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Comparison of Three Stiffness Testers

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ABSTRACT

Stiffness is defined and some of the factors affecting stiffness are given. Also, the underlying principles upon which most stiffness testers are based are given.

Three of the commonly used stiffness instruments are used for this comparison study. They are: Gurley, Smith-Taber, and the Clark. The correlation between the instruments is determined and the stiffness range that each instrument is best suited for is noted.

Comparison of Several Stiffness Testers

Definitions

Stiffness as defined and accepted in present day usage is the ability of paper to support its own weight, the inverse of flabbiness. This definition was set forth in a paper by James d'A Clark(2)published in 1937 and is the definition used by T.A.P.P.I. This ability of paper to support its own weight is proportional to EI/W where E is Young's Modulus, I moment of inertia, and W the basis weight. E I gives the rigidity of paper, which is its property of resisting an applied bending force or its flexural resistance.

Definition of Young's modulus

In earlier times stiffness was used interchangeably with softness, feel, and pliabilty.(1) Softness and stiffness are dependent on the same thing for the Clark Softness Stiffness Tester can be used to determine both; different numerical values obtained by two different formulas from the same reading.(2) At the present time, according to James Strachan, there are three distinct movements apparent in the testing of bending properties or stiffness of paper. (10).

These are:

Micellar Creep.

It is of microscopic dimensions and closely connected with the concept of fringed micelles, and generally speaking in the simplest case under a uniform load, the amount of creep is a logarithmic function of the time of loading.

Elastic Bending

Defined as the property of paper which, when the latter is bent and then released, allows the strip to spring back into its original position.

"As elastic bending of paper increases with degree of beating, it appears probable that the degree of elasticity depends to a large extent on the adherence of the fibers to each other produced by the degree of colloidal dispersion produced during beating." ((10)

Or XX Where is the noun?

See Topper Yearbook Do not quote this way.

Flexural or Frictional Bending

Described as inelastic bending or flexibility due to weakness between fibre ends.

Or XX Sentence —

In the bending or stiffness testing of paper, the three movements go together.

History:

Compared to the other strength tests of paper, the measure of stiffness of all types of paper is relatively recent. The measure of stiffness in board and heavy papers has been known for many years but it was not until the thirties that simple, relatively accurate and reproducible methods for stiffness measurement were introduced. H. Schulz and W. Ewald(5) in 1925 stated that although stiffness was measured for board, there was no defined or numerical measure of stiffness for writing and printing papers. In this same paper(5) they gave a method of determining stiffness for writing and printing paper. This was done by clamping the paper in a curved ~~lip~~ jaw and applying a force at varying distance ~~on the~~ on the free end until the paper bowed down. The stiffness would then be a function of the length of free end before bending and the weight used. The lip of the clamp was curved so that the freeend was in a concave shape because it was stated that paper was usually held in such a manner.

In a paper(9) printed in 1926 another method was given whereby a strip of known length was clamped at one end and the amount of bending of the free end determined, this being a meause of stiffness.

The above two methods are both illustrative of the cantilever type of stiffness testers as described in a paper by James d'A Clark.(2) In this same paper Clark describes some other principles upon which different stiffness testers are based. These are, in addition to the cantilever type:

A. Beam type-strip supported ateach end and a force applied to the middle of the strip.

B. Column type-using a strip of board or heavy paper as a column and determining maximum load it will withstand. It is well known in engineering principles that this is not a relatively satisfactory test.

C. Modified cantilever types: Determing the resistance of a strip of paper, held at one end, to a given point load.

D. Pendulum type-using a strip of paper in a torsion pendulum system. Many different types of stiffness testers have been invented, ~~but~~ they are based on one of the above principles.

Factors Affecting Stiffness:

"Beating is the most important factor in producing rigidity."(4) A strong well-beaten sheet has greater stiffness than a free soft sheet and according to C.A. and J.E. Minor, (3) stiffness is much more sensitive to beater hydration in the case of tag and index stock than is tearing resistance. Fibre length is important for a sheet of maximum stiffness, but referring again to C.A. and J.E. Minor(3) stiffness is more dependent on manufacturing manipulation than it is on quality of fibre. The use of Groundwood in a sheet helps to increase the stiffness.

No matter what quality of fiber is used, the addition of filler decreases the stiffness.(1,4) Also it was found that super calendering affects stiffness, markedly decreasing it.(4) It is readily apparent that basis weight, thickness, and moisture content are in a direct ratio to stiffness. That is why it is necessary to conduct stiffness at constant humidity.

Value of Stiffness Test.

