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Influence of the drill bit tip geometry on the rotary drilling process performed with a hand-held hydraulic drill

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Abstract
In the mining and construction industries, hand drills are used to carry out many processes related to excavation and auxiliary works. Hand drilling is commonly applied for making small diameter holes, especially in hard-to-reach places. In the case of manual drilling, an important parameter is drilling resistance, especially torque. Drilling tools are subject to wear, which has a negative impact on the process of drilling, including resistance and efficiency. A blunt tool lowers the drilling speed and puts more strain on the operator. The article presents the results of laboratory tests of selected parameters of the drilling process carried out with a hydraulic rotary drill. The tests were performed with the use of new drill bits as well as drills characterized by a various degree of wear. The tests were carried out for popular, frequently applied rotary drilling tools, on a unique laboratory stand that enabled setting the feed force and measuring the torque, rotational speed, drilling path, drilling speed as well as the in and out pressure of the drill. A number of characteristics were determined as a function of time and depth of the drilled hole. It was found that tool blunting affects the drilling process in various ways, whereas the intensity of this influence is determined by the type of blunting. The test results can provide a basis for developing a criterion for replacing a drill bit with a new one.

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1. Introduction

In the mining and construction industries, hand drills are widely used in many processes related to excavation, technological processes and auxiliary works. Rotary drilling is carried out with the use of tools called drill bits. Examples of drill bit solutions are shown in Fig. 1.

The rotary mining process is characterized by continuous friction of the tip against the bottom of the hole. Depending on the working conditions and the type of rock being mined, various types of tip wear can be observed. The tip may chip and it is always subject to abrasive wear (Fig. 2). The abrasive wear of the edges causes an increase in the cutting resistance, which translates into a higher torque and a decrease in the drilling speed.

In the case of manual drilling, an increased torque adversely affects the operator, reducing the comfort of work. In addition to the negative impact on the operator, an increase in the resistance and a decrease in the drilling speed also contribute to an increase in the process energy consumption and higher costs.

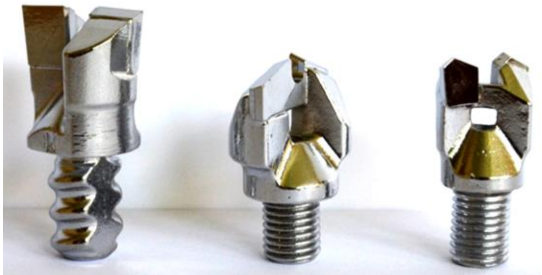

Fig. 1. Examples of drill bits currently available on the Polish market (Kennametal)

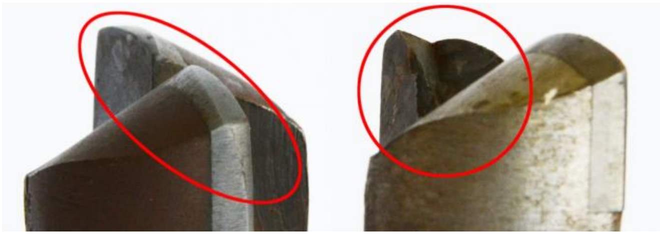

Fig. 2. Examples of drill bit wear

Knowledge about the impact of the type and degree of wear on the cutting resistance of the currently used drill bits will enable formulating recommendations and guidelines on the replacement of drill bit with new ones. Used drill bits are subjected to regeneration, which restores their functional properties.

2. Literature review

Drilling as a mining method is widely used in underground and opencast mining as well as in the construction industry. Among the numerous drilling methods, rotary drilling is one of the most important ones. It is applied not only for manual drilling but also in the case of drilling rigs.. Every rock mining process results in the wear of tools, which increases the energy consumption of the process and reduces the efficiency. Mining tools' durability, rock abrasiveness and cutting forces are the subject of many studies (Bołoz and Midor, 2019; Krauze et al., 2019; Kahraman et al., 2018; Hamzaban et al., 2023; Biały, 2015; Krauze et al., 2015; Bołoz, 2020). In the case of currently used tools for rotary drilling, the impact of the type and degree of wear on the cutting resistance has not been investigated. There are studies from several decades ago, but they concern tools of a different design.

