CUTTING PERFORMANCE ASSESSMENT OF A MEDIUM WEIGHT ROADHEADER AT ÇAYIRHAN COAL MINE

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Approval of the Graduate School of Natural and Applied Sciences

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ABSTRACT

CUTTING PERFROMANCE ASSESSMENT OF A MEDIUM WEIGHT ROADHEADER AT ÇAYIRHAN COAL MINE

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In this thesis, in-situ instantaneous cutting rates of boom type, medium-weight milling type roadheaders (Mk-2B) at Çayırhan Coal Mine are determined by studying previous performance tests and carrying out additional underground cutting tests. Some rock properties such as uniaxial compressive strength, tensile strength, Cone Indenter hardness, Shore hardness, Schmidt hammer rebound hardness and laboratory cutting specific energies are determined by laboratory tests for the rock and coal types encountered in the drivage of roadways. The relations between the instantaneous cutting rates and the above rock characteristics and the laboratory cutting specific energies are established. The results show that instantaneous cutting rates can be best predicted using laboratory cutting specific energy which provides the highest correlation (R^2 = 0.8411) as compared to other rock properties.

The model developed for the medium-weight machine to predict instantaneous cutting rate is compared with those developed earlier for the light-weight and heavy-weight machines. It is determined that improvements in cutting performance with the medium-weight machines as compared to light-weight machines is achieved for the rocks requiring laboratory cutting specific energy greater than 5 MJ/m^3.

Keywords: medium-weight roadheader, performance prediction, cutting specific energy, instantaneous cutting rate

ÖZ

ÇAYIRHAN KÖMÜR MADENİNDE ORTA AĞIRLIKTA BİR GALERİ AÇMA MAKİNESİNİN KAZI VERİMİNİN TAYİNİ

Keleş, Serhat

Yüksek Lisans, Maden Mühendisliği Bölümü

Tez Yöneticisi: Prof. Dr. Naci Bölükbaşı

AĞUSTOS 2005, 58 sayfa

Bu tezde, Çayırhan Kömür Madeninde kullanılmakta olan bumlu, orta ağırlıktaki eksenel tip galeri açma makinelerinin (Dosco MK-2B) yerinde anlık kazı hızları, daha önce yapılmış deney sonuçları incelenerek ve ilave yeraltı kazı deneyleri yapılarak, saptanmıştır. Galerilerin açılmasında karşılaşılan kömür ve kayaçların tek eksenli basma dayanımı, çekme dayanımı, koni delici sertliği, Shore sertliği, Schmidt çekici sertliği gibi bazı kaya özellikleri ve kesme özgül enerjileri laboratuvar deneyleri ile bulunmuştur. Anlık kazı hızları ile yukarıda belirtilen kayaç özellikleri ve laboratuvar kesme özgül enerjileri arasındaki ilişkiler saptanmıştır. Sonuçlar, anlık kazı hızlarının kestiriminde, diğer kayaç özelliklerine göre en iyi korelasyonu (R^2 = 0.8411) laboratuvar kesme özgül enerjisinin verdiğini ortaya koymuştur.

Orta ağırlıktaki galeri açma makinelerinin anlık kazı hızlarının kestirimi için geliştirilen model, hafif ve ağır makineler için daha önce geliştirilmiş modellerle karşılaştırılmış, orta ağırlıkta galeri açma makineleri ile yerinde kazı hızında, hafif

tipte makinelere göre artışın 5 MJ/m^3 üzerinde laboratuvar kesme özgül enerjisi gerektiren kayaçlarda gerçekleştiği saptanmıştır.

Anahtar Kelimeler: orta ağırlıkta galeri açma makinesi, performans kestirimi, kesme özgül enerjisi, anlık kesme hızı

To My Family

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The valuable comments and suggestions of the examining committee namely: Prof. Dr. Tevfik Güyagüler, Prof. Dr. Ümit Atalay, Assoc. Prof. Dr. Aydın Bilgin, and Assist. Prof. Dr. E. Mustafa Eyyuboğlu are gratefully acknowledged.

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Most of all I would like to thank my parents and my brother for their support and patience during this study.

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CHAPTER 1

INTRODUCTION

1.1. General

Roadheaders are the most widely used underground partial-face excavation machines for low to medium strength rocks. They are used for both development and production in soft rock mining industry (i.e. main haulage drifts, roadways, cross-cuts, etc.) particularly in coal, sedimentary rocks, industrial minerals and evaporitic rocks. In civil construction, they find extensive use for excavation of tunnels (railway, roadway, sewer, diversion tunnels, etc.) in soft ground conditions, as well as for enlargement and rehabilitation of various underground structures. Their ability to excavate almost any profile opening also makes them very attractive to those mining and civil construction projects where various opening sizes and profiles need to be constructed.

In addition to their high mobility and versatility, roadheaders are generally low capital cost systems compared to the most other mechanical excavators. Because of higher cutting power density due to a small cutting drum, they offer the capability to excavate rocks harder and more abrasive than their counterparts, such as the continuous miners and borers.

Roadheaders were first developed for mechanical excavation of coal in the early 50s. Today, their application areas have expanded beyond the coal mining as a result of continual performance increases brought about by new technological developments and design improvements. The major improvements achieved in the last 50 years consist of steadily increased machine weight, size and cutterhead power, improved design of boom, muck pick up and loading system, more efficient cutterhead design, metallurgical developments in cutting bits, advances in hydraulic and electrical systems and more widespread use of automation and remote control features. All these have led to drastic enhancements in machine cutting capabilities, system availability and the service life. (Çopur et. al, 1998)

Machine weights have reached from 17 tons up to 120 tons providing more stable and stiffer (less vibration, less maintenance) platforms from which higher thrust forces can be generated for attacking harder rock formations. The cutterhead power has increased significantly from 37 kW approaching to 500 kW to allow for higher torque capacities. Modern machines have the ability to cut cross-sections over 100 m^2 from a stationary point. (Çopur et. al, 1998)

1.2. Objective of the Thesis

An essential prerequisite of any mechanical excavation program is the need to know the mechanical cutting or excavation characteristics of the coal or rocks to be cut. Failure to determine these characteristics may result in failure to reach production objectives and in breakdown of machines which will require expensive replacements. Therefore, before installing costly coal mining or roadway driving machines, it is essential to determine the machinability characteristics of rock materials and to estimate cutting performance of the roadheaders.

The cutting performance can be best predicted by determining the cutting specific energy by standard cutting tests. Up to now, the relationships between the in-situ instantaneous cutting rate (m^3/h) and laboratory cutting specific energy (MJ/m^3) have been determined only for Dosco Mk-2A (23-26 t) and Dosco Mk-3 (70-85 t) type roadheaders (McFeat-Smith and Fowell, 1977; Fowell and Johnson, 1982).

Although Dosco Mk-2A roadheaders with a weight of 23-26 t were considered as medium-weight machines at the time of the research (McFeat-Smith and Fowell, 1977), they were found to be insufficient to provide high performance especially at medium strength rocks and have been gradually replaced by heavier machines. Similarly, Dosco Mk-2A machines are rarely in use nowadays and replaced to a larger extent by Mk-2B types with a weight of 37-44 tons. Therefore, Mk-2A can no longer be considered as a medium weight but should be classified as a light-weight machine (Tucker, a., 1985). Mk-2B with a weight of 37-44 tons and Mk-3 with a weight of 70-85 tons can be considered as medium-weight and heavy-weight respectively.

Although correlations between in-situ instantaneous cutting rate (ICR) and laboratory cutting specific energy were determined for Mk-2A and Mk-3 type roadheaders, such a correlation for medium-weight tunneling machines (34-45 tons) has not been cited yet.

The main objective of this thesis is to investigate the possible relationships between the in-situ instantaneous cutting rate and the specific cutting energy and some rock properties measured in the laboratory. In-situ cutting rates of Dosco Mk-2B machines used in Çayırhan Coal Mine are determined and correlations are established with the laboratory cutting specific energies and some rock properties determined by laboratory tests. The scope of the study is restricted to milling type cutting heads.

The rest of the thesis is organized as follows;

In Chapter 2, literature on roadheaders is reviewed.

In Chapter 3, performance prediction methods are explained.

In Chapter 4, laboratory and field studies are given.

Results and discussions are given in Chapter 5.

Conclusions and recommendations for future studies are presented in Chapter 6.

CHAPTER 2

BOOM TYPE ROADHEADERS

2.1. Introduction

Boom-type roadheader generally is a partial face machine for excavating a roadway in such a way that the material to be removed is disintegrated by the continuous rotation of cutting tools and thrust against the surface of the material at the working face. Roadheader machines have importance in roadheading not simply as a compromise between drill and blast techniques and full-face machines, but as an economic and versatile form of mechanized roadheading where the method of excavation is easily integrated with tunneling operations.

2.2. Application and Advantages of the Partial-face Roadheaders

As in civil construction, the mining applications of the roadheaders have included long drives such as tunneling for long ore-body development drifts, long haulage tunnels, longwall access drifts, and long crosscut developments.

In comparison to drill and blast methods, the main advantages of roadheaders are:

- One machine is capable of cutting, loading and assisting in the erection of supports.

- Compared with conventional driving, a greater advance per manshift is obtained.

- Roof control is improved since the roof and sides of the roadway are not shattered by shotfiring.

- The machine is very stable, easily controlled and capable of cutting a large variety of roadway sections and sizes.

- It is safer since the men are near to the unsupported strata only during the erection of supports.

2.3. Classification of Boom-type Roadheaders

The roadheaders can be classified according to their times of introduction, their rock-cutting abilities and their weights. (Bölükbaşı, 1986)

2.3.1 Classification According to Times of Introduction

2.3.1.1 First Generation

First generation machines were introduced in Western Europe in the 1960's. The lighter models of these early boom miners weighed about 9 tons and could cut soft rocks having compressive strength up to about 40 MPa.

2.3.1.2 Second Generation

Second generation machines were developed around 1970. These machines generally weigh between 22-37 tons. Some of these machines can cut competent rock with compressive strength as high as 85 MPa if the silica content of the rock is low.

2.3.1.3 Third Generation

The third generation, heavy-weight machines became available in 1976. These machines weigh between 45-70 tons and can cut competent rock with compressive strength of 100 MPa.

2.3.1.4 Fourth Generation

Machine weights have reached up to 120 tons around 2000 which can be considered as fourth generation machines. Such machines can cut economically most rock formations up to 100 MPa uniaxial compressive strength (UCS) and rocks up to 160 MPa UCS if favorable jointing or bedding is present with low RQD numbers (Çopur et. al, 1998; Thuro and Plinninger, 1998; Neil et. al, 1994).

2.3.2 Classification According to Weight

Tucker (1985) classified roadheaders according to weight as:

- Light Duty; weight up to 30 t, cutting capabilities up to 70 MPa
- Medium Duty; weight between 34-45 t, cutting capabilities up to 100 MPa
- Heavy Duty; weight over 45 t, cutting capabilities up to 120 MPa

Atlas Copco – Eickhoff established the following classification according to weight (Schneider, 1988);

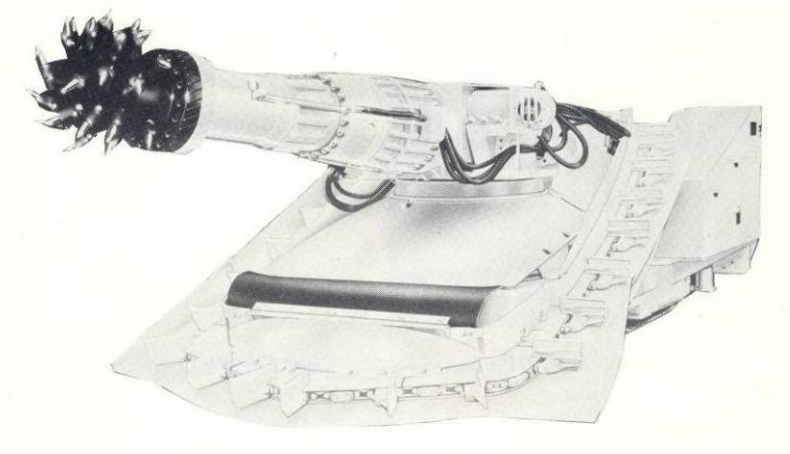
Class	Weight
0	<20 t
I	20-30 t
II	30-50 t
III	50-75 t
IV	>75 t

Neil et. al (1994) refer roadheaders as small size up to 30 t, midsize between 30-70 t and large size between 70-120 t.

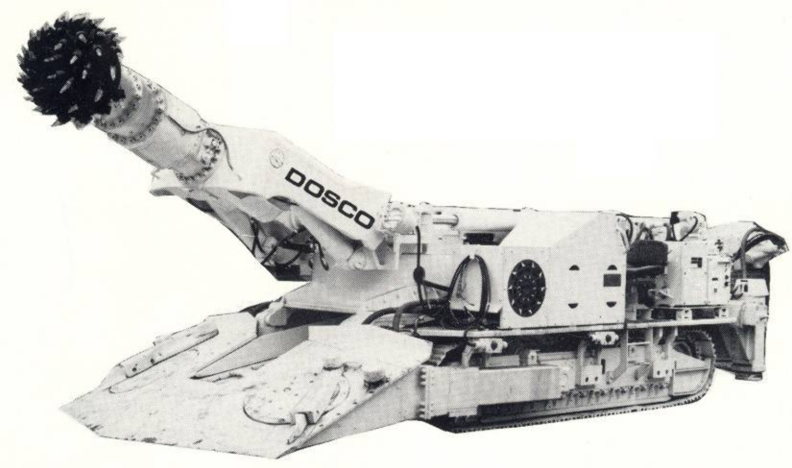
Table 2.1 shows the main types of roadheaders and Table 2.1 shows Mk-2A, Mk-2B and Mk-3 machines which are the typical light, medium and heavy weight machines, respectively.

