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The identification of unusual microscopic features in coal and their derived chars: Influence on coal fluidized bed combustion

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Abstract

During the petrographic study of seven feed coals from different origins, it was found that these coals presented microfeatures such as: material size, shape, weathering, thermally affected particles and contamination. After devolatilization under fluidized bed conditions, some chars presented the consequences of the above mentioned microfeatures, i.e., unreacted coal, unswelled particles, coatings and microstratification.

Since the amounts of the microfeatures observed were low (less than 1%), the present study is essentially observational/descriptional. However, it seems very likely, from the observations that were made, that the occurrence of one or more of these microfeatures in coal, depending on their kind and abundance, may have significant effect on the coal devolatilization.

Keywords: Coal petrography; Microfeatures; Char; Fluidized bed combustion

1. Introduction

Coal originates from the accumulation and preservation of plant debris, and its properties are associated with the bio- and physico-chemical conditions prevalent during organic matter accumulation and the geological history. The result is a heterogeneous highly organic-rich rock.

A microscopic (petrographic) study of coals permits a determination of the amounts and kinds of macerals (analogous to minerals in rocks), minerals and the degree of coalification by measuring the reflectance of collotelinite in reflected light (International Committee for Coal Petrology, 1963; ISO 7404-3, 1984; ISO 7404-5, 1984; ISO 7404-2, 1985). However, despite of the usefulness of petrographic analyses of coal to coke making, petrography is still rarely referred to interpreting results in most coal conversion processes. Additionally, extending coal petrographic analyses to include the determination of "unusual" microfeactures that are not recorded by conventional coal petrographic analysis may substantially improve the knowledge of abnormal behaviour of some coals during utilization (Gray, 1982).

This way, Gray (1982) established a classification of these "unusual" microfeatures and named them as "non-maceral coal microstructures" and studied their consequence in coke making. In this classification, the microstructure categories include: fine coal, pseudovitrinoids, microbrecciated coal, oxidized coal (weathered),

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oxidized (thermal), coarse mineral matter, cenospheres and contaminants.

During research of NO_x and N_2O emissions under fluidized bed conditions, the authors (Valentim et al., 2006-this volume) found that the coals used presented, in different amounts, "unusual" microfeatures such as folds, fractures, oxidation, cokefication, thermally affected particles, coarse mineral matter, microstratification and fine coal agglomerated with binders. In this case, these materials were responsible for abnormal char features observed after the coals heating under devolatilization conditions in a fluidized bed laboratory scale reactor. Thus, the scope of the present paper is the presentation of the above-mentioned situations and the description of their consequences in the char morphology.

2. Microfeatures description

2.1. Fine coal

Apart from considering fine coal to be the particles of less than 5 μm resulting from friable coals, it is also important to consider another category comprising the pellet made by fine coal and a binder also known as "bird" (Laskowski, 2002).

Single fine coal particles can pass through the boiler without being combusted and behave as inert material, which are then released as solids (Bengtsson, 1986; Bend, 1989; Bend et al., 1992).

Bind fine coal, as it will be shown in the results, may coat other particles and their properties also depend on the binder properties.

2.2. Pseudovitrinoids

Pseudovitrinoids were defined for technological purposes by some North American petrographers (Benedict et al., 1968), who subdivided vitrinite in two populations on the basis of reflectance up to 1.4% R. These two populations are referred to as "normal vitrinite" and "pseudovitrinite". Pseudovitrinite is slightly higher in reflectance than normal vitrinite and sometimes exhibits cellular structure or "comma slits", which aid in identification.

Initially, it was though that pseudovitrinite was formed by mild oxidation of the vegetal source material early in the coalification process, but it was latter concluded that the slitted vitrinite may represent an intermediate process between fresh and weathered vitrinite, which would be consistent with reports of reduced fusibility of pseudovitrinite during coke-making (Benedict et al., 1968; Teichmüller et al., 1998a).

2.3. Tectonic features

Tectonic stress is responsible for tectonically affected coal in which banding is gradually obliterated and, ultimately, crushed powdered coal occur in the highly disturbed areas. In this cases, coal may be microfolded, microfaulted, microbrecciated, and both reflectance and anisotropy increase with increasing tectonic deformation (Taylor, 1998).

2.4. Oxidation

Oxidation (weathered) begins as soon as any coal is exposed to oxygen, and the properties of coal–especially those of vitrinite–begin to change. This exposure begins when the coal seam is exposed prior to mining and continues as the coal is extracted, washed, transported and stockpiled.

