

THE EFFECT OF PARTICLE SIZE ON THE COMBUSTION OF WEARDALE COAL

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ABSTRACT

The effect of particle size on the percentage weight loss of a low quality bituminous coal (i.e. Weardale quarry coal) during combustion in air has been studied by thermal analysis. The method of sieving used to prepare samples of different particle size was found to have a significant effect on the results.

INTRODUCTION

The reactivity of coals towards oxidising gases is an important property in connection with their uses such as combustion, gasification and carbonisation. There are many properties that govern the reactivities of coals, and which also contribute to the heterogeneity of coals, for example, carbon content, mineral matter (both quantity and composition), particle size, porosity and texture. In this work the effect of particle size on the percentage weight loss of Weardale coal during combustion in air has been studied.

Weardale quarry coal is an English low quality bituminous coal. It is quarried for use as fuel in the manufacture of cement. The proximate analysis of the coal is, moisture 9.79%, ash (dry basis) 33.63%, "fixed" carbon 46.57%, volatile matter (dry basis) 10.01%. It also has, sulphur 0.71%, calorific value 18208 kJ kg⁻¹, swelling test 2, Gray King-Assay D. The 6-10 inch coal seam consists of two distinct layers, one having a high mineral content, the other a low mineral content.

EXPERIMENTAL

Sample preparation

To prepare samples of different particle size three sieving methods were adopted.

(1) First, a quantity of the original coal was put in the top of a set of 19 cm diameter laboratory sieves stacked vertically in descending order of decreasing mesh size with a collector pan at the base and sieved for 30 minutes using an orbital shaker. The different size

fractions may not necessarily have the same composition, because the larger particles, for example, may have associated with them more mineral matter.

(ii) In the second method, a sample of coal was divided into 6 portions. The first portion was crushed in a pestle and mortar for a short time and placed in a 300 μm sieve with a collecting base pan and shaken for 10-15 minutes. The material remaining on the sieve was lightly crushed with a pestle and mortar and sieved again. This procedure was continued until the whole portion eventually passed through the sieve. The other 5 portions were similarly crushed and sieved to pass through sieves of different mesh size.

This method, in principle, provides samples of identical composition, because the starting material is the same. Each sieved fraction has particles of a size range from the very fine to the mesh size.

Particular attention was paid to the sample preparation. The coal was "crushed" for short durations rather than "ground" as prolonged grinding affects the structure of the coal (ref. 1).

(iii) Thirdly, a sample of coal was divided into 6 portions as above, and the first portion was placed on a set 300 μm mesh size sieve with a 250 μm sieve and a base pan below it. The process of crushing and sieving was continued until all the sample passed through the 300 μm sieve. However only the material remaining on the bottom sieve was taken. This was repeated with pairs of sieves of successive mesh size.

This method provides fractions with an upper and lower particle size. However, the composition of the different fractions may not be the same.

Techniques

Thermogravimetry (TG) was carried out in a Stanton Redcroft STA 781 Thermal Analyser at a heating rate of 10 $^{\circ}\text{C min}^{-1}$ from ambient to 900 $^{\circ}\text{C}$ in a flowing air atmosphere of 37 $\text{cm}^3 \text{min}^{-1}$.

Larger quantities of sample were burnt off in a Griffin electric muffle furnace. Selected samples were examined by scanning electron microscopy using a Jeol JSM-35C Scanning Electron Microscope, x-ray powder diffraction using a Siemens Type F goniometer fitted with a Siemens x-ray tube and copper target, and energy dispersive x-ray analysis using a Link System Series 2 energy dispersive micro-analyser.

RESULTS AND DISCUSSION

Thermogravimetry of sieved fractions

The percentage weight losses during combustion of each particle size

fraction obtained from each of the three sieving methods, are presented in Fig. 1 as histograms (a), (b) and (c).

The results of the first method, Fig. 1a, show that the total percentage weight loss increases with particle size. In general the larger particle size fractions have a greater weight loss. This is attributed to the larger particles having more carbon (i.e. less mineral matter) associated with them.

