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Technological and Economic Analysis of the Application of Surface Miner on the Example of a Limestone Deposit in Poland

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Abstract. Mining a deposit utilizing surface miner is very popular in many countries. Presently, a surface miner has also experimented with extracting different deposits: bauxite, hematite, sandstone, shale etc. Surface miners can completely eliminate drilling and blasting operation and primary crushing unit, thus reducing their associated environmental hazards. Apart from this, the sized excavated material increases transport or conveying efficiency and saves the energy requirement in processing. So far, these machines have not been used in Poland. To evaluate this technology, tests were carried out on one of the limestone deposit in Poland. During these tests, basic parameters of efficiency, output quantity and mining costs were defined. The conducted tests have shown that this technology cannot be used in all geological and mining conditions. Therefore, the article presents the advantages and disadvantages of using surface miner, taking into account the Polish geological and mining conditions.

Keywords: Limestone deposit, Surface miner, Technology of extraction, Non-blasting extraction

1. Introduction

In surface mining, there are increasing restrictions on the use of drilling and blasting operations, which are the primary means of mining rocks with compressive strength exceeding 20 MPa. These limitations are due to the fact that significant impacts from paraseismic vibration, flyrock, and shock waves occurring during these operations negatively affect protected structures or residential clusters in the vicinity of surface mines. In such cases, it is necessary to replace drilling and blasting operations with mechanical mining methods that would allow the extracted mineral to remain economically competitive [1].

Among the many decision-making problems in the process of designing and managing exploitation, and, at the same time, one of the most important ones is the appropriate choice of technical equipment for the implementation of the main technological processes in extraction, which include mining, transport and processing of the mineral. At the same time, it is necessary to ensure appropriate quantitative and technological links between these processes in order to achieve the full efficiency of both the extraction and processing system. It is essential to ensure the quality of the aggregate according to the in-house production control of aggregates [2].

For rocks, with compressive strength of 20 MPa and higher (e.g. limestone, dolomite, sandstone, marl, travertine, etc.) the lowest unit costs (in PLN/Mg of material) are achieved when the blasting technique is applied. Therefore, it is the primary method of mining rock raw materials, but with the existing constraints of paraseismic vibration, airborne shock waves, or rock debris scatter, mines do not have the option of using it close to the mining boundary adjacent to residential areas or protected structures [3]. This restriction may also be established due to the impact of noise from operating machinery [4]. In this situation, despite higher mining costs, other solutions for mining hard rocks are currently being sought.

Market availability of machinery, amount of capital expenditure, operating costs including maintenance etc. are also considered. Each of the factors cited above can be decisive in selecting the method of mechanical rock mining to be implemented.

2. Test site

The first tests of the Wirtgen surface miner for mining rock raw material deposits in Poland were conducted at the "Raciszyn" limestone deposit.

Since it is impossible to use the blasting technology to mine this deposit, it was decided to conduct tests using the Wirtgen 2200 surface miner.

The important fact was that the mine is focused on the production of limestone aggregate with a fraction of 0-31.5 mm. This fraction is widely used in the road construction industry, as a mix for the base road layer, and is the basic raw material for the production of lime powder. In addition, this product is supplied to the conventional power generation sector and, after grinding, is used as a sorbent in flue gas desulfuring

processes. In the case of the analyzed mining company, the 0-31.5 mm fraction accounted for about 70% of the sales volume of all aggregates and is therefore the most representative commercial product for many players in this sector [5].

Table 1 shows the basic physical and mechanical parameters of the "Raciszyn" limestone deposit.

Tab. 1. Physical and mechanical parameters of the "Raciszyn" limestone deposit.

Parameters	Unit	Average values
Bank density	Mg/m^3	2.22
Porosity	%	17.45
Absorbability by weight	%	6.07
Compressive strength	MPa	57
Boehme abrasion test	cm	1.15
Deval abrasion test	%	12.56

The classification of cutability by surface miner includes 5 physical and mechanical parameters of the deposit and divides them into 5 cutability groups [6]. The parameters of the "Raciszyn" limestone deposit, according to the above classification, pointed to the "economic excavation" group.

3. Technical specifications of the Wirtgen 2200 SM surface miner

The tests on the "Raciszyn" limestone deposit were carried out with the use of the only Wirtgen 2200 SM surface miner available on the Polish market. Table 2 shows the exact technical specifications of the Wirtgen 2200 SM surface miner.

Tab. 2. Technical specification of the Wirtgen 2200 SM [7].

