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EFFECT OF FRACTURE MODES ON SHAPE AND SIZE OF COAL PARTICLES AND SEPARATION OF PHASES*

By

J. M. Lytle and L. R. Bunnell
Battelle, Pacific Northwest Laboratory, Richland, Washington 99352
and
K. A. Prisbrey
University of Idaho, Moscow, Idaho 83843

INTRODUCTION

Studies of coal grinding are becoming one of the most important and interesting areas of coal research. Consequently, the Department of Energy sponsored "Study Group on Research Planning for Coal Utilization and Synthetic Fuel Production" emphasized size-dependent phenomena during coal grinding as one of the seven most important areas of research needed for development of an advanced coal and synfuels industry (1, 2). Nearly every use of coal involves grinding to some extent and modern processes are requiring finer and finer coal powders. Knowledge of the properties of these coal powders is essential in developing these processes. For example, knowledge of shapes and sizes of particles is important in defining the viscosity and transport behavior of coal-liquid slurries for combustion or pipeline transport. Knowledge of separation of phases is important in developing beneficiation processes to remove impurities.

The study reported in this paper used microscopy, shape, size and sulfur analyses to show the influence of fracture modes and mechanisms on shape and size of coal particles and separation of phases. The preferential lines of fracture during coal grinding were identified microstructurally and related to the size and shape of particles produced and the separation of mineral and organic phases. For example, weaker phases that were lean in organic sulfur were observed to concentrate into finer particle size ranges and stronger phases that were rich in organic sulfur concentrated into coarser particle size ranges.

EXPERIMENTAL

Two coals of widely differing rank were selected for this study: a lignite from the Fort Union Bed near Savage, Montana and a medium volatile bituminous (MVB) from the Beckley seam near Duo, West Virginia. These two coals (PSOC-837 and PSOC-985) were obtained from the Pennsylvania State University's coal sample bank.

Prior to ball milling, the coals were preground in nitrogen to minus 20 mesh (U. S. standard screen, 840 µm opening size) in a wheel-type pulverizer. The coal (350 g) was transferred in the N_2 atmosphere to a 1.8 L steel ball mill, which was then evacuated and backfilled with helium. During rotation of the mill, coal powders were withdrawn in a long, cylindrical scoop inserted along the axis of rotation through a hole plumbed with a rotary union and ball valves to maintain the atmosphere.

RESULTS AND DISCUSSION

During coal grinding, particle microstructure affected the fracture modes which in turn affected shape and size of particles and separation of phases. Optical micrographs of polished particle cross-sections (Figure 1) illustrate the tendency for separation of organic phases in the early stages of grinding. With both lignite and MVB, fracture tended to proceed preferentially along organic-to-organic interfaces, as shown by the separate and microstructurally more uniform particles already present after the pregrind step and the incomplete but progressing fractures along interfaces in the particles, indicated by arrows.

Fracture also tended to preferentially proceed along mineral-to-organic interfaces and

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cracks and pores. This tendency is illustrated by the scanning electron micrographs of particle cross sections shown in Figure 2. In the lignite particles, cracks and pores--highlighted in the photographs by electron microscope edge effects-- were apparent in the pregrind particles but were depleted after 7 h of grinding. In the MVB particles, mineral inclusions were separated from the organic phases during grinding as shown by the presence of separate mineral particles after 7 h.

Distinct organic phases that were separated during the pregrind step tended to grind at their own individual rates during subsequent grinding (3). The particles that were microstructurally more heterogeneous and contained more cracks and pores were rapidly ground according to the larger set of particle size-dependent rate constants shown in Table I. The stronger particles were ground more slowly according to the set of smaller rate constants.

TABLE I

Breakage rate constants, Si^{a}, (10^{-3} min^{-1}) for lignite grinding where the weaker particles were rate controlling for the first 30 min of grinding. After weaker particles were reduced to fines, the stronger particles controlled the grinding rate.

