The Shatter and Tumbler Tests for Metallurgical Coke^{1,2}

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The Bureau of Mines, in connection with its work on fuels, is conducting at the Southern Experiment Station a study of the physical properties of metallurgical coke in relation to its production and utilization. In connection with this work, a study of present testing methods has been made. This paper describes a series of experiments carried out to determine the best method of procedure and the reproducibility of duplicate determinations with (1) the machine and bag shatter tests, and (2) the tumbler or "hardness" test. Further comparative work is in progress at this laboratory and at coke plants in the district.

The shatter test affords a measure of the relative resistance of coke to breakage in handling. Single determinations by this procedure contain an average error of 1 to 3 per cent, depending on the character of the coke tested.

It is recommended that several screens be used as indicators of the shattering effect, i. e., 2-in., 1.5-in., 1-in., and 0.5-in.

Results of the bag shatter test are in fair agreement with those of the machine shatter test when the bag is dropped four times.

The effect of the size of the pieces of coke in the sample used for

the shatter test upon the absolute and relative value of the results obtained should be further studied.

The tumbler barrel or "hardness" test as at present carried out, i. e., employing 3-in. to 2-in. coke and reporting the result as the percentage remaining on a 0.25-in. screen, has no meaning when the test is applied to coke of varied physical properties. It may have value as applied to the daily testing of coke supplied to a blast furnace whose coke supply is not subject to large variations in resistance to shattering.

If a screen analysis from 2 in. to 0.25 in. be made after the tumbler test, an indication of the quality of the coke is obtained, but such data indicate no property of the coke which would not be shown by an ordinary shatter test.

If the tumbler test be carried out with 0.75- to 0.25-in. coke, the percentage remaining on a 0.25-in. or 0.17-in. screen after the test is probably indicative of the resistance to abrasion. This value, however, is little different for a variety of coke and its meaning in terms of blast furnace or other operation is by no means clear.

THE SHATTER TEST

THE SHATTER test is designed to show the resistance of coke to breakage in handling. The method and apparatus, substantially in its present form, were developed some years ago by D. T. Croxton and have been described by Belden.⁵ Fig. 1 shows the machine shatter test apparatus in use at this Station. It was built in accordance with tentative specifications formulated by Committee D-6 on Coke, from a blue-print supplied through the courtesy of the Koppers Company.

In the test procedure, a 50-lb. sample of coke is dropped four times from a height of 6 ft. upon a steel plate. The percentage of the original sample, which remains on a 2-in. square mesh screen after this treatment, is reported as the shatter test result.

An alternative method of conducting the shatter test has been proposed by C. R. Meissner of the Koppers Company. In this method the procedure is identical, except that the coke is placed in a heavy sulfate bag about 45 in. long by 28 in. wide and rolled from a shelf 6 ft. above a concrete floor or steel plate. Figs. 2 and 3 show a modification of the bag shatter test used in our work.

Examination of the test procedure shows need for consideration of the following points:

- 1—Weight of sample to be employed.
- 2—Method of sampling and size of coke pieces to be taken.
- 3—Mesh of screen used as indicator of the shattering effect and method of conducting the screening.
- 4—Agreement obtainable between results of duplicate determinations.

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⁵ "Metallurgical Coke," *Bur. Mines, Tech. Paper* 50 (1913), 39.

THE TUMBLER BARREL TEST

After the coke is discharged into the bell of the blast furnace it is no longer subject to breakage by impact. The action is then one of slow abrasion as the coke travels down the furnace under the increasing weight of the burden above. A number of workers have developed tests designed to give a relative value for the resistance of coke to mechanical attrition in the furnace. Although there is considerable variation in test procedure, all the methods are the same in principle. A weighed sample of coke is placed in a revolving drum and rotated for a given length of time. Subsequent screen analysis gives a figure said to indicate the friability of the coke, a value not necessarily related to its resistance to shattering by impact.