Weathered coal is primarily identified by its well-developed "oxidation rims" along boundaries and fissures. These halos on edges and cracks represent the depth to which oxidation has penetrated the respective coal particles. Additionally, it may also present rounded edges, oxidized pyrite, swelled clay minerals and secondary mineral coatings on edges (Benedict et al., 1968; Gray, 1982; Teichmüller et al., 1998a,b).

Vitrinite in tectonically or weathered affected coals and pseudovitrinite are less thermoplastic, devolatilize slower than normal vitrinite forming compact char and require a longer combustion time (Nandi et al., 1977; Bengtsson, 1986; Bend, 1989; Bend et al., 1992; Skorupska et al., 1992; ICCP, 1998).

2.5. Thermal alteration

In many sedimentary basins, dykes, sills and other types of magmatic intrusions have intruded coal seams and carbonaceous shales. The heat from such intrusions, which may be up to 1000 °C at the time of the injection, causes changes in the organic matter. This can be changed to natural coke characterized by the presence of mosaic structure and pores. If the transition to coke has not occurred, vitrinite remains sufficiently unchanged to be recognizable, although there may distortion of the structures, and the reflectance and anisotropy will nearly always have increased significantly.

Anthracites may soften a little, if at all, during intrusion and tend to become meta-anthracites, in which case the texture of anthracite are retained, although in chemical composition, optical and other properties, the altered coal approaches graphite (Teichmüller et al., 1998b; Kwiecinska and Petersen, 2004).

According to Cecilia (1985), thermally affected particles by magmatic intrusions may be classified as follows:

(i) Abnormally high-reflectance vitrinite distant from the intrusion;
(ii) Anisotropic anthracitic vitrinite distant from the intrusion;
(iii) Anthracitic vitrinite with shadows, banded and with very fine mosaic;
(iv) Granular coke located near the intrusion;
(v) Porous coke;
(vi) Neoformation constituents such as pyrolytic graphite located very close to the intrusion.

2.6. Coarse mineral matter

Gray (1982) considered coarse mineral matter to be relatively large particles, >100 μm that consist predominantly of mineral matter such as clay, shale, coarse pyrite carbonate, quartz or even bone coal. Coarse mineral matter is an important microfeature to recognize because it gives some information of the extent to which a coal has been beneficiated (Gray, 1982).

2.7. Cenospheres

Cenospheres are generally hollow, rounded particles, showing a higher reflectance than the associated huminite/vitrinite, and do not correspond to any of the established inertinite group macerals. These morphotypes may result from mining, mine ignitions, impending ignitions, excess heat in thermal dryers or can be formed naturally. During different source rock and coal facies research, the majority of the particles observed were of the dense inertoid or crassinetwork/mixed network/mixed type (Gray, 1982; Petersen, 1998).

2.8. Contaminants

Contaminants are observed microfeatures during a coal petrographic analysis. The authors frequently observe higher rank coals particles, in amounts generally less than 1%, incorporated in samples of lower rank coals. Therefore, the microscopic examination permits the identification of the kind and amount of contamination inadvertently or intentionally added. The fine coal pellets should be considered as a contaminant, particularly when it is in amounts that can affect the value of important analytical data.

2.9. Microstratification

Another category not considered by Gray (1982) is the microstratification. When burning coal particles under fluidized bed conditions, particles are crushed to 1–3 mm, this way each particle may be formed by several microlayers that will have different behaviours during devolatilization.

3. Methods and materials studied

3.1. Origin and petrography of the feed coals

Seven different feed coals were used in this study: two Spanish (Esp1 and Esp2) coals obtained from CIEMAT (Spain), one Colombian (Col) coal, three South African (SA1, SA2 and SA3) coals and one U.S.A. (EUA) coal from a Portuguese Power Plant.

To prepare the classical coal particulate block (ISO 7404-2, 1985), the coal was crushed to a top size of 1 mm and after the coal was observed under reflected light by means of a Leitz MPVC microscope with magnifications up to 500×.

3.2. Char production

Chars were obtained from each coal, each of which was subjected to devolatilization in a fluidized bed reactor with 80 mm of internal diameter and 500 mm height. An inert N_2 carrier gas was used in all tests. During the devolatilization, CO and CO_2 amounts were measured with non-disperse infrared analyzers and, when the analyzers could no longer detect these gases, the heating was switched off while maintaining the N_2 flow. Chars were produced at four temperatures (700, 800, 900 and 1000 °C) with a heating rate of ca. 10^4 K/s and the coal was crushed to ca. 1 mm.

3.3. Char petrography

Char samples for reflected light optical microscopy observation were prepared according to the method of Álvarez (1996). A Nikon microscope with 80× magnification (8× objective and 10× eyepieces) was used.