The subject literature offers numerous studies devoted to issues similar to those presented in this article. The wear and quality of mining tools is subject to product life cycle management discussed in many articles on the example of various industries (Saad and Youness, 2023; Skowron, 2015; Siwiec and Pacana, 2021; Midor and Wilkowski, 2021).

The authors of one of the articles (Beste and Jacobson, 2008) raised the subject of the mechanisms of destruction of sintered carbide tips used in button bits. In their investigations, the researchers used high-resolution photos of worn tips.

Many studies quote the results of tests of tools for percussion and rotary-percussion drilling. For example, one article (Saai et al., 2020) presents comparative studies on the abrasive wear resistance of tips made of different grades of sintered carbides, including a diamond-reinforced tip.

One of the articles devoted to drilling in the petroleum and gas industry addresses the topic of tip-hole bottom interaction, including friction and wear, in order to analyse rod deformation (Kessai et al., 2020). Similarly, another article (Gupta et al., 2013) presents the issue of wear and erosion of tools for rotary-percussion drilling in the oil industry.

Research on the efficiency of rotary core drilling was the subject of another study (Sakiz et al., 2022). The authors carried out tests under 12 different working conditions, determining, among others, the cutting resistance, but only for new tools.

The results of research on the impact of the geometry of the composite tool tip on drilling efficiency have been presented in one of the papers (Feito et al., 2014). In addition to the angle of the tip, the authors studied the impact of wear by grinding the tool edge. However, the research concerned completely different, prototype solutions.

One of the studies contains the results of research on the durability of WC carbide tips, taking into account the correlation between the temperature and the rate of wear (Shankar et al., 2020). The tests were carried out for various sandstones.

One can also find the results of research on composite and PDC (Polycrystalline Diamond Compact) button bits that are used for drilling geothermal wells (Liu et al., 2022). The authors studied the cutting resistance as well as other parameters during drilling in sandstone and granite. They also analysed the degree of tool wear.

Another paper presents a method of estimating the torque during rotary drilling with the use of the Kalman filter (Riane et al., 2022). The researchers developed their own torque estimation algorithm, which they verified in laboratory tests.

The authors of one of the papers have predicted the rate of button bit wear rate based on the Rock Abrasivity Index (RAI), which is the product of rock strength and quartz content (Plinninger et al., 2002).

Many centres around the world are conducting research on the drilling process and tool durability. The topics studied concern various drilling methods and different tools. However, the impact of the type and degree of wear of the currently used hand drill bits for rotary drilling on the resistance and efficiency has not been investigated.

3. Experimental

The measurements of drill bits were carried out on a special test stand. The load-bearing element of the station is frame I (Fig. 3a). The sample positioning unit II with a cylindrical natural or concrete sample is placed on the frame. The weight of the sample before testing is approximately 190 kg. The sample is positioned each time before making a hole. Carriage III, equipped with linear bearings, moves on a frame equipped with precise rollers. Drill unit IV is attached to the carriage. The normal force is applied gravitationally by using ten-kilogram V-weights with a total weight of 120 kg. The carriage is lifted by means of a manual wire rope hoist with brake VI.

The most important part of the stand (Fig. 3b), which is also the subject of measurements, is drill 1 - H-WH1 produced by Hydromech S.A., which in the standard version is equipped with a spiral rod 2 and drill bit 3. This set makes holes in sample 4 during the tests. Drill 1 has been mounted in housing 5, which is rigidly connected to lower flange 6. Inside housing 5 there is an inductive sensor 7, which counts the presence of the steel mandrel 8 attached to the spindle in the rear part of the drilling machine, hence the number of mandrel occurrences per minute equals revolutions per minute. Upper flange 6 is pressed against the body of carriage 9 by slide pad 10, transferring the normal force from the carriage through the drill to the rod and drill bit. Inside the body of carriage 9, upper flange 6 is locked axially with lock 11, which supports the housing with the drilling machine during the lifting of the carriage. Upper flange 6 transfers the cutting torque from the drill to torque gauge 12, which is attached to the body of carriage 9 through upper flange 13. The carriage is equipped with a magnetic linear encoder 14, which determines the depth of the drilled hole and the speed of the carriage. The carriage speed v_p is equal to the mechanical drilling speed v_m.

