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Possibility of Using Mechanical Miners in Underground Chromite Mines' Ore Productions and Two Different Examples

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ABSTRACT: Metallic ore prices have been decreasing recently due to unstable supply and demand relations and developed recycling methods of scrap metals. Therefore, Turkish underground metal mines and production methods should be reviewed especially in terms of economical ore cultability. Rapid and productive technologies should be applied as soon as possible to reduce production costs and increase competitiveness. For this purpose, it has been investigated that whether mechanical miners could be used for production and development purposes in chromite mines. In order to realize full-scale cultability tests in the laboratory, primarily miscellaneous investigations were performed in two different chromite mines: Kayseri-Pulpinar and Eskişehir-Kavak. Some information was obtained about production methods and working conditions and then, ore and country rock samples were collected from. After defining optimum cutting conditions, mechanical miners' production rates were estimated via performance prediction methods. Consequently, it has been found out that a mechanical miner could produce approximately three times more chromite than existing mining methods.

1 INTRODUCTION

The necessity of high investment in mining industry dictates mechanized excavation for efficient mining to reduce operating costs. Due to this fact, exploitation methods of different mines in Turkey such as chromite mines have to be revised for more efficient mining operations.

Recently, metal prices in world stock market decreased considerably (Sullivan and others, 2001). The use mechanical excavators such as roadheaders, hydraulic hammers, etc have the potential to increase productivity, since they have continuous, flexible operation capabilities to adapt to existing methods. Some applications of mechanical excavators for ore excavation were reported to be successful (Atlas Copco-Robbms. 1996, Breitrick, 1998).

In order to investigate the possibility of using mechanized excavators in metallic ore formations, first physical and mechanical properties of the ore have to be determined in the laboratory and in situ such as schimidt hammer rebound value.

Rock mechanics tests, such as uniaxial compressive strength (UCS), tensile strength test (TS), Cerchar abrasivity test, static and dynamic modulus of elasticity give preliminary assestment for the machinability of the geologic formation. However full scale cutting tests are strictly advised to be carried out for efficient selection of mechanical excavators in optimum conditions.

2 OBJECTIVE OF THE STUDY

In-situ and laboratory tests are performed to investigate the possibility of using the roadheaders and hydraulic hammers for ore excavation. Objectives of the study are given below.

- Investigation into cutting mechanics of chromite ores and surrounding rocks in selected mines,
- Methods of reducing operational costs and investigating applicability of mechanical excavators such as roadheaders and impact hammers in selected mines.

3 .THE EFFICIENT USE OF MECHANICAL EXCAVATORS IN ORE EXCAVATION

Underground excavation methods are grouped as drill and blast and mechanized excavation. Drill and blast has coarser muck than mechanical excavation thus making it more efficient from specific point of view. Low advance rate, vibration and support problems due to overbreaking and safety concerns limit the applicability of this method (Özdemir, 1994) and mechanical excavation become more economical with increasing tunnel length. (Pakes, 1991).

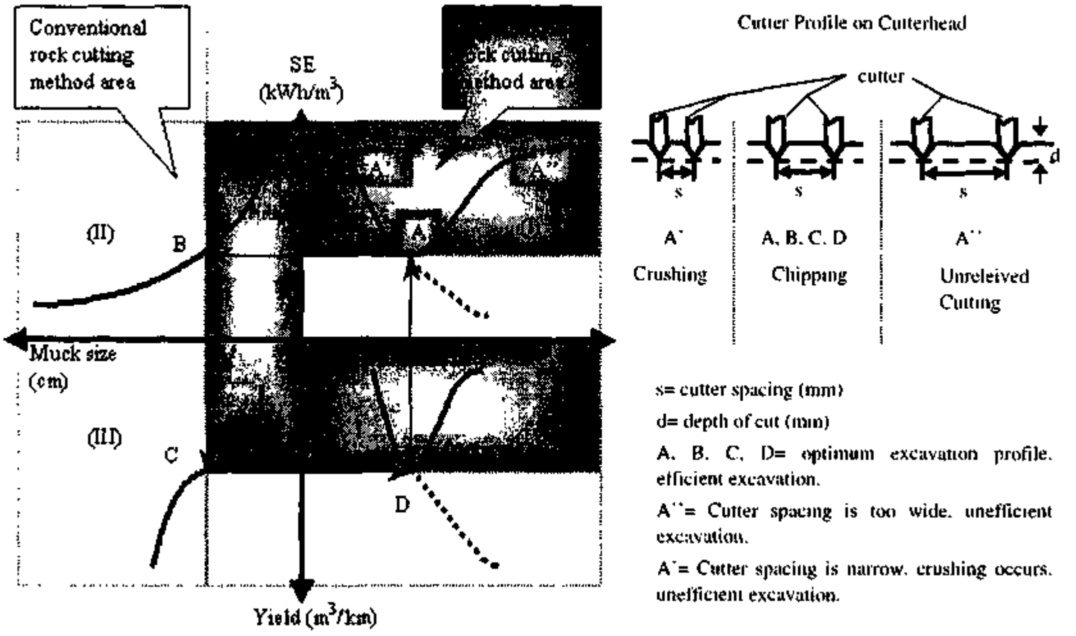


Figure 1. Comparison of conventional excavation to mechanized excavation (Tunçılemır. 2002).

