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THE INFLUENCE OF WATER ASSISTANCE ON THE CHARACTER AND DEGREE OF WEAR OF CUTTING TOOLS APPLIED IN ROADHEADERS

WPŁYW WPROWADZENIA WSPOMAGANIA WODNEGO NA CHARAKTER I STOPIEŃ ZUŻYCIA NARZĘDZI SKRAWAJĄCYCH STOSOWANYCH W KOMBAJNACH CHODNIKOWYCH

In Polish mining industry the majority of headings are drilled by mechanical methods with the use of arm roadheaders. The tangential rotary picks used as cutting tools mounted on them undergo an accelerated process of wear in unfavourable geological and mining or incorrect work conditions. The article briefly presents the construction, nature of work and problems connected with wearing processes of tangential rotary picks mounted on roadheaders heads. There are described directions of performed works aiming to limit the wear of cutting tools applied on roadheaders heads, particularly considering high pressure water individual assistance of the mining process with tangential rotary picks. Implemented solutions of such assistance and obtained results have been included. There is also presented a new solution of water assistance applied in the holders of tangential rotary picks elaborated in the Department of Mining, Dressing and Transport Machines at the University of Science and Technology, Cracow. It relies on inner pressure lubrication with water or low-grade emulsion. The performed laboratory and industrial tests of the solution of the tangential rotary picks lubricated holder have been described.

Keywords: tangential rotary pick, edge wear, mining, water high pressure assistance, lubrication

W polskim górnictwie zdecydowana większość wyrobisk korytarzowych drążona jest metodami mechanicznymi z wykorzystaniem ramionowych kombajnów chodnikowych. Stosowane na ich organach narzędzia skrawające – noże styczno-obrotowe, w niekorzystnych warunkach górniczo-geologicznych lub przy nieprawidłowych warunkach pracy, ulęgają przyspieszonemu, czasami bardzo niesymetrycznemu zużyciu. Wpływa to na prędkość i koszty drążenia tych wyrobisk. W artykule przedstawiono skrótowo budowę, charakter pracy oraz problemy zużycia noży styczno-obrotowych, stosowanych przede wszystkim na organach kombajnów chodnikowych. W tej części skoncentrowano się głównie na nowych rozwiązaniach węglików spiekanych oraz rodzajach uszkodzeń ostrzy noży styczno-obrotowych i wpływie obrotu noża na charakter i stopień zużycia. W następnej części opisano kierunki prowadzonych w Polsce i na świecie prac, mających na celu ograniczenie zużycia narzędzi skrawających stosowanych na organach kombajnów chodnikowych, ze szczególnym uwzględnieniem wysokociśnieniowego, wod-

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nego, indywidualnego wspomagania procesu urabiania nożami styczno-obrotowymi. Przedstawiono wpływ usytuowania i parametrów strumienia wysokociśnieniowego na wielkość zużycia ostrza noża oraz stosowane rozwiązania takiego wspomagania, zarówno w warunkach laboratoryjnych jak i przemysłowych oraz uzyskiwane wyniki. W ostatniej części artykułu opisano wyniki prac z wysokociśnieniowym wspomaganiem pracy noży styczno-obrotowych, prowadzonych w Katedrze MGPiT AGH Kraków. Przedstawiono także konstrukcje i zasadę działania opracowanego w Katedrze MGPiT nowego rozwiązania uchwytu noży styczno-obrotowych, smarowanego wewnętrznie wodą lub niskoprocentową emulsją pod ciśnieniem. Opisano opracowane i wykonane rozwiązania uchwytów smarowanych, przedstawiono konstrukcje specjalnie wykonanych stanowisk laboratoryjnych oraz uzyskane wyniki. Przedstawiono wpływ wprowadzenia smarowania na liczbę obrotów noża styczno-obrotowego w uchwycie i jakościowy oraz ilościowy charakter zużycia ostrza noża. Dla wybranego na podstawie wyników prób laboratoryjnych rozwiązania uchwytu przedstawiono także przebieg oraz wyniki prób przemysłowych, przeprowadzonych w jednej z kopalń węgla kamiennego.

Słowa kluczowe: nóż styczno-obrotowy, zużycie ostrza, urabianie, wodne wspomaganie wysokociśnieniowe, smarowanie

1. Introduction

Nowadays, in Polish coal mining industry most of the first working and preparatory headings are drilled with mechanical methods applying arm roadheaders. It is mainly caused, in comparison to traditional methods using explosives, by a possibility to implement a few operations simultaneously (mining, loading, haulage) and by lower weakening and disturbing rocks structure as well as better fitting of the lining to neat lines which makes the lining transmit lower and more evenly distributed loads. The length of such headings to be implemented between 2010 and 2020 is estimated at the range of 650 to 700 km yearly. In Poland, generally light and medium arm roadheaders are used for that, occasionally the heavy ones (Kotwica, 2010).

Heading excavations, particularly the first working ones, are already performed in rocks of very unfavourable conditions. It concerns mainly the strength of the mined rock centre against uniaxial compression that often exceeds 120 MPa, high rock compactness and its structure. Another important factor is the content of minerals and inclusions in rocks causing fast abrasion and wear of the mining tools, and, in case of inclusions e.g. sphaerosiderites, occurrence of strong sparking during operation. Also, deeper and deeper level of exploited coal depositions has an influence on worsening of physico-mechanical properties of rocks.

The time of preparatory headings implementation is directly connected with the time of wall availability for exploitation, the wall advance or plans of deposit development. However, on the basis of economic analyses, it can be stated that the higher speed of heading mining, the lower is the unitary cost of mining one current metre of a heading (Kotwica, 2010).

The mining speed is significantly affected by cutting tools mounted on roadheaders mining heads, mainly tangential rotary picks and their wear. An increased wearing process of the tools not only limits the mining advance, but it also increases consumption of energy and costs of mining and generates threats such as sparking and the danger of gas explosion and dustiness.

The article presents directions of performed works aiming to limit the wear of cutting tools applied on roadheaders heads, particularly considering water assistance. There is also presented a new solution of water assistance applied in the holders of tangential rotary picks elaborated in the Department of Mining, Dressing and Transport Machines at the University of Science and Technology, Cracow.

2. Construction, nature of work and problems connected with wearing processes of tangential rotary picks

Tangential rotary picks commonly used to arm mining heads of roadheaders are applied due to their higher durability in relation to tangential or radial tools. The construction of a tangential rotary pick comprises a cylindrical holder and conical operating part (body) ended with a sintered carbide insert (fig. 1). The insert (edge) is in a form of a solid of revolution, most frequently a cylindrical conical one and is mounted in the body hole by soldering (Kotwica & Krauze, 2007).

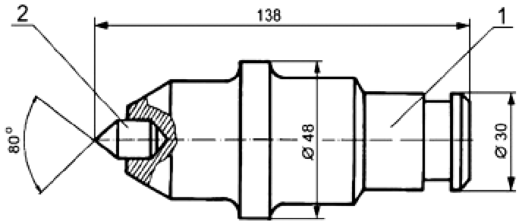

Fig. 1. A construction of a classic tangential rotary pick: 1 – shank, 2 – edge

The tool body (operating part) and the holder are made from one type of material i.e. different steels of different resistance against abrasion and high impact resistance and strength. Steels of high resistance against abrasion, impact resistance and strength are mainly used to produce the body and holder of tangential rotary picks.

