Acta Geodyn. Geomater., Vol. 22, No. 3 (219), 405–412, 2025
DOI: 10.13168/AGG.2025.0028

journal homepage: https://www.irsm.cas.cz/acta

ORIGINAL PAPER

DETERMINATION OF THE EFFECT OF ROCK ABRASIVENESS ON GRINDABILITY USING THREE DIFFERENT EXPERIMENTAL METHODS

Çağrı ALDI

Department of Mining and Mineral Extraction, Caycuma Vocational School, Zonguldak Bulent Ecevit University, Zonguldak, Turkey

Corresponding author's e-mail: cagrialdi67@gmail.com

ARTICLE INFO

Article history:
Received 8 May 2024
Accepted 12 September 2024
Available online 18 September 2025

Keywords:
Hardgrove Grindability Index (HGI)
Abrasiveness
Cerchar
Schimazek
Norwegian Abrasion

ABSTRACT

The abrasiveness characteristics of rocks are a crucial rock property that directly affect cutter design, wear, machine efficiency, rock grindability, and project costs. The primary objective of this study is to investigate the relationship between rock abrasiveness indices and grindability using three different experimental methods: Cerchar, Norwegian Abrasion, and Schimazek tests. These indices serve as widely recognized proxies for evaluating the potential wear behavior of rocks on excavation tools. In this context, six different metamorphic-origin rocks collected from various regions of Turkey were analyzed. Within the scope of the study, data obtained from the Hardgrove Grindability Index (HGI) test were compared with abrasion values obtained from widely used experimental methods in the literature, such as the Cerchar Abrasivity Index (CAI), Schimazek Abrasivity Index (F), and the Norwegian Abrasion Test (AV). Statistical evaluations conducted on the obtained results revealed strong correlations between HGI and CAI, AV and F with R^2 values of 0.75-0.86-0.85 respectively.

INTRODUCTION

In underground and surface excavation applications, mining activities such as tunneling, water, oil, or natural gas extraction, various types of excavation machinery (tunnel boring machines, roadheaders, drills, etc.) are utilized. To achieve desired benefits and select appropriate excavation equipment in mechanized excavation, it is essential to have a thorough understanding of the physico-mechanical and geological properties of the rock formation to be excavated. In this context, particularly, the wear that occurs on cutting tools as a result of the interaction between the rock and excavation machinery not only determines the lifespan of the cutters but also significantly impacts excavation efficiency and project costs (Abu Bakar et al., 2016).

Rock abrasiveness is a fundamental parameter influencing wear on cutters and is a highly significant rock property. Researchers working on this subject utilize various abrasion index test methods, such as CAI, Schimazek Abrasion Index (F), Norwegian Abrasion (AV), Vickers rock hardness number (VHNR), etc., to accurately predict the wear behavior of rocks (Tamrock, 1999; Majeed and Abu Bakar, 2016; Kahraman et al., 2016; Majeed and Abu Bakar, 2019). Among these methods, the CAI test method is widely used by many researchers to determine the wear behavior of rocks due to its ease of application. The Schimazek Abrasion Index, which is examined within the scope of this paper and is an important method for determining rock abrasiveness, provides an indirect wear prediction based on the mineral and tensile strength properties of the rock. Another method is the Norwegian Abrasion Value (AV), developed by NTNU/SINTEF and used for predicting the performance of excavation machinery. The AV value is defined as the wear occurring over time on the cutter in contact with crushed rock particles (Bruland, 2000; Majeed and Abu Bakar, 2019). When compared, the aforementioned abrasion index test methods can be relatively time-consuming and may require a large amount of rock samples (Garzon-Roca et al., 2020). Additionally, special equipment is needed to conduct these tests (Yarali et al., 2018). Tamrock (1999) also described the Hardgrove Grindability Index (HGI) test method among the methods used to determine rock abrasiveness. While the HGI test method is primarily used for analyzing the grindability of coal samples, it has recently begun to be used for determining the grindability of rock samples as well. Particularly, it has gained increasing importance due to its practicality and the ease of obtaining results (Swain and Rao, 2009; Abdelhaffez, 2012).

