Simulation of the mechanical process of gypsum cutting with picks

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Abstract

Several research works have been done to assess the effect of the cutting depth on the cutting forces when using picks. In this case, the cutting tests need im-portant equipment to cut rocks, to register the cutting force and to determine the cutting force value. The purpose of this research work is to simulate the laboratory rock cutting tests to determine the cutting force, using commercial software; and to compare the cutting force values to those obtained in the la-boratory. In the simulation, we took a gypsum rock sample as the specimen,. We simulated the separation of the rock chips from the specimen and the sub-sequent breakage into multiple fragments. In the simulations, a cutting pick was compared with a stationary rock sample. The simulations were conducted at a same constant velocity for different cutting depths. The simulations showed that the depth of cut has a significant effect on the cutting force, and the values of the cutting force in the simulation are very close to those obtained in the laboratory.

Keywords: rock cutting; cutting pick; finite element method; cutting force; cutting process simulation.

1. Introduction

Research on the mechanical excavation of rocks has been undergoing since the 50s when a large interest was given to the rock cutting process to improve the production at low cost. From that time until now, several research works either theoretical, practical or numerical have been carried out, where a number of theories were developed to estimate the intensity of the cutting force and other cutting parameters in the excavation of rocks by machines. Besides, ma-ny empirical studies have assessed the effect of the change of tools and opera-tional variables on the performance of cutting (Gokhan Aydin, 2015), (Xiao-hui Liu, Songyong Liu, Lie Li, and Xinxia Cui, 2015), (Xianqun He, Chaoshui Xu, 2015), (Maria C. Jaime,Yaneng Zhou, Jeen-Shang Lin, , Isaac K. Gamwo, 2015), (Jerzy Rojek, 2014),(Zhang Qianqian, Han Zhennan, Zhang Mengqi, Zhang Jianguang,2015), (Okan Su n, Nuri Ali Akcin,2011), (Pradeep L. Me-nezes, Michael R. Lovell, Ilya V. Avdeev, C. Fred Higgs III, 2014).

Because of the lack of means to carry out the assays, we chose to make a simulation of the laboratory cutting process. The numerical cutting force was compared to that practiced. The pick characteristics, and the effect of the cut-ting depth on the cutting force, based on some research works carried out previously, and in the simulation of the cutting process are presented.

2. Tools characteristics

Three types of picks, according to the shape, are generally used: The radial, the forward, and the point attack picks (Fig.1). The first one has its shank positioned normal to the cutting direction, whereas the second and the last one are both angled backwards using wedge tips. Alternately, point attack picks are essentially forward attack picks with conical instead of wedge shaped tips, with cylindrical shanks. For cutting efficiency, the picks should be correctly desi-gned in terms of the characteristic angles which are the rake and the back clea-rance angles.

Figure 1
(R)Radial, (F) forward attack and (P)point attack picks, (Eyyuboğlu, E.M, 2000).

2.1 Wedge shaped tools

The NCB research results showed that the cutting force is lower as the wed-ges of the picks are narrow. This leads to a more efficient pick, (Whittaker, 1962). However, to avoid weakening the picks, rake and nack clearance angles should not be made too large. A compromise has to be made between tool stre-ngth and cutting efficiency. An optimum chisel shape pick is that with a rack angle of 15 ° allied with a back clearance angle of 60 °.

3. Cutting Force

The cutting force is the force acting on the tool in its direction of cutting. The cutting parameters are shown in Figure 2.Theoretically, (Evan, 1962) put forward a model aiming to calculate the cutting force from the tensile and the compressive strengths of the rock, the bit geometry, and the depth of cut. The Evan model is formulated below in Eqs. (1) and (2). (Bilgin, 2006), (Yilmaz, 2007).

