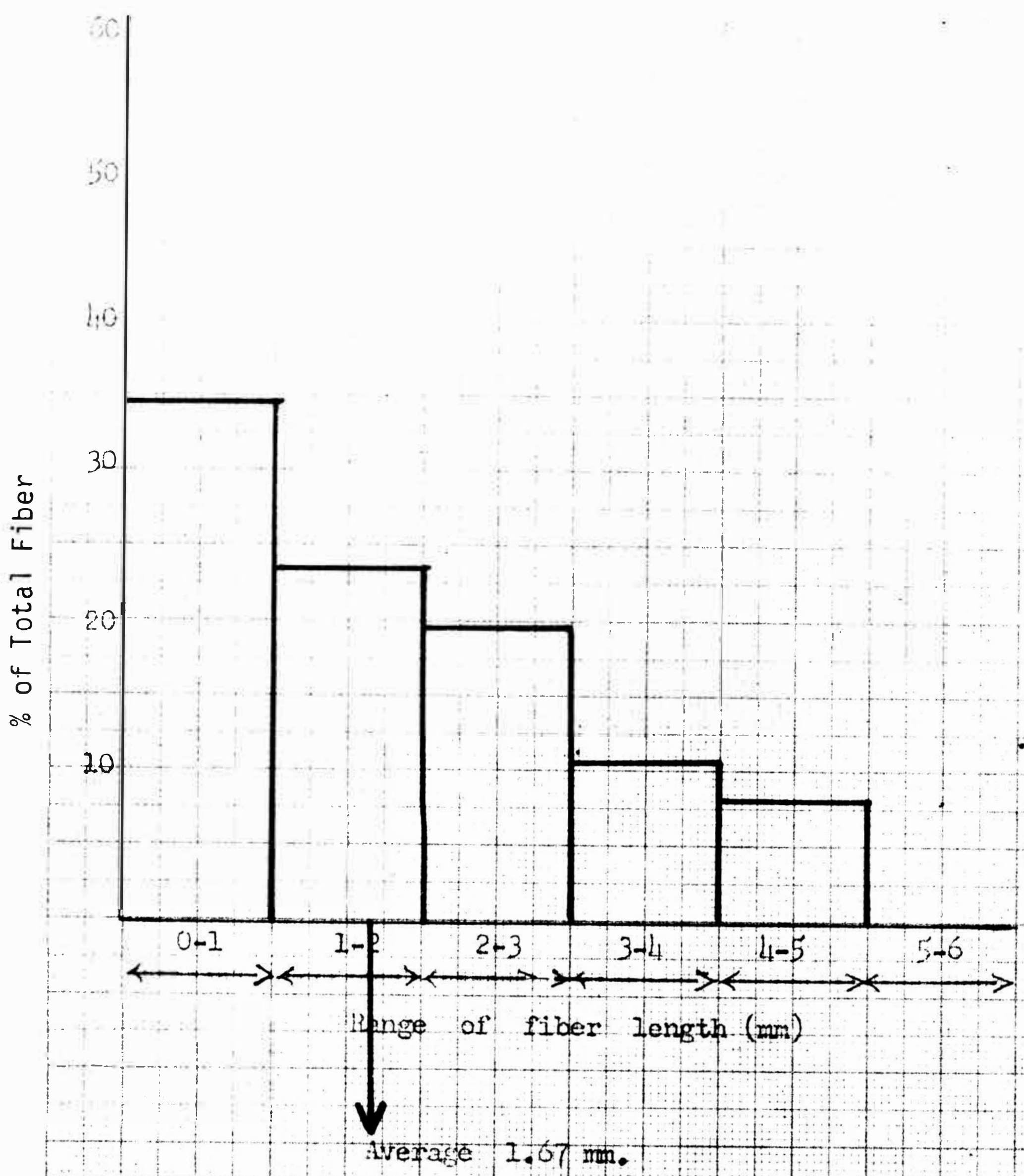
% of Total fibers vs. Range of fibers length Set-3



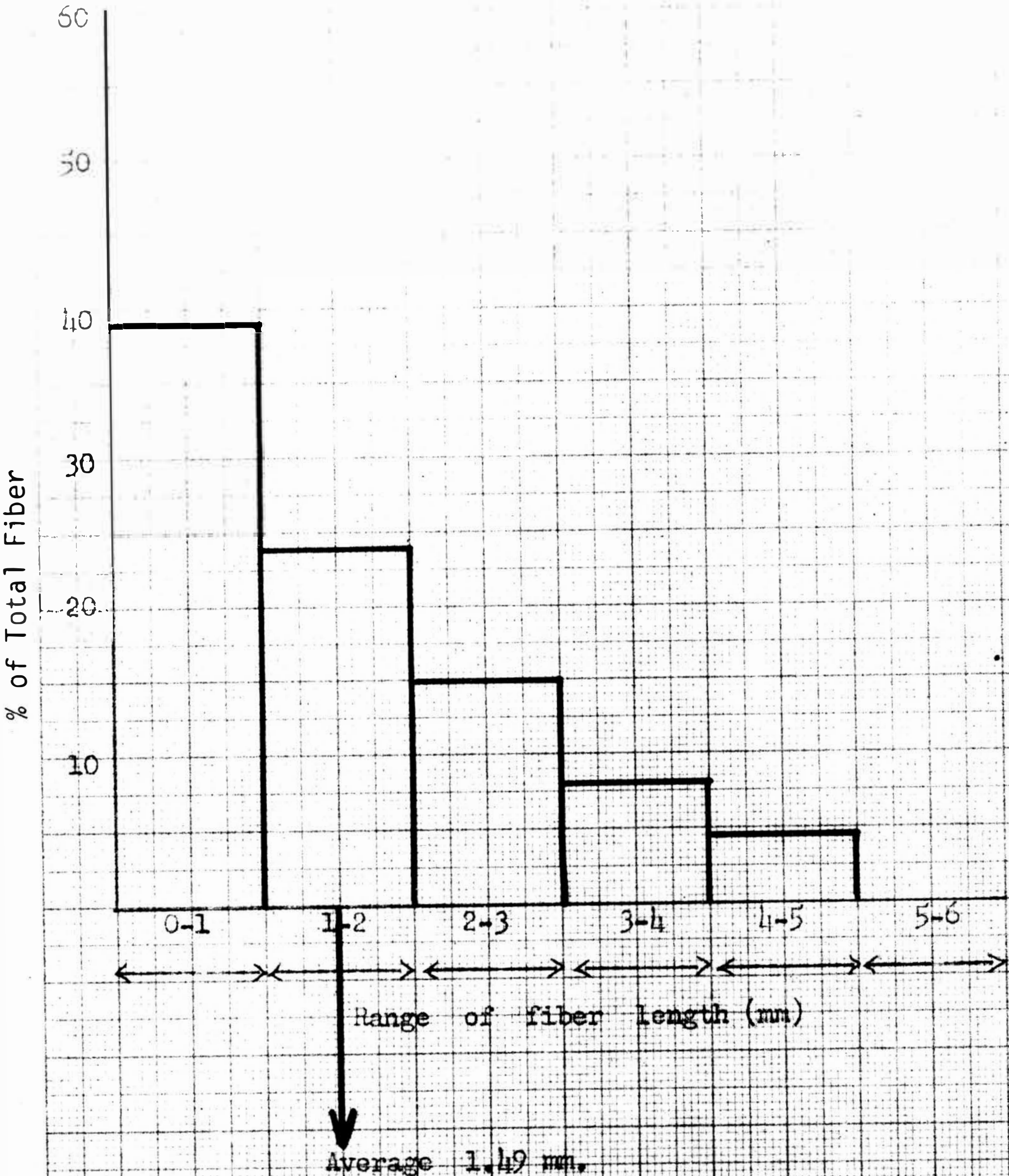
% of Total fibers vs. Range of fiber length. Set - 4