In mining applications, wear and wear-related conditions can be encountered in a wide variety of areas. Particularly, when considering an excavation project, the wear behavior of rocks must be thoroughly examined in terms of material properties and operational costs. Therefore, in engineering applications, it is crucial to consider rock properties

Cite this article as: Aldı Ç: Determination of the effect of rock abrasiveness on grindability using three different experimental methods. Acta Geodyn. Geomater., 22, No. 3 (219), 405–412, 2025. DOI: 10.13168/AGG.2025.0028

Table 1 The rocks used in the study.

Rock Name	Location	Rock Type
Quartzite	Karabuk (Turkey)	Metamorphic
Quartz Schist	Malatya (Turkey)	Metamorphic
Chlorite Schist	Malatya (Turkey)	Metamorphic
Marble	Afyon (Turkey)	Metamorphic
Marble	Balikesir (Turkey)	Metamorphic
Metadiabase	Nigde (Turkey)	Metamorphic

Table 2 The methods recommended for the experiments.

Experiment	Reference	H (mm)	D (mm)	Number of Repeats
Brazilian Tensile Strength (BTS)	ISRM (1978)	27	54	10
Cerchar Abrasivity Index (CAI)	ISRM (2014)	27	54	5-7
Hardgrove Grindability Index (HGI)	ASTM (1993)	Sieve size		3
Norwegian Abrasion Index (AV)	Dahl (2003)	27	54	3

Fig. 1 Hardgrove Grindability Index (HGI) test apparatus.

such as abrasiveness and to strive for practical and accurate predictions of these characteristics.

Sakiz (2021) investigated the relationship between the abrasiveness and grindability of seven different andesite rocks. Considering three commonly used abrasion test methods (Cerchar, Norwegian, Schimazek), the study revealed that the abrasiveness of the rock can be easily determined using the Hardgrove Grindability Index (HGI). However, it was noted that the predictive models developed to determine rock abrasiveness based on HGI are limited to the range of abrasion values of the examined rocks. To develop more reliable predictive models, the study emphasized the need to increase the number of rocks analyzed and to consider rocks of different origins.

The difference of this study from similar studies is that it is the first study to determine the effect of abrasiveness on grindability for metamorphic rocks using three different test methods.

DATA AND METHODS

In this study, various experiments were conducted in laboratories. As part of the fieldwork, six different rock blocks were obtained to supply the rocks required for laboratory studies. The experiments were carried out on samples prepared in suitable dimensions after cutting core samples taken from these blocks.

Both the collection of samples from the field and the execution of laboratory experiments were conducted in accordance with the standards of the International Society for Rock Mechanics (ISRM) and the methods recommended by various researchers. Information about the rocks used in the study is provided in Table 1, while the methods proposed for the experiments are shown in Table 2.

The Hardgrove Grindability Index (HGI) test was conducted to determine the grindability of the rocks, and the results were compared with the strength, drillability, abrasiveness, and excavability values of

Fig. 2 West fully automatic CAI testing apparatus.

Fig. 3 Imaging system using a computer-assisted microscope.

the rocks. The apparatus used in the Hardgrove test is shown in Figure 1. First, 50 grams of rock samples with a particle size of -1180 µm +600 µm were prepared. Then, the prepared samples were ground in the HGI mill at 60 revolutions. Finally, the ground material was sieved through a 200-mesh screen, and the HGI results were calculated using Eq. (1) below.

$$HGI=13+6.93D \tag{1}$$

Here;

HGI: Hardgrove Grindability Index,

D: The amount of rock that passed through the 200-mesh screen.

