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THE SIDE-CRUMBLE ANGLE ψ OF COAL AND THE ENERGY CONSUMPTION OF THE MINING PROCESS AS A FUNCTION OF THE VERTICAL COMPONENT σ_z OF EXPLOITATION PRESSURE

KĄT BOCZNEGO ROZKRUSZENIA WĘGLA ψ ORAZ ENEGOCHŁONNOŚĆ PROCESU URABIANIA W FUNKCJI SKŁADOWEJ PIONOWEJ σ_z CIŚNIENIA EKSPLOATACYJNEGO

Based upon test-bed laboratory measurements representing the digging process of the longwall shearer, the static plane force $P_{śr}$ necessary in the solid rock digging process was estimated. The experiments were perfomed using all the possible values of exploitation pressure, represented by the vertical component σ_z of the stress state (normal to the seam), which can occur within the working area of the cutting device.

The measurements were performed for different kinds of coal at both turns and cutting directions and considering the influence of the situation in which decreased coal coherence planes occurred. The experiments performed allowed the variations of the mineability index A_ψ values, the energy consumption of the digging process *SE* and side-crumble angle ψ as a function of vertical component σ_z of the exploitation pressure to be determined. These experiments were performed for coal specimens at loads ranging between zero up to loading causing resistance destruction on the primary structure and the destroyed structure (*ZS*).

Key words: coal's mineability, mineability index, side-crumble angle, energy consumption of the mining process

Na podstawie badań stanowiskowych odwzorowujących proces urabiania pojedynczego noża przyrządu pracującego na zasadzie skrawania wyznaczona została wartość siły $P_{śr}$, która jest niezbędna do urabiania calizny węglowej. Odwzorowano sposób urabiania ścianowym kombajnem bębnowym oraz strugiem statycznym przy wszystkich możliwych wartościach ciśnienia eksploatacyjnego, reprezentowanego przez składową pionową σ_z stanu naprężenia (prostopadłą do pokładu), jaka może wystąpić w strefie zabioru organu urabiającego pracującego na zasadzie skrawania. Badania przeprowadzono dla różnych węgli przy obydwu kierunkach i zwrotach urabiania, uwzględniając wpływ

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usytuowania płaszczyzn osłabionej spójności węgli. Przeprowadzone badania pozwoliły wyznaczyć przebiegi zmienności wartości wskaźnika urabialności A_ψ, energochłonności procesu urabiania SE oraz kąta bocznego rozkruszenia ψ w funkcji składowej pionowej σ_z (i odpowiadającej jej składowej σ_x wzdłuż długości ściany) ciśnienia eksploatacyjnego.

Wskaźnik urabialności A_ψ (Biały 1982, 2001) uwzględniający kąt bocznego rozkruszenia ψ wyznaczony został z następującego wzoru:

$$A_\psi = \frac{45 p_{śr}}{1 + 0{,}5\mathrm{tg}\psi} \quad [\mathrm{N/cm}]$$

Teoretyczną energochłonność procesu urabiania (Biały 2001a) na podstawie badań laboratoryjnych wyznaczono ze wzoru:

$$SE = \frac{P_{śr} \cdot L}{V} \quad [\mathrm{Jcm^{-3}}]$$

Badania zostały przeprowadzone dla próbek węgla przy obciążeniach σ_z od zera do zniszczenia wytrzymałościowego na strukturze pierwotnej oraz na zniszczonej strukturze (*ZS*). Jak wykazują badania, przebiegi wartości wskaźnika urabialności A_ψ w funkcji ciśnienia eksploatacyjnego są w początkowej fazie rosnące, a następnie maleją. Dotyczy to zarówno skrawów pionowych jak i poziomych, przy czym dla skrawów poziomych przebiegi te są łagodniejsze. Zmieniając dla skrawów poziomych zwrot urabiania (z $P - L$ na $L - P$) otrzymano podobne przebiegi, przy czym różnią się one dość wyraźnie wartościami, co potwierdza występowanie w pokładach węglowych płaszczyzn osłabionej spójności zależnych od kierunku. Wynika stąd, że dla skrawów pionowych ciśnienie eksploatacyjne (σ_z) ma bardzo istotny wpływ na wartość oporów urabiania reprezentowanych przez wskaźnik urabialności A_ψ. Dla skrawów prowadzonych po zniszczeniu wytrzymałościowym (*ZS*) próbki krzywe te wykazują tendencje silniej malejące, natomiast wartości A_ψ przy tej samej wartości ciśnienia eksploatacyjnego osiągają wartości ponad dwukrotnie mniejsze.

Bardzo podobnie przebiega zmienność energochłonności SE procesu urabiania, która dla skrawów pionowych w początkowej fazie jest silnie rosnąca, a następnie maleje. Natomiast dla skrawów poziomych przebieg ten jest łagodniejszy, niezależnie od zwrotu urabiania.

Kąt bocznego rozkruszenia ψ zmienia się w szerokim zakresie w zależności od materiału węglowego. Wpływ na tą zmianę ma również to, czy materiał węglowy jest z przerostami (wtrąceniami) czy bez.

W związku z tym, że dotychczas stosowany podział (Jaszczuk 1933; Jaromin 1985; Kozieł 1996; Szymczyk 1988) w zależności od wartości kąta bocznego rozkruszenia ψ na węgle kruche ($\psi > 60°$) i zwięzłe ($\psi < 60°$) jest niewystarczający, proponuje się wprowadzić następujący podział:

- W_m węgle miękkie $\psi > 70°$,
- W_t węgle twarde $40° < \psi < 70°$
- W_z węgle zwięzłe $\psi < 40°$.

Analiza materiału badawczego wykazała, że dotychczas stosowana klasyfikacja była niepełna, gdyż nie wiązała kąta bocznego rozkruszenia węgla ψ ze wskaźnikiem urabialności A_ψ. Nowa klasyfikacja pozwala precyzyjnie przypisać węgle do odpowiedniej kategorii.

Słowa kluczowe: urabialność węgla, wskaźnik urabialności, kąt bocznego rozkruszenia, energochłonność procesu urabiania

1. Introduction

The coal mining industry is characterized by specific and complex problems resulting from the application of various technical methodologies. These problems already exist in the engineering design, construction and production of machines and devices for mining industry and accumulate and become compounded during their use.

The cutting process is a problem in mining natural coal beds. Various experiments and studies — in Poland and worldwide — have tried to address this problem, leading to the construction and development of different mining devices.

After years of experiments, the cutting machines which appeared to be the most effective in coal mining are also applied in increased-coherence coal mining. Coal mining with milling devices in form of modified barrels is now very common. It is accepted in the Polish mining industry that in order to reach the production rates demanded by economic factors the coal should be mined with tumble heading machines.

The quality of solid coal determines the potential of applying a particular mining machine in certain conditions. In addition to achieving a pre-set production output at minimum cost, the coal's ease of being mined i.e. its mineability is an important consideration.

