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Identifying contaminants of coal-derived inertinite in charcoal briquettes: Preliminary findings of microscopic analysis

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Abstract: Despite the widespread popularity of charcoal-based grilling fuels, extensive studies have highlighted various pollutants linked to their production and combustion, posing potential risks to human health and the environment. Since the presence of impurities has been identified as a factor contributing to elevated emissions of harmful gases and particulate matter, a comprehensive quality assessment of grilling fuels is imperative to effectively manage and minimise potential risks to customer health and safety.

While identifying many impurities in solid biomass fuels is possible through microscopic analysis, identifying fossil coal contaminants in charcoal briquettes can be challenging. The biggest difficulty arises when coal-derived inertinite and man-made charcoal need to be distinguished as both exhibit numerous visual similarities in microscopic images. Therefore, the goal of this study was to examine the optical morphology of inertinite and charcoal with the aim of differentiating them when they co-occur in charcoal briquettes.

The results show that employing high differential interference (DIC) and fluorescence filters, coupled with reflected white light in microscopic analysis, can enhance the observations allowing for easier detection of impurities of inertinite in charcoal-based grilling fuels. Among the most notable distinctions are the high degree of cellular structure preservation and the presence of small pores and protrusions in man-made charcoal; these characteristics are typically absent in the inertinite fragments.

Keywords: charcoal briquettes, coal, DIC filter, fluorescence filter, inertinite, microscopic analysis

INTRODUCTION

Charcoal briquettes have become increasingly popular for grilling and cooking due to their unique attributes. These densified charcoal-based fuels are engineered for consistent shape and size, allowing convenient storage, transportation, and utilisation. Their properties simplify the ignition process, ensure an extended period of even heat distribution, and offer economic advantages as they are more cost-effective than lump charcoal. The charcoal briquettes exhibit also remarkable versatility, being suitable for direct grilling, and indirect cooking in traditional stoves, kamado-style grills, and smokehouses. Moreover, they are characterised by a lower sulphur content and a higher carbon-to-ash ratio than charcoal lumps, further contributing to their appeal in culinary applications (Akowuah *et al.*, 2012; Borowski, Stępniewski and Wójcik-Oliveira, 2017; Jelonek *et al.*, 2020b; Mencarelli *et al.*, 2023).

However, a wide range of pollutants is associated with the production and utilisation of charcoal-based fuels, and many studies have attempted to assess the human health risks arising from exposure to outdoor cooking (Kim Oanh, Nghiem and Phyu, 2002; Kabir, Kim and Yoon, 2011; Viegas *et al.*, 2012; Jiang *et al.*, 2018; Vicente *et al.*, 2018; Jelonek *et al.*, 2020a; Yu *et al.*, 2020; Badyda *et al.*, 2022; Mencarelli *et al.*, 2023; Georgaki *et al.*, 2024). To mitigate these risks, quality benchmarks and testing protocols were established outlining desired fuel properties along with types and maximum allowable quantities of undesirable additives (EN 1860-2:2005). Among these impurities, the norm EN 1860-2:2005 lists organics such as coal and derivatives thereof, petroleum, coke, pitch, and plastic, as well as inorganic materials like glass, slag, rust, splinters of metal, and stone powder. According to the norm, the test for the inadmissible additions is mandatory and must be conducted by microscopic evaluation in the reflected light, using 1,000 point-count analysis on samples prepared following the norms of ISO 7404-2:2009 and ISO 7404-3:2009. To meet the quality criteria, the cumulative volume of all identified impurities in charcoal-based fuels must be ≤1 vol. %. Although the quantity of unwanted additives at such a low level may appear insignificant, it could have a notable impact on the quality of fuels and pose potential risks to customer health and safety (Jelonek *et al*., 2020b). As the quality of fuels affects the quality of combustion gases, the presence of these impurities can lead to elevated emissions of harmful gases such as CO, CO_2, NO_x, SO_2, and polycyclic aromatic hydrocarbon (PAH) compounds, which negatively impact not only thermally processed food but also human well-being and the environment (Badyda *et al*., 2020; Jelonek *et al*., 2020a; Jelonek *et al*., 2020b; Jelonek *et al*., 2021; Badyda *et al*., 2022; Drobniak *et al*., 2023b; Kuś, Jelonek and Jelonek, 2023).

While the standard EN 1860-2:2005 represents a crucial advancement in ensuring the quality of charcoal-based fuels and, consequently, in mitigating the adverse effects associated with their emissions, it is not without its inherent challenges (Jelonek *et al*., 2020b; Drobniak *et al*., 2021a; Drobniak *et al*., 2022). Among them are the absence of mandatory testing in many countries worldwide and limited guidelines for microscopic evaluation of inadmissible additions, a mandatory component of the quality assessment. In recent years, the latter has been addressed by numerous studies that refined terminology and classifications of microscopic components of solid biomass fuels. Although the improved methodology undeniably enhances the characterisation of the fuels, there are still testing challenges that need to be addressed (Jelonek *et al*., 2020a; Jelonek *et al*., 2020b; Dias *et al*., 2021; Drobniak *et al*., 2021a; Drobniak *et al*., 2021b; Jelonek *et al*., 2021; Drobniak *et al*., 2022; Drobniak *et al*., 2023a; Drobniak *et al*., 2023b; Georgaki *et al*., 2024).

Recognition of many contaminants in solid biomass fuels through microscopic analysis is usually not a problem for experienced petrographers (Drobniak *et al*., 2023a). However, when charcoal-based grilling fuels are contaminated with coal fragments, distinguishing between coal-derived inertinite and modern charcoal using standard observation in reflected light is very difficult. This poses a challenge as qualitative-quantitative identification of coal in charcoal-based fuels is extremely important. While coal additives, added purposely or inadvertently introduced during transportation or storage, can reduce moisture content and increase the calorific value of the grilling fuel, they also might increase the formation of ash, slag, CO, CO_2, and SO_x emissions upon combustion, and contribute to higher levels of toxic metals and organic compounds. Coal may also contain sulphides, silicates, and carbonates, which, combined with alkaline ash, lead to faster corrosion of a grill (Cohen-Ofri *et al*., 2006; Jelonek *et al*., 2020a; Jelonek *et al*., 2020b; Jenkins, Baxter and Miles, 1998; Tumuluru *et al*., 2012).

During the microscopic analysis of fossil coal, three groups of macerals (vitrinite, liptinite, and inertinite) can be distinguished (Stach *et al*., 1982; ICCP, 1998; Taylor *et al*., 1998; ICCP 2001; Ward, 2003; Kandiyoti, Herod and Bartle, 2006; Scott and Glasspool, 2007; Pickel *et al*., 2017; Wagner and Falcon, 2023). When charcoal-based fuel is tainted with coal, the identification of these macerals poses minimal challenges when they coexist within a single coal fragment. Identifying individual fragments of vitrinite or liptinite is also relatively straightforward, although in some cases structureless light grey inertinite may have similar optical properties to adjacent vitrinite (ICCP, 2001). In the reflected white light, the colour of the vitrinite group macerals changes progressively from dark grey in low-rank coals to light grey and white in medium and high-rank coals. The surface of vitrinite is usually smooth and shows no relief (except collodetrinite) in comparison to macerals of liptinite and inertinite groups (ICCP, 1998). The colour of liptinite varies from dark grey to brown and black in the reflected white light, and the macerals are relatively easily distinguished due to their fluorescence properties with colours ranging from green-yellow and yellow in low-rank coals to orange at higher maturity. Macerals of the liptinite group can be also distinguished by their structure, shape, and resemblance to the organic constituents they originated from (Scott and Glasspool, 2007; Pickel *et al*., 2017).

