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# ANALYSIS OF ROCK PROPERTIES AFFECTING BIT ABRASIVENESS

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## ABSTRACT

Especially in open pit mines, determining the abrasiveness mechanism of bits is a crucial task for an efficient and economic drilling, excavating and cutting. Either rock properties or material properties of bit are two major factors affecting abrasiveness. In general, present indices and tests may not be convenient for different rock cases and may not represent true results. This is due to complicated nature of the task. So far developed methods determine abrasiveness, mostly, with mechanical properties of bit. However, rock properties are natural parameters of this research branch that can never be ignored. In this study, how rock properties take role in abrasivenesst mechanism of rock bits used in open pit mines is discussed. Many tests have been performed for different rock types takes from open pit mines and the results have been analyzed to generate a reasonable conclusion. $Si0_2$ content, cementation index and Brazilian test (tensile strength) of rock specimens have been related with some previously developed abrasiveness tests and a new designed and developed test, called as Bademlik Abrasiveness test, for a logical interpretation. The results have revealed that rock properties should also be considered for determining abrasiveness characteristics of a rock bit as well as material properties of bit.

## ÖZET

Özellikle açık ocak madenlerinde, keskilerdeki aşınma mekanizmasının belirlenmesi, etkili ve ekonomik bir kazı, delme ve kesme işlemi için çok önemlidir. Hem kayaç özellikleri ve hem de keski materyali özellikleri aşınmayı etkileyen iki önemli parametredir. Genel olarak günümüzde kullanılan aşınma testleri ve indisleri farklı kayaç durumları için uygun olmayabilir ve doğru sonuç vermeyebilirler. Bu durumsa, mekanizmanın karmaşık yapısından kaynaklanmaktadır. Şimdiye kadar geliştirilen yöntemler çoğunlukla keskinin mekanik özelliklerinden yararlanarak aşınma miktarının belirlenmesini esas almaktadırlar. Bununla birlikte, kayaç özellikleri de bu araştırma sahasının ihmal edilmemesi gereken doğal parametreleridir. Bu çalışmada özellikle açık ocaklarda kullanılan keskilerin aşınma mekanizmalarında kayaç özelliklerinin nasıl bir rol oynadığı araştırılmıştır. Bu amaçla, açık ocaklardan alman farklı kayaç tipleri için birçok testler yapılmış ve sonuçlar analiz edilmiştir. Kayaç numunelerinin $Si0_2$ içeriği, çimentolanma indeksi, ve Brezilian testleri (gerilme direnci) önceden geliştirilen bazı aşınma test sonuçlarıyla ilişkilendirilerek, Bademlik Aşınma Testi adı altında yeni bir test yöntemi olarak mantıklı bir yorumlama için tasarlanmıştır. Sonuçlar göstermektedir ki, keskinin aşınma karakteristiklerinin belirlenmesinde keski materyallerinin »özellikleri kadar kayacın özelliklerinin de dikkate alınması gerekmektedir.

## 1. INTRODUCTION

Mechanical excavation systems have been employed widely for mining activities. This necessitates a detailed investigation of abrasiveness mechanism of digging bits. If it is considered for tunnelling machines that bit cost is almost one third of the general expenses, it can be realized that, mentioned subject has economical aspect as well as technical (Bilgin, 1980).

Another point is the increase in energy consumption as abrasiveness of rock bit. It is important to determine abrasiveness characteristics of a formation for a reasonable digging design and bit selection.

Determination of parameters playing a role in abrasion becomes crucial for clearing out the mechanism of abrasiveness. Because bit abrasiveness may be a result of several properties of rock, a single criterion probably produces misleading outcomes.
Several test methods have been developed for providing an index which is employed to estimate the number of bits necessary for digging a unit volume of rock. Widely used methods are;

i- Straight saw cutting test
ii- British coal administration test
iii- Cerchar abrasiveness test
iv- Block cutting test
v- Circle tracking test
vi- İTÜ abrasiveness test
vii- Schimazeck abrasiveness test
viii- Steel cube test

Weight loss of abraded bit, energy consumption, abrasion diameter on bit and pétrographie properties of rock are the parameters of abrasiveness criterion of above methods. Schimazeck and et.al., 1970 have developed an abrasiveness index for sedimentary rocks depending on pétrographie properties, quartz content of rock, grain size of quartz and tensile strength of rock. Even though this approach has been preferred by some of commercial firms producing tunnelling machine, it is not convenient for strata without quartz because abrasiveness of these type strata is accepted as zero which is not a realistic case.