Therefore thorough recognition of seam's characteristics followed by a careful selection of machinery, with special regard to the mining machine in consideration of the local mining/geological conditions is most important. A proper characterization of solid coal's properties using only one attribute is almost impossible due to the many variables describing coal's resistance and the complexity of coal's coherence during destruction in the mining process. In this regard, it is necessary to detect and determine the mechanical properties of the mined coal that shall influence the selection of cutting mining machines (longwall tumble heading machines, static planes) by means of experiments.

The mining process to extract hard coal is normally achieved by the longwall machine-mining system and such a system will be replicated during the experiments.

The mechanical properties of the mined coal are represented by mineability indexes determined more or less exactly by various methods.

In order to characterize the solid coal's properties in the mining process the following factors must be determined:

- the mineability index,
- the side-crumble angle ψ,
- the exploitation pressure value represented by the vertical component of the stress state σ_z,
- the energy consumption involved in the digging process.

A representative mineability index, determined with a measuring device, must display the mining machine's mode of action and the device should possess a cutting knife with an identical or very similar geometry to the knives installed on the actual mining machines.

The mineability index A_ψ is determined on a laboratory test bed. A miniature device whose mode of action represented the tumble heading machine's operation, with a knife geometry similar to the knife installed on the real mining machine under real stress states, was selected for this purpose. The index is related to the real shape of cut groove intersection for this measurement (Biały 1982, 2001).

2. Efficiency of the mining process

Maximum efficiency of mining can be obtained when full use is made of the longwall shearer's power using minimum energy consumption for the mining process. This may only result from the proper and correct selection of the following parameters (Biały 1982; Chodura 1989; Jaszczuk 1993; Jonak 2001; Krauze 1995; Losiak 1966):

- knives and their layout on the mining machine with special regard to the knife-blade geometry,
- the design of the machine,
- rate of head rotation and the tumble-heading machine's feed,
- state of stress in the working area surrounding the machine.

Coal's mineability is the main factor influencing the selection of the mining machine's parameters (aimed at minimising the energy consumption during the digging process).

Other important factors are:

- durability of blades,
- quantitative analysis of the output.

A high knife-blade durability significantly reduces the mining costs by increasing the productivity of the longwall process by shortening the time in which a given amount of coal can be extracted. Therefore the mechanical properties of the coal to be mined assume great importance. The parameters taken in consideration to determine the selection and construction of cutting machines are based upon an exact analysis of these properties if the targets set for the coal seams' exploitation i.e. a high rate of excavations and a minimization of costs are to be achieved.

The estimation and selection of the mining parameters do not always lead to previously set results. This may also result from changes in the mining/geological conditions during digging, including variations in the exploitation pressure as represented by the vertical component σ_z which determes the mineability in the working area surrounding the cutting machine (Biały 1982, 2001).

3. Influence of the stress state in the vicinity of the mining machine on the machine's performance

In the hard-coal mining process using cutting machines the stress state in the heading (mined) area of the seam is very important as it determinates the mineability in this area. This is a result of the exploitation pressure generated by the overlying roof rocks. The primary stress state in solid rock undestroyed by mining activity is three-dimensional. Whilst mining this state is disrupted and digging takes place in a two-dimensional stress state. The exploitation pressure, represented by vertical component σ_z of the stress state, varies in the head of the seam from a maximum value σ_z to a primary pressure component p_z — the value in undestroyed solid rock (Sałustowicz 1968) (Fig. 1).

If the exploitation pressure is low and does not exceed the one-way compression resistance R_c the maximum exploitation pressure, represented by vertical component σ_z, will occur in the head of the longwall (Fig. 1a). In case of mining-resistant coals the longwall heading machine may be thrust back from the solid rock due to forces pressing against the machine itself. In the opposite situation, the maximum exploitation pressure (σ_z) will move far into the seam (Fig. 1b, c). The depth of this transition depends on the relative speed of the rocks' de-stressing and the rate of wall advance. If the wall advance does not follow the de-stressing of the roof-rock and the longwall head, the transition of the maximum value of exploitation pressure (σ_z) into the seam is large (Fig. 1c). The exploitation pressure reaches its maximum value in the seam's depth, therefore an unstressed area forms between the longwall head and the maximum exploitation pressure value σ_z, where the coal is heavily fractured and extrusion (squeezing out) of the coal towards the excavation area occurs.

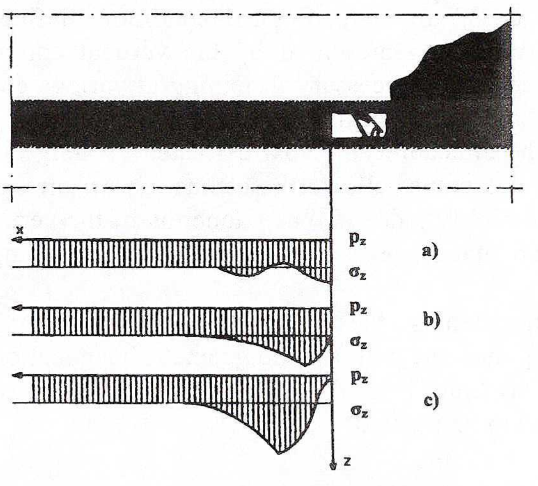

Fig. 1. Exploitation pressure wave characteristics in a mined coal seam as represented by a vertical component σ_z of the stress state

a, b, c — characteristics of exploitation pressures (represented by σ_z) in front of the longwall

Rys. 1. Rozkład fali ciśnienia eksploatacyjnego w wybieranym pokładzie węgla reprezentowanego przez składową pionową σ_z stanu naprężenia

a, b, c — rozkład ciśnienia eksploatacyjnego (reprezentowanego przez σ_z) przed czołem ściany

The coal's mineability is influenced by changes of exploitation pressure represented by the value of the vertical component of the stress state σ_z (mining-resistant and very resistant coals may be as susceptible to the cutting process as low-compactness coals). The value and extension of the exploitation pressure in the coal-seam may be regulated by the excavation progress, but mostly by the impression on the rocks surrounding the excavation (Biały 1982; Borycz 2000; Klich 2001; Sikora 1988).

4. Selection of experimental method

The mechanical mining process, accompanied by the continuous development of machinery and mechanical mining systems, requires the application of more exact methods of estimation of the mechanical properties of the coal to be mined regarding the technique (mode) of excavation applied, the mining-geological conditions in which the process will take place and the nature of the mechanized casing support, in order to obtain a high excavation rate. The key role played by cutting machines in the mining process depends on the estimation of the stress state in the head area of the seam, which in turn determines the mineability in the area (Fig. 1). The vertical component's σ_z of the stress state value (which represents the exploitation pressure) determines the coal's resistance as well as its mineability.