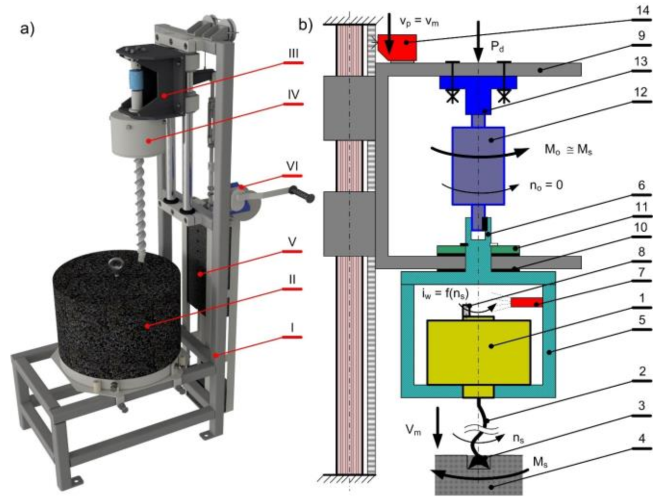

Fig. 3. Test stand:
a. virtual model: I – frame, II – sample, III – carriage, IV – drilling unit, V – weights, VI – wire rope hoist. b. diagram 1 – drill H-WH-1, 2 – spiral rod, 3 – drill bit, 4 – sample subjected to drilling, 5 – drill housing, 6 – lower flange, 7 – inductive proximity sensor, 8 – spindle mandrel, 9 – carriage body, 10 – slide washer, 11 – axial lock, 12 – torque gauge, 13 – upper flange, 14 – magnetic linear encoder

The measuring system consists of the following sensors:

- torque - DFM22-175-S Megatron torque sensor with a permissible torque of 175 Nm with a maximum error of ±0.1%,
- rotational speed - PCID 2ZN Sels inductive sensor allows measuring the rotational speed up to 15,000 rpm (250 rpm) with a maximum error of ±0.25 rpm,
- displacement - Lika SML linear encoder with MT32 magnetic tape with a maximum error of ±0.1 mm,
- pressure - MBS32 Danfoss sensors enabling measurement up to 40 MPa with a maximum error of ±0.5%.

The analysis of used drill bits that are commonly applied in practice enabled making a design of research tools with tips simulating various types and degrees of wear. The popular BOB drill bit with a diameter of 43mm was selected as a basic tool. The subsequently designed drill bits were marked as: new *N*, with a greater angle *K*, with chamfered sides *B*, with a chamfer on the cutting edge *F*, and with a flat bevel *S*, respectively. Selected drill bits have been shown in **Fig. 4**. The stand with the sample before and after testing is presented in Fig. 5, while Fig. 6 shows photos of selected drill bits before testing.

The tests were carried out on an artificial concrete sample with a uniaxial compressive strength of ca 7 MPa. A sample with a diameter of 500x410 mm enables making several dozen holes with a depth of up to 400 mm. The preliminary tests consisted in making four holes with a new drill bit (marked as *N*) for several different values of normal force (Fig. 7). Based on the preliminary tests, the normal force for the proper tests (72 kg) was determined and the correct operation of the stand and the measuring system was confirmed. The proper tests started after applying a load of 72 kg.