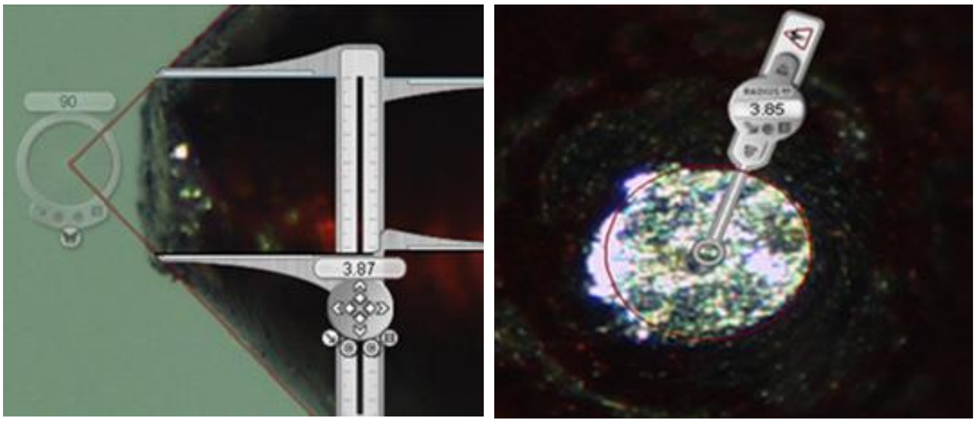

Fig. 4 Measurement of worn tips in horizontal and vertical positions under the microscope.

Fig. 5 Norwegian Abrasion Test apparatus.

To determine the abrasiveness values of the rocks, Cerchar Abrasiveness Index (CAI) tests were conducted. The method proposed by Alber et al. (2013) was taken into consideration in the experiments. The testing apparatus used in the experiments is shown in Figure 2, the imaging system using a computer-assisted microscope is shown in Figure 3, and the measurements obtained from the imaging system are shown in Figure 4.

The Norwegian Abrasion Test, another method used to estimate the abrasiveness of rocks, was developed in the early 1960s at the Department of Geological Engineering at the Norwegian Institute of Technology (Lien, 1961). This test method measures the wear on a tungsten carbide tip over time using powdered rock samples <1 mm in size (Dahl, 2003).

In this test, crushed stone powder smaller than 1 mm is passed under a tungsten carbide tiploaded with a 10 kg weight. The tungsten carbide tip is pressed against the rock powder as itmoves along a circular path on a rotating steel disk. The amount of wear is determined as theweight loss of the test tip in milligrams after 100 revolutions of the steel disk. A total of 100 revolutions corresponds to a test duration of 5 minutes. The Norwegian Abrasion Value (AV) is calculated using Eq. (2).

$$AV = W * 10 \quad (2)$$

Here;

AV: Norwegian Abrasion Value (mg/10 g),

W: Weight loss of tungsten carbide tip after 100 revolutions (mg).

The weight loss measurements of the tungsten carbide tips for each rock sample were recorded, and the corresponding AV values were calculated. This

Fig. 6 Hydraulic press used for the strength test.

Table 3 Experimental results.

Rock Name	HGI	BTS (MPa)	CAI	AV	d (mm)	Q (%)
Quartzite	52.5	21.1	3.5	47.6	1.3	97.1
Quartz Schist	73.8	9.4	4.3	44.2	1.5	43.9
Chlorite Schist	82.5	9.3	3.6	12.5	1.4	74.4
Marble	102.7	8.4	1	1.5	0.7	4
Marble	110.3	6.9	0.9	1	0.3	5
Metadiabase	61.4	15.4	3.3	18	1.1	31.6

test measures the time-dependent wear of the tungsten carbide tip that rubs against the crushed stone powder, providing a quantitative assessment of rock abrasiveness. The test setup is shown in Figure 5.

The Schimazek abrasion indices of the rocks were determined using Eq. (3). Schimazek and Knatz (1970) based on the Brazilian Tensile Strength (BTS), the average grain size of abrasive minerals (d), and the equivalent quartz content (Q).

$$F=d*Q*BTS \quad (3)$$

Here;
F: Schimazek Abrasion Index (N/mm).

The strength values of the rocks were determined using Brazilian Tensile Strength (BTS) tests. The method suggested by ISRM (1978) was applied for the Brazilian Tensile Strength (BTS) test. The hydraulic press used in the experiments is shown in Figure 6.

Additionally, within the scope of the study, rock samples were examined under a polarizing microscope to determine their mineral composition, texture type, grain size and shape, roundness, sphericity, cement type and degree of cementation, and weathering degree. Based on these characteristics, the average grain size of abrasive minerals (d) and equivalent quartz content (Q).