The experimental method is based upon a model representing the real mode of action of the cutting machine and takes account of changes that may occur due to expedient changes of mining/geological conditions influencing the exploitation pressure formation as represented by the vertical component of the stress state σ_z. The P force values necessary in mining at various coal stress states have been estimated in order to determine the mineability index A_ψ value to represent the estimation of the mineability of coal extracted by longwall cutting machines. Determination of these values allows the estimation of mining resistance changes (represented by mineability index A_ψ) as a function of the vertical component σ_z of the stress state (exploitation pressure) depending on changing mining/geological conditions.

The above statement explains the reasons for making laboratory mining tests with the use of model mining machine with a knife geometry identical or similar to the knife installed in the real machine. This allows the influence of the blade's geometry on the measured parameters to be ignored.

5. Mineability index $A\psi$

The total mining resistance that a cutting machine has to overcome consists of:

- hard coal's mining resistance,
- loading of the mined coal on the transporter,
- movement of the mining machine along the longwall face.

Due to the inability to determine the proportional participation of certain resistances in the mining process, along with the fact that the mining machine has to overcome all these resistances, an assumption is made that the mineability index A_ψ as determined on the test bed represents not only the mechanical properties of the mined coal but also other resistances which form an inseparable element of the mining process.

Many mineability indexes (determined through the use of various methods), represent the mechanical properties of the solid coal (Biały 1982; Chodura 1989; Jaszczuk

1993; Jaromin 1985; Kozieł 1996). Additionally, coals have been divided into brittle and compact (Jaszczuk 1993; Jaromin 1985; Kozieł 1996; Szymczyk 1988) depending on the side-crumble angle ψ value (Biały 1982, 2001).

A representative mineability index A_ψ was determined on the test bed by imaging the mode of action of single knife of the cutting machine under a bi-directional stress (and strain) state. Fig. 2 presents the cross-section of the measuring cut groove regarding its real shape.

With regard to the fact that the mineability index value depends on the real groove intersection the side-crumble angle ψ was introduced.

For plastic materials the elementary cutting resistance H_o equals:

$$H_o = \frac{P_{śr}}{F_o} = \frac{P_{śr}}{gb} \tag{1}$$

as:

$P_{śr}$ — mean cutting force [N],
$F_o = gb$ — groove face area for plastic materials,
g — depth of the measuring cut,
b — width of the cutting device's edge.

For brittle materials the elementary cutting resistance H_o equals:

$$H_o = \frac{P_{śr}}{F} = \frac{P_{śr}}{gb\left(1 + \frac{g}{b}\,\mathrm{tg}y\right)} \tag{2}$$

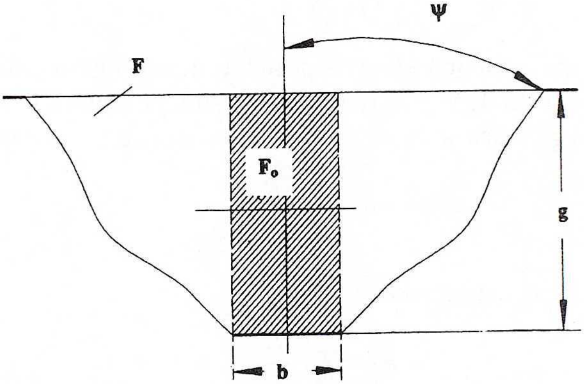

Fig. 2. Real cross-section of the measuring-cut groove
F_o — groove face area for plastic materials, F — groove face area for brittle material, ψ — side-crumble angle, g — depth of the measuring cut, b — width of the cutting device's edge

Rys. 2. Rzeczywisty przekrój poprzeczny bruzdy skrawu pomiarowego
F_o — pole przekroju bruzdy dla materiałów plastycznych, F — pole przekroju bruzdy materiału kruchego, ψ — kat bocznego rozkruszenia, g — głębokość skrawu, b — szerokość krawędzi narzędzia skrawającego

as:

$F = gb\left(1+\frac{g}{b}\,\text{tg}\psi\right)$ — groove face area for brittle material,

ψ — side-crumble angle,

or

$$H_0 b = \frac{P_{śr}}{g\left(1+\frac{g}{b}\,\text{tg}\psi\right)} \tag{3}$$

Which following the Author is marked A_ψ

$$A_\psi = H_o b$$

For plastic materials:

$$A_\psi = \frac{P_{śr}}{g} = A$$

where:

A — mineability index non accounting the side-crumble angle ψ.

For brittle materials:

$$A_\psi = \frac{P_{śr}}{g\left(1+\frac{g}{b}\,\text{tg}\psi\right)} \quad \text{[N/cm]} \tag{4}$$

Index (4) takes into account the real shape of the measuring cut groove intersection.

In testing device (POS-1, Fig. 3) (Biały 1982, 2002; Chodura 1989; Jaszczuk 1993; Kozieł 1996) b and g values were as follows: $b = 2$ cm, $g = 1$ cm therefore:

$$A_\psi = \frac{P_{śr}}{1+0{,}5\text{tg}\psi}$$

the value of force $P_{śr}$ is determined as follows:

$$P_{śr} = F_z \frac{R_k}{R} p_{śr} \eta \tag{5}$$

where:

F_z — measuring device piston area (34.45 cm^2),
R_k — measuring device chain wheel radius (10.365 cm),
R — measuring device arm radius (40.00 cm),
η — device efficiency (0.5),
$p_{śr}$ — chart value in [N].

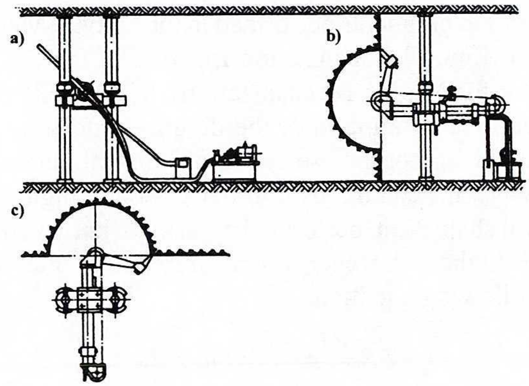

Fig. 3. POS-1 device for mining resistance estimation (mineability index A)
a — oblique, b — normal to the floor (vertical), c — parallel to the floor (horizontal)

Rys. 3. Przyrząd POS-1 do wyznaczania oporów urabiania (wskaźnika urabialności A)
a — skośnie, b — w płaszczyźnie prostopadłej do spągu, c — w płaszczyźnie równoległej do spągu

With regard to the above:

$$P_{śr} = 45p_{śr} \tag{6}$$

Finally the mineability index A_ψ value equals:

$$A_\psi = \frac{45p_{śr}}{1+0.5\mathrm{tg}\psi} \quad [\mathrm{N/cm}] \tag{7}$$

6. Energy consumption of the digging process

One of the basic factors characterizing the regularity of machine selection to given conditions is energy consumption, defined as the proportion of coal loosened (mining) from its entity force (work) necessary and its volume.

