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Hard rock mining – cutting or disk tools

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Hard rock mining – cutting or disk tools

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Abstract. The article presents problems related to the mining of compact and very hard rocks with cutting tools, mainly with tangential-rotary picks. The currently used disc tools, their parameters and the way of working are described. The disadvantages of selected solutions and related obstacles to their wider use in mining have been presented. The directions of further development of disk tools were presented, allowing their use, for example, in mining heads of longwall shearers and roadheaders.

1. Introduction

In underground mines, both in Poland and in the world, one of the most commonly used methods of hard rocks mining, in the process of row minerals excavation and drilling of exploratory and opening-out headings or tunnels is the mechanical method. It allows you to obtain large mining capacity or drilling speed, but also generates a number of hazards or restrictions, depending of used mining tools.

The roadways, especially opening-out headings, are currently excavated in rocks with very unfavorable parameters. This applies above all to the high strength of the rock massive on uniaxial compression, which in many cases exceeds 120 MPa and its structure. Increasingly, it encounters rocks that have a homogeneous structure, which results in their mining encounters serious problems, especially when using mechanical methods. No less important factor is the content of minerals and inclusions in the rocks, causing rapid abrasion and wear of mining tools and in the case of inclusions, for example sphaeroiderites, the occurrence of sparks during mining process [1]. The article presents the applied methods of mechanical mining of rocks, with particular emphasis on cutting and disc tools as well as hazards (dust, spark, wear) and limitations (rock compactness, machine dimensions) occurring in these methods.

2. Machines and tools used in mechanical mining of rocks

Currently, the most commonly used machines for roadway and tunnel excavation in hard rocks are roadheaders, continuous miners, multi-organ combines, special combines and TBM (tunnel boring machines) with full face excavation. Examples of such machines are shown in figure 1. In the case of roadheaders and continuous miners, as well as multi-organ combines, cutting tools are used, mainly tangential-rotary picks. In the case of special combines and full face excavation machines type TBM, symmetrical or asymmetrical disk tools are used.



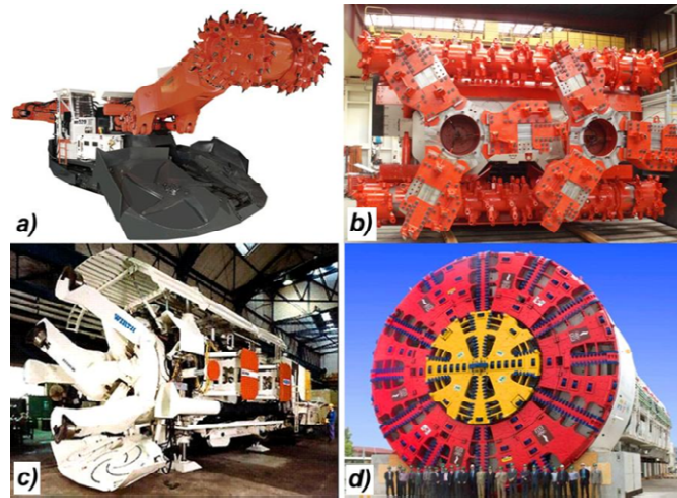


Figure 1. View of: a) roadheader type MR 520 made by Sandvik, b) multi-organ combine type MF 420 made by Sandvik, c) special combine applying undercutting mining method made by Wirth, d) TBM shield full face excavation machine made by Herrenknecht [2,3,4].

2.1. Cutting tools - working principle, advantages and disadvantages

Two types of cutting tools are used on milling heads of mining combines - radial and tangential-rotary picks. On the edges of these picks are mounted sintered carbide inserts or posts. In spite of this, and correctly selected resting and movement cutting angles, these picks are exposed to rapid friction wear, even when soft rocks are mined. However, when mining compact rocks, working part of radial pick can be damaged due to the high bending forces [5].

These inconveniences have caused that nowadays on shearers or roadheaders for hard rocks mining, mainly tangential-rotary picks are used. Thanks to their design and the method of fixing, there are able to rotate in tool holders. These tools are more predisposed to mining rocks, even very hard ones, but they need to maintain proper parameters of their work. They are currently used on mining heads of almost all roadheaders and most of the longwall shearers. The view of the structural solutions of radial and tangential-rotary picks is shown in figure 2 [1,5].

