Correlating uniaxial compression strength and static Young's modulus with Schmidt hardness for prasinites

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ABSTRACT: The scope of this study is to investigate the potential correlation of the Schmidt hammer rebound number with the uniaxial compressive strength and the static Young's modulus of prasinites, a metabasic petrological type outcropping in Attica Peninsula, Greece. Research works of similar content require the direct determination of the mechanical properties under consideration, so sixteen samples of NX diameter were prepared and examined in the laboratory. Then, the interpretation of the results revealed the relationship between the Schmidt hammer rebound hardness with the uniaxial compressive strength and the static Young's modulus of the studied rock materials. The derived empirical equations can provide valuable information for this rock type and can be used for preliminary investigations, at least in the study region.

Keywords: Schmidt hardness, Uniaxial compressive strength, Static Young's modulus, Prasinites.

1 INTRODUCTION

Knowledge of the uniaxial compression strength (UCS) and static Young's modulus (E_s) of the intact rock is a first step to evaluating the in-situ behavior of rock mass. The best straightforward way to determine these parameters is through testing following recognized standard procedures (Bieniawski & Bernede 1979). However, there may be cases where the measurements of these properties are not possible, or their detailed investigation is not required. Under such circumstances, another way of determination is through estimation utilizing the results of less expensive and less sophisticated experimental procedures, such as the index strength tests (Zhang 2016).

Among these techniques, the Schmidt hammer has gained considerable attention. This portable device was first used in the concrete industry by E. Schmidt in 1948 to evaluate the surface hardness of concrete in situ and to overcome laborious experimental procedures (Day 1980). Rock mechanics engineers first used the Schmidt hammer in the middle 60s to estimate the rock strength in situ and the laboratory (e.g., Hucka 1965, Knill & Jones 1965, and Deere & Miller 1966).

The Schmidt hammer measures the repulsion of a spring-loaded mass when it impacts a material surface. The distance of rebound, also known as the Schmidt hammer rebound value (R), is a measure of the surface mechanical strength, as this value depends on the surface hardness, and in turn, hardness depends on strength (Day 1980). Various hammer types have been developed over the years, while the most frequently used are the standard L- and N-type hammers. The N-type has an impact energy roughly three times higher than the L-type (2.207 compared to 0.735 J), and it is commonly used for geomorphological research (Goudie 2006), while in the field of geotechnical engineering, both types are in use (Aydin 2009).

Due to its apparent simplicity and low cost, the Schmidt hammer test is a routine part of a typical laboratory program, and as a result, many researchers have investigated the correlation of the rebound value with various properties of the intact rock, such as the UCS or E_s. The results of these studies indicate the usability of R in estimating these properties (Aydin 2009).

This study aims to investigate the relation of rock hardness measurements, employing the L-type hammer, with UCS and E_s for prasinites, a metamorphic petrological type where limited published results exist regarding their basic mechanical properties (e.g., Xu et al. 1990, Sachpazis 1988 and Kotsanis et al. 2021). Furthermore, we compare our results with the findings of several other studies concerning the most common rock materials and a type of prasinites from North Italy.

2 PREVIOUS STUDIES

Since the pioneering work of Deere and Miller (1966), several researchers examined the correlation of R values with the basic mechanical properties of the intact rock, such as the UCS or E_s, and various empirical relationships have been proposed, either linear in form, according to Equation (1), or nonlinear, according to Equations (2) or (3).

$$Y = a \cdot R + b \tag{1}$$

$$Y = a \cdot e^{b \cdot R} \tag{2}$$

$$Y = a \cdot R^b \tag{3}$$

where Y refers to UCS or E_s, while a and b are considered material constants.

The following Tables list the quoted values for these constant terms from studies employing the L-type hammer on cylindrical specimens of NX diameter. The examined petrological types, as well as the performance of the applied regression analysis (R^2), are also indicated in these Tables.

However, an exception is the work of Xu et al. (1990), where the type of hammer and the diameter of the tested samples are not specified. Also, Aydin & Basu (2005) report results for specimens having a diameter >54.7 mm.

When it was necessary, these terms were recalculated so that UCS and E_s are expressed in MPa and GPa, respectively.

Table 1. Linear relationships between UCS and rebound value R.

Reference	Rock type	a	b	R^2
Deere & Miller (1966)	Various rock types	8.591	-240.56	0.77
Shalabi et al. (2007)	Dolomites-Dolomitic Limestones	3.201	-46.59	0.58
Minaeian & Ahangari (2013)	Conglomerates	0.678	0.00	0.93
Mishra & Basu (2013)	Granites	5.190	-168.10	0.75
Akram et al. (2017)	Limestones	1.174	11.94	0.68
Azimian (2017)	Limestones	2.664	-35.22	0.92

Table 2. Power relationships between UCS and rebound value R.