Energy consumption (energy) values have been estimated using various methods with different equations. These have been elaborated by the many scientific research centres involved in investigating this problem (Biały 2001a; Jaszczuk 1993, 1999; Kozieł 1966).

The energy consumption of the digging process was determined upon laboratory tests by with applying the parameters necessary to assign the mineability index A_ψ value which were determined on the test bed where the single knife of the measuring cutting device's mode of action was represented.

The more realistically the indexes of coal properties used to produce the theoretical energy consumption are represented, the more accurate will be the prediction for the power demand. By this means it is possible to mine effectively (to pre-determined productivity levels) under given mining/geological conditions.

Most recent results of experiments performed in the Instytut Mechanizacji Górnictwa Politechniki Śląskiej (Mining Mechanization Institute of the Silesian Technical University), CMG (Centre for Mining Mechanization) "KOMAG" and worldwide, show that the estimated energy consumption of the digging process is a fundamental parameter for determining the appropriate selection of longwall cutting machines in given mining/geological (longwall) conditions in order to obtain high productivity.

Fig. 4 presents a real shaped cut, performed by a single knife in the digging process.

According to the Author, the energy consumption of the digging process was calculated from the following equation:

$$SE = \frac{P_{śr} \cdot L}{V} \quad [\mathrm{Jcm^{-3}}] \tag{8}$$

where:

$P_{śr}$ — mean cutting force [N],
L — the length of knife-cut [cm],
V — single cut mined coal (rock) volume [cm^3].

The $P_{śr}$ value was calculated as per equation (5) — leading to, with regard to the above values:

$$P_{śr} = 45 p_{śr} \ [\mathrm{N}] \tag{6}$$

Volume V of the coal mined was determined as follows:

$$V = FL \tag{9}$$

where:

L — cut length,
F — coal mined from cut area.

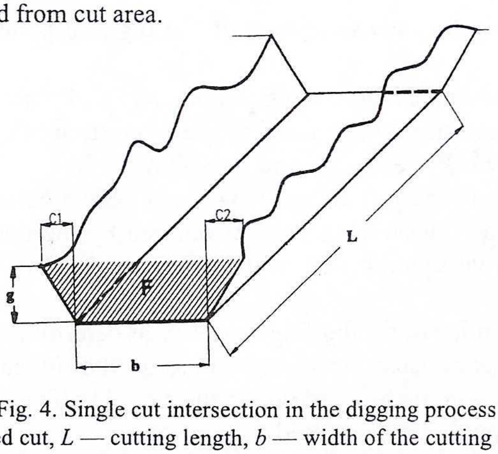

Fig. 4. Single cut intersection in the digging process
F — face area of the mined cut, L — cutting length, b — width of the cutting device's edge, g — depth of the measuring cut, C_1, C_2 — cut widening rates

Rys. 4. Przekrój pojedynczego skrawu w trakcie procesu urabiania
F — pole przekroju urobionego skrawu, L — długość skrawania, b — szerokość krawędzi narzędzia skrawającego, g — głębokość skrawu pomiarowego, C_1, C_2 — wielkości poszerzające skraw

$$F = g\left[b + \frac{C_1 + C_2}{2}\right] \quad [\mathrm{cm}^2] \tag{10}$$

Substituting equation (8)

$$SE = \frac{P_{śr}}{F} \quad [\mathrm{Jcm}^{-3}] \tag{11}$$

Taking into account equation (6), finally equalling:

$$SE = \frac{45 p_{śr}}{F} \quad [\mathrm{Jcm}^{-3}] \tag{12}$$

The energy consumption estimation and the determination of its correlation with the mechanical properties of the medium to be mined enables the necessary information to be obtained to select the appropriate mining machine for given mining/geological conditions. The information on the mining machine's energy demand necessary to realise the mining process will further allow the durability of the tumble heading machine and its elements to be predicted.

7. Experimental results

Laboratory measurements of the influence of exploitation pressure (represented by vertical component σ_z of the stress state) on the mineability index A_ψ, side-crumble angle ψ as well as the energy consumption of the digging process (*SE* values) were performed on a test bed designed and assembled in CMG "KOMAG" in Gliwice, for vertical i.e. normal and horizontal cuts — parallel to the floor and ceiling of the excavation.

Vertical cuts on the original intact structure were performed on coal specimens obtained from KWK "Powstańców Śląskich", KWK "Kleofas" and KWK "Staszic" mines for loads ranging from zero to resistance destruction. The experiments were also performed on coal specimens obtained from the KWK "Kleofas" and KWK "Staszic" mines after resistance destruction i.e. on a destroyed structure (*ZS*).

Horizontal cuts in both cutting directions (i.e. from left to right $L - R$, as well as from right to left $R - L$) were performed on the original intact structure on coal specimens obtained from KWK "Powstańców Śląskich" from zero to specimen's resistance destruction. Then measurements for horizontal cuts in one direction ($R - L$) also after resistance destruction were made for coal specimens obtained from 501 seam of KWK "Staszic". From seam 407 of the KWK "Staszic" mine, coal specimens with and without interlayers (inclusions), vertical cuts on the original intact structure up to resistance destruction and on a destroyed structure were performed.

During the experiments concerning the influence of exploitation pressure, values of force $p_{śr}$ side-crumble angle ψ and cut length L were measured.

The value of the mineability index A_ψ was calculated by means of equation (7), while the energy consumption of the mining process, *SE*, using equation (12).

It was found that the influence of reduced coal coherence planes, as well as the mining direction as a function of exploitation pressure value, changed cutting conditions, especially the mineability index A_ψ, the energy consumption of the mining process SE and side-crumble angle ψ values being taken into account in the experiments performed.

The results obtained are presented on Figs. 5 to 12 and in Tables 1 to 7.

8. Summary

On the basis of upon the charts from Figs. 4 to 12 it will be seen that the direction of cut and stress state in the working area of the cutting mining machine, represented by vertical component σ_z of exploitation pressure has a very strong influence on mineability index A_ψ, side-crumble angle ψ and energy consumption SE of the mining process values. This influence could be characterized as follows:

TABLE 1

TABLICA 1

KWK "Powstańców Śląskich" seam 509							
Vertical cut				Horizontal cut $L-R$		Horizontal cut $R-L$	
No.	σ_z [MPa]	A_ψ [N/cm]	SE [Jcm^{-3}]	A_ψ [N/cm]	SE [Jcm^{-3}]	A_ψ [N/cm]	SE [Jcm^{-3}]
1.	0.09	358	49.89	114	12.58	135	15.56
2.	0.19	622	52.63	146	13.91	—	—
3.	0.34	862	68.32	126	11.83	193	12.89
4.	0.45	801	88.54	135	15.87	—	—
5.	0.56	780	91.15	209	19.87	175	15.26
6.	0.09	414	39.81	111	11.24	225	18.41
7.	0.19	640	53.14	91	9.82	—	—
8.	0.33	752	62.58	154	15.56	243	20.49
9.	0.46	919	90.15	118	18.45	—	—
10.	0.66	790	79.57	137	21.81	243	22.58
11.	0.83	702	70.59	191	22.12	220	20.12
12.	1.26	530	45.18	188	20.35	220	21.81
13.	1.81	—	—	154	19.99	—	—

