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Abrasivity characteristics of rocks from India and Nepal

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ABSTRACT

Over the years, many attempts have been made to define and characterise rock abrasiveness. However, it is found that abrasiveness of rocks is not only difficult to define but also hard to measure. A number of relative rock abrasiveness tests have emerged but their results do not always faithfully reflect the characteristics of the rocks that may be useful in the excavation process. Under the circumstances, an in-depth study of rock abrasiveness is warranted. The present study may provide additional help to fill a gap in this area.

The study has addressed a number of issues on abrasivity of rocks and the objectives included inter-alia the following: 1. Developing and standardising appropriate testing techniques for evaluation of the abrasiveness and microhardness of the mine rocks. 2. Evaluating the abrasivity characteristics of mine rocks from Mosaboni copper mine, Jhinkpani limestone quarry and Indian coal-measure strata, Jharia, all from the Bihar State of India. 3. Evaluating the characteristics of a suite of rocks from Nepal (limestone from Nigale and quartzite from Bhedetar, Dhankuta District, Nepal).

In this study a number of testing methods have been used to evaluate rock abrasiveness of rocks, specially the Cerchar Abrasivity Index (CAI), Schimazek Index and Indian School of Mines Abrasivity Test (ISMAT). The tests were performed in the rock mechanics laboratory of Indian School of Mines (ISM), Dhanbad, India. The results of these tests are discussed in detail. Hopefully, this study on abrasivity characteristics of rocks will aid in the selection of appropriate tools and excavation systems thereby enhancing the work performances and reducing the costs in excavations.

INTRODUCTION

Abrasiveness of rocks indicates their ability to wear out metals and hard alloys in the course of mechanical interaction. The greater the abrasiveness of a rock, higher is the rate of the tool wear-out. High abrasiveness leads to faster blunting of tools and in consequence reduces efficiency. Even a modest degree of blunting along a cutting edge can lead to specific energy increase by several folds. This apart, a blunt tool requires higher average cutting force and generates more airborne dust. Frequent replacements of rock-breaking tools used in drilling, tunnelling and other unit operations cause production delays. The knowledge of abrasive properties of rocks would therefore be of help in choosing the right type of rock breaking tools and thereby raise the efficiency of mining operations.

Recent years have witnessed a significant increase in surface and underground rock excavation by mechanical means. This has caused many problems of tool life and economics with concomitant impact on performance and especially of machine utilization. The problem dimensions also are very wide and include such widely disparate areas such as blast hole drilling in surface mines, continuous mining system using bucket wheel excavator, roadheader in coal measure strata, TBMs in hard rock tunnelling and use of shearer and plow for extraction at the coal face.

The abrasive wear-out of metals and hard alloys depends both on the abrasiveness of the rock and also upon a number of other factors such as: the relation between the hardness of rock and the metal (alloy), the roughness of friction surfaces, the contact pressure, sliding speed and the properties of the cooling medium.

The aggregative economic impact of rock abrasiveness on an excavation system can be summarised as follows:

(i) Direct losses in the form of increased pick consumption per cubic meter of rock excavation.

(ii) Indirect losses which influence the excavation system as a whole. They are:

- reduction in machine availability
- reduced efficiency of picks
- increased dust production
- extension of the project duration etc.

ABRASIVITY MEASUREMENT

As already noted, the abrasiveness of a rock is a complex function of various properties including rock competency, hardness and the mineralogical composition. A plethora of methods have been proposed for the measurement of abrasiveness and their relationship to field or machine performance (Forwell, 1970; ISRM, 1978; Sauna and Peters, 1978). All methods of abrasivity measurement give comparative values and do not simulate exactly the rock/metal interface in a cutting process. Some methods are complicated and time-consuming so that a cheap and rapid method like the Cerchar Abrasivity Index (CAI) or Schimazek method turns out to be very advantageous.

Cerchar Abrasivity Index (CAI) Test

The method developed by Cerchar uses a steel pin (tensile strength 200 kg/mm^2) with a conical point having 90° included angle. The pin is moved over a distance of 1 cm along the rock-surface (test specimen) under a static load of 7 kg. The abrasiveness is then measured by the chamfer produced on the conical tip. The diameter of the wear flat, mesured in 0.1 mm under a microscope is reckoned to be a measure of abrasiveness. The relative Cerchar Abrasivity Index of minerals in relation to quartz are shown in Table 1.