As has been stated before, the stiffness of board and other heavy papers has been important for many years, but today there are very few papers manufactured where some measure of stiffness is not important. Stiffness is of great importance in the case of index cards, letter file paper, and typewriting paper.(10) Also in this day of so many automatic-fed machines, such as printing presses, folding machines, and other conversion machines, stiffness is important whether the feed is by inertia, friction, or pneumatic suction.(10)

Stiffness tests can be of value in manufacturing control for the effect of beater hydration in some types of papers, effect of filler added, and effect of groundwood added.

This increased demand for some measure of stiffness for all different types of papers is the reason for the invention of so many different types of stiffness testers all striving for an instrument which gives accurate, reproducible results for all types of papers. It is for this reason that previous comparison studies of stiffness testers have been undertaken and is the basis for the present study.

Instruments to be used for Comparison.

There are three instruments available on which comparison tests will be conducted. The Gurley, Smith-Taber, and the Clark Softness-Stiffness tester. The staff of The Institute of Paper Chemistry have made two comparison studies of these three instruments, the first a comparison of the Gurley ~~and the Gurley~~ and the Smith-Taber Stiffness Testers,(6) and the second a comparison of The Gurley and the Clark Stiffness tester.(8) These studies were highly accurate and technical in nature and show the degree of accuracy that can be obtained under the optimum conditions of testing. The present study will not attempt to duplicate the work done by the Institute, but will ~~be done in a manner similar to~~

have a more practical approach.

~~what would be done by the average paper tester with out a technical background.~~

Gurley Stiffness Tester.

The Gurley is of the modified cantilever type in that a strip of paper of accurately determined length and width is clamped at one end. ~~and a~~ A vane actuated by a motor applies a force on the free end of the strip. ~~and a~~ A reading is taken ~~just~~ when the end of the vane clears the end of the strip. The vane, is rotated both to the right and left and the stiffness taken as the sum of the two readings. The vane has three holes spaced at varying distances from its center of gravity into which three different weights can be placed. ~~and by~~ By use of factors furnished with the instrument a wide range of stiffness can be measured.

In the studies made by the Institute, (6) it was found that the Gurley had a somewhat higher degree of accuracy and was easier to operate than the Smith-Taber. In the same study it was found that the best reproducibility and accuracy was obtained when the end-point was approached slowly and the strip was handled as little as possible. In the comparison of the Gurley and the Clark Stiffness testers, (8) the Institute found that the Gurley was seriously in error for all papers of light and medium weight. Also the nature of the edge and the smoothness of the sample were found to affect the reading of the Gurley.(7) Any friction between the vane and the paper would tend to increase the apparent stiffness.

For accurate results it is necessary to take the average of five readings and no more than five samples of paper of low stiffness should be measured together.(6) Also it was found that stiffness readings varied directly as the width of the sample and inversely with the square of the length, using samples 2.5 inches or longer.

Smith-Taber Stiffness Tester.

The Smith-Taber is of the modified cantilever type and measures the same physical quantity measured by the Gurley. With the Smith-Taber the strip is again clamped at one end and a measured point load is applied to the free end. The force is actuated by a motor and is applied until the end point (two graduated marks on two separately acuated wheels; the inside one rotated by the force (motor) and the outside one moved by the inner wheel through the strip of paper. For example a strip of high stiffness will actuate the outer wheel a great deal and it will be more difficult to bring the two graduated marks together resulting in a high reading.) The wheel is rotated both to the right and left and the sum of the readings taken. For very light papers a clip is attached to the free end of the strip and the wheel rotated both to the right and left until the clip touches a needle pointer. There are three different ways to vary the sensitivity on the Smith-Taber. The Institute found that the outside limit of accuracy ofthe Smith-Taber was about 5%.(6) It was also found that it was easier to align the strip using the Smith-Taber instrument.

Clark-Softness Stiffness Tester

The Clark Softness Stiffness Tester is of the torsion pendulum type and "consists of two rollers held together by spring pressure, one of which may be turned slowly by means of a worm drive. The line of contact of the rollers coincides with the axis of rotation of the supporting framework, and a pointer attached to the frame indicates the relative angular position of the framework with respect to a rotatable circular scale. A strip of paper having parallel edges is inserted between the rolls. Its overhanging length is adjusted by turning the rolls until, when the framework is turned back and forth through 90 degrees, which is done with a slow geared adjustment, the strip just falls over when each of the two extreme positions is reached. (Hereafter this length will be referred to as "critical length.") Using a millimeter rule, the overhanging length is determined by measuring from an abutment on the framework which is placed at a fixed distance (20mm.) from the line of contact of the rolls."(8)

The Clark Softness Stiffness Tester measures four characteristics which are according to Clark: (2)

Rigidity $= L^3W/10{,}000$

Rigidity factor $= L^3W/100T^3$

Stiffness $= L^3/100$

Softness $= 10^6 \log_{10} (t+1)/L^3W$

where

L = average critical length in cm.