For coal specimens obtained from KWK "Powstańców Śląskich" (seam 509) the experiments were performed by representing the longwall heading machine's and static plane's mode of action in both mining directions. Mineability index values A_ψ for vertical cuts reach values from 3 to 7 times higher than A_ψ for horizontal cuts (Fig. 4). The value of A_ψ varies curves as a function of the exploitation pressure σ_z; these are square functions, which in the early phase increase and then decrease, whereas for vertical cuts these changes are very sharp, in contrast to the distinct curves of the horizontal cuts. After changing the mining direction in the horizontal cuts, similar curves were obtained, but

TABLE 2

TABLICA 2

KWK "Kleofas" seam 417						
	Vertical cut			Vertical cut *ZS*		
No.	σ_z [MPa]	A_ψ [N/cm]	*SE* [Jcm^{-3}]	σ_z [N/cm]	A_ψ [N/cm]	*SE* [Jcm^{-3}]
1.	0.05	262	25.30	0.82	446	42.91
2.	0.21	391	33.95	0.73	321	29.88
3.	0.42	455	37.45	0.54	238	21.39
4.	0.61	445	41.41	0.36	201	16.74
5.	0.83	351	35.12	—	—	—

TABLE 3

TABLICA 3

KWK "Staszic" seam 407						
	Vertical cut			Vertical cut *ZS*		
No.	σ_z [MPa]	A_ψ [N/cm]	*SE* [Jcm^{-3}]	σ_z [N/cm]	A_ψ [N/cm]	*SE* [Jcm^{-3}]
1.	0.00	860	83.90	0.81	1 010	101.01
2.	0.12	1 100	106.30	0.72	950	91.80
3.	0.25	1 240	119.20	0.55	870	80.60
4.	0.40	1 290	125.20	0.40	825	76.00
5.	0.55	1 240	121.60	0.23	785	72.12
6.	0.71	1 120	109.30	—	—	—
7.	0.82	980	95.60	—	—	—

TABLE 4

TABLICA 4

KWK "Staszic" seam 407 with interlayers						
	Vertical cut			Vertical cut *ZS*		
No.	σ_z [MPa]	A_ψ [N/cm]	*SE* [Jcm^{-3}]	σ_z [N/cm]	A_ψ [N/cm]	*SE* [Jcm^{-3}]
1.	0.00	1 160	112.11	0.51	1 110	111.00
2.	0.22	1 235	121.09	0.44	1 100	106.30
3.	0.32	1 230	121.20	0.31	1 040	96.30
4.	0.41	1 201	119.42	0.15	950	80.92
5.	0.52	1 075	107.55	—	—	—

TABLE 5

TABLICA 5

KWK "Staszic" seam 501						
	Vertical cut			Vertical cut *ZS*		
No.	σ_z [MPa]	A_ψ [N/cm]	*SE* [Jcm^{-3}]	σ_z [N/cm]	A_ψ [N/cm]	*SE* [Jcm^{-3}]
1.	0.077	1 121	151.74	0.985	1 223	174.60
2.	0.155	1 108	158.59	0.785	1 047	140.40
3.	0.234	1 107	163.32	0.745	1 105	142.56
4.	0.313	1 222	171.17	0.725	970	126.40
5.	0.394	1 321	190.42	0.635	840	99.22
6.	0.435	1 483	203.16	—	—	—
7.	0.557	1 502	215.00	—	—	—
8.	0.640	1 366	195.01	—	—	—
9.	0.723	1 330	186.78	—	—	—
10.	0.808	1 207	186.36	—	—	—
11.	0.893	1 327	185.48	—	—	—
12.	0.979	1 222	178.16	—	—	—

TABLE 6

TABLICA 6

KWK "Staszic" seam 501						
	Horizontal cut			Horizontal cut *ZS*		
No.	σ_z [MPa]	A_ψ [N/cm]	SE [Jcm^{-3}]	σ_z [N/cm]	A_ψ [N/cm]	SE [Jcm^{-3}]
1.	0.40	281	13.61	1.61	201	17.55
2.	0.42	266	11.66	1.66	181	15.60
3.	0.83	290	10.86	1.58	171	15.29
4.	0.84	291	11.24	1.45	164	12.60
5.	1.25	264	13.95	—	—	—
6.	1.26	281	12.40	—	—	—
7.	1.48	279	15.42	—	—	—
8.	1.44	267	12.36	—	—	—
9.	1.64	263	11.27	—	—	—
10.	1.61	253	10.41	—	—	—
11.	1.76	251	11.85	—	—	—

TABLE 7

TABLICA 7

Coal class	Cut	ψ Value	ψ Change	Value ψ *ZS*	Change ψ *ZS*
W_m	vertical	78–80°	constant	—	—
	horizontal	79°	constant	—	—
W_t	vertical	54–42°	decreases	45–75°	strongly increases
	horizontal	—	—	—	—
	vertical with interlayers	58–40°	decreases	31–34°	constant
W_z	vertical	27–29°	constant	26–27°	constant
	vertical	38–6°	strongly decreases	6–0°	decreases very strongly
	horizontal	24–39°	increases	33–11°	strongly decreases

with clear differences in their values, which proves the presence of directionally--dependant decreased coherence planes in coal seams. This leads to conclusion that for vertical cuts it is the exploitation pressure (σ_z) that strongly influences the mining resistance value (the mineability index A_ψ). The variation of energy consumption of the mining process (*SE*) value is similar. In vertical cuts it rises strongly in the early phase, followed by a decrease (Fig. 5). For horizontal cuts this curve is smoother, despite the direction of cut. The side-crumble angle ψ (Fig. 6) for vertical cuts is constantly decreasing, while for horizontal cuts it increases regardless of the direction of cut.

Angle ψ is about 80° and its value is almost constant (the variability is very small — Table 7). This is because the material (coal) possesses many decreased coherence planes, fissures and pores, and in response to the increase of exploitation pressure on the material (the specimen), an increase of average density occurs and micro-destructions appear on fissures and pores of coal material via the development of new fissures and pores. Coal material obtained from KWK "Powstańców Śląskich" exhibited this type of structure and disintegration of the coal specimen took place after the resistance value was exceeded. The above was proved by a constant, large, side-crumble angle ψ.

This kind of coal material, characterized with such properties shall be called W_m type (soft coal).

