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KRYSTIAN PROBIERZ*, MAREK MARCISZ**

Changes of coking properties with depth of deposition in coal seams of Zofiówka monocline (SW part of Upper Silesian Coal Basin, Poland)

Introduction

The coking properties describe, first and foremost, the usability of coals to making of coke, but may also be an important indicator of the coal rank. These properties occur at strictly determined coal rank range corresponding to medium-rank coals. Under the conditions prevailing in Upper Silesian Coal Basin, depending on specific sites, they may be found at volatile matter V^{daf} ~31% and random vitrinite reflectance R_r = 1,0–1,2%. Both lower rank brown coals (characterized by higher volatile matter than the one mentioned above and lower vitrinite reflectance) and coal of higher rank: low volatile bituminous coals, anthracite coals and anthracites (with lower V^{daf} and higher values of R_r) do not expose the coking properties (Gabzdyl 1989; Probierz 1982, 1989).

The study was focused on investigating changes of the following parameters with the depth of deposition: Roga Index RI, Swelling Index SI and the dilatometric parameters such as: contraction *a* and dilatation *b*.

Roga Index RI is one of the coal properties that is advantageous for coke formation during degasification. RI is used as a parameter in classification technologies to assess the usability of coal for coking processes. It depends on the coal rank and reaches its maximal value for gas-coking and ortho-coking coals (coal type in accordance with Polish Standard: 34 and 35) at the 86% C_o^{daf} carbon content. The RI, apart from the coal rank, is also dependent on the

* Prof., ** DSc. Eng., Silesian University of Technology, Faculty of Mining and Geology, Institute of Applied Geology, Gliwice; e-mail: krystian.probierz@polsl.pl

petrographic composition of coal, the content of reactive components, especially macerals of vitrinite group, and, a decrease in the RI is caused by the contribution of non-reactive macerals of inertinite group (Gabzdyl 1989; Probierz 1982, 1989). Swelling Index SI is generally used for technological classifications as a parameter alternative to RI, as it describes a similar property of coal, but in another way.

The dilatometric parameters *a* and *b* designate coal behavior during heating.

Study on the changes of coal coking properties were run in the area of crucial importance to the Polish coking coal resources base, yet characterized by considerable variability of coal quality and coal rank.

The aim of the study was to forecast changes in the coking properties of coal with the depth of deposition to facilitate better characteristics of coking coal resources to be excavated in the future (Marcisz 2010).

Some of the results quoted in this paper were derived from the authors' work under the framework of POIG.01.01.02-24-017/08 key project "Intelligent coking coal plant in compliance with the requirements of BAT (Best Available Techniques)" co-financed by the European Regional Development Fund and performed for the Institute for Chemical Processing of Coal in Zabrze.

1. Description of the study area

The study area entails Zofiówka monocline situated in the SW part of Upper Silesian Coal Basin, where deposits of general strike close to NNE-SSW and dip 5–20° at ESE. The monocline is an eastern continuation of Jastrzębie fold. It is composed of Upper Carboniferous formations (Namur A-Westfalian A) covered by Miocene and Quaternary deposits with variable thickness up to >850 m (Fig. 1).

The study area is bordered in the western part by coal seams outcrops involving erosive Zofiówka trough with the longitudinal direction and de-levelling reaching up 850 m. In the investigated zone, the so called: "red bed formations" also occur. From the east and the north the study area is demarcated by the boundaries of the mining areas of coal mines where extraction is currently carried out, whereas the southern boundary is constituted by Gorzyce–Bzie–Czechowice–Kęty faults system with the displacement of 150–600 m by S.

The vicinity of this dislocation of a local importance exerted a significant influence on the tectonic outlay and type of the deposit, characterised by the presence of dense local faults system with the displacement value up to 150 m. The main direction of the faults is the longitudinal one.

The study area entails 30 coal seams, starting with coal seam 360/1 (Westfalian A) to coal seam 510 (Namurian B) with the total coal resources of about >240 millions Mg. The extraction time is estimated until 2040, excluding newly surveyed coal resources.

