MECHANICAL AND RELATED PROPERTIES OF SOME EASTERN COALS

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In the mining, preparation, handling, and utilization of coal, the mechanical characteristics of the coal influence both its breakage and the operation of the equipment used. Numerous methods have been developed to measure the hardness, strength, and grindability properties of coal.[1,2,3]* One of these methods, the Hardgrove grindability test, has been widely used to determine the relative ease of grinding coals. This grindability index measures the hardness, strength, and fracture characteristics of coal.[1,4] Further evidence that this empirical index measures a physical coal property was proposed by Brown.[5] Consequently, the Applied Research Laboratory of U. S. Steel determined the Hardgrove grindability indexes of channel samples from mines in the Pittsburgh seam in the Pocahontas seam, and in eastern Kentucky seams (High Splint seam, Winifrede seam, and C seam). These data were obtained to provide information for the selection of face equipment in mining and of facilities for the preparation of coal. In addition, the relative abrasiveness, microtumbler strength,** and Brabender hardness (power required in grinding) of each coal were determined, because these characteristics should also have an important bearing on the selection of equipment.

This paper presents the data obtained from the four types of tests; the results of each test are related to the chemical and petrographic properties of the coals and also compared with one another. In addition, the paper presents a brief discussion of the application of mechanical properties to the coal industry.

The sources of the coal samples used in this investigation are listed in Table I. All samples were full-length channel samples. The Mine No. A, B, C, and D samples from the Pittsburgh seam represent four channel samples that were blended without crushing. The other channel samples were treated as single samples. The samples, which weighed about 200 pounds each, were processed by the method shown schematically in Figure 1. All samples were air-dried to about 1 percent moisture content. The proximate and sulfur analyses, listed in Table II, were determined by ASTM procedures. The petrographic analyses, Table III, were conducted according to the standard method developed by U. S. Steel.[6]

The Hardgrove grindability test was conducted according to ASTM standard D409-51. The Hardgrove apparatus has eight 1-inch balls that roll on a stationary ring and are driven by a rotating ring above. The index represents the weight of material passing 200-mesh sieve after 60 revolutions in the machine. The reproducibility of the index obtained on a sample should check within 2 percent.

The Brabender hardness test was conducted in the Brabender Plastograph adapted for operation as the hardness tester.[7,8] This instrument has a cone mill and an electrodynameter to rotate the grinding element. A 200-gram sample of minus 4 mesh or 16- by 30-mesh coal was fed into the crusher. The power required by the crusher in grinding the coal was recorded in respect to time by the electrodynameter

* See references.
** Also known as microstrength index.

in the form of a diagram. The area drawn in this diagram is used as the hardness index, which is expressed in kilogrammeters. The standard deviation for the entire range was found to be ± 6.5 index points.

The microtumbler test (resistance to degradation by abrasion and impact) was conducted in an apparatus consisting of 2 stainless steel tubes, 1 inch in internal diameter and 12 inches long.[9)] The two tubes are mounted on a frame that can be rotated at a constant speed. Duplicate 2-gram samples of 14- by 28-mesh coal were placed in the tubes with twelve 5/16-inch diameter steel balls and tumbled for 800 revolutions. The breakage was then determined by a sieve analysis and the amount of plus 100-mesh material was recorded as the microtumbler strength. In this test using coal, the standard deviation was ± 1.3 index points.

The abrasion test was conducted on an apparatus consisting of a mortar that holds the charge of coal, a shaft, an arm assembly to hold the wearing blades, and a drill press to provide rotation.[10)] The test consists of rotating the four removable blades at 1500 rpm for 12,000 revolutions in a 4-kilogram sample of minus 4-mesh air-dried coal. After each test the wearing blades are thoroughly cleaned and weighed. The weight loss sustained by the blades in milligrams is used as the index of abrasion. The standard deviation was ± 1.7 index points over the range tested.

Mechanical Tests

The results obtained from each of the four tests used to measure the mechanical properties of the coal are presented in Table IV and compared with one another in the following discussion.

