DOI: https://doi.org/10.68732/853c2671d14605d3

ISBN: 978-9989-2053-6-1

The correlation between the compressive strength and dielectric constant for granites

S. Kahraman
Hacettepe University, Mining Engineering Department, Ankara, Türkiye
sairkahraman@yahoo.com
0000-0001-7903-143X

Ö. Y. Harman
Hacettepe University, Graduate School of Science and Engineering, Ankara, Türkiye

S. Helhel
Akdeniz University, Department of Electrical and Electronics Engineering, Antalya, Türkiye

Abstract

One of the intact rock properties, the uniaxial compressive strength (UCS), is frequently utilized in mining, oil and gas, and civil engineering projects. Samples for a typical UCS experiment must be smooth and precisely sized. It takes a lot of effort and time to complete the UCS test. Additionally, very weak or heavily jointed rocks cannot be used to create samples of the appropriate size. In these situations, the intrinsic rock properties are replaced with estimates of the rock properties derived from indirect tests, which are practical and simple to perform. In particular, measuring the dielectric constant requires very small samples and is very simple.In this study, the UCS and dielectric constant measurements were performed on different types of granite to investigate the relationship between these two parameters. The evaluation of the results showed that for the granites examined there was no correlation the UCS and dielectric constant. However, a reliable equation has been developed for predicting the compressive force by means of a multiple regression analysis including the parameters dielectric constant and quartz content for analysis. The lack of correlation between uniaxial compressive strength and dielectric constant in a simple regression analysis is most likely due to the fact that the values of the dielectric constant of the granites tested varied within a narrow range. Concluding remark is that the UCS of granites can be estimated by a multiple regression analysis equation.

Keywords

The uniaxial compressive strength, Dielectric constant, Granites, Regression analysis.

1 Introduction

The uniaxial compressive strength (UCS) of rock is widely used in mining and construction projects. The standard UCS test is difficult and labor-intensive and requires samples of specific size and uniformity. Furthermore, the required sample sizes cannot be prepared from highly fractured or very weak rock. In addition, in the feasibility studies, indirect estimates of rock properties are often used. For these reasons, the value of UCS should be estimated using indirect methods. Measuring the dielectric constant is much simpler than testing of compressive strength and requires especially very small samples. Ground Penetration Radar (GPR) measurements taken during geological surveys may also be used for the calculation of the dielectric constant of the rock mass. The dielectric constant of the intact rock may be estimated from the rock mass dielectric constant by the Time Propagation Mixing Model (Complex Refractive Index Model - CRIM) (Feng and Sen 1985). The dielectric constant of the intact rock estimated from GPR measurements may be used to estimate the UCS if a strong correlation is established between the two parameters.

Some researchers have studied the relationship between the dielectric constant and certain rock features. Most studies looked at the relationship between the dielectric constant and density and porosity (Olhoeff and Strangway 1975; Ulaby et al. 1988 and 1990; Russell and Stasiuk 1997; Rust et al. 1999; Heggy et al. (2001). Only two studies (ElShafie and Heggy 2012 and 2013) examined the relationship between the dielectric constant and the Schmidt hammer value. There are no studies in the literature on the relationship between the dielectric constant and the UCS of rock. This paper studies the relationship between the dielectric constant and the UCS of granites.

2 Rock types tested

Stone processing plants around Ankara city were visited and the large block samples of granite were obtained. The block samples were transported the laboratory for testing. Table 1 lists the locations of the six different granite types that were sampled.

Table 1. Rock samples used in the study.

Code	Rock type	Location
1	Granite (Kaman rosa)	Kaman/Kırşehir/Türkiye
2	Granite (Kozak)	Kozak/Balıkesir/Türkiye
3	Granite (Beypazarı)	Ankara/Türkiye
4	Granite (Baltic Brown)	Finland
5	Granite (Krasnaya rosa)	Russia
6	Granite (Orange pearl)	India

3 Mineralogical studies

Mineralogical analysis was carried out on the prepared thin sections of each rock type. Mineral compositions were determined by means of a polarizing microscope. The percentage of each mineral was determined by using a point counting device. The types and percentages of each mineral found in the samples are displayed in Table 2.

