

Article

Microhardness of Coal from Near-Fault Zones in Coal Seams Threatened with Gas-Geodynamic Phenomena, Upper Silesian Coal Basin, Poland

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Abstract: Near-fault coal displays some specific structural and textural features. As the distance to the fault diminishes, one can observe ever stronger, gradual degradation of coal, demonstrated by the emergence of structural distortions exogenic in their origin, visible under a microscope. The process of gradual degradation of coal—manifested by the appearance of structural distortions exogenic in their origin—takes place. This can be observed under a microscope. The measurements of the microhardness of structurally altered coal carried out using the Vickers hardness test. For the purpose of this research, a microhardness tester by the CSM Instruments was used. The microhardness of particular structural types of coal was measured. The procedure encompassed both structurally unaltered and altered coal. The tested objects were exogenically fractured fragments, cataclastic, and mylonitic structures. Each of the analyzed structural types displayed a different range of the microhardness, with the highest values confirmed for the structurally unaltered coal. In the case of fractured coal, the microhardness values were somewhat lower. Finally, the lowest values were ascertained for cataclastic coal. Mylonitic coal, in turn, displayed microhardness values similar to those found in the unaltered coal. It was also observed that, in the case of the unaltered, fractured, and cataclastic coal, cracks propagated in the manner typical of brittle materials, whereas the mylonitic coal revealed some degree of elasticity. The analyzed microhardness parameters expose the structural–textural features of coal, particularly when it comes to the degree and character of destruction of the rock’s original matrix. The specific structural–textural composition of particular types of near-fault creations influences both their sorption parameters and the compactness of coal in a seam.

Keywords: Vickers microhardness; faults; structurally altered coal; Upper Silesian Coal Basin

1. Introduction

In coal, there are always more or less complex systems of fractures, cracks or pores [1–4]. Still, it needs to be observed that they may appear in the coal structure as a result of the impact of an increase in the degree of coalification [5], or as a consequence of tectonic distortions affecting a seam [6]. These distortions lead to the appearance of a network of fractures in coal, as well as comminution or even grinding of the coal material [7,8]. This “structurally altered” coal [9] is characterized by lower compactness and increased gas capacity, which, in turn, makes the occurrence of gas-geodynamic phenomena more likely. It is widely believed that almost all gas and rock outbursts occur in areas of tectonic dislocations, as the structurally altered coal that occurs in these areas is “unstable” due to its

lower compactness and high gas capacity [7,8,10,11]. The occurrence of uncontrolled gas-geodynamic phenomena in the seams of the Upper Silesian Coal Basin (USCB) still poses a real threat [12–15]. Because of that, researchers study coals from seams characterized by tectonic distortions and search for alternative methods and parameters which will make it possible to better describe the near-fault material and, what follows, help to develop outburst prevention measures. The near-fault hard coal has been a subject of research for many years at the Strata Mechanics Research Institute of the Polish Academy of Sciences [6,14,16,17]. On the basis of these experiences, as well as analyses of the properties of a large amount of near-fault coal samples, it was determined—among other things—that the coal occurring in such areas always displays some characteristic structural and textural changes, and the percentage share of ‘structurally altered’ coal increases as the distance to the fault diminishes. The degree and intensification of structural changes differ depending on the location, forces acting on the seam, the maceral composition and addition of a mineral substance [6,16,17]. Also, a set of features characterizing particular types of altered structures from near-fault zones were described and collected in a table. On that basis, classification of altered structures of the near-fault coal was compiled [9,18].

Investigating the properties of the structurally altered coal is just as important as determining its amount and classifying it under a proper type. As part of the present paper, an attempt was made to find a parameter which could help differentiate between particular types of structures. Using some previous research into the coal from tectonically distorted areas [9,16,17], it was demonstrated that the content of structurally altered coal is different both quantity- and quality-wise in various near-fault coal seams. Due to a relationship between the coal’s microhardness and its strength [19], the author attempted to determine the microhardness parameters for particular structural types of coal from near-fault areas, using the Vickers hardness test method. Once tests confirmed that the Vickers meter could be used in analyses of structurally altered coal, the author set out to establish if and how particular structural types differ with respect to parameters obtained in the course of microhardness tests. It was assumed that if particular structural types differ with respect to microhardness parameters, it will also be possible to draw certain conclusions concerning the impact of a given structure upon a coal seam. Juxtaposing these results with other coal parameters, it will be possible to make predictions as to outburst inclinations of a tectonically distorted seam.

2. Description of the Research Problem

Coal is a specific creation of heterogenous, non-uniform structure, which makes it difficult to unequivocally establish a physical parameter describing the hardness of that substance [20]. One of the most frequently used methods for measuring coal strength is the Hardgrove Grindability Index (HGI) [20,21]. This method—used to measure a given material’s milling susceptibility [22]—is an indicator speaking of coal’s grindability; the lower its value, the harder the coal structure. The results obtained by means of this method concern the whole analyzed coal fragment, with a full spectrum of its components (maceral groups, mineral substance, and other organic substances) [23,24]. Thus, the method fails to provide us with evaluation of particular components of coal. In order to perform a proper and reliable measurement of particular components of coal, a researcher needs to measure hardness in the micro-scale. A method which is most frequently used to determine the microhardness of coal is the Vickers method [20,21]; at times, the Knoop method is also used [25].