The TG data of the particle size fractions of Weardale coal, prepared by the second method of sieving, Fig. 1b, show that all the fractions have approximately the same percentage weight loss (except the largest one). This is to be expected because in this method of sieving, all fractions should have, in principle, the same composition. It is not clear why the 300 μm fraction has a significantly smaller weight loss.

The TG information of the fractions with various particle size ranges obtained by the third method of sieving, Fig. 1c, show that there is a general decrease in the percentage weight losses with particle size of the fractions.

The high mineral component of the coal seam, already mentioned in the introduction, not only affects the quality of the coal, but more significantly its abundance is related to sample preparation. The two distinct coal seam components were investigated further.

MINERAL INVESTIGATION

Superficially, the two coal components were observed as a matt grey one and a black lustrous one. The former was non-brittle, had a granular texture, and layered planes (as in slate). It contained silvery, white and golden specks (probably of iron pyrites). The black lustrous component was brittle and smooth. It contained white, orange and yellow regions. The white regions were planar strata; and regions of rust orange colour signified iron(III) oxide; and the yellow areas were probably extraneous sulphur. The material had the smell of sulphur.

The latter bright component was most likely to be vitrain (or clarain) (ref. 2), since vitrinite accounts for, in most instances, more than 70-80% of any given coal bed or seam (ref. 3).

Separation

The two components were separated by two methods, namely, (1) visually and by "hand picking" and (2) by flotation (a valid technique in industry), and investigated by thermal analysis.

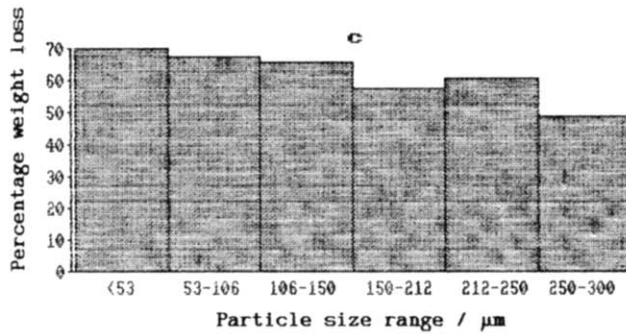
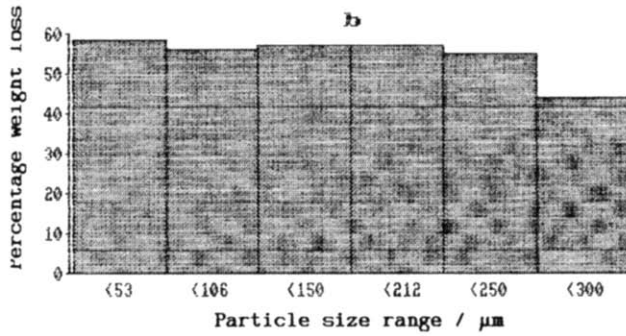
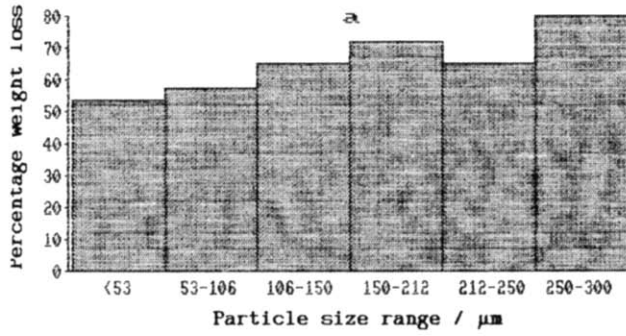


Fig. 1. Histograms showing the percentage weight losses of fractions of Weardale coal obtained by different methods of sieving. (a) method 1. (b) method 2. (c) method 3.

In the first method, the two components were hand separated, based on visual discrimination, each was crushed using a pestle and mortar and then sieved to a size of $<53 \mu\text{m}$.

While sieving the non-brittle component, the silvery metallic content separated from the coal. It was found that the silvery specks separated from the coal were too large to initially penetrate the $53 \mu\text{m}$ sieve, and were assigned a size between $53\text{--}106 \mu\text{m}$.