However, the difficulty in identification arises when a lone fragment of inertinite is present in charcoal fuels, as coal-derived inertinite sometimes appears indistinguishable from the image of modern charcoal fragments. While the inertinite maceral group in coals is highly diverse, similarly to modern charcoal, they exhibit a whitish-gray or bright white colour, sometimes with a yellowish tint in the reflected white light (ICCP, 2001; Drobniak *et al*., 2021a). Both charcoal and inertinite typically exhibit a distinct high relief. The shape and preservation of their cell structure also vary and depend on the origin of the source material, production process (charcoal), and post-depositional history of inertinite (ICCP, 2001).

Fusinite (particularly pyrofusinite), one of the inertinite macerals found in coal, is regarded as the closest equivalent to modern charcoal, as the origin of fusinite and charcoal is associated with high temperatures and low oxygen levels during peat fire or modern pyrolysis process, respectively (Morga, 2010; O'Keefe *et al*., 2013). However, because they come from different source materials (paleo-plants in the case of coal and contemporary plant species used for charcoal production (Wilson *et al*., 2017), some aspects of the original makeup that differentiate them could still be preserved, especially when comparing Carboniferous inertinite that comes from flora much different from the modern one. At the same time, it is important to remember that if such differences exist, they will be more distinctive between Carboniferous and modern plants than between Mesozoic and the current flora (Archangelsky, 1996; Adam, 2009; Mastalerz, Drobniak and Hower, 2021). Therefore, to detect differences the inertinite from Carboniferous coal would be the best material to compare to the modern charcoal.

As the microscopic identification of coal impurities in charcoal could be challenging, the goal of this study was to examine the optical morphology of coal-derived inertinite of Carboniferous age and man-made charcoal and investigate if they can be distinguished using microscopic analysis in reflected white light combined with differential interference contrast (DIC) and fluorescence filters. If using the filters proved effective, the technique would allow for easier quality assessment of charcoal-based BBQ fuels, which would contribute to improving grilling safety and reducing air pollution.

MATERIALS AND METHODS

MATERIALS

A comparative petrographic analysis was conducted on samples of bituminous coals and charcoal briquettes. The coal samples were obtained from nine coal mines situated in the Carboniferous Upper Silesian Basin of south-central Poland (Tab. 1). One type of charcoal briquette manufactured in Poland was purchased from a retail store in three packages, each weighing 2.5 kg. The packages were well mixed, quartered, and about 0.5 kg of the briquettes was selected for further crushing and analysis. The purchased samples came with producer information detailing the briquettes' production temperature (350–400°C), elemental carbon content (70%), as well as moisture (8%) and ash content (12%). Furthermore, based on the petrographic analysis (EN 1860-2:2005), the volume ratio of solid components found in the charcoal briquette was determined as follows: charcoal 99.1%, mineral matter 0.6%, metal 0.1%, rust 0.2%.

Table 1. Basic information about individual coal samples including their source (mine name and seam number), vitrinite reflectance (VR_0), and petrographic analysis results

Coal mine	Seam number	VR_0 (%)	Vitrinite	Liptinite	Inertinite	MM	Geographical coordinates
			vol. %				
Jastrzębie	510/1	1.53	47.0	3.0	46.8	3.2	49.9675° N, 18.6256° E
Pniówek	404/4-405	1.21	61.0	4.8	33.0	1.2	49.9658° N, 18.6890° E
Borynia	407/1-2	1.32	46.2	5.4	45.8	2.6	49.9994° N, 18.6128° E
Zofiówka	510	1.44	48.0	4.4	44.8	2.8	49.9672° N, 18.6220° E
Knurów	507	1.02	41.6	16.6	40.2	1.6	50.2219° N, 18.6721° E
Krupiński	405/3	0.88	58.6	9.4	30.6	1.4	50.0478° N, 18.7747° E
Bolesław Śmiały	207/3	0.44	47.4	9.8	40.6	2.2	50.1407° N, 18.8611° E
Mysłowice-Wesoła	501	0.85	37.2	8.8	46.4	7.6	50.2246° N, 19.0489° E
Siersza	207/1	0.36	31.0	4.0	38.0	27.0	50.1497° N, 19.4536° E

Explanation: MM = mineral matter.
Source: own elaboration.

METHODS

The preparation of samples for microscopic examination followed the methodology of petrographic analysis of coals (ISO 6344-3:2013; ISO 7404-2:2009). All samples were crushed and sifted through sieves to obtain material with a grain diameter of 0.50–0.75 mm. Each sample was then embedded in epoxy and cured to form a plug. Subsequently, the plugs were polished using papers with gradations of 1200, 4000, and Struers' MD-DUR (silk) disc and analysed using a ZEISS AXIOPLAN polarising microscope and a computer-controlled XYZ mechanical table. For each of the coal samples, random vitrinite and inertinite reflectance were measured on 100 points, and a basic petrographic analysis was performed (ISO 7404-3:2009; ISO 7404-5:2009) – Table 1.

Ultimately, the study attempted to determine optical features that distinguish coal inertinite from modern charcoal in reflected white light and oil immersion at 500× magnification. For that purpose, comparative microscopic analysis was performed between inertinites and charcoals of a significant degree of visual similarity. Attention was paid to morphological features like colour, texture, level of cellular structure preservation, fluorescence, and occurrence of relief. To obtain (or enhance) additional characteristics, high differential interference (contrast enhancer) and fluorescence filters made by Zeiss were also used (Zeiss, 2024a; Zeiss, 2024b). In the study, other groups of macerals present in fossil coals, such as vitrinite and liptinite, were not considered due to the absence of these forms in charcoal. The focus was on analyzing the similarities and differences in the microscopic images of inertinite originating from fossil coals and a very similar form dominating in charcoal (Fig. 1).

RESULTS

The initial observation was conducted on a coal sample collected in Jastrzębie mine (VR_o = 1.53%) and modern charcoal of high structural similarity to inertinite (Fig. 2). Charcoal exhibits a lighter colour in the reflected white light. Another noticeable difference is the presence of a strong relief in inertinite, emphasised especially by the use of a differential interference contrast (DIC) filter and the absence of relief in charcoal (Fig. 2 – 002 and 005). The use of a fluorescence filter (Fig. 2 – 003 and 006) shows a slight fluorescence effect in the case of charcoal, a feature that is not present in fusinites, and high reflectance inertinites (ICCP, 2001). However, the most distinctive feature between these two fragments is the presence of small pores covering the entire surface of the charcoal, likely the remnants of the pyrolysis process carried out under controlled conditions (Manabe *et al*., 2007; Hudspith and Belcher, 2017; Maziarka *et al*., 2024) – Figure 2 – 004.