Table 1: Relative Cerchar Abrasivity Index of minerals in relation to Quartz

Mineral	Abrasivity Index
Quartz	100%
Feldspars	70-80%
Olivine	57-60%
Pyroxenes	50-53%
Amphiboles	47-53%
Serpentinites	23-30%
Carbonates	17-34%
Claystones	41%

Schimazek Index

The method of Schimazek involves qualitative analysis and takes into account of the percentage and grain size of constituent minerals and information on cementing, homogeneity and alteration of a rock specimen. A polarising microsope is used to determine the percentage (by volume) of different minerals and mean diameter (mm) of quartz grains or other hard minerals.

The coefficient of wear F or Schimazek Index is calculated by

$$F = \frac{\sigma_t . v . d}{100}$$

where,

σ_t = tensile strength of the rocks (Mpa)
v = percentage (by volume) of hard minerals
d = mean diameter (mm) of quartz or hard minerals.

ISMAT (Indian School of Mines Abrasivity Test)

ISMAT method is also performed to determine the abrasiveness of rocks. This method to determine abrasivity index was developed at Indian School of Mines (ISM), Dhanbad, India, by Professor A. K. Ghose and co-workers. In this method abrasivity index of a rock is determined by using a copper pin with a conical point having 29° inclined angle. The pin is moved over a distance of 1 cm along the broken rock-surface under a load of 2 kg. The copper pin is fixed in a portable handgun type instrument and moved over a surface of specimen for less than one second. The test requires only a simple set-up and very little time.

ABRASIVENESS OF TEST ROCKS

Abrasivity index were determined in ISM Rock Mechanics Laboratory from diamond drill cores obtained from bore-hole MKG-2 of Jharia Block-II (Fig. 1) (Karki, 1987). The cored samples thus obtained and those collected from bore hole MKG-2 were slit on a Highland Park diamond slitting wheel and the ends finished to acceptable dimensional tolerance as per International Society of Rock Mechanics (ISRM) standards. For the tensile strength test and abrasivity test, 10 different samples were taken from each lithological unit of Jharia Block-II.

Similarly large rock lumps were collected from Mosabani copper mine, India, Jhainkpani limestone quarry, India and Bhedetar, Dhankuta district, Nepal (Fig. 1). Before making cores for abrasivity tests, the rebound hardness values were also measured by a Schmidt N-type Hammer. Prepared cores of limestone were taken from Dhankuta district, Nepal, where geological exploration work was being carried out. Cores were taken from different depths and from different boreholes.

Petrographic Analysis

To determine the percentage (by volume) and mean diameter (mm) of quartz and other hard minerals, a number of thin sections were prepared. Thin sections were prepared from each lithological unit after testing tensile strength of the rock. The analysis was carried out using a polarising microscope.

Thin section analysis of rocks helped ascertain the percentage of different mineral constituents, grain size and the nature of matrix etc. These studies were used for computing Schimazek Index and subsequently comparison was made with the abrasivity index determined by the ISMAT method (modified Cerchar method).

Table 2 summarizes the rock strength properties and petrographic description of the rocks tested. The estimated quartz and other hard mineral contents for each of the rock units were determined under the microscope.

Comparative Abrasiveness

From the Cerchar test method, the arithmetic average of five scratches was empirically found to give a representative abrasivity index of rocks. On coarse grained rocks the index can only be measured if more scratches are made. Depending on the roughness of the rock surface and its abrasive mineral content, different scratch pattern will be noticed on the scratch pin. It is therefore very important to follow up a clearly defined measuring method and to run all tests under precisely similar conditions. While performing these experiments special attention has to be given also to the relief of the broken rock surface. The Cerchar abrasibity index of monominaralic rocks is given in Table 3.

Table 4 summarizes the average abrasivity index values derived from the three different testing methods. The results demonstrate that medium-grained sandstones are the most abrasive amongst the coal measure rocks, whereas the carbonaceous shales are the least abrasive.