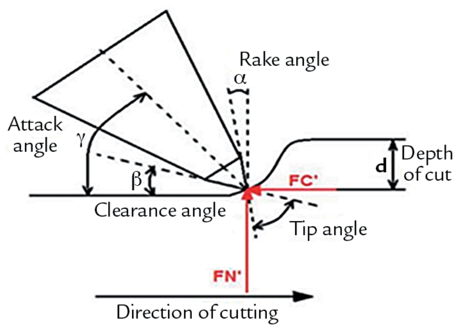

Figure 2
Point attack pick cutting parameters (Su & Akcin, 2011).

$$Fc = \frac{2\sigma_t dw Sin\ \frac{1}{2}\left(\frac{\pi}{2} - \alpha\right)}{1 - Sin\ \frac{1}{2}\left(\frac{\pi}{2} - \alpha\right)}$$

For chisel picks, (1)

$$Fc = \frac{16\pi d^2 \sigma_t^2}{Cos^2(\varphi/2)\sigma_c}$$

For point attack tools, (2)

Where: Fc: cutting force, d: depth of cut, w : tool width, α : rake angle, σ_t : tensile strength, σ_c : compressive strength, ϕ : tip angle.

Roxborough (1973) concluded that, for chisel picks, the practical cutting force is in good correlation with that calculated using Eq. (1).

For point attack tools, a modification has been suggested on Evan's theory by Goktan (1997), who proved that the theoretical values calculated using Eq.(3) were almost the same as those practical ones previously published, (Bilgin 2006).

$$Fc = \frac{4\pi\sigma_t d^2 Sin^2(\varphi/2 + \psi)}{Cos\ (\varphi/2 + \psi)} \quad (3)$$

Where, ψ : The friction coefficient between the cutting tool and the rock.

The other parameters are defined above in Eqs. (1) and (2).

Another modification was also suggested by Roxborough and Liu (1995) on Evan's theory for point attack tools Eq. (4), (Bilgin 2006).

$$Fc = \frac{16\pi\sigma_c d^2 \sigma_t^2}{\left[2\sigma_t + (\sigma_c Cos\,(\varphi/2))(\frac{1+Tan\psi}{Tan(\psi/2)})\right]^2} \quad (4)$$

The parameters are as defined above.

For wedge type picks, some empirical equations were developped by Gok-tan to predict the cutting force (Goktan (1995) and Bilgin (2006).

Nishimatsu (1972) found that the shear strength failure was dominant in cutting high strength rocks, as indicated in Eq. (5), (Bilgin 2006).

$$Fc = \frac{2.\sigma_s d.w.Cos\,(\psi - \alpha).Cos\,(i)}{(n+1).\left[1 - Sin\,(i + \psi - \alpha)\right]} \quad (5)$$

Where, σ_s : the rock shear strength, i : the rock internal friction angle, n : the tress factor, where n =12−(α/5).

The other parameters are as defined above in Eqs. (1).

3.1 Laboratory determination of the cutting force

Practically, Laboratory tests were carried out to determine the cutting force. A Gravor shaping machine was used as a rock cutting rig. The cutting speed can be varied in steps from 90mm/s to 320mm/s. The table can be raised, lowe-red or traversed relative to the cutting tool. The vice can accommodate a test specimen of 400*200*300mm.The clapper box on the cross head of the shaper was modified to accept a triaxial force dynamometer and tool holder capable of accepting most conventional types of cutting tools. Before realizing the la-boratory cutting tests the machine was calibrated.

The cutting force was determined by recording its signal at the cutting force bridge output. A typical cutting force signal is shown on Figure 3. The mean value of the cutting force in millivolts was determined from the cutting force signal registered for each test. For each value of the cutting force in millivolts, the equivalent in Newton was determined (Djouama 1990).

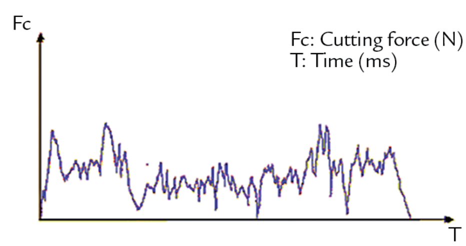

Figure 3
Typical cutting force signal.