Microhardness is a parameter widely used in studying various types of materials, such as metals [26], ceramics [27], or composites [28]. It is also used in analyses of minerals and rocks [29] what seems to be particularly interesting are the microhardness analyses used in identifying particular stages and micro-fractures in carbonates [30]. That method is also used in studies into the relationship between porosity and microhardness in sulfate and saline minerals [31], as well as in determining the degree of weathering of andesite fragments [32], and even in analyses of Palaeolithic stone tool materials [33]. The parameter has also been used for many years in analyses of coal [34,35], including the creations of the Upper Silesian Coal Basin [36–42] and in other coal basins (e.g., Indian coals [21] or high volatile bituminous Kentucky coals [43]). Some researchers use microhardness tests to solve untypical problems.

For example, Hower et al. [43], provided an interesting application of the Vickers microhardness tests in the process of differentiating between almost identical macerals of the vitrinite group. According to a lot of researchers, microhardness is a very good indicator for detecting weathered coal fragments. Most researchers claim that the process of oxidizing results in an increase of microhardness [44–47].

It is not easy to determine the microhardness of coal properly. This is due to the two specific features of coal. Firstly, coal is an organic rock, heterogenous in its structure, which makes it difficult to pick areas that would be the most suitable for research—because of the occurrence of microlithotypes, structural differences, different characteristics of particular maceral groups, presence of non-organic additions, fractures, and micropores [48]. Secondly, coal and its particular components are subject—to a various extent—to brittle or plastic strains, particularly under the influence of faults [9,16,17].

Although the microhardness measurement has certain limitations [49], a lot of researchers have successfully attempted to study fine and heterogenous petrographic components of coal, such as selected macerals from the liptinite or inertinite group [36,37,39,49,50]. Mukherjee et al. [21] even claim that the Vickers microhardness tests are so sensitive that they can be selectively performed on any micro-component of coal.

3. Research Methodology

The Microhardness Tester by the CSM Instruments consists of an indentation (load) part, a motorized XY table, and a microscope part (the Nikon microscope), connected to the NIS-Elements 3.0. image analysis software (Figure 1).

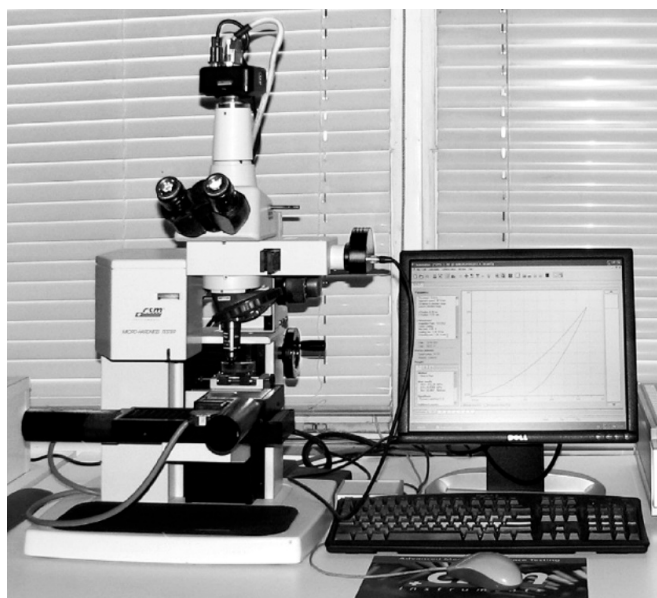


Figure 1. Microhardness tester (CMS Instruments) with image analysis processing LUCIA D [39].

The load can be in the range from 100 mN to 30 N; we used the load $F_{max} = 0.5$ N. The indenter is the Vickers diamond pyramid, and the Vickers microhardness H_V is calculated according to the formula

$$H_V = \frac{F_{max}}{9.81 \times A_c(h_c)} \left[\frac{\text{N}}{\text{mm}^2} \right] \quad (1)$$

where

F_{max} —maximal force (N),

h_c —depth of impact (μm),

A_c —developed contact area (μm^2).

The equipment makes it possible to measure the standard microhardness and determine the elastic modulus E_{IT} of the tested material. The typical course of the measurement curve for vitrinite is shown in Figure 2. The elastic modulus can be calculated from an unloading curve in two ways: using the tangent method and the power law method [51]. We used the power law method, as it should describe the deformation behavior of vitrinite in a better way:

$$E_{IT} = \frac{1 - v_s^2}{\frac{1}{E_r} - \frac{1 - v_i^2}{E_i}} [\text{GPa}] \quad (2)$$

where

E_{IT} —elastic modulus [GPa]

E_i —elastic modulus of indenter (1141 GPa)

v_i —Poisson's ratio of the indenter (0.07)

E_r —reduced modulus of the indentation contact

v_s —Poisson's ratio of the sample (user's selection).

