
NEW METHODS AND INSTRUMENTS

IN MINING

Usability of Digital Shore Hardness Devices in Estimation of Physical and Mechanical Properties of Rocks

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Abstract—In this study, the Shore hardness measurements are made on carbonate rocks using Durometer PCE-1000, Mitech MH310 Hardness Tester and C-2 type Shore Scleroscope, and the results obtained were compared. The usability of digital new generation Shore hardness test devices (Durometer PCE-1000 and Mitech MH310 Hardness Tester) to determine the Shore hardness of the rocks is investigated.

Keywords: Rock hardness, Shore hardness, natural stone, physical and mechanical properties.

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INTRODUCTION

Hardness is one of the most investigated and most complex to understand property of rocks. Hardness is generally expressed as the resistance of the rock against an external mechanical effect. In rock engineering projects which interact with rock such as underground structures, dams, rock foundations, and rock slopes, physical and mechanical properties of intact rocks are very significant. Direct testing for assessing rock strength and deformation is often expensive and takes considerable time, particularly preparing rock samples for testing.

Specific indirect test methods have been developed and used in understanding rock engineering properties. The indirect measures include point load, hardness of Schmidt rebound, hardness of Shore scleroscope, and hardness of abrasion. These experiments are fairly easy to carry out, not costly and take a short time to perform [1]. A mineral hardness is directly related to its chemical and atomic structure, and to a certain degree reflects the mineral's physical and mechanical properties. Hardness is a quality that is easily quantitatively appreciated but not easily described quantitatively. Specific measures were developed to determine hardness, the majority of which evaluate the material's resistance to scratching or indenting [2].

Various hardness testing tests for various types of materials have been proposed. Hardness tests for metallic materials are often developed in parallel with emerging industry. In general, methods of dynamic rebound hardness are commonly used (Schmidt hammer, Shore scleroscope, Leeb hardness, etc.), as they are inexpensive and functional compared to methods of static and indentation based hardness testing (Brinell, Vickers, Rockwell, Knoop, Cherchar; ASTM [3, 4].

Rebound hardness is an indicator of the object rebound to the surface of a rock that is dropped or impacted. The degree of rebound is a function of the amount of energy lost from impact as plastic deformation and a rock failure at the point of impact [4, 5]. Mohs suggested a hardness scale using a standard range of ten minerals to which relative numbers of hardness were assigned [6].

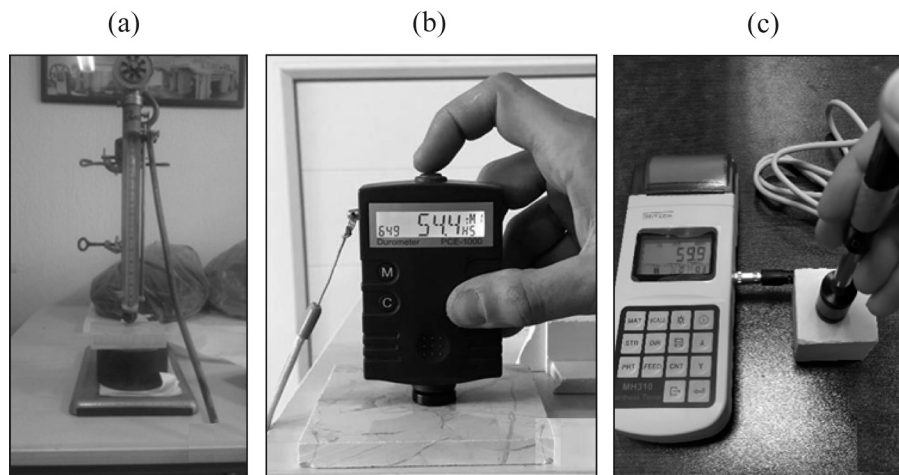


Fig. 1. Shore hardness measurement devices used in the study: (a) C-2 type Shore scleroscope, (b) PCE-1000 durometer, (c) Mitech MH310 hardness tester.