Table 2. Mineral constitutes and percentages of the samples.

Code	Mineral constitutes and percentages (%)							
	Quartz	Orthoclase	Plagioclase	Biotite	Amphibole	Muscovite	Chlorite	Opaque min.
1	28	41	18	9	-	-	4	-
2	12	25	32	16	13	-	2	-
3	25	23	37	2	10	-	-	3
4	14	56	12	13	4	-	-	1
5	29	62	4	3	-	1	-	1
6	24	61	11	3	-	-	-	1

4 Experimental studies

4.1 Sample preparation

NQ (47.6 mm) size core samples were taken from the granite blocks and sawn to specific sizes for the laboratory studies. The height of the cylindrical samples was 95 mm, whereas the disc-shaped samples had a thickness of about 22 mm.Some of the prepared samples are shown in Fig. 1.



Fig. 1 Core sample examples.

4.2 Uniaxial compressive strength tests

Data on the uniaxial compressive test (UCS) were taken from our previous study (Kahraman, 2025). The UCS tests were performed in accordance with the ISRM (2007) suggested methods. The stress level has been set at 0.5-1.0 MPa/s. For each type of rock, the tests were repeated at least five times and the mean value was recorded as UCS. The results of the tests are shown in Table 3.

4.3 Dielectric measurement tests

The complex relative permittivity of the samples was characterised using the cavity perturbation technique at a microwave frequency of 915 MHz. The measurement system comprised a high-Q cylindrical resonant cavity coupled to a vector network analyzer (Fig. 2). To ensure high precision and mitigate systematic errors, the system was calibrated using a Polyamide (Nylon 66) reference sample with a known dielectric constant.



Fig. 2 Dielectric measurement system.

Since the dielectric measurement on cylindrical specimens is difficult, disc specimens were used for the dielectric measurement tests. Eachspecimen was placed in the cavity's maximum electric-field region, and the resulting shift in resonant frequency and change in quality factor (Q) were recorded. The real part of the permittivity values, representing the energy storage capacity were calculated using the Bethe-Schwinger perturbation equations. The dielectric constants (ε_r) of the samples are listed in Table 3.

Table 3. Uniaxial compressive strength and dielectric constant values.

Code	UCS (MPa)	ε_r
1	159.9	5.41
2	132.6	5.54
3	136.0	5.66
4	89.9	5.81
5	155.6	5.87
6	137.1	5.56

5 Results and discussions

The correlation between the UCS and $\varepsilon_r$was examined using the data in Table 3, and as Figure 3 illustrates, no correlation was found between the two parameters. The literature contains no research examining the relationship between the two parameters. Nonetheless, some research (ElShafie and Heggy 2012 and 2013) has discovered a correlation between the dielectric constant and the Schmidt hammer value for pyroclastic and basalt rocks. A correlation between the UCS and ε_r is also anticipated since a correlation between the UCS and the Schmidt hammer value is known to exist. Nevertheless, there is no correlation between the Schmidt hammer value and the dielectric constant in the data from these investigations when basalt and pyroclastic rocks are assessed independently. The fact that the tested granites' ε_r values fall within a small range is probably the reason for the lack of correlation between UCS and e_r.