Table 2.1 Properties of typical roadheaders (Pearse, 1987 and Bölükbaşı, 1986)

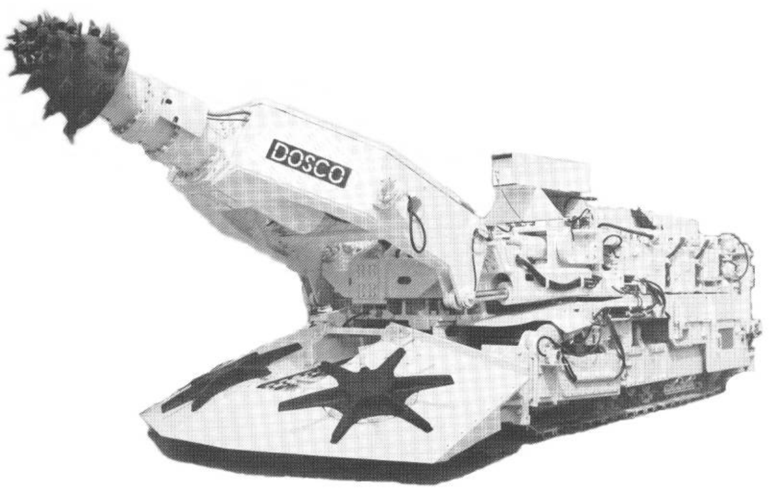
Machine Type	Weight (t)	Head Drive (kW)	Total Power (kW)
ANDERSON STRATCLYDE (UK)			
Boom Miner	22.0	60	120
RH25	25.4	82	157
RH22	35.0	112	187
RH1/3	50.0	90	190
RH1/4	66.0	112	234
RH90	90.0	150	300
DOSCO (UK)			
D.R.C.L.	17.0	37	75
MK2A	23.0-26.0	67	149
SL120	35.0	82	164
MK.2B	38.0	82-112	194-224
LH 1300	43.0	140	286
TB600	81.6	2x190	604
MK3	85.2	140	293
ATLAS COPCO-EICKHOFF (GERMANY)			
ET-100 Series	27.0-34.0	110-132	190/212
ET-200 Series	52.0	200	360
ET-300 Series	78.0-95.0	200/250	380/430
ET-400 Series	97.0-110.0	300	460/480
MACHINE EXPORT (USSR)			
Pk-3	10.8	32	78
Pk-9r	32.0	90	173
MANNESMAN-DEMAG (GERMANY)			
VS3	63.0	160/200	265
VS3/2	75.0	160/200	300
VS4	95.0	132/200	300
MITSUI-MIIKE (JAPAN)			
MRH-S50 13	18.5	50	80
MRH-S100 40	25.0	60/100	145
MRH-S125 23	30.0	75/125	170
VOEST-ALPINE (GERMANY)			
F6-A	12.0	30	60
AM 30	14.5	45	75
AM 45	20.0	75	135
AM 50	22.0	100	155
AM 95	80.0	300	445
AM 100	79.8	235	450
PAURAT (GERMANY)			
E169	44.0	100	185
El 95	46.0	170	263
E134	70.0	115/230	353
E200	115.0	350	512
SALZGITTER (GERMANY)			
STM 100	25.0	100	200
STM 160	45.0	160	257
STM 200	65.0	200	330
WESTFALIA (GERMANY)			
Furchs	6.0	45	52
Luchs	24.0	90	150
WA300 Bison	73.0	300	437



Dosco Mk-2A



Dosco Mk-2B



Dosco Mk-3

Figure 2.1 Typical light (Mk-2A), medium (Mk-2B) and heavy weight (Mk-3) roadheading machines

2.4. Basic Components of Boom Type Roadheaders

2.4.1 Boom, Cutting Head and Picks

2.4.1.1 Boom

Roadheaders can have fixed or telescopic booms. Fixed boom requires the forward movement of the machine body during sumping operations. Telescopic boom is advantageous in that sumping can be carried out by the telescopic action of the boom without the movement of the body.

2.4.1.2 Cutting Head

Boom type roadheaders can be divided into two groups according to the cutting action of the head. (Gehring, 1989; Hekimoğlu, 1984; Alvarez et. al, 2003)

2.4.1.2.1 Milling Type Cutting Heads

For milling type, cutting head rotates in line with the axis of the boom perpendicular to the roadway face; the primary cutting force is exerted sideways. The milling action rips the rock from the face and throws the rock across the floor parallel to the front of the loader head (in comparison, a ripping action throws the rock onto loader head). However, due to the relatively simple in-line gearing between the milling cutting head and the drive motor, milling heads can have smaller diameters than comparable ripper-head machines. Thus, milling booms are better suited for selective mining of ore lenses or bands and for rather soft to medium strength rocks.

2.4.1.2.2 Ripping type Cutting Heads

For ripping-type cutting, the cutting head rotates around an axis parallel to the roadway face. The principle cutting force is provided by the rotary motion of the cutting head, and downward thrust is provided by the boom. Such machines are more suitable for medium to hard rocks.

Figure 2.2 shows the cutting action of the milling and ripping types of cutting heads.

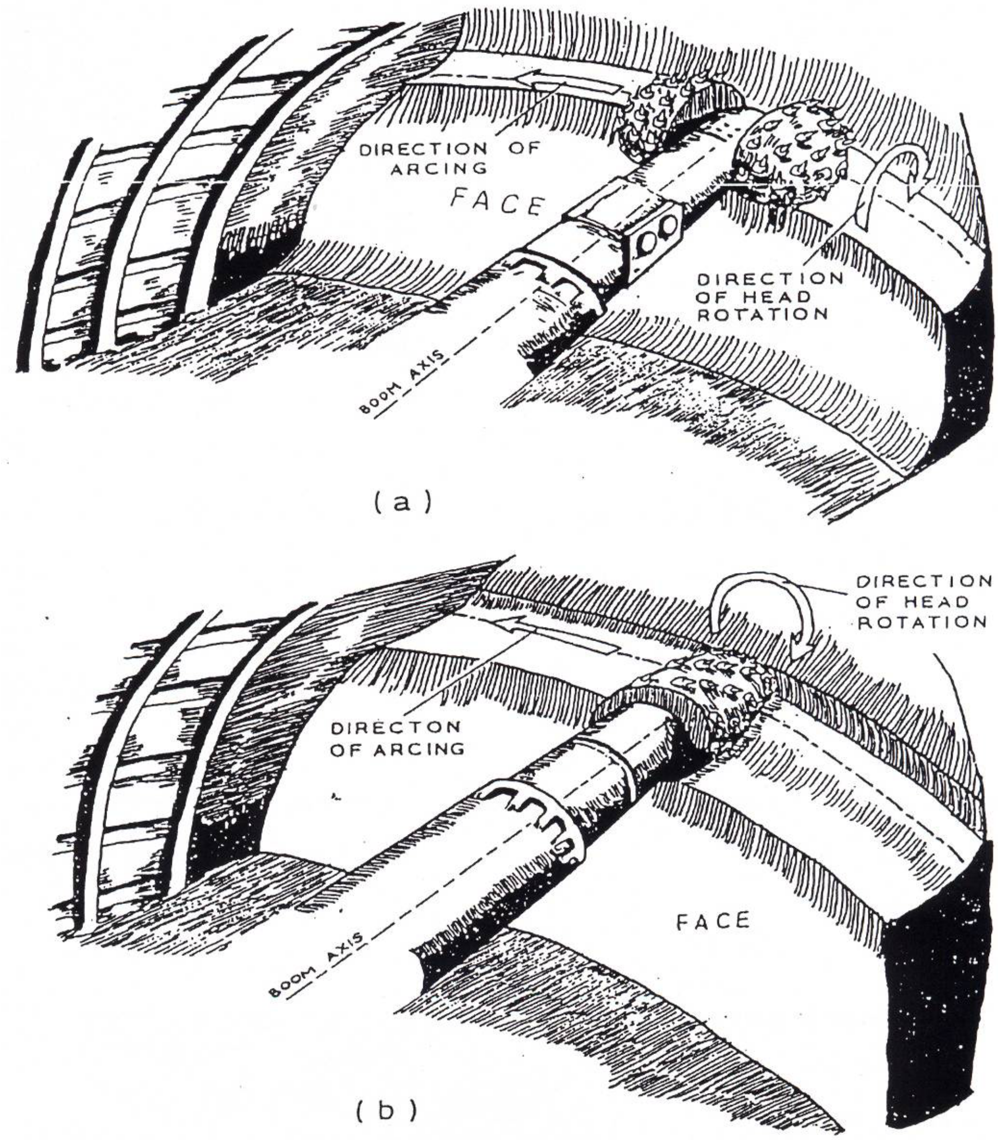


Figure 2.2 Cutting action of roadheaders with; (Hekimoğlu, 1984)

a)Ripping type cutting head b)Milling type cutting head

2.4.1.3 Cutting Picks

Three main types of cutting picks, being radial, forward attack and point attack picks, are usually employed on roadheaders (Figure 2.3).

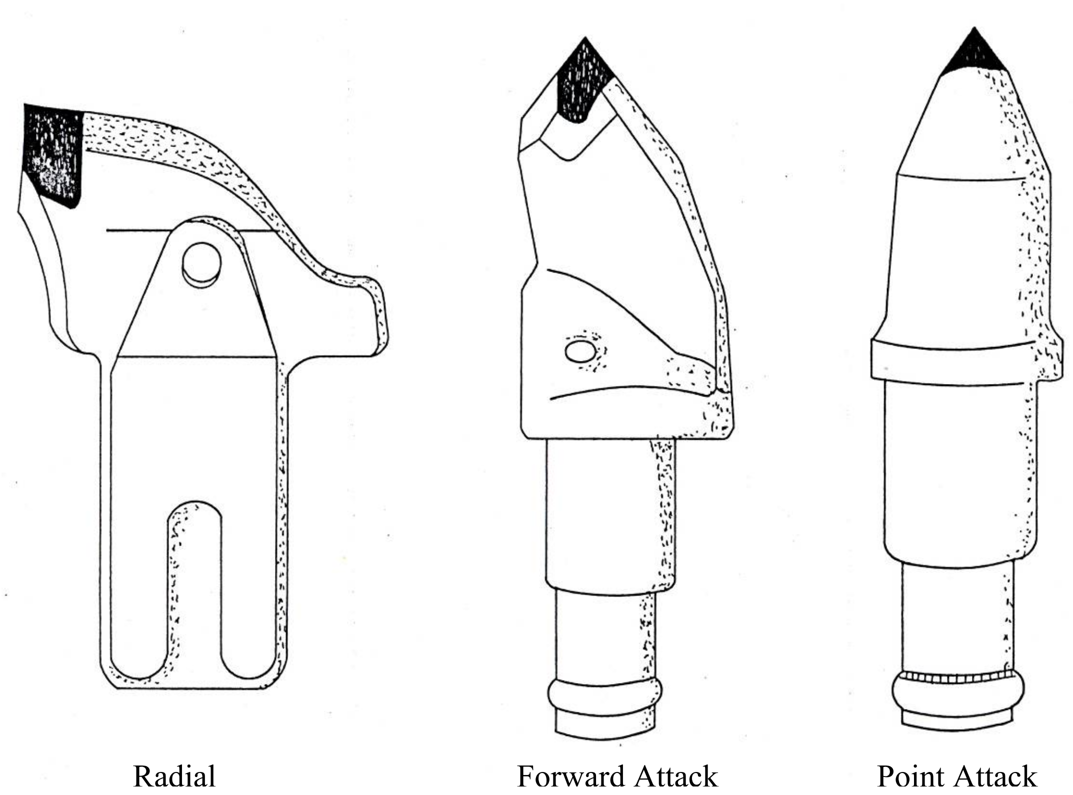


Figure 2.3 Radial, forward attack and point attack picks

Radial picks are generally suitable for cutting soft to medium hard rocks and coal.

Forward attack picks are also termed tangential picks, together with point attack picks due to the orientation of their tool axis. Such picks can also be used for cutting soft to medium hard rocks.

Point attack picks, also known as pencil point tools, have been increasingly employed in medium to hard rock cutting and become an inevitable tool on medium and heavy duty roadheaders. (Eyyuboğlu, 2000)

2.4.2 Loading Unit

Roadheading machine must have sufficient loading and feeding capacity suitable to the amount of material produced by the cutting head. The loading unit may be loading chain, gathering arm loader, loading disc or loading spider type according to the type of the machine. (Pearse, 1987)

2.4.3 Crawlers and the Bridge Conveyor

Roadheading machines move on crawlers and the material loaded by the loading system is carried backward by a chain conveyor towards a rear bridge conveyor which loads the material onto the mine haulage system. Cutting head, loading system feeding conveyor unit and the mine haulage system must work with harmony to obtain efficient operation.

CHAPTER 3

ROADHEADER PERFORMANCE PREDICTION

3.1. Introduction

There are various factors influencing the machine performance in mechanized drivage operations. Table 3.1 outlines the main factors affecting the machine performance and Table 3.2 shows the factors influencing machine utilization.