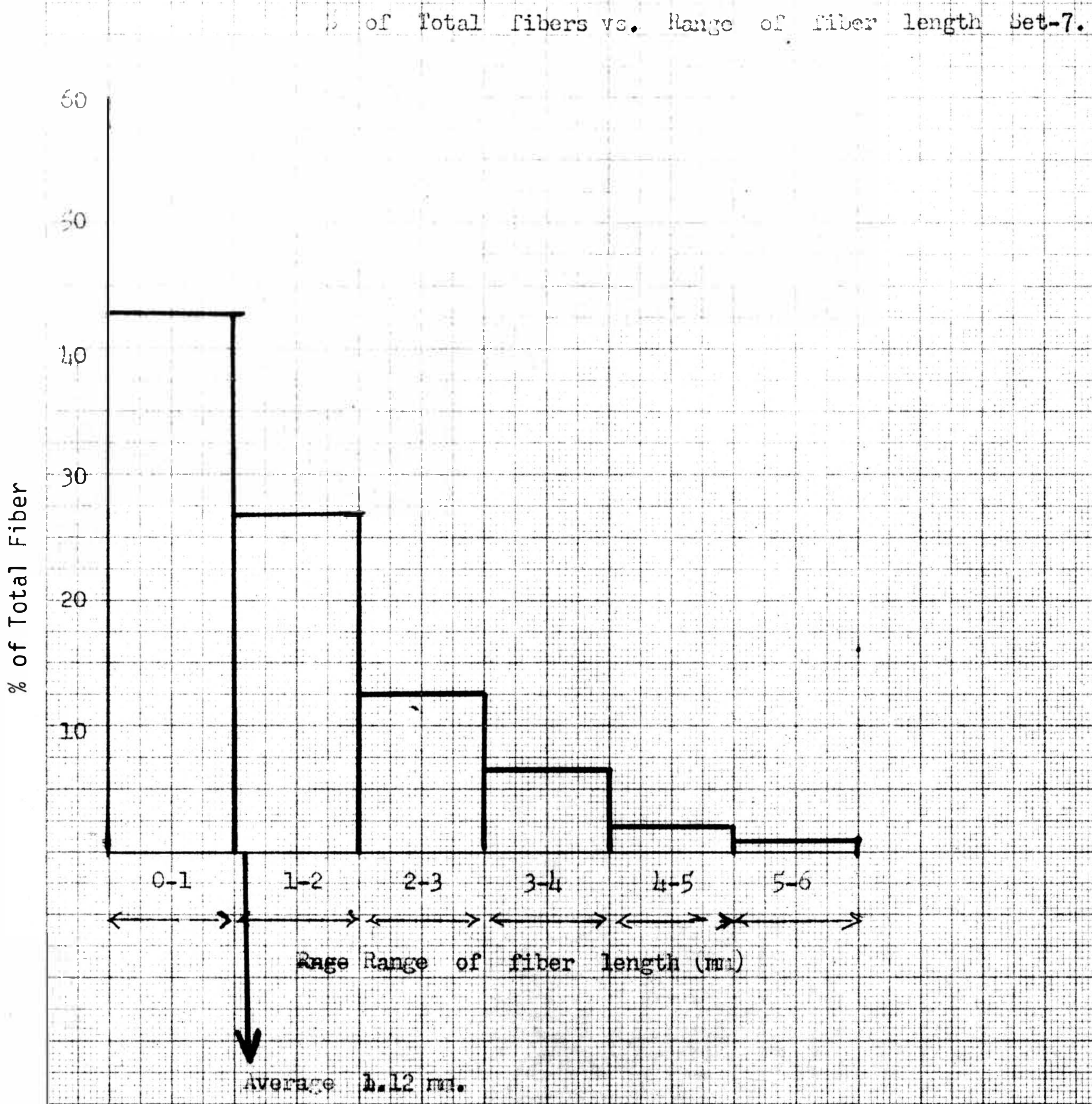


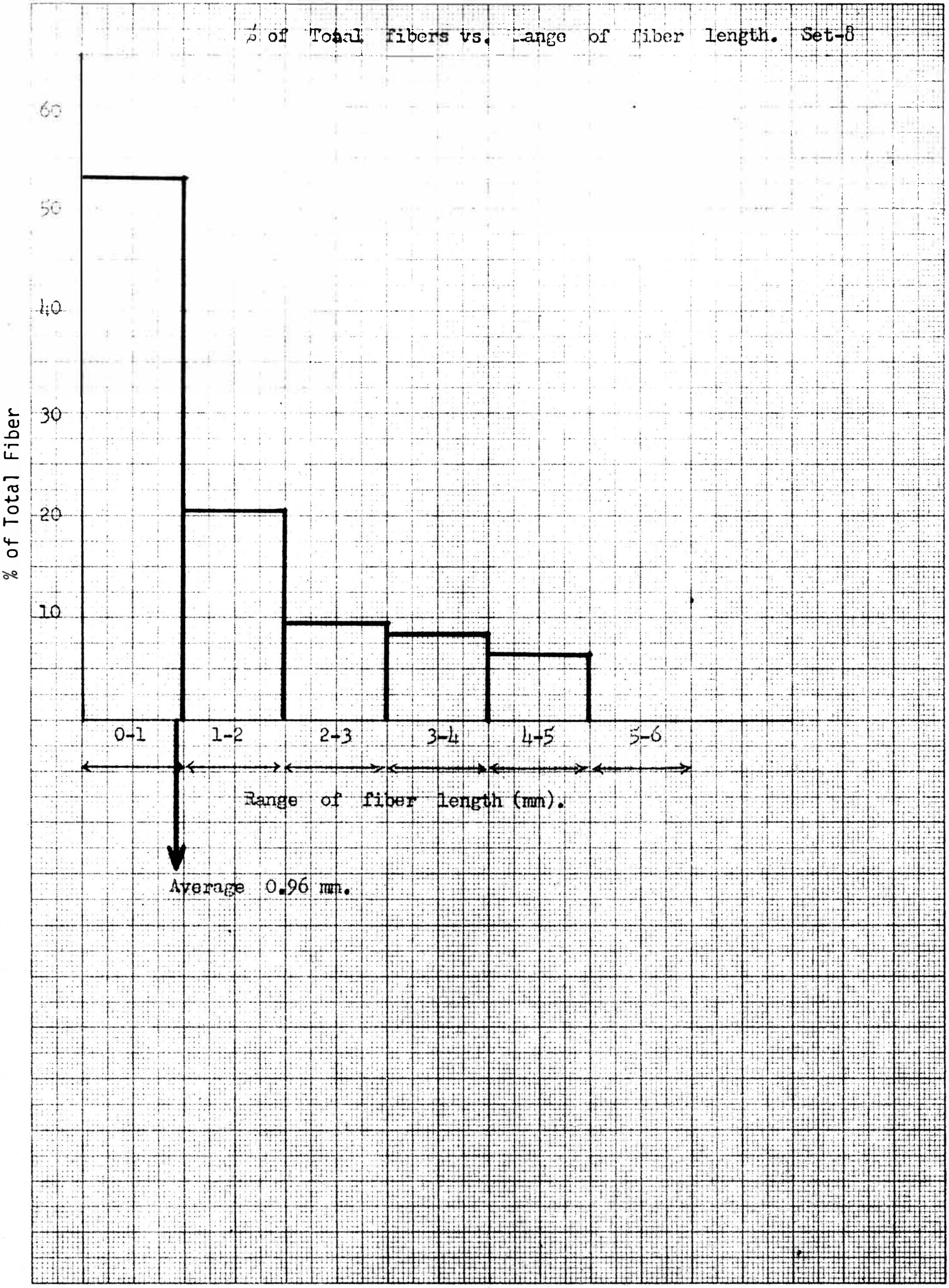
% of Total fibers vs Range of fiber