Reference	Rock type	a	b	R^2
Karaman & Kesimal (2015)	Various rock types	0.0477	2.0043	0.90
Yilmaz & Goktan (2019)	Various rock types	1.00E-04	3.5486	0.84

Table 3. Exponential relationships between UCS and rebound value R.

Reference	Rock type	a	b	R^2
Xu et al. (1990)	Prasinites	2.99	0.06	0.83
Aydin & Basu (2005)	Granites	1.45	0.071	0.85
Sabatakakis et al. (2008)	Limestones-Sandstones-Marlstones	3.10	0.090	0.79
Mishra & Basu (2013)	Schists	2.46	0.060	0.78
Mishra & Basu (2013)	Sandstones	3.79	0.055	0.85

Table 4. Linear relationships between E_s and rebound value R.

Reference	Rock type	a	b	R^2
Deere & Miller (1966)	Various rock types	1.786	-29.58	0.53

Table 5. Exponential relationships between E_s and rebound value R.

Reference	Rock type	a	b	R^2
Xu et al. (1990)	Prasinites	2.71	0.04	0.83
Aydin & Basu (2005)	Granites	1.041	0.06	0.83
Sabatakakis et al. (2008)	Limestones-Sandstones-Marlstones	0.166	0.14	0.74

3 GENERAL MATERIAL CHARACTERIZATION

In the Southern part of the Attica Peninsula, several remnants of prasinites are encountered upon the schistose rocks of the Lavreotiki "Phyllite" nappe. These isolated bodies are massive, slightly weathered to fresh, and pose a characteristic light to moderately dark oil-green color. Mineralogical analysis through PXRD revealed a composition typical of greenschist facies, i.e., actinolite, albite, epidote, and chlorite. Calcite and quartz are also present in variable amounts. The petrographical examination of the samples revealed a fine-grained matrix cross-cut by calcite veins.

4 EXPERIMENTAL PROGRAM

The laboratory program included all the tests required to determine the Schmidt hammer rebound value (R), the uniaxial compressive strength (UCS), and the static Young's modulus (E_s) for sixteen cylindrical specimens of NX diameter (54.5 mm) with a slenderness ratio between 2.5 and 3.0.

The operational procedure for the execution of the Schmidt hammer test was in line with the upgraded suggested method of ISRM (Aydin 2009). Accordingly, each specimen was placed in a horizontal position in a rigid steel V–block while through a guide tube, the hammer was at a right angle to their cylindrical surface. Subsequently, twenty single impacts took place at a distance at least equal to the diameter of the plunger. Finally, the R value was calculated as the average of all the gathered readings.

The uniaxial compression experiments were performed in a 5000 kN-capacity loading frame under lateral displacement control with a constant rate of 15 μm/min, utilizing a circumferential extensometer mounted on the specimen around its mid-height. To measure the induced axial strains, a system of two aluminum rings capable of supporting three linear variable differential transducers (LVDTs) at an angle of 120° apart was attached to the middle third of the specimens. The distance of the rings was measured continuously throughout the experiments, and the axial strain was calculated by the average of the measurements of the three LVDTs. Then, from the near-constant part of the average axial stiffness–axial stress curve, it was possible to deduce the static Young's modulus for the tested materials.

5 RESULTS AND DISCUSSION

According to classification schemes regarding the uniaxial compression strength and the deformability of the intact rock (e.g., IAEG 1979 and ISRM 1981), the prasinites in the study region are rocks of low to very low deformability and high to very high strength. The UCS ranges from 104.5 MPa to 244.1 MPa and E_s from 52.2 GPa to 88.4 GPa, while the Schmidt hammer rebound values range from 34 to 45.

Figure 1 illustrates the dependence of UCS and E_s on the variation of Schmidt hammer rebound value. These mechanical properties are linearly related to R values. The derived relationships show good coefficients of determination (R^2=0.79-0.81) and are described by equations (4) and (5), respectively.