Classifying rock mass properties involves decisions influenced by both experience and analysis. The influence on machine performance of the rock mass can be visualized as a modifier to a prediction using only the rock material properties. Thus, in most cases, the rock mass will advantageously modify the prediction. In general, the machine must be capable of cutting the rock in massive condition, unless the presence of discontinuities can be guaranteed beyond reasonable doubt. In most cases, the use of light blasting may be introduced to induce fractures that the machine can exploit where difficulties are experienced.

The important requirement in mechanized rock excavation is that the cutting element is capable of taking a reasonable depth of cut. The key is to have a stable cutting machine and adequate forces to hold the cutting machine and adequate forces to hold the cutting tool into the rock, avoiding bouncing of the head. Cutting head lacing patterns are of considerable importance. Sumping should be confined to the center of the face avoiding the confinement at the periphery of the tunnel.

To gain a reliable estimate of advance rate the machine must be considered to be integrated into a tunneling system. The interaction of the tunneling operation with other activities has also to be considered.

Table **3.2** has been included to provide in concise form those factors that influence utilization of the machine. It should be realized that increased utilization is the greatest potential area for improvement in overall advance rates.

Table 3.1 Factors influencing machine performance (Fowell and Johnson, 1982)

Main Factor	**Variables**		
Rock Parameters	Intact Properties	Cuttability	
		Cutting Wear	Abrasivity
			Impact Resistance
			Thermal Properties
		Durability	Slurry Make
	Mass Properties	Discontinuities	Volumetric Intensity
			Orientation
			Shear Strength
		Mixed Face Conditions	
		Degree of Variation In Strata (along line of tunnel)	
	Environ-ment	Water	From Within Rock Mass
			From Dust Suppression
		Tunnel Geometry	Size
			Shape
			Gradient
		In-situ Stresses	
Machine Parameters	Cutting Head	No. of Tools	
		Tool Type	Radial/Forward Attack
			Tip Geometry
			Carbide Grade in Tip
		Lacing Pattern	
	Weight	Slewing + Lifting Forces	
		Head Speed	
		Head Power	
		Rigidity of Machine Construction	
	Operational Character	Profiling	
		Guidance	

Table 3.2 Factors influencing machine utilization (Fowell and Johnson, 1982)

Main Factor	Variables	
Downtime	Planned	Maintenance Spares Availability
	Unplanned	Staff Availability Spares Availability Conditions In the Tunnel
Support	Type and Amount Required	
	Erection System	
	Degree of Mechanization	
	Ancillary Operations	Grouting Lagging Boards
Debris Disposal	At the Face	Cleaning Up General Mucking Secondary Breakage
	Behind the Face	Conveyors Mine Cars Water Presence
Ancillaries	Ventilation	
	Dust Extraction	Water/Pumping Equipment Air Ducts for Extraction
	Extensions	Track Power Cables Telephone Conveyor
Labor	Availability	
	Experience/Skill	
	Transport to Face	Distance/Time Method
Organization	Management	Bonus Schemes Communication
	Shift Times	Total Payable Time Production Time
Final Use	Engineering Tolerances	Grade Alignment
Integration	Is tunneling the only on-site activity, or is it competing for resources with other operations (i.e. Mining)?	
Water	A problem of disposal and drainage	

3.2. Prediction Methods

Various rock mechanics parameters and methods can be employed to estimate the machine performance and rock machinability.

3.2.1 Compressive Strength

Uniaxial compressive strength has been the most commonly used parameter for assessment of the likely performance of roadheaders. The present day heavy duty roadheaders can economically cut most rock formations up to 100 MPa UCS and rocks up to 160 MPa UCS if favorable jointing or bedding is present with low rock mass quality. Increasing frequency of joints or other rock weakness make the rock excavation easier as the machine simply pulls or rips out the blocks instead of cutting them. If the rock is very abrasive or the pick consumption rate is more than 1 pick/m^3, then roadheader excavation usually becomes uneconomical due to frequent bit changes coupled with increased vibration and maintenance costs. (Çopur et. al, 1998)

Whilst the uniaxial compressive strength has long been used to estimate the likely performance of roadheading machines, relationships between rock strength and rock cuttability are often vague and relationships between rock strength and rock cutting tool consumption are non-existent for a range of rock types.

Gehring (1989) studied the relationship between ICR and UCS for a milling type roadheader with 230 kW cutter head power and an Alpine Miner AM 100 ripping type roadheader with 250 kW cutter head power. Figure 3.1 shows the relationships obtained.

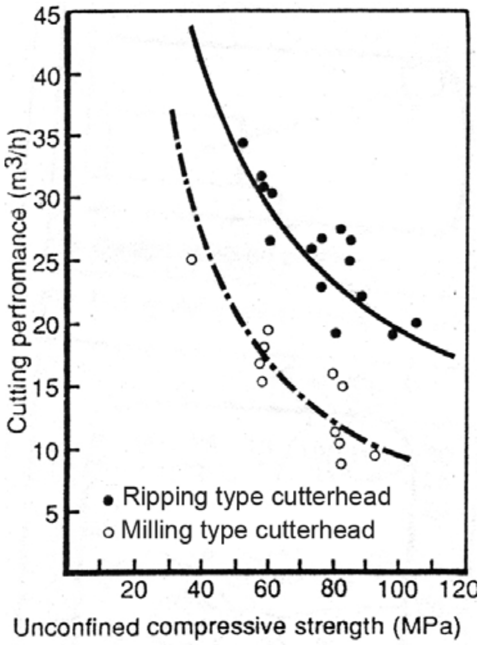


Figure 3.1 Comparison of cutting performance (Gehring, 1989)

He developed the following equations without giving the correlation coefficients:

$L_C = \frac{719}{c^{0.78}}$ for ripping type roadheaders

$L_C = \frac{1739}{c^{1.13}}$ for milling type roadheaders

where

L_C = cutting performance (bank m^3/h),
c = uniaxial compressive strength (MPa)

Bilgin et. al (1996) studied the correlation between ICR, UCS and RQD. Figure 3.2 and Figure 3.3 show the relationship between ICR and UCS for rocks having RQD greater than 50 and less than 50, respectively. No correlation exists for rocks with RQD less than 50.

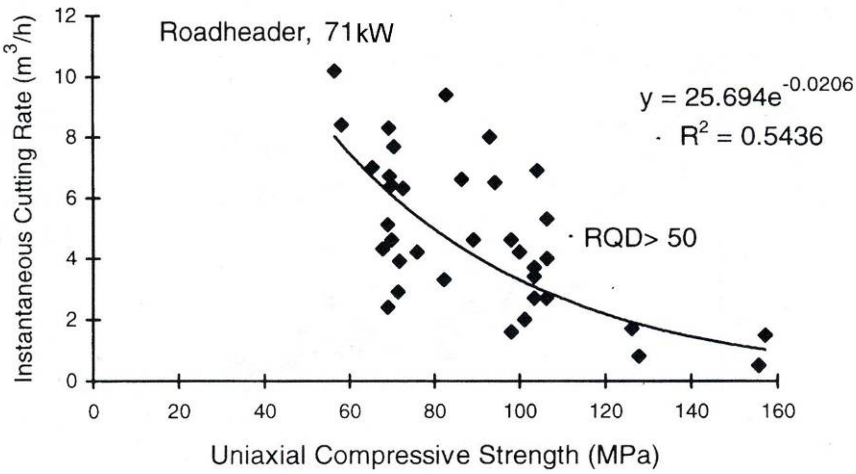


Figure 3.2 The variation of instantaneous cutting rate with uniaxial compressive strength of rock, RQD > 50 (Bilgin et. al, 1996)

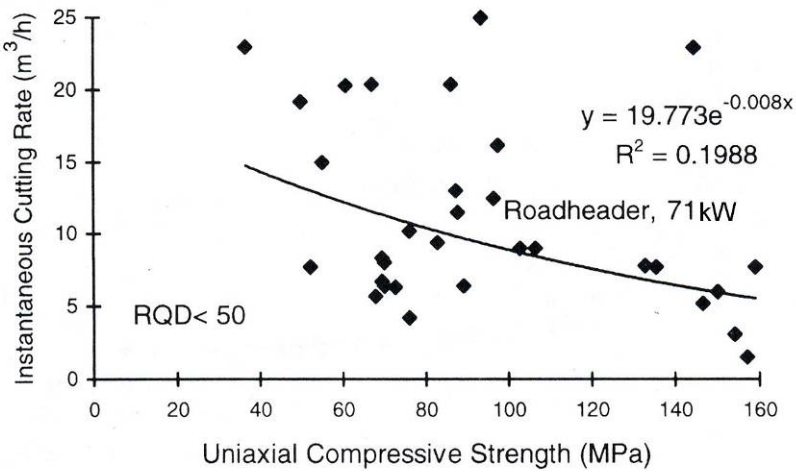


Figure 3.3 The variation of instantaneous cutting rate with uniaxial compressive strength of rock, RQD < 50 (Bilgin et. al, 1996)

Figure 3.4 shows the relationship between ICR and RQD. Results show better correlation as compared to UCS. Correlation has been improved by developing a prediction equation as:

$$ICR = 0.28P\left(0.974\right)^{RMCI}$$

where:

$P =$ Motor power, HP

$RMCI =$ Rock mass cuttability index, MPA

$$= \sigma_c \left(RQD/100 \right)^{2/3}$$

where:

$\sigma_c =$ Uniaxial compressive strength, MPa

$RQD =$ Rock quality designation, % (Bilgin et. al, 1996; Bilgin et. al, 1997; Eskikaya et. al, 1998)

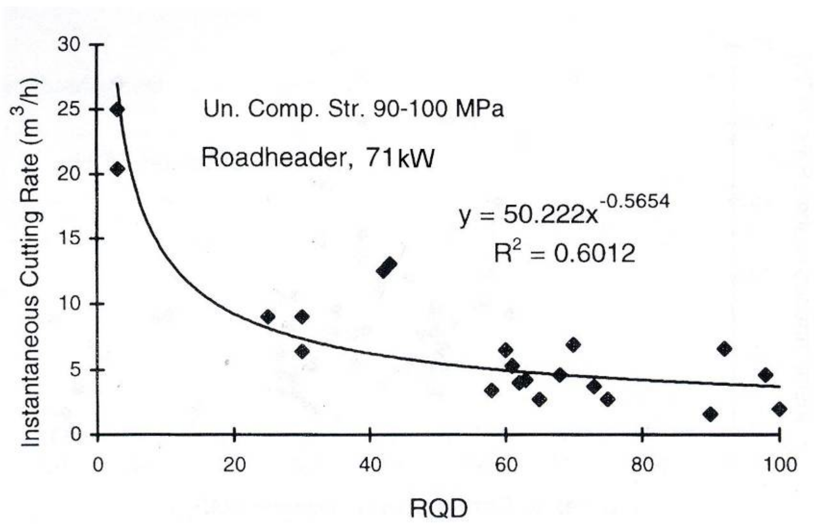


Figure 3.4 The variation of instantaneous cutting rate with RQD, $\sigma_c =$ 90-100 MPa (Bilgin et. al, 1996)

Çopur et. al, (1998) studied the variation of cutting rate with UCS based on available field performance data. Figure 3.5 shows the relationship obtained using different types of roadheaders at the geological conditions encountered. The data shows significant scatter with very low coefficient of determination ($R^2 = 0.29$).

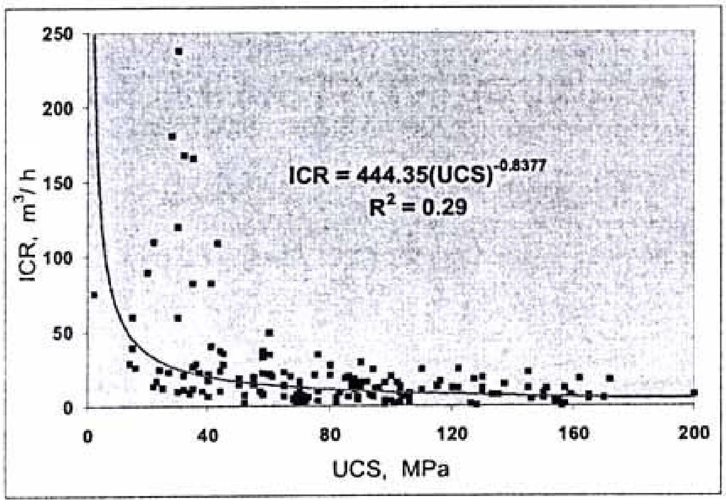


Figure 3.5 Plot of ICR (Instantaneous cutting rate) vs. UCS at different geological conditions encountered and all types of roadheaders (Çopur et. al, 1998)

He obtained higher correlations by developing prediction equations which consider the roadheader weight and cutterhead power for transverse (ripping type) roadheaders. Figure 3.6 and Figure 3.7 show the relationships obtained for sedimentary rocks and evaporitic rocks respectively where;

$$RPI = P \times W / UCS$$

RPI = Roadheader penetration index

W = Roadheader weight (t)

P = Cutterhead power (kW)