The first published record of the tumbler test occurs in a paper by Rossigneaux,⁶ who states that a revolving drum was used for testing metallurgical coke at Anzin in 1883. According to Simmersbach,⁷ drums were used before 1904 for testing coke at Jurjewski, Germany; in Belgium and France similar apparatus containing steel balls was employed. Hewson⁸ describes a procedure in which the drum contained steel balls. Cochrane⁹ gives data obtained with a similar apparatus containing no steel balls. This author carried out daily tests of the coke used by his furnaces for a number of years and claimed to find a relation between test results and the amount of iron produced by his furnaces and the blast pressure required. The English workers gave the name "hardness" to the property of coke measured by their test.

In this country a similar apparatus has been used for some time by Barrett at Youngstown and by Rice¹⁰ of the Bethlehem Steel Company. A similar "rumbler" test was in use in the Birmingham district some ten years ago. Rice, using

⁶ "Propriétés Physiques et Chimiques du Coke Metallurgique," *Génie civil*, 20 (1891), 9, 21.

⁷ *Stahl u. Eisen*, 33 (1913), 512.

⁸ *J. Soc. Chem. Ind.*, 37 (1918), 60.

⁹ *J. Iron Steel Inst.*, 97 (1918), 141.

¹⁰ "Importance of Hardness of Blast Furnace Coke," *Am. Inst. Mining Met. Eng.*, Preprint No. 1030 (1921).

an apparatus containing steel balls, found that over a period of months a low hardness number went hand-in-hand with high blast pressure required to blow a given volume of air through the furnace.

FIG. 1.—MACHINE SHATTER TEST APPARATUS

Drums from 2 to 6 ft. in diameter have been employed, and coke samples of 25 to 900 lbs.

The tumbler test apparatus used at this laboratory is substantially the same as described by Cochrane.⁹ The machine, shown in Figs. 4 and 5, consists of a steel drum of 0.25-in. boiler plate, 30 in. in inside diameter and 18 in. in length. The drum is rotated by means of a motor connected to a standard pitch worm gear at the rate of 18.6 r. p. m. The current to the motor is automatically interrupted after the drum has made 1200 revolutions. The machine is set in the top of a bin. The bin discharges on to a set of circular screens 2 ft. in diameter and having the following square openings between wires: 2-in., 1.5-in., 1-in., 0.5-in., and 0.25-in.

A 25-lb. sample of 3- to 2-in. coke is placed in the apparatus for the test, the cover fastened down, and the drum revolved 1200 times. In the subsequent screen analysis, the screens are shaken and the pieces tested separately to see whether they will pass the openings in any position. This procedure gives a more definite end-point than any method of shaking. The so-called hardness number is reported as the cumulative percentage of the original sample remaining on the 0.25-in. screen. As data were desired on the choice of screens to be used for determining the hardness number, a greater number of screens were used than employed by Cochrane.

Examination of the test procedure shows need for consideration of the following points:

- 1—Weight of sample to be employed.
- 2—Method of sampling and size of coke pieces to be taken.
- 3—Mesh of screen used as indicator.
- 4—Agreement obtainable between results of duplicate determinations.
- 5—Duration of test.

COKE SAMPLES TESTED

The greater part of the work has been carried out on samples of coke from the Birmingham district. Tests have also been made on beehive coke from the Connellsville district, on by-product coke from Benham coal, and on by-product coke from Illinois coal.

TABLE I—DESCRIPTION OF COKE SAMPLES

NAME	TYPE OF OVEN	COKING TIME HRS.	COAL SEAM
Alabama:			
No. 1	Koppers	17	{ 66% Black Creek
No. 2	Beehive	72	{ 34% Mary Lee
No. 3	Semet-Solvay	20	Milldale
No. 4	Beehive	72	Mary Lee
No. 5	Semet-Solvay	16	Brookwood
No. 6	Beehive	72	Brookwood & Milldale
No. 7	Beehive	72	Pratt
No. 8	Semet-Solvay	34	Mary Lee
No. 9	Koppers	19	Pratt
No. 10	Koppers	20	Pratt
No. 11	Beehive	72	Blue Creek
Benham	Wilputte	29	{ 92.5% Keokee
Connellsville	Beehive	72	{ 7.5% Pocahontas
Illinois	Roberts	15	Pittsburgh
Pitch coke	Beehive	72	No. 7