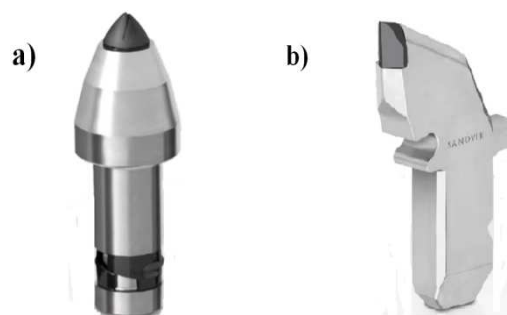


Figure 2. Types of cutting tools used in cutting or milling: a) rotary-tangential pick, b) radial pick [4].

However, the disadvantage of the method of mining rocks by milling is the generation of dust and limitation of the use of this method, associated with the upper limit of rock strength to uniaxial compression or high compactness of these rocks. In connection with the high abrasiveness of such rocks, this results in excessive wear of cutting picks and a decrease in drilling speed. Excessive wear of the tool edge also leads to increased dustiness and the risk of explosion of mine gases, mainly methane, as a result of frictional sparking (figure 3). This problem occurs especially with radial picks. Even the use of rotary-tangential pick reduces this problem only to a small extent.



Figure 3. View of frictional sparking and dustiness during cutting of a rock sample with a rotary-tangential pick and wear of pick wedge.

When mining hardly mineable rocks, the increased wear of tools and the generated dust hazards and gas explosion often result that the process of rock mining is economical unprofessionally (low efficiency and high energy consumption of the mining process, high wear of tools). Work is underway to develop more durable cutting tools, however, even new-generation rotary-tangential pick are not always able to provide the required mining parameters [1, 5].

The new solution of special tools, which can replace traditional tangential-rotary picks was developed in AGH UST. This tools are adapted to attach in standard holders of tangential rotary pick which are commonly used for hard rock cutting, whereas design solution of the picks working part is different than those designed for the standard tangential rotary picks [6]. The new pick is shown in figure 4. The cutting segment is bell or crown-shaped, and the working part is armed at the circumference with eight cone-shaped sintered carbide inserts. Such design solution, instead of traditional cutting with use of standard tangential rotary picks, should allow loosening rock fragments as a result of point pressures exerted by individual sintered carbide inserts. Moreover, non-uniform load of individual sintered carbide inserts should cause increase the tool rotary speed in the holder, at minimal side deflection angle of the cutting tool. After manufacturing of the new tool prototype, preliminary tests at a special laboratory stand were carried out.

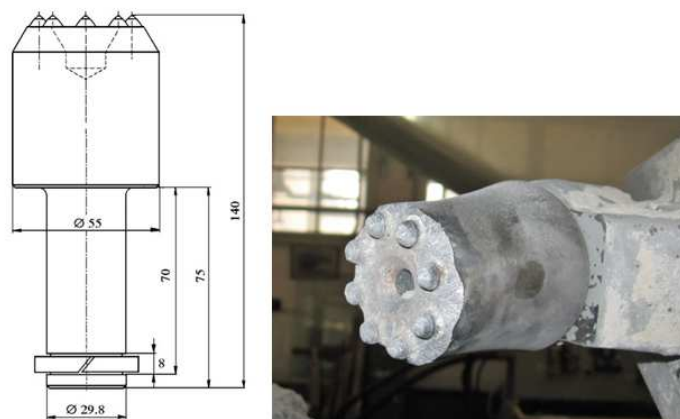


Figure 4. Scheme of the new type of the crown pick and view of new crown pick with 8 carbide inserts with diameter 8 mm after the test [6].

The results of preliminary researches has been satisfactory. Significant rotations and very small wear of new tool were observed. Figure 4 presents the view of this crown pick after sample mining on the total

distance of 1200 m. New type of the tool has been applied in the new solution of roadheader mining head. The mining head of the R-130 roadheader, equipped with new crown picks, was tested in Ilža limestone opencast mine (figure 5a). Working conditions were comparable to the standard mining head with tangential rotary picks operation regime. There were no problems with the head work. During 5 hours of work, a comparable quantity of output (to a standard mining head) was excavated. The difference was only in dimensions of the grain size of the output. The output was homogeneous and fine. No major signs of wear of new tools were observed. The view of one of the new pick after the tests is shown in figure 5b. In order to confirm the effectiveness of these tools, however, research in real conditions in an underground mine is required.