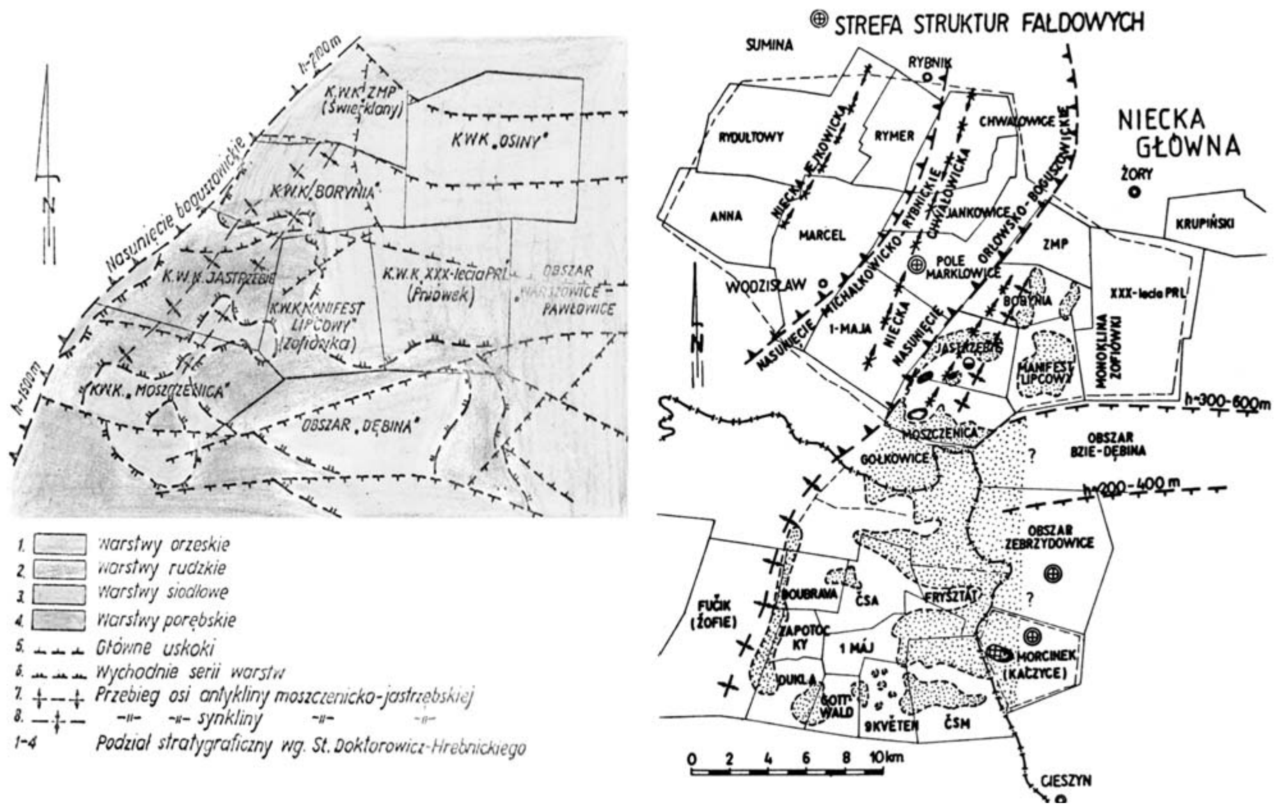

Fig. 1. Location of the study area in view of the geological and structural scheme of the SW part of Upper Silesian Coal Basin (Pniówek hard coal mine = XXX-lecia hard coal mine) (Probierz 1982, 1989). The dotted zones in the Figure on the right indicate the range of the occurrence of the so called: "red bed formations"

Rys. 1. Lokalizacja obszaru badań na tle szkicu geologiczno-strukturalnego SW części GZW (KWK Pniówek = KWK XXX-lecia PRL) (Probierz 1982, 1989). Obszary zakropkowane na prawym rysunku przedstawiają zasięg występowania tzw. utworów pstrych

2. State of prospecting of coal quality parameters in the study area

The study area, i.e. Zofiówka monocline, in view of its strategic importance to the Polish coal resources base, has been a subject of research works in the course of which several issues have been considered, for example, the occurrence and distribution of particular technological coal types, variability of coal rank depending on the petrographic composition of coal seams, characteristics of changes in the coal petrographic composition, as well as changes in the content of alkali, which are very important to the assessment of the properties of coking coals.

Research works and publications about Zofiówka monocline and its vicinity have so far been focused on the relations between changes in coal quality, its rank and petrographic composition and the impact of thermal metamorphism (Gabzdyl, Probierz 1987, 1990; Probierz 1982, 1989).

The research works were carried out as early as in the 1970–1975 on the bases of limited coal samples collected from boreholes and resulting, among other outcomes, in regional maps of coals distribution according to their technological type, RI and V^{daf} (Fig. 2).

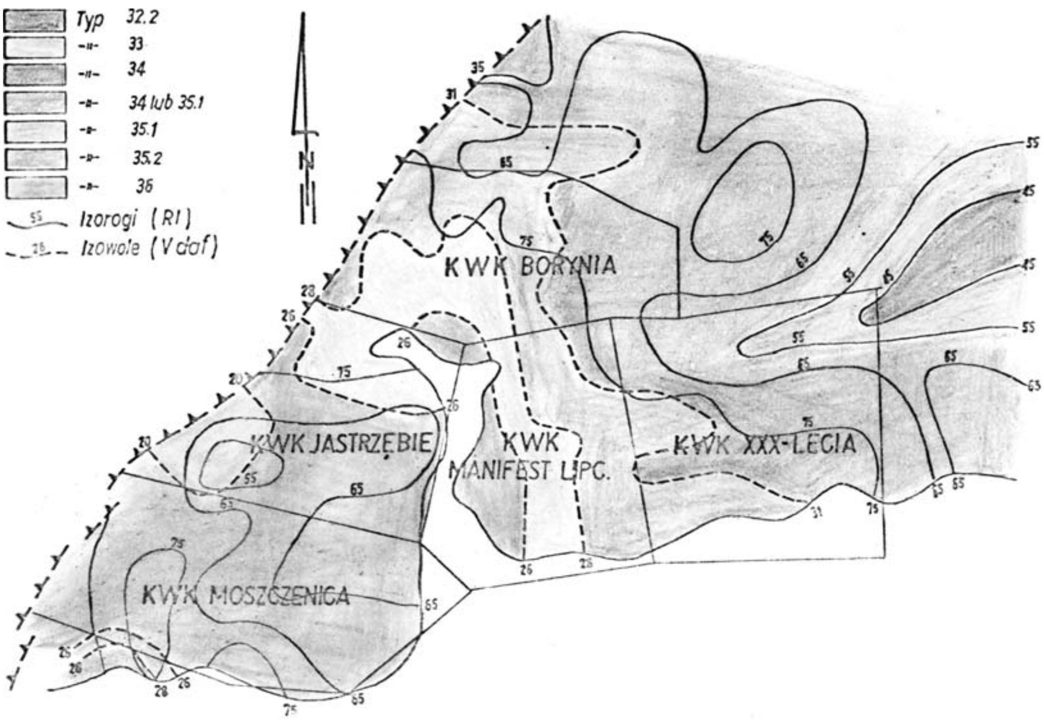

Fig. 2. Changes in Roga Index RI and volatile matter content V^{daf} in the zones of the occurrence of specific coal types in compliance with the Polish Standard PN according to S. Kempa quoted after (Probierz 1989)

Rys. 2. Zmiany zdolności spiekania RI i zawartości części lotnych V^{daf} na tle obszarów występowania poszczególnych typów węgla według PN w obszarze badań według S. Kempa za (Probierz 1989)

On the grounds of the distribution of volatile matter content it was concluded that west of Zofiówka monocline, the zone of the occurrence of highest coal rank (with volatile matter content V^{daf} below 26% and coal types 35.2 or even 36) was dominated by 34 and 35.1 types (Fig. 2) present in the monocline.