length. Set - 5



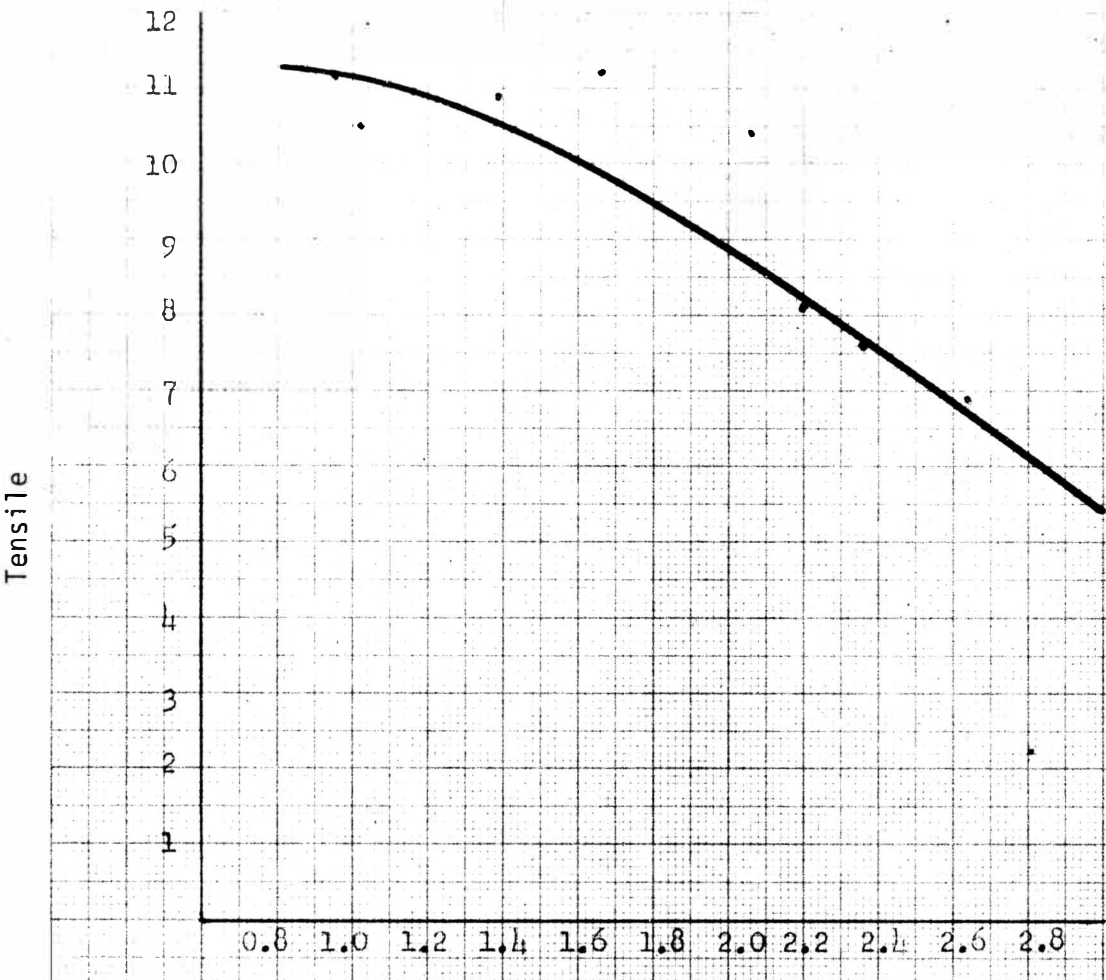
% of Total fibers vs. Range of fiber length. Set - 6.