RESULTS AND ANALYSIS

In this experimental study, a database was prepared using the Hardgrove Grindability Index (HGI), Cerchar Abrasiveness Index (CAI), Brazilian Tensile Strength (BTS), Norwegian Abrasion tests (AV) and petrographic analysis. The results obtained from the experiments are presented in Table 3. The rocks used in the experiments were obtained from Turkey.

In this study, the relationships between the grindability (HGI) and abrasiveness (CAI) of the rocks were examined (Fig. 7). The graph shows a negatively strong relationship between the grindability of the rocks and their abrasiveness. It can be understood from the graph that the higher the abrasiveness of the rocks, the more difficult it is to grind them. In his study, Sakiz (2021) found similar results.

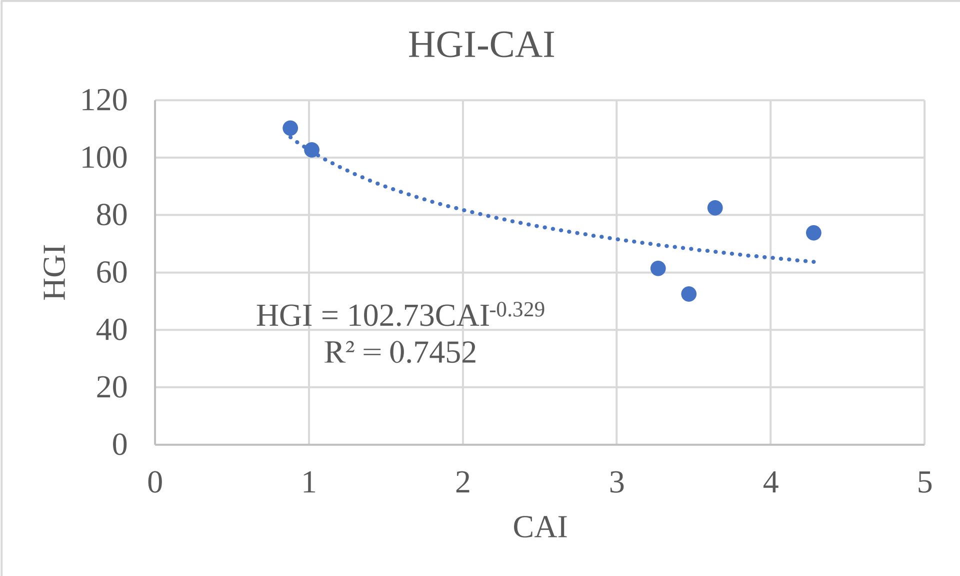

Fig. 7 Relationship between HGI and CAI.

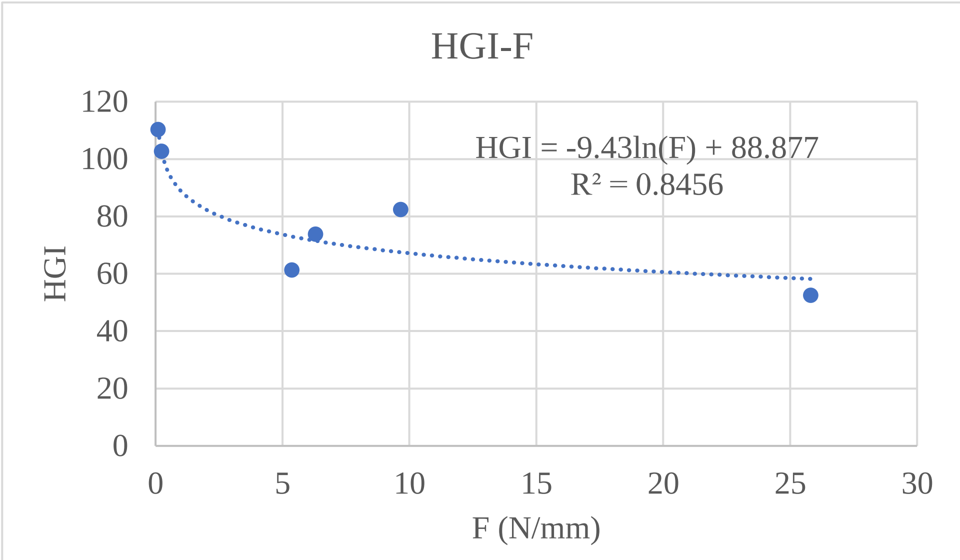

Fig. 8 Relationship between HGI and F.

