The experience of the polish mining industry in assessing the state of rockburst hazard in the upper silesian coal basin mines

Doświadczenia polskiego górnictwa w ocenie stanu zagrożenia tąpaniami w kopalniach GZW

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Abstract

The causes of rockburst occurrence are presented based on the analysis of the rockbursts occurring in the Polish hard coal mines. The scale of the rockburst hazard has been characterized with respect to the mining and geological conditions of the existing exploitation. Of the factors influencing the state of rockburst hazard, the most essential one is considered the depth interval ranging from 600 m to 900 m. The rockburst occurrence risk, with mine tremors of energy $E \leq 10^4$ J, determined based on the statistical data for the period 1987-2007, has increased over the past few years by the order of 2 to 3. The afore mentioned risk for energy $E \geq 10^6$ J remains practically unchanging. This appears to be evidence in support of the idea that the mining operations being conducted at great depth – currently an average depth of mining in the Upper Silesian Coal Basin mines is equal to 702 m – along with the higher rock mass effort, may induce seismic events, of which even the medium size ones can result in rockbursts.

Streszczenie

W oparciu o analizę tąpnięć zaistniałych w polskich kopalniach węgla kamiennego podano przyczyny występowania tych zjawisk. Scharakteryzowano skalę zagrożenia tąpaniami w odniesieniu do warunków geologiczno-górniczych dotychczasowej eksploatacji. Wśród czynników wpływających na stan zagrożenia tąpaniami za najbardziej istotny uznano głębokość z przedziału od 600 m do 900 m. Na podstawie danych statystycznych z lat 1987-2007 określono ryzyko wystąpienia tąpnięcia przy wstrząsach o energiach $E \leq 10^4$ J, które zwiększyło się w ostatnich latach o 2÷3 rzędy. Dla energii $E \geq 10^6$ J praktycznie pozostało bez zmian. Potwierdza to słuszność stwierdzenia, że na dużych głębokościach prowadzenia robót (aktualnie w kopalniach GZW średnio 702 m) wraz z większym wytężeniem górotworu nawet średniej wartości wstrząsy, mogą powodować wystąpienie tąpnięć.

Introduction

An understanding of the causes of occurrence of the higher states of rockburst hazard can lead to the assumption that an essential impact on its change may be exerted by the method and technology of mining as well as by the practically utilized state of knowledge of the rockburst problem. The existing methods of hard coal mining in Poland have been used since the turn of the sixties and seventies of the 20th century. As the methods and technology for reducing the rockburst hazard have made great strides, the number of rockbursts in hard coal mines decreased from 39 in 1972 to 2-3 in the recent years. Between 1995- and 2007 the annual number of recorded rockbursts ranged from 2 to 7 (Fig. 1). The coal output in Poland has continuous decreased since 1978 (Fig 2). However, despite this the number of rockbursts have recently been keeping constant – from 3 to 4 a year over the past 10 years (Fig. 3). In addition to mining and geological conditions, both the shortage of technical equipment needed for system of mining being used and the inadequate level of knowledge of the methods for predictions and combating of the state of rockburst hazard may also influence the rockburst occurrence.

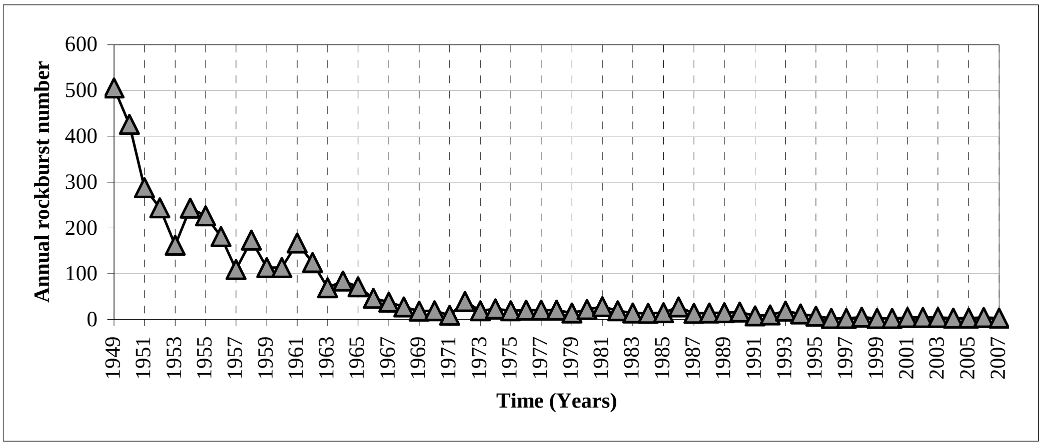

Fig. 1. Number of rockbursts in the Upper Silesian Coal Basin hard coal mines in the years 1949 - 2007
Rys. 1. Liczba tąpnięć w kopalniach węgla kamiennego GZW w latach 1949-2007

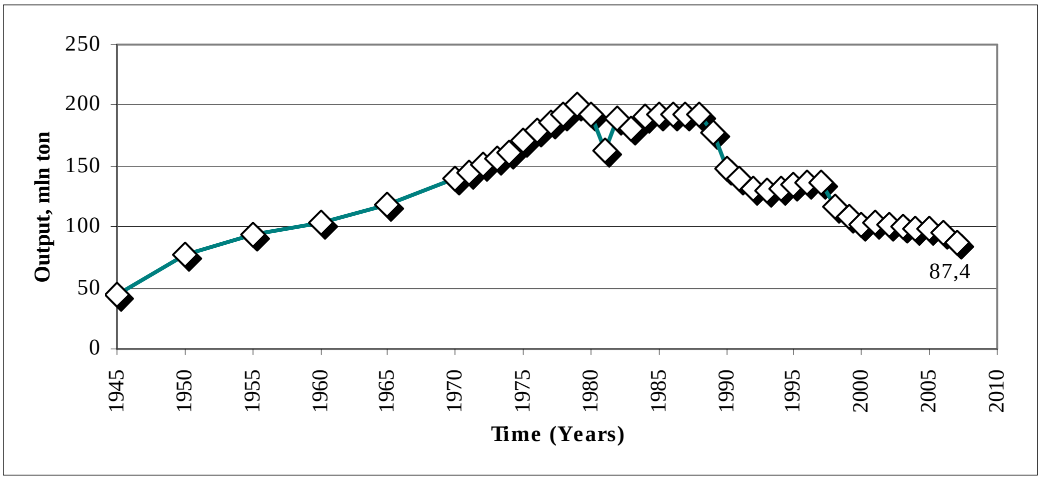

Fig. 2. Hard coal output in the Upper Silesian Coal Basin mines in the years 1945-2007
Rys. 2. Produkcja węgla kamiennego w kopalniach węgla kamiennego GZW w latach 1945-2007