Whereas, the tool edge is armed with different kinds of sintered carbides. They are of a certain shape, chemical composition and mechanical properties. For the needs of underground mining industry, the sintered carbide manufacturers recommend carbides consisting of two phases: tungsten carbide WC (phase α) in a form of hard crystals and a binder which is cobalt (phase β). Their characteristic features are: high hardness and resistance against abrasion, high resistance against compression and relatively high ductility which can vary with the change of cobalt content and the size of tungsten carbide grains. The WC grains are responsible for hardness and resistance against abrasion of the carbide, whereas cobalt for proper ductility. The typical and very significant feature of sintered carbides is a rapid fall of their hardness within the temperature range of 500÷700°C (Kotwica & Krauze, 2007).

High hardness of the carbides is often the reason of their chipping or brittleness. Exemplary types of tangential rotary tools edges damages are presented in fig. 2. In order to limit such cases, the Sandvik Company has elaborated and implemented new generation tangential rotary picks with three-layer carbide of S-Grade type. It has hard and abrasion resistant coating and nucleus, whereas the intermediate part is plastic. The shape of the sintered carbide insert is in a form of a solid of revolution, consisting of a cylindrical part and a conical one. Linear and angular dimensions of the insert are selected considering properties of the mined whole and mining resistance and wear (durability) connected with it.

The shape of the sintered carbide insert for tangential rotary picks is in a form of a solid of revolution, consisting of a cylindrical part and a conical one. Linear and angular dimensions of the insert are selected considering properties of the mined whole and mining resistance and

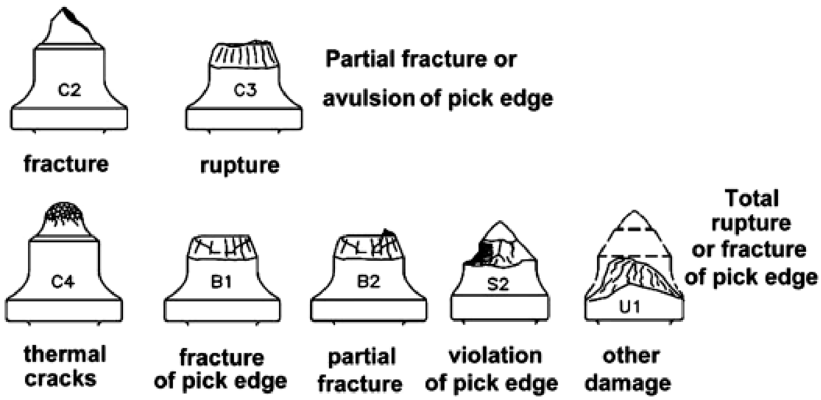

Fig. 2. Types of tangential rotary picks edges damages

wear (durability) connected with it. The types of currently applied sintered carbide inserts on tangential rotary picks are presented in fig. 3. According to conducted tests, the most favourable solutions are carbides of the cap and pileus types (Kotwica & Krauze, 2007).

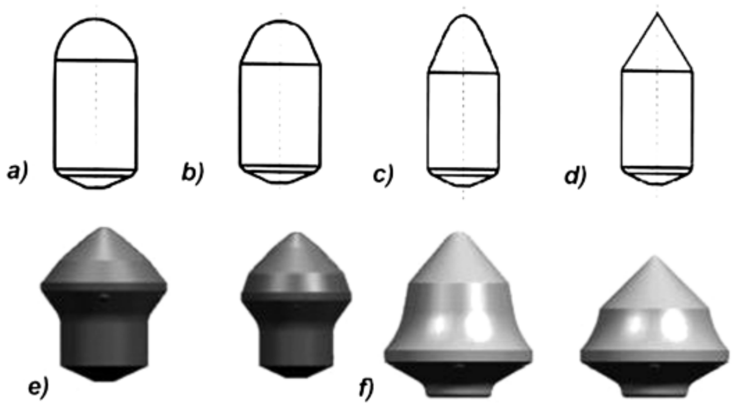

Fig. 3. Types of sintered carbides applied on tangential rotary picks edges:
a) hemispherical, b) parabolic, c) ballistic, d) conical, e) pileus "NB" f) cap type

The shape of the tool and proper method of its mounting in correctly selected holder allows its free rotation and even wear, frequently treated as the self sharpening process. An example of such ideal wear is presented in fig. 4. Obviously, the shape of the tool expressed by linear and angular dimensions and properties of the material used for constructing the body, holder and edge have to meet certain requirements connected with proper realization of the cutting process (motion cutting angles) and the length of operation time (durability). Determination of the requirements will allow to minimize the wearing process of cutting tools in defined mining and geological conditions in which a suitable mining machine operates or is dedicated to operate.

Failing to meet the above listed requirements may result in improper operation of the tool and decay of its rotation in the holder and subsequently its fast wear (Kotwica & Krauze, 2007). A view of a catastrophic wear of the tangential rotary pick edge at incorrectly selected conditions, after about 2 minutes operation on a special laboratory stand is presented in fig. 5.

However, even proper selection of the shape and constructional and material parameters of a tool is often insufficient to provide its required durability. It is mainly connected with the lack of a possibility to rotate the tool in the holder. That is why other solutions are being investigated.

Fig. 4. An example of even wear of cutting tools obtained in laboratory conditions by the Krupp-Widia company

Fig. 5. An influence of a tangential rotary pick rotation decay on the edge wear, a laboratory tests result

One of them is application of individual assistance of the mining process with a tool with high pressure water jet, or some new solutions of tangential rotary picks holders. They are more widely described below.

3. Individual assistance of the mining process with tangential rotary picks with high pressure jets

High pressure water jets assisting the process of mining with tangential rotary picks used on roadheaders heads have been applied for many years. Initially, they were used only as external sprinkling in a form of so called water curtains. However, due to high water consumption and lower efficiency in fighting dustiness as well as higher wear, they are currently used occasionally in accompany of another, co called inner system of sprinkling or assisting cutting tools. The system is presently applied in most of the manufactured arm roadheaders. It enables directing the high pressure water jet exactly in the area of the cutting tool operation. According to the accepted pattern of rock cutting, cracks and micro cracks get created in front of the cutting tool edge, and in the process of rock cohesion disintegration shearing stresses are very important. Whereas, from the side of the application plane, the biggest factor in the wearing process of the tool edge is the friction of the rock plough bottom and the surface. In the process of cohesive rock mining, the resistance the rocks oppose the cutting depends on inner friction and cohesion force. For cohesive rocks the dependence of resistance against cutting, inner friction and cohesion is expressed with the Coulomb formula (Gospodarczyk at al., 1998):

$$\tau = \sigma_n \operatorname{tg}\varphi + C \tag{1}$$

where:

τ — resistance against cutting (shearing stresses), N/cm^2,
σ_n — normal stresses towards the cutting surface, N/cm^2,
φ — inner friction angle, °,
C — rock cohesion, N/cm^2.

