COMPARATIVE SERVICEABILITY AND PROCESSING EFFECTS OF OVAL CAST IRON AND CIRCULAR STEEL RODS IN THE ROD MILL

By

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Summary

Rod mill charges of oval cast iron and of circular steel rods, approximately equal in number, weight, and longitudinal area, have been compared with respect to their serviceability and milling effects on kraft pulp at 4 and at 8 per cent consistences, at a constant speed of rotation of the mill. With one exception the usual physical tests made upon the pulps develop more rapidly and attain higher maximum values by the use of circular rods at each consistence than when milled with the oval rods. This one exception is the development of tearing strength at 4 per cent consistence, which is greater with the oval than with the circular rods. The power consumption required to reach a definite bursting strength factor (0.6 points per pound per ream) is approximately one-fourth less at the 8 per cent consistence and one-twentieth less at 4 per cent consistence with the circular than with the oval rods.

The oval rods appear to exert a pounding action rather than the rubbing or rolling action exerted by the circular rods. In spite of this the oval rods used appear to be as resistant against chipping and fracture as the circular rods. Since this pounding effect will vary with the speed of the mill, the desirability of a further investigation

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of the influence of speed as well as of consistence on the milling properties of the two types of rods is indicated.

Introduction

The purpose of the experiments reported here was to compare the serviceability and processing effects in the rod mill of the usually employed circular rods and of oval cast iron rods.

Before making up a full charge of experimental oval rods, six were cast by the cooperator and sent to the Laboratory for a preliminary test for their serviceability. It was found that these cast iron rods were as durable as the bronze rods now in use at the Laboratory. Accordingly a full set of rods was supplied and the experimental work reported herewith was begun. In all, three rod mill runs were made with the oval cast iron rods; the first for the determination of serviceability and to remove the initial rough surface which would not produce the true effect of a rod which had been in service, and the other two for processing effects, using consistences of 4 and 8 per cent. Comparative processing runs with the circular steel rods were also made at the same consistences.

Apparatus, Materials and Procedure

Apparatus

The rod mill used in this study was the semicommercial mill shown in Figure 1. It is 3 feet in diameter, 5 feet long (inside measure), rubber lined, and can be rotated at speeds varying from 17 to 34 r.p.m. The equivalent of 25 pounds oven-dry pulp, using at 4 to 8 per cent consistence, has been found to be the optimum charge for processing in this mill. The mill can be run continuously or batchwise. When operated continuously pulp and water are introduced by a screw feeding device through one trunnion of the mill, the milled pulp flowing out through the opposite trunnion; sufficient water is fed in with the material to form a pulp suspension of the desired consistence. When operated batchwise, the material to be milled together with the proper quantity of water to give the desired consistence is added through the side manhole. At the completion of a batchwise operation the manhole cover is removed and the mill contents dumped into a screen where the pulp is permitted to drain.

The assortment and weights of the circular steel rods used is shown in Table 1. The full charge of 47 rods had a total weight of 3336.0 pounds and a total longitudinal surface area of 134.7 square feet.

Table 1.--Data on circular steel rod charge

Number of rods	Diameter	Length	Total weight	Total longi-tudinal area
	Inches	Inches	Pounds	Sq.in.
7	1.5	58	245.0	1912.0
17	2.0	58	850.0	6210.0
10	2.5	58	785.0	4555.0
13	3.0	58	1456.0	6710.0

The oval cast iron rods were identical, each having a length of 58 inches and minor and major axes of 2 and 3-1/6 inches, respectively. Their average weight and longitudinal area were 73 pounds and 3.24 square feet. In order to duplicate as nearly as possible the charge of circular rods in number, weight, and longitudinal area, 46 oval rods, having a total weight of 3358.0 pounds and a total longitudinal area of 149.0 square feet were used for the oval charge. Before determining the processing effect of these rods, they were "broken in" by rotating in the mill for 3 hours at 27 r.p.m. with kraft pulp at about 2 per cent consistence.

Material

The kraft pulp used was produced by a Wisconsin paper company. It was kept well covered from dust on the storage floor of the Laboratory in the form of air-dry laps. At the time of use it had a moisture content of 7.95 per cent.

Procedure

As stated, the purpose of the study was to compare the serviceability and characteristic processing effects of oval cast iron and circular steel rods. In all, five rod mill runs were made in which the speed was held constant at 27 r.p.m.