3.2 Effect of the depth of cut on the cutting force

Laboratory cutting tests were carried out on samples of gypsum to assess the effect of the depth of cut on the cutting force, Djouama (1990). The rock samples were prepared prior to testing by sawing into blocks and the cutting surface planed flat to give a constant depth over the length of the cut. Unre-lieved cuttings, (no breakout between adjacent cuts), was carried out to produ-ce the worst case in cutting. The depth of cut was the only variable cutting pa-rameter. Depths of cut of 5, 6.25, 7.5 and 10 mm were taken. Unfortunately, in the laboratory, the biggest depth achieved was 10mm. When a depth of 15mm was tried, the rock sample was broken. Figure 4 shows that the cutting force increases proportionally with increased depth of cut.

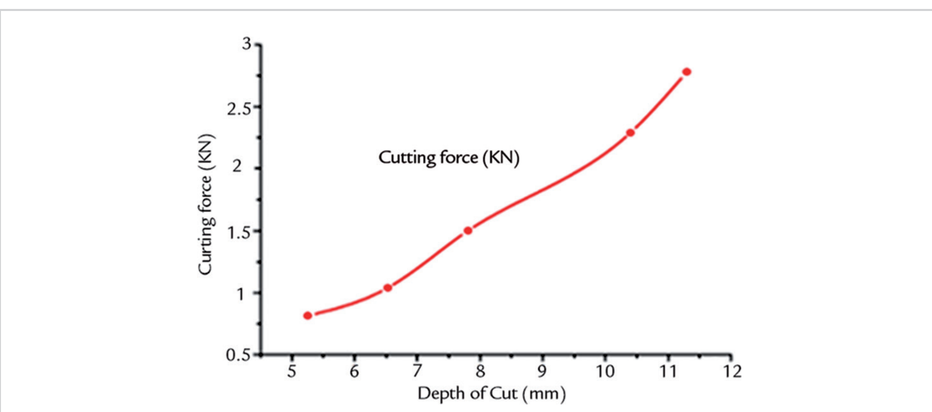

Figure 4
Effect of depth of cut on cutting force, (Djouama, 1990).

4. Simulation of the rock cutting process

4.1 Cutting with a wedge shaped tool

A finite element method software package was used to simulate the rock cutting process, to determine the cutting force values, to compare them to those obtained, in the same cutting conditions in the laboratory, and finally to assess the effect of the depth of cut on the cutting force. The software package has already been used by researchers in 3D mechanical modeling of soil orthogonal cutting under a single reamer cutter based on Drucker_Prager criterion (X. H. Zhu, 2014). The numerical cutting force variation with time obtained for this simulation is presented in Figure 5.

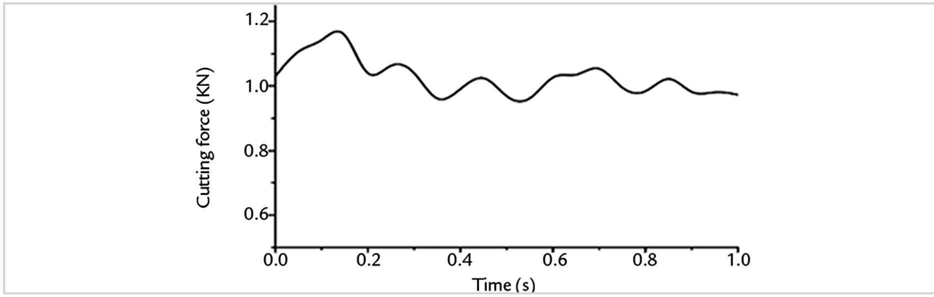

Figure 5
Simulation of the cutting forces variation with time for a depth of cut of 6.25mm.