For rocks at moisture equal or higher than the liquid limit cohesion is very low. But also little moistening of a rock causes a fall of cohesion forces. Also for a rock in a wet state the inner friction gets lowered. That is why for a moist rock cutting a rock chip will take place accompanied by much lower values of shearing stresses or will take place much faster than for a dry rock.

Additionally, when mining a moist rock there is a decrease of the coefficient of friction between mined rock chips and the rock and the tool which makes it easier to remove the output outside the plough increasing the mining efficiency. Whereas, from the side of the application plane, lowering of the coefficient of friction between the rock and the tool side μ_p decreases significantly the friction force T_p and subsequently the amount of produced heat and the tool wear. The water existing between the elements moving in relation to each other, rock chips, the rock and the tool has the function of a lubricant. Application of individual high pressure assistance of mining process tools provides many benefits connected with limitation of mining resistance values, increase of output volume or decrease of wear. However, it must be properly applied. At mining with tangential rotary pick, there are two possibilities of assistance of the tool operation with a high pressure water jet. According to fig. 6 the location of the high pressure nozzle may

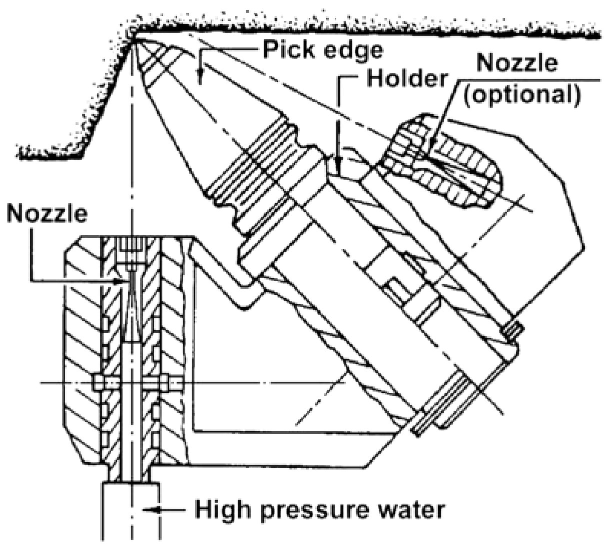

Fig. 6. A diagram of high pressure nozzles distribution at assistance of mining process with a tangential rotary pick

be in front of or in the rear of the cutting tool. The nozzles are located in the tool axis (Gospodarczyk at al., 1998, 2001).

For location of the jet in front of the edge, it is assumed that the distance of the jet reaching the rock from the tool edge should amount at 1-3 mm. Such a configuration allows reduction of forces affecting the tool. It is connected with the fact that the jet reaches the area of cracks zone induced by the tool and additionally weakens the rock structure. It is important to direct the jet more or less parallel towards the tool application plane. Such a location provides best results due to additional hydrotransport of the output by the jet.

For location of the jet in the rear of the tool edge, it is assumed that it should hit the plough bottom and its sides in the distance not higher than 30 mm from the tool edge and be tangentially directed towards the tool application plane. It enables sprinkling the rock in the place most endangered to spark occurrence which may initiate ignition, and moreover such a location of the jet in relation to the application plane allows intensive moistening, for higher feed pressures, the area crushed under the application surface. A view of exemplary applications of high pressure assistance systems on roadheaders heads is presented in fig. 7.

The high pressure nozzle diameter and the pressure of water feeding the nozzle depend mutually. It is connected with the flow rate of a single nozzle. For bigger diameters of nozzles, the value of maximum pressure available at the nozzle mouth for a given high pressure unit of limited efficiency falls. Whereas, at high required pressures, it is necessary to apply nozzles of smaller diameters. Practically, the diameter of nozzles applied for high pressure assistance of cutting tools fits the range from 0,35 to 1.0 mm, whereas the value of pressure in case of assisting the whole mining heads should not exceed 45 MPa. Introduction of assistance with water jets of such or higher values also enables mining rocks of abrasion coefficient reaching 1,0 N/mm, and momentary resistance against single axis compression R_c even 150 MPa. Moreover, application

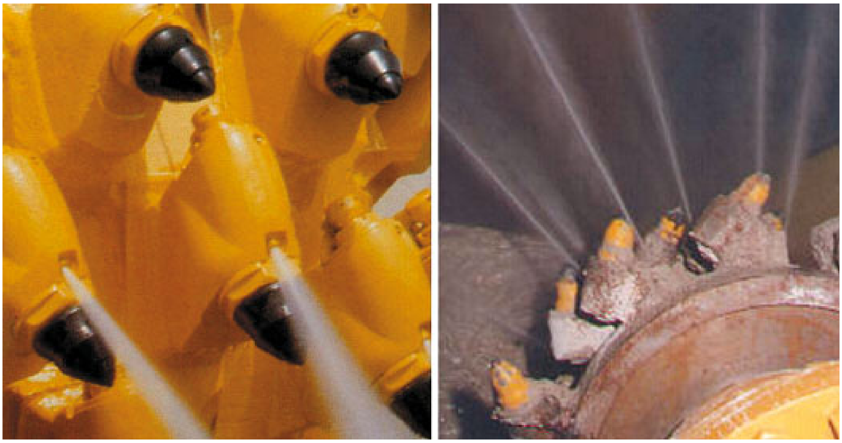

Fig. 7. A view of exemplary applications of high pressure assistance systems on roadheaders heads: on left – in the rear, on right – in the front

of high pressure assistance in lighter roadheaders allows their use without deeper constructional changes in excavations where, in case of mechanical mining only, heavy roadheaders should be introduced with engines installed for mining unit drive of electric power two times higher. However, there is a breakeven point of applying high pressure assistance with water jets. At average electricity consumption at about 120 kW (fig. 8), the introduction of high pressure water jets assistance of pressure values from 100 to 150 MPa, increases the electricity intake by about 2 to 2,5 times (Gospodarczyk at al., 1998, 2001).

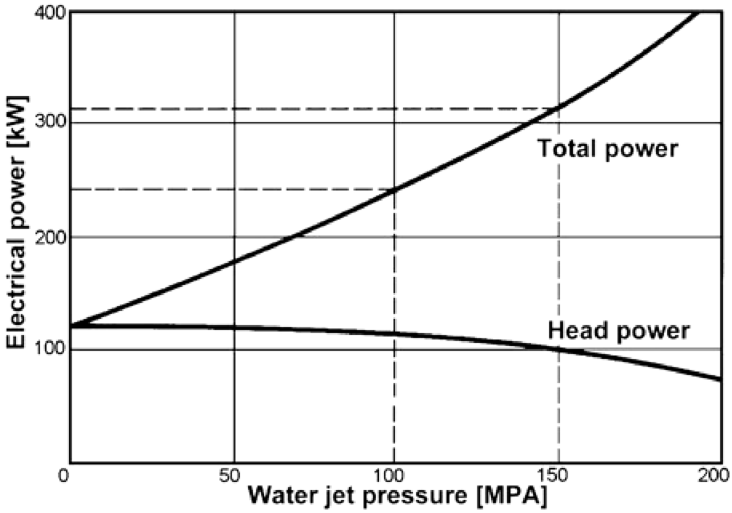

Fig. 8. Electricity consumption at mechanical mining with high pressure assistance