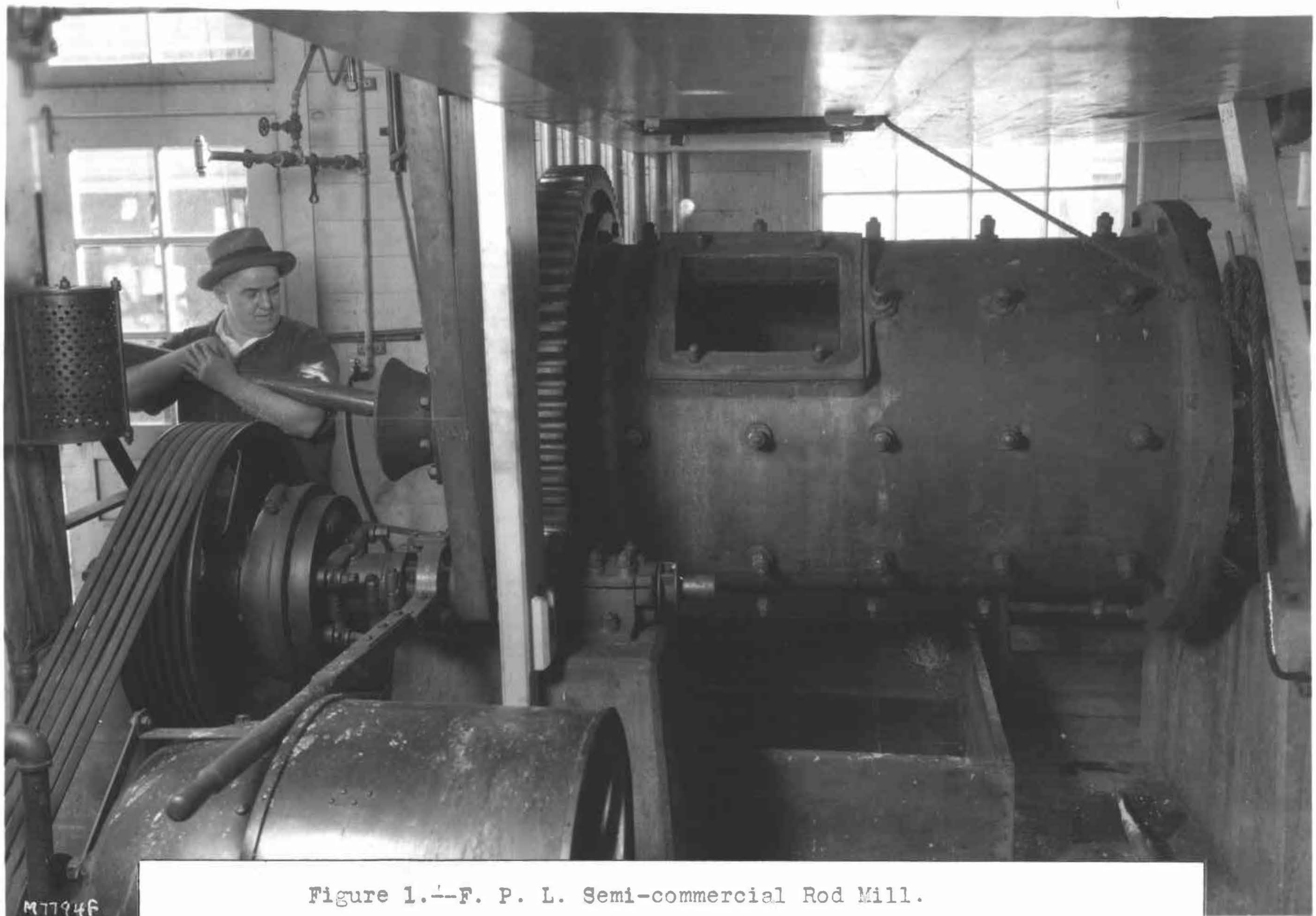

Figure 1.--F. P. L. Semi-commercial Rod Mill.

In the first run to determine serviceability, six cast oval rods were introduced into the mill together with a full charge (37 rods having a total weight of 3660 pounds) of circular bronze rods and 25 pounds (oven-dry) equivalent of sulphite pulp, at 4 per cent consistence, and milling continued for 15 hours. The rods were inspected at intervals during this run for chipping and fracture, and at the end of the run the oval rods were found to have endured the action with no more noticeable detrimental effects than are found with other rods, namely a slight chipping at the ends.

The processing conditions of the four subsequent runs are shown in Table 2.

