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HIGH ENERGY LIQUID JET ASSISTANCE OF ROCK CUTTING PROCESS

Summary. The interaction between rocks and the cutting tool is the main topic of this paper. Methods for classification of the decisive properties in relation to the cutting process are presented. Research on wearing process of the bit tips and pick consumption is described. Influence of the jet assistance on cutting process based on measurements of cutting and normal forces and energy consumption is discussed.

UDZIAŁ STRUMIENIA CIECZY O DUŻYM CIŚNIENIU W PROCESIE URABIANIA SKAŁY

Streszczenie. Tematem niniejszego artykułu są wzajemne związki zachodzące między skałą a urabiającym ją narzędziem. Przedstawiono metody klasyfikowania kluczowych parametrów procesu urabiania. Opisano badania procesu zużycia noży skrawających i energii skrawania. Ponadto poddano dyskusji wpływ strumienia cieczy na proces urabiania w oparciu o pomiar sił skrawania oraz energii urabiania.

1. INTRODUCTION

Cutting of hard rock requires excessive external energy and therefore still presents a special problem for mining and underground civil engineering. Effective and economical cutting of hard rocks depends on the performance of the cutting tool. An ideal cutting tool should have a high cutting performance and low wear and consumption of specific energy. It should be able to penetrate deeply into the rock and generate neither an excessive quantity of dust nor friction ignition. Furthermore, it should maintain a proper optimum temperature and its cost should be low.

Mining practice has demonstrated that none of available tools can satisfy all the above requirements. The results of long-term and extensive activity in the field of cutting tool development reveal that despite the indisputable progress in the solution of the cutting tool geometry, application of new materials and new production technologies the development of a new cutting tools capable to effectively disintegrate hard abrasive rock has been unsuccessful (Vašek, 1992).

2. CUTTING TOOL-ROCK INTERACTION

The cutting tool-rock interaction has not been completely examined so far and therefore greater attention should be paid to this problem. New possibilities for the application of many physical disintegration principles are coming into existence, allowing creative and constructive opportunities for scientists and technicians.

At present, the conventional approach remains based on the principle that greater rock reactions are overwhelmed with greater actions, using heavier and more powerful and more expensive machines.

Due to the interaction of high action and high reaction, a high level of contact stresses is achieved, with negative consequences. High contact stresses result in quick blunting or even failure or the disintegration tool, which was originally the cause of the stress (Fig. 1.).

This problem is generally resolved by changing the mechanical tools more frequently and by manufacturing the tools from more resistant materials.

Fig.1. Worn point attack cutting tools

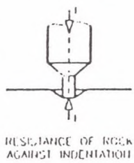
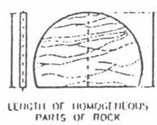
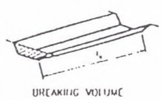
Rys.1. Zużyte ostrza narzędzi skrawających

3. DECISIVE PROPERTIES OF ROCKS

The method of calculating the cuttability of rocks using special testing equipment was developed in Czechoslovakia. The evaluated parameters are WORKABILITY, ABRASIVITY, INDENTATION STRENGTH, DEGREE OF FRACTURING and SPECIFIC ENERGY (Tab. 1., Vašek, 1995).

Table 1

Decisive properties of rocks

Decisive Properties of Rocks	Symbol	Unit	Schematical Sketch of the Mode of Measurement	Calculation	Standard
Workability	*R*	$kN.m^{-1}$		$R = \left(3 + \frac{\sum_{i=1}^{n} \frac{\phi F_{zi\,min}}{h_i}}{\sum_{i=1}^{n} \frac{\phi F_{zi}}{h_i}}\right) \frac{\sum_{i=1}^{n} \frac{\phi F_{zi\,max}}{h_i}}{4n}$	ON 441120
Abrasivity	F_v	$mg.m^{-1}$		$F_v = \frac{G}{L}$	ON 441121
Indentation Strength	σ_{vt}	MPa		$\sigma_{vt} = \frac{\sum_{i=1}^{n} F_{i\,max}}{S_i\, n}$	ON 441121
Degree of Fissuration	*SP*	-		$SP = 1 - \frac{\left[25\sum_{i=1}^{4} f_i + 50\sum_{i=1}^{4} i f_{i-1} + 200(f_k - 100)\right]^2 \xi}{10^4\, l_{max}^2}$	ON 441122
Specific Energy	*SE*	$MJ.m^{-3}$		$SE = \frac{F_z\, l_x}{v}$	