Scanning electron microscopy (SEM) of char was performed at INCAR (Oviedo, Spain) using a Zeiss DSM 942 microscope.

4. Results and discussion

4.1. Coal characterization

In Table 1, the results of the proximate and ultimate analyses together with petrographic composition and rank analyses are listed (following ISO 7404-3, 1984; ISO 7404-5, 1984).

The Spanish coal Esp1 is from the El Bierzo basin located in northwestern Spain and has a mean random vitrinite reflectance of 2.0%, indicating a semianthracite rank. However, in the sample studied, the mean random reflectance value obtained for all vitrinite-like particles was 3.05% R (standard deviation of 1.28% R), leading to the conclusion that Esp1 coal sample was a blend of semianthracite and thermally affected particles. Approximately 30% of this coal sample is naturally thermally affected coal by volcanism or dyke intrusions (Table 1) and another third is mineral matter.

It is important to mention that, although some particles resemble pseudovitrinite with comma slits and serrated fractures on particle edges, they also present a much higher reflectance than the semianthracite collotelinite. By definition (Benedict et al., 1968), the average reflectance of pseudovitrinoid is somewhat higher than that of vitrinoid, but the magnitude of the difference diminishes in the low volatile bituminous rank range above 1.4% R and, in the low volatile bituminous rank range, pseudovitrinoid reflectance matches the vitrinoid reflectance. Additionally, Esp1 sample also contains natural coke particles, suggesting that these particles are thermally affected. In fact, a variety of volcanic rocks is very common in Carboniferous basins of northwestern Spain, mostly in Asturias and Léon districts, where heat-affected coals and natural cokes have been commonly described (Colmenero and Prado, 1993). Cecilia (1985), in a study of natural coke in the Ciñera-Matallana Basin, noted that uncoked coal near magmatic intrusion have abnormally high vitrinite reflectance values.

The Esp2 coal is from the Carboniferous Puertollano Basin in South Central Spain. In the Puertollano Basin, the most important Carboniferous coal reserve in this region, the dominant tectonic deformation is the flexing and fracturing of unfolded strata (Alastuey et al., 2001).

Table 1
Coal samples selected for study; ultimate (daf, wt.%) and proximate (db, wt.%) analyses; vitrinite mean random reflectance; maceral group composition (mineral matter free, vol.%)

	El Bierzo	Puertollano	Carbocol	Sasol	SA	C	Ashland
	Esp1	Esp2	Col	SA1	SA2	SA3	EUA
Rank [a]	Semianthracite	HVB bit.	HVB bit.	HVB bit.	HVB bit.	HVB bit.	HVB bit.
Origin	Spain	Spain	Colombia	S. Africa	S. Africa	S. Africa	USA
Proximate (d[2], wt.%; daf[3], wt.%)							
Ash [b]	32.5	46.04	8.88	10.23	14.14	16.49	13.96
Volatile matter [3]	11.51	47.74	42.37	35.88	34.72	27.83	39.26
Fixed carbon [c]	88.49	52.26	57.74	64.12	64.93	72.17	60.74
Ultimate (daf[3], wt.%)							
Carbon	90.65	76.29	82.01	80.45	77.03	79.03	84.87
Hydrogen	2.93	5.04	5.83	4.96	4.99	4.43	5.09
Nitrogen	1.17	2.15	1.58	2.09	1.74	1.68	1.53
Sulfur	2.98	1.74	0.86	0.77	0.84	0.62	1.08
Oxygen [d]	2.27	14.78	9.72	11.73	15.4	14.24	7.43
Rr% [e]	2.0	0.6	0.6	0.6	0.6	0.7	0.8
Standard deviation	0.38	0.05	0.06	0.04	0.08	0.10	0.04
Vitrinite	48	63	84	43	41	14	68
Liptinite	0	7	3	5	4	5	11
Inertinite	3	30	13	53	55	81	22
Therm. aff. [f]	49	0	0	0	0	0	0

[a] ASTM Designation: D 388-98a (1999) and Damberger et al. (1984).
[b] d—dry.
[c] daf—dry ash free.
[d] By difference.
[e] Vitrinite mean random reflectance.
[f] Thermally affected coal by volcanics.