Table 2.--Data on processing conditions

Rod mill run No.	Rods used: Type	Rods used: Total weight	Rods used: Total rod longitudinal area	Pulp: Consistence	Pulp: Ratio rods to oven-dry pulp by weight	Pulp: Ratio rods to total charge of pulp and water by weight
		Pounds	Sq.ft.	Per cent	Per cent	
49	Circular	3336.0	134.7	8	133.4:1	10.67:1
50	Circular	3336.0	134.7	4	133.4:1	5.34:1
52	Oval	3358.0	149.0	8	134.3:1	10.75:1
53	Oval	3358.0	149.0	4	134.3:1	5.38:1

Note: 25 pounds pulp (oven-dry basis) used for all runs.

At 15-minute intervals during each run samples of pulp were removed for physical tests and the power consumption, as recorded by a watt-hour meter, was noted. Milling was continued until the bursting strength of the pulp as shown by test method No. 98[5] reached a maximum and began to decrease.

[5]Manual of Testing Methods for Wood, Pulp, Stuff and Paper. First ed. 1928.

A summary of the test results and power consumption is shown in Tables 3 and 4 and Figures 2 to 7 inclusive.

Discussion of Results

As shown by the tabulated data, the comparative effects of the oval and circular rods were evaluated by their influence upon the rate of hydration and the cutting of the pulp fibers, using the customary strength tests on sheets of processed pulp, the freeness test and a new "rate of flow" test[6] recently developed here as means of evaluation.

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[6]New Methods of Evaluating Ground-wood Pulp, by L. A. Carpenter and E. R. Schafer. To be presented at 1930 spring meeting of the Technical Association of the Pulp and Paper Industry.

In making the tests several factors believed to affect the rate of hydration, etc., were studied and their bearing on the results discussed below.

Heat Developed by Milling and Its Effects

The changes in temperature produced in the mill are shown in Table 3 and Figure 2. In run No. 49 the bursting strength of the pulp determined by the "rapid method" showed a decrease after 90 minutes milling (method No. 98, Test Manual). Accordingly, the mill was stopped, a test sample was obtained, and the pulp allowed to cool overnight. The following morning another test sample was removed and the processing continued to determine whether or not cooling appreciably affected the processing effects with consequent influence on the freeness and various strength properties.

In each of the other runs the mill was stopped at the end of definite times of milling and the contents allowed to cool overnight. The next morning processing was continued until the constant b of the flow-rate test[6] showed a decrease with continued milling. Thus run No. 52 (oval rods at 8 per cent consistence) was stopped for the night after 150 minutes milling when the Green freeness of the pulp was approximately equal to that of run No. 49 (circular rods at 8 per cent consistence), when the latter was stopped. Runs No. 50 (circular rods at 4 per cent consistence) and No. 53 (oval rods at 4 per cent consistence) were stopped for the night after equal periods of milling rather than after the development of equal freeness values. The time of stopping, however, was taken at the point where the freeness value of the pulp from run No. 52 was approximately equal to that from run No. 49 when the latter was stopped.

Physical tests made on the samples removed from the mill after stopping for the night and just before starting in the morning showed no changes in the constants of the various stuffs.

From the data it is apparent that in run No. 49 using circular rods on the pulp at 8 per cent consistence the rate of temperature rise is very slightly greater than in run No. 52 with the oval rods under similar conditions. At 4 per cent consistence the rates of temperature rise with the circular and oval rods, as shown in the curves for runs Nos. 50 and 53, respectively, are practically equal. In all of the runs the temperatures at any definite period of milling up to 90 minutes fall within a range of 7 degrees. The divergence just noted appears in the runs at 8 per cent consistence after 90 minutes milling. Since the rates of freeness and strength development (see figs. 3 and 5) do not increase in run No. 52 over run No. 49 after 90 minutes milling and do not remain equal in runs Nos. 50 and 53, it is apparent that temperature within the limits studied does not have much influence on the processing effects.

Fiber Properties as Indicated by Freeness (Green)

The freeness values of the rod-milled pulps shown in Table 3 and Figure 3 indicate that the variations in temperature had no effect upon the rate of change of freeness in any of the runs. The freeness is decreased much more rapidly by the circular rods at both consistences than by the oval rods. With either type of rods the freeness values for the low consistence runs are slightly greater than those for the high consistence, at the same time of milling.

At 4 per cent consistence both types of rods, and more especially the oval rods, show an initial period when the freeness decreases but slowly. This period may be required for a homogeneous mixing of the pulp and water before hydration begins. After this initial period, the rate of decrease of freeness at 4 per cent consistence is greater than that at 8 per cent consistence, with both types of rods, until a freeness of about 350 cubic centimeters is reached; thereafter the freeness curves for either type of rod at low and at high consistence become parallel.