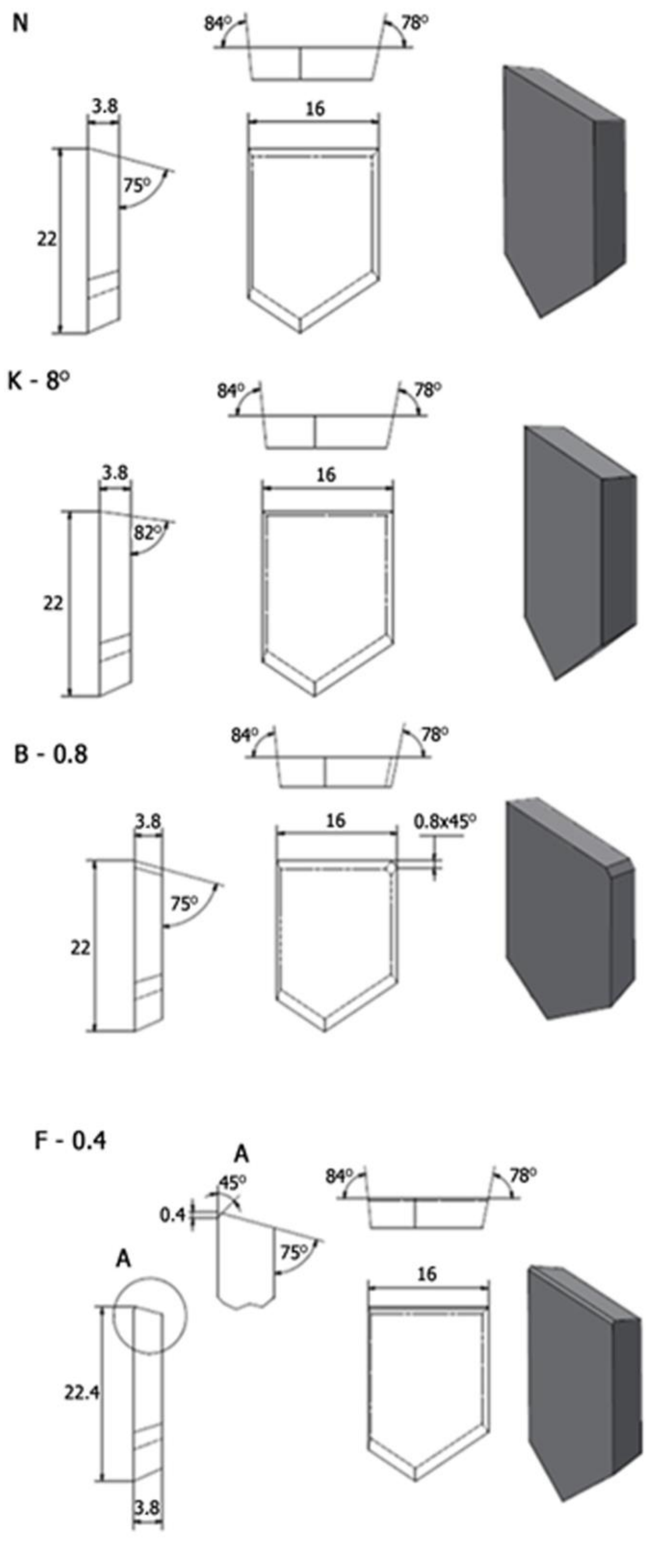

Fig. 4. Drill bits type N, K, B, F intended for testing

Fig. 5. Station with a sample before and after testing

Fig. 6. Photos of sample drill bits F and S before testing

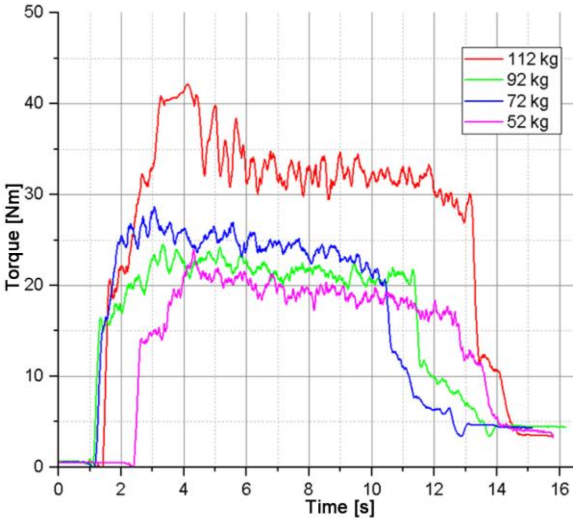

Fig. 7. The Course of the drilling torque for different values of new N drill bit feed force

4. Results and discussion

During the tests, waveforms from all the sensors were recorded. The data was prepared in the form of graphs, which enabled formulating a number of conclusions.

Fig. 8 shows a graph of the measured torque for each modification (type of wear) of the drill bit, starting with the S-type modification, which is characterized by a flat bevel of the tip. As the bevel increases, the torque is observed to decrease. Such a modification significantly affects the geometry of the tip, causing a decrease in the clearance angle to values close to zero. As a result, the rock is crushed by the axial force acting on the drill, and the cutting itself is not very effective. There is also a noticeable increase in the time of drilling a hole. For the extreme values of S reaching 0.2 mm and 1.6 mm, this time is more than five times longer. The torque measured for these tests ranges between 12-23 Nm for samples S 0.2, S 0.8. In the case of sample S 1.6, the torque is much lower and relatively constant throughout the test, ranging from 10 to 12 Nm.

