Depth of the mining exploitation and its progress in the time, and a random dispersion of observed terrain subsidence and their derivatives

J Orwat
Silesian University of Technology, Department of Mining and Geology, Akademicka str., no. 2, 44-100 Gliwice, Poland
E-mail: justyna.orwat@polsl.pl

Abstract. Paper presents the own research results conducted on shaping of random dispersion of the observed deformation indicators of mining terrain, especially subsidence and their derivatives such as inclinations and curvatures. Research were carried out on two examples of the underground mining exploitation, which was done at the small and medium depths. In both cases exploitation took place in an intact rock mass and in the one seam. Hard coal was extracted by the use of the longwall system with a roof rocks cave-in. Exploitation influences were observed after termination of the next exploitation stages and on the two measuring lines, which were stabilized perpendicularly to the longwalls runs. There were calculated the values of the variability coefficients of a random dispersion of the measured deformation indicators depending on an exploitation development in the time and a depth of the performed works. Generally, it can be said that a random dispersion of deformation process of terrain surface grows together with an exploitation depth and an increase its scope, what is especially visible in case of curvatures.

1. Introduction
In each graph of measured deformation indicator can be separated two ingredients, namely the deterministic part and the random part. The second part causes some irregularities in the measured graph of deformation indicator and their occurrence is connected with the cracks of a subsurface layer of rock mass [1].

Topic of a random dispersion in the observed values of deformation indicators (subsidence, inclinations [2], curvatures [3], horizontal displacements [4] and horizontal strains) is widely undertaken in the literature. Researchers are especially interested in the functions approximating an average graph of the measured deformation indicators [5 – 8] and the values of a random dispersion variability coefficient [9 – 12].

In the article have been presented the values of variability coefficient of random dispersion of subsidence, inclinations and curvatures, which have been measured at the geodesic points of two observational lines. These lines have been stabilized on terrain surface located above the eight longwalls and perpendicularly to their runs. Underground mining exploitation of hard coal deposits has been conducted by two different hard coal mines in two seams located at the small and medium depths, and in rock mass intact by other exploration. Random dispersion of measured subsidence and their derivatives has been determined for each exploitation stage (after an exploitation end of subsequent longwalls) and for a changeable depth of exploitation. On the base of made calculations, it was possible
to determine an influence of exploitation development in the time and extraction depth on random dispersion of measured graphs of deformation indicators.

2. Exploitation cases

2.1. Exploitation in the 354 seam at the small depth

Exploitation of the 354 hard coal seam was conducted at the small depth of 285 m by some mining plant located in Poland [13 – 15].

Extraction of hard coal was carried out in the years 1968 – 1971, in an intact rock mass. There was used a longwall system with the fall of roof rocks to the post-mining emptiness. Exploitation took place by the use of four longwalls respectively numbered 1, 2, 3 and 4. The average dimensions of longwalls were amounted 210 m x 770 m. Excavations were conducted at the height of 1.7 m and hard coal seam was located almost horizontally (2° of inclination).

Data, which characterize the exploitation in the 354 hard coal seam, have been juxtaposed in the table 1.

2.2. Exploitation in the 338/2 seam at the medium depth

Some hard coal mine, which is located in the Upper Silesian Coal Basin in Poland, conducted an exploitation of the 338/2 seam at the medium depth of 650 m [16].

Hard coal exploitation took place in the years 1994 – 1996 and was conducted in an intact rock mass. Coal extraction was carried out by the use of the longwall system with a cave-in of roof rocks. There have been four longwalls numbered as 001, 002, 005 and 007. Average length of longwalls was close to 250 m and average run of longwalls was close to 920 m. Height of the excavations was amounted to 2 m. An angle of the seam inclination was amounted 7°.

Basic information about an exploitation of the 338/2 hard coal seam have been presented in the table 1.

| Coal seam          | 354   | 338/2  |
|--------------------|-------|--------|
| Time [years]       | 1968 ÷ 1971 | 1994 ÷ 1996 |
| Exploitation system| the longwall system | the longwall system |
| Fulfillment of emptiness | a roof rocks cave-in | a roof rocks cave-in |
| Numbers of longwalls | 1, 2, 3, 4 | 001, 002, 005, 007 |
| Interval of depth [m] | 270 ÷ 300 | 580 ÷ 700 |
| Longwalls length [m] | 210 | 250 |
| Longwalls run [m]   | 560 ÷ 970 | 750 ÷ 1080 |
| Thickness [m]       | 1.7 | 2.0 |
| Decline [°]         | 2 | 6 ÷ 8 |

3. Surveys

3.1. Surveys on the 1A measuring line

Influences coming from an exploitation of the 354 coal seam were measured on the 1A observational line. It was consisted of 46 measuring points which were stabilized perpendicularly to the runs of longwalls 1, 2, 3 and 4. The average length of the measuring segments was equal 25 m.