Hydrogen-ion Concentrations During Processings

The pH of the samples taken from the various runs was determined colorimetrically by means of suitable indicators

Table 3.--Data on processing effects of circular steel and oval cast iron rods in the rod mill

Processing variable	Rod mill run No.	Milling time (Minutes) 0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270
Temperature ° C.	49	23.0	29.0	32.0	35.0	37.0	39.0	41.5	35.0	37.0	39.0	41.0	...	...	...	...	...	...	...	...
	50	23.0	26.0	28.0	30.0	31.5	33.0	35.0	36.5	31.0	32.0	33.0	34.0	35.0	...	...	...	...	...	...
	52	23.0	28.0	30.0	33.0	35.0	37.0	38.0	39.0	42.0	44.0	46.0	28.0	32.0	34.0	36.0	39.0	42.0	...	...
	53	25.0	28.5	30.0	32.0	33.0	35.0	36.0	38.0	32.5	34.0	35.0	36.5	37.5	39.0	40.0	42.0	43.0	44.0	45.0
Freeness (Green) Cc.	49	700	590	515	328	303	212	135	58	83	38	25	...	...	...	...	...	...	...	...
	50	706	662	556	430	315	227	156	115	65	50	34	27	24	...	...	...	...	...	...
	52	698	630	615	486	439	357	285	238	181	120	98	66	50	40	29	26	18	...	...
	53	708	670	644	596	532	426	316	250	191	146	116	88	65	55	46	38	30	22	19
Flow rate[1] "hydration" Constant b	49	[2]	[2]	0.007	0.015	0.050	0.125	0.235	0.250	0.370	1.00	0.590	...	...	...	...	...	...	...	...
	50	[2]	[2]	[2]	[2]	.020	.033	.127	.175	.192	.285	.180	0.185	0.167	...	...	...	...	...	...
	52	[2]	[2]	.007	.010	.015	.053	.083	.125	.223	.243	.455	.400	.400	0.370	...	...	...	...	...
	53	[2]	[2]	[2]	[2]	.015	.025	.045	.055	.065	.082	.087	.113	.204	.214	0.305	0.223	0.160	0.350	0.625
(Ashcroft) Bursting strength Pt./lb./rm.	49	0.10	0.52	0.52	0.58	0.62	0.68	0.71	0.78	0.80	0.77	0.80	...	...	...	...	...	...	...	...
	50	.05	.23	.39	.48	.49	.55	.57	.58	.57	.60	.58	0.65	0.66	...	...	...	...	...	...
	52	.11	.34	.43	.53	.58	.62	.65	.65	.63	.57	.65	.72	.69	.68	0.62	0.55	0.50	...	...
	53	.07	.18	.29	.33	.47	.52	.51	.56	.58	.60	.62	.61	.60	.62	.57	.57	.54	0.52	0.50
Folding endurance (Schopper) Dbl. folds	49	...	42	35	75	178	148	120	302	316	284	360	...	...	...	...	...	...	...	...
	50	...	6	7	14	15	23	21	25	29	42	45	176	142	...	...	...	...	...	...
	52	...	4	16	26	42	94	28	58	147	103	30	85	78	46	50	20	15	...	...
	53	...	3	4	5	14	18	16	23	22	30	23	25	23	30	28	31	25	25	19
Tearing strength (Elmendorf) Gms./lb./rm.	49	1.00	2.15	2.11	2.00	2.05	2.02	1.90	1.75	1.75	1.63	1.54	...	...	...	...	...	...	...	...
	50	1.10	1.46	1.49	1.30	1.28	1.23	1.39	1.26	1.28	1.15	1.06	1.22	1.07	...	...	...	...	...	...
	52	0.67	1.49	1.81	1.72	1.79	1.90	1.82	1.79	1.62	1.62	1.45	1.47	1.37	1.29	1.44	1.38	1.15	...	...
	53	.73	1.63	1.54	1.72	1.80	1.75	1.57	1.51	1.48	1.41	1.48	1.38	1.41	1.26	1.22	1.24	1.23	1.25	1.11

[1] In equation $T + c = A \times 10^{bR}$, $\underline{T}$ = flow time, $\underline{R}$ = rate of flow of water under constant head and temperature through a mat of pulp at time $\underline{T}$, and $\underline{A}$, $\underline{b}$ and $\underline{c}$ are constants dependent upon pulp properties; $\underline{b}$ is proportional to the transverse strength of the pressed and dried mat.

[2] Pulp too free for particular apparatus set up at time of test.

and prepared color standards. All of the samples showed a constant pH of 8.6, which is the value representing in the city artesian well water used.