In the Hardgrove grindability test the Pittsburgh-seam coals showed indexes from 59 to 63, the eastern Kentucky coals from 41 to 51, and the Pocahontas-seam coals from 90 to 105. Note that the lower the index, the more difficult it is to grind the coal. These data are in good agreement with those reported by the Bureau of Mines.[11)]

The Brabender hardness test gives a measure of the power requirement in grinding the coals; thus, the index represents the work done in grinding the sample. The higher the number the more power is required to grind the sample. As expected, an inverse relationship exists between the Brabender hardness index and the Hardgrove grindability index (Figure 2, Table IV). The correlation with the values obtained from the minus 4-mesh coal was much better than with those from the 16- by 30-mesh coal, even though the Hardgrove grindability test requires 16- by 30-mesh coal. This test showed the differences among the coals from three different locations, as well as considerable variability within each location (Figure 2). This variability may be significant since the extreme values ranged more than would be expected by the standard deviation.

Since the microtumbler strengths of coal indicate the resistance to degradation by abrasion and impact, the natures of this test and the Hardgrove test are very similar. This similarity is clearly shown in the excellent correlation obtained between the results of these two tests (Figure 3). Hence, this test can be used to calculate the Hardgrove grindability index, or vice versa.

The results of the abrasion test are also presented in Table IV. Comparison with the previous work[10)] is limited since that investigation included only one coal, a Pittsburgh-seam coal, in common with the present study. However, the indexes for coking coals were similar. The relationship between the index of abrasion and grindability is shown in Figure 4. From this relationship, these tests must be measuring different properties of the sample. The comparison of these results will be discussed further hereafter.

Factors Affecting the Hardness, Abrasion, and Grindability of Coal

Because of the similarity of the Hardgrove grindability, Brabender hardness, and microtumbler-strength tests, only the results relating the grindability index with the chemical and petrographic analyses of the coals are presented. The relationships of the index of abrasion and the chemical and petrographic analyses are discussed separately.

Hardgrove Grindability

Figure 5 shows the relationship of coal rank (expressed by volatile-matter content) to the grindability index. Confirming published data,[1,4)] the index increased as the volatile-matter content decreased. The trend is then reversed with coals having volatile-matter contents of less than 23 percent. Since the average reflectance of the vitrinoids correlate with the volatile-matter content,[6)] a similar relationship was obtained in Figure 6 between the average reflectance and the grindability index. This relationship of rank and grindability index may be associated with the porosity[12,13)] and elastic properties[13,14)] of the various rank coals.

The effect of ash content on grindability is shown in Figure 7. The low-volatile coals tended to become more difficult to grind when the ash content increased. However, ash content had no apparent effect on the grindability of the high-volatile coals. The low-volatile coals are much softer or more friable than the high-volatile coals and relatively easy to grind; therefore, an increase in hard ash material would make the low-volatile coals harder to grind. In contrast, a higher percentage of ash in the high-volatile coals would have little influence on the grindability, since the coal substance is apparently harder than the ash. Other investigators reported that additions of ash to coals having indexes from 60 to 110 tended to increase or decrease the index to 75.[15)] However, ash content per se does not exert a primary effect on the resistance to grinding, because the type of mineral matter is the main determining factor.

The effect of petrographic constituents on the hardness or strength of coal has been known for some time.[1,2)] In a more recent investigation Harrison discussed the effects of petrographic composition in the breakage of coal.[16)] At the ARL,[17)] the total tough coal was related with the microtumbler strength, which has been shown to correlate well with the grindability index. Therefore, the summation of the micrinoids, resinoids, and exinoids (previously termed total tough coal) was correlated with the Hardgrove grindability indexes. The relationship is shown in Figure 8. A good correlation was obtained with the high-volatile coals from the Pittsburgh seam and eastern Kentucky, where the grindability index decreased as the amount of micrinoids, exinoids, and resinoids increased. In the low-volatile coal samples from the Pocahontas seam, the grindability index increased as these macerals increased. An examination of the data of these low-volatile coals (Tables II and III) indicates that those samples with the least amount of micrinoids, exinoids, and resinoids are associated with the highest rank (Figure 5) and highest ash contents (Figure 7) of these low-volatile coals; whereas those with the greatest amount of micrinoids, exinoids, and resinoids are associated with the lowest rank (Figure 5) and lowest ash contents (Figure 7). Therefore, the correlation obtained for the high-rank coals is doubtful, particularly when the small range (approximately 8 to 14 percent) of the amounts of these entities are considered.