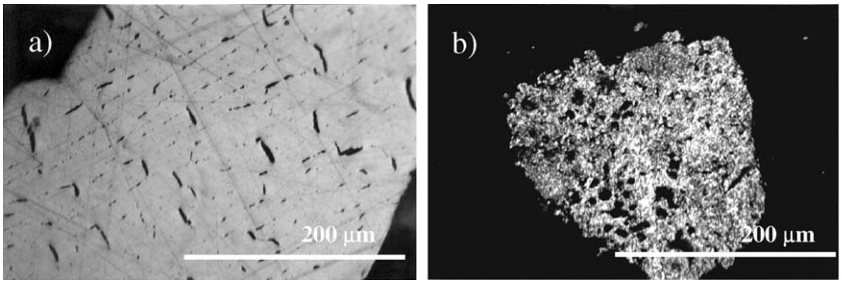

Fig. 1. Esp1 coal: (a) 3.05% R, comma slits, serrated edges, devolatilization pores perpendicular to the stratification revealing a natural thermally affected particle and/or a pseudovitrinite maceral; (b) natural coke characterized by micromosaic texture and devolatilization pores.

Esp2 coal is a high volatile bituminous, vitrinite-rich coal (Table 1). The sample provided is composed of ≈30% of mineral matter by volume. The high amounts of mineral matter are very common in some Spanish coals and the values determined in the Esp2 coal are consistent with the results presented by Alastuey et al. (2001) for the coal seams of Puertollano Basin, Spain.

Reflectance measurements indicate a high volatile bituminous rank for the Colombian coal. The sample is dominated by a high proportion of the vitrinite maceral group (Table 1) but also by bind fine coal. The values present in Table 1 are mineral matter free and did not considered bind fine coal. In that case, the results would be (by volume): vitrinite 70%, liptinite 2.8%, inertinite 10.8%, mineral matter 2.8% and "bind fine coal" 13.6%. The composition of the "bind fine coal": vitrinite 7.0%, inertinite 1.4% and binder 5.2%.

The SA1, SA2 and SA3 coals are high volatile bituminous thermal coals from South Africa, characterized by a large proportion of inertinite exhibiting a wide range of reflectance transitional between the reflectance of vitrinite and high-reflectance inertinite (Table 1).

Finally, EUA coal is from the United States of America and it is a vitrinite-rich high volatile bituminous coal (Table 1).

Based on the individual categories of "nonmaceral microstrutures" defined by Gray (1982) and considering also bind fine coal and microstratification, several images obtained from the coals studied under optical microscopy were chosen to illustrate the most frequently observed microfeatures during optical petrography analysis and SEM:

- Probably due to blending, the Esp1 coal shows a large amount of natural thermally affected coal that is characterized by 3.05%R, but the presence of devolatilization pores perpendicular to stratification, comma slits and serrated edges also looks like pseudovitrinite macerals (Fig. 1a). Another example of a naturally coked coal caused by volcanic or dykes heating under reducing conditions are the particles with anisotropic micromosaic texture also associated with devolatilization pores (Fig. 1b).
- Other features related to the geological history of the coals were observed in the Esp2 coal, which has microfolded plant tissues due to stress caused by earth movements (Fig. 2a). A further example of tectonic effects on coal is illustrated in Fig. 2b, presenting a case of a microbrecciated particle, that is, material that could not accommodate the stress generated by earth crust movements and behaved in fragile way, thus leading to the formation of fissures. At a later stage, these fissures were filled by carbonates.
- Fine coal may be result from coal pulverization during coal preparation. In general, depending on the

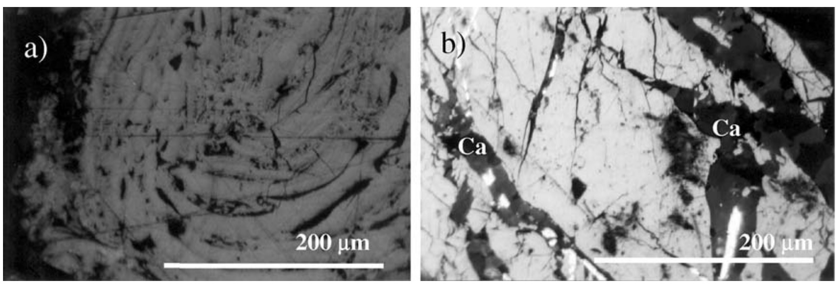

Fig. 2. (a) Esp2 coal: tectonically affected coal. Pressure micro-folded the fossilized plant tissues that are still recognisable in coal; (b) Esp1 coal: tectonically affected coal. Pressure opened micro-fissures on the more fragile coal components. Later these fissures were filled with carbonates (Ca).