Coal obtained from KWK "Kleofas" (seam 417) was mined only with vertical cuts representing the mode of action of longwall heading machines. The mineability index

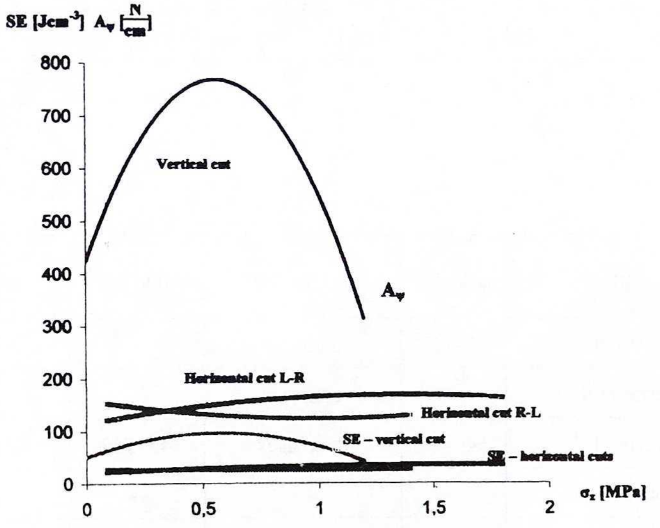

Fig. 5. Mineability index A_ψ and energy consumption of the digging process *SE* as a function of exploitation pressure (represented by σ_z) for vertical and horizontal cuts of coal specimens obtained from KWK "Powstańców Śląskich" seam 509

Rys. 5. Wskaźnik urabialności A_ψ oraz energochłonność procesu urabiania *SE* w funkcji ciśnienia eksploatacyjnego (reprezentowanego przez σ_z) dla skrawów pionowych oraz poziomych próbek węgla pobranych z KWK „Powstańców Śląskich" pokład 509

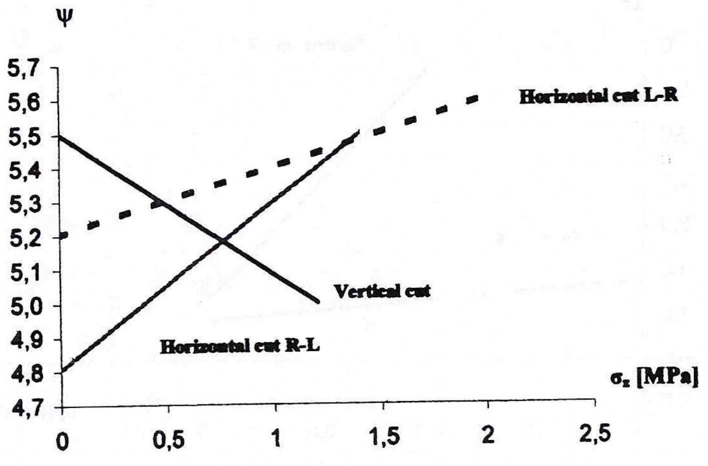

Fig. 6. Side-crumble angle ψ as a function of exploitation pressure (represented by σ_z) for vertical and horizontal cuts of coal specimens obtained from KWK "Powstańców Śląskich" seam 509

Rys. 6. Kąt bocznego rozkruszenia ψ w funkcji ciśnienia eksploatacyjnego (reprezentowanego przez σ_z) dla skrawów pionowych oraz poziomych próbek węgla pobranych z KWK „Powstańców Śląskich" pokład 509

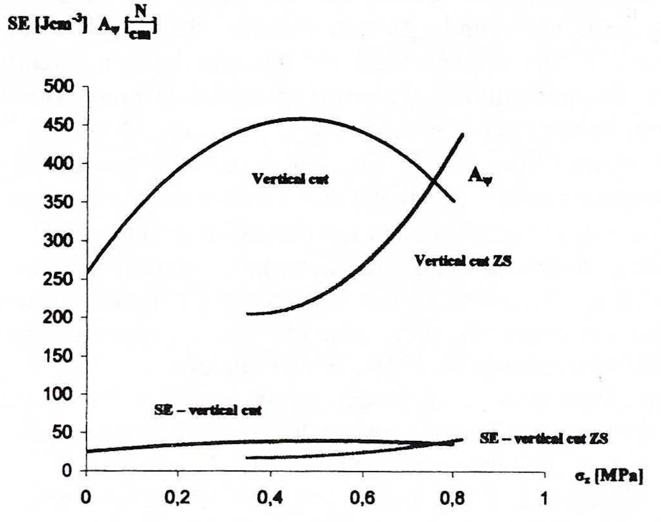

Fig. 7. Mineability index A_ψ and energy consumption of the digging process *SE* as exploitation pressure function (represented by σ_z) for vertical cuts of coal specimens obtained from KWK "Kleofas" seam 417

Rys. 7. Wskaźnik urabialności A_ψ oraz energochłonność procesu urabiania *SE* w funkcji ciśnienia eksploatacyjnego (reprezentowanego przez σ_z) dla skrawów pionowych próbek węgla pobranych z KWK „Kleofas" pokład 417

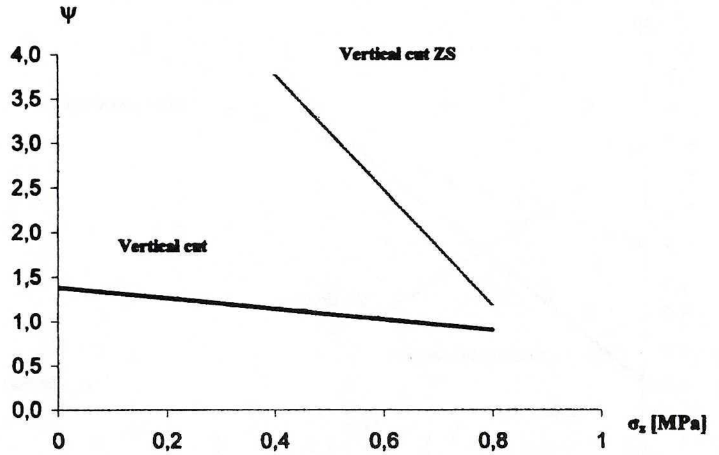

Fig. 8. Side crumble angle ψ as exploitation pressure function (represented by σ_z) for vertical cuts of coal specimens obtained from KWK "Kleofas" seam 417

Rys. 8. Kąt bocznego rozkruszenia ψ w funkcji ciśnienia eksploatacyjnego (reprezentowanego przez σ_z) dla skrawów pionowych próbek węgla pobranych z KWK „Kleofas" pokład 417

A_ψ variation was also estimated, as well as changes of the side-crumble angle ψ and energy consumption of the mining process *SE* as a function of the exploitation pressure (vertical component σ_z). The results obtained clearly show that the pattern of A_ψ variation (Fig. 6) is very similar to that obtained from analysis of coal specimens obtained from KWK "Powstańców Śląskich" (sharply rising in the early phase followed by a decrease). The side-crumble angle ψ (Fig. 8) shows a more pronounced tendency to decrease and varies over a broader range i.e. from 54 to 42°. This means, that coal material obtained from KWK "Kleofas" is more coherent with lower content of decreased coherence planes (cleavage) which allowed the experiments to continue after resistance value was exceeded, i.e. on the destroyed structure (*ZS*). During the experiments on destroyed structures (*ZS*) the side-crumble angle ψ increased sharply (Fig. 8) reaching a value of 75°, which means that the coal material became soft. After the resistance value was exceeded, extra pores and fissures appeared in the coal material, leading to sudden increase of the side-crumble angle ψ.