In the second method for the separation, a liquid column was used having a density intermediate to those of the two components. In order to do this the densities of the two hand-separated components were determined by liquid (water) displacement using a specific gravity bottle. A liquid of intermediate density was prepared by mixing equal volumes of tribromomethane (CHBr_3) and trichloromethane (CHCl_3) having densities 2.89 and 1.59 g cm^{-3} respectively (refs. 4-5).

Samples of the visually separated components were crushed to pass through a $<53 \mu\text{m}$ sieve. Equal quantities (1 g) of these crushed components were mixed together and suspended in the liquid mixture in a separating funnel. The funnel was stoppered, inverted and thoroughly shaken for efficient mixing and wetting of the particles. It was then left to settle.

The larger particle size of the material enabled rapid settling of the separated components. After separation the liquid suspensions of the two components were run off, dried and the residue re-weighed.

Thermogravimetry was performed on each component obtained by the two methods of separation.

Thermogravimetry. Table 1 summarises the TG data of the components of Weardale coal.

The TG results indicate that the black, lustrous brittle component is a carbon rich one, whereas the matt grey, non-brittle component is mainly mineral matter. This is confirmed by their densities.

The densities of the two components hand separated by visual observation were 2.42 g cm^{-3} for the high mineral content (i.e. low carbon) component and 1.38 g cm^{-3} for the low mineral (i.e. high carbon) component.

When a mixture of equal weights (1 g each) of the two components (crushed to $<53 \mu\text{m}$) was separated by flotation, 78.9% by weight of the mixture separated into the upper layer and 21.2% into the lower layer.

TABLE 1
TG data of the components of Weardale coal.

Method Of Separation	Coal Component	Percentage Weight Loss %
Visual	Matt grey Non-brittle	14.50
"	Black, lustrous, Brittle	87.00
Flotation	Lower (Matt grey, non-brittle)	19.00
"	Upper (Black, lustrous, brittle)	84.25

Total recovery of the two samples was effected. The upper layer corresponds largely to the black, lustrous, brittle component and the lower layer to the matt grey, non-brittle, granular component.

The discrepancy in the percentage by weight of components separated by flotation compared with that by visual separation may be explained in two ways. (1) During the flotation, the upper layer may support some particles of the heavier component above it. This phenomenon, however, cannot alone account for the wide discrepancy above. (2) The large lumps of the non-brittle, matt grey component may have significant quantities of smaller particles of the other components associated with it on its external surface as well as within its internal macro-structure. When crushed it is expected that these finer particles are separated and enrich the upper layer during flotation.

Analyses

Lumps of the two components of Weardale coal (separated by visual observation and hand picking) were crushed using a pestle and mortar until they passed through a 53 μm sieve. 1 g samples of the crushed materials were burnt off in an electric muffle furnace at 700 °C for 120 minutes. The high carbon component underwent 88.5% weight loss, and the low carbon component 14.0% weight loss. The products were examined by x-ray powder diffraction and energy dispersive x-ray analysis.

Scanning electron microscopy was used to investigate the microstructure of the partially ashed $<3 \mu\text{m}$ size components of the coal after 15, 30 and 120 minutes at 700 °C.

(i) X-ray diffraction. X-ray diffraction shows that the minerals present are essentially the same in both components of Weardale coal, with α -quartz (SiO_2), sillimanite (Al_2SiO_5) and iron pyrites (FeS_2) being clearly identifiable.

Little change is observed when both components are ashed at 700 °C in the muffle furnace, except for the oxidation of iron pyrites to iron(III) oxide.

Several other peaks were more difficult to explain. These peaks are probably due to the higher intensity peaks of the lower concentration minerals, kirschteinite (CaFeSiO_4) being more evident.

(ii) Energy dispersive x-ray analysis. Table 2 lists the principal elemental constituents of mineral matter found in Weardale coal. It is seen that the elemental mineral constituents are in accordance with many of the minerals shown to be present from the x-ray diffraction analysis (i.e. aluminium, silicon and iron). However, potassium, titanium, and magnesium have as yet not been assigned to any mineral identified.

(iii) Scanning electron microscopy. Plates 1 to 3 show the scanning electron-micrographs for the ashing of the high mineral component of Weardale coal; Plates 4 to 6 show them for the low mineral component.