Comparing coal-derived inertinite from the Pniówek mine and visually similar charcoal from grilling briquette (Fig. 3), the strong relief of inertinite, both in the white reflected light and with the addition of DIC filter is observed. The use of a fluorescence filter yielded no visible differences.

While similar morphological structures can also be observed for the second fragment of inertinite of Pniówek coal and charcoal (Fig. 4). The relief is visible for inertinite but not for

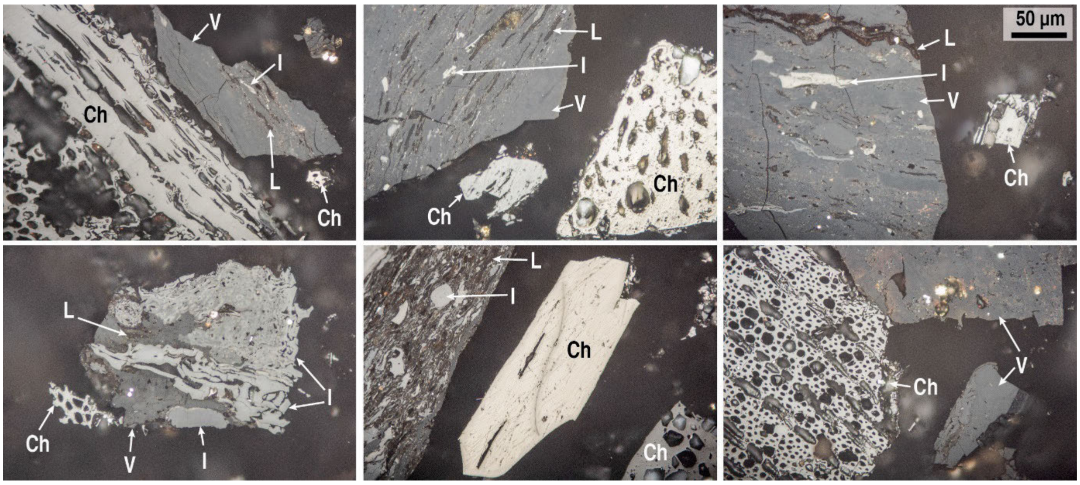

Fig. 1. Photomicrograph showing coal fragments (I – inertinite, V – vitrinite, L – liptinite) identified in charcoal briquette (Ch) samples; reflected white light and oil immersion; the scale bar is identical for all the images; source: Jelonek and Jelonek (2024)

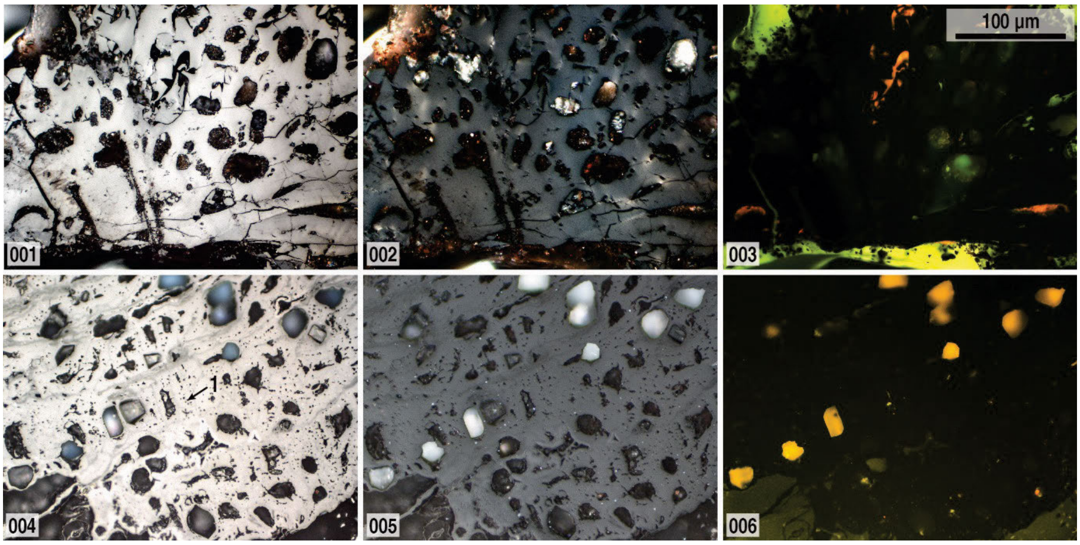

Fig. 2. Photomicrographs of inertinite from Jastrzębie mine (001–003) and charcoal (004–006) taken in reflected white light and oil immersion (1st column), with the addition of differential interference contrast filter (2nd column) or with fluorescence filter (3rd column); note the post-pyrolysis porosity in charcoal in photo 004 (1); the scale bar is identical for all the images; source: Jelonek and Jelonek (2024)

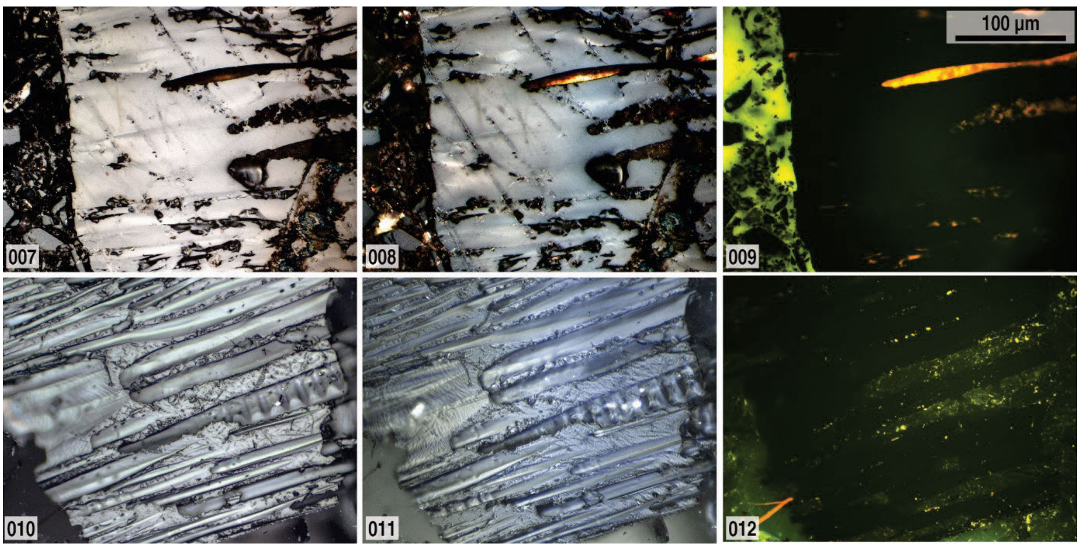

Fig. 3. Photomicrographs of inertinite from Pniówek mine (007–009) and charcoal (010–012) taken in reflected white light and oil immersion (1st column), with the addition of differential interference contrast filter (2nd column) or with fluorescence filter (3rd column); the scale bar is identical for all the images; source: Jelonek and Jelonek (2024)