The energy consumption of the mining process *SE* is characterized by a pattern similar to A_ψ, where the difference between destroyed (*ZS*) and non-destroyed specimen mining is clear. This (*SE*) value can even be halved.

Coal material with such a tendency of side-crumble angle ψ variation shall be called W_t type (hard coal).

Coal specimens with and without interlayers (inclusions) were obtained from KWK "Staszic", from two different seams (seam 407 and 501). The experiments to investigate variations of the mineability index A_ψ, side-crumble angle ψ and energy consumption of the mining process *SE* as a function of the vertical component σ_z (Figs. 9, 11, 12) were conducted in both directions for horizontal cuts in a load range from zero to the specimen's resistance destruction and on the destroyed structure (*ZS*). Coal specimens with interlayers (Fig. 9) show much lower resistance in comparison to specimens without interlayers (about 60% of the value). This refers to both experiments performed within the load range from zero to resistance destruction and on the destroyed structure (*ZS*).

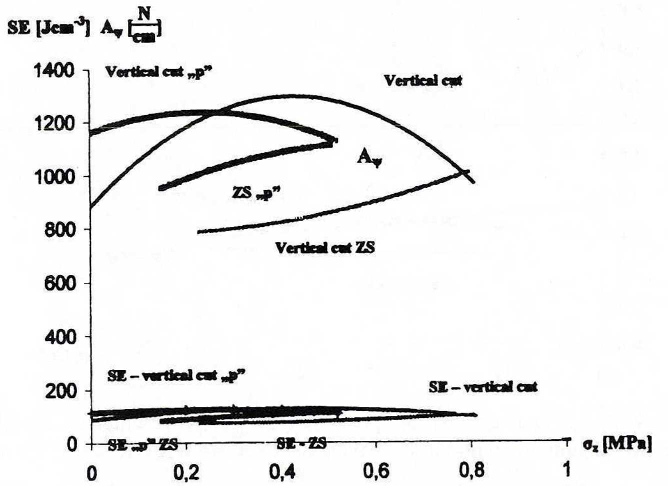

Fig. 9. Mineability index A_ψ and energy consumption of the mining process *SE* as exploitation pressure function (represented by σ_z) for vertical cuts of coal specimens with and without interlayers obtained from KWK "Staszic" seam 407

Rys. 9. Wskaźnik urabialności A_ψ oraz energochłonność procesu urabiania *SE* w funkcji ciśnienia eksploatacyjnego (reprezentowanego przez σ_z) dla skrawów pionowych próbek węgla z przerostami i bez, pobranych z KWK „Staszic" pokład 407

This proves the influence of the two following factors on coal material resistance:

- coal material effort,
- density increase as a result of coal material strain caused by a decrease in porosity and fissure content.

Similarly to the above cases, for vertical cuts the A_ψ curves resulting from the experiments rise in the early phase, and then decrease (they are strongly curved), whereas for horizontal cuts this curve is very shallow (this refers both to specimens with and without interlayers).

The side-crumble angle ψ (Fig. 10) for vertical cuts in case of coal specimens with interlayers varies in the range 58–40° (decreasing) while for the destroyed structure 31–34° (increasing). For coal specimens without interlayers this angle is almost constant, with values from 27 to 29°, and for destroyed structure 26–27°.

For coal obtained from seam 501 (Fig. 13) the side-crumble angle ψ for vertical cuts (only this type of cut was made) shows a rapid decrease in the value of the vertical component, reaching values from 38 to 6°, with loads from zero to the coal specimen's resistance destruction and the virtual disappearance of the side crumble angle ψ (the angle reached 0°) in experiments on the destroyed structure (*ZS*). Exceeding the resistance limit developed distinct fracture planes, but the specimen still kept its coherence — no sudden collapse of the coal material was noticed. This refers to the coal

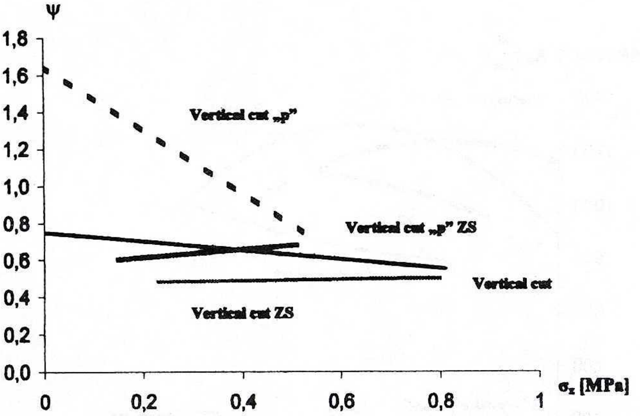

Fig. 10. Side-crumble angle ψ as exploitation pressure function (represented by σ_z) for vertical cuts of coal specimens with and without interlayers obtained from KWK "Staszic" seam 407

Rys. 10. Kąt bocznego rozkruszenia ψ w funkcji cisnienia eksploatacyjnego (reprezentowanego przez σ_z) dla skrawów pionowych próbek węgla z przerostami i bez, pobranych z KWK „Staszic" pokład 407

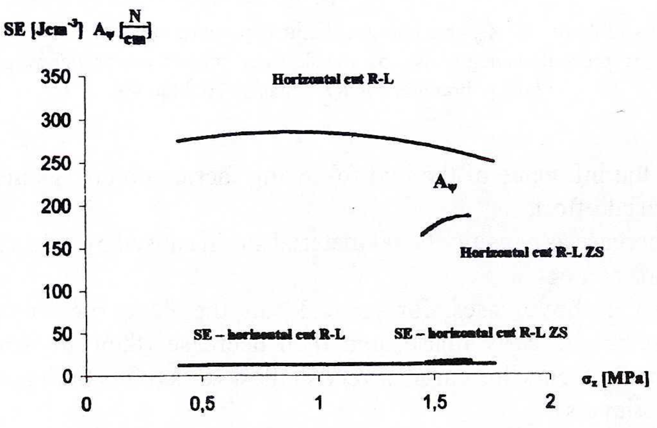

Fig. 11. Mineability index A_{ψ} and energy consumption of the mining process *SE* as exploitation pressure function (represented by σ_z) for horizontal cuts of coal specimens obtained from KWK "Staszic" seam 501