For rough estimation of the consumption of rotating point-attack picks type TN-20 (Czech made), the following empirical relationship was proposed (Vašek 1990):

$$S_p = -\frac{1}{Kk}\ln\left(123 - \frac{(R+200)(F\upsilon+2)}{5410}\right) \quad [\text{pick}\cdot\text{m}^{-3}] \tag{1}$$

where

S_p - pick consumption (pieces m^{-1}),

R - workability (kN m^{-1}),

Fυ - abrasivity (mg m^{-1}),

Kk - coefficient on the quality of picks (for picks TN-20, Kk = 1).

According to this method, rock can be classified as workable or difficult to disintegrate, in relation to the pick consumption. In the case of Ostrava-Karvina coal basin, workable (cuttable) rocks can be classified by following values of decisive parameters: workability of < 700 $kN{\cdot}m^{-1}$, abrasivity < 3.0 $mg{\cdot}m^{-1}$, specific energy < 12 $MJ{\cdot}m^{-3}$ and pick consumption < 0.3 $pieces{\cdot}m^{-3}$.

When cutting rocks above the limit extent of cuttable rocks, the pick wears excessively and it involves a lot of adverse consequences such as increase in specific energy consumption, in friction and temperature, increase in cutting resistance, in vibration and in temperature, increase in crushed fraction, in dust generation and many others negative influences that call for higher expenses and deterioration of the working conditions. Their importance requires solutions to be found by research and production development trials (Khair, Vašek, 1995).

4. WEARING PROCESS OF BIT OF PICKS

Wearing process of the cutting tools that changes the geometry of bit picks involves adverse consequences such as finer production, higher cutting resistance, vibration, increased energy consumption, lower disintegration output, higher bit temperature and thus higher rate of bit wear, increased dust generation and higher danger of ignitions of methane and dust.

The results of theoretical and experimental research can lead to the conclusion that it is necessary to try to PRESERVE POINT O (the cutting edge point with the highest stress), (Vašek, 1983).

Besides the oldest but still widely used exchange of worn cutting tools by new ones as well as the more progressive method of application of high materials exhibiting higher wear hardness, rotation of cutting tools and high pressure water jet assistance can considerably contribute to the elimination of the above mentioned negative consequences and thus extend the range of workable rocks.

5. WATER JET ASSISTANCE OF CUTTING PROCESS

The cutting tool with the assistance of high pressure water jet can have two different modes of use depending on their space-time arrangement. In the first case the high pressure water jet acts on the rock at a considerable time and space distance from the cutting tool, whereas in the second case, the high pressure water jet acts immediately on the spot of the interaction ROCK-CUTTING TOOL.

Experimental research in disintegration of hard rocks performed in the Institute of Geonics (formerly Mining Institute) of the Czech Academy of Sciences in Ostrava revealed that use of high pressure water jet (in time and space distance) can considerably diminish cutting forces on the cutting tool, however, without making full use of the advantages of the high pressure water jet such as cooling the cutting tool, decreasing dust generation, reducing the risk of methane-air mixture ignitions, etc. (Vašek 1990).

Therefore, analyses of many scientists were focused on the effect; of high pressure water jet at the place of the cutting tool-rock interaction (Fowell, Tecen, 1983, Vijay, 1989, Taylor, Furno, 1988, Hood, Knight, Thimson, 1992).

In co-operation with West Virginia University (Vašek, 1994), six cutting bits (three point attack bits and three drag bits) were prepared and tested in the laboratory using linear cutting device (Fig. 2.) that consists of three component quartz force transducer Kistler type 1683A5 (1) with special pick holders (2) and water jet nozzle (3). Water jets were generated under inclination of 45° (stand-off distance 45 mm, water pressure 200 MPa). Rock samples (4) were fixed on the support of the cutting device. Series of tests without and with water jet were performed and evaluated (Khair, Vašek, 1995).