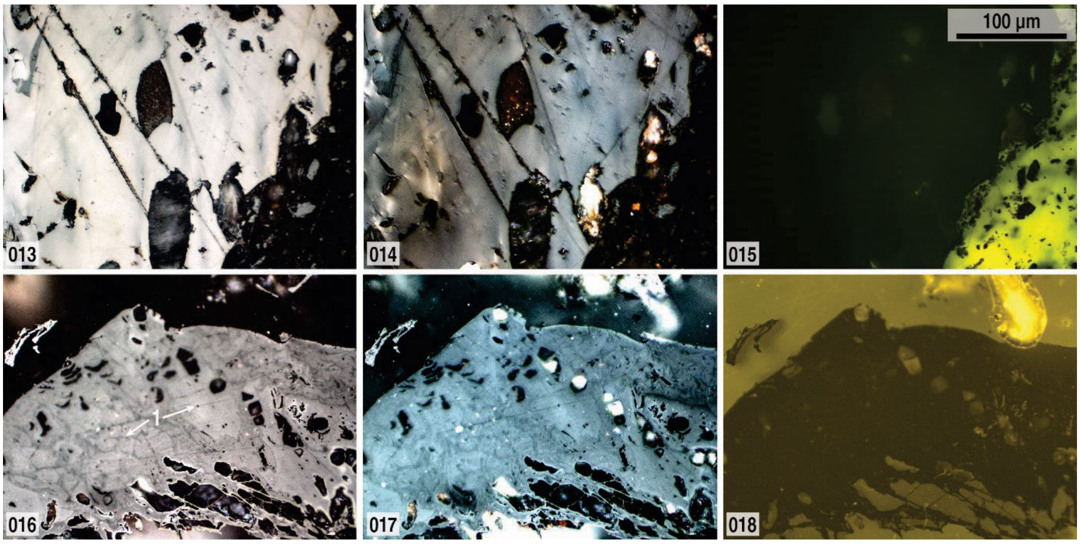

Fig. 4. Photomicrographs of inertinite from Pniówek mine (013–015) and charcoal (016–018) taken in reflected white light and oil immersion (1st column), with the addition of differential interference contrast filter (2nd column) or with fluorescence filter (3rd column); note small protrusions found on the charcoal surface formed likely during uncontrolled air supply to the retort during charcoal production in photo 016 (1); the scale bar is identical for all the images; source: Jelonek and Jelonek (2024)

charcoal both in reflected white light and with a DIC filter. When using a fluorescence filter, no significant differences were observed. However, a very prominent feature distinguishing the fragments was small protrusions found on the charcoal surface likely formed due to uncontrolled air supply to the retort during production (Manabe *et al*., 2007; Hudspith and Belcher, 2017; Maziarka *et al*., 2024) – Figure 4, 016. Such a feature is an important indication of man-made charcoal.

Comparing inertinite from the Borynia mine (VR_o = 1.32%) and charcoal briquette (Fig. 5) did not show a distinct difference. Both inertinite exhibit strong relief, highlighted additionally with the DIC filter (photos 020 and 023). The application of the fluorescent filter allowed to see that the charcoal structure was more regular and less disturbed than the coal (photos 021 and 024).

The second examined pair, including inertinite from the Borynia mine (Fig. 6), contains visually similar broken fragments of inertinite and charcoal. Both fragments show also a very strong relief, making the distinction difficult. However, typical forms of charcoal with well-preserved structures found in grilling fuels can be observed (photo 028). Such forms of charcoal can help with easier identification of man-made fuel (Drobniak *et al*., 2021a).

Inertinite from the Zofiówka mine coal (VR_o =1.44%) and charcoal revealed close similarities, evident both under reflected light and with the DIC filter (Fig. 7). Similar semi-massive structures and a remarkably high relief were observed in both samples. However, the cellular structure of charcoal, further accentuated by the fluorescence filter, exhibited better preservation and manifested distinct fluorescence (indicated by "1" in

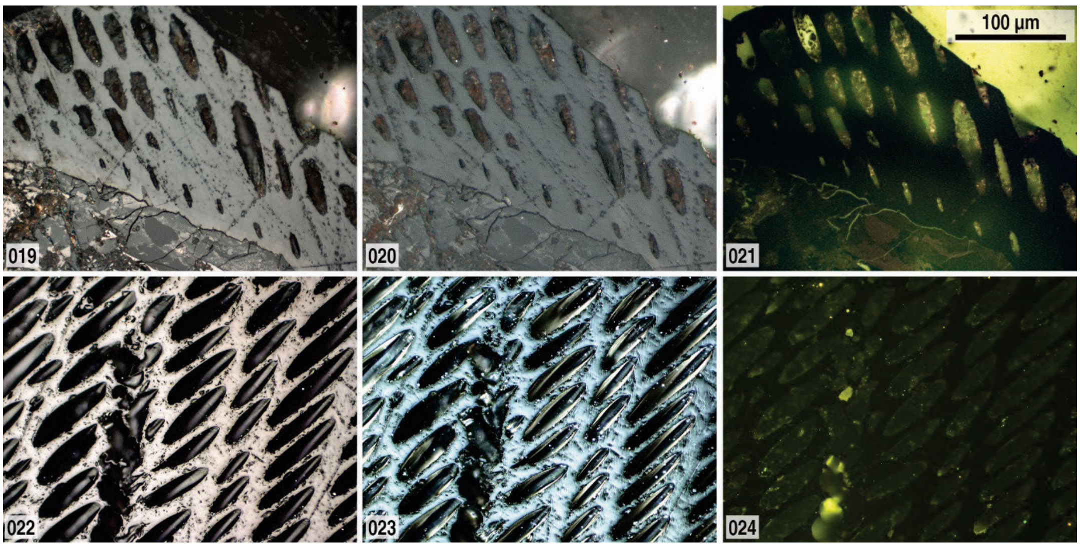

Fig. 5. Photomicrographs of coal from Borynia mine (019–021) and charcoal (022–024) taken in reflected white light and oil immersion (1st column), with the addition of differential interference contrast filter (2nd column) or with fluorescence filter (3rd column); note more regular structure of charcoal (022–024); the scale bar is identical for all the images; source: Jelonek and Jelonek (2024)