Index of Abrasion

The test results indicated that the rank or the petrographic composition of the coal did not show significant relationships with the index of abrasion, the ash or foreign material in the coal being mainly responsible for the abrasion. The relationship of ash content and index of abrasion is shown in Figure 9. Other investigators have reported similar conclusions.[1,10] However, the difference at the same ash content level for coal of similar characteristics are significant, as indicated by the standard deviation of the test. Additional studies are required to determine the causes for this variation.

Referring to Figure 4, the relationship of these two indexes can most likely be associated with rank for the grindability index and ash content or mineral matter for the index of abrasion. For example, the eastern Kentucky samples possessed the lowest grindability index with the highest volatile matter and tough coal, while the index of abrasion of these samples was low because of their very low ash contents.

Application of Mechanical Properties

At the ARL the power required by a mining machine to rip coal was qualitatively related to petrographic properties of the Pittsburgh-seam coal and microtumbler strength.[17,18] Because of the excellent correlation between the grindability index and the microtumbler strength, the Hardgrove grindability index should also show the power required for mining coal with a continuous miner. Since the petrographic analyses showed only a good relationship with the grindability index of high-volatile A coals, additional studies would be required on higher rank coals to determine the influence that their petrographic composition has on the strength of coal or the power requirements for mining this type of coal.

It is interesting to note that the British have been studying the rheological behavior of coal to provide basic data in the design of coal-winning machinery. Some fundamental studies have related coal plowing force,[19] dust formation,[20] and the penetration resistance to a wedge[21] to the strength properties of the coal. Evans came to the conclusion that friable coal fails in shear and hard coal fails in tension. His results indicate that blades should be kept very sharp to efficiently plow hard coal, sharp blades not being so necessary for friable coals.[22] In another study, the friction between coal and metal surfaces was found to be influenced by the rank of coal.[23] The relationship to rank was similar to that obtained with heat of wetting, Knoop hardness, compressive strength, tensile strength in bending and impact strength. Brown and Hiorns have summarized this British work.[2]

This investigation as well as others[24] indicate that the basic information on the strength properties should be useful in the design, selection, and operation of equipment used in the mining, preparation, handling, and utilization of coal. Of particular interest in the last-named field has been the study of the breakage or comminution of coal.[2,5]

Summary

The test results showed that the Hardgrove grindability indexes of the low-volatile coals from the Pocahontas seam were from 90 to 105, those of the high-volatile coals from the Pittsburgh seam from 59 to 63, and those of the coals of eastern Kentucky from 41 to 51. The Brabender hardness indexes and the microtumbler strengths of these coals correlated with the grindability indexes. However, the Brabender hardness index did show considerable variability between samples from the same seam or location. The index of abrasion appeared to measure different properties of the samples and did not show a significant relationship with the other indexes.

The rank of the coal influenced the grindability index as shown in the published data. The index increased as rank decreased; but the trend was reversed with coals having volatile-matter contents (dry ash-free basis) of less than 23 percent. The ash content appeared to decrease the index of the low-volatile coals but did not have an effect on the index of high-volatile coals. In contrast, the amount of micrinoids, exinoids, and resinoids correlated well with the grindability index of these high-volatile coals, but their influence on the index of low-volatile coal is doubtful.

In the index of abrasion, the coal substance apparently contributed little to the abrasion, the ash or foreign material in the coal being mainly responsible for the abrasion.

Previous work at the ARL had shown qualitatively that the petrographic composition and microtumbler strength could be related to the power required by a continuous miner. In this investigation the grindability index has been correlated with both microtumbler strength and petrographic composition, so that this index could also be used. Additional study would be necessary for relating the indexes of high-rank coals to actual practice in the mine.

These results and those of other investigators have indicated that basic information on the mechanical properties of coal should be useful in the design, selection, and operation of equipment in the mining, preparation, handling, and utilization of coal.

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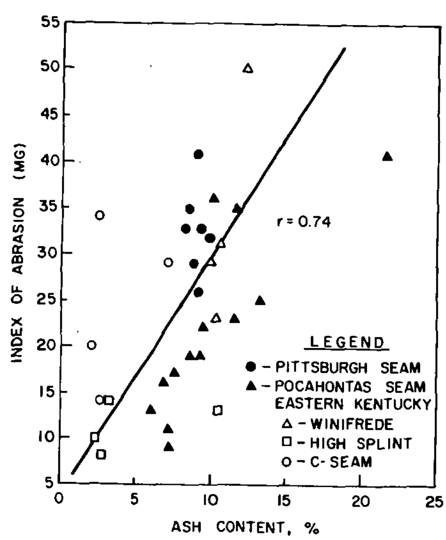