TABLE II—ANALYSIS OF COKE SAMPLES

COKE	PROXIMATE				ULTIMATE						
	Mois- ture	Vol- atile	F. C.	Ash	H	C	N	O	S	B. t. u.	
Alabama:											
No. 1	1.53	3.17	84.75	10.55	1.42	84.00	1.60	1.52	0.74	12718	
No. 2	0.20	0.90	88.57	10.33	0.56	86.79	0.65	0.80	0.85	12624	
No. 3	0.18	1.07	84.92	13.83	0.47	83.59	0.72	0.57	.....	.....	
No. 4	0.50	1.35	86.62	11.53	0.53	85.72	0.82	0.47	0.87	12473	
No. 5	0.8	1.4	87.10	10.70	0.80	85.0	1.3	1.2	1.0	12690	
No. 6	2.39	1.03	85.5	11.06	.....	.....	.....	.....	1.27	12389	
No. 7	0.40	0.48	84.37	14.75	.....	.....	.....	.....	0.78	12139	
No. 8	3.02	2.92	81.30	12.76	0.70	84.21	1.19	0.88	0.72	12079	
No. 9	0.25	1.15	90.70	7.90	0.52	89.16	0.96	0.33	1.11	13044	
No. 10	0.50	2.68	87.74	9.08	0.84	87.14	0.74	1.04	1.10	12929	
No. 11	0.28	0.57	87.97	11.18	0.31	86.73	0.95	0.60	0.80	12452	
Benham	0.9	0.9	91.7	6.5	.....	.....	.....	.....	0.7	13330	
Connellsville	0.48	1.77	86.00	11.75	0.79	84.35	1.22	0.86	0.97	12527	
Illinois	1.3	1.4	86.0	11.3	0.3	86.2	0.4	0.8	0.9	12450	
Pitch coke	0.33	1.07	97.65	0.95	0.55	96.66	0.72	0.62	0.50	14097	

Table I shows the character of the coke samples tested. Table II gives proximate and ultimate analyses of the cokes. Table III summarizes data obtained on physical properties of the coke samples. True density was determined on material ground to pass a 200-mesh screen. Apparent density was determined on 1.75-in. material by a method measuring the volume of water displaced by a weighed amount of the coke.

DETAILED DATA OF MACHINE AND BAG SHATTER TEST DETERMINATIONS

To determine the agreement obtainable between the results of the machine and bag shatter tests and the agreement obtainable between duplicate determinations by each method, a series of tests was run on two by-product cokes made in Alabama. Part of these tests were carried out at the laboratory and part were run at the plant. Sufficient coke to run from five to ten tests was taken at one time and well mixed on the floor before the shatter tests were made. The purpose of the tests was not so much to get a representative sample of the coke contained in the bin or larry car as to secure a large well-mixed pile of coke from which identical samples might be taken.

TABLE III—PHYSICAL PROPERTIES OF COKE SAMPLES

COKE	SHATTER	HARDNESS A ¹	B ²	SPECIFIC GRAVITY True	Apparent	POROS- ITY
Alabama:						
No. 1	70	70	....	1.75	0.96	45
No. 2	74	73	89.1	2.10	1.02	52
No. 3	69	68	89.4	1.96	1.00	49
No. 4	72	67	....	1.91	0.83	57
No. 5	69	71	90.6	2.00	0.99	51
No. 6	64	74	90.2	2.13	1.15	46
No. 7	72	71	88.8	1.91	0.98	49
No. 8	70	74	90.4	1.98	1.05	47
No. 9	70	74	92.3	2.04	1.14	44
No. 10	70	68	....	1.92	0.98	49
No. 11	77	73	....	1.97	0.81	59
Benham	59	73	88.4	1.85	0.91	51
Connellsville	66	71	92.0	1.89	1.02	46
Illinois	42	78	90.5	1.84	0.87	53
Pitch coke	78	76	92.9	2.00	1.16	42

¹ Method using 3- to 2-in. coke; result reported as percentage remaining on a 0.25-in. screen.