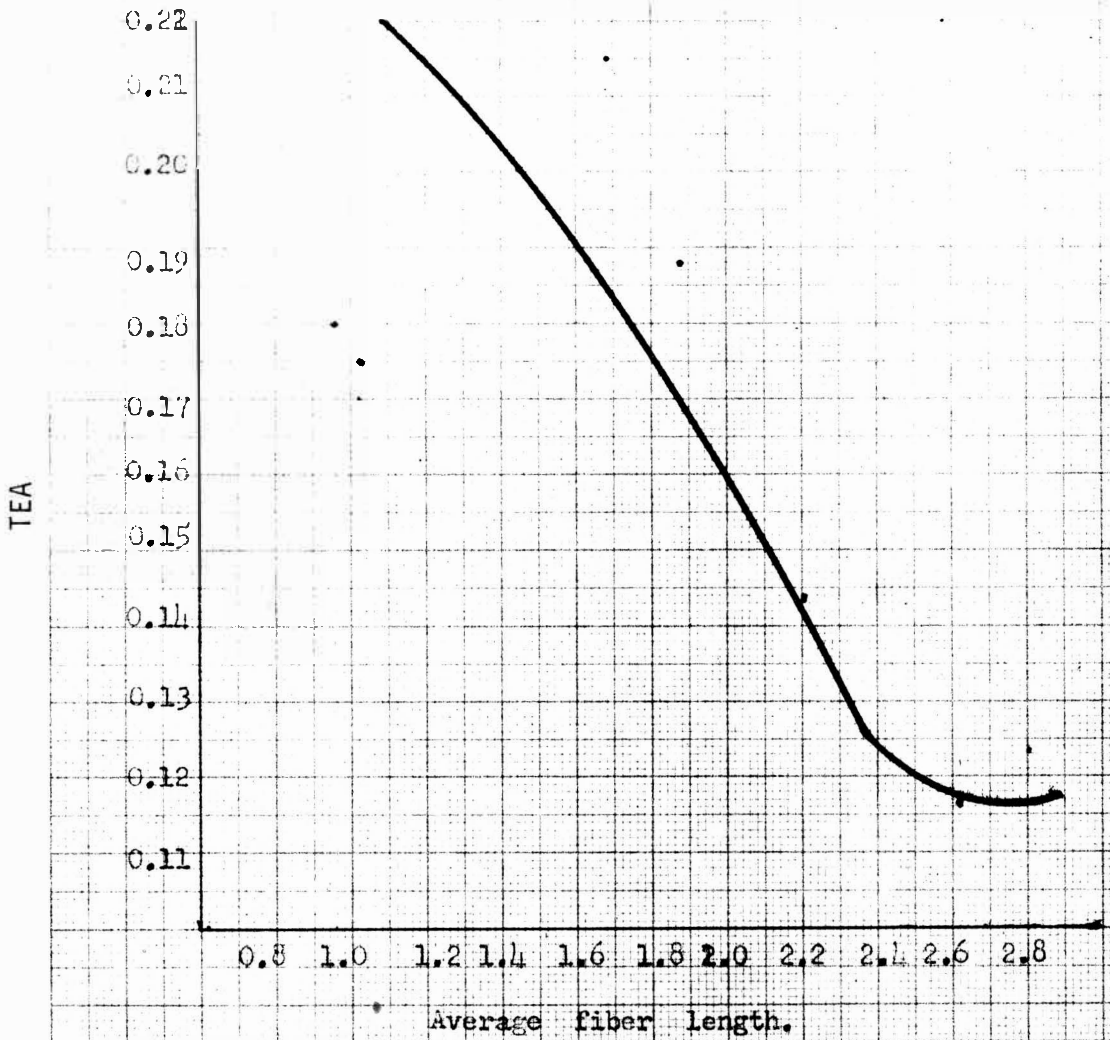

% of Total fibers vs. Range of fiber length Set-7.
% of Total Fiber
50
40
30
20
10
0-1
1-2
2-3
3-4
4-5
5-6
Range of fiber length (mm)
Average 1.12 mm.