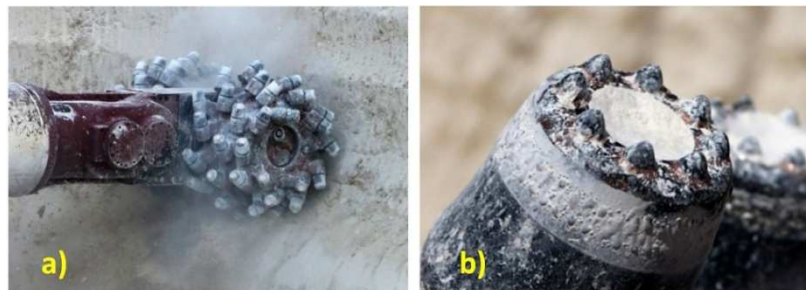


Figure 5. View of the mining head with new crown picks: a) – during the tests in Ilža limestone opencast mine, b) – new crown picks after the tests [6].

2.2. Disk tools - working principle, advantages and disadvantages

The second of the most commonly used methods in the process of mechanical mining of hard rocks is mining by means of static crushing, carried out with the help of wheel tools called disks. Disk tools used for this mining method can be symmetrical or asymmetric. This method consists in pushing the disc edge into a rock massive with the normal force perpendicular to its surface [1]. As a result of this force, the uniaxial compressive strength of the rock is locally exceeded, rock massive is crushed and disk penetrates into the depth g (figure 6). At the same time, the rolling force is applied to the holder, causing the tool to move along the surface of the mined rock. Rotary assembly the disk in the holder allows the disk to rotate around the axis. The ability to rotate the tool in the head reduces the friction forces, which reduces energy loss and generates less toll edge wear and dustiness, compared to cutting tools. In addition, the rotation of the cutting disc causes short contact of the edge section with the rock, which greatly facilitates the removal of heat emitted on the edge of the disk and ensures very long durability of the tool. The typical construction of disk tool consists of shaft, seal, hub, split ring and replaceable cutting ring is shown in figure 7. There are three types of symmetric disk tools: smooth disks, disks armed with carbide insert and toothed discs, in one and double or even triple blades versions. However, the first two types are most often used, which in the view are shown in figure 8. Their diameters can be even up to 500 mm [3,7,8].

TBM disk tools are mounted on the TBM mining head in a certain pattern and cover the entire face. They are exposed to different and sometimes even extreme ground conditions during tunneling, so selecting tools with high quality, reliability and long lifetime is important and critical [7,8]

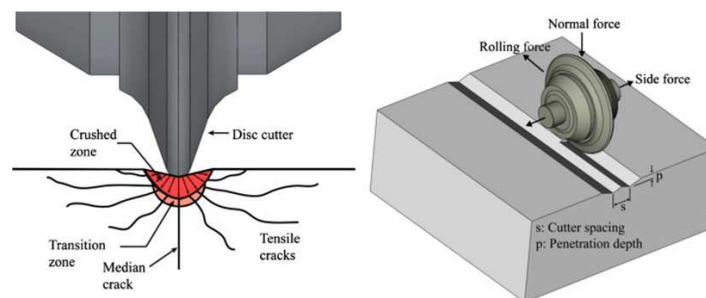


Figure 6. The work principle of a single symmetric disk [3].

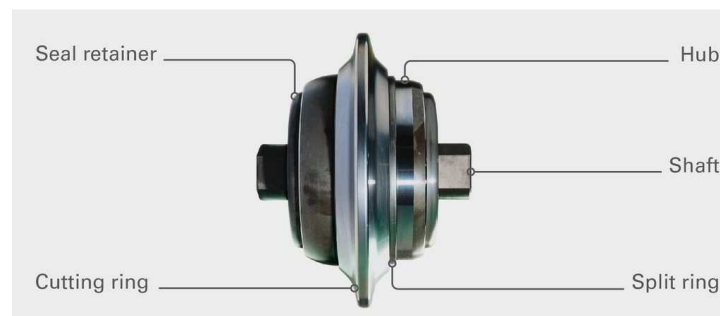


Figure 7. The typical construction of disk tool [3].