TABLE 2

Principal constituents of Weardale coal components ashed for two hours at 700 °C determined by energy dispersive x-ray analysis.

Brittle, High-Carbon Component	Non-Brittle, Low-Carbon Component
Aluminium	Aluminium
Silicon	Silicon
Potassium	Potassium
Iron	Iron
Titanium	Titanium
	Magnesium
	Sulphur

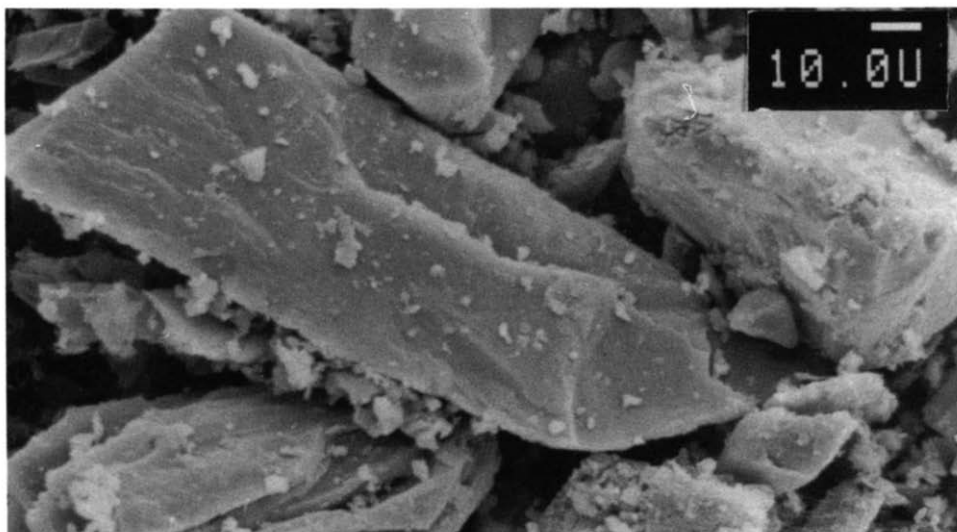
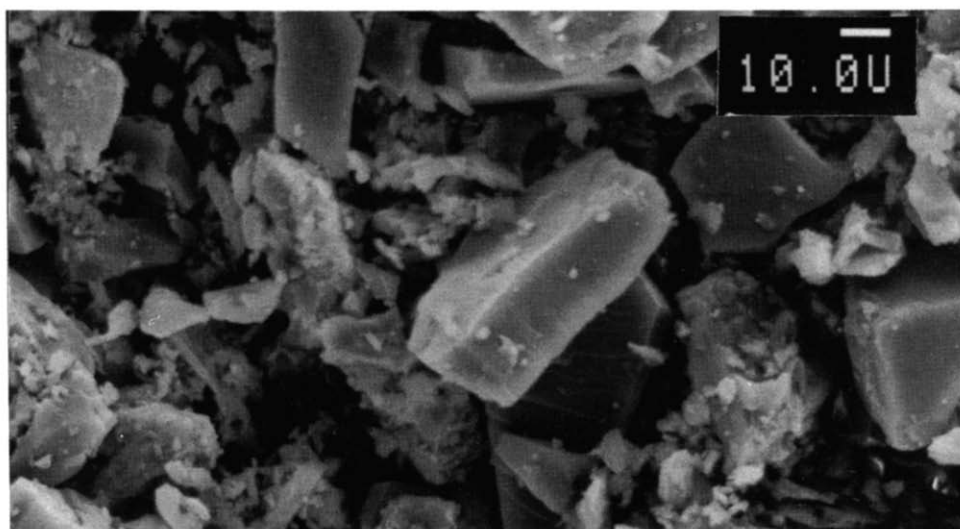


Plate 1. (Above), Scanning electron-micrograph of the high carbon component of Weardale coal burnt off at 700 °C for 15 minutes.

Plate 2. (Below), Scanning electron-micrograph of the high carbon component of Weardale coal burnt off at 700 °C for 30 minutes.



