Testing the possibility of using a selective crushing process for selected types of hard coal

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Abstract. The article describes the design solutions of KOMAG drum crushers. In the case of significant differences in hardness of coal and gangue, these devices are the most appropriate and the cheapest means of preliminary beneficiation of run-of-mine. The results of laboratory tests of susceptibility to selective crushing of selected hard coal types by the drop method are presented. The possibilities of using a drum crusher for deshaling the analyzed materials are determined.

1. Introduction

Hard coal run-of-mine contains a significant amount of gangue, especially in thick grain grades >80 (100) mm. The quantity of stone reaches a value of 30 to even 70% in the grain class> 50 mm [1, 2].

In order to obtain commercial assortments with desirable quantity and quality parameters of hard coal, it is necessary to undergo a series of appropriate processing processes.

The first of them is preliminary deshaling of run-of-mine, which can be done using the differences of coal and gangue density. It takes place in a pulsating water jig [2, 3, 4, 5, 6] and beneficiated with heavy liquid [2, 7] (so-called "wet" method), or using selective crushing [2, 8, 9, 10] (so-called "dry" method).

The purpose of deshaling is to prepare raw material for further beneficiation processes, while also extracting some of the large stone grains from it.

The idea of the "dry" method, known in the world mechanical processing since the early 1950s, consists in dropping the coal and stone grains from a proper height onto a hard surface. Coal and middlings grains, as less compact, break down during the fall. Concise stone grains remain intact.

The device for the process of selective crushing of the run-of-mine is a Bradford type drum crusher, which simultaneously performs processes of grinding, classification and beneficiation. The Polish equivalent of this device is KOMAG type KB drum crusher.

KOMAG KB series drum crushers are most often used for selective crushing of coking coal, characterized by significant susceptibility to crushing, in coal mechanical processing plants, equipped with water pulsating jig for a beneficiation in the broad grain class of 70 (60) -0.5 mm.

Due to the fact that the technology of stone separation in the process of selective crushing requires a significant difference in the compactness of stone and coal, the decision on its use should be preceded by tests of susceptibility to crushing of the potential feed.
The assessment of susceptibility to selective crushing should be determined on the basis of specific parameters of the run-of-mine obtained during the tests of the susceptibility of a given material to spontaneous crushing under the influence of gravity. One of the possibilities of estimating it is the "drop" method, which consists in dropping individual grains of coal and stone into a metal plate from the height close to the assumed diameter of the crusher drum.

The purpose of the article is to present the possibilities of using KB crushers in Polish processing plants.

2. Drum crushers for selective crushing of run-of-mine
Bradford type drum crushers (KOMAG) are devices using the force of gravity and the hardness difference of individual grains intended for selective crushing of hard coal. Figure 1 shows the KB 3200x6000 drum crusher.

![Figure 1. KB 3200x6000 drum crusher.](image)

The main component of the drum crusher is a drum with a horizontal axis of rotation, consisting of a cylindrical part and an inlet and outlet funnel. The cylindrical part of the drum is lined with sieve plates, and the size of the holes in the sieves depends on the technological requirements.

Inside the drum there are shelves, whose task is to move the material along the axis of the drum, while moving it up. Crushed grains, most often coal, leave the device through the holes in the lateral surface, while hard grains, most often stone, are transported along the axis of the drum and leave the device through the outlet opening at its end [10].

Table 1 lists the technical data for a series of drum crushers of KOMAG type KB.
Table 1. Technical data for drum crushers of KB type [11].

| Parameter                     | Unit | KB 2600x4000 | KB 3200x5000 | KB 3200x6000 |
|-------------------------------|------|--------------|--------------|--------------|
| Capability                    | t/h  | to 600       | to 1000      | to 1200      |
| Diameter x length of the drum | mm   | 2600x4000    | 3200x5000    | 3200x6000    |
| Diameter of plate openings    | mm   | 50, 80, 120 or 200 |           |
| Drive power                   | kW   | 45           | 55           | 55           |
| Rotational speed of the drum  | min⁻¹| 10.2 or 6.7  | 9.7 or 6.2   | 9.7 or 6.2   |
| Weight                        | kg   | 31500        | 50500        | 56000        |

Crushing machines are affected by a number of factors, among which the following ones can be distinguished:
- the way of preparing the feed,
- diameter and length of the drum,
- number and location of shelves,
- the size of the holes on the surface of the drum,
- rotational speed of the drum.

Although the process, carried out in drum crushers, is complicated and depends on a number of variables, these crushers have a number of advantages such as a very long life, an easy use and maintenance which in effect result in low machine operation costs.