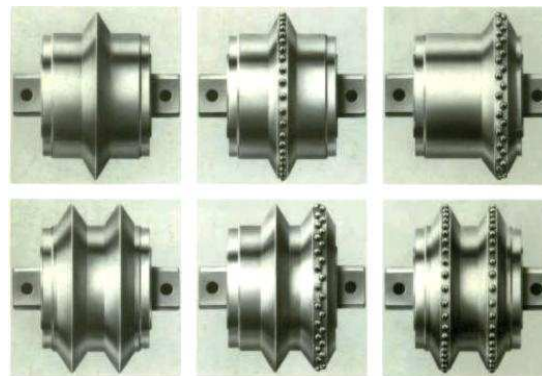


Figure 8. View of smooth disk and disk armed with carbide insert in one and double blades versions [1].

Smooth single blade disk tool can work without visible wear even up to few kilometers of roadway or tunnel advance. In comparison cutting tool lifetime is not more than several cubic meter of wining per piece.

The disadvantage of mining by static crushing is the need to ensure a high pressure force of the tool. Destruction of the stone rock structure occurs as a result of exceeding its uniaxial compression strength. According to the available data, the value of the pressure force per disk tool shown in figure 8 can be as high as 300 kN. In the case of a large number of disk tools on the mining head, this gives a very large value of the total pressure force (depending on the diameter of the body up to 25,000 kN) and many times more value of side expanded force to ensure the stability of TBM work. The mining machine must transfer the reactions coming from the mining head and stabilizing struts. The occurrence of large values of reaction forces occurs large mass (up to 3,500 Mg) and dimensions of the machine (the length of the TBM reaching up to 400 meters). The view of the mining head and TBM from Robbins is shown in figure 9. This results in the limited use of this type of machinery for the drilling of excavations with a very large runout, where very large costs related to their production and construction in the mining excavation can be paid back [1,7,8].

Another untypical solution of a milling machine, which uses a principle of mining by static discs and leaning out the boom in a horizontal plane, is a continuous miner made by ROBBINS, which is shown in figure 9. The mining head is constructed in a form of a larger diameter plate with mining disks mounted with bearings around the perimeter. This unit is mounted on an arm, inside of which there is an engine whose power puts the unit into a rotational motion. The arm's leaning out movement makes the advance motion in a vertical plane. This solution enables excavation of roadway in cross-section similar to rectangle. View of roadway obtained by this machine is shown in figure 10 [6].

A clear drawback of the static crumpling method is necessity to provide large pressure forces to the disks. Whereas, asymmetrical disk tools have been used as mining tools for longwall shearers to increase output of a large size grade. Conducted industrial tests demonstrated usefulness of such equipment for

obtaining higher product graining. Asymmetrical disk tools are applied in the technique of mechanical mining not only as crushing devices but also in the undercutting method.

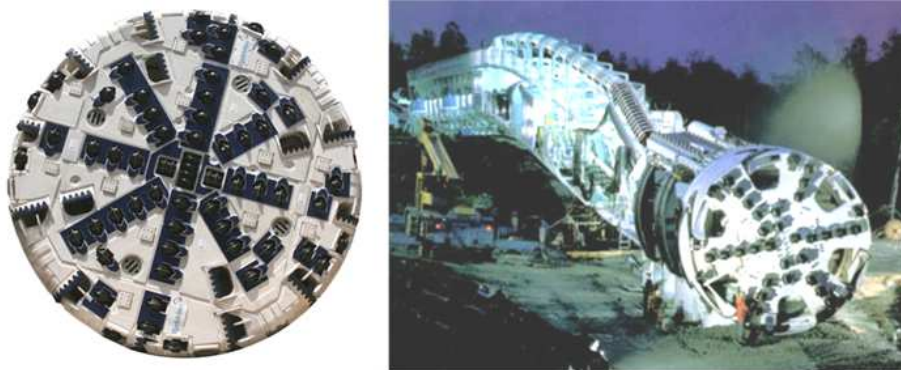


Figure 9. View of mining head with disk tools and TBM complex manufactured by Robbins [6].