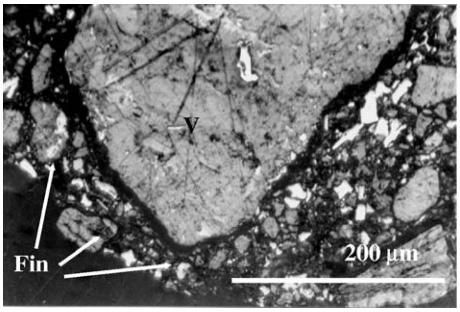

Fig. 3. Col coal: fine coal particles (Fin), produced during mining or milling by the fragmentation of more fragile coal components surrounding a vitrinite particle (V).

coal rank, coals are more or less friable and also the amount of oxidation and/or brecciation fines may also increase (Gray, 1982). This fine coal may be separated by flotation or sieving. However, after mining operations, the fine coal produced can be agglutinated into pellets by binders. In that case, particles of fine coal and binders cannot be separated by sieving when preparing coal for petrographic analysis but its identification is possible using reflected light microscopy or by SEM. In this way, it is possible to determine if bind fine coal particles were incorporated or resulted from milling. Fig. 3 illustrates fine coal "coating" a larger coal particle in the Colombian coal.

4.2. Optical microscopy of char

The investigation of the chars produced illustrates what happens to some of the above-mentioned microfeatures during devolatilization under the conditions used in this study.

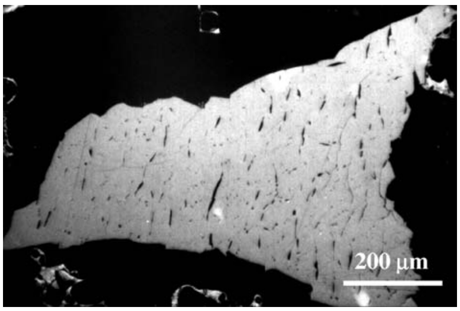

Fig. 4. Esp1 (devolatilization at 700 °C): as in Fig. 1 devolatilization pores perpendicular to the stratification reveal a naturally thermally affected particle. The sharpness of the particle and the absence of any other features also reveal that the particle remained unaltered after being submitted to the devolatilization conditions.

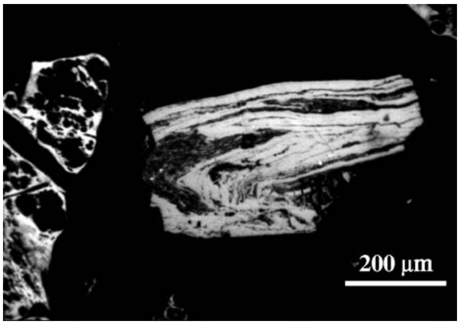

Fig. 5. Esp1 (devolatilization at 800 °C): tectonic folded coal unaltered during the devolatilization conditions.

In some cases, the heating conditions used were not severe enough to significantly modify most of the particles that were classified by Gray (1982) as nonmaceralic microstructures present in parent coals, such as those affected by volcanism (Fig. 1), tectonics (Fig. 2) or particles that are of a higher rank (contamination). Therefore, it is still possible, after devolatilization, to identify the coal particles with some of these microfeatures:

- Coal particles affected by volcanism (Fig. 4), folded by tectonic stress (Fig. 5) or an anthracite particle (Fig. 6) that contaminates a high volatile bituminous feed coal and remains unaltered.
- Fig. 7 illustrates bind fine coal after devolatilization. An aggregate of bind fine coal forming a dense structure (Fig. 7a) is composed of micro-cenospheres, unaltered coal and mineral matter. In this case, these aggregates form a "coat" around larger coal particles, creating a "shell" around degassing particles and preventing them from freely swelling (Fig. 7b). Furthermore, this "shell" will, probably, reduce the superficial area for the access of O_2 for

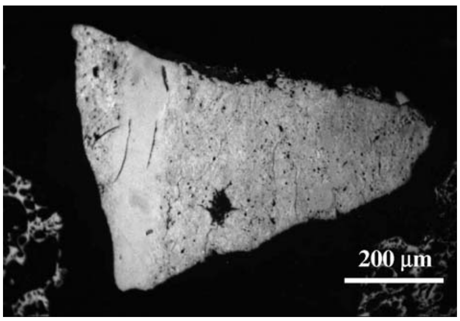

Fig. 6. SA2 coal (devolatilization at 800 °C): anthracite contamination. The devolatilization conditions were not strong enough to affect the anthracitic particle; however, they have affected the high volatile coal particles (down left and right).