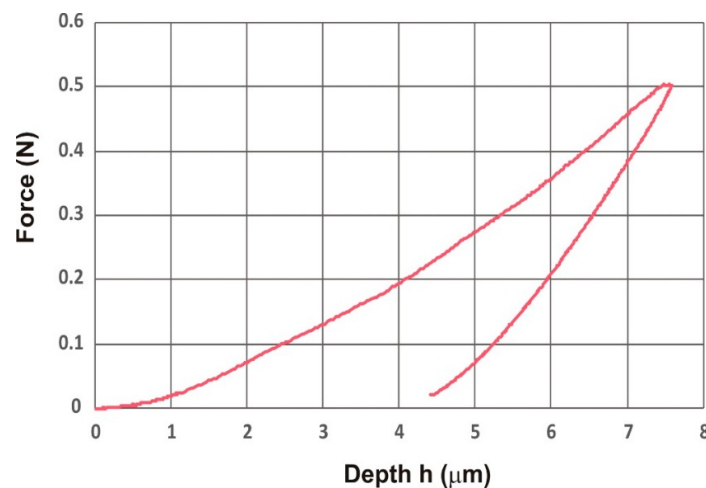


Figure 2. The typical relationship between the indent depth and the indenter force F_{IT} .

The test samples should have a smooth surface and should be fixed perpendicularly in relation to the indenter. Experiments were carried out on polished sections of coal grains. The measurement position was chosen by the microscope, and then the specimen was placed under the indenter. The load was applied by a force-controller with the approach speed of 30%/min, until the maximum load of 0.5 N was reached. Immediately after loading (the time of the maximal loading is 5 s), the indentation impressions were examined with an optical microscope, and an image of the impression was taken to minimize the effect of the environment on the crack growth.

The present paper proposes the application of the results of microhardness tests to the analysis of coal samples collected from near-fault zones of the selected coal seams of the Upper Silesian Coal Basin. The research material was constituted of fragments of coal that were destroyed, degraded by the effect of tectonic forces. The near-fault coal samples were used to make granular preparations (polished microsections). Subsequently, a series of measurements of microhardness (H_V) was carried out, together with measurements of the elasticity module (E_{IT}) by means of the Oliver & Pharr method [51] and the evaluation of the results of the impact of the indenter on the coal surface. The Oliver & Pharr method works best in determining the H_v and E_{IT} parameters in coals [39]. For research purposes, particular structural types of coal were selected, based on the classification of the near-fault coal structures proposed by Godyń [9].

Differences in earlier measurements from the outburst zone and the intact area of the same seam (the “Zofiówka” mine) were found. The vitrinite of the coal from the outburst zone was characterized by lower microhardness H_V and a lower value of the elastic modulus E_{IT} than the vitrinite of the coal from the intact area [52].

4. Research Material

The near-fault coal differs from typical coal from tectonically undisturbed areas inasmuch as the former contains some fragments that are more or less degraded. The content of degraded rock fragments in such coal differs depending on the distance from the fault, the extent and geometry of the fault, and the petrographic features of the deposit. After numerous analyses of coal from near-fault zones collected from various fault areas of the Upper Silesian Coal Basin, it was observed that an increased amount of degraded coal is not necessarily found in the vicinity of a fault. There are faults where the content of the structurally altered substance is from several to a dozen or so percent [Godyń–unpublished results]. However, it is usually the case that the fault areas are characterized by more spectacular degradation of coal structures [6,16,17].

For research purposes, coal from the near-fault zones of the hard coal mines of the Upper Silesian Coal Basin (Figure 3) was selected. All the analyzed seams were to be found in the Załęskie layers of the mudstone series (the Upper Carboniferous formations–Westfal).



Figure 3. Location of research area in the part of Upper Silesian Coal Basin [53].

Each of the samples was analyzed stereologically so that the percentage content of the structurally unaltered and altered coal was established. The analysis, based on the classification of structurally altered coal from areas of tectonic dislocations [9], encompassed the following coals:

1. Unaltered coal—The sole subject of the analysis was the most common maceral from the vitrinite group, i.e., colotelinite. The surface of the analyzed areas was free from exogenic fractures. The only fractures that could be observed in this coal were single and regular endo-microfractures, i.e., fractures resulting from natural coalification processes.
2. Altered coal:
 - a. Cracked coal—It was assumed that the diagnostic feature of this type of structure should be the presence of a network of irregular cracks that appeared as a result of the impact of the exogenic forces, observed in colotelinite.
 - b. Cataclastic coal—In the areas classified as cataclastic coal, we can identify a dense or a very dense network of cracks. Some coal fragments are comminuted to a large extent and mixed. The original structures are partly or totally blurred.
 - c. Mylonitic coal—These structures are characterized by a very high degree of transformation. Particular fragments, previously ground, are dislocated in relation to one another and show traces of secondary pressing. The original structures are totally blurred. Thus, directional structures and secondary cracks may appear.