Scale of Rockburst Hazard and Related Mining and Geological Conditions

The seismic and rockburst hazards occur in the majority of Polish hard coal mines. A number of factors exert an influence on them, of witch the most important can be the following ones (DUBIŃSKI J., KONOPKO W., 2000; KONOPKO W., 1994; KONOPKO W., 1987; KONOPKO W., 2006):

- thick monolithic sandstone layers of high uniaxial compression strength (60 - 150 MPa) occurring in the roof;
- evidence of past mining in the form of remnants, pillars and coal seam edges;
- primary and secondary tectonic settings of the deposit (faults, cleavage);
- mining and coal seam remnants;
- depth of mining operations and the resulting rock mass pressure;
- natural proneness of coal to rockbursts (bumpiness of the roof – coal seam – floor system).

According to the statistical documentation showing locations and conditions of the rockbursts occurred in the years 1998-2007, those events were accompanied by the mine tremors of energy ranging from 10^5 J to 10^8 J. The generated seismicity can undoubtedly be associated with mining operations, especially with the mining and production concentration. In favour of it can testify the fact that as the output continuously tended to fall from about 116 mln metric tons in 1988 to 87,4 mln metric tons in 2007 and the corresponding number of rockbursts averaged at 2-5 each year during that period (Fig. 3), the unit expenditure of energy (JWE) continuously tended to grow (Fig. 4).

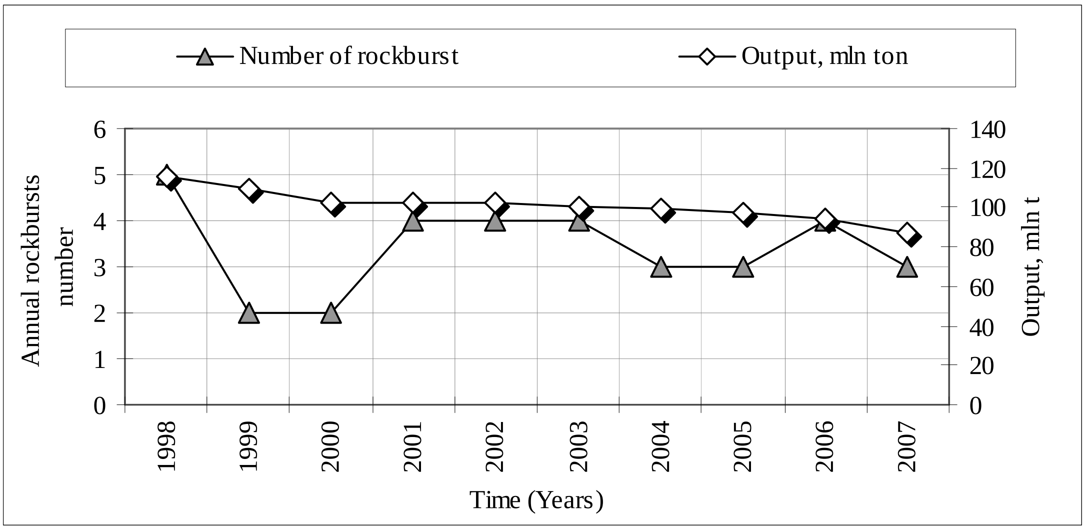

Fig 3. Hard coal output and the number of rockbursts in the Upper Silesian Coal Basin mines in the years 1998 - 2007

Rys. 3. Wydobycie węgla kamiennego i liczby tąpnięć w GZW w latach 1998 - 2007

An increase in seismicity from 6 J/t to 27 J/t, estimated as the energy radiated per 1 ton of coal extracted, has been recorded over the past 10 years. The average value of the seismicity during that period 16,7 J/t.

In table 1 are shown the statistical data that confirm the high seismicity of the Upper Silesian Coal basin rock masses. The above mentioned upward trend of seismicity can distinctly be visible in the high energy of the order of 10^7-10^9 J. This phenomenon can unusually by harmful due to its strong connection with the occurrence of rockbursts.

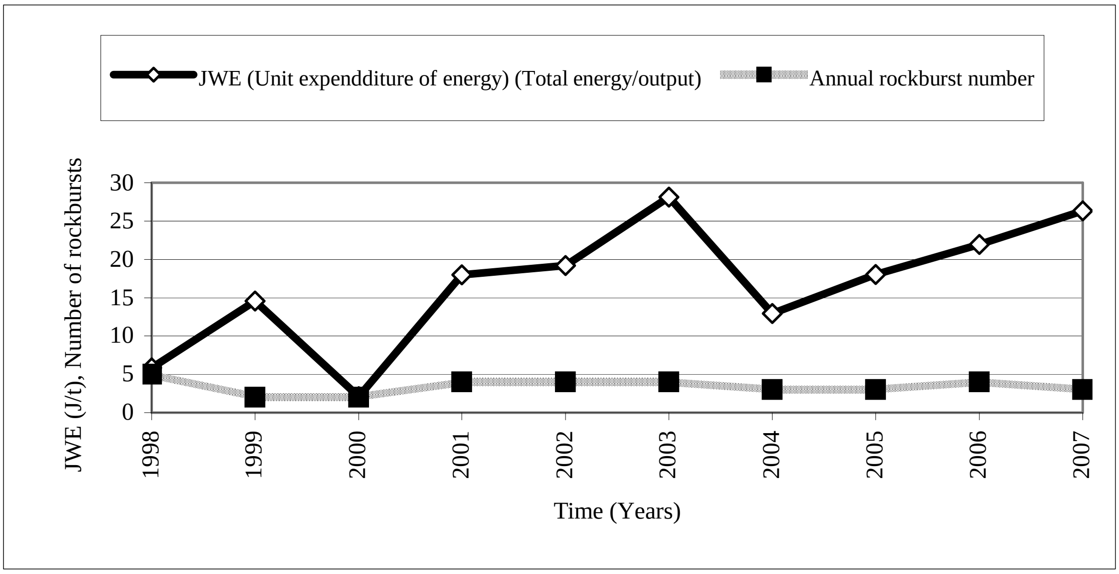

Fig. 4. Unit expenditure of energy (JWE) and the number of rockbursts from the Upper Silesian Coal Basin in the years 1998 - 2007