Particles	Particle size, µm								
	210	149	105	74	53	83	30	20	15
Weaker	10.1	8.2	5.6	4.0	2.8	2.0	1.6	1.0	0.77
Stronger	4.2	2.5	1.4	0.79	0.46	0.26	0.18	0.090	0.046

a. $$\text{rate} = \frac{dm_i}{dt} = -S_i m_i + \sum_{j=1}^{i-1} S_j b_{ij} m_j$$

m_i = mass fraction of size i

S_i = breakage rate constant for size i

b_{ij} = primary breakage fragment distribution

During lignite grinding, the stronger particles contained more organic sulfur than the weaker particles, as can be seen from the particle-by-particle compositional analysis done previously (4). The weaker, more porous, particles averaged 0.26% organic sulfur whereas the stronger, less porous, particles averaged 0.46% (4). During grinding, the sulfur content of a given particle size range steadily increased as the weaker particles passed through that size range and the stronger particles lingered (see Table II). Thus, during grinding, sulfur-rich and sulfur-lean particle size ranges developed, depending on the grinding time.

TABLE II

Average organic sulfur content (percent) of lignite particles as determined by particle-by-particle analysis of particle cross sections using X-ray fluorescence in a scanning electron microscope.

Particle Size, µm	Grinding Time, Minutes		
	15	60	420
20 - 30	0.37	0.38	0.45
5 - 10	0.11	0.19	0.23

The microstructure of coal is a major factor in the sizes and shapes of particles produced during grinding. One of the best examples of the effect of microstructure on shape is the needle-like and plate-shaped particles produced from the fracture of the weaker particles during the initial stages of grinding (Figure 3). As seen in Figure 3, in the 10 to 15 µm particle size range, many needle-like or plate-shaped particles were present after 15 min of grinding, but these particles were no longer present in this size range after 60 and 420 min. The microstructure of the stronger particles did not lead to needle-like or plate-shaped particles but instead blocky and rounded particles were produced throughout grinding. The stronger particles of the 20 to 30 µm size range did, however, become increasingly spherical during grinding, as shown by an increasing shape factor (4 x cross sectional area/perimeter squared) which would be one if the projected shape was a circle.

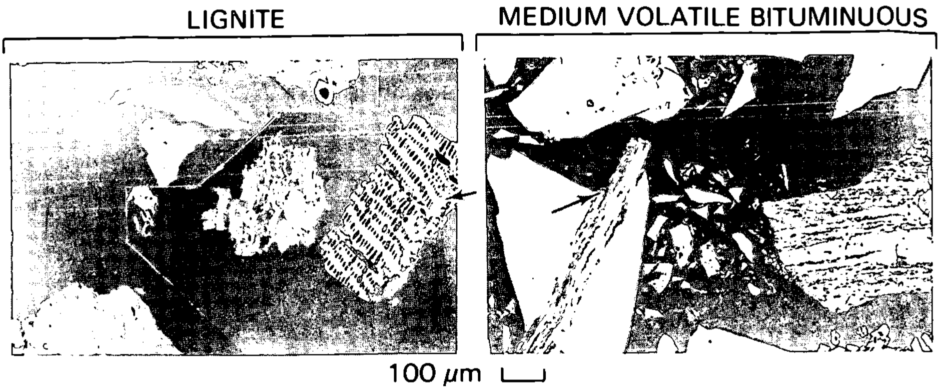

FIGURE 1. OPTICAL MICROGRAPHS OF POLISHED, PREGRIND PARTICLE CROSS SECTIONS SHOWING SEPARATION OF ORGANIC PHASES DURING THE EARLY STAGES OF GRINDING. ARROWS INDICATE FRACTURE PROGRESSING ALONG INTERFACES.