Samples used during the research:

- The W1 sample was taken from the “Borynia–Zofiówka–Jastrzębie” hard coal mine, coal seam no. 404/1 + 405/1. The material comes from the mine face of the ventilation plane V, located at the depth of 1000 m. In August 2010, a sudden outburst of methane occurred in the area, combined with the dislocation of rock material into the mine face. A sample from a sidewall in the vicinity of the fault was selected for microhardness tests. The total content of ‘structurally altered’ coal in the sample was over 17 percent (Table 1);
- The W2 sample was taken from the “Borynia–Zofiówka–Jastrzębie” hard coal mine, seam no. 409/4. In November 2005, an outburst of methane and rocks occurred in the D-6 gate road. After the incident, two faults were revealed, situated in the post-outburst cavern area [12,14]. For the microhardness tests, a sample from the right sidewall of the fault was selected, containing almost 50 percent of structurally altered coal (Table 1);
- The W3 sample was taken from the “Pniówek” hard coal mine, coal seam no. 403/3. In the B-5 longwall, a minor tectonic discontinuity cutting through the seam was discovered, with the upthrown side on the left. For the microhardness tests, a sample from the right side of the fault was selected, containing ca. 50 percent of structurally altered material (Table 1);
- The W4 sample was taken from the “Borynia–Zofiówka–Jastrzębie” hard coal mine, coal seam no. 412 łg + łd. In the G-2 top gate, a fault with a minor left thrust was discovered. For the microhardness tests, a coal hunk extracted from the spot located 1.5 m away from the fault was selected. The content of structurally altered coal in this sample is about 20 percent (Table 1);
- The W5 sample was taken from the “Borynia–Zofiówka–Jastrzębie” hard coal mine, seam no. 406/1. In the F-1 top gate, a fault was revealed, from which samples were extracted for the purpose of further analysis. The content of structurally altered coal material in this sample is circa 44 percent (Table 1);
- The W6 sample was taken from the “Borynia–Zofiówka–Jastrzębie” hard coal mine, seam no. 407/1. The research sample was extracted from the spot located over 10 m away from the fault. This sample contains just a small amount of structurally altered coal material (less than 2 percent of the total capacity—Table 1).

Table 1. Point analysis of coal samples (minerals not included).

Sample No.	W1	W2	W3	W4	W5	W6
Distance from the fault/grain fraction of the sample	Sidewall—fault area (1–2 mm)	Fault—right sidewall (0.5–1 mm)	Fault—right wing (0.5–1 mm)	1.5 m to the right from the fault (0.5–1 mm)	The fault (0.5–1 mm)	Distance from the fault >10 m (0.5–1 mm)
Unaltered coal	82.66	52.01	49.80	80.69	56.34	98.32
Structurally altered coal	Cracked coal	10.6	9.50	17.40	7.36	10.23
	Cataclastic coal	1.23	30.92	21.77	8.67	30.80
	Mylonitic coal	5.25	7.57	11.03	3.28	2.63

5. Obtained Results

The Vickers microhardness passes through a minimum in the range of the carbon content in coal of 88–92% [20], and the minimum H_V of vitrinite from the Czech part of the Upper Silesian coal basin was found in coal with the carbon content of 89% [37]. Due to the fact that an increasing degree of coalification is accompanied by a change in the microhardness of coal, measurements of vitrinite reflectance (R_0) were carried out for all the analyzed samples. Out of these, samples with similar values of R_0 (%) were compared. The mean vitrinite reflectance in all the analyzed samples was between 0.98 R_0 (%) and 1.12 R_0 (%) (Table 2), which corresponds to the high volume bituminous coal -part A [20].

Table 2. Results of the measurements of the mean vitrinite reflectance value for the coal samples analyzed in the present paper.

Sample No.	Mean Vitrinite Reflectance Value R_0 (%)
W1	1.09
W2	1.11
W3	0.98
W4	0.98
W5	1.04
W6	1.11

Around 20–40 series of microhardness measurements were carried out for each of the analyzed types of coal structures. Figure 4 presents sample images taken in the spots where the diamond indenter—the Vickers pyramid—was pressed into the surface, right after the performed microhardness analysis.

Analyses performed with the Vickers microhardness tester made it possible to obtain results concerning three various parameters: the Vickers microhardness H_V (N/mm²), the modulus of elasticity E_{IT} (GPa), and the nature of fractures which appeared after the Vickers indenter was pressed into the analyzed coal structure.

During the analyses of particular structural types of coal, it turned out that the coal material revealing the characteristics of cataclasis and mylonite contained (in cracks and fractures) a substance of a different origin than coal macerals. In order to identify these components, analyses of coal samples in the fluorescent light were carried out. It was discovered that in the fragments built of cataclasis, in some cracks, glue appeared. In mylonite, in turn, the cracks were filled with a mineral substance.