Parameter	Unit	Size
Cutting width	[mm]	2 200
Cutting depth with a direct loading/windrowing	[mm]	0÷300/0÷250
Spacing between the cutting cutters on the drum	[mm]	38
Number of cutters	[Pcs.]	76
Diameter of cutting drum with cutters	[mm]	1115
Maximum tilt of the drum	[°]	5
Motor power	[kW/KM]	708/950
Motor speed	$[min^{-1}]$	2 100
Driving speed	[km/h]	0÷5
Maximum inclination	[%]	90
Kerb weight	[kg]	44 500
Operating weight	[kg]	50 780

The Wirtgen 2200 SM surface miner made a single course of 150 to 200 m during the test, then returned by reversing to the beginning of the work area. This system of work was dictated by a significant limitation, which is the size of the accessible deposit roof, and thus the limited length of the work area. Bulk measurements were made by accurately weighing the excavated raw material on scales installed on the wheel loader and measurements of fuel consumed.

Figure 1 presents the operation of the Wirtgen 2200 SM surface miner with direct loading onto dump trucks at the "Raciszyn" limestone deposit.

Fig. 1. Operation of the Wirtgen 2200 SM combine with direct loading onto technological trucks on the "Raciszyn" limestone deposit.

4. Production results of tests

The operation of the Wirtgen 2200 SM surface miner at the "Raciszyn" limestone deposit can be divided into two working stages: preparation and production. In the preparatory stage, the surface miner levelled the deposit floor in the area to be tested. This stage, which lasted about a week, was characterized by a higher travel speed of the surface miner and a lower efficiency of the machine. Proper operation at full capacity of the surface miner occurred at the production stage. The output obtained during the test was loaded directly onto technological trucks, or, in the second variant, it was left on the floor of the working level for further loading.

To efficiently operate the Wirtgen surface miner, 3 dump trucks (Volvo A40 articulated dump trucks) were required to directly collect the output. Providing a standby technological truck waiting to be loaded in addition to the one currently being loaded was a necessary element in maintaining the smoothness of the milling process. This system ensured continuous operation of the Wirtgen 2200 SM surface miner without the need to stop the process due to an inability to collect the output.

Operating tests carried out on the "Raciszyn" limestone deposit were used to determine the performance of the Wirtgen 2200 SM surface miner. The test results are presented in Table 3.

Tab. 3. The test extraction results of the Wirtgen SM 2200 on the "Raciszyn" limestone deposit.

Item	Unit	Size
Average cutting speed	[m/min]	7.2
Machine test time	[h]	204
Production volume	[Mg]	39,485
Total fuel consumption	[liters]	17,800
Average hourly capacity	[Mg/h]	194
Average fuel consumption per hour	[liters/h]	87.3
Average fuel consumption per tonne	[liters/Mg]	0.45

During the entire test, the Wirtgen 2200 SM operated for 204 hours (according to the machine's timer) and consumed 17,800 liters of diesel fuel. These figures were then used to determine the actual output of the Wirtgen 2200 surface miner at the "Raciszyn" limestone deposit at 194 Mg/h, and average fuel consumption - at 87.3 liters/h.

With a limestone average compressive strength of 57 MPa, the Wirtgen 2200 SM achieved an average cutting speed of 7.2 m/min.

The output produced by the Wirtgen 2200 SM was highly ground. Figure 2 shows the grain size distribution curve of the output produced by the Wirtgen 2200 surface miner at the "Raciszyn" limestone deposit.

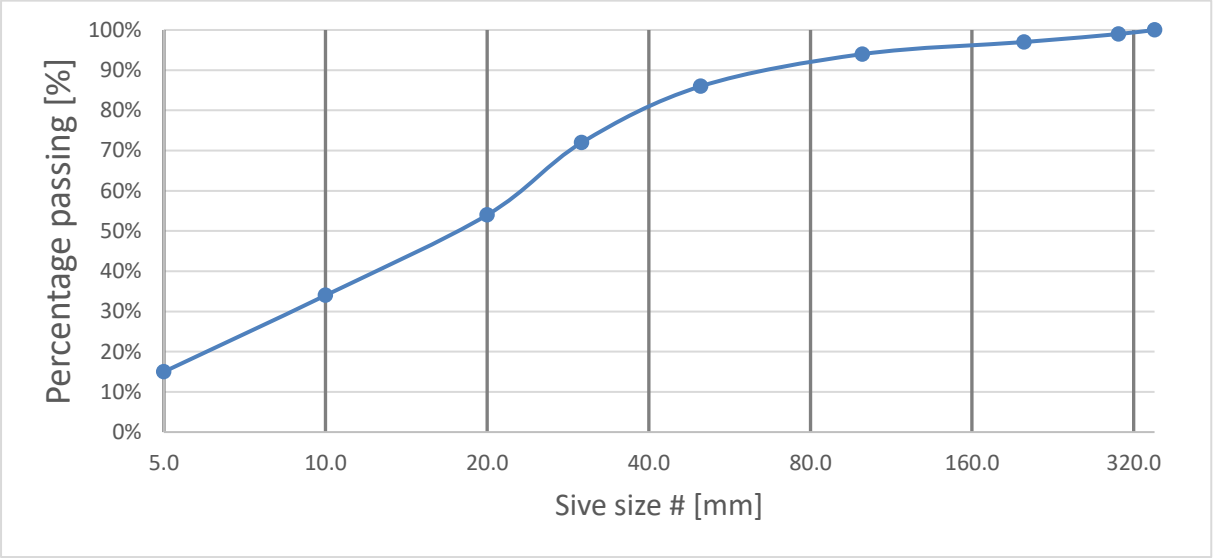

Fig. 2. Grain Size Distribution Curve of the output obtained with the use of the Wirtgen 2200 SM on the "Raciszyn" limestone deposit.