The hypothetical relation between important parameters of mechanical excavation such as specific energy (SE) (the energy needed to excavate unit volume of rock, kWh/m), cutter spacing (s, mm), depth of cut (d, mm), ratio of spacing to depth of cut (s/d) and parameters used in both methods like muck size (cm) and yield volume (nrVkm) are given in Figure 1, which compares the efficiency of mechanical excavation against conventional excavation method.

Point (A) in the region I of Figure 1 shows the optimum s/d for mechanized excavation. An effcient cutterhead design must have appropriate cutter spacing minimizing spesific energy (point A). Therefore the area below point (A) can be defined as conventional excavation area (dotted line in region I.). Although drill and blast method looks more efficient in this area, one should bear in mind that the efficiency of mechanical excavation increases with longer length of tunnel.

Region II in Figure I shows the relation between debris size and spesific energy. Conventional excavation produces coarser debris than mechanical excavation. Debris size in mechanical excavation is controlled through the cutter spacing and depth of cut given optimum spesific energy. In that case debris size in mechanical excavation can not be bigger than point (B). Therefore the left side of the point (B) indicates conventional excavation, ie. drill and blast.

Region III in Figure I shows the relation between yield volume and debris size. There is some factors that limit the yield volume in mechanical excavation. Thereotically yield volume can not exceed the debris volume which is formed by cutter spacing, depth of cut and cut length. For that reason, point (C) shows the end of mechanized excavation capability in terms of yield.

The relation between yield volume and optimum s/d is showed in region IV of Figure I. In mechanized excavation, maximum yield volume and debris size occur at optimum s/d (also the lowest specific energy) which is point D. In drill and blast method "s" is referred to spacing of holes and "d" is depth of holes. Yield volume in drill and blast method will increase by the dotted line and debris size will also increase by the dotted line in region I.

4 PERFORMANCE PREDICTION OF MECHANICAL EXCAVATORS

The general technical requirements of excavation machines, in addition to safety and economy, are selective mining ability, flexibility, mobility, hard and abrasive rock cutting ability.

Geological features (such as joint sets, bedding planes, foliation, hydrogeological conditions, deposit geometry, etc.) and intact rock properties (such as cuttability. abrasiveness, strength, texture, etc.) are the basic input parameters for the efficent selection of mechanical miners and performance prediction.

The predicted cutting performance of a mechanical excavator in the mineral or rock formation is one of the main factors determining the economics of a mechanized mining operation. There arc several methods of prediction and it is advisable to use more than one of lhe.se methods to obtain realistic results. The principal prediction methods are full-scale linear cutting test, small-scale cutting lest (core cutting), an empirical approach, a semi-theoretical approachs and in-situ testing of mechanical excavators.

The full-scale linear cutting test is a reliable approach, since a rock block, 70 cm x 50 cm x 50 m in size, is cut in laboratory with a real life cutter. The cutting force, normal force, sideways force and specific energy values are obtained for different depths of cut and tool spacing values and the production rate of a given mechanical miner is calculated from equation (1 MRostami,1994a).

$$ICR = k \cdot \frac{P}{SE_{opt}} \qquad (1)$$

Where ICR is instantaneous production rate, m/h, P is cutting power of the mechanical excavator, kW, and $SE_{„pl}$ is optimum specific energy, kWh/m^1.

Small-scale cutting test has been developed from extensive in-situ and laboratory tests and it is widely used. (McFeat Smith, Fowcll, 1977,1979)

Emprical performance prediction models are based mainly on past experince and statistical interpretation of previously recorded case histories. Widely used emprical models depends on many tunneling and mining project datas and prediction models are developed for production rates of axial and transverse type roadheaders and impact hammers (Bilgin 1988, 1990, 1996, 1997, Hartman 1992, Eskikaya, 1998). The Rock Mass Cuttability Index (RMCI) is developed for roadheaders and impact hammers and shows (hat production rate can be predicted by uniaxial compressive strength (UCS) and RQD in equation (2).

$$RMCl = UCSx(RQD/100)^{:/1} \qquad (2)$$

where UCS is uniaxial compressive strength, MPa. RQD is rock quality designation, %.