W = Basis weight in grams per square meter

T = thickness of single sheet in thousandths of an inch

t = Basic thickness of single sheet in thousandths of an inch

In the study conducted by the Institute (8) it was found that the overhanging length had to be long enough to require an angle of rotation of greater than 90 degrees. The overhanging length is then shortened until the angle of rotation is 90 degrees. It was found that there was a straight line relationship between the overhanging length and the angle of rotation.

The reproducibility of the Clark Tester was found to be about the same as the Gurley, that is about 3% as an outside limit.(8) The Clark rigidity was correlated with flexural rigidity by the use of a torsion pendulum and it was found that they differed only by some constant of proportionality and therefore it was valid to use the Clark Stiffness Tester for testing stiffness.

OUTLINE OF EXPERIMENTAL WORK

Samples

In order to get samples of which the complete history was known, it was decided the author work with Yale Brandt in the preparation of multi-ply handsheets. For the manner in which the handsheets were made, reference should be made to Brandt's report.

These samples were conditioned in the constant humidity room which was maintained at 50% relative humidity and 77 degrees Fahrenheit. The samples were conditioned for at least 24 hours before any tests were made. All of the tests were made in the constant humidity room under the above constant conditions.

Manner of Conducting Tests

In forming the handsheets, difficulty was experienced in keeping the weights constant in the various sets. Therefore, to reduce the variation that would have been caused by the variation in weight, samples were taken from each sheet for stiffness measurement on all three instruments. The handsheets showed no directional effect, but even so samples for all three instruments were cut in the same direction. Six samples were tested on each set with all three instruments, and the average taken as the stiffness.

The samples for the Clark stiffness were all 7 inches long and 2 inches wide, the length being limited by the size of the handsheet. This limit in length made it necessary to add a weight to the strip and correct for the critical length by the use of the equation given by Clark.

This equation is:

$$L = l \left[\frac{1}{1 - 0.37 \log \left(\frac{10\ Wa}{w\ l} - 1 \right)} \right] = l \left[A \right]$$

Where

W = total added weight

w = weight of strip in grams

a = length of entire strip in cm.

l = overhanging length of strip in cm.

The calculation in the above equation is simplified by the use of a table, where the quantity in the brackets, $\left[A \right]$ is given for various values of the ratio $\frac{Wa}{wl}$. From the critical length thus obtained, the rigidity was then determined for each set. The rigidity is calculated by:

$$\text{Rigidity} = \frac{L^3 W}{10{,}000}$$

Where W equals the basis weight in grams per meter which compensates for the variations in basis weight.

All samples for the Gurley instrument were 2 inches wide and 1.5 inches long. The readings were then converted to the standard 1 by 3 inch sample by the use of the table furnished with the instrument.

For the Smith-Taber instrument, all samples were cut using the Triple cut Shear that can be obtained with the instrument. This gave a test sample 1.5 X 2.75 inches.

Results

The results are tabulated in Table I.