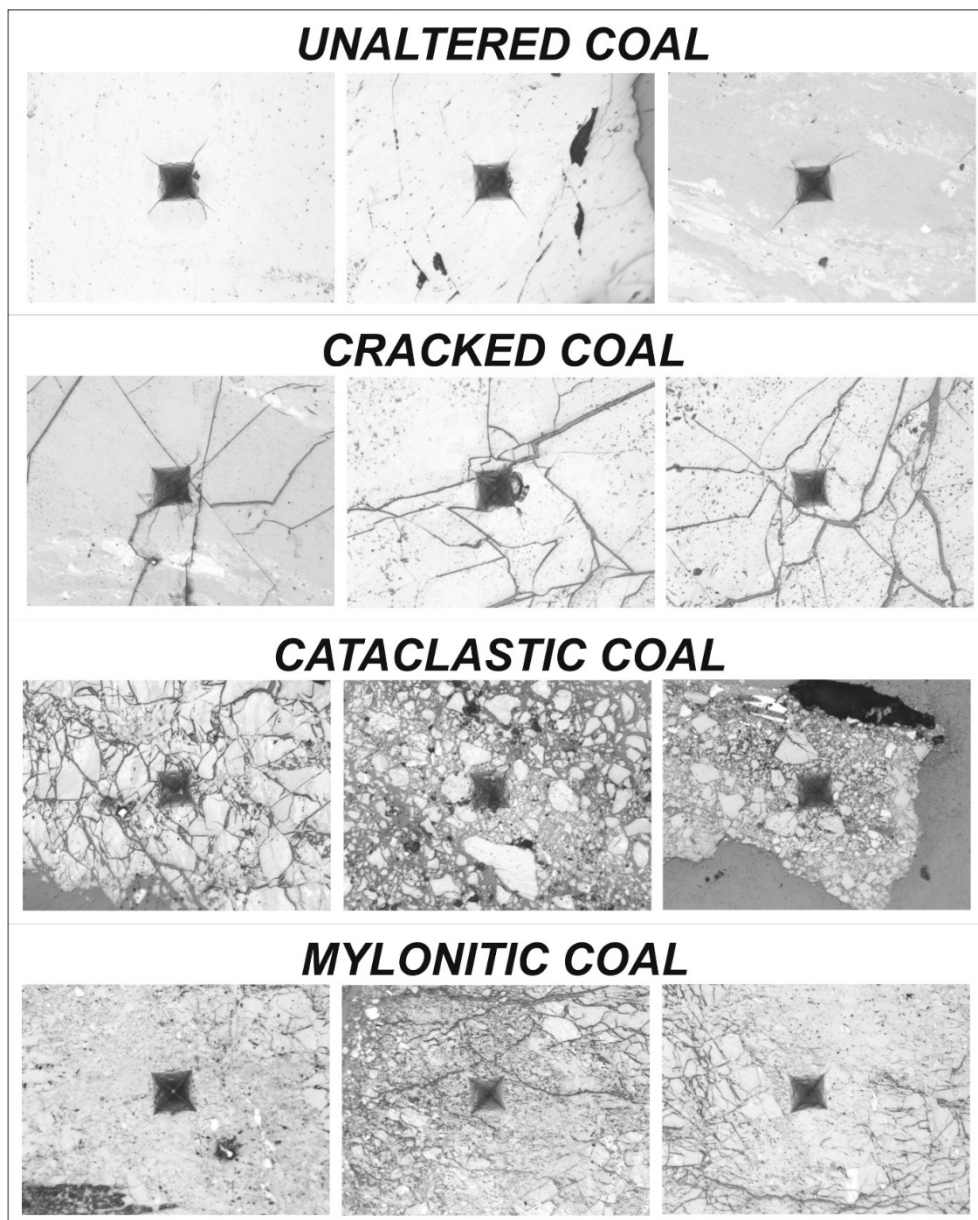


Figure 4. Coal structures in the spots of microhardness measurements. Photographs after the microhardness analysis, with a marked imprint, taken at a magnification of 200×, reflected light.

5.1. Vickers Microhardness Analyses

The measurements of the Vickers microhardness demonstrated that for structurally unaltered coal—with just a few fractures—the values of the Vickers microhardness were from about 44 to almost 70 N/mm² (Figure 5), with the mean value 58.66 N/mm² (Table 3, Figure 6). The presence of exogenic fractures—and, above all, the formation of cataclasis—resulted in weakening of the coal structure, which was the consequence of a decrease in microhardness (Figure 5). The microhardness values for fractured coal were between 32 N/mm² and 65 N/mm², with the mean value 50.41 N/mm² (Table 3, Figure 6). In the case of the coal which displayed the characteristics of cataclasis, the values of the Vickers microhardness were significantly lower—from 33 N/mm² to 54 N/mm² (Figure 5), with the mean value 44.78 N/mm² (Table 3, Figure 6). The situation was quite different in the case of the coal displaying the characteristics of mylonite: the presence of this structure determined a significant increase in microhardness (Figure 5). The values of this parameter were from ca. 47 N/mm² to 68 N/mm², with the mean value 57.53 N/mm² (Table 3, Figure 6). The results show that, in the case of

coal structures displaying the characteristics of mylonite, the value of microhardness is almost as high as in the case of structurally unaltered coal. It is likely that such high microhardness is connected with substantial pressing of the original substance composed of coal and an addition of a mineral substance, whose presence was confirmed by analyses in fluorescent light.