Rys. 4. Jednostkowy wydatek energetyczny (JWE) dla GZW na tle liczby tąpnięć w latach 1998 - 2007

Tab 1. Seismicity of the Upper Silesian Coal Basin rock masses in the years 1998 - 2007 (STEC K., 2007)
Tab 1. Aktywność sejsmiczna górotworu GZW w latach 1998 - 2007 (STEC K., 2007)

Year	Number of mine tremors (n_w) of energy E, J					
	10^5	10^6	10^7	10^8	10^9	Σ
1998	572	86	5	0	0	663
1999	941	183	10	1	0	1135
2000	877	192	18	1	0	1088
2001	927	192	18	0	0	1137
2002	1135	171	18	0	0	1324
2003	1302	193	28	1	0	1524
2004	845	112	16	0	0	973
2005	1256	180	14	1	0	1451
2006	976	168	26	2	0	1172
2007	833	99	5	1	1	939

The rockburst occurrence inseparably generates the effects in mine workings as well as casualties. This aspect of rockburst hazard appears to be mostly undesirable from the practical point of view. The measures undertaken to prevent the hazard of mine tremors and rockburst occurrence are designed to reduce these dangerous symptoms of the rockburst and seismic events. Table 2 shows the number of rockbursts and the resulting casualties, as well as the output (including the output from the coal seams being under rockburst hazard), and the number of mine tremors and the scale of damage caused by the rockbursts. The number of casualties and the effects in the form of damage done to excavations during the period under discussion remain approximately at the similar level and the incidence rate reached an average value of 0,14.

Tab 2. Coal output, high energy tremors and the effects of rockbursts in the Upper Silesian Coal Basin mines in the years 1998 - 2007
Tab 2. Wydobycie węgla, wstrząsy wysokoenergetyczne oraz skutki tąpnięć w kopalniach GZW w latach 1998 - 2007

Year	Total output	Output from coal seams under rockburst hazard		Incidence rate (casualties /output)	Number of rockbursts	Rockbursts – related casualties		Effects in excavations	
	mln tons		% of total			lethal	remaining (severe and light)	destroyed and collapsed, m	damaged, m
1998	116,0	42,2	36,4	0,14	**5**	2	**14**	239	184
1999	109,2	38,2	35,0	0,03	2	0	3	0	119
2000	102,2	37,0	36,2	0,00	2	0	0	0	120
2001	102,8	37,6	36,6	0,20	4	2	19	0	**668**
2002	102,1	42,2	41,3	0,20	4	3	17	0	590
2003	100,4	41,8	40,9	0,18	4	2	16	110	145
2004	96,99	39,2	39,4	0,11	3	0	11	0	358
2005	99,5	41*	41,2*	0,13	3	1	12	0	270
2006	94,5	42,15	44,6	**0,25**	4	4	20	0	>510
2007	87,4	44,6*	49,43*	0,11	3	0	10	0	530

* - approximate data

26 such events have occurred in 34 cases of rockbursts in the excavations and gate roads being under the influence of abutment stress. The remaining 8 cases occurred in the passageways situated behind the stress zones induced by current mining operations.

Tab 3. Consequences of the rockbursts that occurred in longwall coalfaces and headings of the Upper Silesian Coal basin mines in the years 1998 - 2007

Tab 3. Skutki tąpnięć w ścianach i wyrobiskach chodnikowych w GZW w latach 1998 - 2007

Year	Number of rockbursts	Headings off the active face line	Coalfaces	Gate roads	Coalfaces along with a gate road
1998	5	2	1	2	-
1999	2	-	1	-	1
2000	2	2	-	-	-
2001	4	2	-	2	-
2002	4	-	-	4	-
2003	4	1	-	1	2
2004	3	1	-	-	2
2005	3	-	-	-	3
2006	4	-	-	1	3
2007	3	-	-	3	-
Σ	34	8	2	13	11

In the tab. 3 are specified the locations of rockburst effects from the view – point of the type of an excavation and its position with respect to the abutment stress zone. Such a subdivision has been dictated by different values of the pressure (rock efforts) around the excavations and their variable structures.

Mining and Geological Conditions during Mining the Coal Seams under Rockburst Hazard

Apart from the event mechanisms, a rockburst can only occur in the case of superposition of specific geological (fractures, cleavage, faults, seismogenic layers) and mining (edges, remnants, direction of face advance under the hanging wall or incumbent roof strata, in the fault zone or in the undisturbed zone, in the vicinity of pillars) conditions under which mining operations progress.

Characteristics of the rockburst locations obtained based on the collection of archival materials (PATYŃSKA R., 1987-2007) allow systematizing positions of the work lines (coalfaces or roadways) with respect to the rock mass discontinuities related to local faults. Most of the rockbursts (more than 60%) have occurred in the areas where the face line was positioned in the downthrown side and the roof exhibited cleavage being incumbent relative to the direction of mining. In some few cases, the rockbursts have not been related to faults.

The rockbursts have mainly produced the effects in the gate roads in which the coalface line was positioned close to fault planes (<25 m). As shown from the rockburst catalogue (PATYŃSKA R., 1987-2007), in some 47% of cases the rockburst consequences were occurring at a distance of 50 m from the plane of the closest faults. It follows from the angle between the face line and the closest fault that the smaller the face line – fault angle, the higher the likelihood of rockburst occurrence.

Assessing the distances between the rockburst effects and the seismic event sources, one can come to a conclusion that the smaller the distance the more serious the effects (PATYŃSKA R., 2004).

The current recording of seismicity allows, among others, assessing daily variations in values of the unit expenditure of energy (JWE, J/t), or the values of the expenditure of energy (WE, J/t), related to face advance rates. The reported data (KONOPKO W., 1984) undeniably show that, just before each rockburst occurrence, very distinct changes (increases and decreases) in the daily expenditures of energy in relation to the seismicity background values of the area under study have occurred.