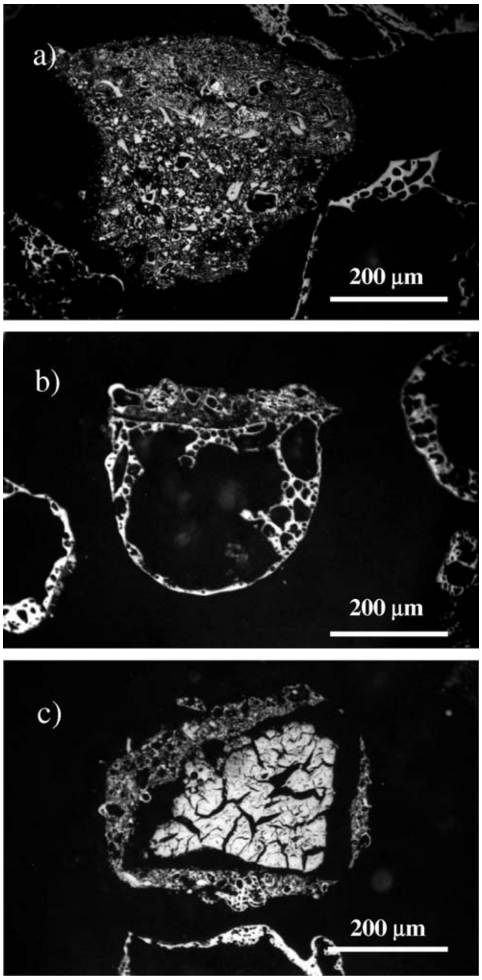

Fig. 7. (a) SA2 (devolatilization at 700 °C): charred fine coal. The particle (centre) is made by an agglomeration of micro cenospheres and unaltered fine coal. (b) Col coal (devolatilization at 700 °C): charred fine coal (on top) and deformed cenosphere. Bind fine coal that was originally coating a larger coal particle did not allow it to properly swell, resulting in a deformed cenosphere. (c) Col coal (devolatilization at 900 °C): oxidized coal. Instead of swelling, the natural oxidized particle shrunk inside a coat made of mineral matter and fine coal that preserved its original shape.

subsequent char oxidation reactions. In Fig. 7c, the coating of fine coal around non-swelling coal particles can be observed.

- Weathered, oxidized coal microfeatures are very characteristic and may be identified after heating if the conditions were not severe enough. Weathering has adverse effects on coal devolatilization and combustion efficiency and, in general, coals subjected to weathering oxidation loose their plastic properties; therefore, instead of swelling, they usually shrink (Bengtsson, 1986; Bend, 1989; Bend et al., 1992). This case is particularly well illustrated by Fig. 7c where a coat of fine coal still has the shape of the original oxidized coal particle, while the former opened cleats and shrunk when heated.
  Fig. 8 compares an oxidized (weathered) coal particle, with characteristic cleats and rims of oxidation (centre right), with a melted and swollen particle (centre left) from the same coal. Again, it is possible to see that oxidized (weathered) coal is unable to swell when heated and therefore shrinks and open fractures.
- Coarse mineral matter was also considered a nonmaceral microstructure by Gray (1982). Although is commonly analyzed together with organic matter, it is characterized separately. The presence of this component is obviously not desirable because it does not burn, damages the mills, causes slagging and fouling during combustion, and strongly contributes to the formation and subsequent emission of fly ash, sulphur and trace elements (Williams et al., 2001; Goodarzi, 2002). Fig. 9 illustrates coarse mineral matter in coal after being subjected to devolatilization conditions.

4.3. SEM analyses

SEM is another method to investigate coal “unusual” microfeatures subjected to devolatilization conditions. In fact, reflected light microscopy and SEM are two techniques that complement each other in the study of combustion particles (Menéndez et al., 1993).

The SEM technique clearly showed how some of these microfeatures developed during devolatilization. Specifically, the understanding of the behaviour of fine coal and mineral matter became more complete using this technique. Furthermore, it is also possible to observe surface structures that may be related to weathering and natural thermal effects. Finally, the application of SEM revealed that coal microstratification, i.e., the original

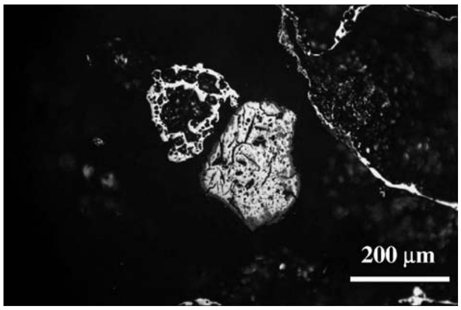

Fig. 8. EUA coal (devolatilization at 1000 °C): the image allows comparing the behaviour of a plastic particle (centre left) and a non-plastic naturally oxidized coal (centre right).

bedding planes in coal, also seems to affect the behaviour of organic matter, by presenting devolatilization chambers with a preferred orientation (Thomas et al., 1993) and, therefore, justified the inclusion of microstratification as a petrographic microfeature in the case of fluidized bed combustion.