² Method using 0.75- to 0.25-in. coke; result reported as percentage remaining on a 0.17-in. screen

FIG. 2—BAG SHATTER TEST APPARATUS

Table IV gives a condensed record of the tests made with both machine and bag shatter procedure. Conclusions to be drawn from the data are as follows:

1—Single determinations by the shatter test procedure contain an average error of 1 to 3 per cent depending on the character of the coke. Several duplicate determinations should be made.

2—Results of bag and machine shatter tests are in fair agreement.

3—A lower shatter test value is obtained when full length pieces of coke are used than when a run-of-oven sample is taken.

4—Stock coke at the Semet-Solvay plant has not deteriorated in strength as measured by the shatter test.

TABLE IV—SUMMARY OF SHATTER TEST RESULTS

COKE	Coking Time Hrs.	Size Coke Used	Type of Test	No. of Deter- minations	Mean Value Per cent on 2-in. Screen	DEVIATION FROM MEAN Av. Max.	WHERE TESTED
Alabama: No. 8	34	F. L.	M	5	71.8	±1.0 ± 2.2	Bureau of Mines Station
	34	F. L.	B	10	68.9	3.3 12.9	
	34	R. O.	M	13	76.3	3.0 12.3	
	34	R. O.	B	17	77.3	2.0 5.7	
Alabama: No. 5	16	F. L.	M	9	71.8	0.9 1.8	At plant
	16	R. O.	M	10	69.6	2.7 6.6	
			B	8	67.1	1.7 4.6	
	15.5	R. O.	M	25	61.9	2.1 8.1	
			B	23	63.3	1.5 4.8	
	15.5	R. O.	M	21	63.5	1.9 6.0	
			B	25	64.1	1.8 4.8	
	16.5	R. O.	M	26	62.5	1.3 4.0	
	16.5	R. O.	M	23	65.1	0.8 2.6	
	25	R. O.	M	24	65.0	1.1 4.0	
Alabama No. 5: Stock coke ¹	24	R. O.	M	10	67.4	1.3 2.9	
Stock coke ²	..	R. O.	M	10	66.1	0.9 2.1	

F. L. indicates that pieces of coke about half the width of the oven were used for the test.

R. O. indicates that run-of-oven coke screened over a 2-in. screen was used for the test.

¹ In stock pile for one year.

² In stock pile for two years.

TABLE V—DAILY SHATTER TEST DATA AT BY-PRODUCT PLANT
(ALABAMA NO. 5)

Month	Number of Tests	Mean Monthly Shatter Test Value	DEVIATION OF DAILY RE- SULTS FROM MEAN Average Maximum
1921-22			
October	15	63.3	±2.7 ±7.3
November	23	67.6	3.0 9.6
December	27	68.3	2.4 7.7
January	20	66.5	2.5 6.5
February	20	66.2	3.4 9.8
March	10	67.0	1.4 3.0

Table V shows the difficulty of drawing conclusions from a single shatter test determination. The table gives condensed data from the daily shatter test records of a by-product plant. One shatter test is made each day at this plant under normal conditions. Daily results show a somewhat higher deviation from the mean value for the month than is shown in the experiments run by the writers on coke from a single oven. This indicates that there is probably some real difference in the quality of the coke from day to day, but the difference is evidently too small to be detected by a single determination.

TABLE VI—MACHINE SHATTER TESTS WITH SIZED COKE
Through 3-in. on 2-in. screen

On Screen analysis after test, cumulative per cent	Ala. No. 8 (Av. of 18 tests) (150 pieces in 50-lb. sample)	Ala. No. 5 (Av. of 9 tests) (170 pieces in 50-lb. sample)
2-in.	75.3	91.2
1.5-in.	91.2	95.9
1-in.	95.9	98.7
0.5-in.	98.7	97.4
2-in.	97.4	90.1
1.5-in.	90.1	95.3
1-in.	95.3	98.2
0.5-in.	98.2	98.2
Deviation of single deter- mination from mean:		
Average	±2.1	1.1
Maximum	±9.8	2.9