At the KOMAG Institute of Mining Technology, different drum crusher versions have been developed enabling the "dry" deshaling process to be carried out directly in underground mines. The construction solutions facilitate transport and assembly in underground conditions. Assuming more difficult working conditions of the crusher in underground conditions, the drive power was increased to 75 kW [10, 11].

3. Research and tests at KOMAG

3.1. Methodology and scope of research project

Crushing susceptibility tests were performed for two types of coal from three mining plants being parts of the Ruda Mine:
- Bielszowice - type 34.2 (gas and coking coal),
- Halemba - type 34.2 (gas and coking coal),
- Pokój - type 33 (gas coal).

The tests of the run-of-mine samples were carried out at the KOMAG laboratory, using a test rig equipped with a 75 mm thick steel plate, a 810 mm high cover, and an elevation allowing the grains to be crushed by drop [12].

During the tests, using the drop method, the samples of coal and stone were dropped at random from the height of 2 m. Figures 2-4 present examples of coal and stone from the tested types of coal. Before the crushing tests, the weight and size of the primary grains > 80 mm were determined.
During the material crushing tests a series of single grains discharges were made. The series means a multiple of one grain drop > 80 mm until it is completely crushed to grains below 80 mm. The maximum number of discharges was 30.
After each drop, grains <80 mm were sieved and the grains above this size were dropped until they crushed below 80 mm or up to 30 discharges. After every 5 drops the weight of these grains was determined.

3.2. Test results

Bielszowice Mine

Material characteristics
The weight of coal grains submitted to crushing ranged from 4 kg to 20.2 kg and their sizes varied from 18 x 17 x 14 cm to 33 x 33 x 24 cm. The weight of stone grains ranged from 11.4 kg to 17.6 kg and their sizes varied from 25 x 24 x 15 cm to 45 x 27 x 10 cm.

Tests of dropping coal
The smallest number of discharges required to break up the coal grains completely was 7. In seven individual trials coal was completely crushed to <80 mm after 7, 12, 14, 16, 17, 19 and 23 discharges. In two trials, coal was broken up after 15 discharges. In a single sample, the grain was not completely crushed after 30 discharges, and 2.8% of the grains remained. The average number of coal discharges during crushing was 16.8.

The results of coal discharges are summarized in Table 2. The $W_z$ symbol indicates grain dimensions, while $M_z$ - its initial weight.

| Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|----------|----------|----------|----------|----------|
| $W_z = 31 \times 31 \times 19$ cm | $W_z = 28 \times 22 \times 20$ cm | $W_z = 38 \times 24 \times 22$ cm | $W_z = 33 \times 33 \times 24$ cm | $W_z = 29 \times 27 \times 13$ cm |
| $M_z = 14.39$ kg | $M_z = 9.19$ kg | $M_z = 15.99$ kg | $M_z = 20.18$ kg | $M_z = 8.05$ kg |

| Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % |
|----------------------|-----------|----------------------|-----------|----------------------|-----------|----------------------|-----------|----------------------|-----------|----------------------|-----------|
| 0                    | 100.0     | 0                    | 100.0     | 0                    | 100.0     | 0                    | 100.0     | 0                    | 100.0     | 0                    | 100.0     |
| 5                    | 68.3      | 5                    | 39.9      | 5                    | 58.4      | 5                    | 36.4      | 5                    | 66.1      |
| 10                   | 26.1      | 10                   | 13.9      | 10                   | 9.4       | 10                   | 9.0       | 10                   | 39.6      |
| 15                   | 11.7      | 12                   | -         | 14                   | -         | 15                   | -         | 15                   | 18.6      |
| 20                   | 4.9       |                      |           |                      |           |                      |           |                      |           |
| 25                   | 3.9       |                      |           |                      |           |                      |           |                      |           |
| 30                   | 2.8       |                      |           |                      |           |                      |           |                      |           |

| Sample 6 | Sample 7 | Sample 8 | Sample 9 | Sample 10 |
|----------|----------|----------|----------|-----------|
| $W_z = 32 \times 23 \times 14$ cm | $W_z = 32 \times 28 \times 20$ cm | $W_z = 18 \times 17 \times 14$ cm | $W_z = 33 \times 28 \times 19$ cm | $W_z = 28 \times 28 \times 17$ cm |
| $M_z = 9.42$ kg | $M_z = 15.78$ kg | $M_z = 3.96$ kg | $M_z = 14.87$ kg | $M_z = 7.14$ kg |

| Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % |
|----------------------|-----------|----------------------|-----------|----------------------|-----------|----------------------|-----------|----------------------|-----------|
| 0                    | 100.0     | 0                    | 100.0     | 0                    | 100.0     | 0                    | 100.0     | 0                    | 100.0     |
| 5                    | 26.1      | 5                    | 27.8      | 5                    | 11.6      | 5                    | 35.5      | 5                    | 35.2      |
| 10                   | 10.4      | 10                   | 6.8       | 7                    | -         | 10                   | 17.5      | 10                   | 16.9      |
| 15                   | -         | 15                   | 4.2       | 15                   | 0.6       | 15                   | 5.0       |
| 20                   | 3.9       |                      |           | 16                   | -         | 17                   | -         |

Tests of dropping stones
In none of the 5 trials, the stone below 80 mm after 30 discharges was crushed. Weight loss of stone over 80 mm was about 26%. The results are shown in Table 3.
The results of coal discharges are summarized in Table 4.

| Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|----------|----------|----------|----------|----------|
| W<sub>c</sub>=24x22x14 cm | W<sub>c</sub>=25x24x15 cm | W<sub>c</sub>=27x24x15 cm | W<sub>c</sub>=31x25x11 cm | W<sub>c</sub>=45x27x10 cm |
| M<sub>c</sub>=17.60 kg | M<sub>c</sub>=11.37 kg | M<sub>c</sub>=19.61 kg | M<sub>c</sub>=14.99 kg | M<sub>c</sub>=12.71 kg |

| Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % |
|----------------------|----------|----------------------|----------|----------------------|----------|----------------------|----------|----------------------|----------|
| 0                    | 100.0    | 0                    | 100.0    | 0                    | 100.0    | 0                    | 100.0    | 0                    | 100.0    |
| 5                    | 93.9     | 5                    | 78.6     | 5                    | 99.5     | 5                    | 98.2     | 5                    | 86.9     |
| 10                   | 92.0     | 10                   | 58.0     | 10                   | 97.9     | 10                   | 97.0     | 10                   | 77.4     |
| 15                   | 91.3     | 15                   | 53.6     | 15                   | 97.0     | 15                   | 82.8     | 15                   | 74.9     |
| 20                   | 90.8     | 20                   | 36.9     | 20                   | 96.1     | 20                   | 82.2     | 20                   | 70.7     |
| 25                   | 88.5     | 25                   | 33.6     | 25                   | 95.1     | 25                   | 81.9     | 25                   | 69.7     |
| 30                   | 80.9     | 30                   | 32.6     | 30                   | 93.5     | 30                   | 79.9     | 30                   | 63.7     |

### Halemba Mine

**Material characteristics**

The weight of coal grains submitted to crushing ranged from 7.8 kg to 21 kg and their sizes varied from 28 x 24 x 15 cm to 44 x 34 x 24 cm. The weight of stone grains ranged from 15.4 kg to 38.6 kg and their sizes varied from 40 x 21 x 16 cm to 66 x 24 x 14 cm.

**Tests of dropping coal**

The smallest number of discharges required to break up the coal grains completely was 5. In four trials, coal was broken up after 7 discharges. In seven individual trials coal was completely crushed to <80 mm after 5, 9, 12, 13, 14, 17 and 18 discharges. The average of the number of coal discharges during crushing was 9.9. The results of coal discharges are summarized in Table 4.

| Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|----------|----------|----------|----------|----------|
| W<sub>c</sub>=31x26x16 cm | W<sub>c</sub>=43x34x24 cm | W<sub>c</sub>=30x20x18 cm | W<sub>c</sub>=28x24x15 cm | W<sub>c</sub>=34x28x18 cm |
| M<sub>c</sub>=12.27 kg | M<sub>c</sub>=21.00 kg | M<sub>c</sub>=9.66 kg | M<sub>c</sub>=7.66 kg | M<sub>c</sub>=19.01 kg |

| Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % |
|----------------------|----------|----------------------|----------|----------------------|----------|----------------------|----------|----------------------|----------|
| 0                    | 100.0    | 0                    | 100.0    | 0                    | 100.0    | 0                    | 100.0    | 0                    | 100.0    |
| 5                    | 93.9     | 5                    | 78.6     | 5                    | 99.5     | 5                    | 98.2     | 5                    | 86.9     |
| 10                   | 92.0     | 10                   | 58.0     | 10                   | 97.9     | 10                   | 97.0     | 10                   | 77.4     |
| 15                   | 91.3     | 15                   | 53.6     | 15                   | 97.0     | 15                   | 82.8     | 15                   | 74.9     |
| 20                   | 90.8     | 20                   | 36.9     | 20                   | 96.1     | 20                   | 82.2     | 20                   | 70.7     |
| 25                   | 88.5     | 25                   | 33.6     | 25                   | 95.1     | 25                   | 81.9     | 25                   | 69.7     |
| 30                   | 80.9     | 30                   | 32.6     | 30                   | 93.5     | 30                   | 79.9     | 30                   | 63.7     |
Tests of dropping stone