There were carried out the measurements of points heights and distances between these points. The points heights were measured by the use of a precise leveller and the invar laths. Lengths surveys were done by the use of an invar wire.

Geodesic surveys have been done after each exploitation stage. Therefore have been obtained four graphs for subsidence, inclinations and curvatures (after first longwall, after two longwalls, after three longwalls and after four longwalls).

Information about configuration of an observational line no. 1A contains the table 2.
3.2. Surveys on the 1 measuring line

Subsidence, inclinations and curvatures of mining terrain caused by exploitation of the 338/2 coal seam were measured on the observational line number 1. This line was consisted of 53 measuring points and was established perpendicularly to the longwalls runs. The average distance between subsequent points of line was amounted about 37 m.

The points heights measurements were carried out by the use of a precise leveller with an accuracy of 0.1 mm. There was used a geometric levelling from the middles of line sections with double targeting. Surveys of segments lengths were conducted with the use of a distance-meter device with an accuracy of 1 mm.

The points heights and the sections lengths have been done in the same time and after the end of the next exploitation stages. That’s why have been obtained four graphs for each deformation indicator: after the 001 longwall; after the 001 and 002 longwalls; after the termination of exploitation in longwalls number 001, 002 and 005; after an exploitation end of the longwalls 001, 002, 005 and 007.

Table 2 presents the data about the geometry of a measuring line number 1.

| Measuring line | IA | I |
|----------------|----|---|
| Location in relation to the longwalls | perpendicularly | perpendicularly |
| Number of measuring points | 46 | 53 |
| Distance between points [m] | 20 ÷ 30 | 15 ÷ 60 |

4. Results of surveys

4.1. Observed graphs of subsidence

On the base of differences of points heights measured before and after the end of subsequent exploitation stages, there were calculated the subsidence values in each measuring point:

\[ S_{i}^{\text{meas}} = H_{i}^{A} - H_{i}^{B} \]  \hspace{1cm} (1)

where:

- \( H_{i}^{A} \) – absolute height of the \( i \) point after an exploitation end [m];
- \( H_{i}^{B} \) – absolute height of the \( i \) point before an exploitation beginning [m];
- \( S_{i}^{\text{meas}} \) – measured subsidence of the \( i \) point [mm].

The subsidence graphs, which were observed at the points of measuring line no. 1A after an exploitation termination in: the 1 longwall, the 1 and 2 longwalls, the 1, 2 and 3 longwalls, the 1, 2, 3 and 4 longwalls, have been shown at the figure 1.

Subsidence measured at the observational line no. 1 after an exploitation end in: the 001 longwall, the 001 and 002 longwalls, the 001, 002 and 005 longwalls, the 001, 002, 005 and 007 longwalls, have been shown at the figure 4.

The maximal values of subsidence measured at the 1A and 1 lines have been juxtaposed in the table 4.

4.2. Observed graphs of inclinations

Observed values of inclinations were calculated as a difference of subsidence measured in the \( i+1 \) and \( i \) points divided by measured length between the \( i \) and \( i+1 \) points:

\[ I_{i,i+1}^{\text{meas}} = \frac{S_{i+1}^{\text{meas}} - S_{i}^{\text{meas}}}{L_{i,i+1}^{\text{meas}}} \]  \hspace{1cm} (2)

where:

- \( I_{i,i+1}^{\text{meas}} \) – measured inclination of the \( i,i+1 \) segment [mm/m];
The inclinations graphs, which were observed at the sections of measuring line no. 1A after an exploitation end in: the 1 longwall, the 1 and 2 longwalls, the 1, 2 and 3 longwalls, the 1, 2, 3 and 4 longwalls, have been shown at the figure 2.