Benefits connected with applying high pressure water jets assistance of tangential rotary pick operation are significant. The high pressure jet from a nozzle located in front of the tool is forced into the area of cracked rock and moistens it which makes the mining process easier by lowering the rock strength. Additionally, at higher amounts of forced water, there is a possibility of easier output removal outside the plough through hydrotransport. Whereas, at high pressure of the assisting jet, a crack cut by it in the tool axis should lower the mining resistance and decrease the energy needed to disintegrate the rock by weakening its structure. The tool edge penetrates the cut gap as a wedge and tears the rock apart (Kotwica, 1998). However, in this option the moistening of the rock from the side of application surface cannot be taken for granted so it can cause increased friction of the surface against the rock and creation of sparks behind the cutting edge in the plough. This possibility is reduced to zero when the high pressure jet is directed from the rear of the tool directly into the plough. Though moistening the bottom and sides of the plough, a potential spark is put out immediately. The moistened rock also decreases coefficient of rock friction against the tool sides, and consequently the wear of the tool. It also limits the amounts of produced dust, especially at a blunt edge. Apart from direct factors listed above, there should be also considered indirect influence of the jet on decrease of dustiness due to edge wear through intensive cooling of the tool. It is connected with phenomena accompanying the decrease of friction coefficient like decrease of holding down force and the edge operation temperature. There are a few results of introducing high pressure assistance of the process of compact rocks mining with tangential rotary picks.

Research studies concerning the issue have been performed in European research centres, in the USA, Australia and also in the Department of Mining, Dressing and Transport Machines at AGH University of Science and Technology in Cracow. A big part of the studies included assisting compact rock mining with radial tools. At water jets pressure values reaching 45 MPa, significant reductions of values of holding down (up to 45%) and cutting (up to 25%) forces were obtained as well as lowering the temperature of the tool edge by more than three times, or as in the test by Hood a possibility of effective mining of a compact rock – granite at two times deeper level of cutting at assistance of 50 MPa jets and the same value of the cutting and pressure force (Hood at all., 1990). In most cases the jet was located in front of the edge. Such a location of the jet in relation to the tangential rotary pick edge for lowering the forces value on the tool was confirmed by laboratory tests performed by Ozdemir (Hood at al., 1990). Their results are presented in fig. 9. The best results were obtained at the distance of the jet to the tool edge of about 3 mm.

Similar results were obtained during tests of assistance of tangential rotary picks on arm roadheaders heads performed in Bergbau Forschung (Kleinert, 1985). In this case the total wear of tools was additionally measured. Fig. 10 presents results obtained during water assistance with jets of 0,6 mm diameter of tools mounted on a transverse unit, at mining a rock block of 83 MPa resistance.

Whereas, applying mining assistance of tangential rotary picks with jets in rear of the edges, only slight reduction of the value of cutting and holding down forces was obtained. However, the studies confirmed a high influence of such assistance on lowering the tools wear. Underground tests in the Heinrich Robert mine using the roadheaders AM-105 were performed during heading mining in rocks of momentary compressive strength up to 180 MPa (Gospodarczyk at al., 1998). Rear assistance with jets of pressure up to 40 MPa and diameter of about 0,6 mm enabled effective rock mining at visible reduction of the tangential rotary picks of 22 mm carbide diameter wear per one unit of output. The tests results for different values of cutting speed are presented

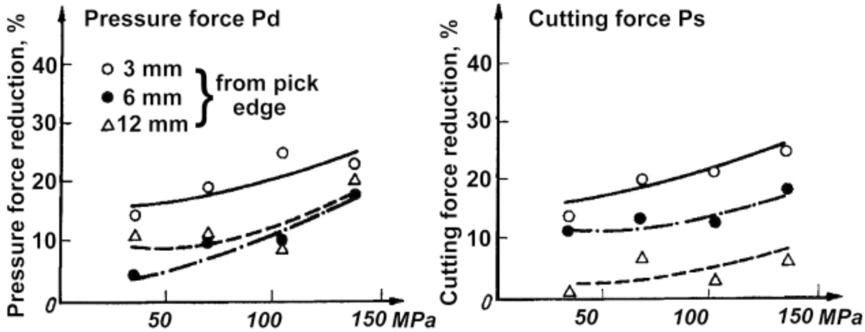

Fig. 9. An influence of water jet location in relation to the tangential rotary pick edge on lowering the values of cutting and holding down forces at mining sandstone at depth of 25 mm

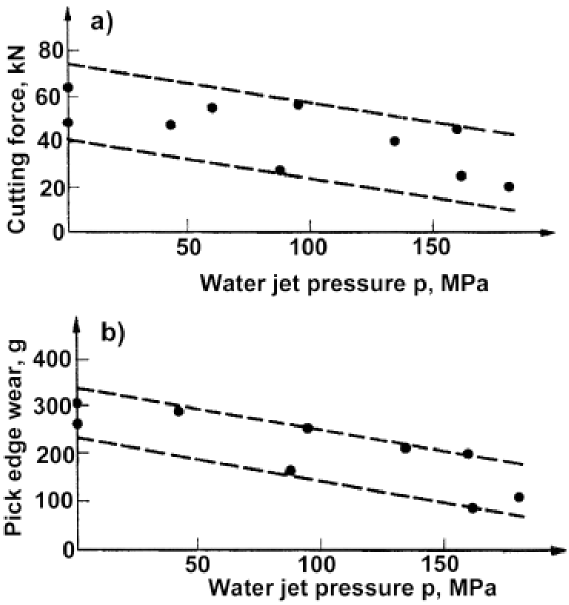

Fig. 10. An influence of high pressure assistance on: a) value of cutting force of the tool, b) wear of tangential rotary picks during mining a rock block of 83 MPa resistances

in fig. 11. The tools wear decreased almost by three times for the most frequently applied cutting speed of 2,5 to 3 m/s.

Most of the performed tests on the influence of the introduced water assistance of tangential rotary picks on their wear confirmed its reduction. However, the tests were performed in the aspect of quantity and not quality. Lower wear was confirmed but its character was not examined neither was even wear during mining. Moreover, it was observed several times that after finishing tests

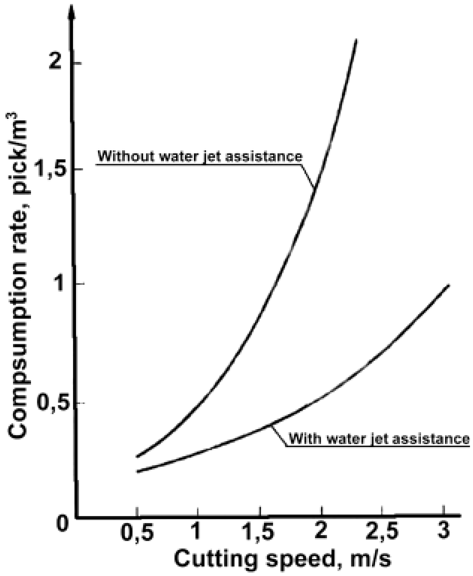

Fig. 11. Wear of tangential rotary picks during mining a heading face with the AM-50 header without ant with high pressure assistance

the tools rotation in the holders got blocked due to sedimentation and drying of wet dust from the mined rock. Consequently it led during further tests to uncontrolled, very uneven wear. That is why the Department of Mining, Dressing and Transport Machines at AGH University of Science and Technology in Cracow started works towards limiting or eliminating the phenomenon. The works results are presented below.