In the 1980–1989 in the investigated area, apart from the description of the variability of coal coking properties, pioneer studies were run focusing on the determination of vitrinite reflectance and petrographic composition of coals. The petrological studies were administered to several samples, indicating random vitrinite reflectance of R_r = = 0,96–1,14%. Apart from the determination of the petrographic composition (the percentage of macerals of vitrinite, liptinite and inertinite group) microlithotypes were also quantitatively established.

The analysis of coal quality parameters in the vertical profile did not indicate any explicit dependence on variability in lithology. The only exception was a sandstone profile between seams 407 and 409 with the thickness of over 50 m, in the mining area of Zofiówka coal mine (previously bearing the name of “Manifest Lipcowy”), where constant values of volatile matter content V^{daf} with depth were indicated. This sandstone level did not show any increase in coal rank.

The characteristics of the lateral changes in coal quality revealed the presence of various quality range values in the investigated Zofiówka monocline:

— high $V^{daf} \geq 31\%$, high RI > 72 and high $b > +100\%$;
— ow $V^{daf} < 31\%$, low RI > 72 and high $b > +100\%$;
— high $V^{daf} \geq 31\%$, low RI < 72 and low $b < +100\%$;
— low $V^{daf} < 31\%$, low RI < 72 and low $b < +100\%$.

The zones with high values of RI and *b* have a big percentage of macerals from the vitrinite group and small percentage of macerals from the inertinite group (especially typically inertinite). The zones with low values of RI and *b* have a small percentage of macerals from the vitrinite group and constant percentage of macerals from the inertinite one (especially typically inertinite in a technological sense). The coals in these zones also differ in terms of microlitic types, with bigger or smaller percentage of reactive or inertial components (Probierz 1982).

In the late 1990s the intensity of coal quality analyses was smaller, however, studies on the determination of the petrographic composition of deeper situated coal seams were still run (Probierz, Komorek 1994).

Further, more thorough research was conducted starting with 2001 and entailing, among other factors, the determination of the technological types of coal at different stages of deposits recognition, monitoring the quality in the deposits by means of treatment processes required for commercial purposes and investigations into the petrographic composition. The obtained results contributed to better knowledge of the variability of coal quality in the discussed area (Gabzdyl, Probierz, Marcisz, Wasilczyk 2003; Marcisz 2010; Morga 2007;Probierz, red., 2003; Probierz, Komorek, Lewandowska 2006; Probierz, Zając 2001, 2002; Probierz, Borówka 2009; Wasilczyk 2004).

Nevertheless, the studies and investigations did not render new data on the regularity of the lateral and vertical distribution of coals, coal quality parameters, including coal coking properties.

3. Method

In the studies the results of previously made determinations of coal quality are considered, especially in view of the needs of coal companies that still extract coal in the study area.

As far as previously presented study results are concerned, the number of samples (and the determined values of particular quality parameters) increased in the last 20–30 years,

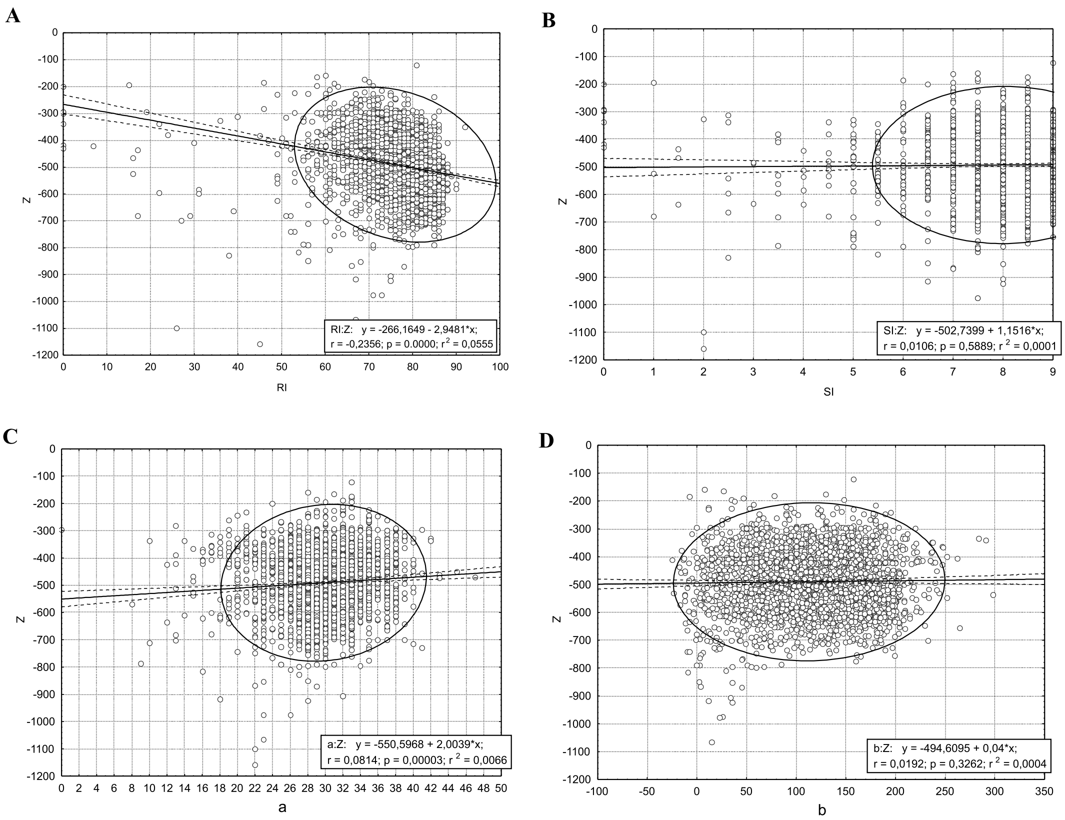

Fig. 3. Changes in the coking properties of coals with depth Z [m]
A – Roga Index RI, [–], B – Swelling Index SI, [–], C – contraction *a*, [%], D – dilatation *b*, [%]

Rys. 3. Zmiany własności koksowniczych z głębokością Z [m]
A – zdolność spiekania RI, [–], B – wskaźnik wolnego wydymania SI, [–], C – kontrakcja *a*, [%],
D – dylatacja *b*, [%]