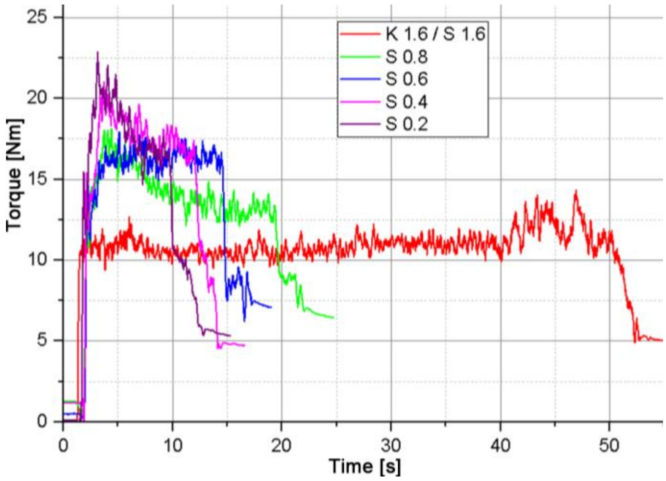

Fig. 8. Torque measurement for the S-type modification

The subsequent results concern measurements for the K-type modification, which consisted in changing the angle of the tip. Fig. 9 shows a graph of the torque measured for these samples. By default, the tip angle for the new drill bit was 75°.

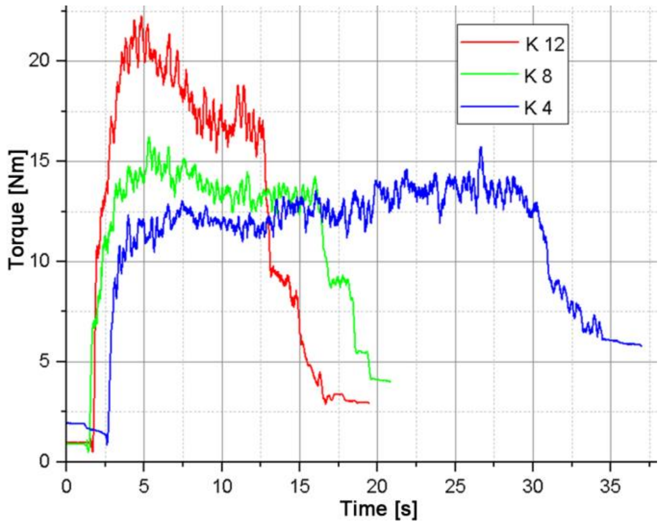

Fig. 9. Measurement of torque for the K-type modification

The modification was aimed at creating drill bits with tip angles of 78°, 82° and 86°. An increase in the angle resulted in a proportional increase of the hole drilling time, which for the maximum angle was almost twice as long as in the case of lower values. It should be noted that the increasing of tip angle adversely affects the clearance angle and the angle of attack.

Reducing these values to zero, especially the effective clearance angle, causes a decrease in the cutting efficiency.

In the case of the F-type modification, the cutting edge is chamfered. This gives the effect of a typical, most popular blunting of the tip. The results of torque measurement have been shown in Fig. 10. For this type of geometry change, no such large differences can be seen in the recorded data. However, it is visible that the drill bit with the least interference in geometry, which has been marked with a red line, made the hole in the shortest time. For tools with the largest chamfers: 0.6 mm and 0.8 mm, the torque was initially slightly lower, and the drilling process itself took longer. The torque values vary between 15 Nm and 22 Nm. However, the differences themselves are not very significant and only a large blunting of the tip would result in greater differences in the drilling resistance.