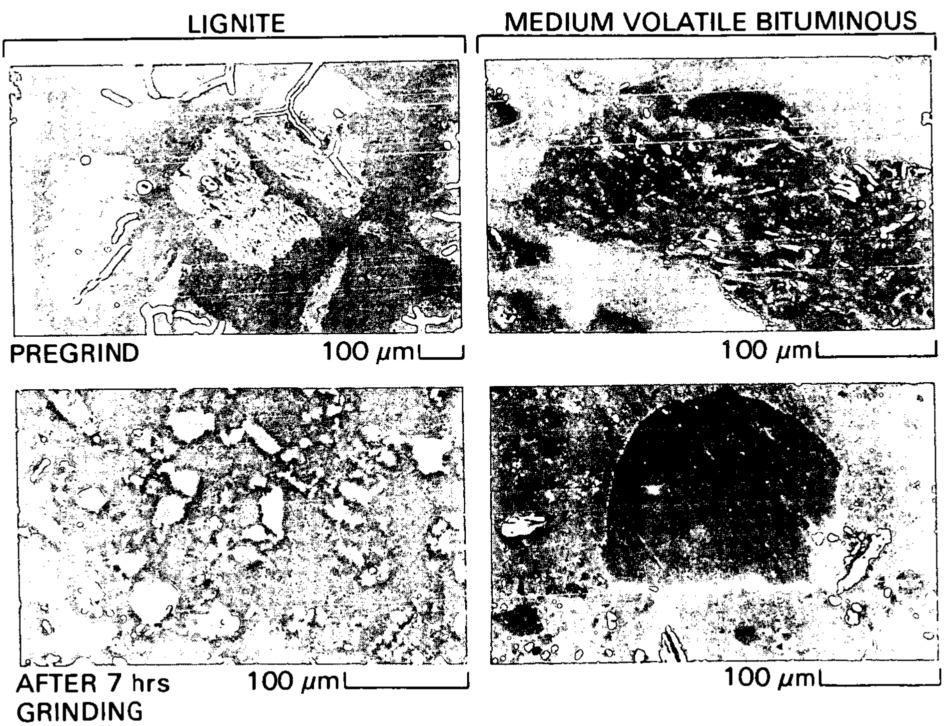

FIGURE 2. SCANNING ELECTRON MICROGRAPHS OF PARTICLE CROSS SECTIONS SHOWING THE DEPLETION OF PORES AND CRACKS AND THE SEPARATION OF MINERAL INCLUSIONS.