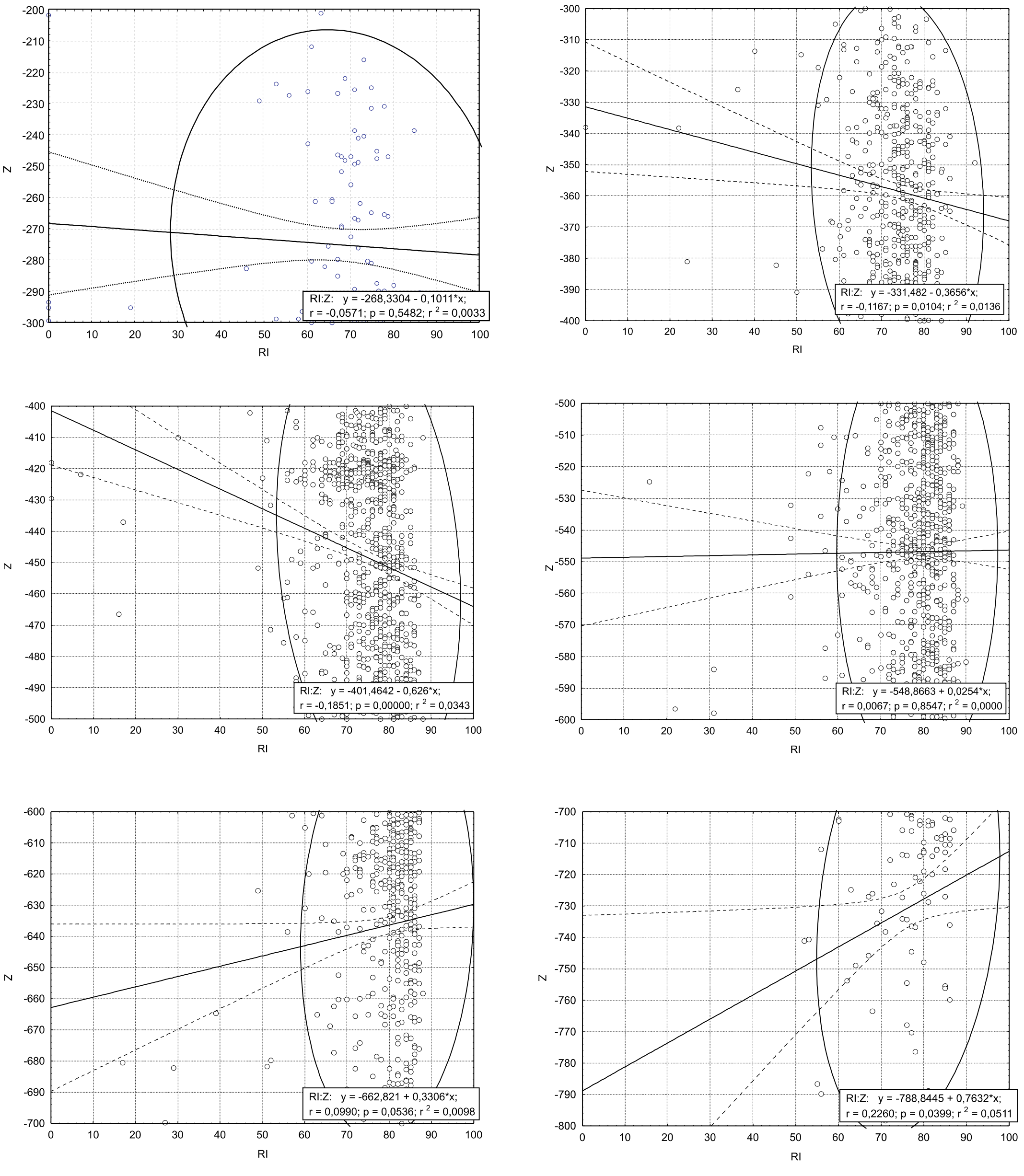

Fig. 4. Changes in Roga Index RI [-] with depth Z [m] at the designated 100 m ranges at depth 0–800 m

Rys. 4. Zmiany zdolności spiekania RI [-] z głębokością Z [m] w wyznaczonych stumetrowych przedziałach głębokościowych w zakresie głębokości 0–800 m p.p.t.