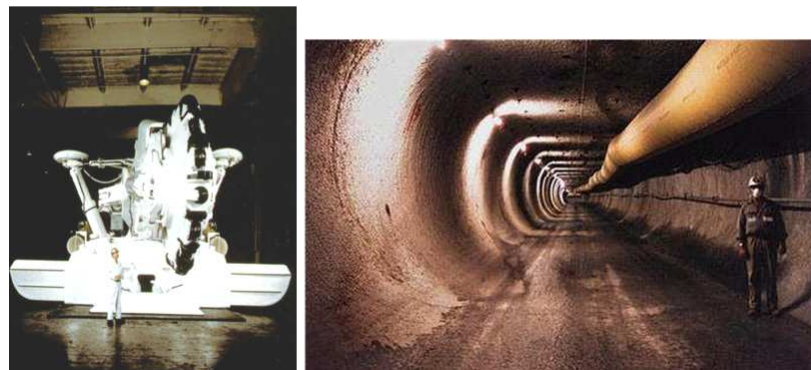


Figure 10. View of Mobile Miner MM130 made by Robbins and excavation performed by this machine in Broken Hill Mine [6].

The principle of the undercutting method is mining a rock by its cutting off towards a free space. A disk tool affects the rock tangentially to the surface of the mined body, similarly as for cutting tools, but the difference is that here it uses the disk rolling movement which efficiently eliminates sliding friction in favor of rolling friction. Figure 11 presents a diagram of mining with this method. Application of disk tools in that way lowers energy consumption and pressure force. It allows designing mining machines with respectively lower energy demands and lower requirements concerning stability than in case of machines equipped with classical disks, operating perpendicularly towards the surface of a mined body [9].

In the case of this method, however, there are strongly varying lateral forces on the edges of disk tools. This is the reason for the difficulty in properly taking over the reaction on the disk tool holders and their bearing. Therefore, after the initial research of a machine developed by Wirth, using this method, equipped with four swinging and rotating arms and ending with positive results at the end of the twentieth century, the further development of machines using the new method of mining rock was stopped [9]. The view of the Wirth machine used undercutting method and the effects of its work is shown in figure 12.

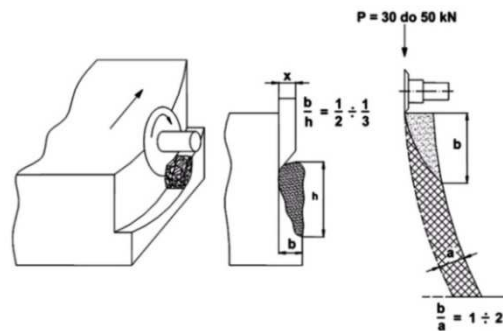


Figure 11. Diagram of the undercutting method mining principle [9].

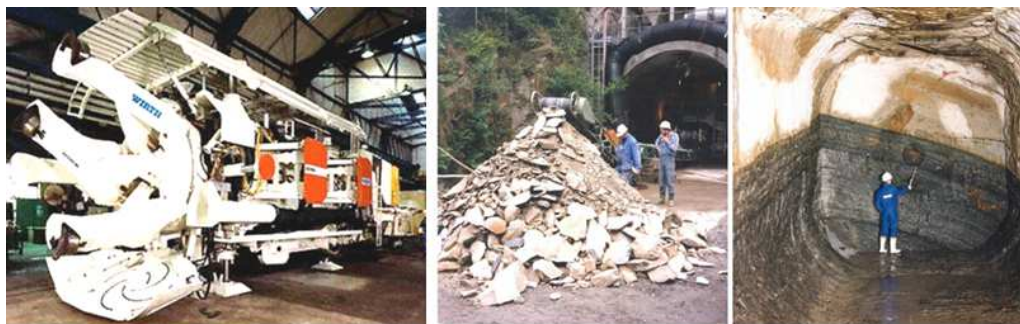


Figure 12. view of the Wirth machine used undercutting method and the effects of its work [9].