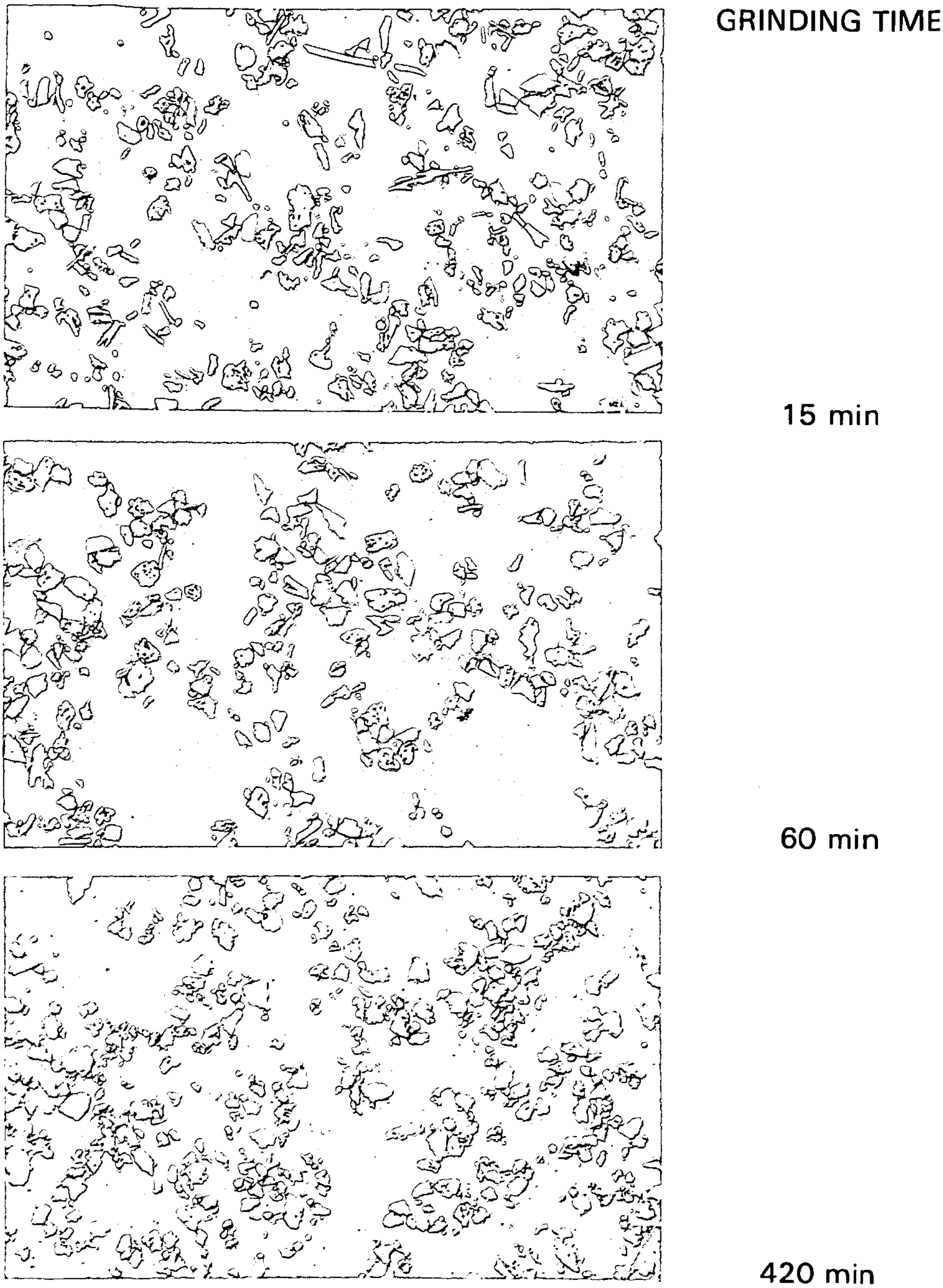

FIGURE 3. OPTICAL MICROGRAPHS OF 10 TO 15 μm LIGNITE PARTICLES AFTER VARIOUS GRINDING TIMES.

The shape factor was 0.47, 0.47 and 0.62 after 15, 60 and 420 min of grinding, respectively.

CONCLUSIONS

During coal grinding, the modes and mechanisms of fracture change with time and particle size. Fracture tends to proceed preferentially first along organic-to-organic interfaces, then along mineral-to-organic interfaces and cracks and pores: first, through the largest cracks and pores, then through gradually smaller cracks and pores as encountered by the stress field. Thus, particles with limited porosity and mineral inclusions are the stronger particles that tend to grind at lower rates.

Modeling studies indicate that two sets of comminution rate constants are required to model the grinding of lignite because weaker components control the rates initially and stronger components control the rates later in grinding.

These modes and mechanisms of fracture cause changes in the shape and size of particles and the separation of phases. The shapes and sizes of particles are first changed by fracture through organic-to-organic interfaces, then by the microstructure of the weaker phases and finally by the microstructure of the stronger phases. During lignite grinding, the weaker phases produce needle-like or plate-shaped particles that are changed to more blocky and rounded shaped particles as particle size is decreased. The stronger phases produce blocky and rounded shaped particles that become more rounded with longer grinding times.

In both coals the organic phases are separated initially by the tendency for fracturing preferentially through organic-to-organic interfaces. Then the stronger phases are ground more slowly than the weaker phases. The stronger phases of lignite have greater organic sulfur content than the weaker phases. Thus, there is a stage in grinding where low-sulfur particles are concentrated in the fines and high-sulfur particles are concentrated in the larger size ranges.

Mineral phases are separated from the organic phases during grinding. The extent of separation depends on the size distribution of the mineral phases and the extent of grinding.

The size and shape of particles and the separation of phases are important factors in modern coal processes. For example, in producing and using coal-liquid slurries important factors include coal-to-liquid ratio, rheological properties of slurry, particle size distribution and mineral content. The results of this study impact all of those factors. The shapes of particles can have a marked effect on slurry viscosity as well as the packing density of slurries, thus, it may be advantageous to grind a coal more extensively in some cases to produce more rounded particles. The potential for removal of mineral impurities increases with grinding time. However, the potential for removal of organic sulfur may be greater at an intermediate stage of grinding. Thus, detailed knowledge of the coal grinding process can greatly increase the potential for more efficient and environmentally safe ways of using coal.

LITERATURE CITED

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