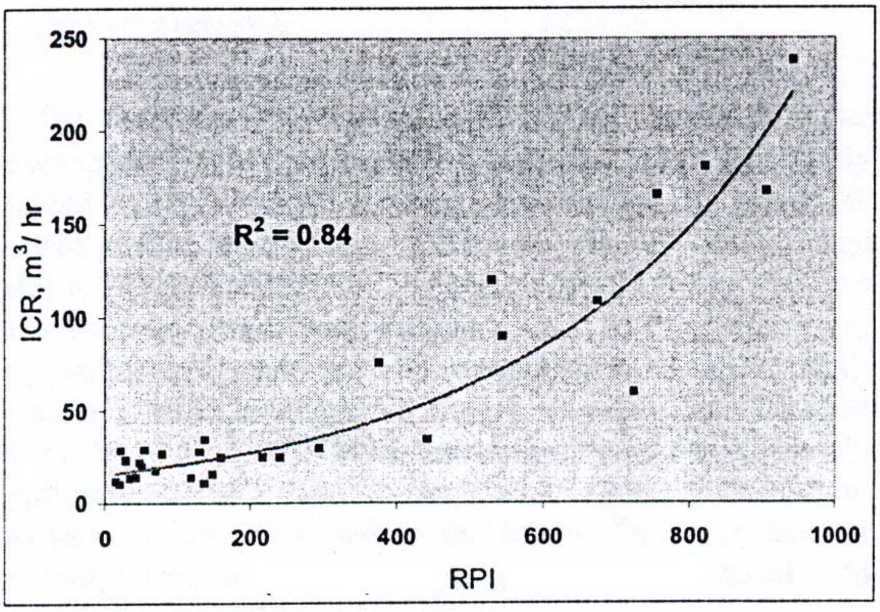


Figure 3.6 Plot of ICR vs. RPI for sedimentary rocks and transverse roadheaders (Çopur et. al, 1998)

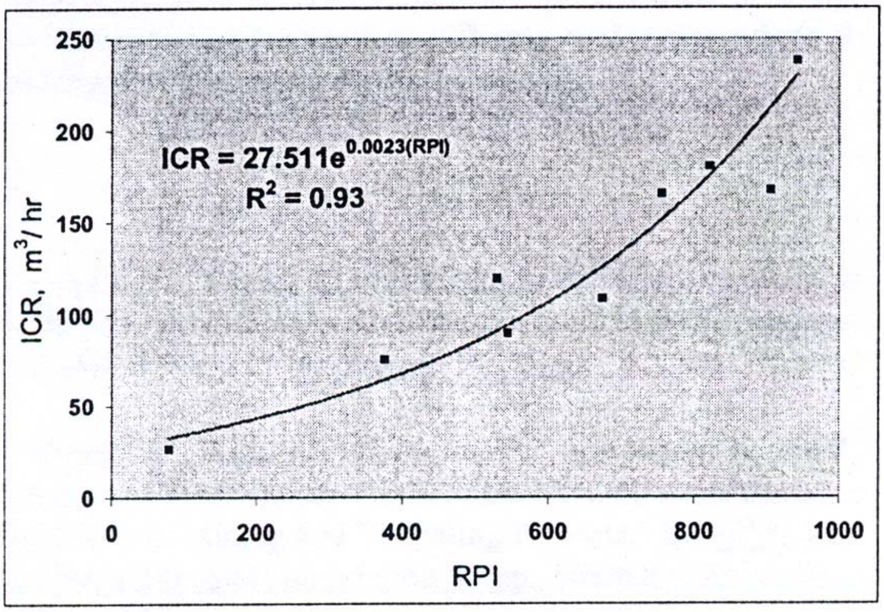


Figure 3.7 Plot of ICR vs. RPI for evaporitic rocks and transverse roadheaders (Çopur et. al, 1998)

Thuro & Plinninger (1999) determined the relationship between the cutting rate and the uniaxial compressive strength for 132 kW roadheader as shown in Figure 3.8. They have found that the correlation between UCS and cutting performance is not sufficient (Thuro and Plinninger, 1999).

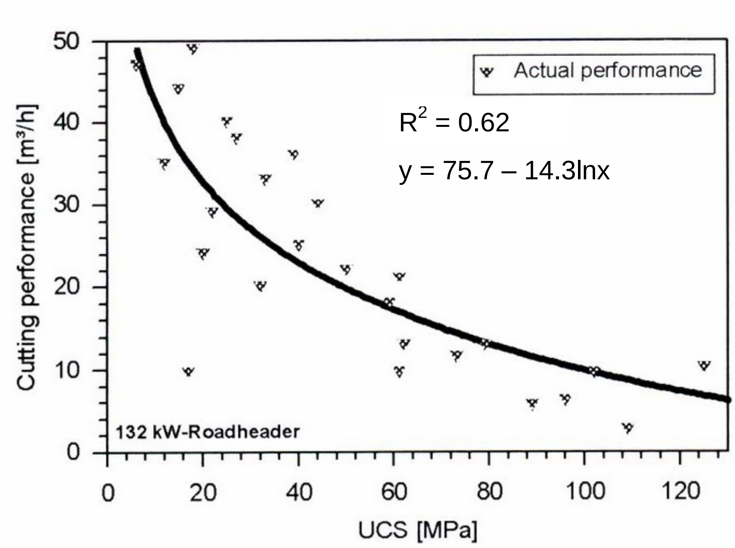


Figure 3.8 Cutting performance correlated with compressive strength of 26 rock samples (Thuro and Plinninger, 1999)

They obtained higher correlation by putting cutting performance against specific destruction work W_Z (kJ/m^3) which has been introduced by Thuro (1996), Thuro and Spaun (1996a, 1996b). Figure 3.9 shows the correlation curve.

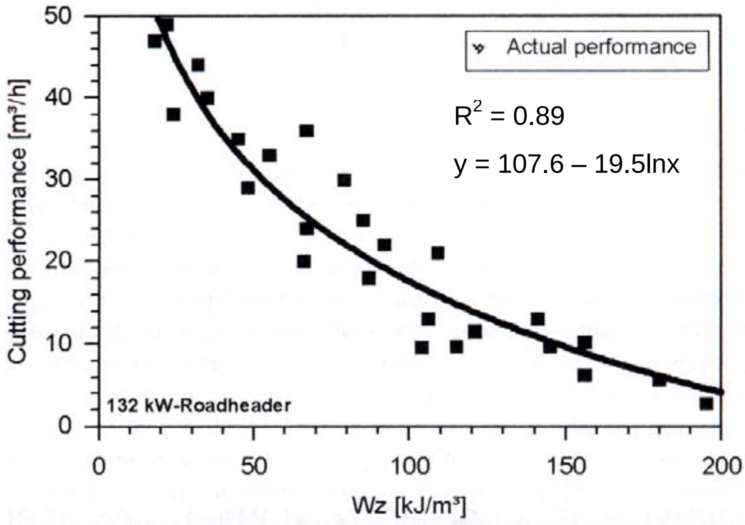


Figure 3.9 Cutting performance correlated with destruction work of 26 rock samples (Thuro and Plinninger, 1999)

As a result, although the uniaxial compressive strength of the rock to be excavated is often quoted as a measure of cuttability, the compressive strength alone is a poor predictor of machine performance if other effective factors such as machine weight, cutterhead power and other effective rock properties such as discontinuity spacing in the rock mass, brittleness of the material and abrasivity are not considered (McFeat-Smith, 1977; Fowell and Pycroft, 1980; Fowell and Speight, 1984; Thuro and Plinninger, 1999).

3.2.2 Tensile Strength

Though models of rock failure under attack by drag tools using the shear strength of a rock have been proposed by some researchers (McFeat-Smith, 1977), the model used by Evans (Evans, 1962) for coal, taking the tensile strength as the main criteria has found wider acceptance for predicting cutting forces in brittle materials.

Roxborough (1977) has shown that a modification to Evans' theory can be applied successfully to a number of rock materials to predict cutting forces. This approach does not yield the complete machinability characteristics of a rock as it is based solely on the tensile strength property of the rock and cutting tool geometry.

3.2.3 Cone Indenter Hardness

The NCB cone indenter, which was developed by MRDE in U.K., is a portable instrument capable of giving a measure of rock strength without requiring the preparation of accurately shaped and finished specimens. The cutting action of drag-pick tools has been shown to be primarily an indentation action and rather good relationship exists between the cone indenter hardness and performance of selective roadheading machines employing drag pick type cutting tools (McFeat-Smith, 1977; MRDE, 1977).Table 3.3 gives the relationship between standard cone indenter hardness and the cutting performance.

Although the cone indenter gives some indication of cuttability, it is not applicable for all rocks since deviations have also been observed where rocks with low indenter numbers required high cutting energies (Fowell and Pycroft, 1980).

Table 3.3 Application of Dosco Roadheaders in massive sandstone beds relative to the standard cone indenter hardness (McFeat-Smith, 1977)

Standard Hardness		Cutting performance
6	6.0	Only selective cutting of these rocks is possible if in bands less than 0-30 cm thick.
5		Roadheaders are not suited to these rocks. Some progress possible if softer bands present in face. Blasting will probably be required to assist excavation.
4	4.0	Roadheader may cut satisfactorily if picks are changed regularly. High cutting energies (8-11 MJ/m^3) and vibrations will severely reduce life span of machine components
3	3.0	Moderate drivage rates. May be as low as 10 m^3/h in hardest rocks
	2.5	
2		Satisfactory progress can be made. Cutting rates of 12-15 m^3/h likely
	1.8	
1		Roadheaders excellently suited to these rocks. Good drivage rates can be expected (up to 20 m^3/h).

3.2.4 Shore Hardness

This method is suggested for the hardness determination of rocks, using the shore scleroscope (ISRM, 1981).

The shore scleroscope has proved to be a valuable laboratory tool for the determination of rock hardness with good correlation to uniaxial compressive strength (Atkinson et. al, 1986). Although the shore hardness indicates the machinability to a certain extend, it may give unreliable results for some rocks especially where samples have large number of hard crystals.

3.2.5 Schmidt Rebound Hardness

Schmidt hammer is suggested for the hardness determination of rocks in laboratory or in-situ. Schmidt hammer rebound values have been correlated with compressive strength by a number of workers (Atkinson et. al, 1986), but this method is of limited use on very soft or very hard rocks (ISRM, 1981).

Goktan and Gunes , 2004 determined Schmidt hammer rebound number by applying 15-20 continuous impacts at each test point and calculated the mean excluding suspected low values. Correlation of Schmidt rebound numbers determined as explained above against net cutting rates for a roadheader with cuttinghead power of 90 kW provided relatively high coefficient of determination(R^2 = 0.73) as shown in Figure 3.10.

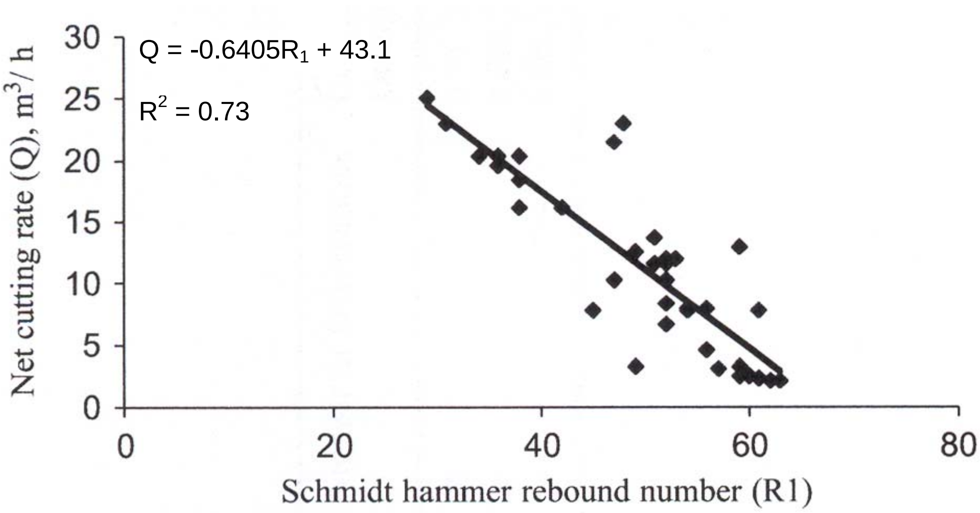


Figure 3.10 Relationship between Schmidt hammer rebound values and net cutting rate (Göktan, 2005)

Although a close correlation between Schmidt hammer rebound number and the advance rate of roadheaders was obtained for some rocks, rebound number was found to be insufficient to define the cuttability of rocks in general (Poole and Farmer, 1978).

3.2.6 Laboratory Cutting Specific Energy

Although the previously mentioned methods give some indication about the cuttability, it can be concluded that it is not advisable to attempt to predict cuttability from a single rock material parameter since it is a function of a number of parameters such as strength, brittleness and abrasivity. A good correlation has been found to exist between in-situ machine performance and laboratory cutting specific energy (McFeat-Smith and Fowell, 1977; Fowell and Johnson, 1982).

Specific energy is a commonly accepted measure of cutting efficiency and when obtained under standardized conditions, provides a realistic and meaningful measure of rock cuttability since it includes the effect of the most of the rock parameters.

Specific energy can be defined as the work done to excavate unit volume of rock and quoted in megajoules per cubic meter (MJ/m^3). It has been found that this laboratory measure of specific energy provides a good indication of likely machine performance. Figure 3.11 and Table 3.4 show the relationship obtained between the laboratory cutting specific energy (SE_L) and field instantaneous cutting rate (ICR) for Dosco Mk-2A and Dosco Mk-3 type roadheaders (McFeat-Smith and Fowell, 1977; Fowell and Pycroft, 1980). Although Mk-2A machine was considered as a medium-weight machine earlier, it is classified under the light-weight machines nowadays, as mentioned before.