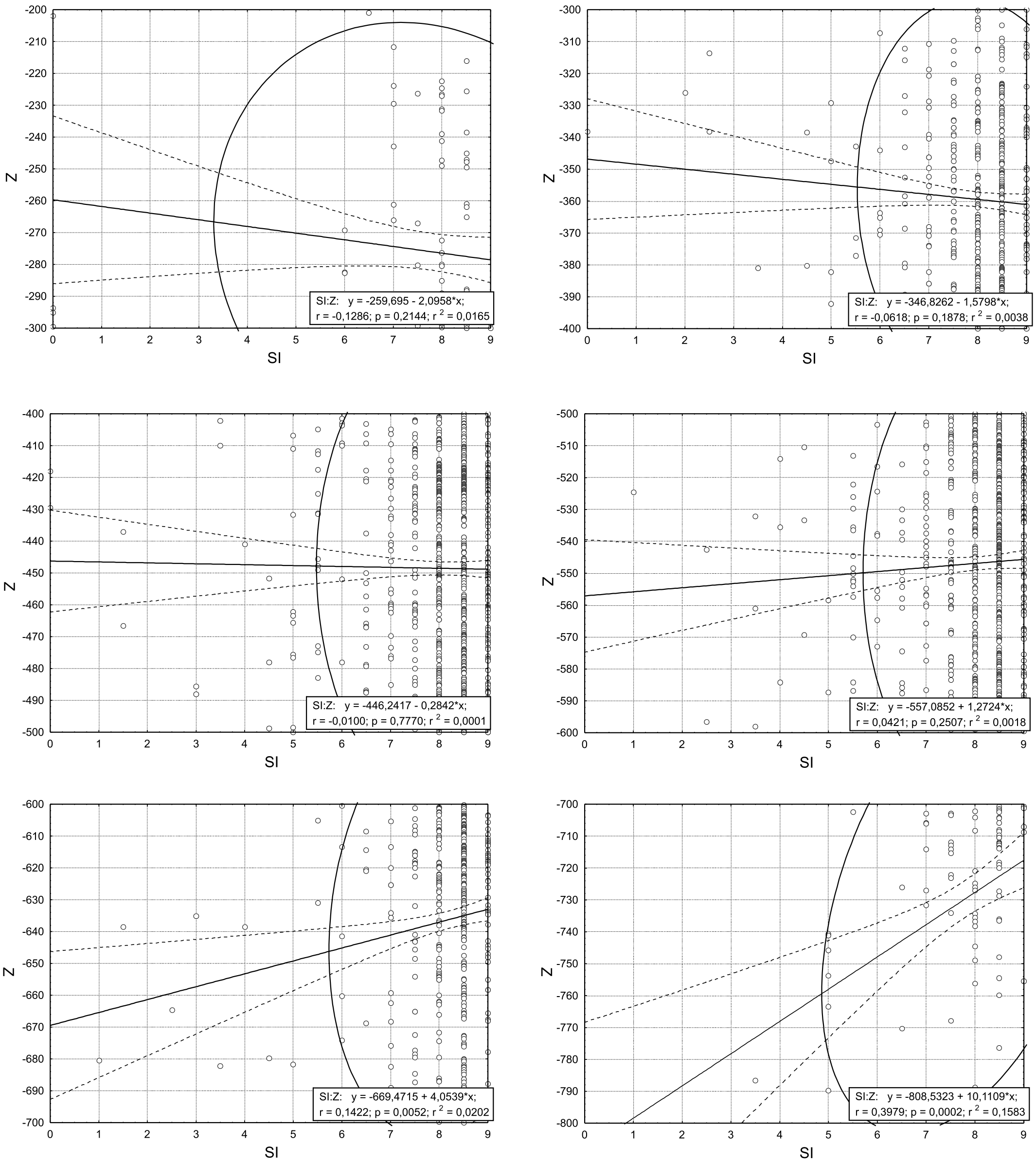

Fig. 5. Changes in Swelling Index SI [-] with depth Z [m] at the designated 100 m ranges at depth 0–800 m

Rys. 5. Zmiany wskaźnika wolnego wydymania SI [-] z głębokością Z [m] w wyznaczonych stumetrowych przedziałach głębokościowych w zakresie głębokości 0–800 m p.p.t.

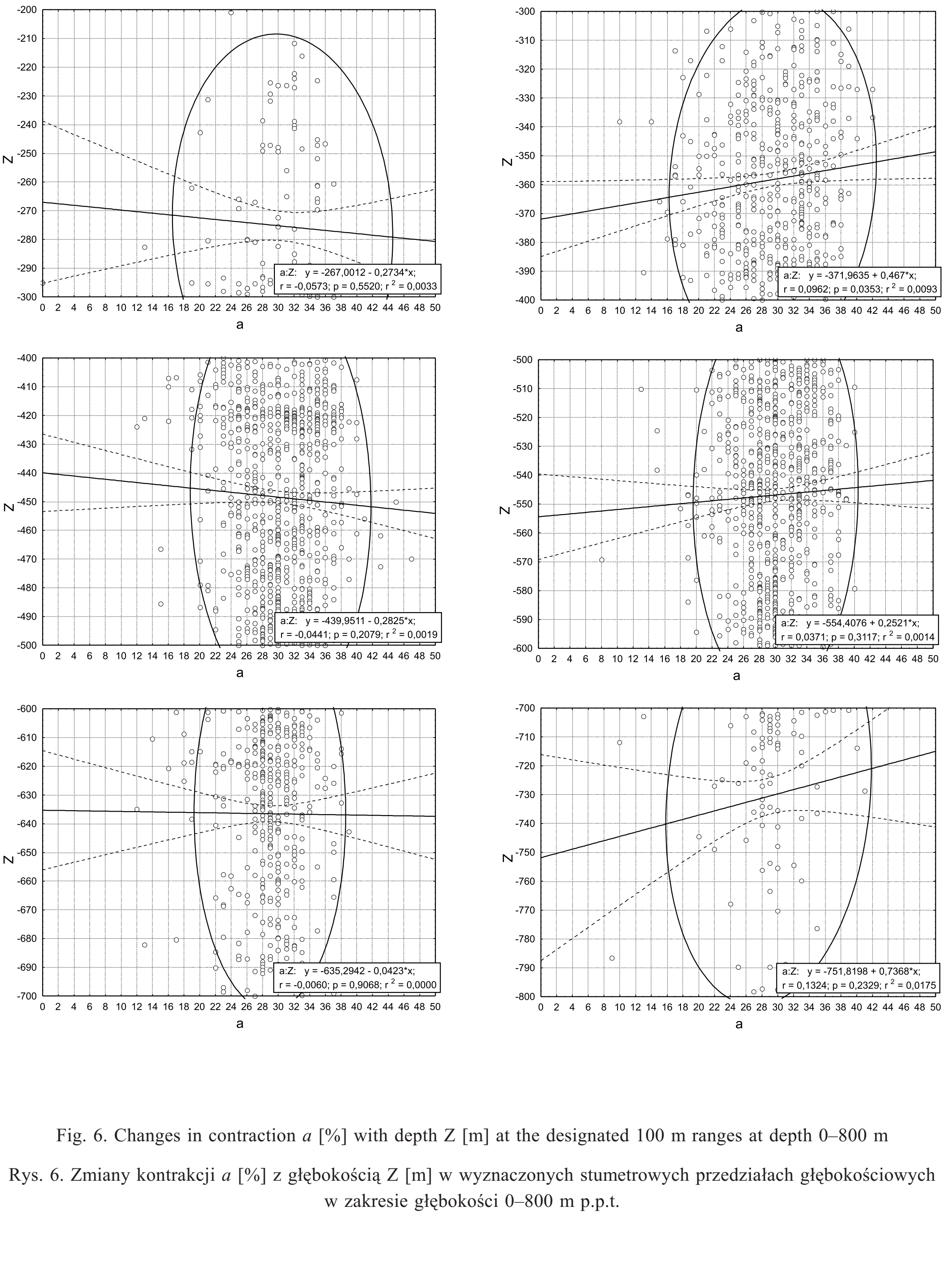

Fig. 6. Changes in contraction *a* [%] with depth Z [m] at the designated 100 m ranges at depth 0–800 m

Rys. 6. Zmiany kontrakcji *a* [%] z głębokością Z [m] w wyznaczonych stumetrowych przedziałach głębokościowych w zakresie głębokości 0–800 m p.p.t.