"Hydration" of Stuffs

For the measurement of "hydration" effects, a method recently developed at the Laboratory,[6] and which is based upon the rate of change of the flow rate of water through a uniform mat of pulp under constant head and temperature, was used. The change of flow rate, R, with time, T, during which the rate as measured is expressed by the equation

$$T + c = A \times 10^{bR}$$

in which A, b, and c are constants characterizing the pulp.[7]

[7] The derivation of the equation and the calculation and application of the constants will be given in the report referred to under 6.

From the determination of the modulus of transverse strength of pressed and dried mats of pulp it has been found that the values obtained are mathematically related to the constant b. From certain considerations it appears that hydration of pulps is the main factor affecting the modulus of transverse strength. It can be concluded, therefore, that the degree of "hydration" can be related to values of b.

The data presented in Table 3 and Figure 4 show the relationships between milling time and the values of b from the flow-rate equation. In run No. 49 using the circular rods on pulp at 8 per cent consistence the "hydration" as shown by the values of b develops at a markedly greater rate and reaches a higher maximum than in the other three runs. The rates of "hydration" in runs Nos. 50 and 52 using circular rods on pulp at 4 per cent consistence and oval rods on pulp at 8 per cent consistence, respectively, are practically equal, but as might be expected, the maximum reached is higher in run No. 52 because of the higher consistence. As shown in run No. 53, the oval rods on pulp at 4 per cent consistence produced a very slow hydrating effect, as measured by this method.

A peculiar effect in this latter run is found in the two maximums obtained. At 210 minutes the value of b reaches a maximum after which it has a straight line drop for 1/2 hour more milling. At 240 minutes the value of b again begins to increase and continues to do so until the end of the run at 270 minutes. It is probable that the effect of the rods in this case is analogous to the action of the beater on some pulps which develop two maximum bursting-strength values during beating.

In each run there is a horizontal break in the milling time -- b curves between the b values 0.18 and 0.25. In runs Nos. 49 and 50 these breaks occur at the periods when the mill was cooled overnight, which led at first to the belief that the cooling affected the rate of flow relationship. However, since similar breaks occur in runs Nos. 52 and 53 within the same narrow limits of b, the first 30 minutes before stopping the mill, and the second 75 minutes after starting the mill the next morning, it appears that a marked change took place in the pulp at this stage in processing. The cause of this behavior is left for future investigation. It plainly is not connected with the type of rod used.

Ashcroft Bursting-strength Properties

The bursting strengths of hand sheets prepared from the pulps are shown in Table 3 and Figure 5. The rate of strength development is greatest in run No. 49 followed in decreasing order by runs Nos. 52, 50, and 53, respectively. The maximum strength developed is likewise in the same order.

In run No. 52 using the oval rods on pulp at 8 per cent consistence, there are two distinct maximums the highest of which is considerably below the maximum developed in run No. 49 with the circular rods at the same consistence.

Up to 75 minutes milling time, the circular rods at 4 per cent consistence effect a greater rate of strength development than the oval rods, after which the strength remains about constant for 1 hour. Thereafter the strength again increases gradually until the end of the run. During the interval of little change in the values in this run, the strength-producing properties of the pulp in run No. 53 (oval rods) slightly exceeds that of the pulp in run No. 50 (circular rods). However, the maximum reached in run No. 53 is below that reached in run No. 50 after its final increase.

Schopper Folding-endurance Properties

From Table 3 and Figure 6 it is apparent that the rate of development as well as the maximum folding endurance is greatest in run No. 49 using the circular rods at 8 per cent consistence. The comparison of run No. 52 (oval rods, 8 per cent consistence) and run No. 50 (circular rods, 4 per cent consistence) is of interest. The rate of folding endurance development in run No. 52 was much more rapid than in run No. 50 and the maximum is reached sooner, but this maximum is lower than that reached eventually with the circular rods at the lower consistence. Run No. 53 using the oval rods on pulp at the lower consistence shows a very low maximum strength.

Apparently the consistence of the charge is the controlling factor in this effect because at 8 per cent consistence there are steep rises in the milling time-folding endurance curves. This has also been observed in industrial studies. All of the points do not lie on the curves as well as in some of the other tests but this is due to the fact that the folding test is very much influenced by the nonuniformity of the test sheets, and that highly uniform hand sheets are difficult to produce.

Elmendorf Tearing-strength Properties

In tearing strength the hand sheets made from the stuffs of run No. 49 (circular rods, 8 per cent consistence) again show a faster rate of development as well as a higher maximum than any of the others; this is shown in Table 3 and Figure 7. In all of the runs the tearing strength reaches a maximum value within a very short time (15 to 60 minutes) and then rapidly falls off with continued milling. The small increases in the strength values near the end of runs Nos. 52 and 53, although included as part of the curves, are probably due to nonuniform hand sheets; definite secondary tearing-strength maximums are, however, sometimes obtained in tests on beaten stocks.