4. Application of water assistance in tangential rotary picks holders

As already mentioned increased and uneven wear of tangential rotary picks edges results from mainly reduction or even decay of the tool rotation in the holder. One of the main causes of the situation is worsening of cooperation conditions of the tool shank surface and the inner surface of the holder sleeve due to elements of dust and output penetrating both of them. It increases resistance of the tool rotation in the holder.

In order to solve the problem the Department of Mining, Dressing and Transport Machines at AGH University of Science and Technology in Cracow undertook attempts to bear the shanks of tangential rotary picks in holders to change dry or semi dry friction for mixed or half liquid friction. Because of limited constructional space defined by the tools dimensions, their holders and heads bodies as well as low rotary speed, obtaining liquid friction was not possible. Alternative methods of rolling bearing of tangential rotary picks were elaborated. It was to decrease the values of friction coefficient and consequently resistance of the tool rotation. A few solutions of rolling bearing holders using needle bearing and angular bearing were worked out (Kotwica & Maziarz, 2004).

In case of slide bearing, it was taken into consideration to apply exchangeable slide bushings made from hardened materials, self-lubricants, plastics based of PTFE or reinforced with carbon fibre or composite. However, the bearings of such types would work in unfavourable conditions (slide speed is low, and pressure high) which could create problems with the bearing durability. It was then suggested to force lubrication of cooperating surfaces of the holder sleeve and the tool shank.

In the elaborated solution the dry friction was replaced with boundary friction or mixed one which gets created as a result of partial division of unevenness tops and their moistening or covering with e.g. emulsion or liquid. The solution of modernized holder of RM8 system with forced lubrication is presented in fig. 12. In the solution the lubricant (low-grade oil and water emulsion or clean water) is distributed under pressure through the hole of the tubing barb 2 to four grooves in the sleeve 3 mounted in the tool holder 1 (Kotwica & Maziarz, 2004; Kotwica, 2005, 2010).

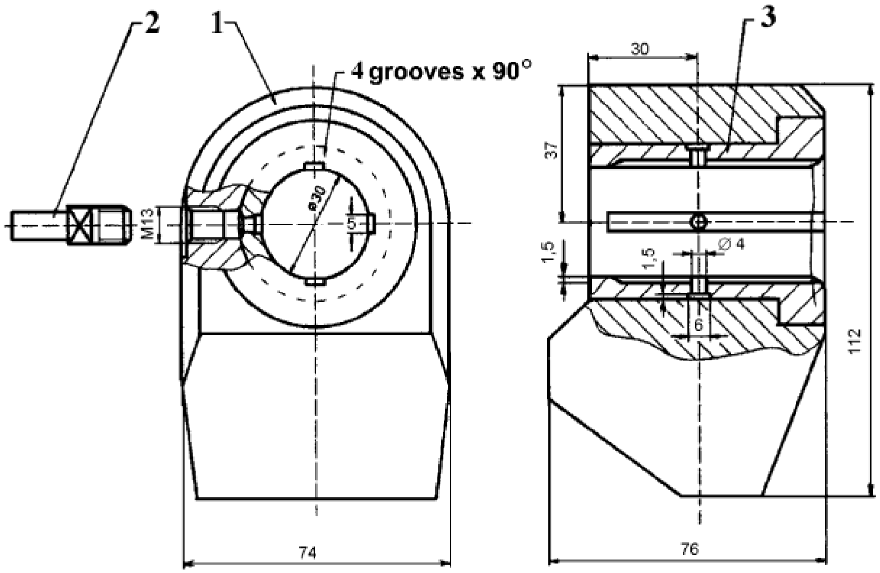

Fig. 12. Modernized, lubricated holder of tangential rotary picks of the RM8 system:
1 – tool holder, 2 – supply tubing barb, 3 – sleeve

In order to check efficiency of the suggested solutions, two prototype holders were manufactured – one with a rolling bearing, the other one lubricated and they underwent preliminary examinations on a special laboratory stand to determine the influence of the method of the tool mounting on the number of their rotations in the holder. The stand (fig. 13) allows mining a concrete sample on side surface at stable mining parameters such as depth, cutting pitch and speed and defined angles of the machine setting. The tests were performed as comparative ones for new

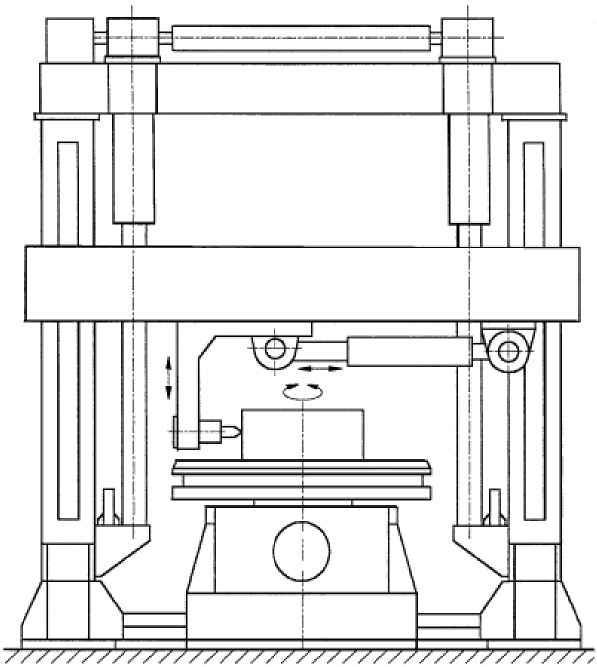

Fig. 13. A diagram of a special stand for examining individual mining tools

solutions of holders and the standard RM8 holder with the tool shank bearing in an exchangeable sleeve. For all tests tangential rotary picks of RM8-520 type were used with the diameter of carbide insert of 20 mm. The number of tools rotations was measured. During the tests the depth of cutting g = 9 and 12 mm was changed as well as side deflection angle v within the range from 0 to 45°. The rock sample resistance to single axis compression R_c = 65 MPa was stable as well as the cutting speed v at about 1,25 m/s and the pitch t = 12 mm. The sample mining was performed at its whole width and markers on the tools shanks or heads allowed counting the number of rotations per 1 minute. The measurement was performed for determined conditions of the tool operation. The lubricated holder was fed with 1,5% oil water emulsion in one of the cases and with clean water in the second one. In both cases the value of feed pressure p = 1,5 MPa. The obtained results of the rotations number measurement are presented on a diagram in fig. 14.