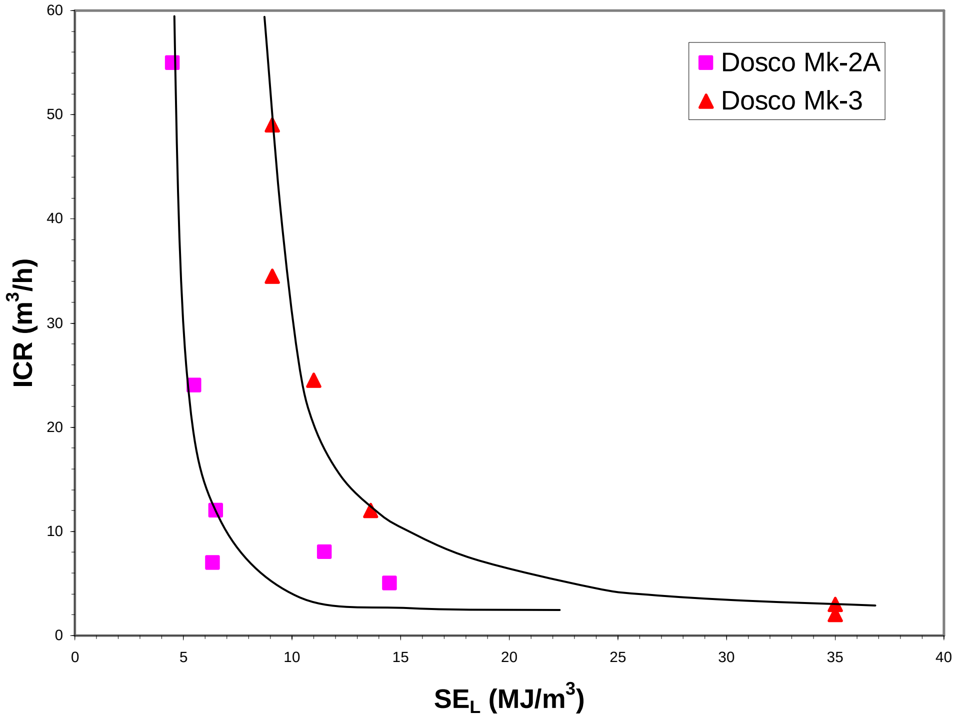


Figure 3.11 Prediction of cutting rate from laboratory specific energy (Fowell and Johnson, 1982)

Table 3.4 Roadheader performance relative to laboratory specific energy (Fowell and Pycroft, 1982)

Lab. spec. energy (MJ/m^3)	Cutting Performance (Dosco Mk-2A)	Lab. spec. energy (MJ/m^3)	Cutting Performance (Dosco Mk-3)
20	Machines can only cut these rocks at economic rates if they occur in thin bands (less than 0.3 m). Short term replacement of machine components may be required due to substantial cutting vibrations	32	Machines can cut only thin bands of these rocks and tool wear will be exceptionally high. Short-term damage to machine can be expected.
15	Poor cutting performance. Excavation may have to be assisted by blasting for rock at top end of scale. Shattered inserts should be expected. Regular replacement of slightly worn picks will improve energy requirements and reduce component wear. Point attack tools may be more beneficial.	25	Poor cutting performance particularly in massive rocks. Pick wear critical and cutting will improve by frequent inspection. Point attack picks essential.
12	Moderate-poor cutting performance. Shattered pick inserts can still be expected although less common. For abrasive rocks picks must be inspected frequently.	17	Moderate cutting performance to good at bottom of category. Picks should be inspected and changed regularly particularly when excavating abrasive rocks.
8	Moderate to good cutting performance with very low wear of machine components. Picks must be inspected and changed regularly particularly when excavating abrasive rocks.	8	Machine well suited to these rocks and rapid advance rates can be anticipated. Regular inspection and replacement of tools still advantageous.
5	Machine well suited to these rocks. Good advance rates can be anticipated. Regular inspection and replacement of worn picks still advantageous.		

CHAPTER 4

LABORATORY AND FIELD STUDIES

4.1. Introduction

Field studies were performed in Çayırhan Coal Mine with Dosco Mk-2B roadheaders. Rock and coal samples collected during the field studies were tested at METU laboratories to determine mechanical properties. This chapter focuses on laboratory and field studies.

4.2. Laboratory Studies

Rock and coal samples are taken from the same types of material at which in-situ cutting performance tests were carried out with Dosco Mk-2B machines at Çayırhan Coal Mine. Rock properties were determined and cutting tests were carried out to determine laboratory cutting specific energy.

4.2.1 Uniaxial Compressive and Tensile Strength Determination

Uniaxial compressive and tensile strengths were determined according to ISRM suggested methods (ISRM, 1981).

4.2.2 Cone Indenter Hardness Determination

Figure 4.1 shows the NCB Cone Indenter used in the tests. The NCB Cone Indenter is a portable instrument capable of giving a measure of rock strength without requiring the preparation of accurately sized specimens. The instrument is designed to determine the hardness of rock by measuring its resistance to indentation by a hardened tungsten carbide cone.

It comprises a portal steel frame 175 mm long in which a steel strip is clamped along a longitudinal axis. In the middle of one longitudinal side of the frame a dial gauge is inserted in such a way that its probe is in contact with one side of the steel strip. In the middle of the opposite longitudinal side of the frame is fitted a micrometer with a hollow spindle into which is inserted a tungsten carbide cylinder with a conical tip having a 40° cone angle. The flat base of the cylinder is in contact with a steel ball so that the cylinder is free to rotate in its mounting. The micrometer is used to measure the amount of indentation and the gauge indicates the distance the spring is deflected.

Figure 4.1 NCB Cone Indenter

The cone indenter hardness value for any particular test is obtained by dividing the force (i.e. spring deflection) necessary to cause penetration by the amount of penetration that has occurred. Thus cone indenter number variation

$$I = \frac{D}{P}$$

where D = nominal deflection of steel strip (representing force) and P = penetration of specimen by cone. Cone indenter numbers are determined as standard (I_s), weak

(I_w) and modified (I_m) depending on the types of rocks, for medium, weak and high strength rocks respectively. (MRDE, 1977)

4.2.3 Shore Hardness Determination

Figure 4.2 shows the C-2 type shore scleroscope used in the tests. The shore scleroscope consists of a diamond or tungsten carbide tipped mass which is fitted into a vertical guide tube and set at a predetermined height. Practically, the mass is raised by suction about 300 mm. The specimen is mounted on the anvil situated below the tube and the mass is allowed to fall freely onto the surface of the specimen by squeezing the rubber bulb of the equipment. After striking the surface the mass rebounds and the height of rebound which is indicated on a graduated tube, is a measure of the samples resilience. The test requires smooth flat surfaces and the specimen should have a minimum test surface of 10 cm^2 and a minimum thickness of 1 cm. At least 20 hardness determinations should be taken. (ISRM, 1981)

Figure 4.2 Shore Scleroscope

4.2.4 Schmidt Rebound Hardness Determination

Figure 4.3 shows the L-type Schmidt hammer used in tests. The plunger of the hammer is placed against the specimen and is depressed into the hammer by pushing the hammer against the specimen vertically. Energy is stored in a spring which automatically rebounds at a prescribed energy level and impacts a mass against the plunger. The height of rebound of the mass is measured on a scale and is taken as the measure of hardness. If instrument is not vertically downward pointed, gravitational effect due to inclination of hammer must be accounted and the results should be corrected for inclination. At least 20 individual tests shall be conducted on any rock sample. (ISRM, 1981)

Figure 4.3 Schmidt Hammer

4.2.5 Laboratory Cutting Tests

The object of the cutting test is to investigate the relationship between force, rock product and cutting efficiency within the standard cutting depth for the single pick cutting in rock specimen. The lower the specific energy the more efficient is the cutting process. This test has been developed by Roxborough and Phillips (1974) to simulate the cutting action of a drag pick tool and to measure the corresponding cutting properties of rock materials.

4.2.5.1 Procedure

The cutting tests were carried out on the blocks at the following standard cutting conditions (Fowell and Johnson, 1982):

Depth of cut : 5 mm

Cutting speed : 150 mm / s

Type of cutting pick

Rake angle : -5°

Back clearance angle : 5°

Cutting width : 12.7 mm

Composition : Tungsten carbide with 10%cobalt

The experiment steps are:

- The rock is cut at standard conditions,
- The recording paper is analyzed and mean cutting force (Fc) is calculated in MN,
- The length cut (L) is measured in meters,
- The amount of rock cut is weighed and using its density the volume of the rock cut is calculated. Then laboratory cutting specific energy is calculated by the following formula:

$$Laboratory\ cutting\ specific\ energy\ (SE_L) = \frac{Mean\ cutting\ force\ (MN) \times Length\ cut\ (m)}{Yield\ (m^3)}$$

$$= MJ/m^3$$

Figure 4.4 shows the main variables of drag tools in rock cutting.

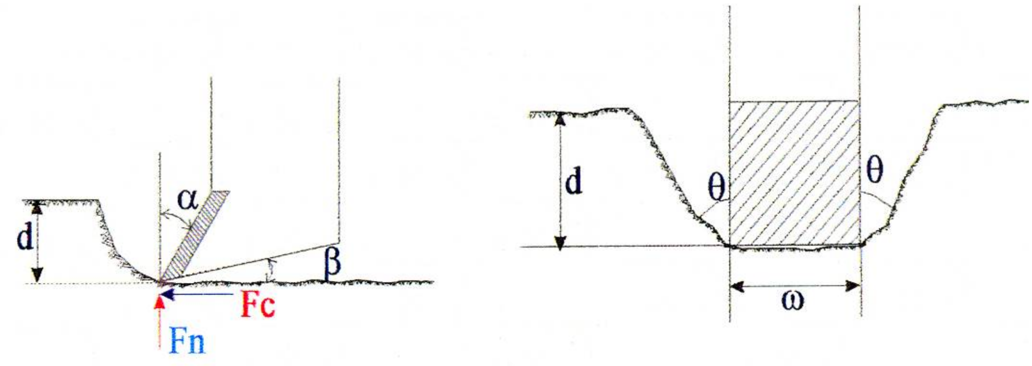


Figure 4.4 Drag tool variables (Eyyuboğlu, 2000)

Where;

Fn = Normal force

Fc = Cutting force

α = Rake angle

d = Depth of cut

θ = Breakout angle

ω = Pick width

β = Back clearance angle

4.2.5.2 Rock Cutting Setup

Figure 4.5 shows the general view of the rock cutting test setup used in the studies.

Figure 4.5 Rock cutting setup

4.2.5.2.1 Shaping Machine

The cutting test rig is a modified MKE HS 600 shaping machine, having a stroke of 625 mm and a power of 4 kW. The rig can be raised, lowered or traversed relative to the cutting tool and can accommodate a block of rock having a length of 50 cm, a width of 35 cm and a height of 30 cm. The cross-head of the shaper has been modified to accept a triaxial force dynamometer and a tool holder.

4.2.5.2.2 Triaxial Dynamometer

A dynamometer is an instrument for measuring dynamic forces. The triaxial dynamometer used in the tests resolves the force acting on the tool during cutting into three mutually perpendicular components; the in-line cutting force, the normal force tending to push the tool out of the rock and the lateral force tending to move the tool sideways. For cuttability study and the specific energy determination only the cutting force component is recorded and continuously integrated onto an ultraviolet multi-channel recorder with the help of an integrator.

4.2.5.2.3 Recording Unit

Recording unit consists of a SE 995 6-channel alternating current bridge conditioning unit (exitation output of 5 volts), a SE 6151 conditioning amplifier, a SE 6150 12 channel ultra-violet oscillograph and an integrator.

Electrical signals coming from the dynamometer are amplified and the direct cutting and mean forces are recorded on the ultra-violet paper as shown in Figure 4.6.

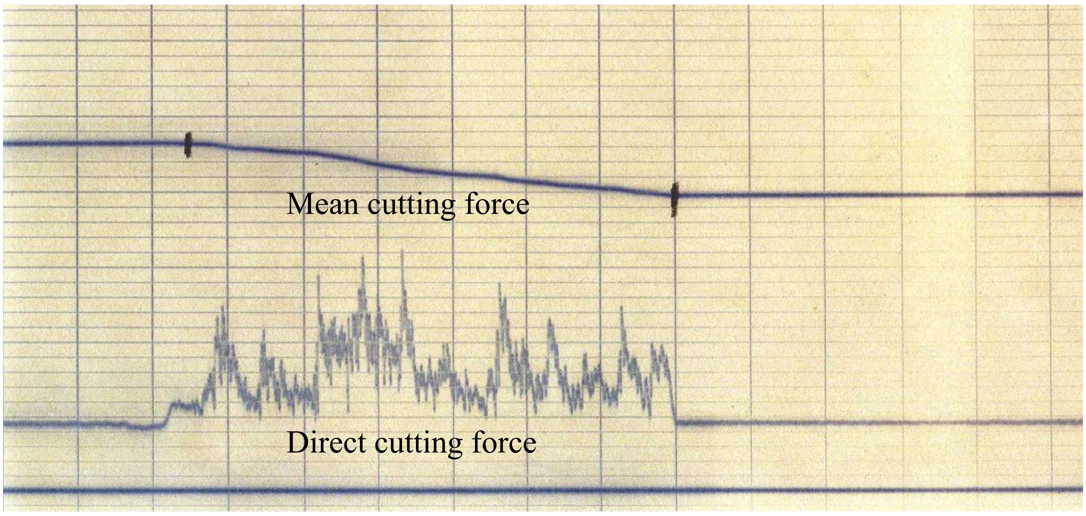


Figure 4.6 Typical records of direct and mean cutting forces on an ultraviolet paper

In order to calculate the mean forces on the cutting tool it is necessary to measure the area under the analogue trace. This area can be measured physically using a planimeter, but this would be a laborious and time consuming process. This is achieved in the integrator circuit. The output from this circuit is effectively the summated area under the trace. By dividing the output at any instant of time by the distance or time covered, the answer will be directly proportional to the mean force.