The tearing strength values of the hand sheets made from stuffs prepared at 4 per cent consistence in run No. 53 are considerably higher than those representing run No. 50 (oval rods, 8 per cent consistence). This is the only case in which the oval rods show any superiority in processing efficiency over the circular rods. The reason for the oval rods being superior in developing tearing-strength properties at low consistence and inferior at 8 per cent consistence, is perhaps best brought out by the following observations on the way the two types of rods fall as the mill rotates.

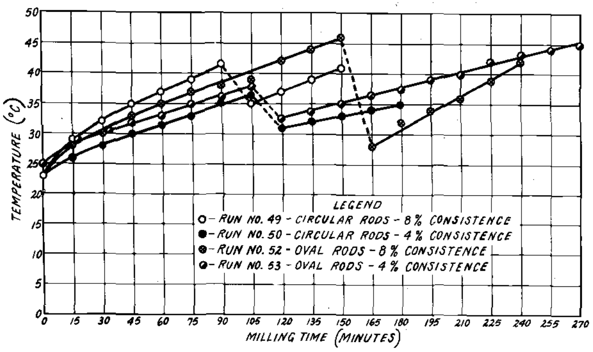

FIG. 2
THE RELATION BETWEEN MILLING TIME AND HEAT DEVELOPED IN ROD MILL

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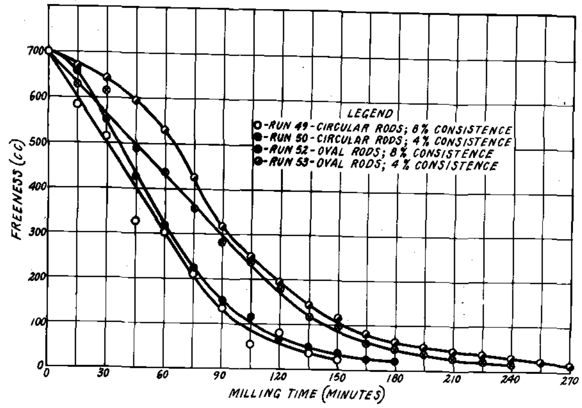

FIG. 3
THE RELATION BETWEEN MILLING TIME AND FREENESS OF PULPS

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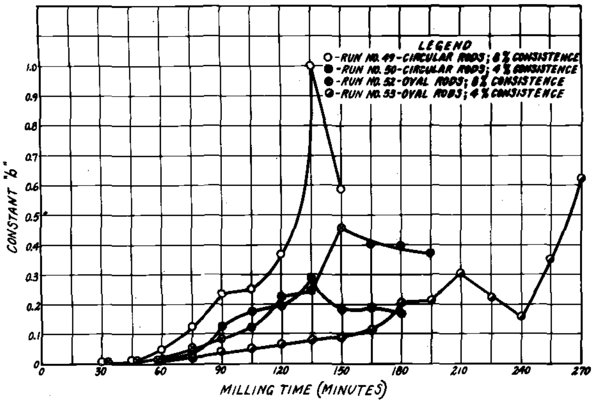

FIG. 4
THE RELATION BETWEEN MILLING TIME AND FLOW RATE HYDRATION - CONSTANT "b"

M136945

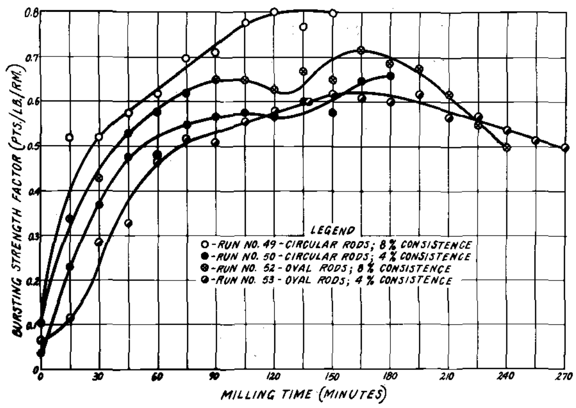

FIG. 5
THE RELATION BETWEEN MILLING TIME AND ASHCROFT BURSTING STRENGTH VALUES OF HANDSHEETS MADE FROM STUFFS

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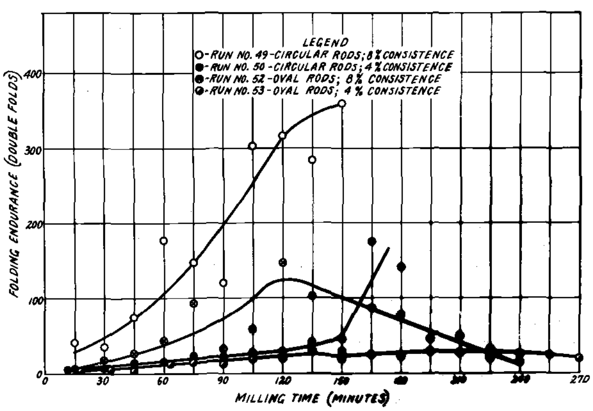