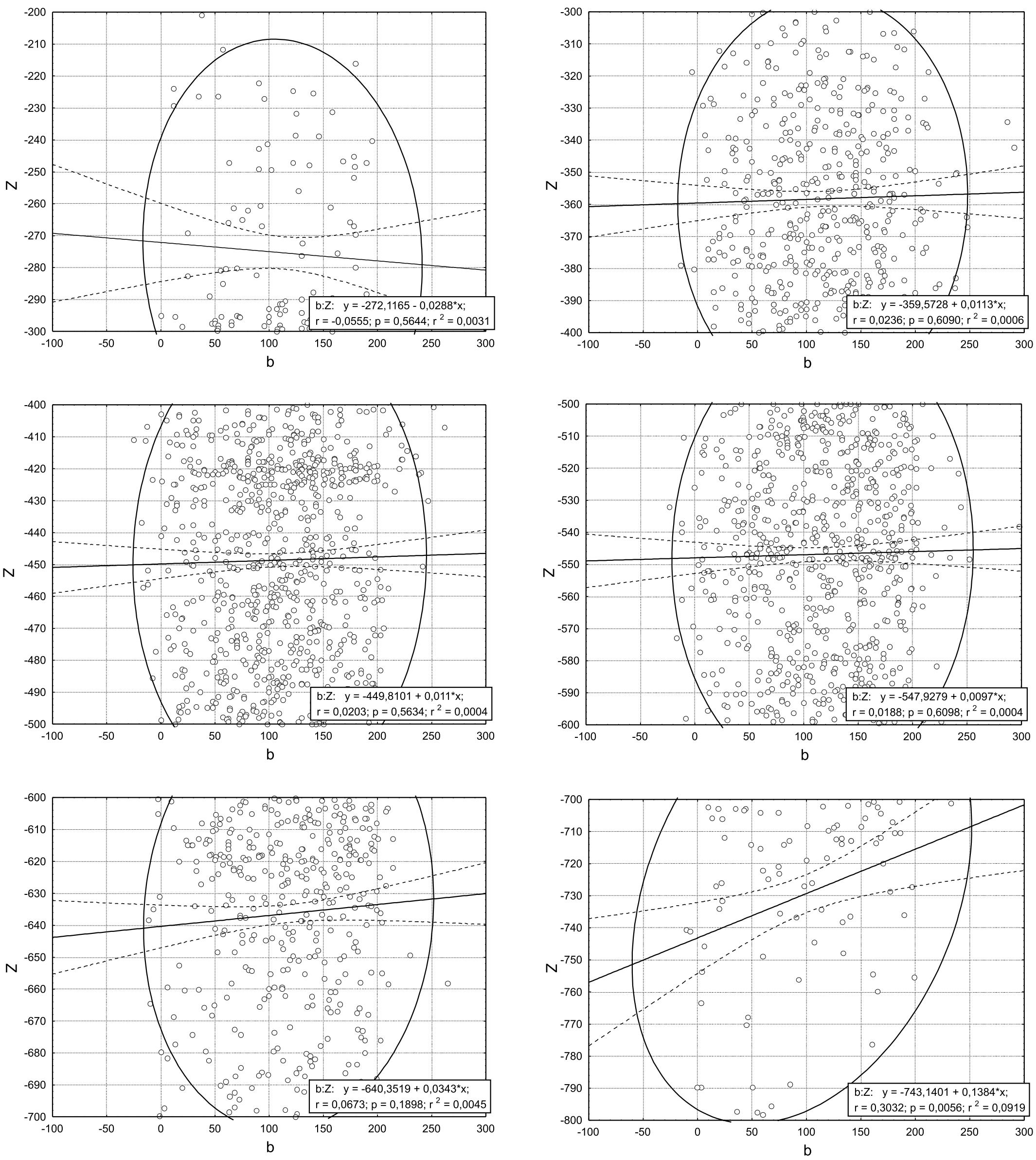

Fig. 7. Changes in dilatation *b* [%] with depth Z [m] at the designated 100 m ranges at depth 0–800 m

Rys. 7. Zmiany dylatacji *b* [%] z głębokością Z [m] w wyznaczonych stumetrowych przedziałach głębokościowych w zakresie głębokości 0–800 m p.p.t.

TABLE 1

Number of samples and changes in Roga Indx RI [-] in the designated depth ranges

TABELA 1

Liczba próbek i zakres zmian zdolności spiekania RI [-] w przedziałach głębokościowych

No.	Depth	Number of samples	Correlation coefficient	Values of RI		
				min.	max.	mean
1	0 – –100	0	–	–	–	–
2	–100 – –200	10	0.48	15	81	59
3	–200 – –300	113	–0.06	0	86	67
4	–300 – –400	481	–0.12	0	92	74
5	–400 – –500	813	–0.19	0	88	75
6	–500 – –600	744	0.01	16	90	79
7	–600 – –700	381	0.10	17	88	80
8	–700 – –800	83	0.23	52	87	76
9	–800 – –900	7	–0.61	38	78	60
10	–900 – –1000	5	0.08	67	75	72
11	–1000 – –1100	2	1.00	26	67	47
12	–1100 – –1200	1	–	45		

TABLE 2

Number of samples and changes in Swelling Index SI [-] in the designated depth ranges

TABELA 2

Liczba próbek i zakres zmian zdolności spiekania SI [-] w przedziałach głębokościowych

