U. S. Department of Agriculture, Forest Service
FOREST PRODUCTS LABORATORY
In cooperation with the University of Wisconsin
MADISON, WISCONSIN

BALL MILL METHOD FOR DETERMINING MAXIMUM STRENGTH OF PULPS

March 7, 1927
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The Ball Mill

The ball mill used at the Forest Products Laboratory is a double domestic jar mill listed as four gallon capacity, as made by the Abbe Engineering Company, New York City. It consists of two porcelain jars each approximately 15 inches in length by 12 inches in diameter and one inch thick, each jar being covered by a wrought-iron jacket. A thick porcelain cover fitted with a rubber gasket and held in place by a screw clamp fits tightly over the open end of each jar making an absolutely water-tight compartment. The volume of each mill is approximately 16,000 c.c.

The Pebbles

The pebbles used are of a good quartz and granite formation, and as nearly round as is possible to find them. They vary in size from a large filbert to a walnut. Approximately 5,000 grams of pebbles displacing 1780 c.c. of water at 22° C. are used in each mill. Pebbles as nearly as possible of the same size, weight, and number are used in each mill, being checked up after each 15,000 revolutions
of the mill, and new pebbles introduced to replace the weight and volume lost due to wearing away. From two to three grams are lost between each inspection.

**Preparation of the Pulp**

Five or 600 grams of air dry pulp are needed for each run. The pulp is first run through a coarse screen (No. 18 or 20). If the pulp is dry it will screen much faster if soaked in warm water for a short time before screening. The screened pulp is caught in small "Box screens" and then put in a coarse cloth bag and as much water as possible is pressed out in a wine press. Next the pulp is shredded, thoroughly mixed and a representative moisture sample taken. The rest of the pulp is packed in one or two battery jars and covered tightly to prevent change in moisture content. The moisture sample should be left in the oven over night to insure complete drying.

After the percentage of moisture in the pulp has been determined, an amount equivalent to 100 grams of air dry pulp is weighed out for each batch and each placed in a battery jar of 3-liter capacity. Then 2000 c.c. of filtered tap water 22° C. to 25° C. is added to each jar, allowance being made for the moisture in the pulp, and the mixture kneaded with the fingers to insure thorough breaking of all lumps. Usually five such batches are enough although six or seven are sometimes necessary depending on the pulp.
Preparation of the Ball Mill

If the room temperature is greater than 250 C. or less than 200 C., it is advisable to run the mill a short time with the stones and about 3 liters of water, at the desired temperature, in order to run the first batch at the required temperature. With a variation of 2° or 3° in temperature, the difference in the results of the tests is negligible.

The speed of the mill must be checked, and adjusted to 66 r.p.m. This is easily done with the aid of the counter fastened to one end of the shaft.

The Run

Usually two different cooks are run at the same time, although one may be run with the same degree of accuracy. Time is saved by running one cook in each jar.

One of the battery jars containing the mixture of pulp and water previously prepared is dumped into one of the jars of the mill together with the proper amount of pebbles. The other jar is loaded in the same manner. The covers are clamped on and the mill set in motion. Successive batches are run for increasing periods of time up to 80 and sometimes to 160 minutes depending upon the quality of pulp. Sufficient batches are run at 10 or 20 minute intervals to show that the maximum bursting strength has been reached.
Ordinarily batches are run at 20, 40, 60, 80 and 100 minutes requiring 1320, 2640, 3960, 5280 and 6600 revolutions respectively. The batches are best timed by the number of revolutions, this method being the most accurate.

**Making the Hand Sheets**

When the batch has run the required number of revolutions, the charge, consisting of pulp, pebbles, and water is dumped from the pebble mill into a ten-quart pail and the mill then rinsed carefully with a hose, so that none of the fibers are lost. The charge is dumped into a strainer box which has been placed in the stone vat from which the hand sheets are made. The strainer box is made of very heavy 1/2 inch mesh wire.

The pulp is thoroughly washed from the pebbles and strainer box into the stone vat which is filled with water up to a mark which indicates that 20 liters have been added. From this dilution, six hand sheets are dipped, one dip for each sheet, the stock being stirred thoroughly by hand before each dip. After a little practice there is no trouble in dipping a sheet which is uniform throughout. The sheets are pressed on to the small felts and later squeezed about 10 minutes in a letter press.

**Procedure Using the Sheet Machine**

From the dilution in the stone vat, six sheets are made by dipping 500 c.c. for each sheet in a copper measure.
The sample is then emptied into one of two gallon measures. The measure is filled with water and the mixture poured back and forth from one measure to the other five or six times. The mixture is then poured into the deckle box of the sheet machine quickly, and distributed evenly by moving the measure back, forth and criss-cross. The drain valve is immediately opened instantly and wide. The suction is allowed to continue for five seconds after the water is out of the deckle box. The deckle box is then turned back on its hinge and the plate bearing the wire and sheet removed. The plate is turned over on a pile of moist felts and pressed down. The plate and wire are lifted from one edge leaving the sheet on the felt.

**Drying the Sheets**

The test sheets are partially dried on a steam drying cylinder and hung up in a constant humidity room for at least 12 hours where a 65 per cent relative humidity is maintained. The wet sheets are dried to only 75 per cent dry on the drying cylinders, for over-drying or heating may cause weakening of the fibers and impair the accuracy of the strength tests.