The tests indicated that in case of rolling bearing, even at zero deflection angle of the tools, they rotate in the holder. Also good, though not so favourable results were obtained with the holder with forced lubrication. However, it this situation the side deflection angle had to be at least 6°. Whereas, for the sleeve holder even the tool deflection by 45% did not cause its higher or even irregular rotations. An increase of the cutting depth from 9 to 12 mm influenced the number of rotations, especially in the sleeve and lubricated holders. High pressures at deeper levels of cutting significantly increased resistance and slowed the tool rotation. However, the complicated construction of rolling bearing, requiring high precision at assembling processes may not be accepted for application in underground conditions on mining heads (Kotwica, 2005, 2010). That is why the lubricated holder solution got examined more thoroughly in the further part.

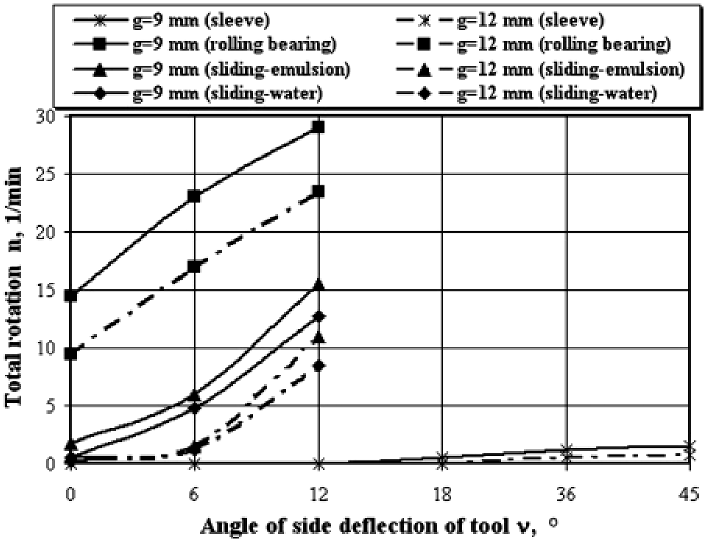

Fig. 14. An influence of the tool side deflection angle *v* on the number of its rotations in the function of cutting depth and type of holder

5. Results of laboratory and industrial tests performed in the Department of Mining, Dressing and Transport Machines, AGH Cracow

On the bases of the analyses of the above described results, designs were elaborated and new solutions of holders for tangential rotary picks with forced lubrication were implemented. Also designs for attaching plates for the holders and attaching ends feeding the lubricating medium were worked out. Due to different types of currently used tangential rotary picks and their differentiated geometrical parameters, only holders for tools of the shank diameter of 30 mm were elaborated. After conducted analyses, there were chosen solutions of a through sleeve with straight and helical grooves, a through graded sleeve and a closed sleeve with helical grooves and without them. The lubricating medium was delivered via four holes made every 90° on the sleeve circuit. The grooves were made in the way they could deliver the lubricant towards the face surface of the sleeve. The sleeves were pressed in a standard tool holder applied on the AM-50 roadheaders heads ((Gospodarczyk at al., 2005). A view of two exemplary sleeves and a holder mounted on a attaching plate, ready for further examinations is presented in fig. 15.

The tests performed on the stand for examining single cutting tools require a lot of work load and time. In order to tests the elaborated solutions of holders, it was suggested to work out and implement a stand which would allow, at minimal costs, performing tests of resistance of the tools rotation in the holders. A design for such a stand is presented in fig. 16.

The base of the stand is a frame 1 that articulates a liftable plate 2 mounted. The construction of the plate allows mounting bases of tools holders with holders and tools. Cut-outs on the liftable plate enable movement of holders along the plate. In the front part of the frame there is

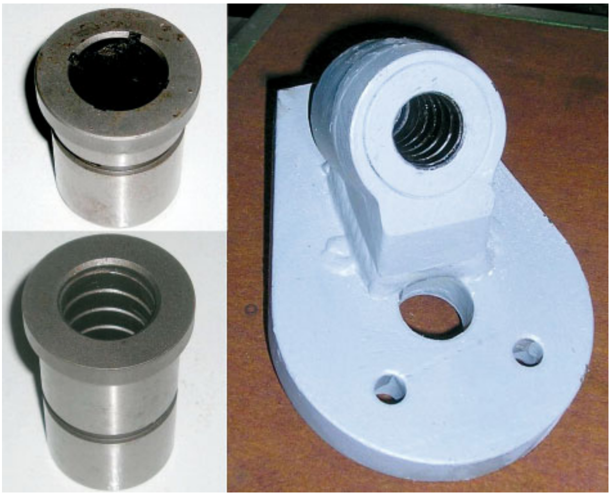

Fig. 15. A view of implemented solutions of a through sleeve with straight grooves and a closed sleeve with a helical groove and a holder mounted on an attaching plate

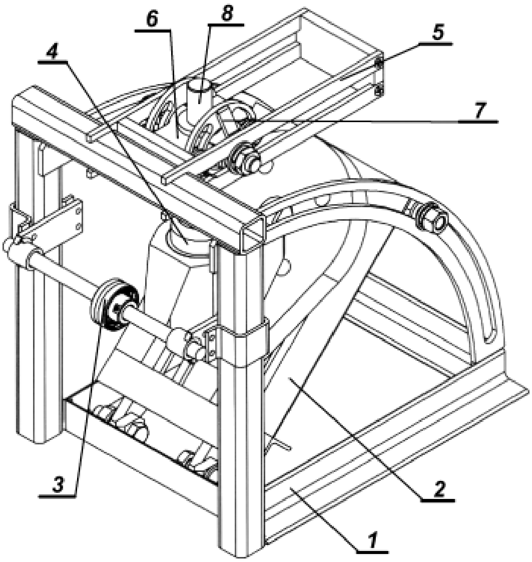

Fig. 16. A model of a laboratory stand for examining resistance of the tools rotation in holders

mounted a roller set 3, also with the ability to move. Whereas, in the upper part of the frame there is welded guide of the weight set 5. The weight set 6 moves on it with a possibility to rotate due to kidney type cut-outs on side plates of the set 7. In the weight set there is placed a weight 8 in a stroke mode and it presses with controlled force the tool 4 located in the holder. It can press the tool in its axis or from aside at a certain angle. Additional elements of the stand are special clamping rings for tangential rotary picks heads.

The stand tests relied on mounting on the liftable plate the examined tool holder with a tangential rotary pick with the ring. There was a string wound on the ring, rolled on the roller 3 and ended with a hook with attached weight of controlled value. After loading the tool top with a weight of a certain mass and in demanded direction, the value of weight attached to the hook was increased until the tool rotation was observed in the holder. Knowing geometrical parameters of the sleeve and holder in which the sleeve was pressed in as well as the value of the force affecting the string causing rotation of the tool in the holder, it is possible to assess the coefficient value of friction between the tool head and the sleeve surface and possibly the holder. General formula to assess the friction coefficient will have the following form:

$$\mu = \frac{M \cdot F}{Q \cdot S_o} \tag{2}$$

where:

M — value of the force moment at which the rotation of the tool in the holder took place,
F — surface area of the tool and holder contact,
Q — value of vertical force loading the tool,
S_0 — polar static moment of the surface in relation to its centre of gravity.