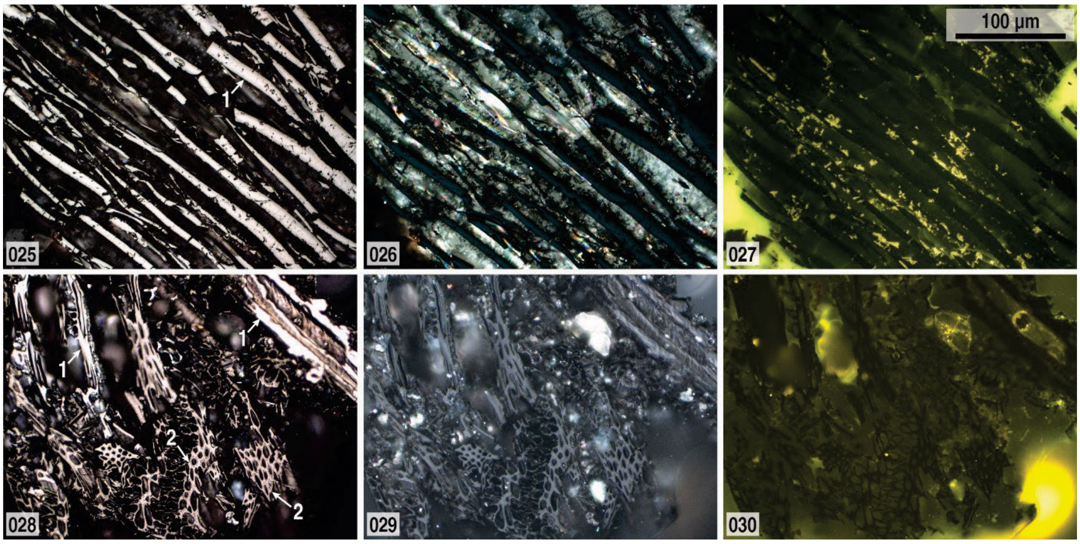

Fig. 6. Photomicrographs of inertinite from Borynia mine (025–027) and charcoal (028–030) taken in reflected white light and oil immersion (1st column), with the addition of differential interference contrast filter (2nd column) or with fluorescence filter (3rd column); note visually similar fragments found both in charcoal and inertinite on photos 025 and 28 (1), and typical forms of charcoal found in grilling fuels in photo 028 (2); the scale bar is identical for all the images; source: Jelonek and Jelonek (2024)

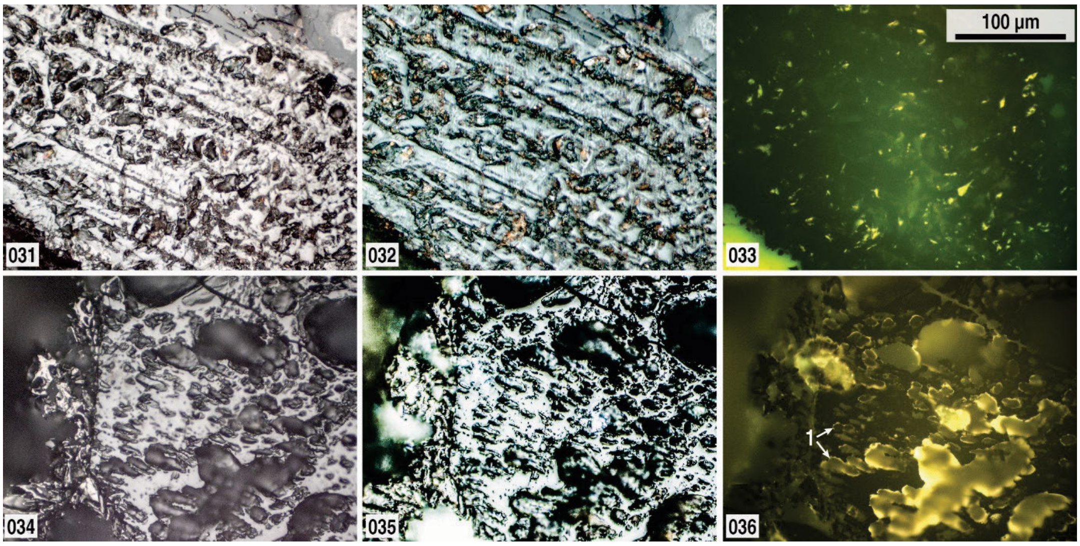

Fig. 7. Photomicrographs of inertinite from Zofiówka mine (031–033) and charcoal (034–036) taken in reflected white light and oil immersion (1st column), with the addition of differential interference contrast filter (2nd column) or with fluorescence filter (3rd column); note the cellular structure and fluorescence of the charcoal fragment (036 – 1); the scale bar is identical for all the images; source: Jelonek and Jelonek. (2024)

photo 036), a feature absent in inertinite. This observation underscores the potential of utilising the fluorescence filter to yield unique insights, particularly when charcoal and inertinite show similar relief.

Inertinite fragments from the Knurów coal mine (VR_o = 1.02%) were compared to charcoals of similar structure and colour (Fig. 8). Inertinites show strong relief, enhanced by the DIC filter. As with the earlier observations when using the fluorescence filter, charcoal displayed a significantly better preserved cellular structure, evident in photos 042 and 048 (1).

Inertinite derived from coal from the Krupiński mine (VR_o = 0.88%) and charcoal exhibit semi-massive structure, and similar colour and reliefs visible especially with application of the DIC filter (Fig. 9). Despite the absence of fluorescence in either case, the application of the fluorescent filter exposed a notably more uniform cellular structure in charcoal, exemplified in photo 054 (1).

In another example, inertinite (IR_0 = 1.61%) from the Bolesław Śmiały coal mine and man-made charcoal display highly preserved structures under white reflected light (Fig. 10, 055 and 058). Nevertheless, upon the application of the DIC filter, a distinctive relief and spatial structure become evident in charcoal, representing a characteristic feature of contemporary wood pyrolysis products (photo 059). Notably, the DIC filter reveals no relief in the inertinite sample, its cells appeared thick and lacked spatial effects (photo 056). Furthermore, the utilisation of a fluorescence filter enhances the well-preserved