The grain size distribution curve of the excavated material obtained with the Wirtgen 2200 SM confirms the high level of fineness of the raw material. Its size does not exceed the 0-350 mm fraction, and the P80 index for the obtained feed was 38 mm.

The uniformity of the output is also relatively favourable. The degree of uniformity of grain size was determined as:

$$U = \frac{d_{60}}{d_{10}} = \frac{23}{4} = 5{,}75 \qquad (1)$$

where:
U - degree of uniformity of grain size;
d_{60} - diameter of 60% of grains [mm];
d_{10} - diameter of 10% grains [mm].

5. Economic results of the tests

In the economic analysis of the operation of the Wirtgen SM 22200 surface miner on the "Raciszyn" limestone deposit, only the direct costs of the cutting process were considered and related to 1 Mg of the excavated material.

The most significant share in the costs of excavation with the Wirtgen 2200 SM surface miner on the "Raciszyn" limestone deposit was attributed to the cost of renting the machine. If a machine is purchased, a similar level of cost is to be expected due to the depreciation of the machine. Fuel consumption was another important component of the overall costs. Together, these two costs accounted for 71% of total costs.

The cost also included the salaries of 2 operators and the cost of replacing the cutters on the cutting

drum.

The results of the mining test with the Wirtgen SM 2200 surface miner on the "Raciszyn" limestone deposit are presented in Table 4.

Tab. 4. Economic results of the test of extraction of the Wirtgen SM 2200 on the "Raciszyn" limestone deposit.

Types of costs	Unit	Amount	Share
Surface miner rental	[PLN]	90,533	38%
Flat rate for additional mileage	[PLN]	26,306	11%
Service/insurance/transport	[PLN]	8,458	4%
Interchangeable tools (cutters)	[PLN]	3,303	1%
Operator service	[PLN]	31,570	13%
Total fuel cost	[PLN]	78,320	33%
Cost of water and other costs	[PLN]	2,000	1%
Total	[PLN]	**240,489**	100%

Considering the fact that 39,485 Mg of limestone were excavated during the tests and the costs amounting to PLN 240,489 were incurred, the unit cost of excavation with the Wirtgen 2200 surface miner on the "Raciszyn" limestone deposit was PLN 6.09/Mg.

6. Conclusions

The tests of the surface miner were the first of such tests carried out in Poland. To date, hydraulic hammers, vibration rock breakers or rippers have been used to mechanically mine hard rock materials.

These tests provided an excellent opportunity to conduct empirical measurements of the main parameters of the Wirtgen 2200 surface miner on the "Raciszyn" limestone deposit.

In addition to such parameters as effective capacity, fuel consumption per hour, output grain size, and, finally, the unit cost of mining, other important factors have been indicated that should be taken into account when designing the exploitation of deposits with the use of this mining machine.

An important factor affecting the milling combine's performance is the effectiveness of the workplace length. Having to manoeuvre and change the direction of cutting significantly increases the machine's downtime, limiting its productivity. Therefore, the optimal way to operate the surface miner is in a circular motion to ensure its uninterrupted operation. However, this requires a large surface area of the workplace.

Small caverns and inhomogeneities in the deposit were also significant impediments to the operation of the surface miner. When a cavern was encountered, it was necessary to identify it, open it by hydraulic hammer, and backfill it with additional material so that the surface miner would be able to drive over it.

Two operators were required to operate the machine on the Raciszyn limestone deposit. One of them controlled the machine from the operator's cab, and the other one supervised the machine's progress while standing next to it.

The surface miner creates smooth surfaces, both on the slopes and on the floor of the working level. This results in improved geotechnical safety and fewer transport road maintenance problems.

The disadvantages include a high excavation cost, which amounted to PLN 6.09/Mg on the "Raciszyn" limestone deposit. This result is incomparably higher than for the blasting technique (1.5-2.0 PLN/Mg).

However, it should be noted that the surface miner allows direct loading onto technological trucks, eliminating the need to load the excavated material with an additional machine (hydraulic excavator or wheeled loader). The specified cutting cost, therefore, already includes the cost of loading and the first processing stage, in some cases.

The last of the important issues noticed during the tests was that, in addition to fuel consumption, the surface miner required a large amount of water to cool the cutting drum. This needs to be factored into the logistics of fuel and water deliveries.

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