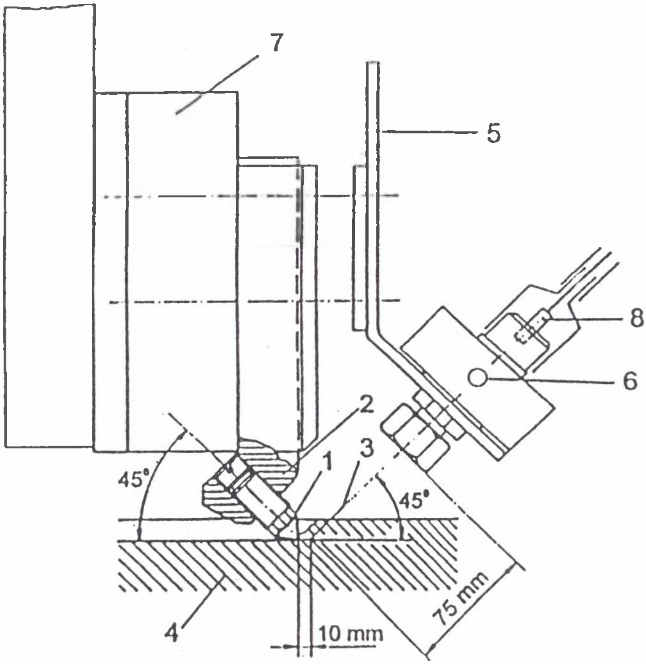


Fig. 2. Water jet assisted cutting bit arrangement:
1- cutting bit, 2 - bit holder, 3 - water jet, 4 - workpiece, 5- water jet holder, 6 - high pressure water jet inlet, 7 - pressure transducer

Rys.2. Nóż skrawający wyposażony w dyszę wodną:
1 - nóż skrawający, 2 - mocowanie noża, 3 - dysza wodna, 4 - urabiana skala, 5 - oprawa dyszy, 6 - doprowadzenie wody pod wysokim ciśnieniem, 7 - przetwornik ciśnienia

Under given testing conditions, no notable influence of water jet assistance to point attack bits or drag bits on decreasing of mean and peak cutting forces was observed. In many cases, the mean and peak cutting forces were even higher for cutting bits with water jet assistance (Khair, Vašek, 1995). Furthermore, no remarkable differences in character of cutting grooves were observed (see Fig. 3).

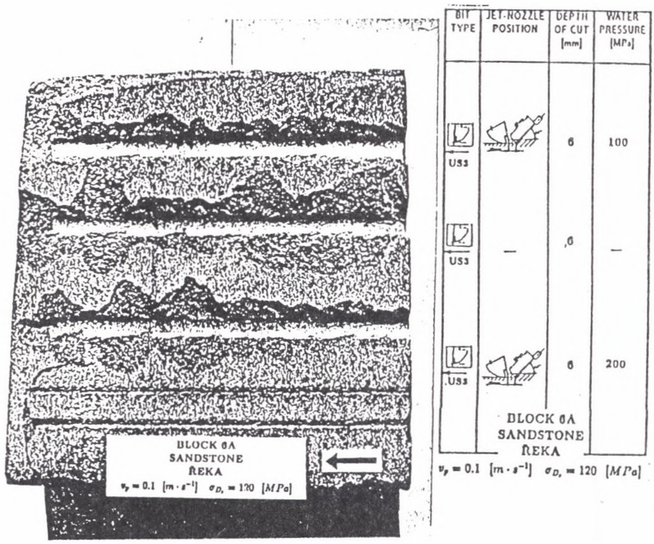


Fig. 3. Cutting grooves made in block of Godula sandstone No. 6A with and without water jet assistance ahead of the drag cutting tool (water pressure 100, 0, 200 Mpa, depth of cut 6 mm, compressive strength of the rock 120 MPa)

Rys.3. Skrawy wykonane w piaskowcu Godula 6A z i bez udziału strumienia wody poprzedzającego nóż skrawający (ciśnienie wody 100, 0, 200 MPa, głębokość skrawu 6 mm, wytrzymałość na ściskanie skały 120 MPa)