In the years 1998-2007, the small numbers of rockbursts and their effects notwithstanding, these quantities, as compared with previous periods, no longer show downward trends, but on the contrary, trends, but on the contrary, some upward trend, particularly in the case of seismic events recordings of energy lower then 10^6 J, could be observed. This could probably be related to the output from individual coalfaces and to an increase in depth of mining. Below are presented the data on the coalface productivity against the number of coalfaces (TRENCZEK S., 1997-2006). The data show that in spite of a decrease in the annual mean number of active coalfaces (both with stowing and with caving), an increase in the output from each panel could be observed.

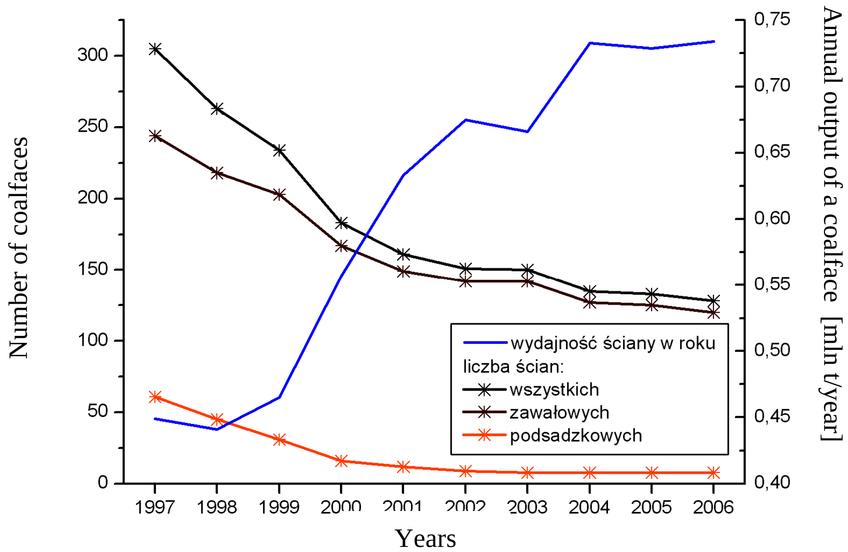

Fig. 5. Annual mean number and output of active coalfaces in the years 1997-2006 (TRENCZEK S., 1997-2006)

Rys. 5. Średnioroczna liczba i wydajność czynnych ścian w latach 1997-2006 (TRENCZEK S., 1997-2006)

Depth of Mining and Rockburst Hazard

The average depth of mining, in close proximity of which a rockburst occurred during the past 10 years, is about 810 m (a minimum depth and a maximum depth being 620 m and 1150 m, respectively) (PATYŃSKA R., 1992-2007)

In making a plot of the number of rockbursts occurred against the coal seam depths, the following data were obtained:

- 8 rockbursts at the actual depth interval ranging from 620 m to 690 m;

- 12 rockbursts at the actual depth interval ranging from 700 m to 770 m;
- 2 rockbursts at the actual depth interval ranging from 820 m to 890 m;
- 9 rockbursts at the actual depth interval ranging from 900 m to 970 m;
- 3 rockbursts at the actual depth interval ranging from 1050 m to 1150m.

The depth of coal seam group No. 500, at which as far as 25 rockbursts have occurred, range from 620 m to 970 m. It is hard to say that just such a depth could be the most dangerous. The number of rockbursts should rather be referred, for example, to the number of coalfaces or to the output from the depth intervals. A depth of about 770 m could be suspected to be associated with the highest output and hence with the highest number of rockbursts. It is worth to note that, nowadays, the average depth of mining in the Upper Silesian Coal Basin mines is 702 m. This can easily be accounted for rockbursts occurring at a depth close to the depth most coalface are being mined at.

In the remainder of cases, the following amounts of rockbursts were recorded:

- coal seam group No. 400 – 5 rockbursts – the average depth 880 m (from the interval 745-1150 m);
- coal seam group No. 600 – 2 rockbursts – the average depth 930 m;
- coal seam group No. 700 – 2 rockbursts – the average depth 1050 m.

In comparing the depth of mining of coal seam group No. 500, considered to be "the most dangerous", with the other coal seam groups, it is easy to find that depth appears to be not great even if the overlying coal seam group No. 400 is taken into account.

The depth interval, at which rockbursts occurred in the years 1987-2007 (151 cases), ranges from 400 m to 1150 m (Tab. 4). The variation in rockburst occurrence at this interval obtained based on the analysis of the partial distribution of the average depths is shown in Fig 6.

Tab. 4. Depth ranges for the rockbursts occurred in the years 1987- 2007
Tab. 4. Zakres głębokości przy tąpnięciach w latach 1987 - 2007

Data	Rockburst depth ranges						
Depth, m	400-499	500-599	600-699	700-799	800-899	900-999	1000-1150
Number of rockbursts, n_t	5	6	**35**	**44**	**36**	19	6
The average depth at a given interval, m	437,5	568	649,17	739,13	839,09	938	1118
The average depth, m	759,9						

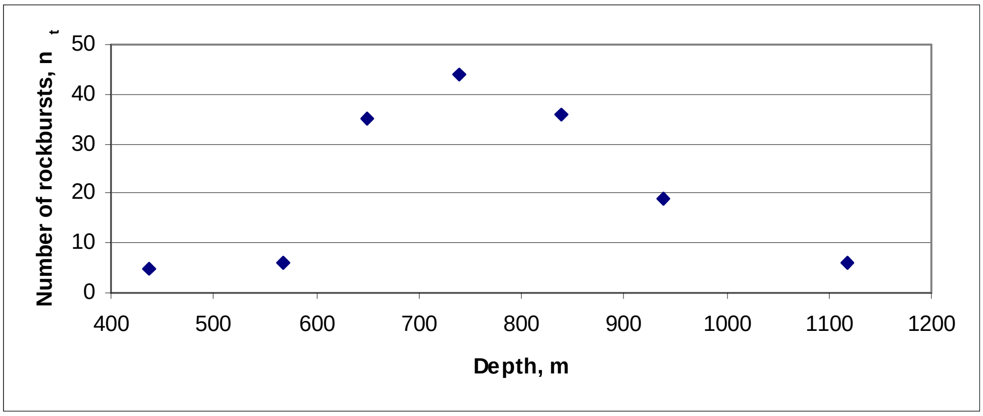

Fig. 6. Relationship between the number of rockbursts occurred in the years 1987-2007 and the depth of mining
Rys. 6. Zależność liczby tąpnięć w latach 1987 - 2007 od głębokości eksploatacji

The depth of coal seam mining influences the hazard state indirectly. It is one of the factors that characterizes the area being under hazard and indirectly contributes to the undesirable interaction with other mining and geological factors. The data obtained based on a relationship between the rockburst occurrence and the number of factors N, regarded as the causes of rockbursts, indicate a high rockburst hazard in the case of combined interaction of several of the above mentioned factors (Fig 7). The main geological factors having the power of deciding on the rockburst occurrence are the seismogenic layers and faults. They became visible in turn in 150 and 113 cases of 151 analyzed rockbursts occurred in the years 1987 - 2007. They have become visible as combined in 112 cases. The other group of factors called the mining factors cab be the edges and remnants (133 rockbursts), the goaf (118 rockbursts), the pillars (91 rockbursts) and the excessive paneling (88 rockbursts). In 38 cases of rockburst occurrence all the factors have been recorded as occurred together.