4.3. Field Studies

Cutting performances of Dosco Mk-2B machines have been provided from the previous measurements carried out on different rock types encountered in driving A2301, F0710 and G4007 roadways. (Eyyuboğlu, 2004)

4.3.1 Çayırhan Coal Mine

Çayırhan district located 125km North-West of Ankara is one of the most important lignite coal-fired electricity generation center in Turkey with a capacity of 5 Mt/a underground coal production and 4.3 billion kWh energy generation per annum (3.5% of the total energy generation of Turkey). The coal mine is the first fully mechanized underground mine in Turkey and is also the most modern one. Figure 4.7 shows the location map of the Çayırhan Coal District.

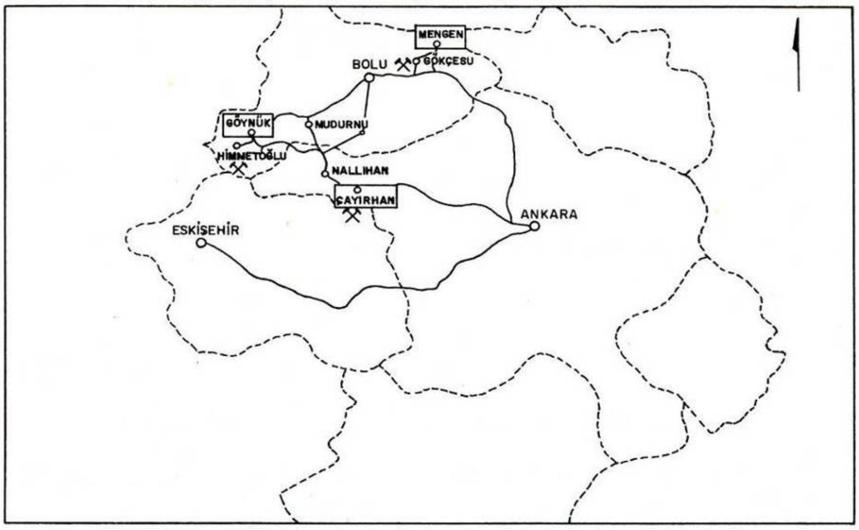


Figure 4.7 Location map of Çayırhan coal mine (Ceylan, 1987)

4.3.1.1 Geology

Çayırhan region is composed of metamorphic, volcanic and sedimentary rocks which are agglomerate, clay, carbonate, silica and volcanic tuffs (Helvacı, 1985). Figure 4.8 is a vertical section showing the coal seams and main rock types.

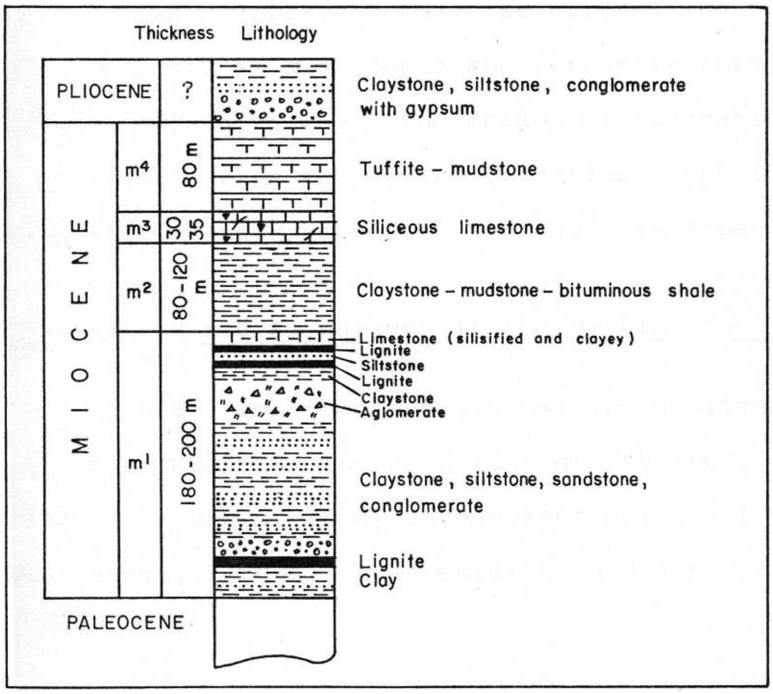


Figure 4.8 Vertical section (O.A.L. records)

Mining operations in Çayırhan district, so far, have been performed in A, B, C and F fields as shown in Figure 4.9.

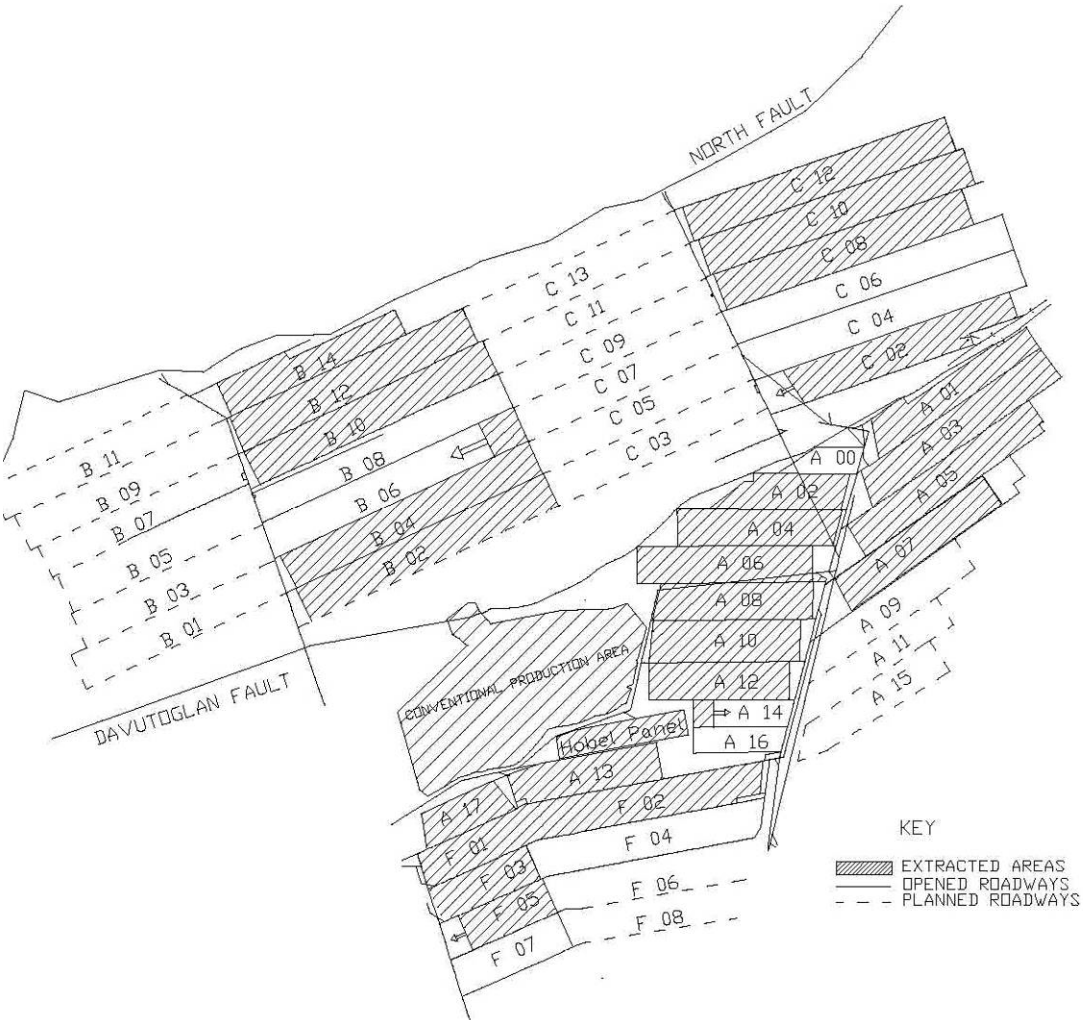


Figure 4.9 Çayırhan Coal Mine Plan (Eyyuboğlu and Bölükbaşı, 2004)

4.3.2 Test Procedure

In-situ cutting tests were carried out using Dosco Mk-2B which had a cutting head diameter of about 600 mm, power of 112 kW and fitted with 24 point attack cutting picks. Majority of the in-situ cutting test results were available previously and additional tests were conducted on rock types encountered during the research period. Figure 4.10 shows the general layout of the roadway drivage.

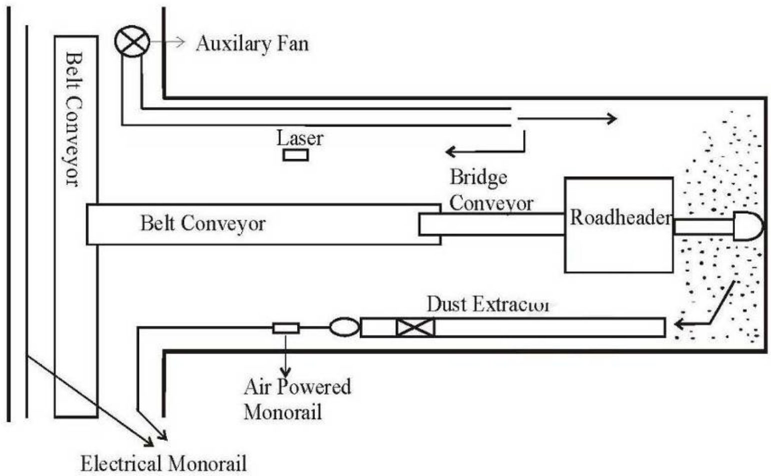


Figure 4.10 General layout of roadway drivage (Eyyuboğlu and Bölükbaşı, 2004)

Most of the roadways have been driven 5.5 m wide by 5 m high using Dosco Mk-2B roadheaders to include lower and upper seam with an intercalation of around 0.8 m.

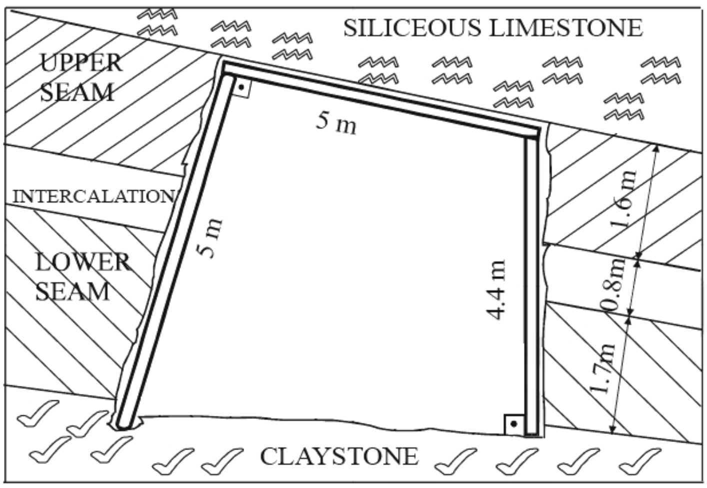


Figure 4.11 Gateroads driven to include both seams (Eyyuboğlu and Bölükbaşı, 2004)

The roadway face is prepared before the cutting test applied. The roadheading machine is positioned in line with the roadway axis and a smooth arc shaped face was obtained by carrying out horizontal cutting. Figure 4.12 shows the roadheader positioning in horizontal traversing.

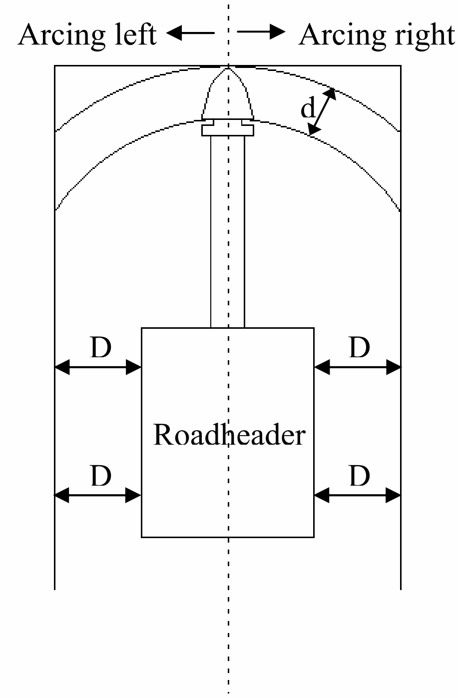


Figure 4.12 Positioning of the roadheader for horizontal traversing

To measure the instantaneous cutting rate (ICR), cutting head is fully sumped into the face at the center perpendicularly at a depth of about 40 cm and time required to make a cut in traversing towards right or left horizontally is recorded. Knowing the depth of cut and the time required , volume of the material cut can be calculated and the ICR can be determined as m^3/h.

CHAPTER 5

RESULTS AND DISCUSSIONS

Rock properties and the laboratory cutting specific energy determinations were carried out on rock samples whose in-situ cutting rate determinations had been completed before.