Prediction of roadhcader production rate is estimated using equation (3).

$$ICR=0.28xPx(0.974)^{RMO} \qquad (3)$$

Where ICR is instantaneous cutting rate in m'/h, P is cutting power of the roadheader in kW.

Hydraulic hammer performance model was developed using data collected in Istanbul Metro Project. According to this model the performance of a hydraulic hammers can be estimated using equation (4).

$$IBR=4.26P(RMCir"^{w} \qquad (4)$$

Semi-emprical performance models utilize computer models. Machine manufacturers, research institutes and consultants have their own computer models(Çopur, 1999, Roslami&Özdemir, 1994b).

For an in-situ machine testing, a new or used machine is hired and tested in-situ (Carlin East Gold Mine; Breitrick, 1998). This method is very expensive and time consuming but gives the most realistic performance prediction results.

5 ROCK MECHANICS AND CUTTING TESTS

Many research works were carried out in the past years to form the fundamental aspects of rock cutting mechanics. Chromite is an important mineral of Turkey mining industry but it has never been subjected to rock cutting tests prior to this study. It is obvious that structural properties of chromite ore will effect cutting mechanism. Mechanical excavators should be consiously used in metallic ores because of their abrasivenes.s. In order to understand better cutting characteristics of chromite ores laboratory cutting tests were performed for this study.

There are two levels of grade in Kayseri Pınarbaşı-Pulpınar chromite mine, these are called high (46-50% Cr$_2$0,) (rock 1) and medium (42-46% Cr$_2$Oj) (rock 2) grade ores. Samples are taken from high, medium grade ores and country rock harsburgite (rock 4) and from Eskişehir Kavak chromite mine which has low grade chromite (20-25% GiOO (rock 3) and surrounding serpantinite (rock 5). Rock mechanics and cutting tests were performed on these samples.

Linear cutting tests were carried out on rock samples using a Sandvik S35-H80 conical cutter. After triming the surface of the samples, depth of cut is adjusted to 5 mm and 10 mm and s/d ratio to 1,2, 3, 4, 5 and releieved and unrelieved cutting tests were carried out. The aim of these tests was to obtain optimum s/d, average cutting and normal force, maximum cutting and normal force, yield and to calculate specific energy using equation 5. Test results give the optimum specific energy which will be used in performance estimation (Roxborough, 1973, Bilgin, 1989, Rostami, 1993).

$$SE_{„,\,1} = \frac{\quad}{Q}\ (MJ/m^{1}\ \ kWh/m\ ) \qquad (5)$$

wheie $SE_{„p}$, is optimum specific encıgy, FC ıs mean cutting toıce kN, Q is yield. mVkm in optimum ıatio ot s/d

Rock mechanic test are earned out accoıdıng to ISRM suggested methods and results are given in Table 1

Table 1 Rock mechanics test results of samples tested

Rock	γ	UCS	BTS	E_{st}	E_{kn}	SHRV	CAI
1	4 03	32 2	3 7	3 5	31 2	28-37	2 12
2	3 39	46 9	4 5	2 3	76 4	43	1 60
3	2 88	46 5	3 7	2 9	35 2	42	2 40
4	2 65	57 7	5 5	2 1	16 1	35 59	0 80
5	2 49	38 1	5 7	2 3	13 9	39 58	1 00

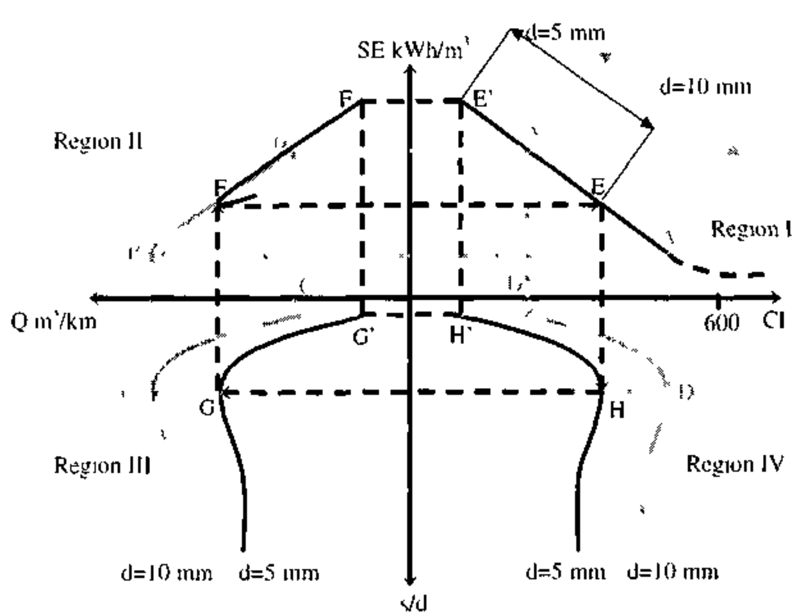
γ = Density (g/cm³) UCS=Uniaxial compressive strength (MPa) BTS=Tensile strength (MPa) E_{st}=Static elasticity modulus (GPa) E_{kn}=Dynamic elasticity modulus (GPa) SHRV=Schmidt hammer rebound value (N type) CAI=Cerchar abrasivity index