In three trials, the stone was completely crushed to <80 mm after 14, 27, and 29 discharges. In two attempts, the stone was partly crushed. Weight loss of grain class> 80 mm was about 94%. The results are shown in Table 5.

Table 5. Tests of dropping stone - Halemba Mine [12].

| Sample | Weight, kg | Number of discharges | Weight, % |
|--------|------------|----------------------|-----------|
| Sample 1 | W = 34x32x23 cm, M = 19.90 kg | 0 | 100.0 |
| Sample 2 | W = 66x17x11 cm, M = 16.63 kg | 5 | 60.4 |
| Sample 3 | W = 66x29x14 cm, M = 38.61 kg | 10 | 32.2 |
| Sample 4 | W = 40x21x16 cm, M = 15.37 kg | 15 | 14.4 |
| Sample 5 | W = 41x32x21 cm, M = 31.12 kg | 20 | 3.4 |

Pokój Mine

Material characteristics

The weight of coal grains submitted to crushing ranged from 4 kg to 21.4 kg and their sizes varied from 30 x 21 x 9 cm to 36 x 24 x 19 cm. The weight of stone grains ranged from 5.3 kg to 25.8 kg and their sizes varied from 24 x 24 x 7 cm to 44 x 22 x 19 cm.

Tests of dropping coal

The smallest number of discharges required to completely break up the coal grains was 14. In five individual trials coal was completely crushed to <80 mm after 7, 9, 10, 12, 15, 27 and 29 discharges. In two trials, coal was broken up after 13 discharges. In a single sample, the grain was not completely crushed after 30 discharges, and 5.8% of the grains remained. The average number of coal discharges during crushing was 16.5. The results of coal discharges are summarized in Table 6.

Table 6. Attempts to dislodge coal – Pokój Mine [12].

| Sample | Weight, kg | Number of discharges | Weight, % |
|--------|------------|----------------------|-----------|
| Sample 1 | W = 57x21x19 cm, M = 16.31 kg | 0 | 100.0 |
| Sample 2 | W = 25x25x20 cm, M = 11.26 kg | 5 | 8.8 |
| Sample 3 | W = 18x15x13 cm, M = 3.23 kg | 10 | 9.0 |
| Sample 4 | W = 26x20x19 cm, M = 10.18 kg | 15 | 15.0 |
| Sample 5 | W = 27x27x11 cm, M = 5.89 kg | 20 | 20.0 |
The average values of discharges were calculated. The calculations included the function of the number of discharges for the tested run-of-mine material (coal, stone), average values of discharges were calculated. The calculations included the weight of analyzed grains. In order to compare the susceptibility to crushing, the class 80 mm output was analyzed as a function of the number of discharges for the tested run-of-mine. For each tested material (coal, stone), average values of discharges were calculated. The calculations included the weight of analyzed grains. The results of the calculations are collected in Table 8 and illustrated graphically in Figures 5-7.

### Table 7. Attempts to dislodge the stone – Pokój Mine [12].

| Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|----------|----------|----------|----------|----------|
| $W_r = 44 \times 22 \times 19$ cm | $W_r = 24 \times 24 \times 7$ cm | $W_r = 26 \times 16 \times 8$ cm | $W_r = 33 \times 24 \times 14$ cm | $W_r = 23 \times 23 \times 18$ cm |
| $M_r \geq 25.76$ kg | $M_r \geq 5.31$ kg | $M_r \geq 5.53$ kg | $M_r \geq 20.32$ kg | $M_r \geq 15.49$ kg |

| Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % | Number of discharges | Weight, % |
|----------------------|-----------|----------------------|-----------|----------------------|-----------|----------------------|-----------|----------------------|-----------|
| 0                    | 100.0     | 0                    | 100.0     | 0                    | 100.0     | 0                    | 100.0     | 0                    | 100.0     |
| 5                    | 93.0      | 5                    | 22.4      | 5                    | 36.9      | 5                    | 96.5      | 5                    | 80.0      |
| 10                   | 65.8      | 10                   | -         | 10                   | 19.9      | 10                   | 90.0      | 10                   | 43.5      |
| 15                   | 58.5      | 15                   | 18.6      | 15                   | 87.3      | 15                   | 29.1      |                     |           |
| 20                   | 55.4      | 17                   | -         | 20                   | 77.1      | 20                   | 15.9      |                     |           |
| 25                   | 39.9      | 25                   | 71.4      | 25                   | 69.2      | 25                   | 12.1      |                     |           |
| 30                   | 29.3      | 30                   | 69.2      | 30                   | 4.7       |                     |           |                     |           |