The value of the force moment M was calculated using the formula:

$$M = P \cdot r \cdot \sin\alpha \tag{3}$$

where:

P — force of gravity affecting the weight hung on the string,
g — gravitational acceleration,
r — radius of string winding on the ring,
$\sin\alpha = 1$, because the angle between the direction of P force action and the r radius is right.

The surface area of the tool and holder contact was calculated using the value of the tool shank diameter and the diameter of the sleeve or tool head (if it is smaller than the sleeve diameter). The value of vertical force loading the tool depends on the weight and tool mass. Whereas, the polar static moment of the surface in relation to its centre of gravity was calculated from the formula:

$$S_0 = \frac{2}{3}\pi\left(r_1^3 - r_2^3\right) \tag{4}$$

where:

r_1 — radius of the sleeve or tool head (if it is smaller than the sleeve diameter),
r_2 — radius of the tool shank.

Estimation of the coefficient value of the friction between the tool head surface and the surface of sleeve and holder is possible only if the load acts towards the tool axis and friction resistances between the tool shank and sleeve are omitted. In other cases it is only possible to compare calculated values of force moment at which the rotation of the tool in the holder took place.

For each holder there were several tests using tools with a shank of 30 mm diameter but of different diameters of the head, without or with assistance of the holder with low-grade emulsion or water at pressure of about 1,5 MPa and flow rate from 0,5 to 1 dm^3/min. The location and value of the force loading the tool were altered as well as the condition of surface between the tool head and the sleeve (it was polluted with tiny stone dust).

In comparison to tests performed with holders without assistance, the best results were obtained in case of closed holders. Even clean water applied at the pressure of 1 MPa and flow rate of 1 dm^3/min caused decrease of the rotation resistance from 50 to 80%. Lubrication with emulsion at the same parameters decreased the resistance by up to 5 times. In case of the open holder water assistance made the value of friction coefficient fall by about 25-40%. The surface pollution with dust or sand negatively affects the tools rotation resistance. The resistance values for the open holder increased by 3-3,5 times and for the holder more than 4 times.

Holders lubrication with emulsion significantly improves the situation at surfaces polluted with dust and sand. During lubrication with emulsion at flow rate of 1 dm^3/min and pressure of 1 MPa, only after dozens of seconds the value of resistance was lowered by a few times. The most favourable was the closed holder and the open one with straight grooves. The lubricant flowing between the sleeve surface and the tool head quite effectively washed out pollution. The value of rotation resistance measured after one minute lubrication was only slightly higher than in case of lubricating clean holders.

On the basis of obtained results, the holders with closed straight sleeve and the open one with straight grooves were selected for further tests on the stand for single tools examination. Tests of mining with the use of holders assisted with water and low-grade emulsion were performed and comparative tests of mining using tools of the same type without and with high pressure jet assistance in front of and in the rear of the tool were conducted. The tests with assisted holders were performed for tools of the Boart Longyear company of 138-139 mm height, 55 mm head diameter and carbide post diameter of 22 mm and two mining depths of 9 and 12 mm, assisted by 1,5% emulsion and water at pressure of about 1.0 MPa and flow rate of 1 dm^3/min. Whereas, mining without and with assistance with the use of the same tools was conducted only for depth of 9 mm, at water pressure of 45 MPa and diameter of 0,8 mm. Annular concrete samples were mined at the side surface. Their resistance against single axis compression was about 105 MPa at cutting speed of 3 m/s and total path of cutting at 2500 m at side deflection angle at about 9°. A view of tools during mining tests without and with assistance is presented in fig. 17, whereas a view of the holder with open sleeve with straight grooves, assisted with low-grade emulsion at intervals of every 0,5 s from the assistance inclusion is presented in fig. 18 (Kotwica, 2005, 2010).

During mining with tools mounted in holders assisted by both water and emulsion, occurrence of more or less regular rotation of the tools was observed. It caused regular and slight wear of the tools edges. Moreover, it was found that both the tool surface and cooperating surfaces of the tool heads are clean without pollution which does not take place in case of tools assisted with high pressure water jets or dry operating. A view of one of the tools and the surface of a holder with closed sleeve, after tests of rock sample cutting at the length of about 1000 m, with holder water feed is presented in fig. 19. The obtained results of tools edges wear measurements during the tests seem to be interesting. A view of tools mining without assistance and with front or rear assistance, as well as a tool mounted in open holder assisted with emulsion is presented in fig. 20.

The results of both quantitative and qualitative wear are significant. The wear measurement was conducted with the use of optical microscope allowing imaging the tool edge profile. Such measurement for each tool was performed in three plates every 120° before and after mining

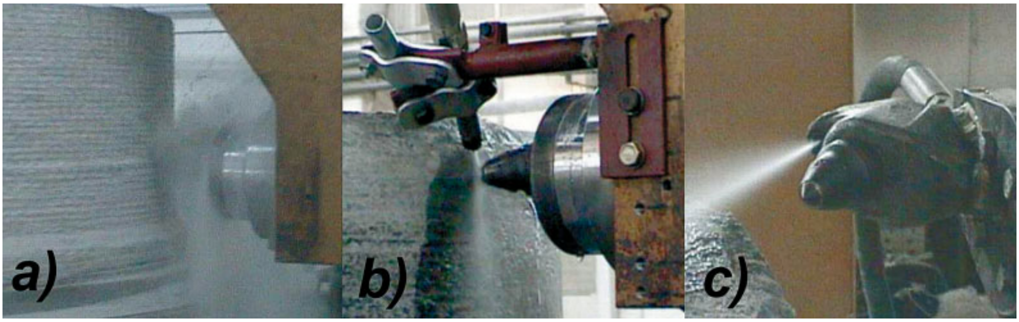

Fig. 17. A view of mining a concrete sample with a tool: a) without high pressure assistance, b) with front assistance, c) with rear assistance

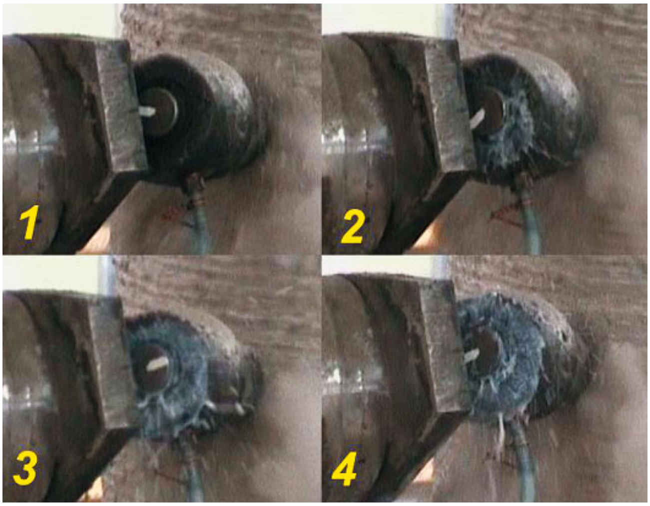

Fig. 18. A view of a holder with open sleeve with straight grooves assisted with low-grade emulsion at intervals of every 0.5 s from the moment of assistance addition

tests. Applying a computer programme Matlab, each profile was described with polynomial curve, imaging solid of rotation. The differences of solid volume before and after mining tests was determined and the obtained result was averaged (Kotwica, 2005, 2010).