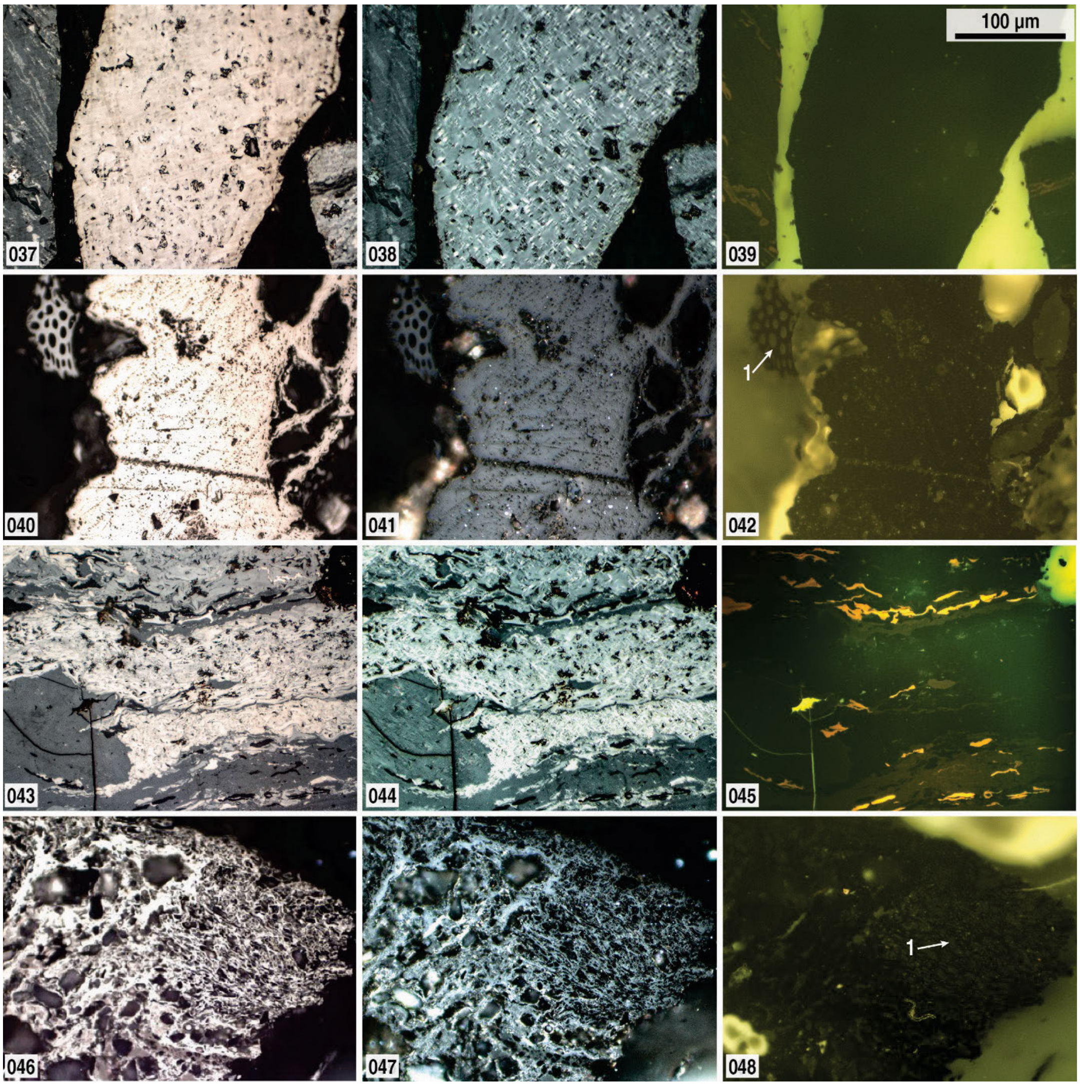

Fig. 8. Photomicrographs of coal from Knurów mine (037–039 and 043–045) and charcoal (040–042 and 046–048) taken in reflected white light and oil immersion (1st column), with the addition of differential interference contrast filter (2nd column) or with fluorescence filter (3rd column); note the well-preserved cellular structure in charcoal (042 and 048 –1); the scale bar is identical for all the images; source: Jelonek and Jelonek (2024)

cellular structure in charcoal (photo 060), a feature absent in the inertinite.

The analysis of inertinite (IR_0 = 1.40%) from the Mysłowice-Wesoła coal mine and charcoal revealed a striking contrast in cellular structure. The charcoal cross-section displayed a well-preserved original plant cell structure (photo 064), whereas the inertinite exhibited a distorted and collapsed structure (Fig. 11, 061). This disparity facilitates a clear distinction between inertinite and charcoal in this case. While both samples exhibit relief when viewed through the DIC filter, the use of a fluorescence filter brought to light the presence of regular cells in charcoal (photo 066) and their absence in inertinite.

The final pair utilised inertinite (IR_0 =1.78%) from the Siersza mine coal, and charcoal of a very similar thin-walled cellular structure. However, the structure was well preserved in charcoal, and significantly degradaded in inertinite (Fig. 12, 067–070). Both fragments showed relief, visible especially with the application of the DIC filter. The well-preserved cellular structure observed in charcoal fragment was accentuated both by the DIC and fluorescence filters.

DISCUSSION

Unwanted additions in charcoal-based fuels may elevate combustion emissions of CO, CO_2, NO_x, SO_2, and PAH compounds, highlighting the importance of comprehensive analytical methods for identifying such impurities (Badyda *et al*., 2020; Badyda *et al*., 2022; Jelonek *et al*., 2020b). While reflected light microscopy unquestionably improves fuel characterisation, challenges persist in identifying some of the components. One notable challenge involves distinguishing fossil coal-derived inertinite from man-made charcoal, as they exhibit numerous visual similarities in microscopic images. As the occurrence of coal impurities (up to 2.2 vol. %) is known from previous studies of charcoal-based grilling fuels (Jelonek *et al*., 2020b; Drobniak *et al*., 2021a), their proper identification and quantification would be much desired.

This study shows that one of the most distinguishing features between inertinite and charcoal is the degree of cellular structure preservation (Tab. 2). In most instances, charcoal exhibits a better preserved, albeit occasionally stretched, net-like structure that closely resembles the composition of contemporary

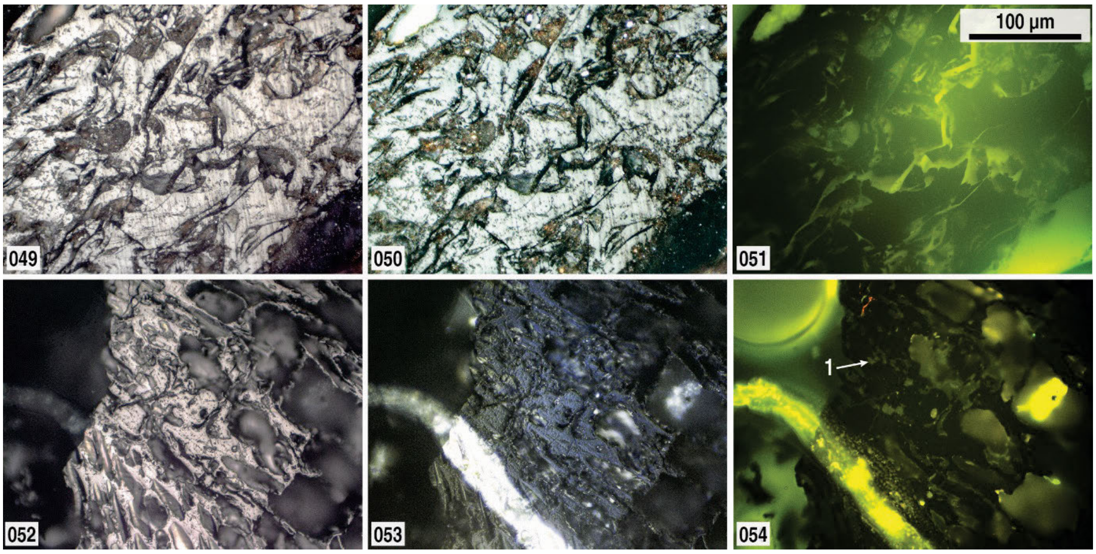

Fig. 9. Photomicrographs of inertinite from Krupiński mine (049–051) and charcoal (052–054) taken in reflected white light and oil immersion (1st column), with the addition of differential interference contrast filter (2nd column) or with fluorescence filter (3rd column); note the well-preserved cellular structure in charcoal in photo 054 (1); the scale bar is identical for all the images; source: Jelonek and Jelonek (2024)