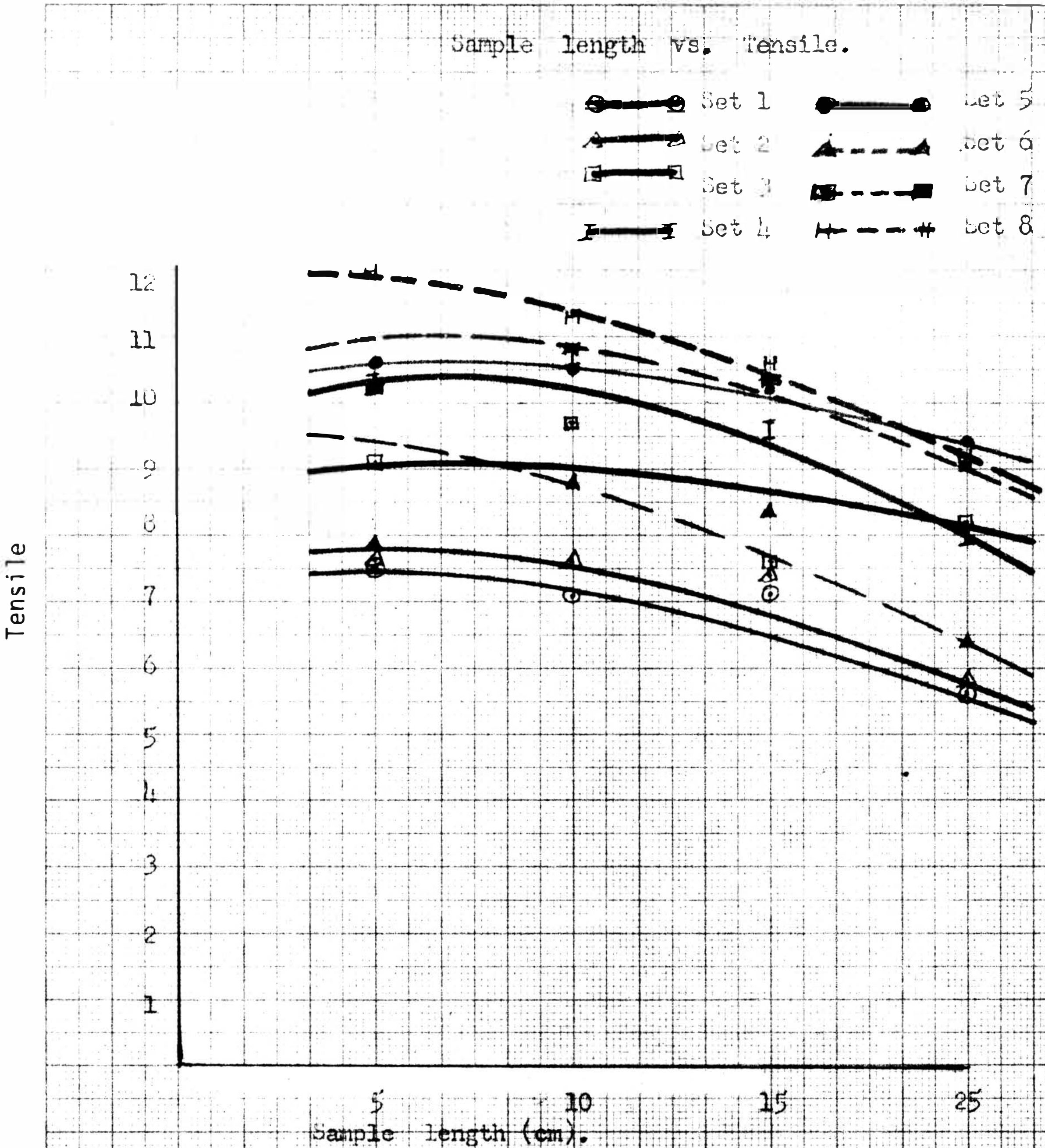

% of Total Fibers vs. Range of fiber length. Set-8
% of Total Fiber
60
50
40
30
20
10
0-1
1-2
2-3
3-4
4-5
5-6
Range of fiber length (mm).
Average 0.96 mm.

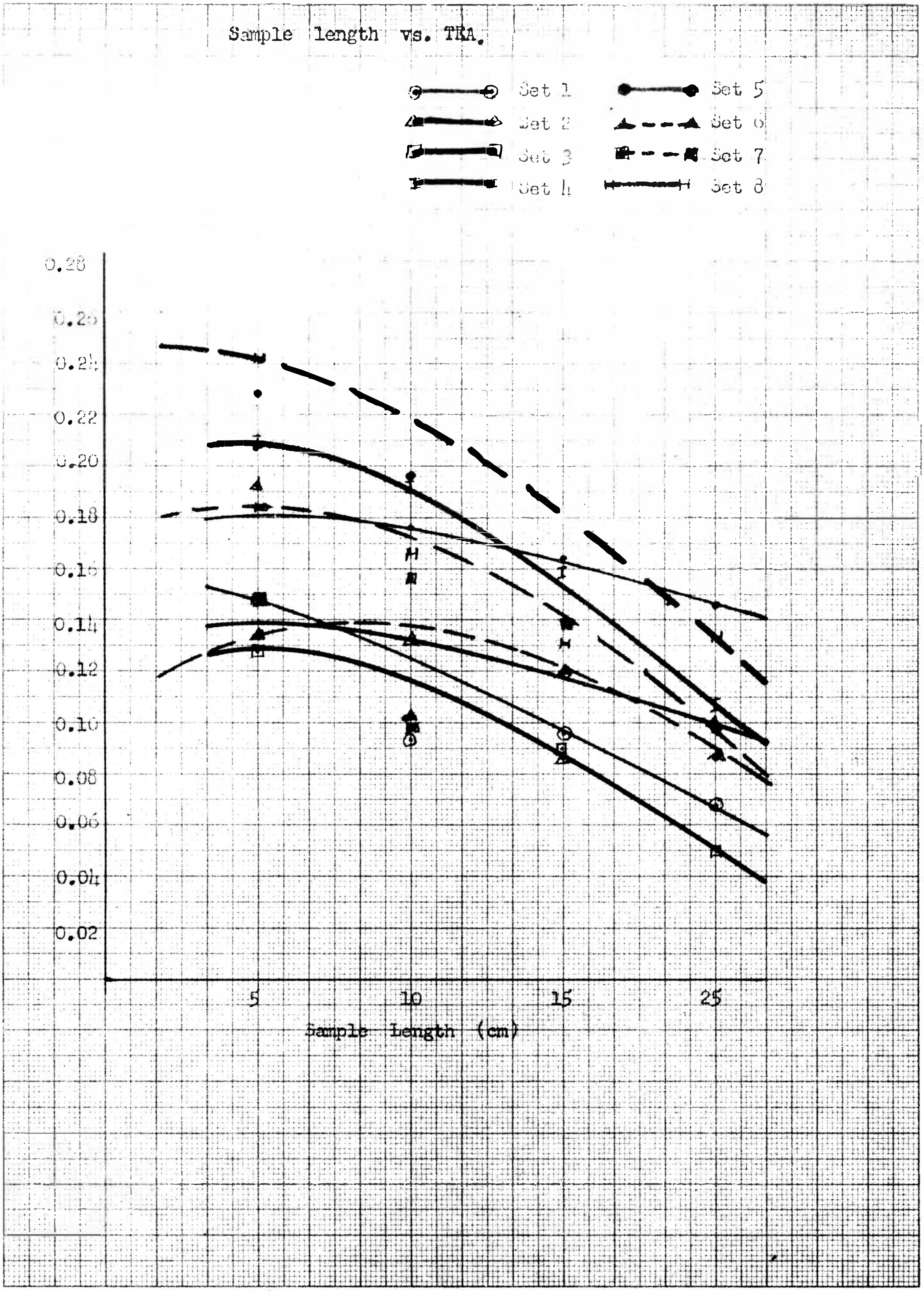
Average fiber length vs. Tensile.