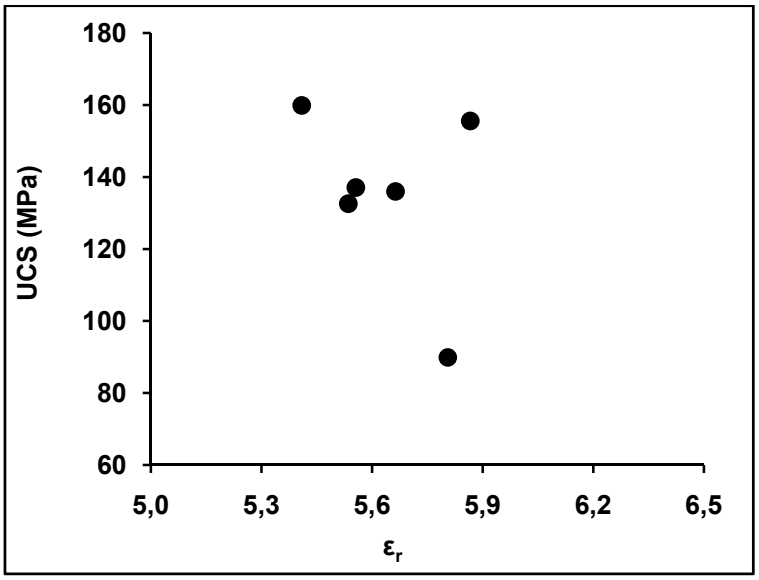


Fig. 3 Correlation between uniaxial compressive strength and dielectric constant.

A rock's dielectric constant is significantly influenced by the minerals that comprise it. The quartz mineral has a ε_r value of about 4.5, which is much lower than the ε_r values of the other minerals (6-7) that comprise granite. It is believed that granites' ε_r value is significantly impacted by their quartz content. Therefore, quartz content was added to the analysis along with the ε_r value in order to create an equation to estimate the UCS value using multiple regression analysis. The resulting equation with high correlation coefficient (r = 0.85) is:

$$UCS = -54.03\varepsilon_r + 2.56Q + 383.35 \quad (1)$$

Where UCS Uniaxial compressive strength (MPa)
ε_r Dielectric constant
Q Quartz content (%)

The 3D surface graph is shown in Figure 4 for Eq. 1. It can be seen in Figure 4 how the fitted response values relate to two continuous variables based on Eq. 1.

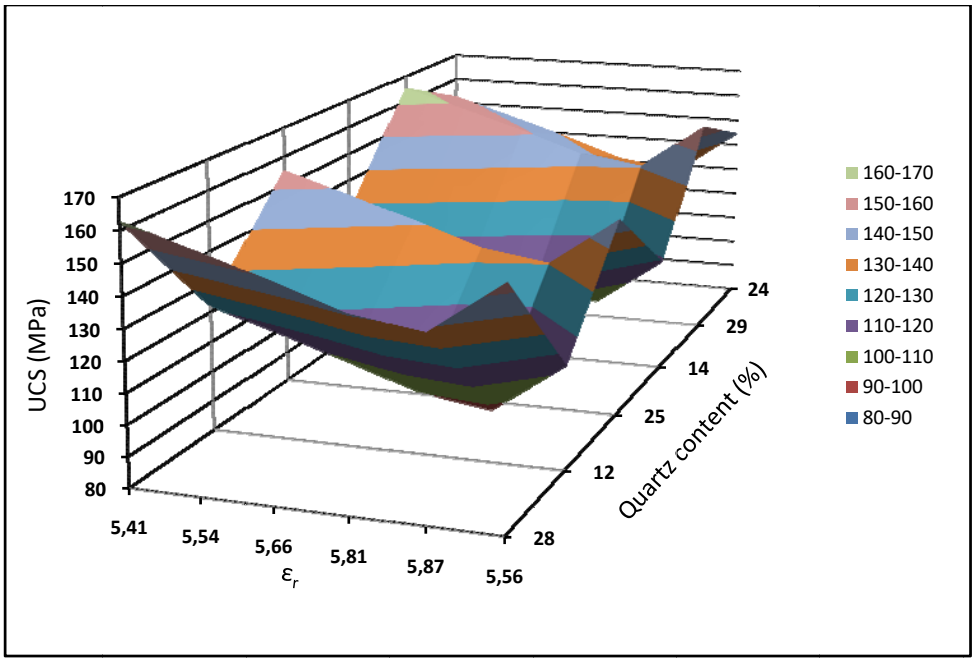


Fig. 4 The 3D surface graph 4 for Eq. 1.