3. Future of disk tools application

For many years, work has been carried out on the development of new construction solutions for mining heads of roadheaders or mining methods that allow effective mining of hardly workable rocks. One of such solutions is a mining head, developed and tested at the Colorado School of Mines [1]. To reduce the values of mining forces, symmetrical mini-disks with a diameter of 125 mm were used. The biggest problem is the bearing of disks, connected with their heavy load. Several solutions for the bearing of tools and a technical design of the body were developed, on the basis of which the prototype was made. The mining head model, along with the arrangement diagram of the tools on its surface, is shown in figure 13. The results of the trials were satisfactory, but no detailed data on this subject.

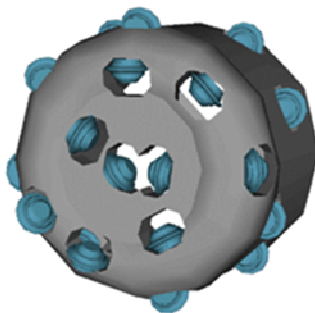


Figure 13. Spatial model of mining head with symmetrical mini disk tools [1].

There were other concepts of use on the mining heads mainly asymmetrical disks, in which the basic idea was to use the disk as a chipping tool. Thanks to this, energy consumption and the value of the pressure force are smaller, which gives the possibility of constructing a mining machine with lower energy parameters, smaller requirements due to stability criterion, as in the case of classic disks operating perpendicular to the rock surface. In the case of machines using this technique, inter alia, by Aker Wirth and Atlas Copco, this

method showed full usefulness [2, 10]. The only drawback was the complex way of machine control and the large value of reaction forces operating on the machine. View of the Aker Wirth MTM 6 machine developed for the Rio Tinto Company as part of the "Mine of the future" project for the new Resolution copper mines in Arizona as well as Oyu Tolgoi copper and gold mine in Mongolia and the Atlas Copco alternate solution of MMM machine (Modular Mining Machine) is shown in figure 14.

That is why the idea of the undercutting method was developed in the Department of Mining, Dressing and Transport Machines, AGH University of Science and Technology, in order to design an innovative construction of mining head, equipped with mini asymmetrical disk tools [1, 5].

At first an attempt was undertaken to work out a solution of a mining unit equipped with mini disk tools, mounted directly on the head body. Due to high load of the disk tools and low effectiveness of mining, this solution was given up. As a result of thorough analysis of the world technique condition, and results of own tests of rocks mining with asymmetrical disk tools (of diameter up to 160 mm), the Department started tests to devise a new conception of a mining head.

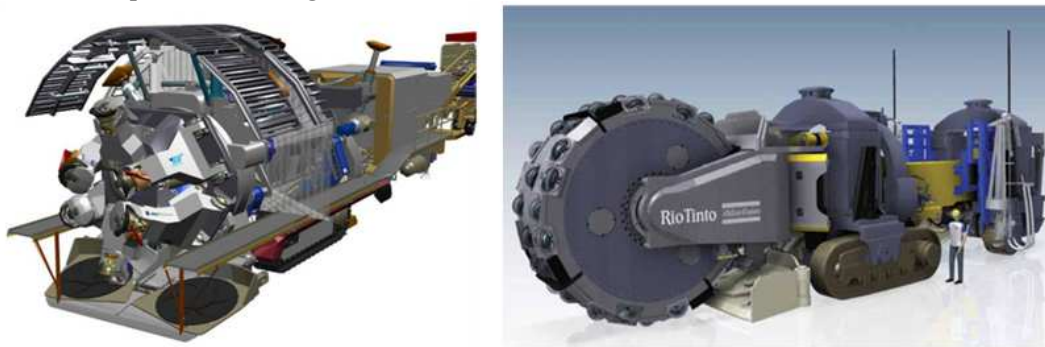


Figure 14. Visualization of a miner MTM 6 made by Aker Wirth with mining head equipped with 6 disc arms and MMM Modular Mining Machine made by Atlas Copco with a disc milling head, designed for Rio Tinto Company [2, 10].