The hardness of a test surface is measured by determining whether one of the mineral criteria scratches it or not. Scratch hardness can be a useful tool for simple but rough evaluation and has the advantage that there is no need for instrumentation, but it leaves much to be desired as a basis for quantitative measurement and is seldom used in engineering [2]. C-2 type Shore scleroscope has been commonly preferred tool in characterizing rock materials because of its decades of practical and economical use. The physical and mechanical properties of rocks are the most important parameters in the design of ground workings and in the classification of rocks for engineering purposes and Shore hardness also can be used to estimate physical and mechanical properties of rocks. The hardness test, hardness of rocks and the relationship between hardness and physical/mechanical properties have been investigated in [1–5].

This study is primarily to investigate the usability of durometer instead of C-type Shore scleroscope and determine a relationship between Shore hardness and physical/mechanical properties of the rocks examined in this study.

1. MATERIALS AND METHODS OF STUDY

Shore hardness values of 13 different carbonate rocks were determined on the same samples using three different devices (C-2 type Shore scleroscope, digital durometer PCE-1000 and MH310 hardness tester (Fig. 1). The experiments were carried out on 13 carbonate rocks from different regions of Turkey (Table 1).

Table 1. Carbonate rock samples

| Sample code | Origin | Region |
|-------------|-------------|-----------|
| CR-1 | Sedimentary | Burdur |
| CR-2 | | Bursa |
| CR-3 | | Isparta |
| CR-4 | | Isparta |
| CR-5 | | Isparta |
| CR-6 | | Isparta |
| CR-7 | | Bursa |
| CR-8 | | Kastamonu |
| CR-9 | | Denizli |
| CR-10 | | Antalya |
| CR-11 | | Antalya |
| CR-12 | | Antalya |
| CR-13 | | Antalya |

Table 2. Shore hardness values

| Sample code | SH-1 | SH-2 | SH-3 |
|-------------|-------|-------|-------|
| CR-1 | 58.98 | 54.15 | 51.82 |
| CR-2 | 60.45 | 59.43 | 58.80 |
| CR-3 | 49.73 | 42.52 | 40.72 |
| CR-4 | 41.10 | 43.23 | 44.96 |
| CR-5 | 54.98 | 52.18 | 53.53 |
| CR-6 | 55.15 | 57.44 | 55.34 |
| CR-7 | 58.93 | 54.60 | 56.84 |
| CR-8 | 60.10 | 57.54 | 57.81 |
| CR-9 | 41.68 | 45.12 | 44.88 |
| CR-10 | 30.18 | 39.76 | 41.00 |
| CR-11 | 30.48 | 38.72 | 39.89 |
| CR-12 | 40.13 | 31.80 | 35.37 |
| CR-13 | 42.20 | 30.20 | 37.01 |

Shore hardness experiments were carried out in Süleyman Demirel University, Mining Engineering Department, Excavation Mechanics and Natural Stones Technology and Kırşehir Ahi Evran University Kaman Vocational School Natural Stone Analysis Laboratory. Shore hardness tests were carried out in accordance with ISRM standard under similar external conditions [7, 8]. Shore hardness values obtained by C-2 type Shore scleroscope, PCE-1000 durometer and Mitech MH310 hardness tester were designated as SH-1, SH-2 and SH-3, respectively (Table 2). For each sample, 20 readings were made by each device and the arithmetic average was taken as the end value.

Physical and mechanical properties were determined out in accordance with the related standards [7, 9–11]. Total porosity was found using TS EN 1936 standard, sound speed propagation—TS EN 14579, wide wheel abrasion (abrasive strength)—TS EN 14157, uniaxial compressive strength and Brazilian tensile strength—ISRM. The test results are presented in Table 3.

2. RESULTS AND DISCUSSION

It was observed that Shore hardness values obtained by using different measurement devices on the same samples were close to each other, and the values measured were not statistically different (Fig. 2).