Measurement of relative abrasiveness of rocks from Mosabani mine, indicates that the granitic gneiss are higher in abrasiveness vis-a-vis the chlorite-biotite-quartz schists.

Limestone from Jhainkpani, Bihar as well as from Dhankuta, Nepal indicate moderate values of abrasiveness (less than sandstones and quartzite and higher than shale). It may be noted, however, that compared to the values reported

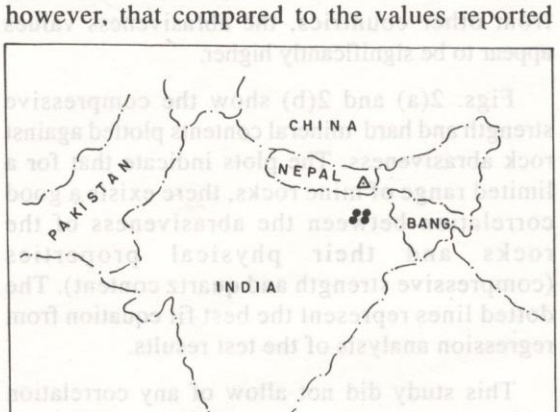

Fig. 1: Location map of rock samples.

Table 2 : Rock Strength and percentage of hard mineral content.

Rock Type/Location	Uniaxial Compressive Strength (Mpa)	Tensile Strength (Mpa)	Hard Mineral Content (%)	Mean Diameter of Hard Minerals (mm)
Coarse-grained sandstone, Jharia, Bihar, India	40-70	4.6-6.4	67	0.61
Medium grained sandstone, Jharia, Bihar, India	45-85	6.8-8.9	73	0.362
Fine-grained sandstone, Jharia, Bihar, India	60-95	4.9-7.5	76	0.223
Shale, Jharia, Bihar, India	35-60	5.0-7.2	35	0.058
Carbonaceous shale, Jharia, Bihar, India	30-35	4.1-5.3	30	0.068
Mica peridotite, Jharia, Bihar, India		4.7-13.5	67	0.148
Pink liestone Jhinkpani, Jharia, Bihar, India	60-70	4.2-9.5	22	0.123
Off-white limestone Jhinkpani, Bihar, India	50-70	4.5-9.0	17.5	0.112
Crystalline limestone Nigale, Dhankuta district, Nepal	65-70	4.0-7.5	17	0.372
Granitic schists, Mosabanni mine, India	100-110	9.0-11.0	85.5	0.190
Chlorite-biotite -quartz schists Mosabani mine, India	78-95	7.8-8.7	81	0.160
Quartzite, Dhankuta, Nepal	195-225	15-22	91	0.178

from other countries, the abrasiveness values appear to be significantly higher.

Figs. 2(a) and 2(b) show the compressive strength and hard mineral contents plotted against rock abrasiveness. The plots indicate that for a limited range of mine rocks, there exists a good correlation between the abrasiveness of the rocks and their physical properties (compressive strength and quartz content). The dotted lines represent the best fit equation from regression analysis of the test results.

This study did not allow of any correlation with cutter wear, but it would be expected that higher the quartz content and compressive strength of the rock, the greater would be the wear on tools. The rates of cutter wear are clearly different in each rock type, with the shales producing the least wear and the sandstone the most.

Table 3: Cerchar Abrasivity Index of minerals and monomineralic rocks

Mineral/Rock	Abrasivity Index
Quartz, Quartzites	5.6-6
Feldspars (K, Na, Ca)	4.2-4.8
Olivine (Mg, Fe), Dunites	2.4-3.6
Pyroxenes, pyroxenites	3.0-3.2
Amphiboles, Amphibolites	2.8-3.2
Serpentines, Serpentinites	1.4-1.8
Limestone, Dolomites	1.0-2.0
Claystones	2.5