Through 5-in., on 3-in. screen

On Screen analysis after test, cumulative per cent	Ala. No. 8 (Av. of 9 tests) (47 pieces in 50-lb. sample)	Ala. No. 5 (Av. of 9 tests) (60 pieces in 50-lb. sample)
2-in.	75.8	86.1
1.5-in.	86.1	92.8
1-in.	92.8	96.2
0.5-in.	96.2	71.8
2-in.	71.8	86.0
1.5-in.	86.0	94.0
1-in.	94.0	98.0
0.5-in.	98.0	98.0
Deviation of single deter- mination from mean:		
Average	±1.8	1.1
Maximum	±3.8	2.5

Table VI shows a series of tests made on coke sized to pass a 3-in. and remain on a 2-in. screen and to pass a 5-in. and remain on a 3-in. screen. These determinations were made in the hope of securing more reproducible results, on account of the increased number of pieces in the 50-lb. sample and the uniformity obtained by the closer sizing.

FIG. 3

Results indicate somewhat better reproducibility. The interesting development from these tests lay in the data obtained when the material passing a 2-in. screen after the shatter test was subjected to further screen analysis. It will be seen that whereas Cokes 8 and 5 show 76 per cent and 72 per cent, respectively, on the 2-in. screen, the value on the 1.5-in. screen, 86 per cent, is identical for the two cokes. When the 0.5-in. screen is used as the indicator of the shattering effect, we find that 96 per cent of Coke 8 remained on

the screen as against 98 per cent of Coke 5. The producer of Coke 5, on being reproached for the inferiority of his product, might well point out that screening on a 2-in. screen

FIG. 4—TUMBLER TEST APPARATUS

is a more or less empirical procedure and that his coke showed less material passing the 0.5-in. screen than did Coke 8. It is therefore believed desirable to use a number of screens as indicators of the resistance to shattering.

Table VII compares shatter test results on four cokes where the material after the test has been subjected to screen analysis. This table indicates the desirability of using the four screens, for it shows that Cokes 8 and 5 differ little in resis-

TABLE VII—COMPARISON OF SHATTER TEST RESULTS WHEN FOUR SCREENS ARE EMPLOYED

COKE	Screen Analysis after Test, Cumulative Per cent			
	On 2-in.	1.5-in.	1-in.	0.5-in.
Alabama No. 8	75.8	86.1	92.8	96.2
Alabama No. 5	71.8	86.0	94.0	98.0
Benham	59.0	72.5	83.7	94.9
Illinois	41.6	62.0	81.2	96.0

tance to shattering, while the Benham and Illinois cokes are more fragile, whatever screen is employed as indicator.

It is not believed advisable to change the design of the present apparatus, although more reproducible results would no doubt be obtained if a larger apparatus and correspondingly larger sample of coke were employed. From two to five duplicate determinations (the number depending on the variation between duplicate test results with the coke in question) should be made.

We desire a value from the shatter test procedure which will show the intrinsic merit of the coke, a value by which cokes varying widely in physical characteristics may be compared. From our data it is evident that attention should be paid to the size of coke pieces taken. For example, the shatter test value on Coke 8 was 72 per cent when pieces half the width of the oven were used and 76 per cent when run-of-oven coke was used. If the run-of-oven coke had been handled more before the test, this result might have been still higher.

The size and number of the large or "full length" pieces vary considerably between different plants. The advisability of employing a standard size should be considered. For the present, lacking the large amount of data necessary to determine the effect of sizing on the absolute and relative value of the shatter test result, it is recommended that large pieces about half the width of the oven be employed. With beehive coke, pieces 7 to 10 in. in length should be used, the sample being obtained as recommended in the tentative specifications of Committee D-6.

In screening the coke after the shatter test, it has been found best to put through the screen all pieces which will go through in any position. This procedure has given a better reproducible value than any method of shaking.

DETAILED DATA OF TUMBLER TEST DETERMINATIONS

The large samples of coke used for shatter test determinations were employed in making the tumbler tests. In the tentative specifications of the A. S. T. M., coke for the test is sized to pass a 3-in. and remain on a 2-in. square mesh screen. Owing to the difficulty experienced with Coke 8 in duplicating results when this size coke was employed,

FIG. 5

a series of tests was made with various sizes of coke. A number of experiments were made to investigate the possibility of decreasing the time required for the test.