Inclinations measured at the segments of observational line no. 1 after an exploitation termination in: the 001 longwall, the 001 and 002 longwalls, the 001, 002 and 005 longwalls, the 001, 002, 005 and 007 longwalls, have been shown at the figure 5.

The extreme values of inclinations measured at the 1A and 1 observational lines have been presented in the table 4.

4.3. Observed graphs of curvatures

The curvatures values, which were observed at two neighbouring sections of the measuring lines, were calculated as a subsidence difference of three neighbouring points divided by an average length of these sections:

\[
C_{i,-1,i+1}^{\text{meas}} = 2 \frac{S_{i+1}^{\text{meas}} - 2S_i^{\text{meas}} + S_{i-1}^{\text{meas}}}{L_{i-1,i+1}^{\text{meas}}} \quad (3)
\]

where:

- \(C_{i,-1,i+1}^{\text{meas}}\) – measured curvature of the i-1,i and i,i+1 segments \([10^{-6} \cdot 1/m]\);
- \(L_{i-1,i+1}^{\text{meas}}\) – measured length of the i-1,i and i,i+1 segments \([m]\);
- \(S_i^{\text{meas}}\) – measured subsidence of the i-1, i and i+1 points \([mm]\).

The curvatures graphs, which were observed at the neighbouring segments of the 1A measuring line after an exploitation ending in: the 1 longwall, the 1 and 2 longwalls, the 1, 2 and 3 longwalls, the 1, 2, 3 and 4 longwalls, have been presented at the figure 3.

Curvatures observed at the neighbouring segments of the 1 measuring line after an exploitation end in: the 001 longwall, the 001 and 002 longwalls, the 001, 002 and 005 longwalls, the 001, 002, 005 and 007 longwalls, have been shown at the figure 6.

The curvatures extreme values observed at the 1A and 1 measuring lines have been juxtaposed in the table 4.

5. Average graphs of measured deformation indicators

To calculate the values of variability coefficient of random dispersion, it’s necessary to determine the average graphs of measured deformation indicators and the average values of extreme, observed deformation indicators.

5.1. Average graphs of observed subsidence

Average values of subsidence measured at the points of the 1A, 1 observational lines and after the end of subsequent exploitation stages in the 354, 338/2 hard coal seams, have been obtained by the use of the least squares method. Approximation of average graphs of measured subsidence has been done by the use of smoothed splines [17]. It has been used the R computer programme and its function named ‘smooth.spline’. This function uses the following parameters:

- \(df\) – number of the freedom degree assuming the values from 0 to \(n\), where \(n\) is number of measuring points;
- \(spar\) – smoothing parameter of approximating function assuming the values from 0 to 1, where 0 denotes a total lack of smoothing and approximating function assumes the form of approximated function;
- \(\lambda\) – penalized criterion;
- $cv$ – cross validation, when $cv = truth$ then occurs the leave-one-out validation, if $cv = false$ then occurs the general cross validation ($GCV$).

In the table 3 have been juxtaposed the values of parameters of the smooth.spline function which has been used to determination of average graphs of subsidence observed at the measuring lines and after the specified stages of exploitation. This table also contains the values of matching measurer of the average subsidence graphs to the measured subsidence graphs namely a correlation coefficient.

### Table 3. The parameters values of the smooth.spline function.

| Exploitation stage                      | df  | spar      | $\lambda$ | GCV    | $R_s$ |
|-----------------------------------------|-----|-----------|-----------|--------|-------|
| After one longwall                      | 23  | 0.27      | $1.39 \cdot 10^6$ | 151.25 | 0.9999 |
| After two longwalls                     | 16  | 0.40      | $1.01 \cdot 10^5$ | 1148.60 | 0.9995 |
| After three longwalls                   | 18  | 0.42      | $7.49 \cdot 10^6$ | 1169.78 | 0.9996 |
| After four longwalls                    | 17  | 0.47      | $1.13 \cdot 10^5$ | 2124.79 | 0.9990 |
| Exploitation stage                      |     |           |           |        |       |
| After one longwall                      | 19  | 0.37      | $4.64 \cdot 10^6$ | 75.56  | 0.9997 |
| After two longwalls                     | 18  | 0.40      | $6.38 \cdot 10^6$ | 245.75 | 0.9998 |
| After three longwalls                   | 18  | 0.46      | $8.77 \cdot 10^6$ | 604.97 | 0.9996 |
| After four longwalls                    | 13  | 0.55      | $3.92 \cdot 10^5$ | 1541.09 | 0.9988 |

From the data juxtaposed in the table 3 result that a quality of matching of subsidence average graphs to their measured graphs generally decreases with an increase of exploitation range, what is confirmed by:

- the decreasing values of freedom degree number and correlation coefficient between the average and measured values of subsidence;
- the growing values of smoothing parameter, penalized criterion and general cross validation.