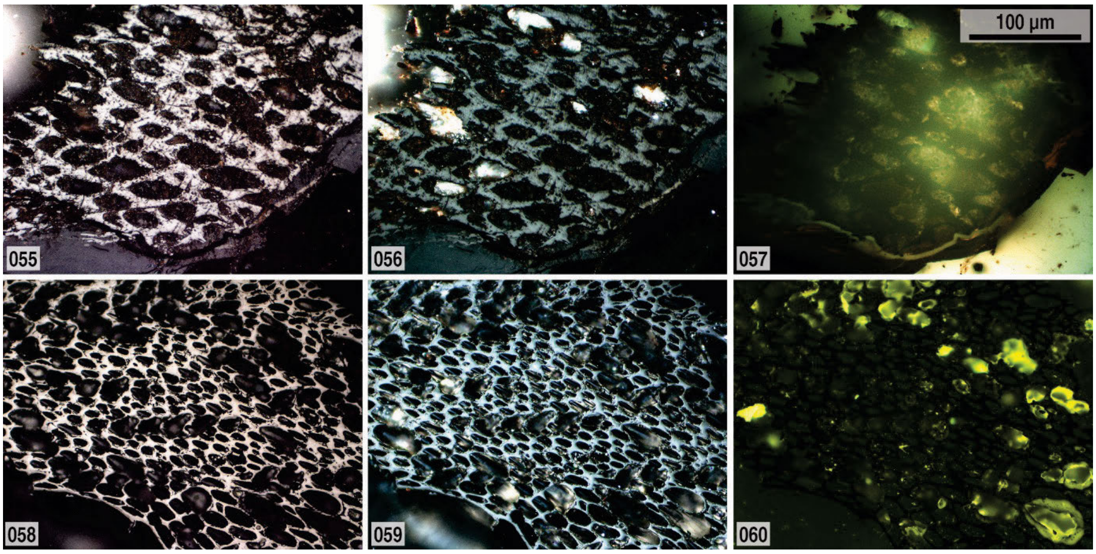

Fig. 10. Photomicrographs of inertinite from Bolesław Śmiały mine (055–057) and charcoal (058–060) taken in reflected white light and oil immersion (1st column), with the addition of differential interference contrast filter (2nd column) or with fluorescence filter (3rd column); note the distinctive relief and spatial structure in charcoal (058–060); the scale bar is identical for all the images; source: Jelonek and Jelonek (2024)

plant materials utilised for fuel production. In contrast, numerous inertinites from the analysed Carboniferous coal samples show often damaged, sometimes semi-massive structures. These structural distinctions of charcoal are observable under reflected white light and are further accentuated through the application of DIC and fluorescence filters. In the material studied, inertinites with clearly defined cellular structures were identified only occasionally (Figs. 5 and 10). In such cases, the cells either remain empty or were filled with clay minerals, pyrite, or carbonates. In comparison, cell lumens in charcoal were typically empty or filled by silicates (Allue, Euba and Solé, 2009).

While cellular preservation remains an important optical feature helping to distinguish between analysed inertinites and charcoal fragments, the assessment of colour during microscopic observation proved to be the least informative characteristic. When examined under reflected white light, the colour spectrum of both inertinites (Kruszewska and Dybova-Jachowicz, 1997) and charcoals extends from white to white-gray, and dark gray, occasionally featuring a distinctive white-yellow hue (particularly in the case of pyrofusinite). This change in colour, from darker to lighter, reflects an increase in the reflectance of organic matter, therefore, when comparing fragments of various reflectance, the colour alone should not be used to distinguish inertinite from charcoal. The drawback of this study was the difficulty of finding inertinite-charcoal pairs of similar visual appearance and comparable reflectance values, except for inertinites from the Pniówek and Zofiówka mines (Tab. 2). It is plausible that variations in relief or fluorescence properties might be less

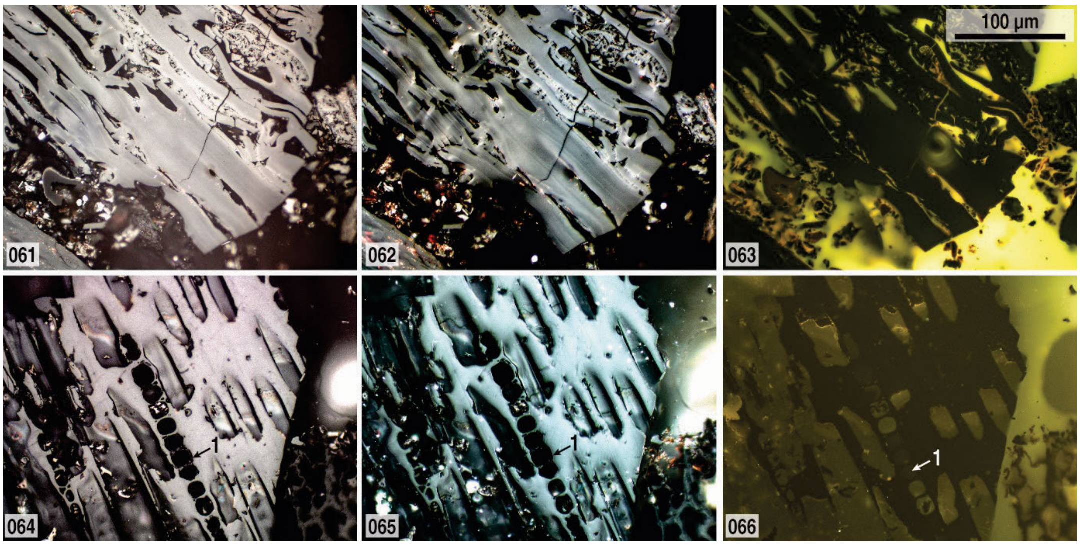

Fig. 11. Photomicrographs of coal from Mysłowice-Wesoła mine (061–063) and charcoal (0064–066) taken in reflected white light and oil immersion (1st column), with the addition of differential interference contrast filter (2nd column) or with fluorescence filter (3rd column); note a well-preserved original plant cell structure in the cross-section of charcoal on photos 064 to 066 (1); the scale bar is identical for all the images; source: Jelonek and Jelonek (2024)