Groups of five to fifteen samples were prepared at the same time. Large pieces were broken to pass the 3-in. screen and remain on the screen chosen for the lower limit. The sample was well mixed and 25-lb. portions were weighed out for the tests.

TABLE VIII—SUMMARY OF TUMBLER TEST DATA

COKE	No. of Determinations	Screen Analysis after Test, Accumulative Per cent on Screen					Av. Diameter of Coke Pieces after Test, in.	REMARKS
		2-in.	1.5-in.	1-in.	0.5-in.	0.25-in.		
Alabama:								
No. 1	2	12.7	42.0	57.4	69.9	70.1	1.15	
No. 2	2	10.0	40.0	56.5	71.0	73.0	1.14	
No. 3	2	15.1	36.1	51.2	65.6	68.1	1.10	
No. 4	2	12.8	38.6	54.2	68.1	67.0	1.10	
No. 5a	5	12.2	38.6	58.8	72.5	74.7	1.15	16.5-hr. coke
No. 5b	10	12.3	34.9	53.1	68.7	72.5	1.10	16-hr. coke
No. 1c	8	10.6	36.8	55.2	68.6	70.7	1.09	15.5-hr. coke
No. 5d	5	18.1	34.4	58.6	65.7	67.6	1.14	24-hr. coke, in stock 1 year
No. 5e	5	21.5	43.3	57.7	69.5	71.1	1.24	25-hr. coke
No. 6	3	10.2	37.0	53.7	71.2	73.6	1.10	
No. 7	3	14.5	45.1	59.4	70.0	71.4	1.21	
No. 8	2	10.2	43.2	59.1	72.2	73.6	1.24	
No. 9	3	14.3	38.8	57.3	71.3	73.6	1.17	
No. 10	4	14.2	38.9	54.0	66.8	67.9	1.12	
No. 11	2	18.2	51.9	61.4	65.6	73.0	1.25	
Benham	3	11.0	25.4	41.8	69.2	72.8	0.99	
Cornellsville	5	18.1	39.2	52.8	68.5	70.6	1.13	
Illinois	8	2.6	12.3	33.6	72.5	77.5	0.85	
Pitch coke	3	37.6	71.1	75.1	75.3	75.6	1.16	

TABLE IX—REPRODUCIBILITY OF TUMBLER TEST DETERMINATIONS

COKE	No. of Determinations	Mean "Hardness" No. ¹	Deviation of Single Determinations from Mean	
			Average	Maximum
Alabama No. 8	13	73.5	±1.2	±2.5
Alabama No. 5	18	70.7	0.4	0.9
Benham	5	72.8	0.9	2.3
Illinois	8	77.5	0.6	2.0

¹ Percentage of original sample remaining on 0.25-in. screen after test.

TABLE X—TUMBLER TESTS WITH VARIOUS SIZES OF COKE

SIZE OF COKE THROUGH	No. OF TESTS	"HARDNESS" NUMBER ¹			
		Alabama No. 8		Alabama No. 5	
		Mean Value	Deviation of Single Determinations from Mean	Mean Value	Deviation of Single Determinations from Mean
3-in.	2-in.	25	5	25	5
3	1	6	5	78.5	1.1
3	1.5	5	7	75.6	0.9
3	2	13	10	73.5	1.2
3	2.5	6	..	75.7	3.0
2.5	2	3	..	76.7	0.9
2	1	..	5	..	..
2	0.5	25	11	79.6	1.2
1.5	0.5	5	..	81.6	1.2
0.75	0.25	5	..	90.4 ²	0.5

¹ Percentage of original sample remaining on 0.25-in. screen after test.

² Percentage of original sample remaining on 0.17-in. screen after test.