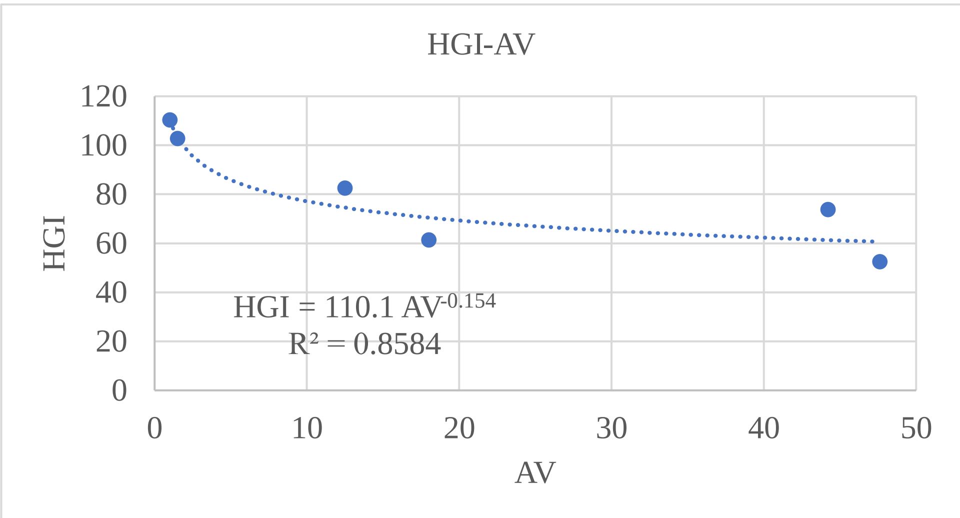

Fig. 9 Relationship between HGI and AV.

The relationships between the grindability (HGI) and abrasiveness (F) of the rocks were examined (Fig. 8). The graph shows a negatively logaritmic relationship between the grindability of the rocks and their abrasiveness. It can be understood from the graph that the higher the abrasiveness of the rocks, the more difficult it is to grind them. In his study, Sakiz (2021) found similar results.

The relationships between the grindability (HGI) and abrasiveness (AV) of the rocks were examined (Fig. 9). The graph shows a negatively strong relationship between the grindability of the rocks and their abrasiveness. It can be understood from the graph that the higher the abrasiveness of the rocks, the more difficult it is to grind them. In his study, Sakiz (2021) found similar results.

CONCLUSIONS

With this study, the effect of the abrasiveness of metamorphic rocks on grindability was investigated for the first time using three different experimental methods. The Cerchar Abrasiveness Index was compared with the Hardgrove Grindability Index, and a high negative correlation was found between these two parameters. As the abrasiveness of the rocks increases, their grindability becomes more difficult. A similar relationship was also obtained between the Schimazek Abrasiveness Index and the Norwegian Abrasiveness Index with the Hardgrove Grindability Index. In future studies, similar research should be conducted on sedimentary and igneous rocks, and the results should be compared with those obtained from this study. Additionally, the reliability of the study's findings should be more clearly demonstrated by increasing the number of samples. The strength, drillability, hardness, brittleness, fragility, excavability, and petrographic properties of the rocks should also be determined, and their effects on grindability should be evaluated. Evaluations should not only be conducted using simple regression analysis but should also be analyzed using methods such as multiple regression analysis and deep learning to investigate the combined effects of these parameters on grindability.

ACKNOWLEDGMENTS

The results presented in this paper are based on experimental studies. I would like to thank Dr. Haşim Duru for his invaluable assistance in the experimental work.

CONFLICTS OF INTEREST

The author declares that I have no conflicts of interest.

AUTHOR CONTRIBUTION DECLARATION

The author confirms sole responsibility for the entire study, including conceptualization, methodology, investigation, writing, and final approval of the manuscript.

FUNDING DECLARATION

The article does not include any financial support.

REFERENCES

Abdel Haffez, G.S.: 2012, Correlation between Bond Work Index and mechanical properties of some Saudi ores. J. Eng. Sci., 40, 1, 271–280.