Average graphs of measured subsidence obtained on the way of approximation have been shown at the figures 1 and 4, and the average values of maximal, observed subsidence have been juxtaposed in the table 4.

### 5.2. Average graphs of observed inclinations

Average values of inclinations measured at the sections of the $1A$, $I$ observational lines and after the termination of next exploitation stages in the $354$, $338/2$ hard coal seams, have been calculated from the average values of measured subsidence, by the use of the formula (2) [18].

Average graphs of observed inclinations have been presented at the figures 2 and 5, and the average values of extreme, measured inclinations have been shown in the table 5.

### 5.3. Average graphs of observed curvatures

Average values of curvatures measured at two neighbouring segments of the $1A$, $I$ observational lines and after the ending of following exploitation stages in the $354$, $338/2$ hard coal seams, have been calculated on base of the average values of measured subsidence, from the formula (3) [7, 19 – 21].

Average graphs of observed curvatures have been shown at the figures 3 and 6, and the average values of extreme, measured curvatures have been presented in the table 6.
Figure 1. Measured and average graphs of subsidence at the measuring line no. 1A after the end of subsequent exploitation stages in the 354 hard coal seam.

Figure 2. Measured and average graphs of inclinations at the measuring line no. 1A after the end of subsequent exploitation stages in the 354 hard coal seam.

Figure 3. Measured and average graphs of curvatures at the measuring line no. 1A after the end of subsequent exploitation stages in the 354 hard coal seam.

Figure 4. Measured and average graphs of subsidence at the measuring line no. 1 after the end of subsequent exploitation stages in the 338/2 hard coal seam.

Figure 5. Measured and average graphs of inclinations at the measuring line no. 1 after the end of subsequent exploitation stages in the 338/2 hard coal seam.

Figure 6. Measured and average graphs of curvatures at the measuring line no. 1 after the end of subsequent exploitation stages in the 338/2 hard coal seam.
Table 4. Measured and average values of extreme subsidence.

| Subsidence | $S^\text{meas}_{\text{max}}$ [mm] | $S^\text{aver}_{\text{max}}$ [mm] |
|------------|----------------------------------|----------------------------------|
| Exploitation stage the 1A line |
| After one longwall | -1310 | -1304 |
| After two longwalls | -1608 | -1597 |
| After three longwalls | -1650 | -1640 |
| After four longwalls | -1697 | -1682 |
| Exploitation stage the 1 line |
| After one longwall | -575 | -564 |
| After two longwalls | -1315 | -1326 |
| After three longwalls | -1518 | -1506 |
| After four longwalls | -1568 | -1568 |

Table 5. Measured and average values of extreme inclinations.

| Inclination | $I^\text{meas}_{\text{max}}$ [mm/m] | $I^\text{aver}_{\text{max}}$ [mm/m] | $I^\text{meas}_{\text{min}}$ [mm/m] | $I^\text{aver}_{\text{min}}$ [mm/m] |
|-------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| Exploitation stage the 354 coal seam (the 1A line) |
| After one longwall | 13.72 | 13.29 | -13.87 | -13.40 |
| After two longwalls | 13.37 | 11.19 | -14.77 | -13.17 |
| After three longwalls | 13.32 | 11.66 | -14.93 | -13.24 |
| After four longwalls | 11.69 | 9.14 | -14.77 | -12.10 |
| Exploitation stage the 338/2 coal seam (the 1 line) |
| After one longwall | 3.49 | 3.35 | -3.68 | -3.47 |
| After two longwalls | 5.52 | 5.22 | -7.48 | -6.90 |
| After three longwalls | 4.54 | 4.18 | -7.85 | -6.85 |
| After four longwalls | 4.77 | 3.45 | -7.92 | -5.98 |

Table 6. Measured and average values of extreme curvatures.