Such measurement enables not only calculation of volumetric tool edge wear, but also determination of the wear character, even or uneven. For tools presented in fig. 19 their volumetric wear results are presented in fig. 21.

Mining without assistance caused catastrophic wear of not only edge itself but also the half of the tool head. Whereas, wear of tools edges with application of high pressure water jet assistance was a few times lower and comparable for location of the jet in front and rear position. Lubrication of the holder with low-grade emulsion caused even higher, by more than 25-30% reduction of wear.

Fig. 19. A view of a tool edge and holder surface with closed sleeve after tests of rock sample cutting at the length of about 1000 m, with holder water feed

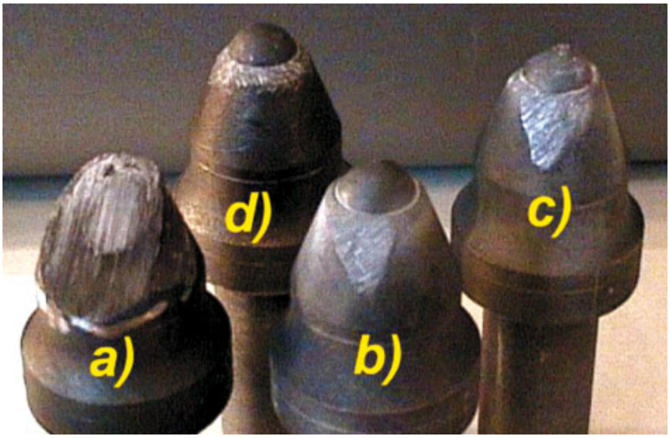

Fig. 20. A view of tools edges after mining tests: a) without assistance, b) with assistance from the front, c) with assistance from rear, d) in lubricated holder

Comparing the character of the wear, it can be visually ascertained that for mining with high pressure water jet there occur traces of uneven wear which subsequently may lead to fast tool destruction. The tool edge mounted in a lubricated holder is worn very evenly. It is confirmed by results of profiles measurement under an optical microscope. Exemplary profiles for a tool edge assisted with water jet from rear and a tool in a lubricated holder are presented in fig. 22.

The influence of introducing assistance of holders lubricated with water on the quantity and character of tangential rotary picks wear was confirmed by field and industrial tests performed with the use of arm roadheaders AM-50 (Gospodarczyk at al., 2005, 2007). Two cutter gibs of cutting heads were conducted – one equipped with holders with open sleeves with straight grooves and the second one with closed sleeves. The holders were assisted through canals created

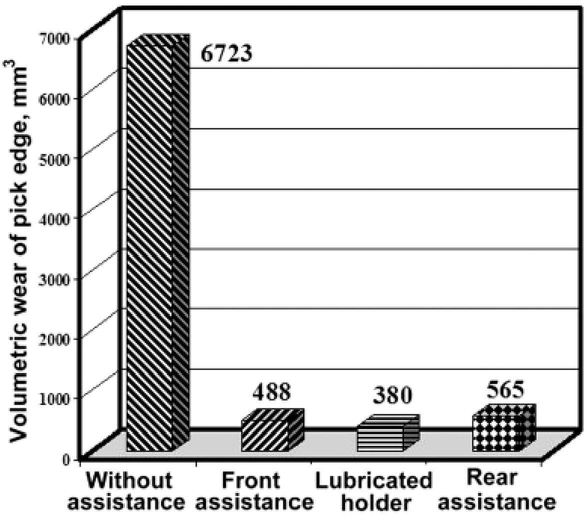

Fig. 21. Volumetric wear of tools edges after mining tests without and with high pressure assistance and in assisted holder

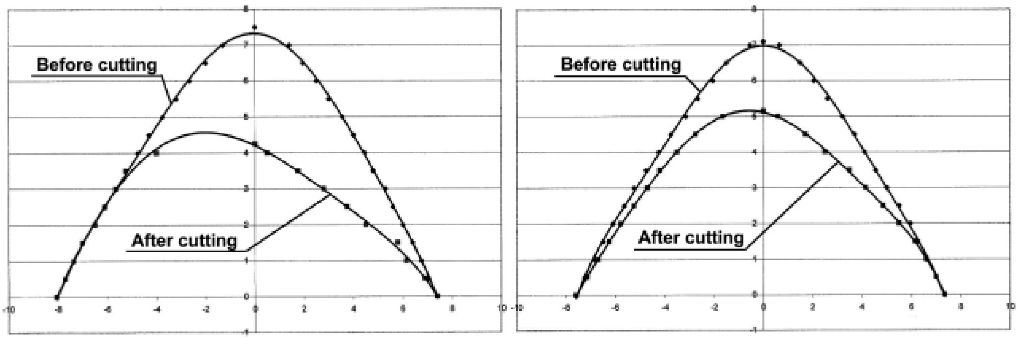

Fig. 22. Exemplary profiles of tangential rotary picks edges wear at mining with assistance from rear (on left) and with lubrication (on right)

in the head by water under pressure of 1,5 MPa and flow rate of 60 dm^3/min, circa 1 dm^3/min per a holder. A view of cutter head with open sleeves with straight grooves, after addition of assistance is presented in fig. 23.

Field tests were conducted on a large-size concrete block of resistance against single axis compression of about 60 MPa. The block was mined for the same time with the use of standard heads and heads with lubricated holders. A significantly smaller, even by 50%, and very even wear of tools edges was obtained. The results were more favourable for holders with closed sleeves. However, the tools tended to fall out the holders – problems with proper mounting.

The same results were obtained during underground tests in ZG "Janina" in Libiąż when mining a hard coal-rock face (Kotwica, 2010). The comparative tests of standard heads and the ones with lubricated holders were performed for a longer period of time (two working shifts per one head). Most of the tools mounted in lubricated holders did not show traces of wear or pollution after tests, whereas on standard heads 50% of tools could not be used any longer and were polluted. A view of standard heads and the ones with lubricated holders after mining tests is presented in fig. 24.

Fig. 23. A view of tool mounted on the head `of AM-50 roadheader in lubricated holders with open sleeve, after addition of water assistance

Fig. 24. A view of a mining unit after underground mining tests: on left – head with tools in standard holders, on right – head with "clean" tools mounted in holders lubricated with water

6. Summary

Mining of compact rocks with mechanical methods with the use of arm roadheaders with heads with tangential rotary picks is currently the most popular method of drilling headings. However, it is connected with increased wear of cutting devices. High effects are obtained applying new generation tools with multilayer carbide, pileus and cap types. But in order to increase durability, safety and cutting devices work efficiency, it is necessary to apply assistance of tools mining process with high pressure water jets. At present, due to fighting explosion and dustiness threats, the system with rear assistance is preferred. However, as it was demonstrated by performed tests, better results can be obtained by application of water assistance (lubrication) of tool holders, even with clean water. The method enables increase of tangential rotary tools rotation in the holder and subsequently allows obtaining lower and more even wear of tools edges.

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