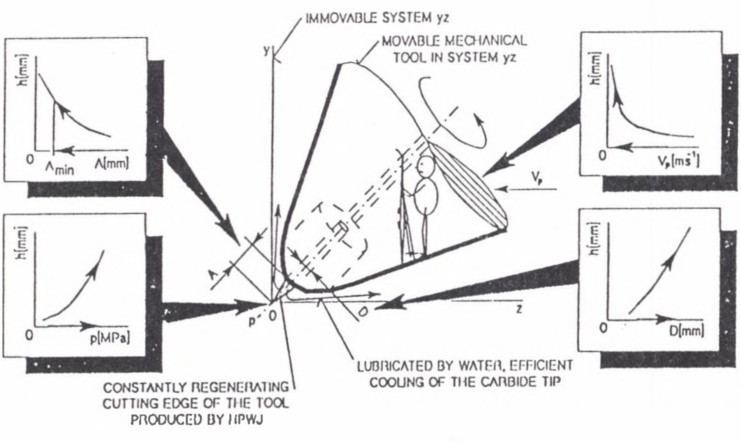


Fig. 4. Sketch of the tool with water jet through cutting bit

Rys.4. Schemat narzędzia urabiającego z dyszą wodną umieszczoną wewnątrz noża skrawającego

Results in this area of research lead the author to the conclusion that further analyses focused on the effect of high pressure water jet assistance have to include also tests with high pressure water jet directed through the cutting bit. Therefore, the design of a new cutting tool was proposed (Fig. 4.).

First laboratory experimental results obtained with the new cutting tool have indicated remarkable decrease of the cutting forces during the disintegrating process. In some places along the cutting lines the cutting forces dropped even close to zero values. Direct contact between the cutting bit and disintegrated rock was also considerable decreased (Fig. 5., Table 2). This phenomenon can lead to more effective cutting process with very low value of friction coefficient between cutting bit and rock. In addition to that the development of a new generation of the cutting tools preserving the mostly stressed point 0 of the cutting edge by high pressure water jet should be started. New research activity in this area has been already initiated (Sitek et al., 1995).