| Curvature | $C^\text{meas}_{\text{max}}$ [$10^6$ 1/m] | $C^\text{aver}_{\text{max}}$ [$10^6$ 1/m] | $C^\text{meas}_{\text{min}}$ [$10^6$ 1/m] | $C^\text{aver}_{\text{min}}$ [$10^6$ 1/m] |
|-----------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| Exploitation stage the 354 coal seam (the 1A line) |
| After one longwall | 287.40 | 278.54 | -191.84 | -185.45 |
| After two longwalls | 235.79 | 187.11 | -199.47 | -158.58 |
| After three longwalls | 267.08 | 185.56 | -196.48 | -153.48 |
| After four longwalls | 253.16 | 147.39 | -190.02 | -118.17 |
| Exploitation stage the 338/2 coal seam (the 1 line) |
| After one longwall | 82.63 | 67.30 | -37.52 | -27.86 |
| After two longwalls | 91.48 | 67.29 | -62.79 | -43.99 |
| After three longwalls | 91.08 | 53.63 | -67.37 | -39.32 |
| After four longwalls | 86.67 | 37.10 | -71.00 | -31.80 |

6. Variability coefficient of random dispersion of measured deformation indicators

Variability coefficient of random dispersion shows, how big are fluctuations of graph of measured deformation indicator caused by a random factor.

Value of random dispersion variability coefficient is expressed as a percentage and calculated as a quotient of deformation indicator standard deviation and modulus of average value of extreme, measured deformation indicator:
$$M_D = \frac{\sigma_D}{D_{\text{extr} \text{av}}} \cdot 100\%$$  \hspace{1cm} (4)$$

where:

- $\sigma_D$ – standard deviation of the $D$ deformation indicator;
- $D_{\text{extr} \text{av}}$ – average value of extreme, measured the $D$ deformation indicator;
- $M_D$ – random dispersion variability coefficient of the $D$ deformation indicator.

In the table 7 have been presented the values of variability coefficients of random dispersion which have been calculated for the graphs of deformation indicators noted at the measuring lines no. $IA$, $I$ and after the end of next exploitation stages in the $354$, $338/2$ hard coal seams.

**Table 7.** Random dispersion variability coefficients of the measured deformation indicators.

| Variability coefficient | $M_S$ [%] | $M_I$ [%] | $M_C$ [%] |
|-------------------------|-----------|-----------|-----------|
| **Exploitation stage**  | **the $354$ coal seam (the $IA$ measuring line)** | | |
| After one longwall       | 0.28      | 1.24      | 3.26      |
| After two longwalls      | 1.18      | 5.23      | 12.96     |
| After three longwalls    | 1.23      | 5.51      | 13.84     |
| After four longwalls     | 1.83      | 8.93      | 20.10     |
| Average value            | 1.13      | 5.23      | 12.54     |
| **Exploitation stage**  | **the $338/2$ coal seam (the $I$ measuring line)** | | |
| After one longwall       | 0.76      | 3.64      | 5.78      |
| After two longwalls      | 0.65      | 3.71      | 10.67     |
| After three longwalls    | 1.05      | 7.08      | 27.22     |
| After four longwalls     | 1.88      | 10.37     | 37.59     |
| Average value            | 1.09      | 6.20      | 20.32     |
| **Average value for 2 lines** | 1.11      | 5.72      | 16.43     |

Values of variability coefficients of random dispersion of the measured deformation indicators presented in the table 7 indicate that the least random dispersion occurs in case of the observed subsidence (is equal to about 1 %) and the observed curvatures are characterized by the largest random dispersion (middling is equal to 16.5 %). The random dispersion of inclinations is contained in the interval between a subsidence random dispersion and a curvatures random dispersion (is equal to about 6 %). On the base of this it can be said that the random dispersion of measured deformation indicators increases with an increase of an order of subsidence derivative.

It can be seen that a random dispersion of the observed deformation indicators generally grows after the end of exploitation of next longwalls. So it can be said that an exploitation range is a factor which determines the value of random dispersion variability coefficient.

Average values of variability coefficients of random dispersion of the measured deformation indicators, calculated for the $I$ measuring line and for an exploitation of the $338/2$ hard coal seam which was conducted at the medium depth, generally are greater than the values of these coefficients which have been calculated for the $IA$ measuring line and for an exploitation of the $354$ hard coal seam which was located at the small depth. It shows that a random dispersion of the observed deformation indicators increases with an exploitation depth.