In 93 cases of rockbursts, the mining operations two factors: (1) edges and remnants , (2) goaf. The above obtained results show that the past mining can play a very important role in generating rockbursts, which in conditions of the Upper Silesian Coal basin appears to be a widespread phenomenon.

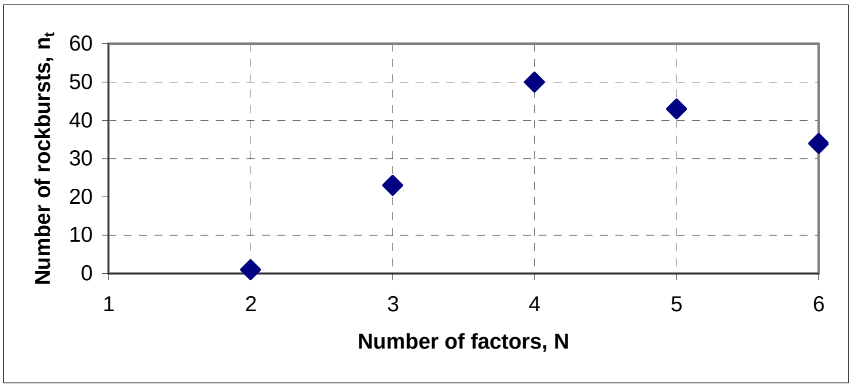

Fig 7. Contribution of the number of factors to the causes of rockbursts in the years 1987-2007
Rys. 7. Udział liczby czynników w przyczynach tąpnięć w latach 1987-2007

It follows from the comparison of geological and mining factors that the occurrence of even one factor from each group (both geological and mining) can contribute to the increase in rockburst hazard.

From among of 151 rockbursts, in 133 cases was observed a simulations contribution of the following two factors: (1) seismogenic strata, (2) edges and remnants in overlying coal seams. A significant contribution of the factor called the pillars appears during the partial and total extractions. As many as 90 rockbursts have occurred in the pillars, the roof of which being composed, among others, of seismogenic strata. The contribution of three factors (seismogenic strata, edges and remnants, faults) has been recorded in as many as 100 cases of rockburst occurrence.

In conclusion, it should be noted that in analyses of the assessment of the state of rockburst hazard both the geological factors (seimogenic strata, faults) and the mining factors (edges and remnants, goaf) can be of major importance.

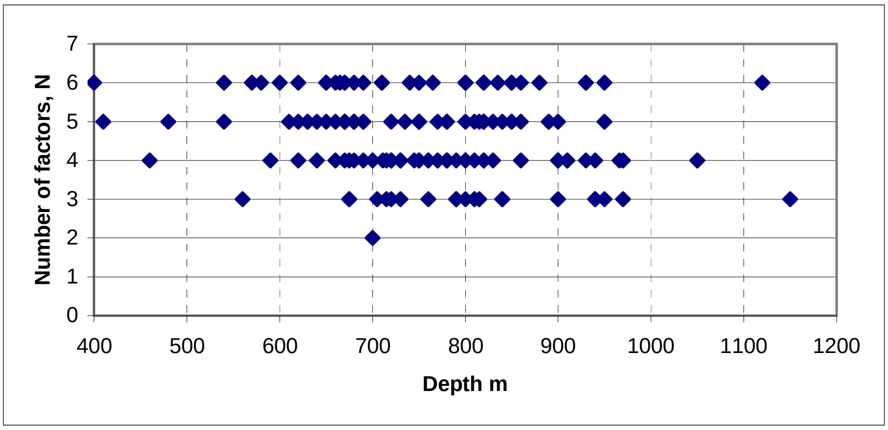

Fig. 8. The number of factors contributing to the occurrence of rockbursts at a given depth in the years 1987 - 2007

Rys. 8. Liczba czynników wpływających na występowanie tąpnięcia na danej głębokości w latach 1987 - 2007

The above mentioned rockburst hazard inducing mining factors (seismogenic strata, edges and remnants, goaf) can particularly be harmful at greater depths (H=600-900 m) and may constitute a real rockburst hazard.

A serious rockburst hazard (71 cases of rockburst occurrence) can occur in the case of combined interaction of all the above mentioned mining factors (Fig. 8), including one geological factors, the fault.

It is important to note that the greater the number of combined factors occur, the stronger the mine tremor can be released by the ground, and this the more likely a rockburst will be inducted (Table 5).

Tab 5. The occurrence of rockbursts in dependence on the energy of tremors and number of related factors
Tab 5. Występowanie tąpnięć w zależności od energii wstrząsu i liczby czynników je warunkujących

	10^3	10^4	10^5	10^6	10^7	10^8	10^9
6	-	4	**10**	**12**	6	2	
5	1	8	**14**	**11**	7	1	1
4	1	5	**11**	**20**	**11**	2	-
3	-	3	**12**	7	1	-	-
2	-	-	1	-	-	-	-
1	-	-	-	-	-	-	-

The two rockbursts associated with seismic events of energy of the order of 10^3 J that occurred during the period under study were related to 4 and 5 factors and the depth of mining 750 m and 590 m, respectively. The rockbursts with seismic events energy of the order of 10^5 J occurred during the simultaneous interaction with at leas two factors. However, the rockbursts with seismic events of energy equal to or higher than 10^6 J were recorded already with three contributing to the hazard. Therefore, the most dangerous for mining appear to be the conditions of occurrence of a comination of the following 4 or 5 factors:

– seismogenic strata 150 rockbursts;
– edges and remnants 133 rockbursts;
– goaf 118 rockbursts;
– faults 113 rockbursts;
– pillar (washout, horst) 91 rockbursts.