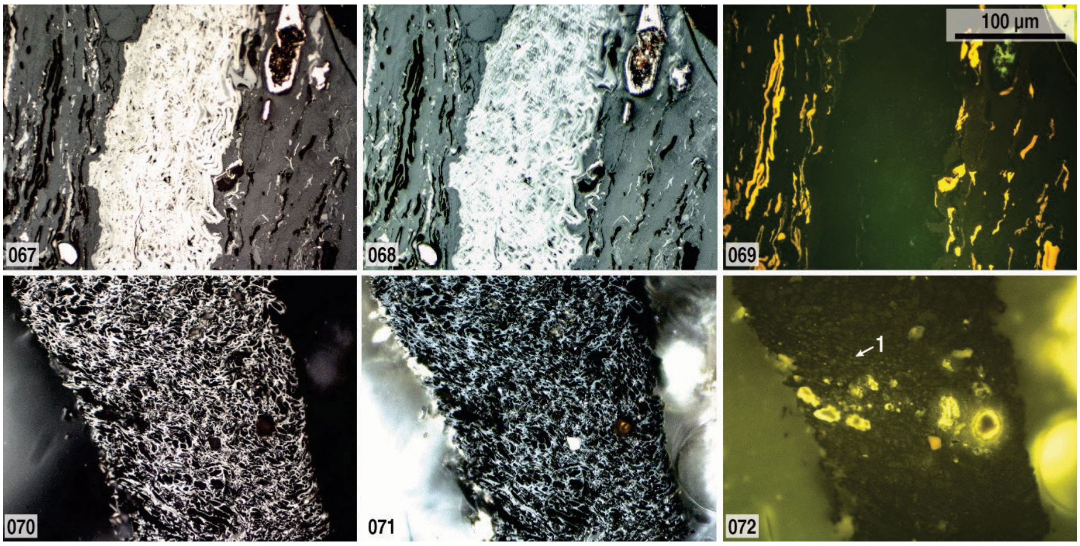

Fig. 12. Photomicrographs of coal from Siersza mine (067–069) and charcoal (070–072) taken in reflected white light and oil immersion (1st column), with the addition of differential interference contrast filter (2nd column) or with fluorescence filter (3rd column); note the well-preserved cellular structure in charcoal in photo 072 (1); the scale bar is identical for all the images; source: Jelonek and Jelonek (2024)

pronounced when reflectance values are similar. Nevertheless, even under such circumstances, it is anticipated that charcoal would generally exhibit better preservation of cell structure.

In the microscopic analysis of the studied samples, inertinite derived from coal displayed no fluorescence, whereas a minor fluorescence effect was observed for two charcoals (Figs. 2 and 7). While the origin and significance of fluorescence in certain charcoals remain uncertain, due to its sporadic occurrence, this phenomenon cannot be relied upon for identification purposes, particularly given that some semifusinites may exhibit fluorescence at low reflectance (ICCP, 2001).

Another feature noted in the examined inertinite and charcoal samples was a relief that was further highlighted with the DIC filter. The microscopic images consistently showcased a significant relief in inertinites, with only one exception (Fig. 10). Nevertheless, as numerous charcoal fragments also exhibited relief (Tab. 2), therefore relief cannot be regarded as a unique characteristic. However, as mentioned earlier, a comparison of the fragments of equal reflectance could give better insight into the significance of the relief as a distinguishing feature.

Finally, during the microscopic examination, two additional distinct features of charcoals were identified. One of the charcoal samples exhibited the presence of small pores covering the entire surface of the charcoal (Fig. 2). These pores were identified as remnants of the pyrolysis process conducted under controlled conditions. Another sample showed small protrusions on the charcoal surface, formed, most likely, as a result of uncontrolled air supply to the retort during the production process (Fig. 4). Both of these features, although present only on a few studied particles, can serve as strong indicators of man-made charcoal and constitute crucial characteristics to be mindful of during microscopic analysis.

Table 2. Comparison of inertinites and charcoals' features analysed in this study

Figure	Coal-derived inertinite			Modern charcoal		
	mine	relief	Fl	relief	Fl	other
2	Jastrzębie	yes	no	no	yes	small pores
3	Pniówek	yes	no	no	no	–
4	Pniówek	yes	no	no	no	small protrusions
5	Borynia	yes	no	yes	no	better preserved structure
6	Borynia	yes	no	yes	no	better preserved structure
7	Zofiówka	yes	no	yes	yes	better preserved structure
8	Knurów	yes	no	no	no	better preserved structure
8	Knurów	yes	no	no	no	better preserved structure
9	Krupiński	yes	no	yes	no	better preserved structure
10	Bolesław Śmiały	no	no	yes	no	better preserved structure
11	Mysłowice-Wesoła	yes	no	yes	no	better preserved structure
12	Siersza	yes	no	yes	no	better preserved structure

Explanation: Fl = fluorescence. Source: own study.

Lastly, it is important to note that the conducted comparative analysis was confined to inertinites sourced from the Carboniferous Upper Silesian Coal Basin (Gabzdyl and Hanak, 2005) and charcoal briquettes manufactured in Poland. Some observed differences between charcoal and inertinites could potentially be attributed to distinctions between modern plants and Carboniferous vegetation. To gain a more comprehensive understanding, future investigations should extend to inertinites from coals of other ages, where vegetation significantly differed from that of the Carboniferous era (Archangelsky, 1996; Iglesias, Artabe and Morel, 2011). Additionally, it is crucial to recognise the potential influence of pyrolysis conditions on the morphological characteristics of charcoal (Dias Junior *et al.*, 2020; Surup *et al.*, 2019; Tintner *et al.*, 2018; Bielowicz, 2019). In the present study, the specific conditions of pyrolysis were not known, preventing a comprehensive assessment of their impact on the observed morphological differences. Future research should consider incorporating this information for a more thorough exploration of the relationships between pyrolysis conditions and the resulting characteristics of charcoal.

CONCLUSIONS

Given the vast array of structural variations inherent in inertinite and charcoal, this study undertakes the challenging task of offering preliminary observations on their optical characteristics and the potential for their distinguishing in microscopic examination. The observation employed the combination of white reflected light with high differential interference (DIC) and fluorescence filters, thereby facilitating an enhanced analysis of their texture, cellular structure preservation, fluorescence, and the manifestation of relief.

Preliminary observations show inherent challenges in differentiating between coal-derived inertinite and charcoal, emphasising that such distinctions may not always be possible. While charcoals typically demonstrate better-preserved cellular structure, the overall similarity of the optical features makes it often difficult to distinguish them from coal-derived inertinites with a large degree of certainty. The presence of small pores or protrusions on the charcoal surface resulting from the controlled pyrolysis process, are good indicators of the man-made process, but such features were present only occasionally. The application of high differential interference and fluorescence filters undoubtedly enhances microscopic analysis, contributing to improved detection of relief, enhanced depth of field, preserved cellular structure, and fluorescence phenomena. It is essential, however, not to assess these features separately, instead, a comprehensive analysis of various optical characteristics should be pursued whenever feasible. Adopting such an approach would elevate the precision and reliability of impurities identification during microscopic observations of charcoal briquettes.

Although further research is required to refine the methodology for distinguishing between inertinite and charcoal in microscopic analysis, the preliminary findings are promising and insightful. The future steps should include comparing the specimens of the same reflectance and also include inertinites from other than Carboniferous coals. It is also crucial to explore additional techniques to address the complexities of identification beyond the inertinite and charcoal samples examined in this study.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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