No.	Depth	Number of samples	Correlation coefficient	Values of SI		
				min.	max.	mean
1	0 – –100	0	–	–	–	–
2	–100 – –200	10	0.42	1.0	9.0	7.0
3	–200 – –300	95	–0.13	0.0	9.0	7.5
4	–300 – –400	456	–0.06	0.0	9.0	8.0
5	–400 – –500	812	–0.01	0.0	9.0	8.0
6	–500 – –600	745	0.04	1.0	9.0	8.0
7	–600 – –700	385	0.14	1.0	9.0	8.0
8	–700 – –800	83	0.40	3.5	9.0	7.5
9	–800 – –900	7	–0.34	2.5	8.0	6.5
10	–900 – –1000	5	0.03	6.5	8.0	7.5
11	–1000 – –1100	2	1.00	2.0	7.0	4.5
12	–1100 – –1200	1	–	2.0		

TABLE 3

Number of samples and changes in contraction *a* [%] in the designated depth ranges

TABELA 3

Liczba próbek i zakres zmian kontrakcji *a* [%] w przedziałach głębokościowych

No.	Depth	Number of samples	Correlation coefficient	Values of *a*		
				min.	max.	mean
1	0 – –100	0	–	–	–	–
2	–100 – –200	9	0.07	28	33	31
3	–200 – –300	110	–0.06	0	41	31
4	–300 – –400	479	0.10	10	42	29
5	–400 – –500	816	–0.04	12	47	30
6	–500 – –600	745	0.04	8	40	30
7	–600 – –700	385	–0.01	12	39	29
8	–700 – –800	83	0.13	9	41	29
9	–800 – –900	7	–0.32	16	29	24
10	–900 – –1000	5	0.23	18	32	25
11	–1000 – –1100	2	1.00	22	23	23
12	–1100 – –1200	1	–	22		

TABLE 4

Number of samples and changes in dilatation *b* [%] in the designated depth ranges

TABELA 4

Liczba próbek i zakres zmian dylatacji *b* [%] w przedziałach głębokościowych

No.	Depth	Number of samples	Correlation coefficient	Values of *b*		
				min.	max.	mean
1	0 – –100	0	–	–	–	–
2	–100 – –200	9	0.29	–7	158	69
3	–200 – –300	110	–0.06	0	220	112
4	–300 – –400	473	0.02	–15	291	115
5	–400 – –500	811	0.02	–25	262	110
6	–500 – –600	736	0.02	–23	298	117
7	–600 – –700	381	0.07	–11	265	118
8	–700 – –800	82	0.30	–10	233	96
9	–800 – –900	6	–0.29	–9	45	18
10	–900 – –1000	5	0.17	12	36	26
11	–1000 – –1100	1	–	15		
12	–1100 – –1200	0	–	–	–	–

together with the depth of coal seams extraction, starting with several samples and reaching about 2700 samples. The determinations were made for channel samples and borehole samples. The statistical analyses conducted on the bases of the determinations designated the ranges of the variability of the parameters (minimal, maximal, mean) for the entire sample population.

On the base of obtained results, the population was divided into sub-sets contained in 100 m depth ranges, from 0 to 1200 m. For each of the sub-sets, the following factors were designated: number of samples, ranges of parameters variability (min., max., mean) and their correlation coefficients in relation to depth Z.

4. Results

The coking properties of coal seams of Zofiówka monocline, analysed in the depth range of 0 – 1200 m, vary in a wide scope: Roga Index RI = 0–92, Swelling Index SI = 0.0–9.0, contraction *a* = 0–47%, dilatation *b* = –25 – +298% (Fig. 3).

Low values of the correlation coefficients and the scatter of the results in the determinations of particular coking parameters as seen in Fig. 2 led to the limitation of the observation field to 100 m depth ranges, each separately analysed (Fig. 4–7, Tables 1–4), with only deep sections subjected to the analysis, where at least 30 samples were determined.

The best prospected ranges, in view of sampling, are depths of –400 – –500 m (from 811 to 816 samples for a given parameter) and –500 – –600 m (from 736 to 745), for which the correlation coefficients assume low values (r = 0.01–0.40).

Conclusions

The coals from seams located in Zofiówka monocline reveal Roga Index RI = 0–92, Swelling Index SI = 0–9, contraction *a* = 0–47%, dilatation *b* = –25–+298% (Table1–4).

A relatively big variety of the values of coking parameters in such limited area may not result from a complicated geological structure (tectonics) but also from influence of thermal metamorphism observed in its western part, manifested as anthracite deposits at coal seam 504/2 and 505/1 within the operational zone of Moszczenica coal mine (now closed down) and the occurrence of the so called “red bed formations”, also found in the vicinity of the outcrops of Zofiówka trough (Fig. 1).

The variability in the values of coal coking parameters with depth in the deposit of Zofiówka monocline does not facilitate their forecasts. This is important to coal producers (mines extracting coal in the area of crucial significance to the Polish coking coal resources base) as well as to coal purchasers. i.e. coking plants that manufacture coking coal of highest quality and demand deliveries of coal with strictly defined parameter values.