Administration of British Coal has developed a criterion depending on specific energy needed for cutting a unit volume of rock (Szlavin, 1974)

New Castle University has developed a Straight Saw Cutting test based on the idea of weight loss of saw due to abrasion.

The result of experiments for determining the relation between abrasion and quartz were not positive (West, 1981). Such a situation has underlined that other factors should be considered, too.

French Coal Research Foundation (Cerchar) has developed an abrasiveness index relating the diameter of bit bluntness and a classification system of rock abrasivity based on this index (West, 1989). However, it is known that the system is not convenient for determining the abrasivity property of weak and hard rocks.

Steel Cube test is performed by abrading both rock and a steel cube at the same time and conditions. Abrasion at unit time is the basic criterion of this test.

A high correlation between abrasiveness obtained by the test and bit consumption has been reported in an investigation, in England (West, 1981 ).

This much number of experiment methods for predicting abrasion can be explained with the complicated mechanism of abrasivity of rocks on bits. It can be said that, there is not a standard experiment method.

In this study, a practical abrasiveness index is aimed to be developed. It is based on rock properties acting on bit abrasiveness mechanism under different conditions.

## 2. MATERIAL AND METHOD

Silicate percentage (SİO2), cementation degree and mechanical strength have been used as the basic parameters for an abrasiveness index. Rock specimens taken from igneous, sedimentary and metamorphic rocks have been used for abrading rock bits. Their effect on abrasion mechanism has been observed. Chemical analysis of 10 different type of rock specimens have been performed and their silicate contents have been handled (Table 1).

As strength between particles gets higher, duration of contact of bit and hard minerals like quartz will increase which causes more abrasion and requirement of more cutting force.

Table 1. SİO2 contents of specimens

| Sp.No | Rock Type | $Si0_2$(%) |
|---|---|---|
| 1 | Sandstone+Clay | 16.08 |
| 2 | Andésite 1 | 60.45 |
| 3 | Peridotite | 47.00 |
| 4 | Limestone+Clay | 12.25 |
| 5 | Tuff | 76.40 |
| 6 | Marl | 51.22 |
| 7 | Granite | 62.86 |

| | | |
|---|---|---|
| 8 | Sandstone | 70.59 |
| 9 | Andesite2 | 90.87 |
| 10 | Marble | 2.94 |

Strength at bonds of particles is directly proportional with cementation index and direct strength (West, 1981). In the study, cementation index of rock has been determined as a function of water absorption amount of rock. Absorption has been calculated using equation;

$$k = \frac{W_2 - W_1}{W_1} * 100 \qquad (1)$$

where,

k = cementation index

$W_1$ = weight of sample after heated at 105° for 24 hours, g.

$W_2$ = weight of sample after keeping in water for 24 hours, g.

Cementation index (CI) obtained in laboratory has been represented in Table 2.

Table 2. Cementation index of specimens

| Sp.No | Rock Type | CI |
|---|---|---|
| 1 | Sandstone+Clay | 4.95 |
| 2 | Andésite 1 | 1.49 |
| 3 | Peridotite | 0.22 |
| 4 | Limestone+Clay | 1.52 |
| 5 | Tuff | 16.18 |
| 6 | Marl | 11.82 |
| 7 | Granite | 0.06 |
| 8 | Sandstone | 0.54 |
| 9 | Andesite2 | 1.77 |
| 10 | Marble | 0.05 |

Because mechanical strength of rock is effective on bit abrasiveness, a serious of tensile strength tests has been performed by Brazilian test (indirect tensile strength test). Sample cores, which have been drilled out by a 54.3 mm-(▷ diamond drill machine and having L > D/2 length-diameter relation, have been loaded by a hydraulic test machine. Below equation has been used for calculation of tensile strength (McFeat and Smith, 1977);

$$\sigma_t = \frac{2 * P}{\pi * D * L} \qquad (2)$$

where,

a, = tensile strength, $kg/cm^2$

P - load at failure, kgf

D = diameter of specimen, cm

L = length of specimen, cm

2.1. Abrasiveness Experiments

In the study, three different abrasiveness experiments representing related mechanisms have been performed;

i- Steel Cube abrasiveness test

ii- Drill Workbench abrasiveness test

iii-Bademlik Percussive abrasiveness test.