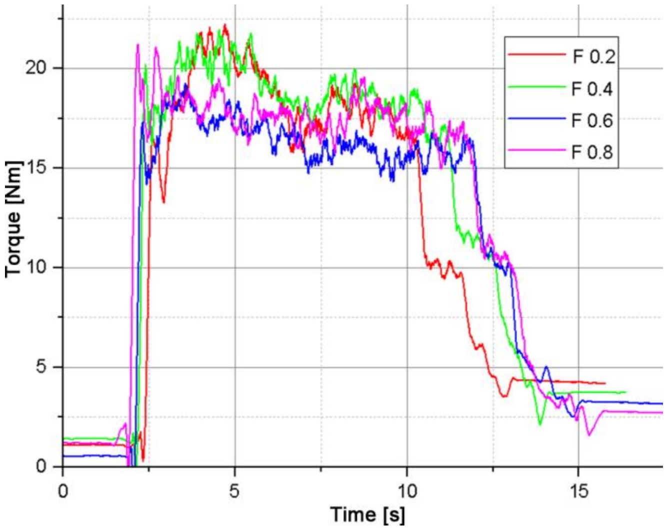

Fig. 10. Torque measurement for the F-type modification

The B-type geometry modification consisted in chamfering the tip sides from the inside. Bevelling of the tips from the outside has a negative impact on the drilling process, as the outer edges are involved in the cutting of the bottom of the hole and its walls. The test results for the B-type modification are shown in Fig. 11. There was a problem with temporary stoppage of the drill during the measurement of the B 1.2mm sample, so the test had to be repeated, which is visible in the graph. No significant differences in the obtained results were observed for particular degrees of wear of the B-type drill bit. Compared to other modifications, the torque measured for the B-type wear is characterized by higher values in the range of 20 - 30 Nm. It can therefore be concluded that such modification, regardless of its size, increases the cutting resistance.

Next, the displacement of the drill during drilling was analysed as a function of time. The drill displacement, i.e. the depth of the hole as a function of time, also affects the assessment of the drilling speed. This analysis was based on the measurement results for each modification, including the new N drill bit. The results are shown in Fig. 12.