### Table 8. Class 80-0 mm products depending on the number of discharges [12].

| Number of discharges | Bielszowice Mine | Halemia mine | Pokój Mine |
|----------------------|------------------|-------------|------------|
|                      | Coal, %          | Stone, %    | Coal, %    | Stone, %   | Coal, % | Stone, % |
| 0                    | 0                | 0           | 0          | 0          | 0       | 0        |
| 5                    | 57.5             | 7.3         | 88.0       | 36.9       | 73.9    | 18.3     |
| 10                   | 85.4             | 13.0        | 97.8       | 59.6       | 91.7    | 40.5     |
| 15                   | 95.7             | 17.3        | 99.6       | 76.5       | 96.9    | 47.1     |
| 20                   | 98.9             | 20.9        | 100.0      | 86.8       | 97.9    | 55.2     |
| 25                   | 99.5             | 22.4        | -          | 89.1       | 98.8    | 63.2     |
| 30                   | 99.7             | 26.1        | -          | 89.7       | 99.7    | 69.1     |
The greatest susceptibility to crushing was characterized by the run-of-mine from the Halemba Mine. The coal crushed completely after 18 discharges at the drop height of 2 m, and the average discharge of coal was 9.9.

After making 18 discharges of stone grains in the 80-0 mm class, about 85% of the material was crushed. A small difference in susceptibility to crushing, to the assumed grain size, between coal and stone can limit the effect of selective crushing of material in a drum crusher.

The run-of-mine from the Bielszowice Mine and the Pokój Mine was characterized by a smaller susceptibility to crushing. The run-of-mine was not crumbled completely.

At the maximum number of discharges at the level of 30 the percentage output of crushed coal in 80-0 mm class from the Bielszowice Mine and Pokój Mine was 99.7%.

The above results were obtained at the average number of coal discharges at the level of 16.8 (Bielszowice Mine) and 16.5 (Pokój Mine). After making 30 discharges of stone grains from the Bielszowice Mine in the 80-0 mm class, about 26.1% of the material was crushed, and from the Pokój Mine it was 69.1%.

The results of susceptibility tests to crushing stone >80 mm from the run-of-mine of the Pokój Mine and mainly of the Bielszowice Mine, despite the lower "brittleness" of coal grains, indicate a possibility of obtaining positive results of the material selective crushing in a drum crusher.

![Figure 5](image.png)

**Figure 5.** Class 80-0 mm output depending on the number of discharges - Bielszowice Mine [12].
Figure 6. Class 80-0 mm output depending on the number of discharges – Halemba Mine [12].

Figure 7. Class 80-0 mm output depending on the number of discharges – Pokój Mine [12].
4. Conclusions
The analysis of the test results, aimed at a determination of the possibility of using a selective crushing process for coking coal (type 34.2) and gas coal (type 33), showed that the use of drum crushers will enable partial deshaling of the run-of-mine with slight losses of coal in the waste.

During the tests, simulating the operation of the drum crusher with 80 mm holes, these losses were up to 4.3% after 15 discharges and up to 0.6% after 30 discharges.

Coal grains from the Halemba Mine were most susceptible to crushing. Simultaneously, a high susceptibility of gangue grains to crushing will reduce the selectivity of the process and will cause that a significant part of the crushed stone grains will participate in further technological processes. Depending on the number of discharges, their output, in relation to the total numbers of these grains in the feed, varied from 36.9% for 5 discharges to 89.7 for 30 discharges.

The biggest differences in susceptibility to crushing of coal and stone were recorded in the case of the run-of-mine from the Bielszowice Mine, which after 30 discharges exceeded 70%.

Despite the fact that both types of the run-of-mines (Halemba Mine and Bielszowice Mine) represent coal 34, the obtained results show a significant difference in the susceptibility to crushing of the tested material.

Therefore, in order to determine a possibility of using the selective crushing process and ensure its high effectiveness, the decision to use a drum crusher should be preceded by tests enabling to determine the feed crushing potential.

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