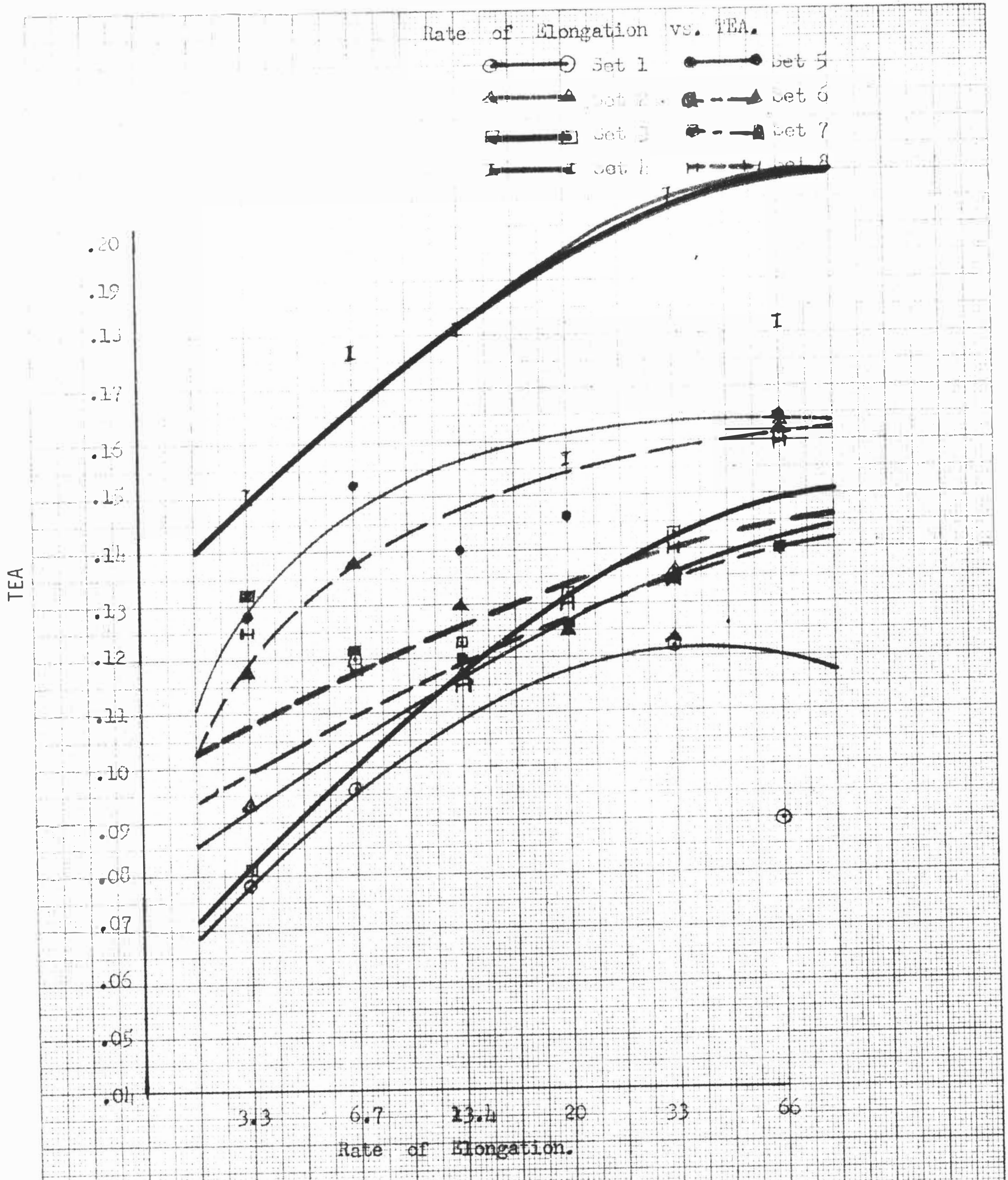


Average fiber length vs. TEA.