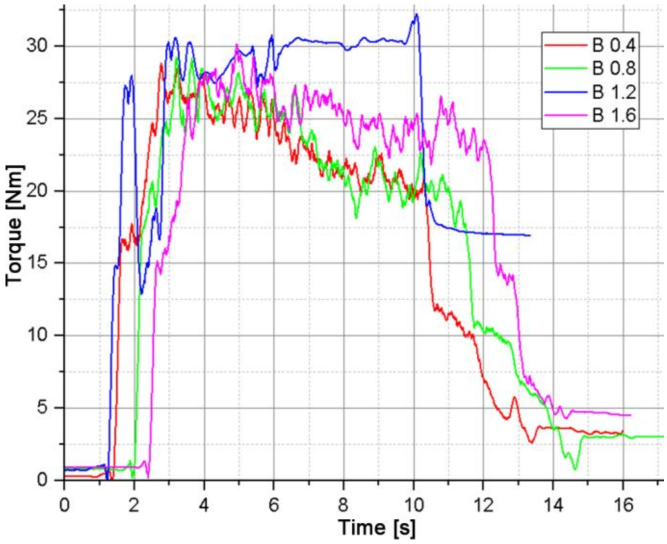

Fig. 11. Torque measurement for the B-type modification

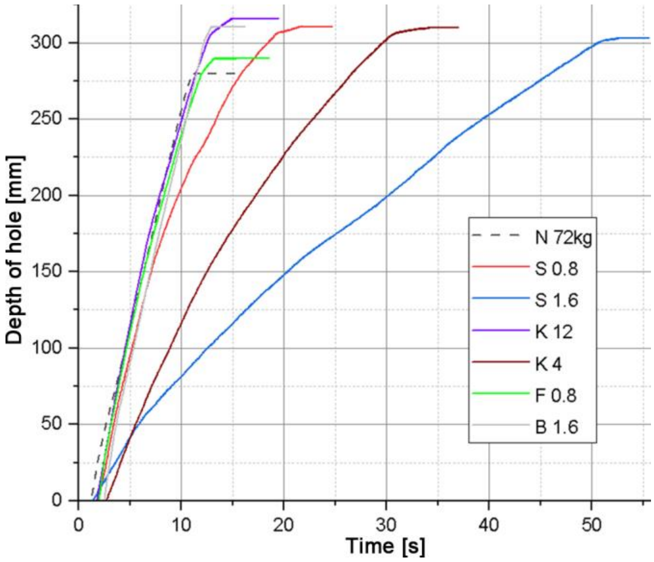

Fig. 12. Hole depths as a function of time

The diagram includes S-type tools: S 1.6 mm and S 0.8 mm, K 4 and K, as well as F 0.8mm and B 1.6mm drill bits. The new drill bit has been marked with a dotted line. Differences in the maximum drilling depth, i.e. the depth of the finished hole, result from different starting points for drilling the hole and different heights of drill bits, which are due to different types and degrees of their wear. However, these discrepancies do not have a significant impact on the waveforms subjected to analysis, because the slope of the curve to the time axis is of key importance. The greater the angle of curve inclination, the higher the drilling speed. The analysis of the graph allows concluding that the K 12, F 0.8 mm and B 1.6 mm drill bits were characterized by a speed comparable to that of a new drill bit. Therefore, the effect of these types of wear on the drilling speed is practically negligible. However, in the case of K 4, S 0.8 mm and S 1.6 mm modifications, an evident decrease in speed is visible. Compared to the S 0.8mm modification, the S 1.6 mm drill bit made a hole in a twice longer time. In this case, a visible effect of rock being crushed by the flat surface of the drill bit can be observed. It results in the failure to keep proper cutting angles, and, in consequence, long and energy-intensive drilling. In the case of the K4 drill bit, the situation is similar because of the too large angle of the tip.

The results describing the drilling depth as a function of time were used to draw graphs of the so-called mechanical drilling speed. The measurement system of the stand and an appropriate program in LabView also allow measuring the speed directly in the process of drilling. Fig. 13 shows graphs of mechanical drilling speed versus time for various drill bit modifications. Each curve shows an evident decrease in the drilling speed as the depth of the hole, increases. In the case of the B-type modification, the decrease is not significant; the speed stabilizes in the initial stage of drilling. However, significant changes are observed for the remaining modifications. The speed decreases noticeably in the case of longer measurements, such as S 1.6 mm and K 4. Drill bits with a large angle of the tip have a smaller cutting depth per revolution, which results in a longer drilling time, but also a lower drilling resistance torque. As the layer being cut is small and the resistance torque is lower, it is easier to maintain the drilling speed. However, the drilling speed for the B-type modification is relatively constant and the torque is high. Stabilization of the mechanical drilling speed is in this case is influenced by the fact that the selected modification does not have a significant impact on the drilling efficiency. The analysis of the remaining data indicates evident decreases in the drilling speed, which are associated with the increasing degree of drill bit wear and increased resistance involved in the removal of cuttings from the hole.

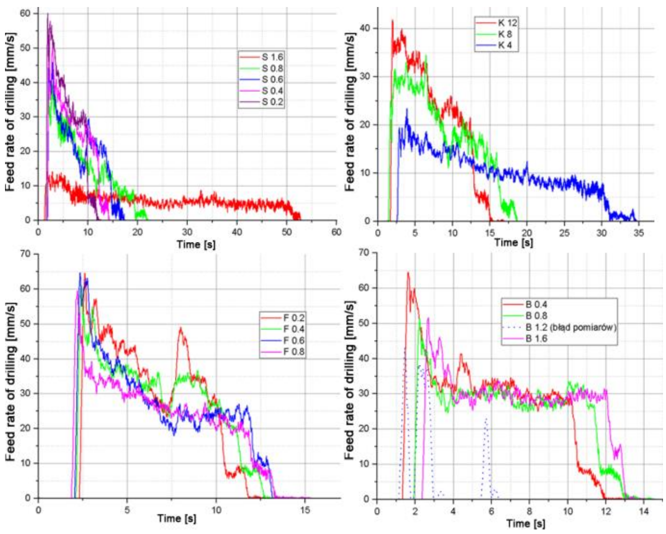

Fig. 13. Mechanical drilling speed as a function of time

Another analysed parameter was the rotational speed of the drill bit as a function of time, calculated on the basis of indications of the inductive proximity sensor, which recorded signals from the mandrel rotating with the rod. One impulse per revolution was obtained, which, however, is sufficient for such high rotational speeds. The results have been presented in Fig. 14. Based on the obtained graphs, two groups of drill bits with similar rotational speeds can be identified. Drill bits F 0.8 mm, K4 and N were characterized by a higher rotational speed within a range of approx. 500 to more than 600 revolutions per minute, while in the case of other drill bits this value ranged from 300 to more than 400 revolutions per minute. The graph of tools' rotational speed had only a cognitive value, while the most important was the analysis of the mechanical drilling speed and the torque.