Figure 9. Effect of Ash on the Index of Abrasion

Table I

Channel Sample Identification

Seam	Code Mine	Code Section	County, State
Pittsburgh	A	Composite of 4 channel samples	Greene, Pa.
Pittsburgh	B	Composite of 4 channel samples	Greene, Pa.
Pittsburgh	C	Composite of 4 channel samples	Greene, Pa.
Pittsburgh	D	Composite of 4 channel samples	Washington, Pa.
Pittsburgh	E	1	Washington, Pa.
Pittsburgh	E	2	Washington, Pa.
Pittsburgh	E	3	Washington, Pa.
Pittsburgh	E	4	Washington, Pa.
Eastern Kentucky			
C Seam	F	1	Harlan, Ky.
C Seam	F	2	Harlan, Ky.
C Seam	F	3	Harlan, Ky.
C Seam	F	4	Harlan, Ky.
High Splint	G	1	Harlan, Ky.
High Splint	G	2	Harlan, Ky.
High Splint	G	3	Harlan, Ky.
High Splint	G	4	Harlan, Ky.
Winifrede	H	1	Harlan, Ky.
Winifrede	H	2	Harlan, Ky.
Winifrede	H	3	Harlan, Ky.
Winifrede	H	4	Harlan, Ky.
Pocahontas No. 3	I	1	McDowell, W. Va.
Pocahontas No. 3	I	2	McDowell, W. Va.
Pocahontas No. 3	I	3	McDowell, W. Va.
Pocahontas No. 3	I	4	McDowell, W. Va.
Pocahontas No. 3	J	1	McDowell, W. Va.
Pocahontas No. 3	J	2	McDowell, W. Va.
Pocahontas No. 4	K	1	McDowell, W. Va.
Pocahontas No. 4	K	2	McDowell, W. Va.
Pocahontas No. 4	K	3	McDowell, W. Va.
Pocahontas No. 4	K	4	McDowell, W. Va.
Pocahontas No. 3	L	1	McDowell, W. Va.
Pocahontas No. 3	L	2	McDowell, W. Va.
Pocahontas No. 3	L	3	McDowell, W. Va.
Pocahontas No. 3	L	4	McDowell, W. Va.