$$UCS = 9.69 \cdot R - 208.56 \tag{4}$$

$$E_s = 2.53 \cdot R - 25.92 \tag{5}$$

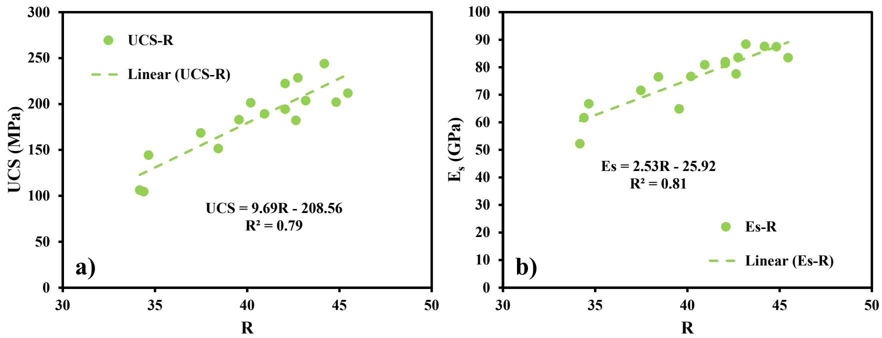

Figure 1. Empirical relationships for prasinites in this study a) UCS-R and b) E_s-R.

According to Aydin & Basu (2005), linear correlations are common in cases where the examined rocks exhibit relatively uniform microstructures. This condition also applies in this study as the tested materials are slightly weathered to fresh.

Our results confirm the findings of previous studies regarding the existence of a relation between UCS and E_s with Schmidt hammer measurements. However, the derived equations differ from others, as can be seen in Figure 2 and Figure 3.

Such differences may be attributed to different experimental procedures (gathering and reduction of data) and different structural characteristics of the examined rocks (Aydin & Basu 2005).

The mineralogical examination of the tested materials reveals the presence of significant amounts of clay minerals (chlorites), which may reduce the values of R. The influence of clay minerals on the decrease of Schmidt hardness measurements has also been reported in the case of evaporitic rocks (Rahimi et al. 2022).

Our results differ significantly from those obtained for prasinites in North Italy (Xu et al. 1980). These differences may be due to the different structural characteristics of these rocks and to the data-gathering procedure adopted in this study. Other factors, such as the type of hammer and the size of the specimens, may also contribute to this difference.

Based on the above observations, it is evident that employing a random empirical equation quoted in the literature without considering all the factors that govern its formulation can lead to erroneous estimates.

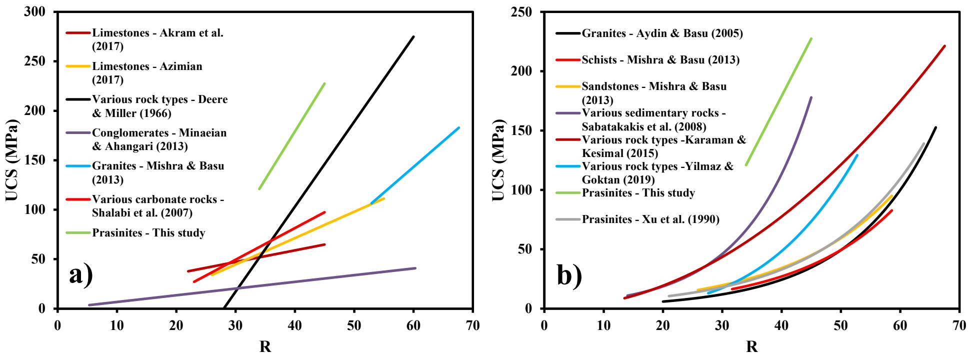

Figure 2. Comparison of the developed equation in this study, in terms of UCS-R, with previously published a) linear and b) non-linear relationships.

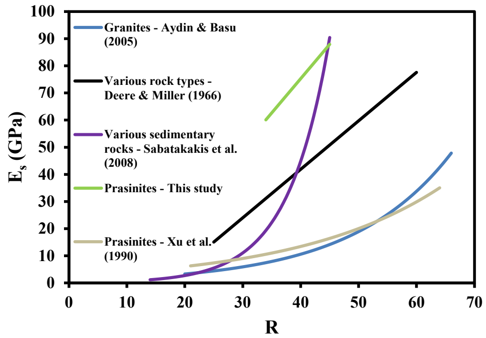

Figure 3. Comparison of the developed equation in this study, in terms of E_s-R, with previously published relationships.

6 CONCLUSIONS

In this study, a laboratory program was conducted to determine the Schmidt hammer rebound value (R), the uniaxial compressive strength (UCS), and the static Young's modulus (E_s) for sixteen specimens of prasinites, a metamorphic rock type from the South part of Attica Peninsula. From the interpretation of the mechanical data, linear equations were derived for the dependence of UCS and E_s on R values. These findings can be used for preliminary investigations, at least in the study region, and they enrich our knowledge regarding the values of Schmidt hardness that can be exhibited for hard and stiff rocks.

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