Results of tensile strength tests are represented in Table 3.

Table 3. Tensile strength of specimens

| Sp.No | Rock Type | $o_t$ (MPa) |
|---|---|---|
| 1 | Sandstone+Clay | 3.462 |
| 2 | Andésite 1 | 7.942 |
| 3 | Peridotite | 16.516 |
| 4 | Limestone+Clay | 8.274 |
| 5 | Tuff | 7.842 |
| 6 | Marl | 1.471 |
| 7 | Granite | 7.845 |
| 8 | Sandstone | 9.141 |
| 9 | Andesite2 | 8.944 |
| 10 | Marble | 6.462 |

2.1.1. Steel Cube Abrasiveness Test (SCAT)

A steel cube having dimension of 2.54 cm (1 inch) and medium hardness (St-70) and a rock specimen having weight of 900 g. have been rotated for 3 hours in a polishing apparatus with rotary drum (West, 1981).

Percentage of hourly weight loss of steel cube which has been rotated with rock specimens which have been saturated with water, is the basic criterion for determining abrasiveness (Table 4).

Table 4. Results of SCAT index

| Sp.No | Rock Type | SCAT |
|---|---|---|
| 1 | Sandstone+Clay | 80.3 |
| 2 | Andésite 1 | 155.3 |
| 3 | Peridotite | 105.4 |
| 4 | Limestone+Clay | 82.2 |
| 5 | Tuff | 76.6 |
| 6 | Marl | 48.9 |
| 7 | Granite | 113.0 |

| | | |
|---|---|---|
| 8 | Sandstone | 204.9 |
| 9 | Andesite2 | 110.0 |
| 10 | Marble | 41.8 |

SCAT is;

SCAT=[(Wi -$W_2$)AV,*100/3]*10-$^4$ (3)

where,
$W_1$ = initial weight of bit, g.
$W_2$ = weight of bit after digging, g.

According to this table, it is able to said that sandstone has the highest SCAT index value.

2.1.2. Drill Workbench Abrasiveness Test (DWAT)

In the experiment, a cylindrical rock specimen is exposed to stroke of a St-60 steel bit having length of 3.8 cm and width of 2.0 cm and speed of 90 rpm. With 15 seconds. After digging, percent loss in the weight of bit has been used to prepare an abrasiveness index (Table 5);

DWAT=[(W, -$W_2$)AV!*100]*10-$^4$ **(4)**

where,
$W_1$ = initial weight of bit, g.
$W_2$ = weight of bit after digging, g.

Table 5. DWAT index of specimens

| Sp.No | Rock Type | DWAT |
|---|---|---|
| 1 | Sandstone+Clay | — |
| 2 | Andésite 1 | 1519 |
| 3 | Peridotite | 3866 |
| 4 | Limestone+Clay | 408 |
| 5 | Tuff | — |
| 6 | Marl | 654 |
| 7 | Granite | 1028 |
| 8 | Sandstone | — |
| 9 | Andesite2 | 1035 |
| 10 | Marble | — |

According to this index table also, peridotite has the highest DWAT index value.

2.1.3. Bademlik Percussive Abrasiveness Test (BPAT)

The experiment has been designed and developed in this study. The principle of experiment is such that a weight including a steel bit is released from a height on to a truncated rock specimen. Percent loss of steel bit determines the index. In application stage, a weight of 315 grams including a steel bit has been released 100 times from a height of 25 cm on to cylindrical rock specimen. Abrasiveness index has been prepared by using the relation;

BPAT=[(W,-$W_2$)/$W_I$*100]*10$^{'2}$ (5)

$W_1$ = initial bit weight, g.
$W_2$ = last weight, g.

Results of this new approach are presented in Table 6.