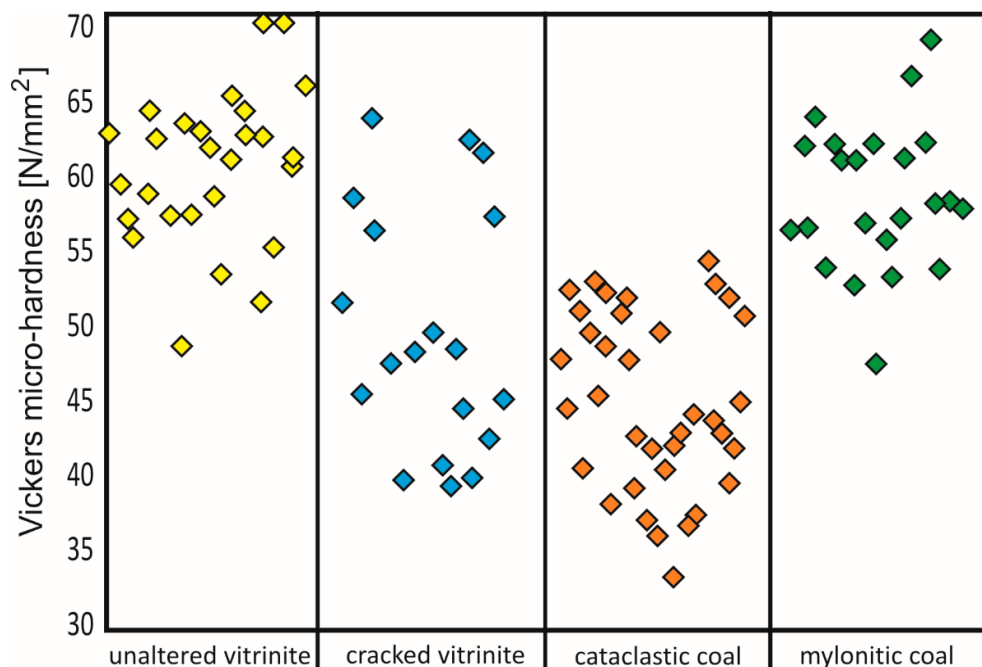


Figure 5. Values of the Vickers microhardness for the analyzed coal samples.

Table 3. Statistical parameters of microhardness determined for particular structural types of coal.

	Statistical Parameters	Vickers Microhardness H_V (N/mm ²)	Modulus of Elasticity E_{IT} (GPa)
Unaltered vitrinite	Mean	58.66	5.87
	Maximum	69.79	6.91
	Minimum	43.81	4.97
	Number of measurements	30	30
	Standard deviation	6.63	0.48
Cracked vitrinite	Mean	50.41	5.51
	Maximum	65.05	7.03
	Minimum	39.43	4.52
	Number of measurements	19	19
	Standard deviation	8.69	0.74
Cataclastic coal	Mean	44.78	5.16
	Maximum	53.78	6.44
	Minimum	33.40	4.08
	Number of measurements	36	36
	Standard deviation	5.71	0.50
Mylonitic coal	Mean	57.53	5.80
	Maximum	67.94	8.36
	Minimum	44.71	4.54
	Number of measurements	24	24
	Standard deviation	5.40	0.82

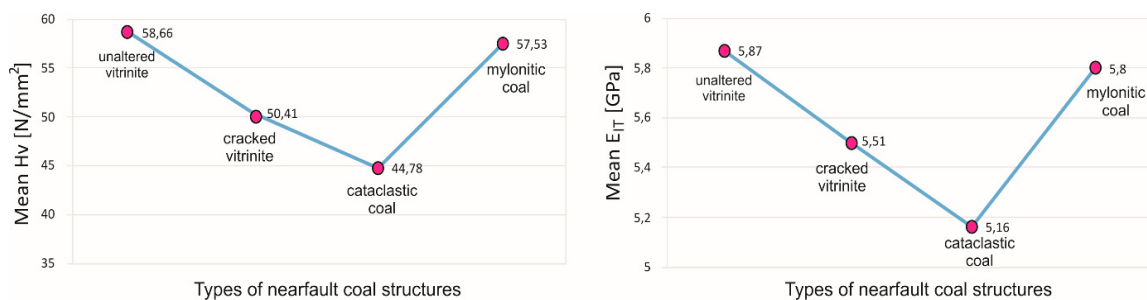


Figure 6. The mean values determined from all the measurements of microhardness H_V and the elasticity module E_{IT} .

5.2. Elasticity Modulus

The general elastic modulus of a substance predicates about its strength and the possibility of its deformation. The higher the modulus value is, the greater force is needed to obtain the same deformation [39].

Mean values determined from the elasticity modulus showed that, in the case of unaltered coal and coal with mylonitic structures, a greater force is needed for a given deformation to appear than in the case of fractured coal and, more importantly, coal with cataclastic structures (Figure 6). This result was also confirmed by the outcome of studies based on microhardness tests [52]. The curve of means of the elasticity module and the microhardness curve have a similar course (Figure 6) and, in both cases, the weakest material turns out to be cataclastic coal.

During analyses of the relationship between microhardness and the elasticity module (Figure 7), it was observed that in unfractured vitrinite this relationship was almost linear in its nature. When microhardness increases, the value of the elasticity module increases, too. For vitrinite, the module value is between 5.2 GPa and 6.9 GPa (the mean value is 5.87 GPa). A similar result was obtained during the analysis of fractured vitrinite fragments. In this case, the relationship between microhardness and the elasticity module is also linear, except that the mean values of both parameters are slightly lower: when we speak of the elasticity module, it is between 4.5 GPa and 7 GPa (the mean value 5.51 GPa) (Figures 6 and 7). However, the situation becomes quite different in the case of cataclastic coal. Here, there is no obvious relationship between microhardness and the elasticity module; some randomness can be observed, and measurement results do not appear linear (Figure 7). In cataclastic coal, the determined values of the elasticity module are between 4.1 GPa and 6.4 GPa. The mean values of microhardness (44.78 N/mm²) and of the elasticity module (5.16 GPa) are considerably lower than in the case of the two types of structures discussed above. Still, the biggest deviations occur in areas built of coal with mylonitic structures. Although the mean values of microhardness (57.53 N/mm²) and of the elasticity module (5.80 GPa) are higher than in the case of fractured and cataclastic structures, the relationship between these two parameters is none; it is characterized by complete randomness, and measurement points are scattered chaotically (Figure 7).