Compiessive and tensile strength tests are earned oui using 55-110 mm (NX) and 55 mm-55 mm core sizes and ELE 3000 hydraulic press Load cell, Ivdt and x-y recorder to measure the static elasticity modulus Pundit equipment is used toi dynamic elasticity N type Schmidt hammei is used both m-situ and laboratory Ceıehaı abrasıvıtıy index test is peiloimed to predict the cuttei consumption

Debus si/e dıstıubıtıon is vciy important loi chıomıte ore +25 mm traction have hıgheı puce on the market Sieve analysis is applied to yield to find the sue dıstıubıtıon on optimum cutting debris Coaiseness index is calculating using sieve analysis results 0 125, 0 5, 2, 8. 25 mm sieves are used m sieve analysis producing 6 ructions thus cumulative sum gives the coaiseness index

6 RESULTS AND DISCUSSION

The relations between coaiseness index (CI) specilic eneigy (SE), spacing to depth ol cut latio (s/d) and yield volume (Q) are gcneiahzed m hypothetical in Figure 2



t-iguie 2 Rtlatıoııs between coaiseness index (CI) and specific eneigy (St) MHO ot spacing to depth ot cut lado (s/d) and yield volume (Q) foi 10 and 5 mm depih ot cut (Tunçdemıı 2002)

In region II ot Figure 2 point (B) has the maximum yield volume and optimum specific eneigy foi 10 mm depth ot cut Point (B') has the minimum yield volume and maximum specific eneigy Point (F) and (F) are same as the point B and B' but they represent 5 mm depth ot cut

Point (C) in region III shows that highest yield volume occuis at optimum s/d foi 10 mm depth ot cut Poınl (C) indicates s/d latio which has the minimum yield volume foi the same depth of cut Point (G) and (C) represent the same phenomenon as point (C) and (C) loi 5 mm depth ol cut

The highest coarseness index for 10 mm depth of cut occurs at optimum s/d which is point (D) in region IV. Point (D') is the minimum coarseness index which is at the minimum s/d tor 10 mm depth of cut. Point (H) and (H") shows the same results as point (D) and (D') but they belong to 5 mm depth of cut.

According to the Figure 2 there is strong relation between specific energy and coarseness index which is inversely proportional. Specific energy for higher depth of cut (10 mm) realizes lower values of specific energy and higher coarseness index values (region I A-A' curve). Coarseness index increases as depth of cut and yield increase. Cutter spacing also effect coarseness index, which has the maximum value at the optimum s/d point. Specific energy has the minimum value at this point.

As a results of these high correlations it may be concluded that specific energy can be estimated by analyzing the particle size distribution of yield for medium to hard rock.

7 EVALUATION OF SELECTED MINES FOR MECHANICAL EXCAVATION

Cutting parameters such as optimum specific energy, maximum and average forces of cutting and normal forces, are determined in laboratory tests for selected mines and results are summarized in Table 2.

Table 2 Sumniaiy of cutting test lesults to selected mines

Rock	s/d„,„	d„,„	FC	F C FC	FN	F'N FN	CI	SE
1	3	10	395	3.60	272	3.26	395	3 9
2	2	10	516	2.78	379	2.51	431	64
.1	3	9	455	3.08	363	2 83	465	5.0
4	S	9	911	2.87	944	241	467	8.4
5	3	9	444	3.17	484	2.65	434	6.2

s = culteı spacing, d=deptli of cut. d„,„ =dcpth of cul loi optimum conditions (mm). FC=mean culling force (kg). F'C=ma\imuni cutting toi ce. FN=mean noiimil lorce (kg). FN = maximum noimal foice. Cl=coaisencss index. SE„ı„=spLcitk' energy foi optimum cutting condition« (kWh/m'l

Results given in Table 2 are used for performance prediction and equations (1), (2), (3), (4) to estimate net cutting rate (nrVh), production rate (t/h). Results are eiven Table 3.