Table 6. BPAT index Of specimens

| Sp.No | Rock Type | BPAT |
|---|---|---|
| 1 | Sandstone+Clay | 11.70 |
| 2 | Andésite 1 | 11.91 |
| 3 | Peridotite | 12.30 |
| 4 | Limestone+Clay | 12.87 |
| 5 | Tuff | 5.04 |
| 6 | Marl | 0.39 |
| 7 | Granite | 11.59 |
| 8 | Sandstone | 13.31 |
| 9 | Andesite2 | 11.36 |
| 10 | Marble | 12.19 |

## 3. EVALUATION OF RESULTS

Quartz ($Si0_2$) content of rock, cementation index and tensile strength are fairly important parameters for determining abrasiveness. The results of experiments have been evaluated to find a correlation between above parameters and related index of experiment.

### 3.1. Steel Cube Experiment

It is observed that individually, non-of quartz content ($Si0_2$), cementation index (CI) and tensile strength ($a_t$) can be used to express abrasion mechanism of bits. However, a multiple regression analysis has provided a reasonable fitness;

SCAT=65.7+1.5($Si0_2$)-6.13(CI)-1.18$o_t$ (6)

Correlation coefficient (R) of individual and multiple regression are given in Table7.

Table 7. Correlation coefficients of SCAT

| Rock Property | R(%) |
|---|---|
| $Si0_2$ | 56 |
| Cementation Index | -41 |
| Tensile Strength | 39 |
| Multiple | 84 |

3.2. Drill Workbench Experiment

Tensile strength has shown a good correlation with DCAT throughout others. However, a multiple regression has provided still the best correlation with a function shown below;

$$DCAT= -293.5+17(SiO_2)+140(CI)+355at \quad (7)$$

Related results of goodness of fit are presented in Table 8.

Table 8. Correlation coefficients of DCAT.

| Rock Property | R(%) |
|---|---|
| $Si0_2$ | 18 |
| Cementation Index | -37 |
| Tensile Strength | 84 |
| Multiple | 97 |

Tensile strength of rock looks as a good determinant of bit abrasiveness, here. However, a function including all parameters has shown a very good correlation.

3.3. Bademlik Abrasiveness Experiment

In this test, cementation index has provided a good explaining of the behaviour of bit abrasiveness. Even, multiple function could present a correlation with BPAT as much of CI;

$$BPAT= -11.95-0.17(SiO_2)-0.54(CI)+0.2\sigma_t \quad (8)$$

Correlation coefficients obtained in this new approach are given below;

Table 9. Correlation coefficients of BPAT

| Rock Property | R(%) |
|---|---|
| $Si0_2$ | -29 |
| Cementation Index | -87 |
| Tensile Strength | 53 |
| Multiple | 88 |

Cementation index has a negative but highly correlated relation with BPAT individually. It looks beneficial to express abrasiveness of a bit using a single parameter rather than multiple, because multiple regression has provided almost the same correlation.

4. DISCUSSION AND CONCLUSION

This study has revealed that rock properties are natural parameters of abrasiveness mechanism. Laboratory experiments which have been performed to determine bit abrasiveness mechanism on igneous, sedimentary and metamorphic rock specimens, have revealed that tensile strength ($a_t$) in Drill Workbench technique, cementation index (CI), Bademlik Abrasiveness test and all quartz content ($Si0_2$), CI and a, in Steel Cube test can be accepted as variables highly correlated with related indices. Additionally, for all of three experiments, multiple regression analysis have approved that $Si0_2$, CI, $o_t$ are reasonable parameters together to represent a relation with related index. Why rock properties, which are effective on abrasiveness are different for each test can be explained such that; abrasiveness mechanism of Steel Cube test is resulting from tangential forces mostly while mechanism of Drill Workbench test is affected by both tangential and normal stresses and abrasiveness mechanism of Bademlik test is mostly shaped by normal forces. The correlation research between three tests has failed which means each test represents a different abrasiveness mechanism.

Abrasiveness is dependent on a number of parameters including both bit and rock properties. Individual parameters can explain only a part of whole mechanism. So comprehensive models or simulation systems can provide more accurate results in design stage of digging.

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