It should be emphasized that obtained values of variability coefficients of random dispersion of measured subsidence, inclinations and curvatures are smaller than their values which occur in the literature [12].
7. Summary and conclusions
In the article have been presented two examples of hard coal exploitations which have been realized by two mines located in the Upper Silesian Coal Basin, in Poland. Both exploitations were conducted in an intact rock mass and in one seam but at different depths, namely at the small and medium depths. Hard coal extraction was carried out by the use of the longwall system with a roof rocks cave-in.

For purpose of observation of the mining exploitation influences on terrain surface, there have been taken the geodesic measurements at the observational lines. These lines have been stabilized perpendicularly to the longwalls runs. On the base of points heights and sections lengths measured before and after termination of the subsequent exploitation stages, there have been calculated the values of subsidence, inclinations and curvatures.

In order to determination of average graphs of observed deformation indicators, it has been done an approximation of subsidence by the use of the least squares method and the smoothed splines. Average graphs of measured inclinations and curvatures have been determined from an average graph of measured subsidence.

The results of conducted approximation are inter alia the average values of extreme, measured deformation indicators which are necessary to obtainment of the values of variability coefficients of random dispersion of observed deformation indicators.

As a result of the values calculations of these coefficients conducted for the various stages and depths of exploitation, it can be said that:

- a random dispersion of deformation process of terrain surface grows with an increase of the exploitation depth and range;
- a random dispersion of measured deformation indicators increases with an increase of an order of subsidence derivative.

8. References
[1] Kowalski A and Jędrzejec E 2015 Archives of Mining Sciences 60(2) 487
[2] Orwat J 2017 17th International Multidisciplinary Scientific GeoConference SGEM vol. 17 (Bulgaria – Albena) p 289
[3] Orwat J 2017 17th International Multidisciplinary Scientific GeoConference SGEM vol. 17 (Bulgaria – Albena) p 979
[4] Sikora P 2016 Archives of Mining Sciences 61(4) 749
[5] Stoch T, Niedojadło Z, Sopata P and Moskała S 2014 Mining Review 70(8) 113
[6] Popiołek E, Ostrowski J and Milewski M 1995 Mining Review 1(11) 1
[7] Orwat J 2018 IOP Conf. Ser. – Materials Science and Engineering vol. 294 pp 012030-1 – 012030-10
[8] Orwat J and Mielińska R 2018 AIP Conf. Proc. vol. 1978 pp. 390005-1 – 390005-4
[9] Popiołek E and Ostrowski J 1981 Ochrona Terenów Górzniczych 58
[10] Popiołek E and Ostrowski J 2005 Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie vol. 2 p 3
[11] Stoch T 2005 Wpływ Warunków Geologiczno – Górniczych Eksploatacji Złoża na Losowość Procesu Przemieszczeń i Deformacji Powierzchni Terenu Praca Doktorska Niepublikowana (Kraków: Akademia Górnico – Hutnicza)
[12] Kowalski A 2007 Nieustalone Górnicze Deformacje Powierzchni w Aspekcie Dokładności Prognoz (Katowice: Główny Instytut Górnictwa)
[13] Orwat J and Mielińska R 2017 AIP Conf. Proc. vol. 1863 pp. 130003-1 – 130003-4
[14] Orwat J 2017 AIP Conf. Proc. vol. 1863 pp. 130004-1 – 130004-4
[15] Mielińska R and Orwat J 2017 AIP Conf. Proc. vol. 1863 pp. 130005-1 – 130005-4
[16] Orwat J 2017 Systemy Wspomagania w Inżynierii Produkcji 6(3) 171
[17] Orwat J and Mielińska R 2018 AIP Conf. Proc. vol. 1978 pp. 390005-1 – 390005-4
[18] Orwat J 2018 IOP Conf. Ser. – Materials Science and Engineering vol. 294 pp. 012029-1 – 012029-10
Acknowledgement
The results which have been presented in this article are the effect of work financed by the Ministry of Science and Higher Education in Poland, by means of a transfer of funds designated for the statutory activity of the Silesian University of Technology in Gliwice, Faculty of Mining and Geology (project no. BKM-535/RG-5/2018 [06/050/BKM18/0064]).