4.3.1. SEM backscatter electron mode images

- It becomes clearly visible that fine coal was bind and that part of the binder incorporated mineral matter-rich fine particles (Fig. 10a–b). Fig. 10a illustrates the adverse effect of fine coal in combustion, because it shows a “shell” made of mineral matter and micro-cenospheres around char particles (Fig. 10b).
- This SEM mode also revealed the microstratification of clay with organic matter (Fig. 10c).

4.3.2. SEM secondary electron mode images

As stated above, the backscattered electron mode images are especially useful to identify mineral matter. However, the use of SEM secondary electron mode images is also a powerful tool for examining chars, as it provides very vivid three-dimensional images of the char surface.

It was also possible to observe by this technique that some of the microfeatures identified in the coals after devolatilization conditions remained unaltered or were partially reacted, or played a role in the char morphology formation.

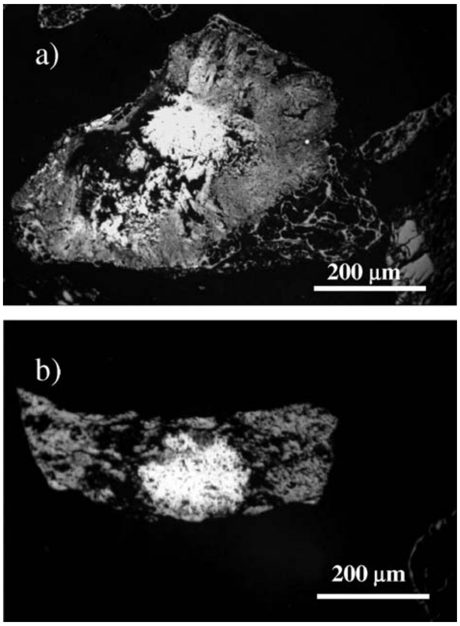

Fig. 9. (a) Esp2 coal (devolatilization at 700 °C): mineroid. Siderite ($FeCO_3$) partially degraded by the heating; (b) SA2 coal (devolatilization at 800 °C): mineroid. Coarse pyrite (FeS_2) partially degraded by heating.

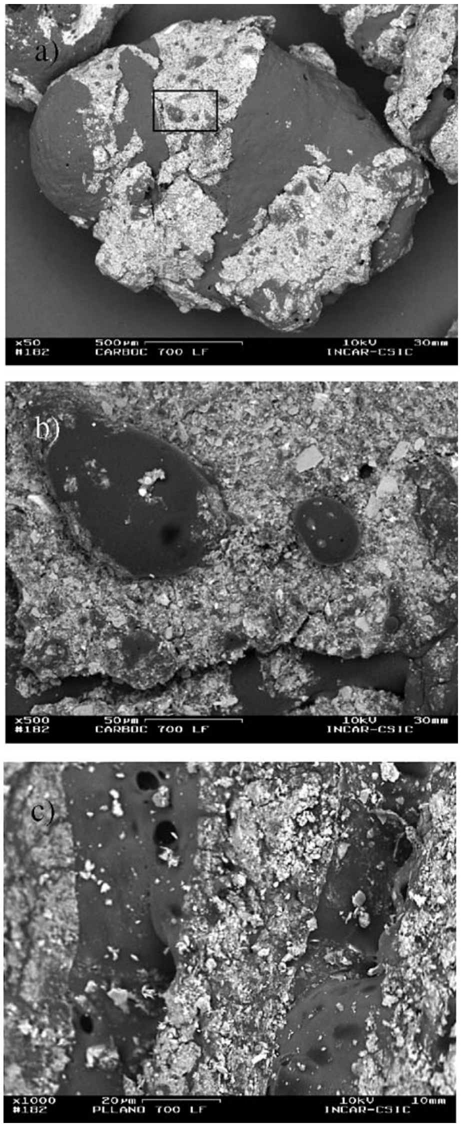

Fig. 10. SEM backscatter electron images (devolatilization at 700 °C): (a) Col coal: organic plastic material (dark grey) coated by fine mineral matter (white) and fine coal micro-cenospheres (dark grey); (b) magnification of the square in (a): after heating fine coal developed micro-cenospheres (dark grey) cemented by mineral matter (light grey); (c) Esp2 coal: intercalations of clay (bright) and organic matter (dark grey). The image also illustrates the original microstratification of the coal.