Instantaneous cutting rate (m^3/h) does not represent the average cutting rate (m^3/h) during the whole shift, but it is the net cutting rate per unit time. On the other hand, average cutting rate per shift will be affected by other operations like supporting, maintenance, etc.

5.1. In-situ and Laboratory Results

Table 5.1 gives the in-situ cutting performance (ICR) and laboratory cutting specific energy results for the rock types encountered in roadway drivages. Table 5.2 gives the rock property test results for the same type of rocks.

Table 5.1 In-situ cutting performance and laboratory cutting specific energy results

No	Rock Type	Instantaneous Cutting Rate (m^3/h) ICR	Laboratory Specific Energy (MJ/m^3) SE_L
1	Clayey Limestone (1)	14.19	6.70
2	Clayey Limestone (2)	15.73	10.19
3	Calcereous Tuff (1)	19.85	7.75
4	Calcereous Tuff (2)	19.63	5.38
5	Siltstone (1)	18.25	7.38
6	Claystone (1)	17.13	7.28
7	Siltstone (2)	36.36	4.00
8	Claystone (2)	27.16	5.67
9	Marl	28.81	4.65
10	Coal (Lower Seam)	47.47	3.87
11	Coal (Upper Seam)	65.61	2.84

Table 5.2 Rock property test results

No	Rock Type	Compressive Strength (MN/m^2)±s.d.	Tensile Strength (MN/m2)±s.d.	Cone Indenter Hardness (I_s)±s.d.	Schmidt Rebound Hardness±s.d.	Shore Scleroscope Hardness±s.d.	Density (g/cm^3)
1	Clayey Limestone (1)	69.06 ± 7.01	6.80 ± 0.73	2.785 ± 0.28	30.17 ± 4.1	24.50 ± 1.50	1.89
2	Clayey Limestone (2)	62.58 ± 9.70	6.16 ± 0.66	2.524 ± 0.39	39.17 ± 3.4	31.50 ± 3.50	1.72
3	Calcereous Tuff (1)	47.98 ± 14.20	3.66 ± 0.66	1.935 ± 0.57	38.75 ± 3.2	21.54 ± 5.86	1.83
4	Calcereous Tuff (2)	61.40 ± 11.27	4.69 ± 0.85	2.476 ± 0.45	27.75 ± 8.6	24.00 ± 1.00	1.93
5	Siltstone (1)	29.23 ± 2.90	2.34 ± 0.78	1.816 ± 0.10	22.00 ± 5.9	22.00 ± 2.00	1.86
6	Claystone (1)	26.37 ± 2.60	3.75 ± 0.56	1.492 ± 0.24	41.25 ± 3.2	27.50 ± 2.50	1.95
7	Siltstone (2)	22.70 ± 2.50	1.82 ± 0.57	1.936 ± 0.19	37.75 ± 4.4	19.79 ± 1.92	1.57
8	Claystone (2)	19.20 ± 1.40	2.73 ± 0.41	1.215 ± 0.13	35.13 ± 5.4	18.62 ± 1.49	1.97
9	Marl	14.52 ± 4.47	2.40 ± 0.33	1.310 ± 0.18	20.00 ± 3.2	16.83 ± 3.75	1.74
10	Coal (Lower Seam)	10.20 ± 3.19	2.15 ± 0.46	1.126 ± 0.27	48.50 ± 2.67	40.00 ± 3.5	1.53
11	Coal (Upper Seam)	7.09 ± 2.35	1.94 ± 0.35	0.930 ± 0.06	51.00 ± 2.14	34.00 ± 3.0	1.53

5.2. Analysis and Discussion of Results

Relationships are determined between in-situ instantaneous cutting rates against laboratory cutting specific energies and other rock properties. Figures 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6 show the relationships obtained and the coefficients of determination (R^2). Since large anomalies are obtained especially against Schmidt and Shore hardnesses and no problem exists to cut coal efficiently even with light-weight roadheaders; correlation equations are determined both by including and excluding coal.

5.2.1 Instantaneous Cutting Rate versus Uniaxial Compressive Strength

Figure 5.1 shows the relationship between ICR and UCS.

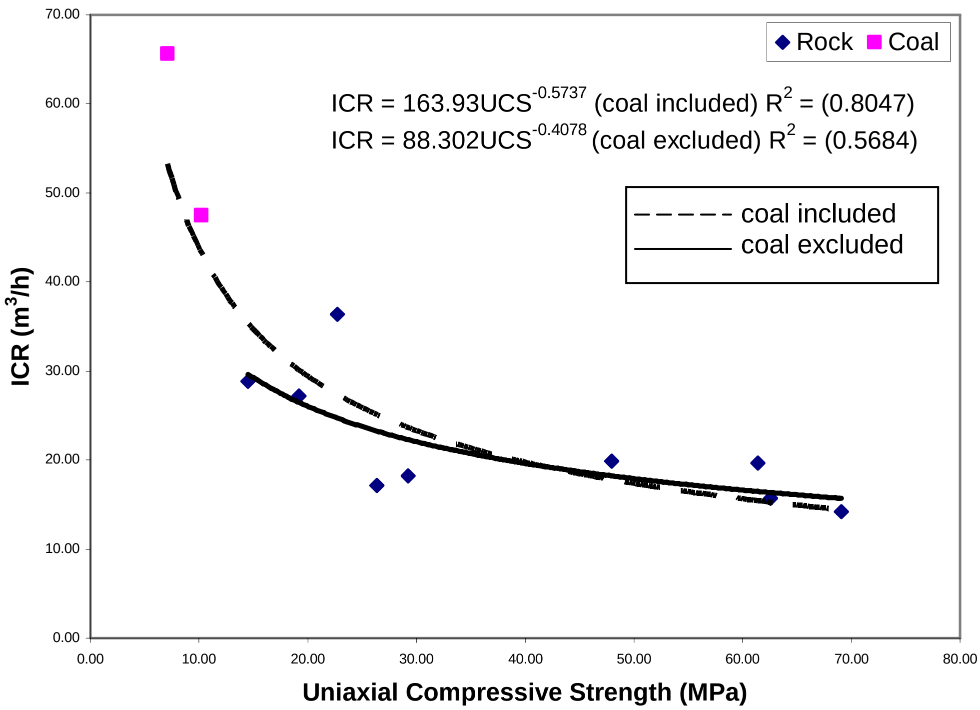


Figure 5.1 Relationship between instantaneous cutting rate and uniaxial compressive strength

As it is shown in Figure 5.1, correlation is not sufficiently high between ICR and UCS when coal is excluded (R^2 = 0.5684) but it becomes very high when coal is included. This indicates that, although UCS gives good indication of the rock cuttability in general, insignificant relations can be encountered for certain rocks depending on their other physical properties.

5.2.2 Instantaneous Cutting Rate versus Tensile Strength

Figure 5.2 shows the relationship between the instantaneous cutting rate and the tensile strength of the rocks.

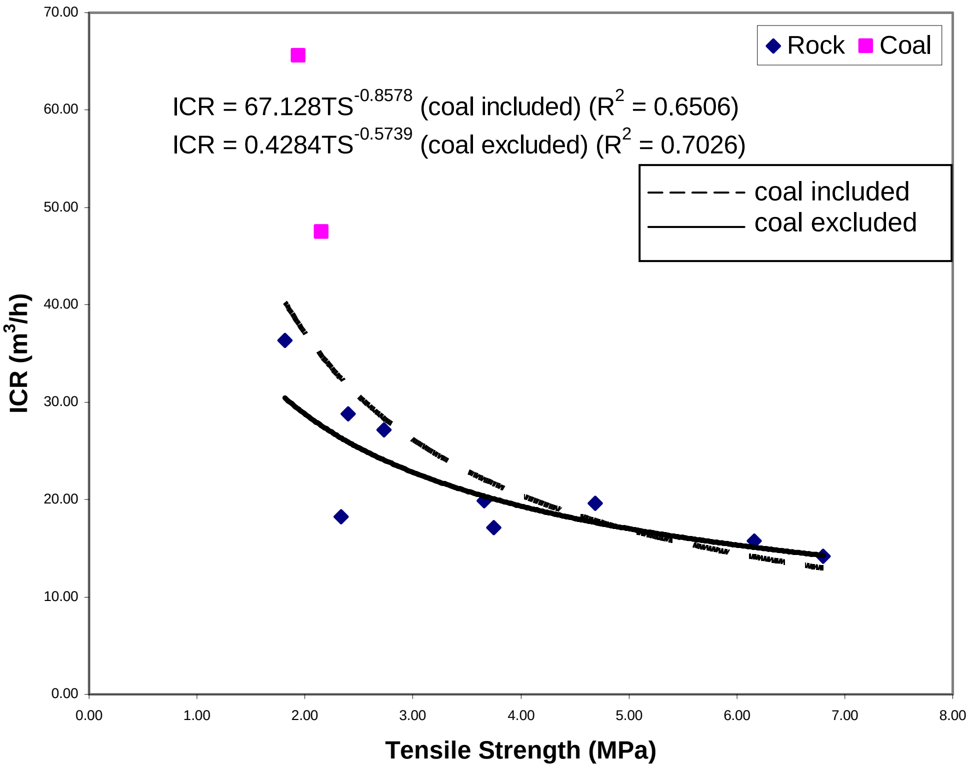


Figure 5.2 Relationship between instantaneous cutting rate and the tensile strength

As can be seen from Figure 5.2, reasonable correlations exist between ICR and tensile strength for both cases, including the coal (R^2 = 0.6506) and excluding the coal (R^2 = 0.7026).

It can be concluded that, although tensile strength can be used for predicting the machine performance, correlation coefficient is not sufficiently high.

5.2.3 Instantaneous Cutting Rate versus Cone Indenter Hardness

Figure 5.3 shows the relationship between the instantaneous cutting rate and the cone indenter hardness of the rocks.

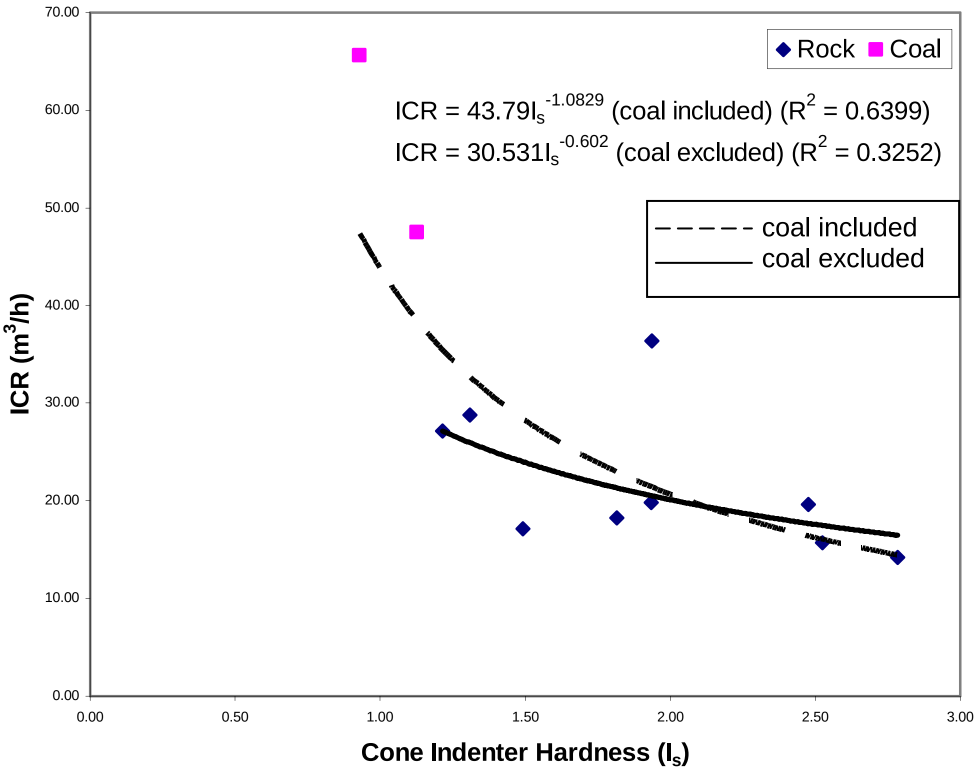


Figure 5.3 Relationship between instantaneous cutting rate and cone indenter hardness

Although insignificant correlation exists between ICR and I_s without coal (R^2 = 0.3252), correlation increases significantly when coal is included (R^2 = 0.6399). The reason for low correlation may be due to the inhomogeneous character of some rock types which include hard silicate layers.

5.2.4 Instantaneous Cutting Rate versus Schmidt Hammer Rebound Value

Figure 5.4 shows the relationship between the instantaneous cutting rate and the Schmidt hammer rebound values of the rocks.