A perfectly sharp wedge shaped tool was positioned on the side of the gyp-sum rock sample (Fig. 6). Cutting depths of 5, 6.25,7.5 and 10 mm were used. The pick was moved at a velocity of 162 mm/s over a cutting distance of 20 mm. During the cutting process, when the tool hits the rock specimen, chips begin to form and then separate from this later. An attack angle of 21^0, a tip angle of 42^0, a clearance angle of 33^0, a rake angle of 15^0 and a friction an-gle of 8.5^0 between the rock and the pick were used through out the simulation.

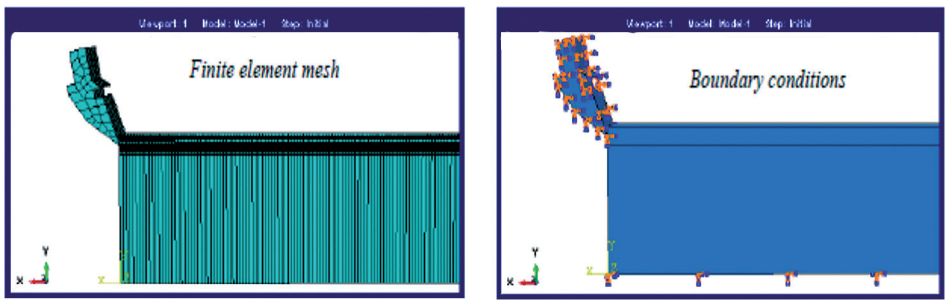

Figure 6
Numerical simulation of rock cutting by wedge shaped tool.

4.2 Numerical results and discussion.

Figure 7, shows the numerically computed stress distributions obtained in the specimen for cutting depths of 6.25 and 10 mm. We notice that the maxi-mum effective stress is located at the tip of the pick. The chip separation crite-rion could be based on the failure criterion of the specimen. We notice also that the size and the shape of the rock fragment increase with increasing depth of cut.

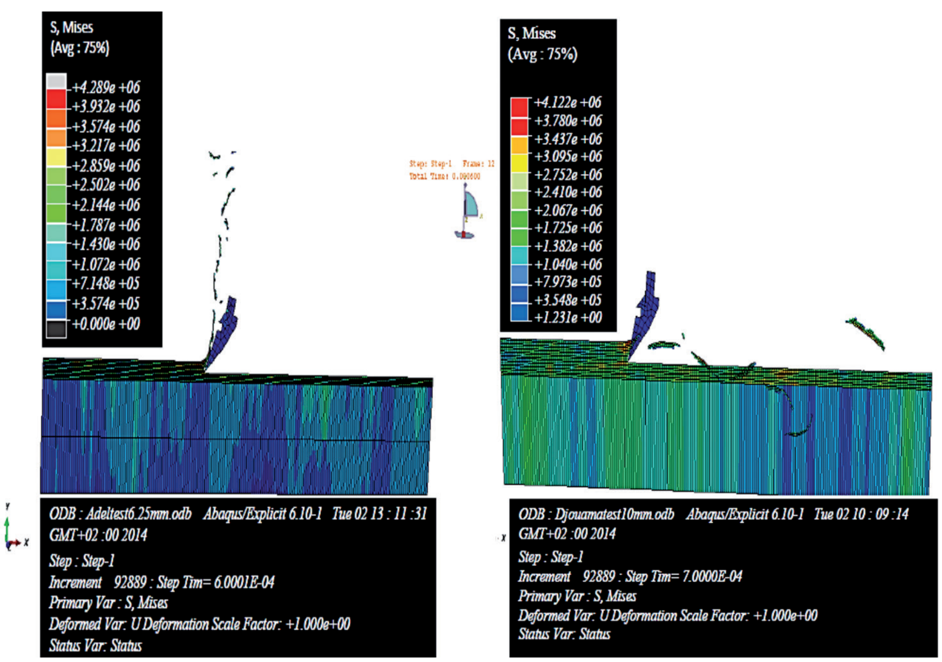

Figure 7
Chip formation during rock cutting tests (depth of cut d = 6.25 and d=10mm).