Abu Bakar, M.Z., Majeed, Y. and Rostami, J.: 2017, Effects of rock water content on CERCHAR Abrasivity Index. Wear, 368,132–145. DOI: 10.1016/j.wear.2016.09.007

Alber, M., Yarali, O., Dahl, F., Bruland, A., Käsling, H., Michalakopoulos, T.N., Cardu, M., Hagan, P., Aydin, H. and Ozarslan, A.: 2014, ISRM suggested method for determining the abrasivity of rock by the Cerchar abrasivity test. Rock. Mech. Rock Eng., 47, 1, 261–266. DOI: 10.1007/s00603-013-0518-0

ASTM: 1993, Standard test method for the Hardgrove Grindability Index (HGI) of petroleum Coke, Des. D5003–19.

Bieniawski, Z.T. and Hawkes, I.: 1978, Suggested method for determining tensile strength of rock materials, Part 1. Suggested method for determining direct ten-sile strength. Int. J. Rock Mech. Min. Sci., 15, 99–103. DOI: 10.1016/0148-9062(78)90003-7

Bruland, A.: 2000, Hard rock tunnel boring. PhD. Dissertation, Vol. 3, Advance rate and cutter wear, Norwegian University of Sciences and Technology of Trondheim (NTNU), Report No. 1B-98.

Culshaw, M.G.: 2015, The ISRM suggested methods for rock characterization, testing and monitoring: 2007-2014. In: Ulusay, R. (Ed.), Bull. Eng. Geol. Environ., 74, 4, 1499–1500. DOI: 10.1007/s10064-015-0780-3

Dahl, F.: 2003, DRI, BWI, CLI standards, NTNU, 20.

Garzón-Roca, J., Torrijo, F.J., Alonso-Pandavenes, O. and Alija, S.: 2020, Cerchar Abrasivity Index estimation of andesitic rocks in Ecuador from petrographical properties using artificial neural etworks. Int. J. Geomech., 20, 5, 04020036. DOI: 10.1061/(ASCE)GM.1943-5622.0001632

Kahraman, S., Fener, M., Käsling, H. and Thuro, K.: 2016, The influence of textural parameters of grains on the LCPC abrasivity of coarse-grained igneous rocks. Tunn. Undergr. Space Technol., 58, 216–223. DOI: 10.1016/j.tust.2016.05.011

Lien, R.: 1961, An indirect test method for estimating the drillability of rocks. Dotorate Dissertation, NTH Department of Geology, Norway, (in Norwegian).

Majeed, Y. and Abu Bakar, M.Z.: 2016, Statistical evaluation of CERCHAR Abrasivity Index (CAI) measurement methods and dependence on petrographic and mechanical properties of selected rocks of Pakistan. Bull. Eng. Geol. Environ., 75, 3, 1341–1360. DOI: 10.1007/s10064-015-0799-5

Majeed, Y. and Abu Bakar, M.Z.: 2019, Effects of variation in the particle size of the rock abrasion powder and standard rotational speed on the NTNU/SINTEF abrasion value steel test. Bull. Eng. Geol. Environ., 78, 3, 1537–1554. DOI: 10.1007/s10064-017-1211-4

Sakiz, U.: 2021, Estimation of abrasion behavior of andesite rocks by Hardgrove Index (HGI) test method. International Conferences on Engineering and Natural Sciences, 9 pp., (in Turkish).

Schimazek, J. and Knatz, H.: 1970, The influence of rock structure on cutting speed and pick wear of roadway drivage machines. Glückauf, 106, 274–278, (in German).

Swain, R. and Rao, R.B.: 2009, Alternative approaches for determination of Bond Work Index on soft and friable partially laterised khondalite rocks of bauxite mine waste materials. J. Miner. Mater. Charact. Eng., 8, 9, 729–743. DOI: 10.4236/JMMCE.2009.89063

Tamrock: 1986, Handbook of underground drilling, 2nd edition. Collins Books LLC, 328 pp.

Yarali, O., Aydin, H., Sakiz, U., Duru, H. and Bulut, S.: 2018, Evaluation of rock abrasiveness by three different test methods. Mining, 5, 1, 45–56, (in Turkish).