In this design motion of tools will be forced, and will cause mining of a rock body with tools along complex movement trajectory. It allows crossing of mining lines of individual disk tools, and facilitates mining compact rocks through breaking off rock furrows. It should lower energy consumption of the process [6, 11]. Disk tools were mounted on separate plates that could rotate on the mining head body, and are propelled independently from it. The works were performed in cooperation with the REMAG Company. It was planned to work out and adapt the new head solution for a medium type roadheader KR150. The view of spatial model and ready mining head mounted on the KR150 roadheader is shown in figure 15.

The preliminary tests were performed on artificial large size concrete block of uniaxial compressive strength up to 80 MPa prepared at REMAG Company. The best effects of the work – large graining of the output, low engines load, and limited vibrations were obtained for the head body rotations at counter clockwise direction of value 20 rpm, and the plates rotations at clockwise direction of value 60 rpm. The change of direction of the head body or plates with disk tools rotation onto the opposite had a highly negative influence on the engines load and disk tools, and the plates wear.



Figure 15. The new mining head solution with disc tool of complex trajectory: a) – spatial model, b) - view of KR150 roadheader mining head ready before field tests [11]. 1 – main gear, 2 – auxiliary gear, 3 – disc plate, 4 – input shaft, 5 – central gear wheel, 6 – orbital gear wheel, 7 – pinion, 8 – face gear, 9 – output shaft, 10 – support, 11 – connector, 12,13 – bearings, 14 – body gear, 15 – hydraulic engine.

In order to check the influence of mounting and the deflection angle of the rotational axis of the disk tool, new exchangeable holders of these tools were made which allow disk tools mounting at an angle of -5° , 45° and 90° relative to the surface of the plate. The view of the plates with disk tools with these holders during field tests are shown in figure 16. Only the disk tools mounted at an angle of -5° allowed for proper work, without significant wear [12].

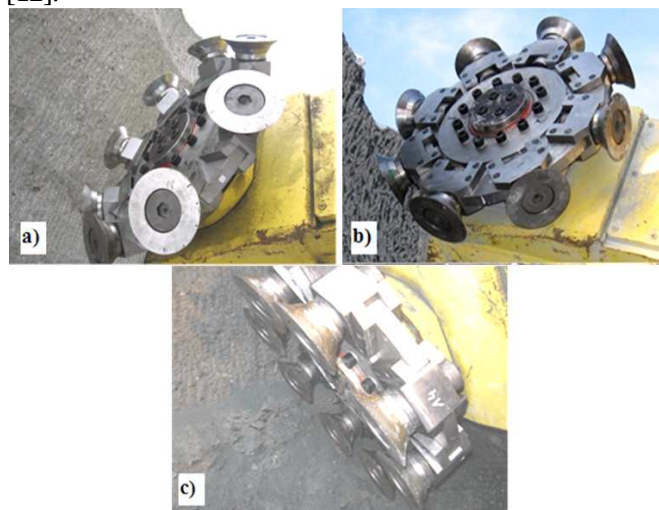


Figure 16. A view of the plates with disk tools mounted in the holders at an angle of: a) 45° , b) 90° and c) -5° relative to the surface of the plate [12].

During the last phase of the field tests, the mining head was mounted on a larger roadheader FR250 - manufactured by FAMUR company, with more weight - over 65 tones and equipped with a larger power electric motor - 250 kW. This allowed for better, more stable operation of the mining head and the possibility of mining at greater depths. The view of this roadheader and mining head before the trials is shown in figure 17[13].



Figure 17. A view of FR250 roadheader with new mining head with disk tools before the field tests [13].

During the tests, using disk tools made of different materials and by various methods, the efficiency of mining was checked. Disk tools had the same diameter - 170 mm and wedge angle of 45° . They were made of tool steel, Hadfield or low-alloyed (GS42CrMo4) cast steel and ADI spheroidal cast iron. The tools manufactured from tool steel type NZ3 were full-hardened, to a hardness of over 55 HRC. The tools manufactured from tool steel type 36HNM were surface-hardened and tempered. Tools made of cast steel and cast iron were machined after casting. After this mechanical treatment, it was noticed that especially tools made of cast steel had numerous castings defects - blisters and pores. These tools have been disqualified.