FIG. 6
THE RELATION BETWEEN MILLING TIME AND FOLDING ENDURANCE OF HANDSHEETS MADE FROM STUFFS

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M19246F

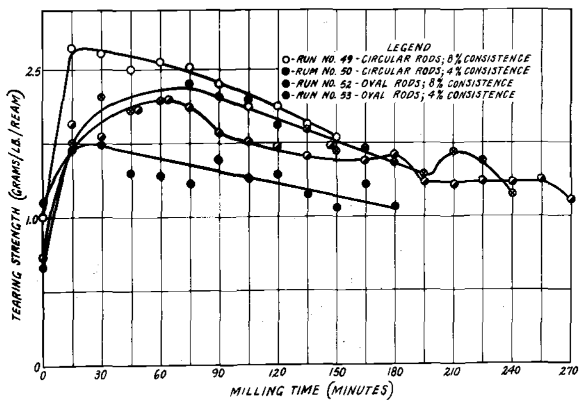

FIG. 7
THE RELATION BETWEEN MILLING TIME AND ELMENDORF TEARING STRENGTH VALUES OF HANDSHEETS MADE FROM STUFFS

M136975

Falling of Rods

The trunnions at both ends of the mill were opened so that the action of the two types of rods could be observed in milling pulps at different consistences and at different rotational speeds of the mill.

The oval rods were found to have a tendency to pile up on the interior rising wall of the mill until a certain height was reached, whereupon the several top rods would fall or "cascade" as a unit to the bottom of the mill. As the speed of the mill and the consistence were increased, the height to which the rods were elevated before falling was increased accordingly.

The circular rods appeared to roll or slide more easily over one another and along the interior wall of the mill, so that there was comparatively less piling up and cascading of the rods.

The effects of changes in speed and consistence of the pulp on the piling up of the rods are shown in Table 4. The "cascading" angle is defined as the average angle which the exposed surface of the rods in the mill would make with the horizontal. This angle was determined by observation through the end of the mill, using the average height of the rods against the wall of the mill and the horizontal plane.

Table 4.--Data on the cascading of oval and circular rods in the rod mill as affected by speed and consistence

Speed of mill	Consistence (approximate)	Cascading angle	
		Oval rods	Circular rods
R.p.m.	Per cent	Degrees	Degrees
18	10	40	40
27	10	60	55
30	10	60	55
34	10	90	80
18	1	25	15
34	1	45	25
18	Water only	25	15
34	Water only	45	25

Although the values given in the table are not exact, they do show the relative piling up of the rods under different conditions.

From the results it is evident that, since the oval rods are carried higher in the mill and tend to fall rather than to roll upon one another, they produce a pounding rather than a rubbing or rolling action which is characteristic of the circular rods. This difference in action becomes more pronounced as the consistence is lowered. It is undoubtedly this pounding action which causes the pulp at 4 per cent consistence to develop higher tearing-strength properties when milled with the oval rods. This is on the assumption that the tearing-strength properties depend upon a close interlacing of fibers, and that this interlacing is facilitated by the partly loosened fibrils which are produced to a limited degree more effectively by a pounding than by a rubbing action.

Power Consumption

The power consumed during each of the runs is shown in Table 5.

The amounts of power necessary to develop a bursting-strength value of 0.6 point per pound per ream in the hand sheets made from the stuffs are used as a basis of comparison inasmuch as this is the usual strength developed in hand sheets of commercially beaten kraft pulps. Since the rate of development of strength-producing properties in run No. 50 decreased considerably after about 0.5 point per pound per ream was reached, the amounts of power necessary to develop this lower bursting-strength factor in the hand sheets are also included in the table.

From the data it is evident that for developing properties in the stuffs producing high bursting strength in papers, the circular rods are more economical of power than oval rods, solely because the time required is less. To develop a bursting-strength factor of 0.6 at 8 per cent consistence with the circular rods required only about 75 per cent of the power expended with oval rods; to develop a bursting-strength factor of 0.5 required only 64 per cent on the same basis. At 4 per cent consistence the power expended by the circular rods was approximately 95 and 74 per cent, respectively, of the requirements of the oval rods.