Seismicity and State of Rockburst Hazard

In order to determine the influence of energy of seismic events on the state of rockburst hazard, an analysis of the average values of the unit expenditure of energy (JWE, J/t) calculated per 1 ton of coal output in the years 1987-2007 was performed (Fig. 9).

The variation in a number of tremors, especially with respect to individual orders of energy, arises both from the varying output ranging from 192,7 mln tons in 1987 to 87,4 mln tons in 2007 and the mining and geological conditions encountered during mining operations. The factors not related to mining should also be taken into account. Such a significant variation in the unit expenditure of energy (JWE) defined as energy J/ton of output (Fig. 9) cannot be convincingly explained only by mining factors (KONOPKO W., PATYŃSKA R., 2008).

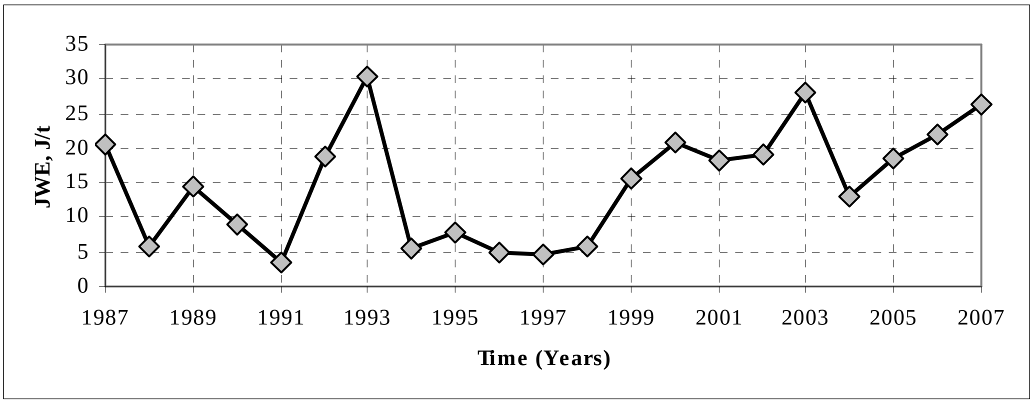

Fig. 9. Distribution of the unit expenditure of energy (JWE, J/t) in the years 1987 - 2007
Rys. 9. Rozkład Jednostkowego Wydatku Energetycznego (JWE, J/t) w latach 1987 - 2007

It is evident from the distribution of the number of rockbursts versus output shown in Fig. 10 that in conditions of the Upper Silesian Coal Basin with the output over 100 mln tons of coal, the annual mean rockburst number was 8 during the period given in the Figure. With the coal output below 100 mln tons that number of rockbursts dropped to 3 cases a year.

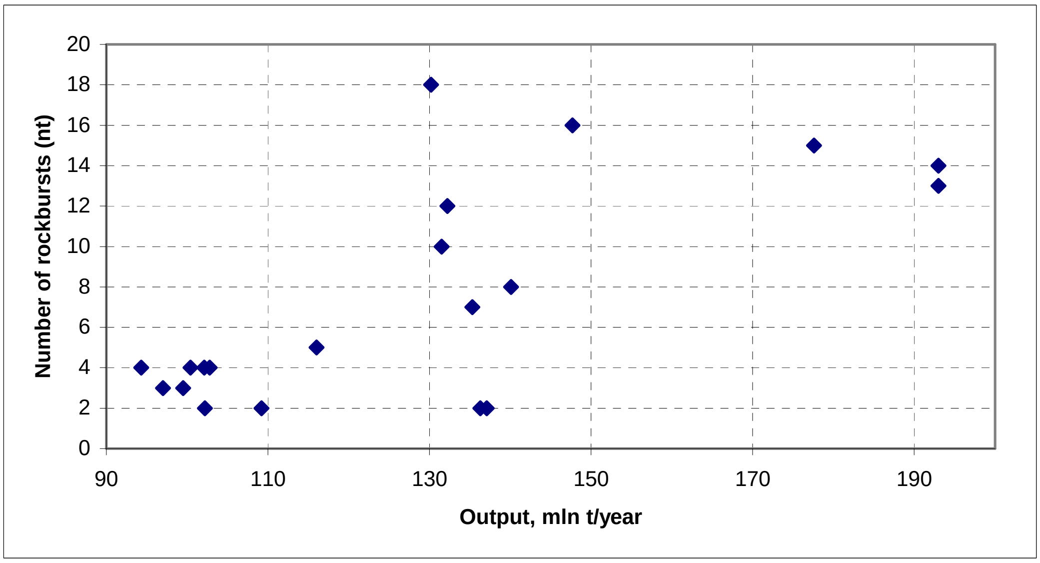

Fig. 10. Dependence od the number of rockbursts on the coal output in Poland in the years 1987 - 2007
Rys. 10. Zależności liczby tąpnięć przy produkcji węgla w Polsce w latach 1987 - 2007

The distribution of the number of rockbursts relaive to the mine tremor energy (Fig. 11) shows that the maximum number, i.e. 48 and 50, of rockbursts were recorded with energy of the order of 10^5 J and 10^6 J, respectively. The percentage shares of a particular number of tremors in a total amount of 151 events recorded in the years 1987 - 2007 are summarized as:

- 2 rockbursts of energy of the order 10^3 J – 1,3 %
- 20 rockbursts of energy of the order 10^4 J – 13,2 %

- 48 rockbursts of energy of the order 10^5 J – 31,8 %
- 50 rockbursts of energy of the order 10^6 J – 33,1 %
- 25 rockbursts of energy of the order 10^7 J – 16,6 %
- 5 rockbursts of energy of the order 10^8 J – 3,3 %
- 1 rockburst of energy of the order 10^9 J – 0,7 %.