During concrete block mining with larger cutting depth, the best results were obtained for tools made from tool steel type 36HNM. After one hour operation there were not significant traces of wear observed. In the case of disk tools made from tool steel NZ3, already after very short work numerous edge breaks as well as cracking and breakage of the part of tools were noticed.

However, in the case of disk tools made of ADI cast iron, no breakage of the tool edge but its systematic abrasive wear was observed. The outside diameter of cast iron tools after about 30 minutes of work was decreased to value of about 135-140 mm. This diameter value did not allow further work. The wear view of tools made from tool steel NZ3 and ADI type cast iron is shown in figure 18. The reason of quick tools wear was probably to large cutting depth and movement speed of mining head. Combination of both of these parameters caused a heavy load on the tools [13].

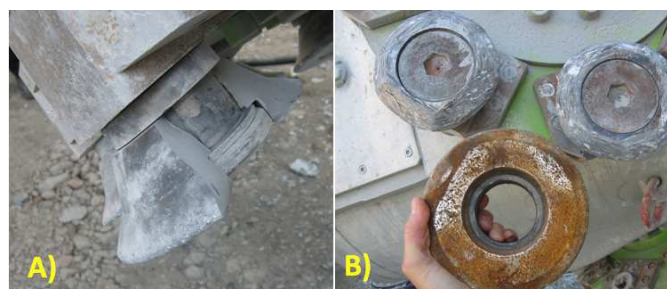


Figure 18. A view of disk tool wear: A) made from steel type NZ3, B) made from ADI cast iron [13].

4. Summary

The mining of compact rocks with roadheaders with milling bodies seems to be currently the most popular method. As of today, attempts to use mini disk tools (up to 180 mm in diameter) on the roadheaders mining heads offer promising results. However, the biggest drawback in their case is durability. The implementation of these tools, for example, using the forging method and the appropriate heat treatment can give good results.

However, symmetric disk tools with a diameter of 400 - 500 mm, working with static crumpling, mounted on the mining heads of TBM machine, have very high durability but in this case very high value of pressure force require huge dimensions, weight and costs of the whole machine. This makes them economically viable in the case of large (over a few kilometers) runnout of excavations. The undercutting

method using non-symmetrical disk tools with a diameter of about 400 mm, mounted on swing arms, offer also promising results. The new Aker Wirth machine are able to mine excavations in compact rocks with reduced energy consumption of the mining process and high granulation of the output.

References

- [1] Kotwica K and Klich A 2011 Maszyny i urządzenia do drążenia wyrobisk korytarzowych i tunelowych *Instytut Techniki Górniczej KOMAG Gliwice*
- [2] Brochures and information materials of Aker Wirth
- [3] Brochures and information materials of Herrenknecht
- [4] Brochures and information materials of Sandvik
- [5] Klich A at all 1998 Niekonwencjonalne techniki urabiania skał. *Wydawnictwo Śląsk, Katowice*
- [6] Kotwica K at all 2016 Wybrane problemy urabiania, transportu i przeróbki skał trudnourabialnych, Part 1 *Wydawnictwa AGH*
- [7] Brochures and information materials of Mannesmann Demag
- [8] Brochures and information materials of Robbins
- [9] Weber W 1994 Drążenie chodników o różnych przekrojach przy pomocy techniki tylnego wycinania - Maszyna firmy Wirth-HDRK „Continuos Mining Machine” Sympozjum TMB Herne nt. Drążenie chodników w górnictwie węgla kamiennego. Siemianowice Śl
- [10] Brochures and information materials of Atlas Copco
- [11] Kotwica K 2018 Atypical and innovative tool,, holder and mining head designer for roadheaders used to tunnel and gallery drilling in hard rock *Tunneling and Underground Space Technology* **8**, pp.493-503
- [12] Kotwica K at all 2017 Wybrane problemy urabiania, transportu i przeróbki skał trudnourabialnych, Part 2 *Wydawnictwa AGH*
- [13] Kotwica K at all 2018 Wybrane problemy urabiania, transportu i przeróbki skał trudnourabialnych, Part 3 *Wydawnictwa AGH*