5.3. Characteristic Impressions

The character of micro-impressions in vitrinite changes with various types of coal. It indicates whether a substance is brittle or ductile. The occurrence of micro-cracks after an impression is also very important, as the development of micro-cracks testifies to the ability of a substance to accumulate energy to explode in stages instead of a steady continuous failure [37].

During the analysis of impressions left after the application of the Vickers pyramid, it was observed that the examined coal structures display different degrees of fracturing (Figure 4). Pressing the indenter into non-cracked fragments of vitrinite always leaves not only an impression of the indenter itself, but also visible cracks which start at the vertexes of the impression. A similar situation is observed in the case of cracked coal. Here, however, the micro-cracks starting at the vertexes of the

impressions are not as visible as in the case of the ‘clean’ vitrinite. Moreover, sometimes it is impossible to determine if a given crack emerged as a result of the measurement procedure, or if it had been there before the measurement. As for cataclasis and mylonite, the situation is quite different: pressing the indenter into the coal material leaves virtually no additional cracks. After the measurement procedure, the impressions of the Vickers pyramid were visible only; there are no additional cracks and deformations (Figure 4).

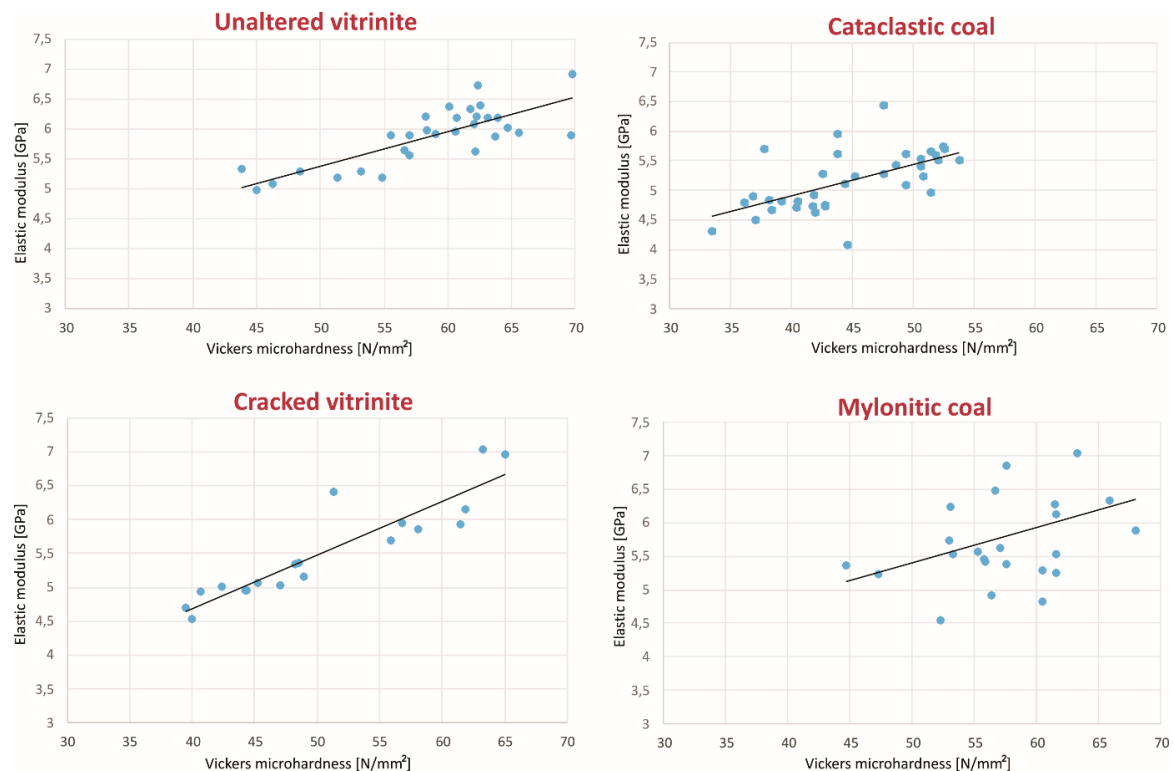


Figure 7. Relationship between the Vickers microhardness and the elasticity module for particular structural types of coal.

6. Conclusions

The research presented in this paper involved analyses carried out by means of the Vickers microhardness tester. The measured parameters were: microhardness, the elasticity module, and the character of impressions with cracks. The research material was coal from the areas of tectonic faults in medium-rank coal seams of the Upper Silesian Coal Basin. Four types of structures occurring in tectonically altered hard coal were analyzed: unaltered coal, cracked coal, cataclastic coal, and mylonitic coal. The conclusion was that the analyzed parameters differ depending on a given parameter.

On the basis of the analysis of the H_V microhardness parameter, the authors demonstrated that the values of microhardness for particular structural groups are classified within similar ranges. The lowest values are characteristic of cataclastic coal and coal with cracks created by the impact of exogenic forces. In mylonitic coal, the microhardness values turned out to be similar to those measured upon unaltered coal.