Table II

Proximate Analysis of Mine Channel Samples

Seam	Mine Code & Section	Proximate Analysis*, percent (minus 4 mesh) VM	VM, (daf) basis	FC	Ash	Sulfur, percent	Proximate Analysis, percent (16 by 30 mesh) VM	VM, (daf) basis	FC	Ash	Sulfur, percent
Pittsburgh	A	36.6	40.5	53.7	9.7	2.47	36.8	40.5	54.1	9.1	2.10
Pittsburgh	B	36.3	39.8	54.8	8.9	2.52	36.7	40.0	55.1	8.1	2.00
Pittsburgh	C	36.4	39.7	55.4	8.2	2.31	37.1	40.4	54.7	8.2	2.26
Pittsburgh	D	29.3	38.8	46.2	24.5	1.29	30.1	39.6	45.8	24.1	1.11
Pittsburgh	E-1	34.9	38.4	56.0	9.1	0.98	35.0	38.1	56.9	8.1	0.95
Pittsburgh	E-2	36.4	40.2	54.2	9.3	1.82	35.8	38.8	56.4	7.8	1.43
Pittsburgh	E-3	34.4	37.6	57.2	8.4	1.14	34.3	37.4	57.5	8.2	1.02
Pittsburgh	E-4	34.4	37.8	56.7	8.8	1.73	35.0	38.0	57.1	8.9	1.62
Eastern Kentucky											
C Seam	F-1	35.0	37.6	58.0	7.0	0.53	34.8	37.5	58.0	7.2	0.50
C Seam	F-2	36.3	37.1	61.6	2.0	0.43	36.6	37.3	61.5	1.9	0.41
C Seam	F-3	37.2	38.2	60.1	2.7	0.48	37.3	38.3	60.2	2.5	0.46
C Seam	F-4	36.1	37.0	61.5	2.4	0.44	36.6	37.3	61.4	2.0	0.40
High Splint	G-1	36.5	37.7	60.3	3.2	0.50	37.6	38.8	59.3	3.2	0.51
High Splint	G-2	35.0	39.1	54.6	10.4	0.56	36.2	40.3	53.7	10.1	0.54
High Splint	G-3	37.8	38.7	59.8	2.4	0.46	38.6	39.5	59.1	2.3	0.47
High Splint	G-4	38.5	39.6	58.7	2.8	0.50	39.0	40.1	58.2	2.8	0.50
Winifrede	H-1	34.1	38.1	55.4	10.5	2.32	34.5	38.3	55.5	10.0	1.78
Winifrede	H-2	34.6	39.4	53.3	12.1	1.81	34.8	39.3	53.7	11.5	1.65
Winifrede	H-3	35.4	39.4	54.4	10.2	1.07	35.9	39.8	54.3	9.8	0.99
Winifrede	H-4	36.1	40.0	54.1	9.8	1.69	36.7	40.5	53.9	9.4	1.60
Pocahontas No 3	I-1	15.9	17.2	76.5	7.6	0.67	15.7	17.0	76.6	7.7	0.64
Pocahontas No. 3	I-2	15.4	16.5	77.7	6.9	0.60	15.6	16.8	77.4	6.9	0.61
Pocahontas No. 3	I-3	15.0	17.0	73.4	11.6	0.68	14.8	16.6	74.2	11.0	0.63
Pocahontas No. 3	I-4	14.7	16.9	72.1	13.2	0.89	14.4	16.6	72.1	13.5	0.89
Pocahontas No. 3	J-1	17.1	18.4	75.7	7.2	0.61	17.1	18.5	75.2	7.7	0.58
Pocahontas No. 3	J-2	17.2	19.4	71.3	11.5	0.52	16.6	18.8	71.6	11.8	0.51
Pocahontas No. 4	K-1	15.2	17.8	70.1	14.7	1.23					
Pocahontas No. 4	K-2	15.0	16.6	75.6	9.4	0.61					
Pocahontas No. 4	K-3	15.2	16.9	74.8	10.0	0.82					
Pocahontas No. 4	K-4	14.1	18.0	64.4	21.5	0.69					
Pocahontas No. 3	L-1	19.0	20.8	72.4	8.6	0.51					
Pocahontas No. 3	L-2	20.0	21.3	74.0	6.0	0.56					
Pocahontas No. 3	L-3	21.4	23.6	69.2	9.3	0.58					
Pocahontas No. 3	L-4	20.5	22.1	72.4	7.2	0.57					