Table 5.--Data on power consumption with oval and circular rods

Rod mill run No.	Type rods used	Consistence of pulp	Power consumed to develop a bursting strength of -- 0.6 pt./lb./ream: Time required	0.6 pt./lb./ream: K. W. hours	0.6 pt./lb./ream: Horsepower days per ton: 3 x 5 foot mill batchwise	0.6 pt./lb./ream: Horsepower days per ton: 6 x 12 foot mill continuous	0.5 pt./lb./ream: Time required	0.5 pt./lb./ream: K. W. hours	0.5 pt./lb./ream: Horsepower days per ton: 3 x 5 foot mill batchwise	0.5 pt./lb./ream: Horsepower days per ton: 6 x 12 foot mill continuous
		Per cent	Minutes				Minutes			
49	Circular	8	55	8.0	35.7	23.5	27	4.1	18.3	12.1
50	...do...	4	135	18.3	81.8	54.0	53	7.1	31.7	21.0
52	Oval....	8	65	10.6	47.4	31.2	39	6.4	28.6	18.9
53	...do...	4	135	19.1	85.4	56.2	70	9.6	42.9	28.3

The power consumption figures which are given in horsepower-days per ton for batchwise operation of the 3 by 5 foot rod mill can be converted to those for continuous operation of a 6 by 12 foot commercial mill by multiplying by 0.66.

General Discussion of Data

The freeness tests showed that the circular rods at both consistences "slowed" the pulp more rapidly than did the oval rods. Since the "slowness" of a pulp as measured by the usual type of freeness tester is affected by both hydration and particle size, it is impossible to determine by this test whether the pulp is beneficially hydrated or injuriously cut. However, by comparing the various strength curves of bursting, tearing, and folding resistance against milling time, the principal effects of the rods may be somewhat evaluated.

The high bursting and tearing strength and folding endurance developed by the pulp from run No. 49 indicates that hydration with a minimum of cutting was responsible for its rapid decrease of freeness. On the other hand, although the freeness curve for run No. 50 is approximately the same as that for run No. 49, the lower bursting-strength maximum obtained indicates a lesser degree of "hydration," while the decidedly lower folding endurance and tearing strength show that considerably more cutting has taken place in run No. 50 than in run No. 49.

In runs Nos. 52 and 53 using the oval rods on pulps at 8 and 4 per cent consistences, respectively, the freeness values show that there is less hydration or cutting, or both, than with the circular rods. The lower bursting strength developed in run No. 52 indicates that the degree of hydration is less than in run No. 50, while the lower folding and tearing tests of the former show a greater cutting action taking place. The amount of cutting, however, is not enough to make up in its effect on freeness for the lower degree of hydration, and therefore the freeness curve does not correspond with those of runs Nos. 49 and 50.

In run No. 53 the hydration is somewhat below that of run No. 50 as shown by the lower bursting-strength values, but the cutting as shown by the folding endurance curves is about equal. The tearing-strength curves indicate that less cutting took place in run No. 53 than in run No. 50. It appears logical that the pounding action of the oval rods at the low consistence in run No. 52 where a cushioning effect of the pulp was at a minimum, caused the ends of the fibers to split into fibrils to a greater degree than the rubbing caused by the circular rods in run No. 50. These fibrils were probably responsible for a more intimate interlacing of fibers and therefore a higher tearing strength, although the fiber lengths of the two pulps may have been equal.

Although from the results of these tests the oval rods are inferior to circular rods for "beating" pulp, they may prove superior for refining the softened chips from the semichemical cooking processes. For this purpose a maximum of attrition and separation of fibers is desired. A further study along this line would be desirable in the future.

Conclusions

From a comparative study of circular and oval rods in the rod mill the following conclusions can be drawn:

1. The hydration as measured by the flow-rate method and the rates of development and maximums of bursting, tearing, and folding strengths are greater with the circular than with the oval rods at 8 per cent pulp consistence, and, therefore, the power requirement for processing a given pulp to the desired stuff would be considerably lower with circular rods.

2. At 4 per cent consistence, the same conclusions can be drawn except with the tearing strength where the rate of development as well as the maximum value of this property is lower with the circular rods than with the oval rods.

3. The difference in processing effects of oval and circular rods may be ascribed to the different manner in which they fall in the mill. Rotational speed and consistence are the two important factors in their influence upon milling efficiency and effects.

4. The serviceability of the oval cast iron rods is apparently equal to that of the circular steel rods in a rubber-lined mill, there having been no chipping or fracturing in this study.