Table 3 Pertoimance prediction lor selected mines.

Rock	SE$_{opt}$	ICR1		ICR2		CCR	
		a	b	c	d	e	f
1	3.9	20.7	83	19.7	79	0.53	0.132
2	64	12.6	43	15.8	54	0.40	0.118
3	5.0	16.2	47	16 0	46	0 60	0.208
4	8.4	9.5	25	14.1	37	0.20	0.075
5	6.2	12 9	32	17.9	45	0 25	0.100

SE„,„ = specific energy for optimum cutting conditions, 1CRI= instantaneous cutting rate (kWh/m) foi 100 kW loadheader a(mVh)-b(i/h). ICR2= instantaneous cutting rate (kWh/m') lor 33 kW impact hammer c(mVh)-d(t/li). CCR=Cullei Consumption foi Roadheaders e(cuttei/ m')-f(cuttei7t)

Field studies carried out by Nizamoglu (1978) and Fowell (1993) give die relation between Cerchar abrasivity index and cutter consumption. The prediction equations for cutter consumption are used for selected mines and results are given in Table 3.

According to rock mechanic lest results (Table 1) Pmarbaşı-Pılpmar and Kavak chromite ore and country rocks are classified as medium and hard rock. Thus boom type miners with a power of 100 kW or 33 kW hydraulic hammer can be used for excavation (Bilgin, 1994).

Excavators performance prediction given in Table 3 for high graded chromite, is calculated as below :

High graded chromite ore has the optimum specific energy for 10 mm depth of cut which is 3,9 kWh/m as seen from Table 3. For a boom type miner with a power of 100 kW the instantaneous cutting rate (ICR) may be calculated using equation (1):

$$ICR = 0.8\frac{100kW}{3,9kWh/m^3} = 20,7\ m^3/h$$

Production rate may be calculated using the specific gravity of chromite as :

Production rate = 4,03 x 20,7 = 83 t/h

Hydraulic hammer having a power of 33 kW, will have the following production rate;

For RQD 100% and compressive strength of 32,2 MPa, RMCI may be calculated using equation (2);

RMCI = 32,2MPax(100/100)-"= 32,2 .MPa

Using RMCI in equation (4);

$$IBR = 4.26 x 33kW x (32,2)^{-0567} = 19,7\ mVh.$$

Production rate for hydraulic hammer with a power of 33 kW is 79 t/h.

Pınarbaşı-Pulpınar mine operates 330 days/year. 3 shifts/day and annually output is between 100000 - 120000 tons of ore. Annual output for "/< 46-50 Cr.0, grade chromite ore with a 100 kW boom type miner and utilization of %50 per shift, may be calculated as :

330 day/year x 3 shift/day x 8 hour/shift x 0.50 utilization factor x 83 t/h = 328 680 t/ycar.

The annuall outputs for above excavation conditions using 100 kW boom type miner and 33 kW hydraulic hammer are calculated and results are aiven in Table 4.

Table 4.Annual output for chromite oie in case die use of mechanical excavators

Rock	CSTO	OT,,,,	OT,,
1	100-120.000	328.680	312.840
2		170.280	213.840
3	80-100.000	186.120	182.160

CSTO=Current Status Total Output (1). OT_H»,=Total Output toi 1(M) kW roadheader (l/year), OT,,=Total Output for 33 kW impact hammer (t/year).

In this study the mining of chromite ore is investigated only in cutting characteristic point of view. In order to use mechanical excavators for production, underground mine layout, equipments, support and ventilation systems should be reviewed in detail.

8 CONCLUSIONS

Compressive strength of three different chromite ore and country rocks serpantinite and harsburgile changes between 32,2-57,7 MPa and they can be classified as medium to hard rock according to Bieniawski's rock classification (Bieniawski, 1989). Linear cutting tests were conducted on selected ore samples.

Cutting tests and performance prediction estimations based on a boom type miner with a cutting head power of 100 kW for selected mines give a possible increase of annual output from 120 000 l/year to 328 680 t/year (up to 3 times) for chromite ore.

The most important factor that limits excavation method is debris size distribution for chromite ore. The main reason is +25 mm particles have higher price on market. In this case it is necessary to increase annuall output with respect to debris size. Emprical performance models showed that hydraulic hammer will perform coarser debris and capable of high output (312 840t/year from Table 4).

An important selection criteria for mechanical excavator is cutter consumption which occupies maximum share in operational cost. Metallic ore excavation will increase cutter consumption. Thus hydraulic hammer can be more efficient than boom type miners if the tool consumption is considered.

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