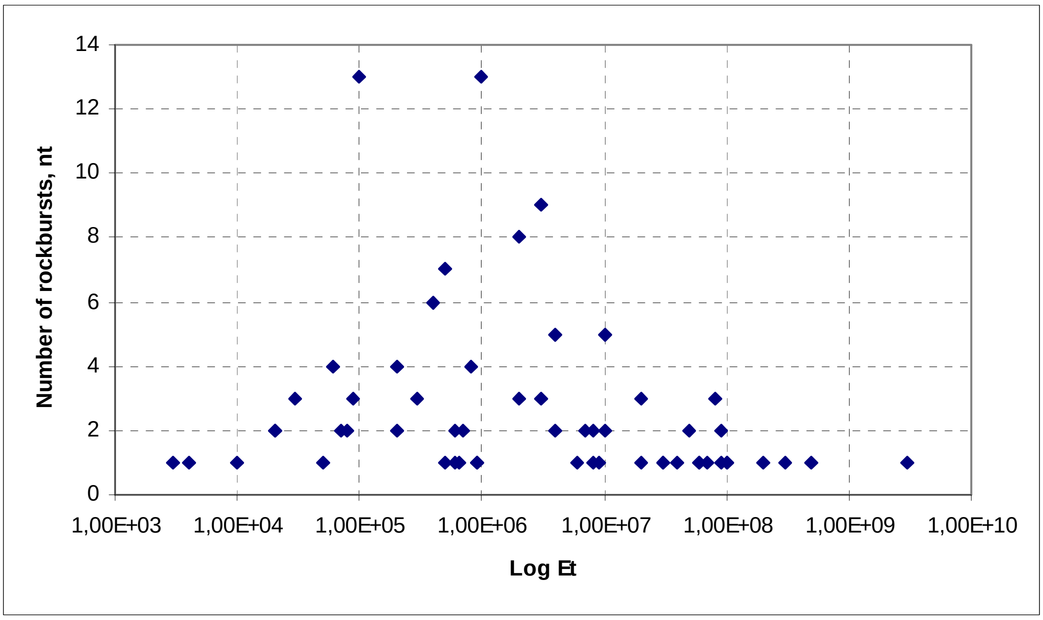

Fig. 11. Dependance of the numbers of rockbursts on the values of energy of seismic events in the years 1987 - 2007

Rys. 11. Udział liczby tąpnięć w zależności od wartości energii wstrząsu sejsmicznego w latach 1987 - 2007

Statistical information on the rockbursts occurred in the years 1987-2007, with regard to the share of the number of tremors from the Upper Silesian Coal Basin mines among the individual energy intervals indicates an energy interval of $\geq 10^5$ J as the inteval for which the probability of inducing a rockburst by a seismic avent of a given energy for the periods from 1977 to 1982 and from 1987 to 2006 has been astablished (Fig. 12).

This dependence presents the rockburst occurrence risk with the specific number and energy of mine tremors. From the plot it is evident that for the period from 1987 to 2006 the risk can be in the ranges 10^{-4} – 10^{-5} and 10^{-3} – 10^{-4} with the mine tremor energy of the order of $10^{\ 3}$ J and 10^4 J, respectively. Even with mine tremor energy of the order of 10^9 J, the probability can be less than 1, amounting to about 0,5. Depending on the equation, one may come to a conclusion that with either predicted or recorded mine tremors of energy of the order of 10^4 J, the rockburst occurrence probability can relatively be low. It is assumed that it can be within the risk tolerance limits. With doth found and predicted mine tremor energy $E \geq 10^5$ J, it is essential that the rockburst occurrence prevention to mitigate the hazard state should be carried out (KONOPKO W., PATYŃSKA R., 2008).

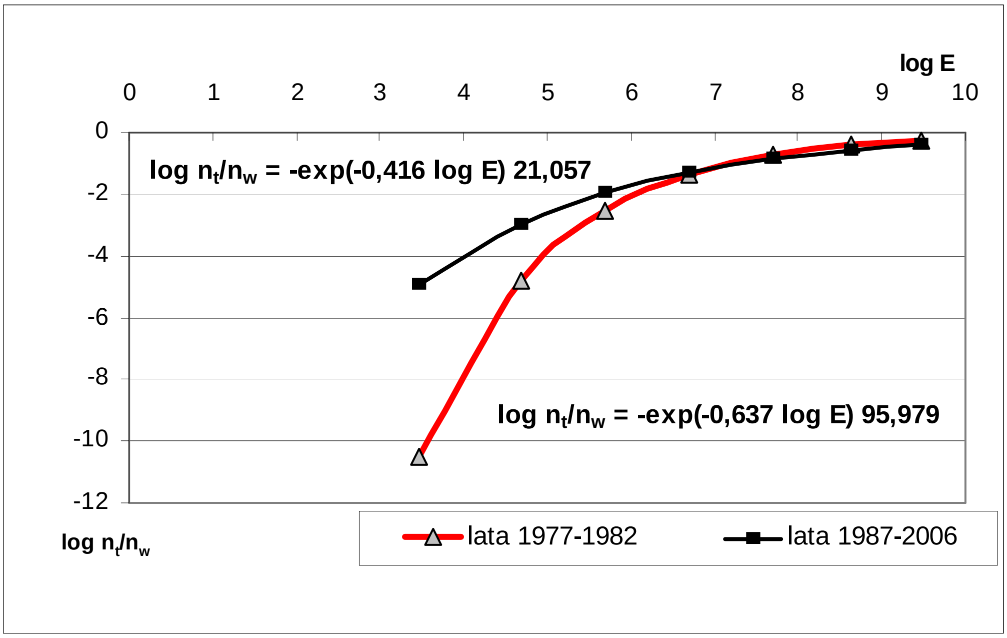

Fig 12. Probability of the rockburst occurrence plotted against the number and energy of mine tremors (KONOPKO W., PATYŃSKA R., 2008).
Rys. 12. Prawdopodobieństwo wystąpienia tąpnięcia w zależności od liczby i energii wstrząsów górotworu (KONOPKO W., PATYŃSKA R., 2008).

In comparison with the similar investigations carried out based on the data from the years 1977-1982, the occurrence risk of the rockbursts with low and average energies has increased even by the order of 2 to 3 (Fig. 12). However, with energy $E \geq 10^6$ J, it remained unchanging. The above data confirm the theory that at greater mining depths (averaging 702 m nowadays and 486 m in 1977) and with the resulting higher rock mass effort, even the medium energy mine tremors can bring about the occurrence of dynamic events.

Conclusion

Despite a smaller number of rockbursts and their consequences recorded over the past 10 years, a certain upward trend in the state of rockburst hazard can be observed, especially as far as the seismicity of the rock mass is concerned. It may probably be associated with the amount of output and work concentration at individual longwall panels as well as with great mining depths.