**Preparation for Testing**

As soon as the sheets are thoroughly air-dried the sheets are pressed in the letter press for 5 or 10 minutes to flatten them out smooth. They are then trimmed on a R-32
paper cutter to 5" x 7" and hung up in the humidity room with a relative humidity of 65 per cent for two hours before testing. In that time they are brought to equilibrium and are ready to be tested under standard conditions.

From these six sheets the four best are selected and used for bursting and tearing strengths. One of the remaining sheets is used for folding and tensile tests and the other sheet is filed with the test data.

**Bursting Strength Test**

The Ashcroft tester is used for bursting strength. The four sheets are weighed on a balance to a tenth of a gram, cut diagonally and eight tests made along one of the diagonal edges of each sheet making a total of 32 tests for each batch. This enables us to get a fair average of the test. The average test divided by the average weight of one of the four sheets gives the average bursting test per unit of weight of sheet. This result multiplied by the constant 4 gives the so-called unit weight test. The pounds per ream can be computed as follows:

\[
\frac{\text{sq.in./rm.of 500 sheets} \times \text{No.of gr.in 4 sheets}}{\text{c.in. in 4 hard sheets(5x7)} \times \text{No.of gr.in 1 lb.}} = \text{lbs./rm/of 500 sheets}
\]

By dividing the average test by the lbs./rm., we get the pts./lb./ream, which is a standard measure of the bursting strength of paper.

9.99 x wt. in gm. of 4 sheets 4x6 = ream wt. 24 x 36 x 500.
Tearing Strength

The other triangular half of each sheet is used for the tearing test, the Elmendorf Tearing tester being used which registers the grams of force required to make the tear. Three tests are made on each or a total of six crosswise and six lengthwise of the sheet. This data is computed into grams of force per pound per ream by the following steps:

\[ \text{Sum of the 12 tests} \times \text{Elmendorf's tearing test factor}^* = \text{Grams of force} \]

Calculation of Elmendorf tearing test when five tests across and five in the machine direction are made on two sheets in the tearing tester.

\[ \frac{\text{Sum of 10 tests} \times 8}{10} \times \frac{4 \times 5 \times 7 \times 453.7}{24 \times 36 \times 500 \times \text{wt. of 4 sheets}} = \text{Grams of force/lb./ream} \]

or

\[ \frac{\text{Sum of 10 tests}}{\text{Wt. of 4 sheets}} \times \frac{8 \times 4 \times 5 \times 7 \times 453.7}{10 \times 24 \times 36 \times 500} = \text{Grams/lb./ream} \]

or

\[ \frac{\text{Sum of 10 tests}}{\text{Wt. of 4 sheets}} \times 0.118 \text{ (constant)} = \text{Grams/lb./ream} \]

\[ \frac{\text{Area of a ream (sq.in.)} \times \text{wt. of 4 sheets (grams)}}{\text{Area of 4 sheets (5x7x4)} \times \text{grams per pound (453.6)}} = \text{lbs./ream} \]

*To reduce scale readings to force in grams, when tearing 1 sheet multiply by 16, 2 sheets by 8, 4 sheets by 4, and 8 sheets by 2.
Combining the two, we have --

\[ \frac{\text{Sum of 12 tests} \times \text{Elmendorf's factor}}{\text{Number of tests}} \times \frac{\text{Area of 4 sheets} \times (5 \times 7)}{\text{Area of ream} \times \text{wt. of 4 sheets}} \]

= grams of force per pound per ream.

In this formula we have two variables - the sum of the 12 tests and the weight of the 4 sheets. The rest can be worked up into a constant.

\[ \frac{\text{Sum of 12 tests}}{\text{Wt. of 4 sheets}} \times \frac{16 \times 4 \times 5 \times 7 \times 453.7}{12 \times 24 \times 36 \times 500} = \text{grams of force/lb. per ream} \]

or

\[ \frac{\text{Sum of 12 tests}}{\text{Wt. of 4 sheets}} \times 0.196 \] (constant = grams of force/lb./ream

Constant for 4 x 6 sheets - 0.1344

Or to sum this all up into one general formula, we have --

\[ \frac{\text{Average test} \times \text{area of 1 sheet} \times \text{tearing test factor (Elmendorf)}}{\text{Average wt. per sheet} \times \text{area of 1 ream} (24 \times 36 - 500)} \]

Grams of force per pound per ream.

**Folding and Tensile Tests**

The folding and tensile tests are made on the Schopper testing machines. Eight strips are cut, four across and four lengthwise, from one of the remaining sheets, two of each being used for the folding tests and two of each for the tensile tests.

The strips are cut 15 mm. in width and 100 mm. in length for the folding tester. This machine registers the
number of double folds required to break the strip under a maximum tension of 1000 grams.

For the tensile test strips 50 mm. in length are used, and the scale registers the number of kilograms required to break the strip. This machine also registers the percent stretch at the point of failure.

From the kilograms required to break the strip, and the weight of the strip, the breaking length in meters can be computed in the following manner:

\[
\frac{\text{Av. tensile str. (kg.) \times No. of strips \times length of strips in mm.}}{\text{Wt. of strips}}
\]

breaking length in meters.

The data from these tests are plotted, and from the curves, the time required to reach the maximum and the manner in which the maximum is approached can be read at a glance. The data and curves together with the sample sheets are fastened together and filed.