The following observations were the most relevant obtained:

- Fig. 11a shows a non-swelled char with a surface fracture pattern, which agrees with the patterns

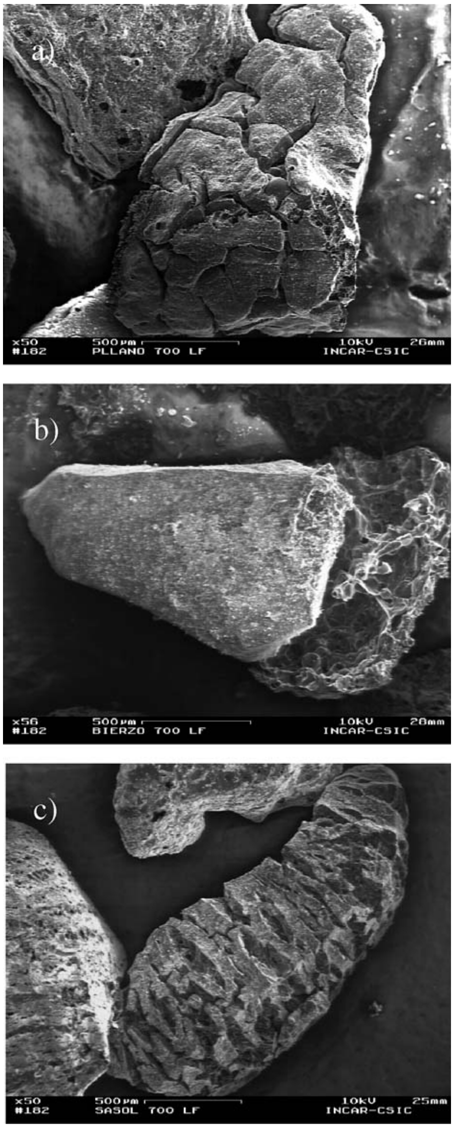

Fig. 11. SEM secondary electron images (devolatilization at 700 °C): (a) Esp2 coal: the surface cleat pattern and the absence of swelling suggest that this was originally a naturally oxidized coal particle. (b) Esp1 coal: unaltered surface and sharp corners of a natural thermal affected particle (left) glued to a semi-anthracite plastic fragment (right). (c) SA1 coal: the preferred orientation planes on the particle surface are a consequence of the coal original bedding planes that have determined a preferential growing direction.

presented by oxidized (weathered) coal and derived chars observed under reflected-light microscopy;

- Fig. 11b shows an unaltered sharp particle glued to a devolatilized coal particle (right). Because the origin of the sample is Esp1 coal (see Table 1), which contains almost one third thermally affected particles and one third semianthracite, it is possible that the unaltered particle originated from the thermally affected particles.
- Microstratification has already been referred to as a factor influencing char morphology (Thomas et al., 1993) and, from Fig. 11c, it is possible to see that the fractures have a preferred orientation determined by the original bedding planes of the coal.

5. Final considerations

In addition to the conventional analysis, Gray (1982) defined the category of the nonmaceralic microstructures for application in coal and coke petrography. However, some subcategories are maceral features and others are not microstructures. This way, it was considered more correct to name these as “unusual” microfeatures or more simply just as microfeatures.

During the investigation of the emissions of NO_x and N_2O from fluidized bed combustion, the authors found that the coals used presented different kinds and amounts of these features. After devolatilization, the respective chars presented the consequences of these features. Unfortunately, only in the case of thermally affected particles and bind fine coal were the amounts quantifiable. Therefore, the result of this work is essentially observational and descriptive.

The utilization of reflected-light microscopy and SEM allowed the identification of coal particles thermally affected, tectonized, weathered, coarse mineral matter, bind fine coal and contamination:

- In the resulting char, it was observed that the conditions used (700 °C–1000 °C in N_2 atmosphere) were not severe enough to significantly change the thermally affected, tectonized and weathered particles or contamination by anthracite. In fact, most of the particles did not swell and weathered coal shrunk.
- The Colombian coal (Col) contained considerable amounts of bind fine coal that during devolatilization coated normal coal particles and deformed the forming cenospheres.
- After heating, it was still possible to observe and identify some coarse mineral matter.
- The grain size used in fluidized bed combustion (≈ 1 mm) preserved the coal microstratification and the resulting char morphology is also a consequence of microstratification.

Finally, the authors conclude that these microfeatures may partly explain poor combustion efficiency and, for that reason, the study should be expanded.

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