TABLE XI—EFFECT OF DURATION OF TUMBLER TEST AS SHOWN BY SCREEN ANALYSIS, PER CENT

Time Rotated—Minutes	15	30	45	60	75	90	105	120
On 2-in.:								
Alabama No. 8	46.1	33.8	24.6	17.8	13.9	12.2	9.9	8.6
Alabama No. 5	34.8	21.1	11.8	7.5	4.5	2.8	2.3	1.1
Illinois	8.8	3.9	1.7	0.9	0.7	0.7	0.6	0.6
On 1.5-in.:								
Alabama No. 8	66.7	55.2	46.1	39.2	34.5	31.3	27.8	24.7
Alabama No. 5	62.7	48.8	39.4	32.9	26.4	22.2	18.6	15.1
Illinois	28.6	19.0	12.6	7.9	5.6	4.1	2.8	2.7
On 1-in.:								
Alabama No. 8	78.4	68.4	60.5	54.1	49.8	45.5	41.8	38.0
Alabama No. 5	76.9	66.0	57.8	51.1	45.5	40.6	36.4	32.8
Illinois	54.5	42.9	33.9	27.6	23.2	19.4	15.8	13.2
On 0.5-in.:								
Alabama No. 8	87.2	80.5	73.7	68.4	64.2	60.4	56.2	52.9
Alabama No. 5	85.8	78.2	71.0	65.2	60.3	55.9	52.5	49.2
Illinois	84.5	77.4	72.2	66.7	62.1	57.9	54.4	51.9
On 0.25-in.:								
Alabama No. 8	88.8	82.3	75.5	70.1	66.0	62.1	57.8	54.5
Alabama No. 5	87.7	80.1	72.9	67.0	62.1	57.7	54.4	51.0
Illinois	88.3	81.8	76.8	71.7	67.1	63.3	60.3	56.8
Average size of material after test, inches:								
Alabama No. 8	1.75	1.51	1.32	1.17	1.06	0.99	0.91	0.84
Alabama No. 5	1.64	1.37	1.15	1.02	0.90	0.81	0.76	0.69
Illinois	1.14	0.96	0.85	0.74	0.68	0.63	0.58	0.56

Table VIII summarizes results obtained with the standard procedure, using 3- to 2-in. coke. Figures in the column headed "0.25-in." give the "hardness number" as usually reported. Table IX shows the reproducibility obtainable with duplicate determinations. Table X summarizes results obtained when various sizes of coke were employed. Table XI shows the effect of the duration of the test. The rotation of the drum was stopped at intervals of 15 min. over a period of 120 min. and the usual screen analysis made. The entire sample was put back in the apparatus after each screening.

The tumbler test procedure seems capable of producing more duplicable results than does the shatter test procedure,

FIG. 6—SCREEN ANALYSIS OF COKES AFTER TUMBLER BARREL TEST

the result probably of smaller and closer sizing of the sample and the duplicable mechanical nature of the test.

As seen from Table XI reducing the upper size limit (1) gives somewhat more reproducible results with Coke 8 but does not increase the reproducibility with Coke 5; (2) gives results for the two cokes which show a decreasing difference until the 0.75- to 0.25-in. size is reached, where results for both cokes are practically identical; and (3) gives results whose values are increasingly higher as the size of the material tested is diminished.

The data in Table XI suggest that two factors determine the amount of coke broken to pass the 0.25-in. screen: (1) impact, and (2) abrasion. The smaller the size of the coke pieces, the less will be the effect of impact and consequently the higher will be the "hardness" number or the percentage of coke remaining on a 0.25-in. screen after the test. This suggests further that a coke which shatters easily and is broken into small pieces early in the test period may come through the test with a very high percentage remaining on the 0.25-in. screen. The crushing due to impact of the large pieces will have been eliminated early in the procedure without necessarily crushing a large amount of the coke sufficiently fine to pass a 0.25-in. screen. This suggests, further, that the tumbler test, as at present made, has little value as a criterion for judging a variety of cokes.

Table VIII and Fig. 6 bring out this point very clearly. If judged according to the standard procedure for the tumbler test, we should say that the Illinois coke was extremely hard since it shows 77.5 per cent remaining on the 0.25-in. screen. However, we note that only 15 per cent of the Illinois coke