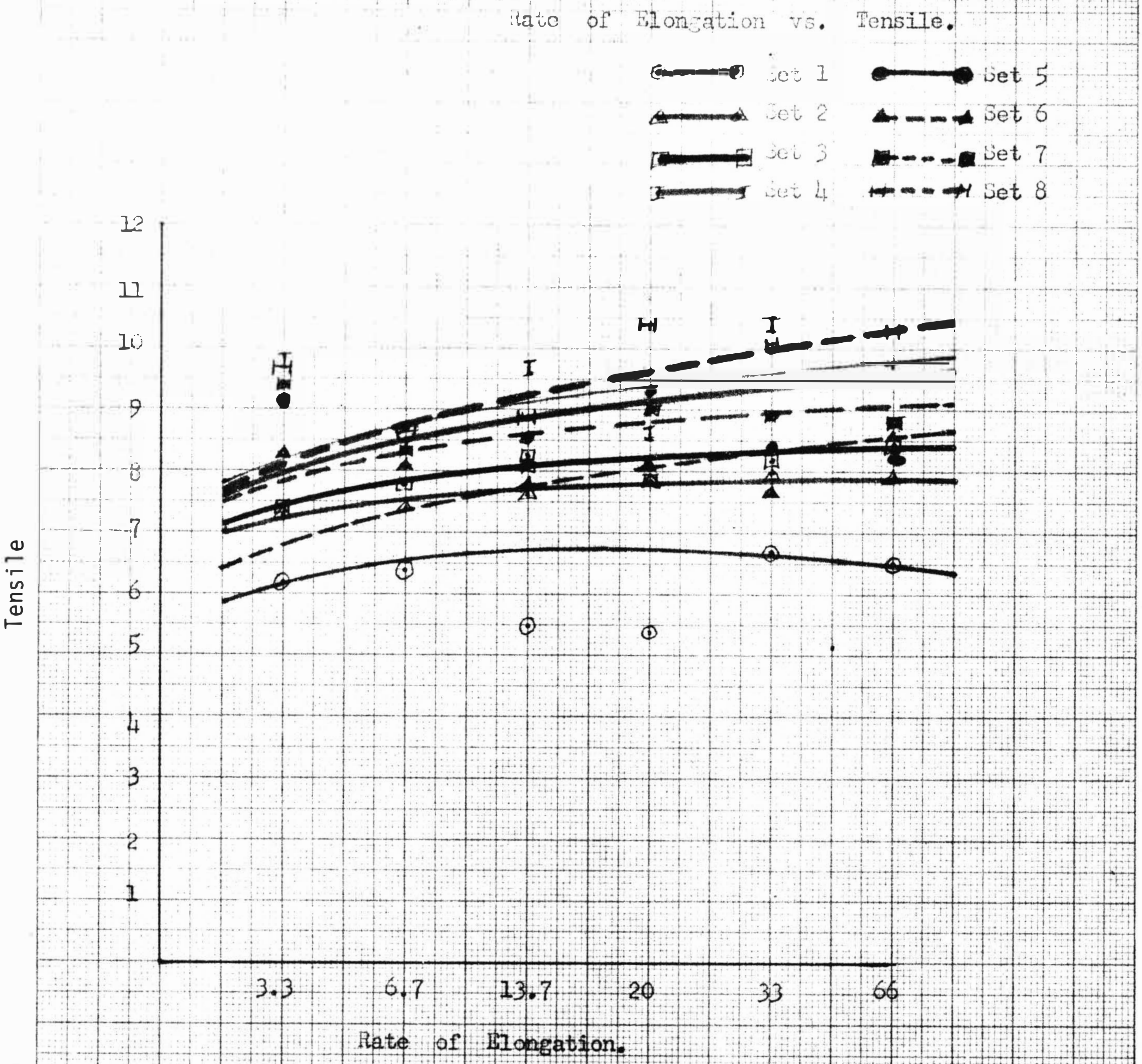



Sample length vs. Tensile.
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
Tensile
12
11
10
9
8
7
6
5
4
3
2
1
5
10
15
25
Sample length (cm).


Sample length vs. TEA.
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
TEA
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
5
10
15
25
Sample Length (cm)



Millimeters to the Centimeter


Rate of Elongation vs. Tensile.
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
Tensile
12
11
10
9
8
7
6
5
4
3
2
1
3.3
6.7
13.7
20
33
66
Rate of Elongation.

CONCLUSION

Previous investigations into the effect of sample length, rate of loading and fiber length on tensile and TEA have been carried out with the presence of a number of variables which could be expected to effect the results.

Fiber length had an effect on the results of tensile and TEA tests. The main source of strength for the sheets was felt to be from fiber entanglement. As tensile and TEA are more dependent on the bonding of the sheet, which in this investigation was present to only a small degree, little correlation was found between these factors and fiber length.

Sample length had an effect on the results of tensile and TEA in this investigation. In this, results depends upon the area of the sample and for this reason TAPPI Standard for measuring tensile has certain length and width. The ratio of length to width is important in this investigation.

Tensile and TEA were found to be effected by the rate of loading. As the rate of loading increased the stretch of the sample increased.

LITERATURE CITATIONS

1. Cross, C.F., and Bevan, E.J., "A Textbook on Papermaking", Chap. VII, 5th ed. London, E & FN Spon. Ltd., (1920).

2. Strachan, J., Proc. Tech. Sec., Paper Makers' Assoc. Gt. Brit. & Ireland 6, 139 (1926).

3. Campbell, W. B., Paper Trade J. 95, 29 (Oct. 25, 1932).

4. Clark, J. d'A., Paper Trade J. 115, 26: 36-42 (Dec. 24, 1942).

5. Campbell, W.B., Ind. Eng. Chem. 26, No. 2: 218 (Feb. 1934).

6. Van den Akker, J.A., TAPPI 35, 13 (1952).

7. Cottrall, L.G., TAPPI 33, 471 (1950).

8. Clark, d'A., Paper Ind. and Paper World 25, 382, 507A (1943).

9. Schafer, E.R., and Santaholma, M., Paper Trade J. 97, No. 19: 40 (Nov. 9, 1933).

10. Campbell, W.B., Paper Trade J. 100, No. 7: 35-38 (Feb. 14,1935).

11. Nadelman, A.H., TAPPI 38, 5: 151-153A (May, 1955).

12. Van den Akker, J.A., Lathrop, A.L., Voelker, M.H., and Dearth, L.R., TAPPI 41, No. 8: 416-425 (Aug. 1958).

13. Arlov, A.P., "Fundamentals of Papermaking Fibers", Transactions of the Cambridge Symposium, Tech. Sect. Paper Makers' Assoc. Gt. Brit. 273-281 (Sept. 1957).