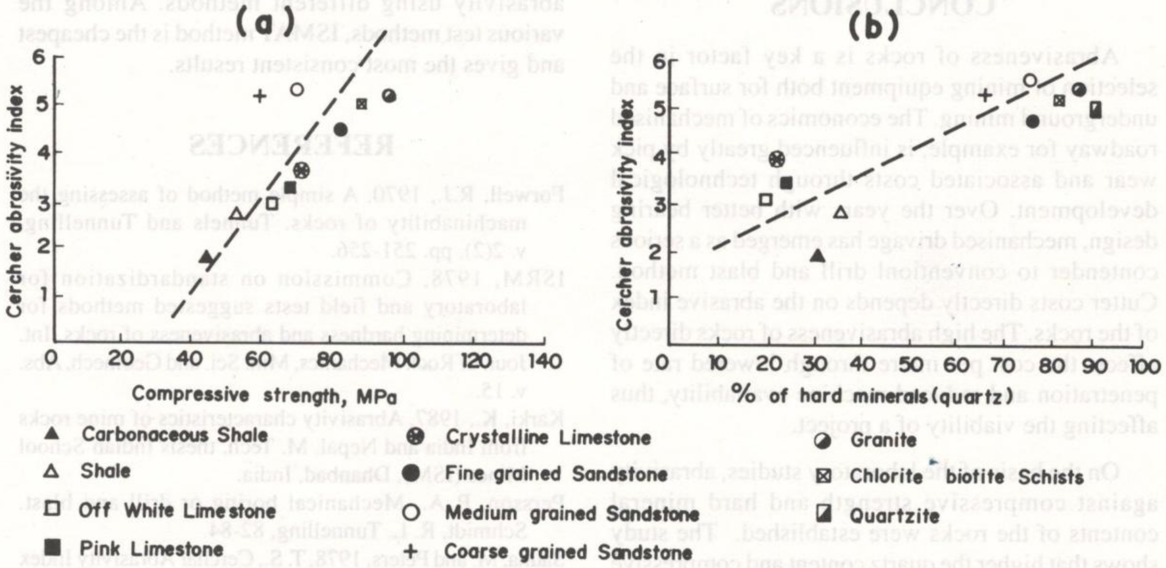

Fig. 2(a): Relation between abrasiveness and compressive strength. (b) Relation between abrasiveness and quartz content.

Table 4 : Comparativeness Abrasivity Index of the rocks under study.

Tested Rocks/Location	CAI (Cerchar Abrasivity Index)	ISMAT (ISM Method)	Schimazek Index
Coarse-grained sandstone, Jharia, Bihar, India	5.05	5.43	2.367
Medium grained sandstone, Jharia, Bihar, India	4.52	6.31	2.005
Fine-grained sandstone, Jharia, Bihar, India	4.30	5.10	1.083
Shale, Jharia, Bihar, India	2.20	3.5	0.125
Carbonaceous shale, Jharia, Bihar, India	1.73	2.32	0.109
Mica peridotite, Jharia, Bihar, India	3.90	6.20	0.929
Pink liestone Jhinkpani, Jharia, Bihar, India	3.024	3.95	0.196
Off-white limestone Jhinkpani, Bihar, India	2.45	3.91	0.136
Crystalline limestone Nigale, Dhankuta district, Nepal	3.80	-	0.228
Granitic schists, Mosabanni mine, India	5.00	5.47	2.065
Chlorite-biotite -quartz schists Mosabani mine, India	4.78	5.51	1.165
Quartzite, Dhankuta, Nepal	4.56	5.23	2.780

CONCLUSIONS

Abrasiveness of rocks is a key factor in the selection of mining equipment both for surface and underground mining. The economics of mechanised roadway for example, is influenced greatly by pick wear and associated costs through technological development. Over the years with better bearing design, mechanised drivage has emerged as a serious contender to conventionl drill and blast method. Cutter costs directly depends on the abrasive index of the rocks. The high abrasiveness of rocks directly affects the cost per metre through lowered rate of penetration and reduced machine availability, thus affecting the viability of a project.

On the basis of the laboratory studies, abrasivity against compressive strength and hard mineral contents of the rocks were established. The study shows that higher the quartz content and compressive strength of the rocks, the greater would be the abrasivity.

The study has clearly demonstrated that there are wide divergences in the measured values for abrasivity using different methods. Among the various test methods, ISMAT method is the cheapest and gives the most consistent results.

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