From the analysis of the conditions under which rockbursts occur in hard coal mines, it may be found an influence of the coalface line location with respect to the directions of weakened cohesion planes and fault planes on the rockburst hazard and seismicity in mining areas. Locating coal faces under the roof with hanging cleavage appears to be more disadvantageous than locating coal faces under the roof with the incumbent cleavage. An increase in output from the areas classified among the third degree of rockburst hazard has been observed for many years. This prompts one to make a statement that it is imperative to conduct distressing mining operations that would allow safe extraction of both the adjacent over – and underlying coal seams.

The synthesis of the conditions of rockburst occurrence in hard coal mines in the years 1987-2007 allows summarizing the following statements and conclusions:

1. The hard coal output declined from 192,7 mln tons in 1987 to 87,4 mln tons in 2007. In 1987, the caving method of mining and the hydraulic filling method of mining accounted for 81,6 % and 16.8% of the total output, respectively. However in 2006 they accounted for 95,4% and 4,5%, respectively. The remaining output (1,6%) in 1987 was obtained using the rock filling method of mining. The average mining depth increased from about 552 m to 702 m during that period. The output obtained from the coal seams classified among those being under rockburst hazard accounted for 26,4% and 49,4%of the total output in 1987 and 2007, respectively.
2. The mining operations were inducing mine tremors of energy up to 10^9 J. The unit expenditure of energy (JWE) per unit total output (ton) ranged from 3,6 to 30,3 J/t, averaging 16,7 J/t.
3. The energy of seismic events associated with the rockbursts ranged from $3 \cdot 10^3$ J to $3 \cdot 10^9$ J. The occurrence probability of a rockburst given the energy of a seismic event of the order of 10^3 J, was in the range $10^{-4} \div 10^{-5}$. These rockbursts should be regarded as incidental, occurring in unusually unfavorable mining and geological conditions. However, in the case of a mine tremor with energy of the order of 10^9 J the risk maintains its position at a level of 0,5. In the case of mine tremors of the order of 10^4 J, a reasonable recommendation would be the employment of appropriate monitoring of the hazard state and if that hazard should appear to rise, them adequate preventive measures must be undertaken.
4. The basic factors that promote the rockburst occurrence are as follows:
   - seismogenic strata,
   - edges and remnants,
   - goaf,
   - faults,
   - pillars,
   - excessive paneling.

   Their interaction becomes more severe when the depth of mining operations keeps increasing.
5. The higher energy of a mine tremor and the greater mining depth are, the lower number of factors can be enough to cause the rockburst occurrence. The rockbursts with seismic events of energy even of the order of 10^3 J, were recorded with the simultaneous interaction of at least four factors. However with seismic events of energy $E_o \geq 10^5$ J, the rockburst can occur already in the presence of one of the above mentioned factors.

References

DUBIŃSKI J., KONOPKO W.: Tąpania – ocena – prognoza – zwalczanie. (Rockbursts – Assessment – Prediction – Combuting). Wydawnictwo GIG, Katowice, 2000

KONOPKO W., PATYŃSKA R.: Warunki występowania tąpnięć w kopalniach węgla kamiennego. (Rockburst Occurrence Conditions in Hard Coal Mines). Przegląd Górniczy, Nr 1/2008, str. 12-17. Katowice, 2008

KONOPKO W.: Doświadczalne podstawy kwalifikowania wyrobisk górniczych w kopalniach węgla kamiennego do stopni zagrożenia tąpaniami. (Experimental Principles of Classifying Excavations in Hard Coal Mines by Degrees of Rockburst Hazard). Prace Naukowe GIG, Nr 795, Katowice, 1994

KONOPKO W.: Głębokość eksploatacji a zagrożenia tąpaniami. (Mining Depth and Rockburst Hazard). Przegląd Górniczy Nr 11/12, 1987

KONOPKO W.: Stan i przyczyny zagrożenia tąpaniami w kopalniach węgla kamiennego Górnośląskiego Zagłębia Węglowego. (State and Causes of Rockburst Hazard in the Upper Silesian Coal Basin Hard Coal Mines). Bezpieczeństwo Pracy w Górnictwie Nr 3, 1984

KONOPKO W.: Wyrobiska – nie pokłady – zagrożenie tąpaniami. Podstawy nowelizacji przepisów. (Mine Workings – Coal Seams – Rockbursts Hazard. Foundations for the Amendments to Regulations). Bezpieczeństwo pracy i ochrony środowiska w górnictwie. Nr 8, 2006

PATYŃSKA R., (1987-2007): Bank danych o tąpaniach. (Data Bank on Rockbursts). Dokumentacje prac planowych GIG z lat 1987-2007. Archiwum Zakładu Tąpań i Mechaniki Górotworu GIG, Katowice

PATYŃSKA R., (2004): Tąpania a tektonika GZW. (Rockbursts and Tectonics of the Upper Silesian Coal Basin). XXVII Zimowa Szkoła Mechaniki Górotworu, Kraków, str. 741-753.

PATYŃSKA R.: Zagrożenie tąpaniami. Raport roczny (za lata 1992-2007) o stanie podstawowych zagrożeń naturalnych i technicznych w górnictwie węgla kamiennego. (Rockbursts Hazard. Annual Report (for the years 1992-2007) on the State of Basin natural and Technical Hazards in the Hard Coal Mining Industry). Praca Głównego Instytutu Górnictwa, pod kierunkiem W. Konopko, Katowice 1992-2007.

STEC K.: Aktywność sejsmiczna Górnośląskiego Zagłębia Węglowego – 30 lat ciągłej obserwacji przez Górnośląską Regionalną Sieć Sejsmologiczną. (Seismicity of the Upper Silesian Coal Basin – 30 Years of Continuous Observations Carried out by the Upper Silesian Regional Seismic Network). Przegląd Górniczy Nr 7-8, 2007

TRENCZEK S.: Charakterystyka akcji przeciwpożarowych w kopalniach węgla kamiennego w okresie lat 1997-2006. (Characteristic of Fire- Fighting Actions in Hard Coal Mines during the Years 1997-2006). Materiały XXIV Seminarium naukowo–technicznego na temat: Ratownictwo Górnicze - Teoria i Praktyka. XXXIII Dni Techniki ROP 2007. Rybnik, 24.10.2007. Wyd. WGiG Pol. Śl., Gliwice 2007

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