* VM - volatile matter FC = fixed carbon

Table III

Petrographic Analysis* of Mine Channel Samples

Seam	Code Mine & Section	Vitrinoid Type 7	8	9	10	11	12	13	14	15	16	17	18	19	SFR	SFI	F	Tough Coal M	E	R	Total	MM
Pittsburgh	A	7.0	46.2	16.8											0.6	1.2	6.3	9.3	5.5	1.0	15.8	6.1
Pittsburgh	B	5.1	34.7	31.1	1.4										1.2	2.5	5.5	7.2	4.9	0.8	12.9	5.6
Pittsburgh	C	0.7	38.7	29.7											1.3	2.7	6.5	9.8	5.1	0.4	15.3	5.1
Pittsburgh	D		26.4	36.3	0.7	1.3	0.7	0.7							1.1	2.2	4.4	5.8	4.4	0.8	11.0	15.2
Pittsburgh	E-1		20.9	45.5	5.0										0.9	1.7	5.6	8.8	5.8	0.8	15.4	5.3
Pittsburgh	E-2		35.8	34.4											1.2	2.3	4.6	10.7	5.3	-	16.0	5.7
Pittsburgh	E-3	0.7	23.0	42.4	3.5										1.2	2.3	5.4	11.1	5.1	0.4	16.6	4.9
Pittsburgh	E-4		15.2	56.6	0.7										0.8	1.7	3.9	9.8	5.1	0.8	15.7	5.4
Eastern Kentucky																						
C Seam	F-1		1.3	34.9	27.3										1.3	2.5	6.7	12.6	8.6	0.7	21.9	4.1
C Seam	F-2		2.7	28.0	35.4	0.7									1.3	2.5	5.0	14.6	8.0	0.6	23.2	1.2
C Seam	F-3		1.9	24.6	38.1										1.2	2.4	6.0	15.5	8.0	0.8	24.3	1.5
C Seam	F-4		0.6	27.7	36.1										0.9	1.5	6.8	16.2	8.2	0.4	24.8	1.4
High Splint	G-1	3.6	25.0	22.4											2.9	5.8	7.1	22.7	8.3	0.4	31.4	1.8
High Splint	G-2	14.3	24.4	11.7	0.5										3.0	6.0	6.7	18.0	8.8	0.7	27.5	5.9
High Splint	G-3	0.9	18.3	26.5											3.8	7.6	5.3	23.3	11.4	1.5	36.2	1.4
High Splint	G-4	11.9	26.4	15.6											2.1	4.1	7.0	21.8	8.2	1.3	31.3	1.6
Winifrede	H-1	0.6	24.0	32.7											2.7	5.5	4.6	14.7	7.5	1.2	23.4	6.5
Winifrede	H-2	1.0	25.9	24.3	0.5										2.3	4.7	7.1	17.0	8.3	1.3	26.6	7.6
Winifrede	H-3		28.8	25.4	3.5										2.1	4.2	6.0	16.4	6.3	1.4	24.1	5.9
Winifrede	H-4	0.5	27.7	24.5											2.0	3.9	6.6	19.9	8.2	1.3	29.4	5.9
Pocahontas No. 3	I-1											38.0	32.3		-	5.5	8.2	11.7	-	-	11.7	4.3
Pocahontas No. 3	I-2										0.7	42.5	25.8	0.7	-	6.0	9.8	10.2	0.4	-	10.6	3.9
Pocahontas No. 3	I-3											33.3	31.3	3.4	-	7.3	8.3	9.7	0.1	-	9.8	6.6
Pocahontas No. 3	I-4											21.5	41.0	7.0	-	5.7	9.2	7.5	0.4	-	7.9	7.7
Pocahontas No. 3	J-1										42.5	30.7			1.3	5.4	6.2	9.7	0.1	-	9.8	4.1
Pocahontas No. 3	J-2									21.5	42.4	5.6			-	7.6	6.5	9.5	0.4	-	9.9	6.5
Pocahontas No. 4	K-1								0.7	1.4	6.4	24.1	31.9	6.4	0.9	3.7	6.2	9.3	0.3	-	9.6	8.7
Pocahontas No. 4	K-2											18.7	33.5	14.7	-	5.9	9.3	12.4	0.2	-	12.6	5.3
Pocahontas No. 4	K-3										0.7	24.7	36.5	6.9	-	6.5	6.4	12.5	0.1	-	12.6	5.7
Pocahontas No. 4	K-4										15.1	32.3	18.4		0.9	3.7	5.6	10.9	0.1	-	11.0	13.0
Pocahontas No. 3	L-1								33.7	33.0	3.5				1.2	4.6	5.2	13.3	0.6	-	13.9	4.9
Pocahontas No. 3	L-2							1.4	35.5	30.8	0.7				1.2	4.7	8.2	13.2	0.6	-	13.8	3.7
Pocahontas No. 3	L-3							8.4	52.9	8.4					1.8	7.0	3.4	12.8	-	-	12.8	5.3
Pocahontas No. 3	L-4							1.5	45.1	26.2					0.7	3.0	5.8	13.2	0.4	-	13.6	4.1

* M = micrinoids
E = exinoids
R = resinoids

SFR = semifusinoids, reactive
SFI = semifusinoids, inert
F = fusinoids
MM = mineral matter

Table IV

Comparison of Various Methods to Determine Hardness and Grinding Properties of Coal