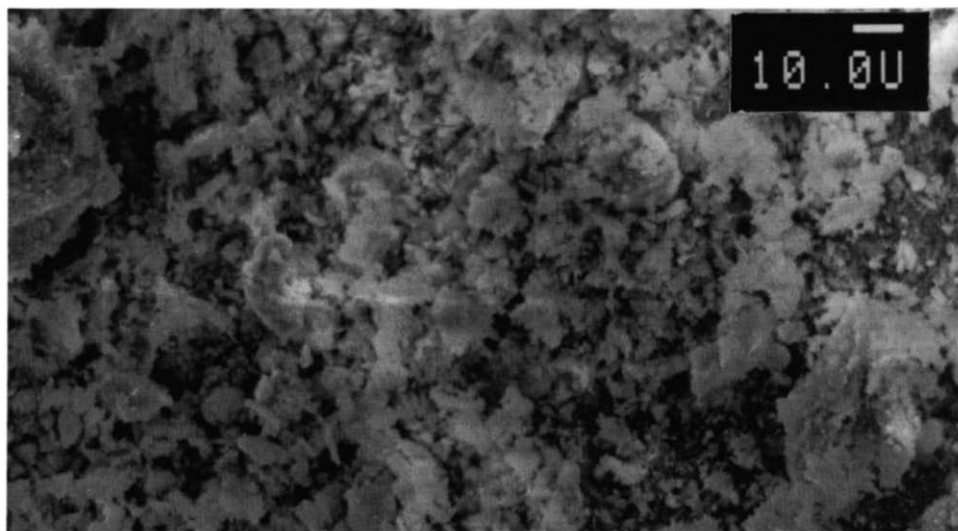
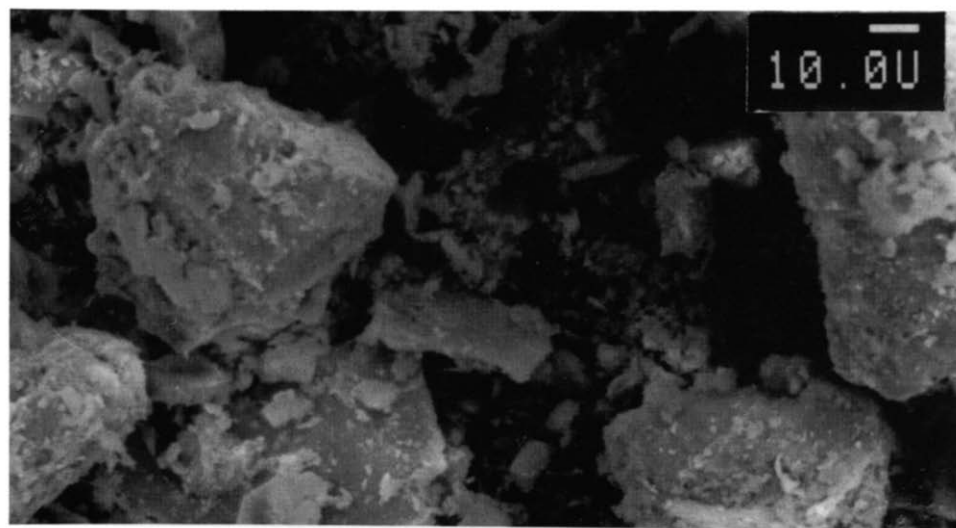


Plate 3. (Above), Scanning electron-micrograph of the high carbon component of Weardale coal burnt off at 700 °C for 120 minutes.

Plate 4. (Below), Scanning electron-micrograph of the low carbon component of Weardale coal burnt off at 700 °C for 15 minutes.