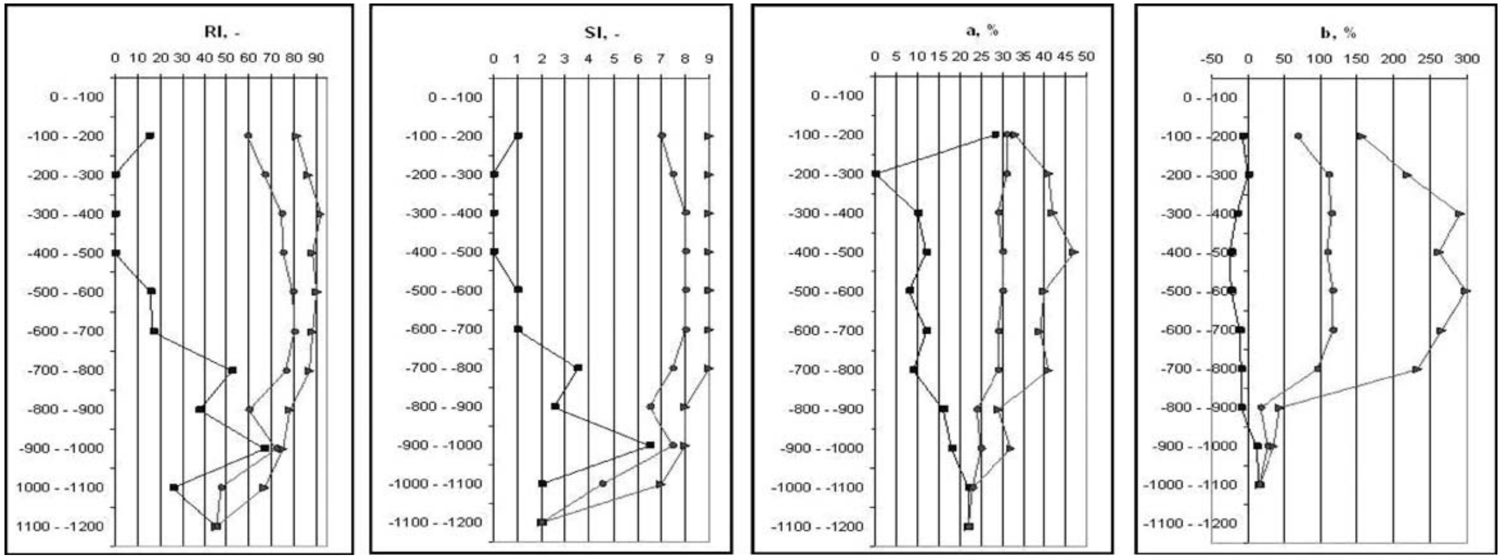

Fig. 8. Characteristics of the changes in coal coking parameters with depth Z [m]
in Zofiówka monocline deposit

Rys. 8. Charakterystyka zmian wartości parametrów koksowniczych z głębokością Z [m]
w złożu monokliny Zofiówki

In the observations of the changes of coking parameters of coals with depth within Zofiówka monocline area. Some general trends in the variations of their mean values may be distinguished (Fig. 8):

— at the depth range up to –300 m the mean values of coking parameters increase: RI = 59–67, SI = 7.0–7.5, *a* = 31%, *b* = +69% (*a* and *b* are an insignificant exception to this rule);
— at the depth range of –300 to –700 m the mean values of coking parameters are relatively constant, reaching the highest values in the depth profile: RI = 74–80, SI = 8.0 *a* = 29–30% (exception), *b* = +112–+118%;
— at the depth range below – 700 m the mean values of all coking parameters decrease: being the lowest in the depth profile: RI = 72–45, SI = 7.5–4.5, *b* = +25–+23%, *a* = 26–18%.

The trends in the changes of RI, SI, *a* and *b* changes illustrated in Fig. 8 are noticeable especially for the mean and maximal values. They were not indicated by means of regression lines for the entire sample population (Fig. 3) and for the subpopulations (Fig. 4–7). The absence of the trends for the minimal values may be easily explained by the weathering processes and by thermal metamorphism. In both cases. the coals subjected to the impact of both processes lose their coking properties. In fewer cases, weaker coking properties of the investigated coals may result from the petrographic composition. for example, higher percentage of non-reactive components (inertinite macerals).

A significant improvement in the degree of prospecting the coking parameters of the investigated coals deposited at Zofiówka monocline (increased number of samples and the depth of sampling) makes it possible to forecast the distribution of the changes in the parameters with depth with more detail (also as far as the lateral distribution is concerned).

The present state of the coking properties recognition at Zofiówka monocline coal seams is not remarkably divergent from the data derived in the previous years. It should still be assumed that the distribution of the coking parameters of coals in the study area is shaped as an outcome of regional metamorphism and the associated impact of thermal metamorphism.

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WŁASNOŚCI KOKSOWNICZE A GŁĘBOKOŚĆ WYSTĘPOWANIA POKŁADÓW WĘGLA KOKSOWEGO W ZŁOŻU MONOKLINY ZOFIÓWKI

Słowa kluczowe

Górnośląskie Zagłębie Węglowe, monoklina Zofiówki, węgiel kamienny, własności koksownicze, skład petrograficzny węgla

Streszczenie

Przedstawiono charakterystykę zmian własności koksowniczych (zdolności spiekania RI, wskaźnika wolnego wydymania SI, kontrakcji a, dylatacji b) wraz z głębokością, w złożu węgla koksowego monokliny Zofiówki. Wyniki badań uzyskano w obszarze o podstawowym znaczeniu dla polskiej bazy zasobowej węgli koksowych, które charakteryzują się znaczną zmiennością jakości i uwęglenia. Uwzględniono około 2,7 tys. oznaczeń własności koksowniczych wykonanych dla próbek bruzdowych węgla, które pobrano w pokładach czynnych kopalń. Celem badań było określenie ewentualnych trendów zmian wartości parametrów koksowniczych w głębszych, nieeksploatowanych dotychczas partiach złoża i prognozowanie tych parametrów. Wykazano, że wartości średnie parametrów koksowniczych z głębokością początkowo wzrastają do głębokości około –300 m, następnie wykazują dość stałe wartości, zaś od głębokości –700 m maleją.

CHANGES OF COKING PROPERTIES WITH DEPTH OF DEPOSITION IN COAL SEAMS OF ZOFIÓWKA MONOCLINE (SW PART OF UPPER SILESIAN COAL BASIN, POLAND)

Key words

Upper Silesian Coal Basin, Zofiówka monocline,hard coal, coking properties, petrographic composition

Abstract

The scope of the study is the description of coking properties (Roga Index RI, Swelling Index SI, contraction *a*, and dilatation *b*) changing with depth in Zofiówka monocline deposit. The results were derived from an area which is of crucial importance to the Polish coking coal resources base, characterised by considerable variability of coal quality and coal rank. About 2,7 thousand samples of coking properties were considered for channel samples collected at the seams of currently operating coal mines. The objective of the research was to designate possible trends in the changes of the coking parameters of coal in deeper, so far unexcavated seams and the forecasts of these parameters. The mean values of coking parameters change with the depth of deposition, initially rising up to the depth of about –300 m, and next, rendering fairly constant values, whereas, decreasing from the depth of –700 m.