Seam	Code Mine & Section	Hardgrove Grindability Index	Brabender Hardness Index: Minus 4 Mesh	Brabender Hardness Index: 16 by 28 Mesh	Microstrength Index	Index of Abrasion
Pittsburgh	A	63.5	98.1	145.9	37.8	32
Pittsburgh	B	60.1	77.6	145.0	39.5	41
Pittsburgh	C	62.0	87.6	131.1	--	33
Pittsburgh	D	60.8	84.9	52.4	44.5	99
Pittsburgh	E-1	59.4	108.5	141.7	--	26
Pittsburgh	E-2	60.3	101.1	50.3	41.0	33
Pittsburgh	E-3	60.3	91.2	127.8	--	35
Pittsburgh	E-4	60.9	109.7	139.1	38.7	29
Eastern Kentucky						
C Seam	F-1	50.9	125.4	144.0	39.4	29
C Seam	F-2	49.5	129.9	145.1	--	20
C Seam	F-3	50.8	139.9	125.5	--	14
C Seam	F-4	52.3	97.0	132.5	44.3	34
High Splint	G-1	43.2	127.8	114.0	--	14
High Splint	G-2	42.2	94.7	124.3	49.9	13
High Splint	G-3	41.6	108.3	111.8	--	10
High Splint	G-4	42.9	97.0	116.2	47.1	8
Winifrede	H-1	46.5	126.7	102.7	48.4	31
Winifrede	H-2	45.1	108.4	126.6	--	50
Winifrede	H-3	44.9	129.1	139.3	49.1	23
Winifrede	H-4	45.3	163.4	141.5	--	29
Pocahontas No. 3	I-1	98.4	70.1	138.0	11.1	17
Pocahontas No. 3	I-2	95.1	64.3	129.8	--	16
Pocahontas No. 3	I-3	91.3	65.2	110.5	--	35
Pocahontas No. 3	I-4	89.9	77.1	93.6	13.7	25
Pocahontas No. 3	J-1	97.6	52.5	139.3	--	9
Pocahontas No. 3	J-2	101.1	86.1	151.6	10.8	23
Pocahontas No. 4	K-1	93.4	42.7	89.0	18.5	--
Pocahontas No. 4	K-2	100.3	40.5	102.7	--	22
Pocahontas No. 4	K-3	93.2	28.4	98.1	13.3	36
Pocahontas No. 4	K-4	94.2	54.2	102.5	--	41
Pocahontas No. 3	L-1	104.1	33.6	75.2	--	19
Pocahontas No. 3	L-2	102.2	29.6	78.7	8.7	13
Pocahontas No. 3	L-3	102.1	48.6	77.8	--	19
Pocahontas No. 3	L-4	105.2	32.0	80.0	8.6	11