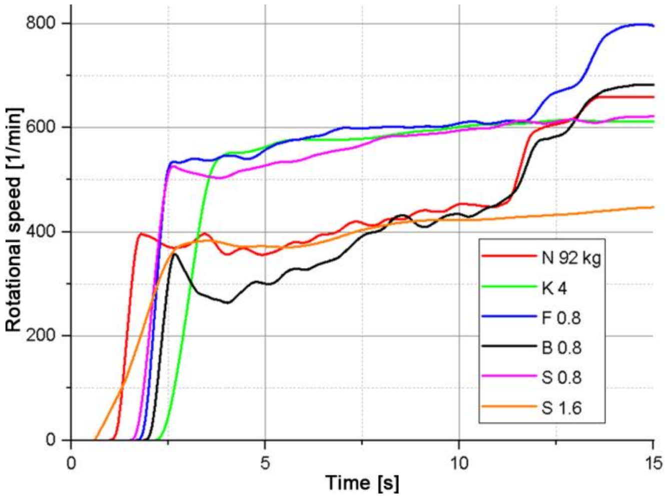

Fig. 14. Rotational speed during drilling

5. Summary and conclusions

Rotary drilling is commonly applied in the mining and construction industries for making small diameter holes, frequently in hard-to-reach places. The most popular methods involve the use of drills with a hydraulic drive. This type of equipment makes it possible to work in difficult conditions, while maintaining a low weight at a high torque. Such drills enable drilling in salt, coal, concrete and many other minerals.

The stand used for testing allows carrying out a series of measurements and recording quantities that are significant from the point of view of the drilling process. Based on the analysis of the common types of wear, it was possible to make special drill bits the geometry of which simulated blunt drill bits. For the purposes of the research, the prepared sample had parameters similar to those of rocks intended for manual drilling. Twenty drill bits were subjected to measurements, which allowed examining the impact of the modified geometry and normal force on individual parameters.

In the case of drill bits with the B-type modification, there was no significant effect on the drilling parameters in relation to new drill bits. Even a greater degree of wear did not affect the speed. The torque was relatively high, but the drilling itself was similar to that of a new drill bit.

In the case of modifications of the S-type or K-type tip, the impact is very noticeable. These modifications significantly affect the load on the drill and extend the cutting time. The cutting itself becomes increasingly less effective as the degree of blunting increases. The drilling speed drops, and in many cases the decrease is significant. Depending on the type of wear, different torque values were obtained during drilling.

Each measurement provides a lot of information, not only with regard to the type and degree of blunting, but also the depth of the hole. In the article, selected correlations have been presented, while the obtained results can be analysed in many ways.

The obtained results allowed formulating a number of conclusions regarding both quantity and quality. It was determined which types of wear have the greatest impact on the drilling process and which exert only a marginal influence. In addition, the influence of the degree of blunting of the drill bit tip on the drilling resistance and effectiveness was determined, which allowed specifying recommendations on the criteria for the replacement of the drill bit with a new one.

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钻头尖端几何形状对手持式液压钻机旋转钻孔过程的影响

關鍵詞

旋转钻机
液压钻机
手持式钻机实验室测试
采矿钻机

摘要

在采矿和建筑行业中，手钻用于执行许多与挖掘和辅助工程相关的过程。 手动钻孔通常用于制作小直径孔，特别是在难以到达的地方。 在手动钻孔的情况下，一个重要的参数是钻孔阻力，尤其是扭矩。 钻井工具会受到磨损，这会对钻井过程产生负面影响，包括阻力和效率。 钝的工具会降低钻孔速度，给操作员带来更大的压力。 本文介绍了使用液压旋转钻机进行的钻孔过程的选定参数的实验室测试结果。 测试是使用新的钻头以及具有不同磨损程度的钻头进行的。 这些测试是在一个独特的实验室台上对流行的、经常使用的旋转钻孔工具进行的，该实验室台可以设置进给力并测量扭矩、转速、钻孔路径、钻孔速度以及钻头的进出压力。 许多特性被确定为时间和钻孔深度的函数。 研究发现，刀具钝化以多种方式影响钻孔过程，而这种影响的强度则由钝化的类型决定。 测试结果可以为制定更换新钻头的标准提供依据。