The results of the measurements of the E_{IT} elasticity module for particular structural types confirmed that, in the case of unaltered coal and mylonitic coal, a greater force is needed for a given deformation to be created than in the case of cracked coal and, more importantly, the cataclastic coal. Thus, the cataclastic coal once again turned out to be the weakest material.

Some important information was obtained from analyzing the relationship between microhardness and the elasticity module. When microhardness increases, the value of the elasticity module increases, too—however, the obtained graphs show that in unfractured coal the relationship between H_V and

E_{IT} is almost linear in its nature. In fractured coal, in turn, the juxtaposition of these two parameters reveals a slight deviation from the determined trend line. The situation is quite different in the case of cataclastic and mylonitic coal. In both cases, the arrangement of the points from the measurements of H_V and E_{IT} is non-linear, and the points are significantly dispersed. The difference between these two types of structures concerns the fact that in cataclasis, the values of H_V and E_{IT} are much lower than in mylonite.

The analysis of the results of the microhardness and elasticity module measurements, carried out for particular types of altered structures of near-fault coal, demonstrated that the microhardness of coal is strongly connected with structural types of this rock.

When it comes to interpreting the fractures created by the Vickers indenter, the most notable thing is that both unaltered coal and slightly altered coal (i.e., fractured coal) display small but visible micro-cracks starting at the vertexes of the impression. However, these secondary fractures do not appear in strongly altered coal (i.e., cataclastic and mylonitic coal). The conclusion is that in such strongly altered coal, the processes that led to its grinding and further evolution ‘relaxed’ the coal material so that it displays a certain degree of elasticity and is free from brittle deformations. In the case of vitrinite—where the scale of brittle fracturing is marginal—the appearance of brittle fractures was a direct result of the application of the Vickers indenter.

As for the effect of increased microhardness in mylonite, it is most probably the consequence of very strong pressing of this quite specific material, the diminishing of its pore area. Moreover, analyses carried out in fluorescent light showed that mylonite could be contaminated with some sort of a mineral, which could also result in an increase in microhardness. Still, it is a heterogeneous material, which is confirmed by considerable scattering of the H_V and E_{IT} results.

The impact of altered structures on a tectonically deformed coal seam.

In recent years, research into structurally altered coal from near-fault areas have been conducted [6,9,14,16–18]. As part of that research, a lot of seams occurring in near-fault zones have been analyzed. In these areas, no outbursts were initiated, in spite of the fact that coal deposited there consisted of structurally altered components in several to even 50%. Also, coal from the zones in which gas-geodynamic phenomena took place has been subject to analyses. An example of such a situation is the gas and rock outburst that killed three miners in the Zofiówka mine (the southern part of the Upper Silesian Coal Basin) back in 2005. Following that incident, two fault crevices situated in the area of a post-outburst cavern were revealed [12,14]. The material collected from the location where the incident occurred consisted of structurally altered coal in up to 80% in some parts. Another example of occurrence of a gas-geodynamic phenomena was the 2010 incident in the Pniówek mine (the southern part of the Upper Silesian Coal Basin), where a sudden outflow of methane combined with dislocation of rock mass to the mine face took place. No one was hurt as a result of that incident. The samples collected at the area of the incident consisted of structurally altered coal in 18%, at the maximum [16].

Analyzing the coal from the areas in which outbursts occurred, as well as the samples from the near-fault zones in which such phenomena did not happen, one may ponder what was the reason behind the differences in the coal behavior. The problem of outbursts is a very complex and ambiguous one, and its causes are to be looked for in broadly understood geological and gas-related factors [54]. One such factor could also be the amount and nature of the structurally altered coal from near-fault zones.

The coal material containing more mylonite reveals a small tendency to crush. At the same time, it is characterized by smaller macroporosity than cataclastic coals [55]. Also, the value of microporosity in such material increases [56,57]. This is because the tectonic strains which change the physical and chemical properties of such coal may lead to altering the capacity of coal in relation to methane [57]. However, research also shows that describing tectonically distorted coals by means of the Langmuir isotherm is not right from a scientific perspective—because of the specific structure of the analyzed material [56]. This may influence the interpretation of the sorption results for such strongly altered coal.

A material that stands in contrast to mylonitic coal is cataclastic coal. In macro scale, it can be seen that it is a weak material, easy to scatter and usually lusterless. These low strength parameters are reflected by the results of the measurements of the Vickers microhardness. In comparison with the ‘standard’ (unaltered) coal, such coal has greater total porosity, too, which results in changes in the kinetics of the sorption processes, as well as in an increase of the sorption capacity of such material [15].

By comparing the results of research into coal samples from near-fault zones, it was noticed that in places where outbursts occurred, the structurally altered material consisted almost entirely of fractured and cataclastic coal, whereas in the near-fault areas where outbursts did not happen in spite of the very strong changes to the coal structure (up to 50% of structurally altered coal in the total capacity), a substantial share of mylonitic coal appeared ([6,16,17] and unpublished materials). Taking into account specific features of mylonite and cataclasis, confirmed by means of the Vickers microhardness tests, it can be assumed that the mutual relationship between these substances might have an impact on decreasing (mylonite) or increasing (fractures and cataclasis) inclinations of a coal seam to uncontrolled gas-geodynamic phenomena. That subject, in spite of promising results, calls for more detailed analyses conducted using a greater number of near-fault coal samples.

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