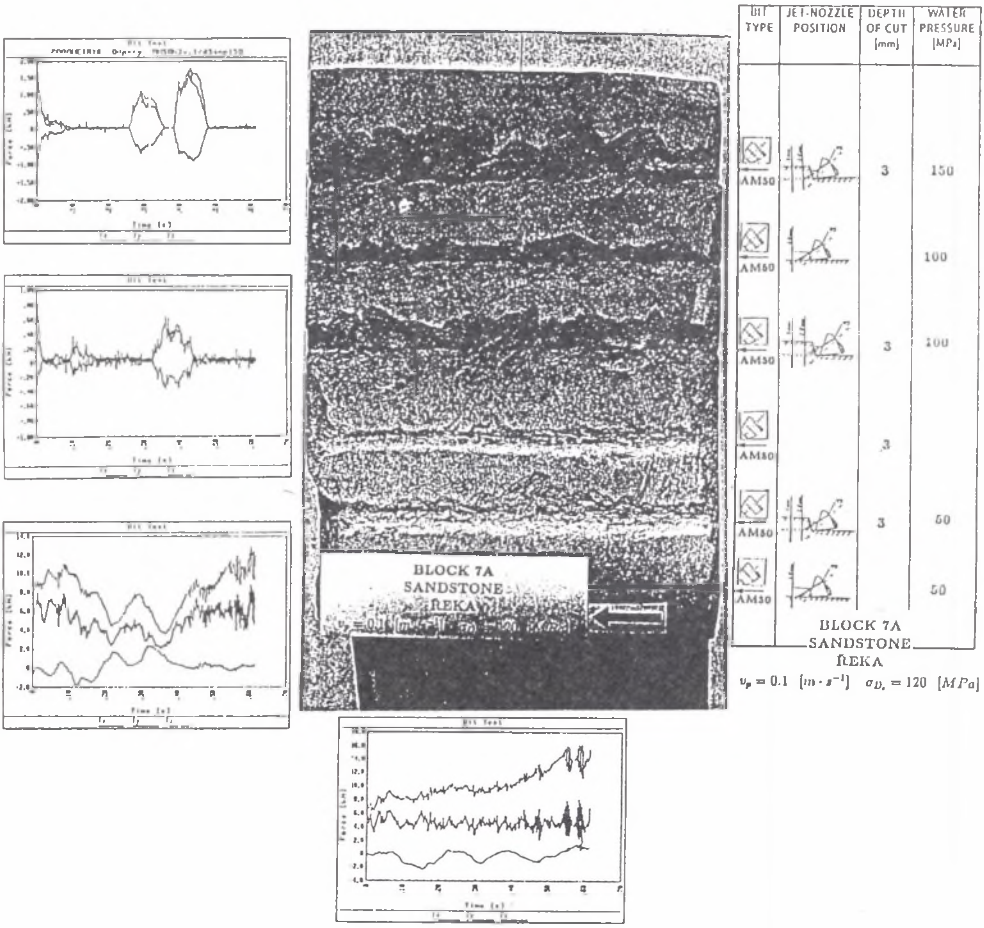


Fig. 5. Cutting grooves made in block of Godula sandstone No. 7A with assistance of water jet through point attack cutting bit (water pressure 150, 100, 100, 0, 50, 50 MPa, depth of cuts 3, 0, 3, 3, 3, 0 mm, compressive strength of the rock 120 MPa)

Rys.5. Skrawy wykonane w piaskowcu Godula 7A z i bez udzialu strumienia wody poprzedzającego nóż skrawający (ciśnienie wody 150, 100, 100, 50 i 50 MPa, głębokość skrawu 3, 0, 3, 3, 3, 0 mm, wytrzymałość na ściskanie skały 120 MPa)

Table 2

Results of measuring of mean and peak cutting forces (water jet assisted)

Bit. No.	Type of Bit	Cutting Depth	Water Pressure	Mean Cutting Force			Ratio F_z/F_y	Peak Cutting Force			Ratio F'_z/F'_y	Rock Yield	Total.Spec. Energy Cons.	Block No.
		h [mm]	[MPa]	F_x [kN]	F_y [kN]	F_z [kN]		F'_x [kN]	F'_y [kN]	F'_z [kN]		V [$m^3.10^{-4}$]	SE [$MJ.m^{-3}$]	
AM 50	point attack bit	3	150	-0,16	0,35	0,33	0,94	0,22	1,87	1,76	0,94	7,55	464,6	7A
		-	100	0,00	0,00	0,00	-	0,00	0,00	0,00	-	2,45	774,7	7A
		3	100	0,04	0,12	0,12	1,00	0,14	0,88	0,63	0,72	4,40	433,0	7A
		3	-	-0,38	10,25	4,55	0,44	1,62	16,22	8,15	0,50	1,90	143,7	7A
		3	50	0,22	7,86	4,88	0,62	2,35	12,76	8,71	0,68	1,83	526,7	7A
		-	50	0,00	0,00	0,00	-	0,00	0,00	0,00	-	0,45	1491,1	7A

6. CONCLUSION

The harder and more abrasive the rock is, the less effective and more expensive the cutting process with traditional cutting tools becomes. Water jet assistance ahead of the cutting tool did not provide expected results under given conditions. On the other hand, the water jet assistance through the cutting bit seems to offer a very progressive method for cutting of hard and abrasive rocks.

7. ACKNOWLEDGEMENT

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STRESZCZENIE

Tematem niniejszego artykułu są wzajemne związki zachodzące między skałą a urabiającym ją narzędziem. Przedstawiono metody klasyfikowania kluczowych parametrów procesu urabiania (tablica 1). Opisano badania procesu zużycia noży skrawających i energii skrawania. Przedstawiono schemat narzędzia urabiającego z dyszą wodną umieszczoną przed i wewnątrz noża skrawającego (rys. 2 i 4). Ponadto poddano dyskusji wpływ strumienia cieczy na proces urabiania w oparciu o pomiar sił skrawania oraz energii urabiania (rys. 3 i 5 oraz

tablica 2). Stwierdzono, że umieszczenie dyszy wodnej przed nożem skrawającym nie przyniosło oczekiwanych rezultatów. Natomiast wariant z dyszą zlokalizowaną wewnątrz noża skrawającego znacznie zwiększa możliwości urabiania skał twardych i zwiększa trwałość urządzeń skrawających.