Rys. 11. Wskaźnik urabialności A_{ψ} oraz energochłonność procesu urabiania *SE* w funkcji ciśnienia eksploatacyjnego (reprezentowanego przez σ_z) dla skrawów poziomych próbek węgla pobranych z KWK "Staszic" pokład 501

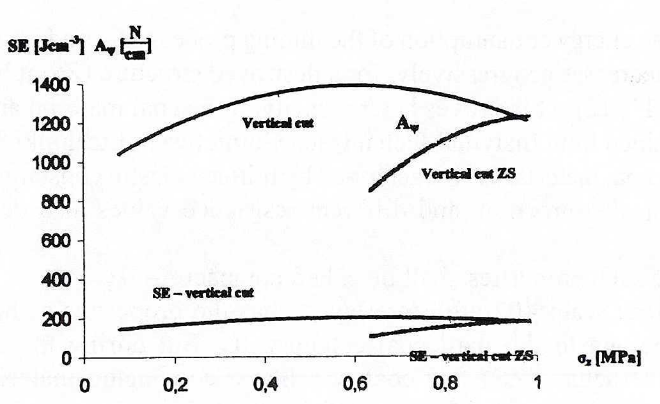

Fig. 12. Mineability index A_ψ and energy consumption of the mining process *SE* as exploitation pressure function (represented by σ_z) for vertical cuts of coal specimens obtained from KWK "Staszic" seam 501

Rys. 12. Wskaźnik urabialności A_ψ oraz energochłonność procesu urabiania *SE* w funkcji ciśnienia eksploatacyjnego (reprezentowanego przez σ_z) dla skrawów pionowych próbek węgla pobranych z KWK „Staszic" pokład 501

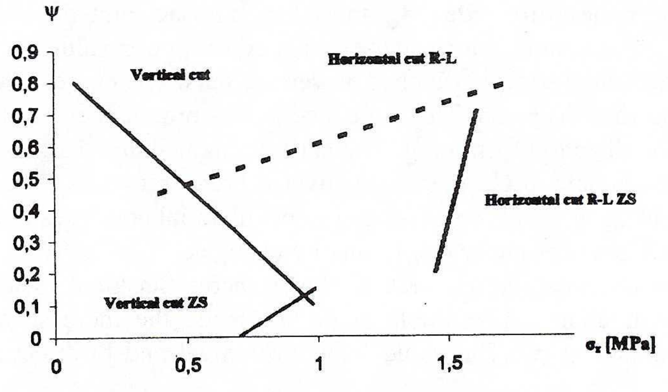

Fig. 13. Side-crumble angle ψ as exploitation pressure function (represented by σ_z) for vertical and horizontal cuts of coal specimens obtained from KWK "Staszic" seam 501

Rys. 13. Kąt bocznego rozkruszenia ψ w funkcji ciśnienia eksploatacyjnego (reprezentowanego przez σ_z) dla skrawów pionowych i poziomych próbek węgla pobranych z KWK „Staszic" pokład 501

specimens obtained both from seam 407 with and without interlayers and from seam 501. Further experiments on the destroyed structure (*ZS*) showed re-consolidation of the fracture planes formed, the coal material hardening and the practical extraction of the material towards the groove of the measuring cut leading to the side-crumble angle ψ value becoming almost zero. For horizontal cuts the side-crumble angle ψ change is similar (Fig. 13), although this change is not so rapid. Within a load range from zero to the coal specimen's resistance destruction the angle ψ varies from 24 to 39°, while for a destroyed structure (*ZS*) the angle decreases from 33 to 11°.

Although the energy consumption of the mining process *SE* as a function of exploitation pressure decreases progressively, for a destroyed structure (*ZS*) it has a decreasing trend (Figs. 9, 11, 12). This proves heterogeneity of the coal material and, according to the results obtained from Instytut Mechanizacji Górnictwa Politechniki Śląskiej (Radzik 1982), that the coal material is characterized by thirteen elastic constants and a different χ depending on the direction, and different resistance values also depending on the direction.

The coal of such properties shall be called compact — W_z.

The coal from seam 407 with interlayers, has the properties of hard coal, therefore it shall belong to the hard coal category W_t. But during the experiments on the destroyed structure (ZS) this coal was like a compacted material — W_z. This was due to the interlayers (inclusions) of the material having a different resistance than coal.

Conclusions

1. On the basis of the experiments concerning the influence of the exploitation pressure on the mineability index A_ψ and taking into account the real shape of the measuring-cut groove intersection and the energy consumption value it can be stated that this pressure has a very strong influence on vertical cuts. The curves rise sharply in the early phase and then decrease. This influence is less pronounced for horizontal cuts, regardless of the direction of mining. The curves obtained are shallower.

2. The side-crumble angle ψ changes over a broad range depending on the coal material. The change depends on whether the coal material possesses interlayers (inclusions) or not. Differences occur due to quality changes.

3. Coal material obtained from KWK "Powstańców Śląskich" (seam 509) showed virtually no changes in side-crumble angle ψ despite the increase of the value of the vertical component σ_z. The value for both vertical and bi-directional horizontal cuts was 80°.

4. For coal specimens obtained from KWK "Kleofas" the side-crumble angle showed a stronger tendency to decrease (54 to 42°), while in case of the experiments on the destroyed structure (*ZS*) its value was similar to that for soft coal (the side-crumble angle increased to 75°).

5. The coal obtained from KWK "Staszic" possessed a very small side-crumble angle ψ value (seam 407) with a decreasing, increasing or constant tendency depending on whether specimens with or without interlayers were being tested. During the experiments with vertical cuts on the destroyed structure, despite the decrease in the vertical component (seam 501) a sudden decrease of side-crumble angle ψ occurred, which meant fulfillment of the knife's working area — in this case cutting took place only within the knife's width (Fig. 2, area F_o).

6. It must be recognised that the currently accepted division of coals (Jaszczuk 1993; Jaromin 1985; Szymczyk 1988), dependant on the side-crumble angle ψ value, into

brittle ($\psi > 60°$) and compact ($\psi < 60°$) is no longer adequate. The following division is now suggested (Table 7):

- W_m soft coals $\psi > 70°$,
- W_t hard coals $40° < \psi < 70°$
- W_z compact coals $\psi < 40°$.

Confirmation of the points of demarcation between the various coal categories will necessitate further experimental work.

7. There is a practical possibility of influencing the change (decrease) of A_ψ value as well as energy consumption of the mining process *SE*, by making changes to the casing support, thereby affecting the value of the vertical component σ_z.

8. With application of an appropriate casing support (if mining-geological conditions allow) a stress state can be created in the coal seam leading to structural destruction of the coal layers (formation of new decreased coherence planes), and the energy consumed by the mining process will be reduced.

9. If the coal structure is destroyed the energy requirement for the mining process is halved in comparison with that needed for an intact structure.

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