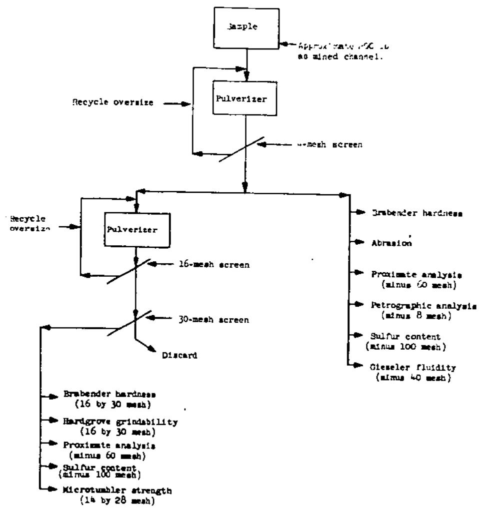

Figure 1. Sampling Procedure

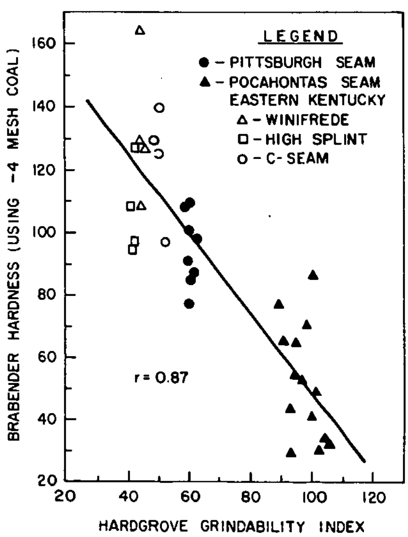

Figure 2. Relationship of Brabender Hardness and Hardgrove Grindability Index

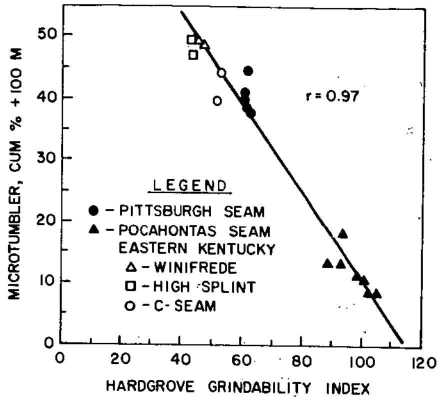

Figure 3. Relationship of Microtumbler Strength and Hardgrove Grindability Index

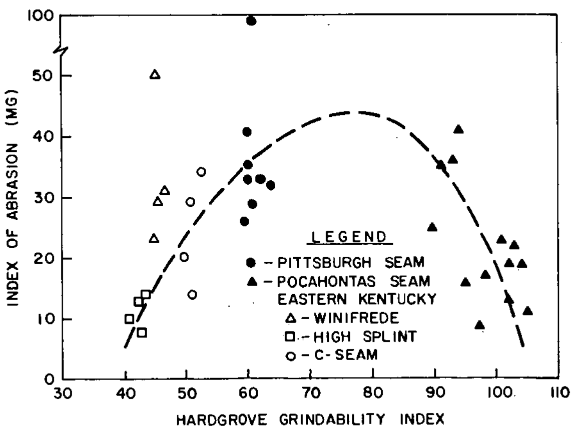

Figure 4. Relationship of Index of Abrasion and Hardgrove Grindability Index

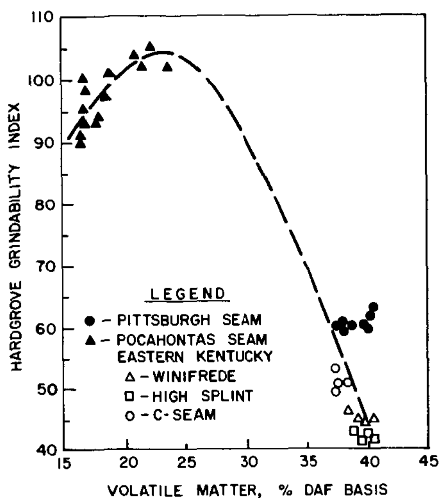

Figure 5. Relationship Between Hardgrove Grindability and Coal Rank

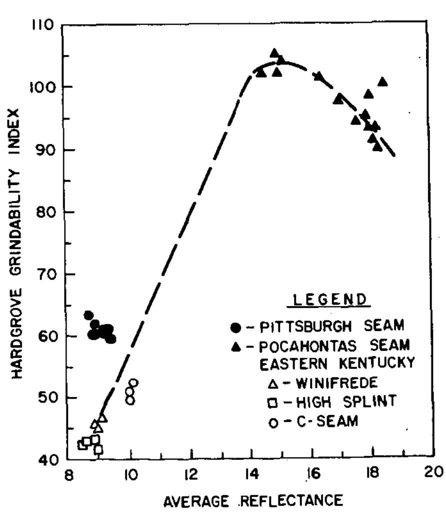

Figure 6. Relationship Between Hardgrove Grindability Index and Rank

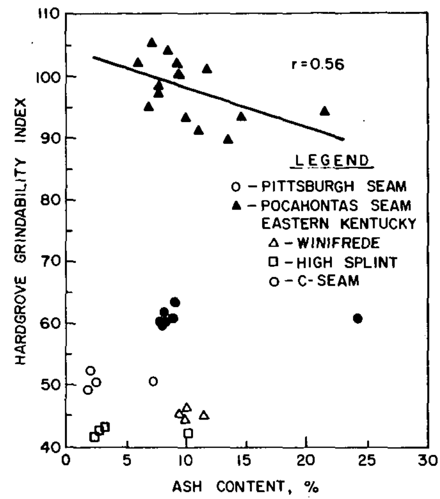

Figure 7. Effect of Ash on Hardgrove Grindability Index

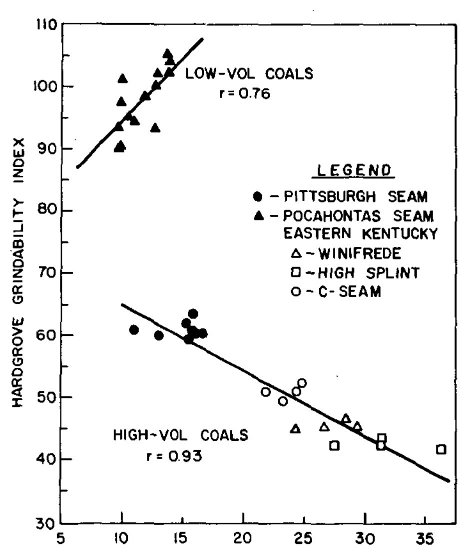

Figure 8. Effect of Petrographic Composition on the Hardgrove Grindability Index