6 Conclusions

Compressive strength, dielectric constant, and mineralogical data were assessed in order to create an equation for estimating the uniaxial compressive strength from the dielectric constant for granites. The analysis of the findings could lead to the following conclusions.

For the granites under test, no relationship was revealed between the dielectric constant and uniaxial compressive strength. Using multiple regression analysis, a reliable equation that considered the quartz content and dielectric constant was developed to predict compressive strength. The dielectric constant values of the tested granites most likely varied within a small range, which is why there was no correlation between uniaxial compressive strength and dielectric constant in the simple regression analysis. It was determined that the UCS of granites could be estimated using the multiple regression analysis equation. Granites with different mineralogy and dielectric constants or other rocks should be included in the analysis for future research.

Acknowledgement

We would like to thank the Hacettepe University-Scientific Research Projects Coordination Unit for funding (Project no. FUK-2025-21804).

References

ElShafie A, Heggy E (2012). Dielectric Properties of Volcanic Material and Their Role for Assessing Rock Hardness in The Martian Subsurface. 43rd Lunar and Planetary Science Conference, Texas (USA), March 19–23, 2012.

ElShafie A, Heggy E (2013) Dielectric and hardness measurements of planetary analog rocks in support of in-situ subsurface sampling. Planetary and Space Science 86: 150–154. https://doi.org/10.1016/j.pss.2013.02.003

Feng S, Sen PN (1985) Geometrical Model of Conductive and Dielectric Properties of Partially Saturated Rocks. Journal of Applied Physics58: 3236–3243.

Heggy E, Paillou P, Ruffie G, Malezieux JM, Costard F, Grandjean G (2001) On Water Detection in The Martian Subsurface using Sounding Radar. Icarus154: 244–257. https://doi.org/10.1006/icar.2001.6717

ISRM 2007 The complete ISRM suggested methods for rock characterization, testing and monitoring: 1974–2006. Suggested Methods Prepared by the Commission on Testing Methods, International Society for Rock Mechanics, R. Ulusay and J.A. Hudson (eds.), Compilation Arranged by the ISRM Turkish National Group, KozanOfset,. Ankara, Türkiye.

Kahraman S (2025). Investigation of the Drillability of Magmatic Rocks with Diamond-Impregnated Drill Bits. Research Project (FHD-2024-21169), Hacettepe University (in Turkish).

Olhoeft GR, Strangway DW (1975) Dielectric Properties of the First 100 Meters of The Moon. Earth and Planetary Science Letters24: 394-404. https://doi.org/10.1016/0012-821X(75)90146-6

Russell J K, Stasiuk M V (1997) Characterization of volcanic deposits with ground-penetrating radar. Bulletin of Volcanology 58(7): 515–527. https://doi.org/10.1007/s004450050159

Rust AC, Russell JK, Knight RJ (1999) Dielectric constant as a predictor of porosity in dry volcanic rocks. Journal of Volcanology and Geothermal Research 91: 79–96. https://doi.org/10.1016/S0377-0273(99)00055-4

Ulaby FT, Bengal TH, East JR, Dobson MC, Garvin JB, Evans DL (1988). Microwave dielectric spectrum of rocks. Radiation Lab. Tech. Report. No. 023817-1-T. Dept. of Elect. Eng. and Computer Sci., Univ. of Michigan, Ann Arbor.

Ulaby FT, Bengal TH, Dobson MC, East JR, Garvin JB, Evans DL (1990) Microwave Dielectric Properties of Dry Rocks. IEEE Transactions on Geoscience and Remote Sensing 28 (3): 325-336. https://doi.org/10.1109/36.54359