14. Brencht, W., and Klemm, K., Pulp and Paper Mag. Canada 54, 72-80 (Jan. 1953).

15. Grund, E., and Steinschneider, M. Papier-Fabr. 36, No. 1: 1-12 (Jan. 1, 1938).

16. Doughty, R.H., Paper Trade I. 93, No. 15: 44-49, 54 (Oct. 8, 1931).

17. Doughty, R.H., Paper Trade J. 94, No. 9: 29-34, (March 3, 1932).

18. Clark, J. d'A., Pulp and Paper Mag. Can. 49, No. 10: 101 (Sept. 1948).

19. O'Leary, M. J., Scribner, B.W., Missimer, J.K., and Arving, J.T., TAPPI 35, No. 7: 289-293 (July 1953).

20. Harrison, H.A., Proc. Tech. Sec., Paper Makers' Assoc. Gt. Britain Ireland 11: 78-79 (Oct. 1930).

APPENDIXES

TABLE I

Set No.*	SAMPLE LENGTH 5 cm		SAMPLE LENGTH 10 cm		SAMPLE LENGTH 15 cm		SAMPLE LENGTH 25 cm	
	Tensile	TEA	Tensile	TEA	Tensile	TEA	Tensile	TEA
1	7.5	0.148	7.1	0.095	7.1	0.096	5.6	0.067
2	7.6	0.128	7.6	0.099	7.4	0.091	5.7	0.055
3	9.1	0.192	9.7	0.133	7.6	0.087	8.2	0.104
4	10.3	0.217	10.7	0.193	9.6	0.159	8.5	0.127
5	10.6	0.228	10.5	0.175	10.2	0.163	9.4	0.146
6	7.9	0.135	8.8	0.108	8.4	0.120	6.4	0.078
7	10.3	0.184	10.8	0.157	10.4	0.139	8.1	0.098
8	12.0	0.242	11.3	0.166	10.6	0.131	9.2	0.133

TABLE II

Set No.	Average Fiber Length	Tensile	TEA
1	2.62 mm	6.9	0.116
2	2.37 mm	7.6	0.126
3	2.19 mm	8.1	0.144
4	1.87 mm	10.4	0.188
5	1.67 mm	11.2	0.206
6	1.49 mm	10.9	0.200
7	1.12 mm	10.4	0.175
8	0.96 mm	11.1	0.180

TABLE III

Set No.*	Rate of Elong. 3.3 Tensile	Rate of Elong. 3.3 TEA	Rate of Elong. 6.7 Tensile	Rate of Elong. 6.7 TEA	Rate of Elong. 13.4 Tensile	Rate of Elong. 13.4 TEA	Rate of Elong. 20 Tensile	Rate of Elong. 20 TEA	Rate of Elong. 33 Tensile	Rate of Elong. 33 TEA	Rate of Elong. 66 Tensile	Rate of Elong. 66 TEA
1	6.2	0.078	6.4	0.096	5.5	0.053	5.4	0.062	6.7	0.122	6.3	0.090
2	7.3	0.093	7.4	0.120	7.2	0.117	6.8	0.095	7.9	0.136	7.9	0.164
3	7.4	0.081	7.8	0.120	8.2	0.122	7.9	0.132	8.6	0.143	8.9	0.161
4	9.8	0.150	8.4	0.177	9.7	0.181	8.6	0.158	10.7	0.210	9.6	0.181
5	9.1	0.128	8.8	0.152	8.5	0.140	9.2	0.146	8.4	0.130	8.2	0.165
6	8.3	0.118	8.1	0.138	7.7	0.130	7.9	0.125	7.7	0.124	8.4	0.163
7	9.4	0.138	8.4	0.122	8.1	0.120	9.0	0.126	8.9	0.134	7.8	0.140
8	9.7	0.125	8.7	0.118	8.9	0.115	10.4	0.130	10.1	0.140	10.3	0.160

* Set 1 No cutting
Set 2 1st cutting
Set 3 2nd cutting
Set 4 3rd cutting
Set 5 4th cutting
Set 6 5th cutting
Set 7 6th cutting
Set 8 7th cutting

TABLE IV

Set 1. - 2.64 mm Average

% of Total Fibers	Length (mm)
31.7	0.87
27.2	2.40
13.2	3.00
[illegible].7	4.14
21.0	5.16

Set 2. - 2.37 mm Average

% of Total Fibers	Length (mm)
36.1	0.92
23.2	2.00
17.2	3.12
9.3	4.31
12.25	5.42

Set 3. - 2.19 mm Average

% of Total Fibers	Length (mm)
31.0	1.21
36.2	2.19
[illegible].0	3.59
[illegible].2	4.10
[illegible]7.2	5.14

Set 4. - 1.87 mm Average

% of Total Fibers	Length (mm)
25.2	0.9
17.1	1.55
18.1	3.03
15.5	5.72
23.1	2.07

Set 5. - 1.67 mm Average

% of Total Fibers	Length (mm)
34.7	0.69
[illegible].0	1.97
19.5	2.18
10.25	3.67
8.1	4.84

Set 6. -

% of Total Fibers	Length (mm)
39.0	0.78
24.25	1.69
15.25	2.43
8.0	3.41
4.75	4.96

Set 7. - 1.12 mm Average

% of Total Fibers	Length (mm)
42.5	0.58
27.25	1.42
12.5	2.19
6.5	3.69
2	4.26
1	5.42

Set 8. - 0.96 mm Average

% of Total Fibers	Length (mm)
53.2	0.43
20.7	1.1
9.7	2.55
8.7	3.00
6.5	4.5