TABLE I

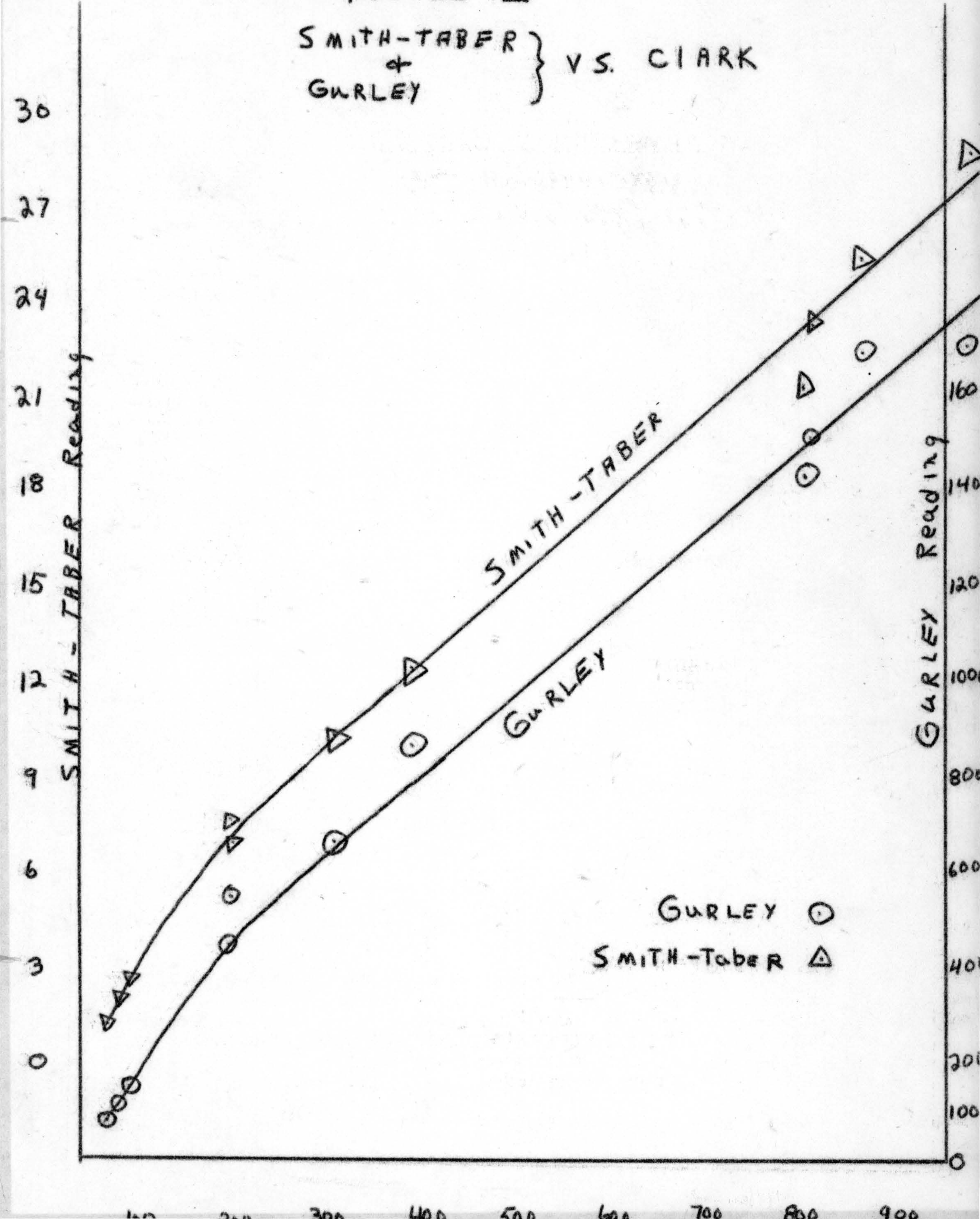
Sample	Basis Weight gms./M	Clark Rigidity $\frac{L^3W}{10,000}$	Gurley Standard Sample	Smith-Taber Standard Sample
1 - 1 BW	60.5	87	106	2.0
2 - 1 BW	60.5	87	102	2.0
3 - 1 BW	69.3	98	149	2.6
4 - 1 BW	55.0	72	80	1.1
1 - 2 BW	123	204	544	6.8
2 - 2 BW	126	310	666	10.2
3 - 2 BW	106	205	444	7.5
4 - 2 BW	134	392	865	12.3
1 - 3 BW	185	863	1685	25
2 - 3 BW	174	811	1510	23
3 - 3 BW	182	980	1688	29
4 - 4 BW	170	805	1420	21

Figure I shows the relationship between the three instruments obtained by plotting the Gurley and the Smith-Taber readings against the corresponding Clark rigidity readings.

Conclusions

By referring to the table and the graph, it is evident that the three instruments correlate fairly well especially in the higher ranges. In the lower range the Gurley and Smith-Taber still correlate, but both vary from that of the Clark. This bears out the findings of the Institute; that there is a linear relationship between the Gurley and the Smith-Taber and also with the Clark in the higher ranges.

FIGURE I


SMITH-TABER & GURLEY } VS. CLARK
SMITH-TABER Reading
GURLEY Reading
30
27
24
21
18
15
12
9
6
3
0
160
140
120
100
80
60
40
20
10
0
SMITH-TABER
GURLEY
GURLEY
SMITH-Taber
400
700
800
900

Referring again to the table, it is apparent that in the higher ranges, the readings of the different instruments vary by some integer. That is, the Gurley reading is about twice that of the Clark and the Clark reading is approximately 30 times as large as the Smith-Taber.

All three instruments are designed to operate over wide stiffness ranges, but in actual operation each is better suited for certain stiffness ranges. The Clark works best in the low stiffness ranges and is the most accurate in this range. The Gurley is best suited for the intermediate ranges, and the Smith-Taber for the higher ranges. Therefore, the question as to which instrument would be best used depends upon the type and variety of products being tested.

Summary

Stiffness is defined and some of the factors affecting stiffness are given. The fundamental principles upon which most stiffness instruments are based are also given.

Three instruments which are available and most commonly used form the basis for this study. They are the Gurley, Smith-Taber, and the Clark. Papers of varying stiffness ranges were tested on all three instruments to determine the correlation between the instruments.

It was found that there was a fair degree of correlation between all three instruments in the higher stiffness ranges, but not in the lower range. Also, although each instrument is designed to operate over a wide stiffness range, each instrument works best for a certain stiffness range.

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