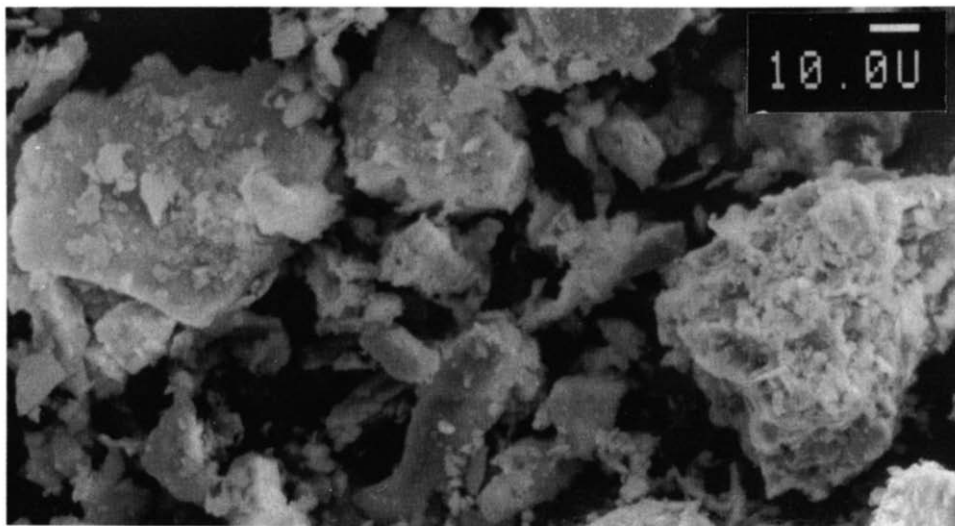
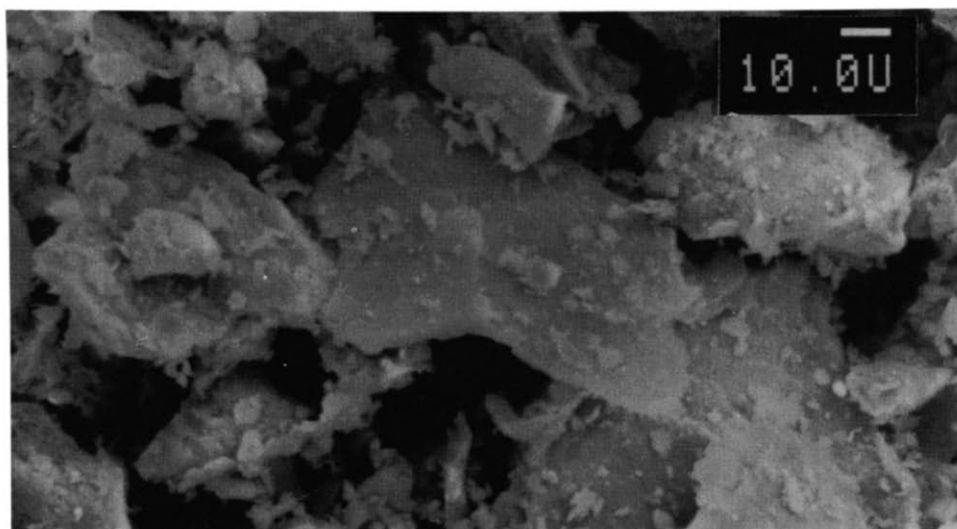


Plate 5. (Above), Scanning electron-micrograph of the low carbon component of Weardale coal burnt off at 700 °C for 60 minutes.

Plate 6. (Below), Scanning electron-micrograph of the low carbon component of Weardale coal burnt off at 700 °C for 120 minutes.



Results show that the ashing of the brittle high-carbon component of Weardale coal was not evident after 15 minutes at 700 °C (giving 33.6% weight loss), with regular well defined particles observable. After 30 minutes of ashing (53.8% weight loss) there was a decrease in general particle size along with a less well defined "feathery" ash present, and subjection to 120 minutes ashing (88.5% weight loss) showed a drastic decrease in particle size due to decomposition. The very small particles of mineral matter that appear after carbon burn-off suggests that the mineral matter is incorporated in coal, and is not separate.

The non-brittle low-carbon component of Weardale coal incurred no signs of decomposition after 15 (13.2% weight loss), 60 (13.4% weight loss) and 120 minutes (14.0% weight loss) ashing at 700 °C. No significant changes in particle size were observed.

CONCLUSIONS

- (1) Weardale coal is heterogeneous, being able to be hand separated into high and low carbon components.
- (2) Evidence from TG suggests that the mineral matter is associated largely with the small particle size fraction.
- (3) X-ray diffraction suggests that the non-brittle low-carbon component inherently forms the mineral matter content found in the brittle high-carbon component.

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