It can be observed that the cutting forces are affected by the depth of cut. The cutting force is low for 5mm and 6.25mm depth of cut and increases with increasing depth of cut (Fig.8). Numerical values of cutting forces were com-puted during simulation. In the same way as in the result of the practical tests, it can be observed that the cutting force increases with increasing depth of cut.

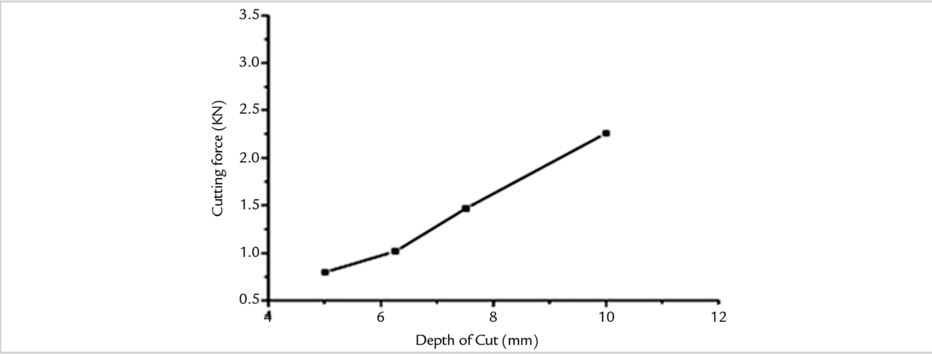

Figure 8
Simulation of the effect of depth of cut on cutting force.

Table 1 and Figure 9 shows the comparison of numerical and experimental cutting forces. It can be noticed that the numerical cutting force values are very close to the experimental ones.

Depth of cut (mm)	Cutting forces numerical (KN)	Cutting forces experimental (KN)
5	0.806	0.804
6.25	1.032	1.03
7.5	1.477	1.471
10	2.258	2.254

Table 1
Effect of the depth of cut on the cutting force, by simulation and by laboratory tests.

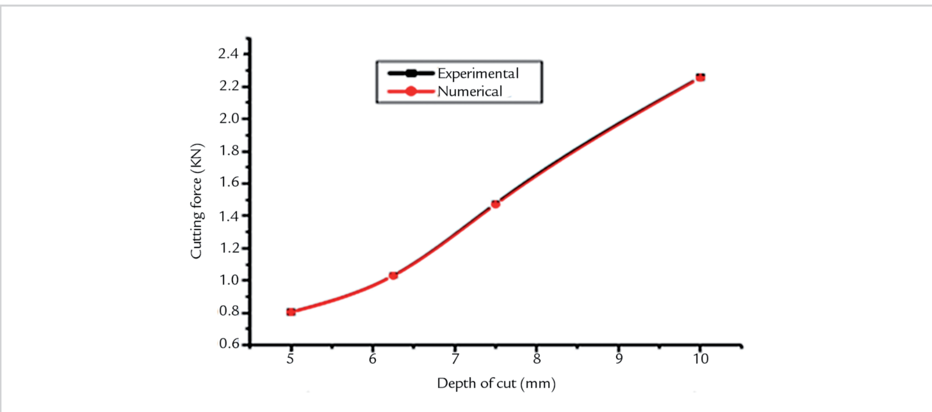

Figure 9
Comparison of numerical and experimental cutting forces.

5. Conclusion

In the present investigation, a commercial finite element software package was used to assess the formation and the separation of the chip during rock chip cutting.The amount and the morphology of discontinuous chips formed during cutting varied significantly with the depths of cut. The mean values of the cutting force were also simulated. Comparing the values of the cutting force obtained by simulation to those obtained in laboratory, under the same conditions, it can be well observed that the numerical and experimental cutting forces are very close and have the same effect of the depth of cut on both of them.

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