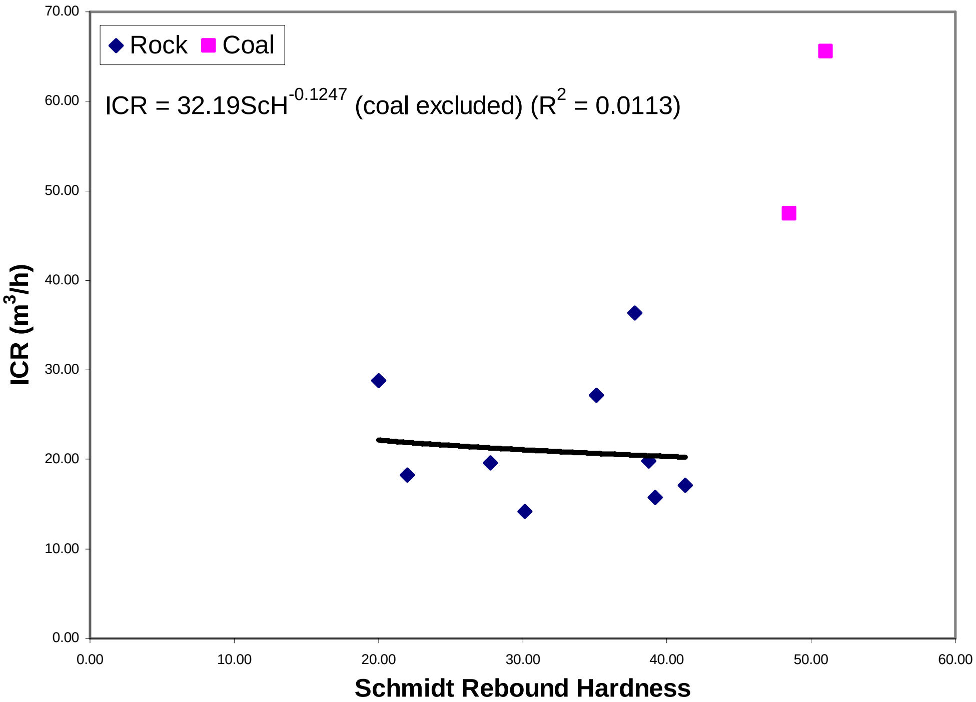


Figure 5.4 Relationship between instantaneous cutting rate and Schmidt hammer rebound values

Since Schmidt hammer rebound test gives very erroneous results especially for coal having no correlation to its UCS, it cannot be used for predicting the in-situ cutting performance. Therefore only the curve for coal excluded case is given in Figure 5.4.

As it is seen from figure, the relationship between ICR and Schmidt hammer rebound value is insignificant ($R^2 = 0.0113$).

5.2.5 Instantaneous Cutting Rate versus Shore Hardness

Figure 5.5 shows the relationship between the instantaneous cutting rate and the Shore hardness of the rocks.

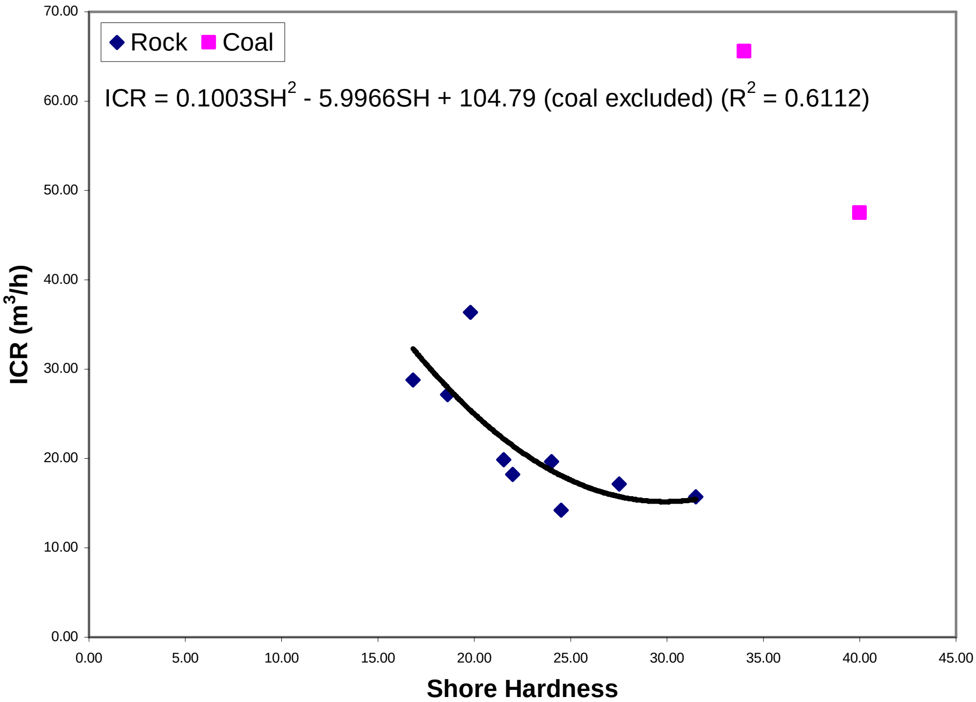


Figure 5.5 Relationship between instantaneous cutting rate and shore hardness

As it is seen, there is reasonable correlation (R^2 = 0.6112) between ICR and shore hardness. Since coal gives exceptionally high shore hardness values like Schmidt hammer which cannot be correlated to its UCS, only the curve for coal excluded case is given.

5.2.6 Instantaneous Cutting Rate versus Laboratory Cutting Specific Energy

Figure 5.6 shows the relationship between the instantaneous cutting rate and the laboratory cutting specific energy results of the rocks.

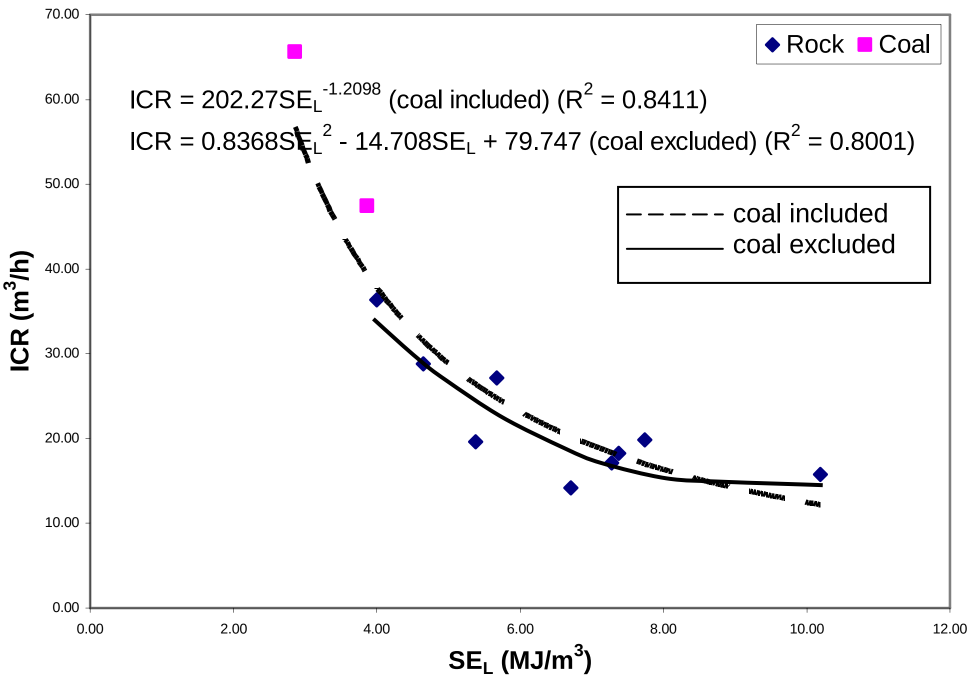


Figure 5.6 Relationship between instantaneous cutting rate and laboratory cutting specific energy

Figure 5.6 shows that very high correlation exists between ICR and SE_L for both cases, including the coal ($R^2 = 0.8411$) and excluding the coal ($R^2 = 0.8001$).

This can be explained by the fact that, the effects of most rock parameters are reflected to SE_L in carrying out direct cutting tests in the laboratory. SE_L, on the other hand, does not include the effect of rock mass quality factors of the rock and assumes the rock as massive. But ICR values predicted from SE_L provides the safe limits, because ICR will increase depending on the decreasing character of rock mass quality.

It can be concluded that the laboratory cutting specific energy method gives the best results for predicting the roadheader in-situ cutting performance as compared to some other rock properties.

5.3. Comparison of Performance Prediction Curve of the Medium-Weight Dosco Mk-2B roadheader with those of Light-Weight (Dosco Mk-2A) and Heavy-Weight (Dosco Mk-3) Roadheaders

Figure 5.7 compares the location of the performance prediction curve obtained for the medium-weight Dosco Mk-2B with those determined earlier for the light-weight (Dosco Mk-2A) and heavy-weight (Dosco Mk-3) roadheaders by McFeat-Smith and Fowell (1977); and Fowell and Johnson 1982.

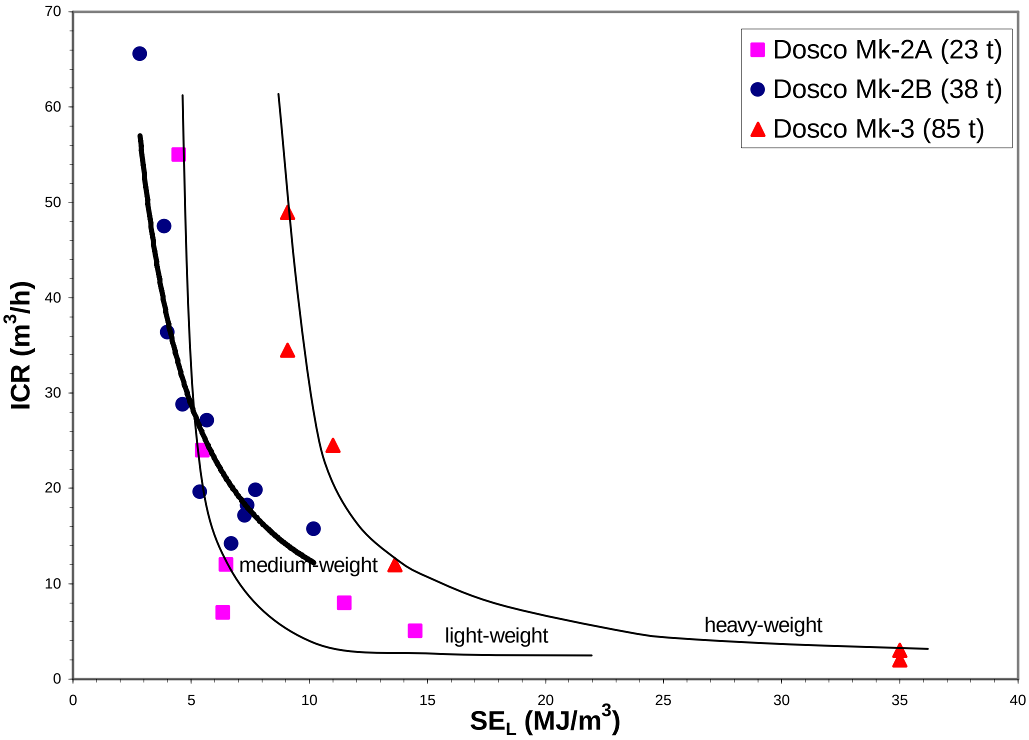


Figure 5.7 Comparison of the performance prediction curve for the medium-weight machines with those of light-weight and heavy weight machines

It can be seen from Figure 5.7 that no cutting performance advantage can be achieved by using a heavier machine for very low strength rocks and coal. Medium-weight machines start to be advantageous and benefit in cutting performance is realized for the rock types requiring laboratory cutting specific energy greater than 5 MJ/m^3.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The major conclusions derived from this study and recommendations can be summarized as follows:

- Uniaxial compressive strength (UCS) provides high correlation against ICR when coal included (R^2 = 0.8047), but rather low when coal is excluded (R^2 = 0.5684). Therefore UCS, alone, is not sufficient to estimate in-situ cutting performance of roadheaders since deviations may occur depending on other properties of the rocks.

- Tensile strength provides similar correlation against ICR for both coal included (R^2 = 0.6506) and excluded (R^2 = 0.7026) cases. Although good relationship exists, significance is not sufficiently high.

- Cone indenter hardness shows low correlation with coal (R^2 = 0.6399) but no correlation for rocks (R^2 = 0.3252) and cannot be good predictor of ICR especially if a rock includes hard silicate layers, nodules or hard crystals.

- Schmidt hammer rebound and Shore hardness tests give very high hardness numbers which are irrelevant to coal strength and cannot be used for the assessment of ICR for coal.

- Schmidt hammer rebound values show no correlation against ICR and cannot be used for predicting machine performance for the range of rocks tested.

- Shore hardness shows relatively low correlation against ICR (R^2 = 0.6112) for the range of rocks tested. Therefore performance prediction for rocks can be made with low precision.

- Laboratory cutting specific energy provides the highest correlation both with coal (R^2 = 0.8411) and without coal (R^2 = 0.8001). Prediction of in-situ cutting performance of a roadheader can therefore be made significantly by carrying out laboratory cutting test and determining specific cutting energy which will include the effects of most rock properties.

- Cutting performance predictions will indicate minimum values since the effects of joints, fractures and rock mass quality characteristics are not reflected to SE_L results. The presence of such systems and lower rock mass quality will cause an increase in the estimated performances.

- Medium-weight roadheaders provide no advantage over light duty machines for coal and soft rocks requiring a laboratory cutting specific energy of less than 5 MJ/m^3. Increase in cutting performance of a medium-weight roadheader as compared to a light-weight machine starts at about 5 MJ/m^3 and gradually increases. In-situ cutting performance of a medium-weight Dosco Mk-2B machine is around four times the performance of a light-weight Dosco Mk-2A machine for a rock requiring a laboratory cutting energy of 10 MJ/m^3.

The following recommendation can be made for further studies:

- The model is developed for Mk-2B medium-weight machine using the limited range of rock types available in Çayırhan district. If possible, similar size or other types of machines at different rock characteristics should be studied to achieve more reliable model covering wider range of rocks and machine sizes.

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