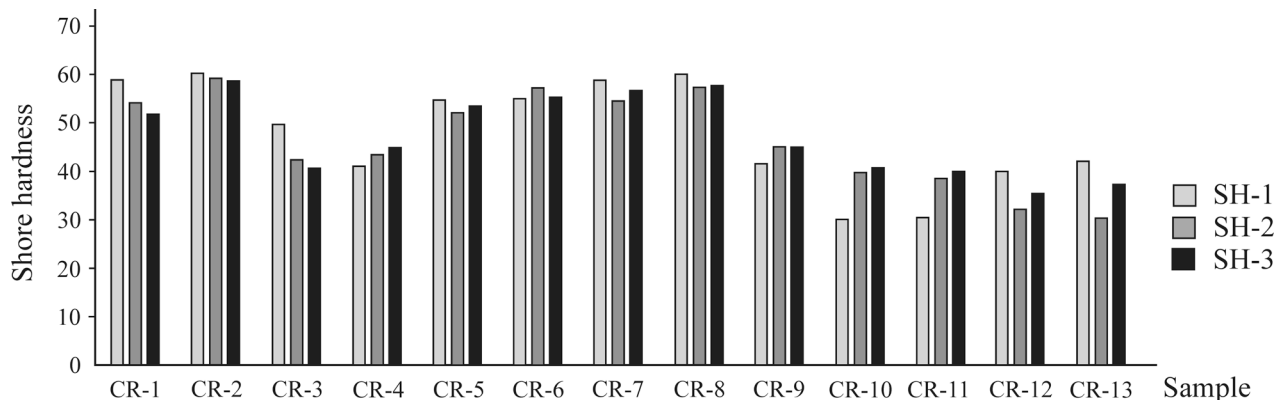
**Fig. 2.** Shore hardness values of the natural stone measured with different devices.



Fig. 3. Relationships: (a) SH-1/SH-2 and (b) SH-1/SH-3.

Relationships between Shore hardness values obtained by C-2 type Shore scleroscope, PCE-1000 durometer and Mitech MH310 hardness tester were examined with the help of graphics (Fig. 3). The most useful graph for displaying the relationship between two quantitative variables is a scatterplot. A scatterplot displays the strength, direction, and form of the relationship between two quantitative variables. A correlation coefficient r measures the strength of that relationship ranging $-1 \div 1$. Coefficient $r = -1$ corresponds to perfect negative correlation, $r = 1$ —perfect positive correlation, $r = 0$ —lack of linear relationship between two quantitative variables [12]. Doymuş [13] interpreted correlation coefficient “very poor” in the range of $0-0.25$; “weak” in the range of $0.26-0.49$; “medium”— $0.50-0.69$; “high”— $0.70-0.89$ and “very high”— $0.9-1.0$. High relationships were determined between SH-1 and SH-2 with a correlation coefficient of $r = 0.82$ and between SH-1 and SH-3 with a correlation coefficient of $r = 0.84$. It shows that digital new generation Shore hardness test devices could be used trustworthy in determining Shore hardness of the rocks. PCE-1000 durometer and Mitech MH310 hardness tester are digital, they measure more precisely than C-2 type Shore scleroscope.

Relationships between the determined physical and mechanical properties of rocks used in the study (Table 3) and Shore hardness values determined by different devices (Table 2) were investigated. They were analysed by simple regression method and distribution graphs were created (Fig. 4).

Table 3. Physical and mechanical rock properties

| Sample code | Total porosity T_p , % | Sound speed propagation V_p , m/s | Abrasive strength W_d , mm | Uniaxial compressive strength σ_c , MPa | Brazilian tensile strength σ_r , MPa |
|-------------|-----------------------------|--|---------------------------------|---|--|
| CR-1 | 0.69 | 6237 | 18.05 | 113.12 | 7.98 |
| CR-2 | 1.11 | 6103 | 17.84 | 113.57 | 7.40 |
| CR-3 | 5.29 | 3954 | 21.96 | 118.74 | 5.73 |
| CR-4 | 6.29 | 3217 | 22.38 | 108.66 | 5.60 |
| CR-5 | 0.97 | 6376 | 18.58 | 160.47 | 6.00 |
| CR-6 | 1.13 | 6281 | 16.76 | 138.43 | 6.70 |
| CR-7 | 1.45 | 6306 | 15.67 | 146.87 | 5.67 |
| CR-8 | 1.08 | 6422 | 17.00 | 116.18 | 7.00 |
| CR-9 | 11.09 | 5197 | 16.46 | 47.99 | 4.32 |
| CR-10 | 7.09 | 4202 | 25.94 | 75.40 | 2.95 |
| CR-11 | 11.98 | 4270 | 21.72 | 73.09 | 2.95 |
| CR-12 | 12.96 | 4305 | 25.80 | 43.40 | 3.57 |
| CR-13 | 12.33 | 4295 | 23.81 | 47.67 | 3.75 |

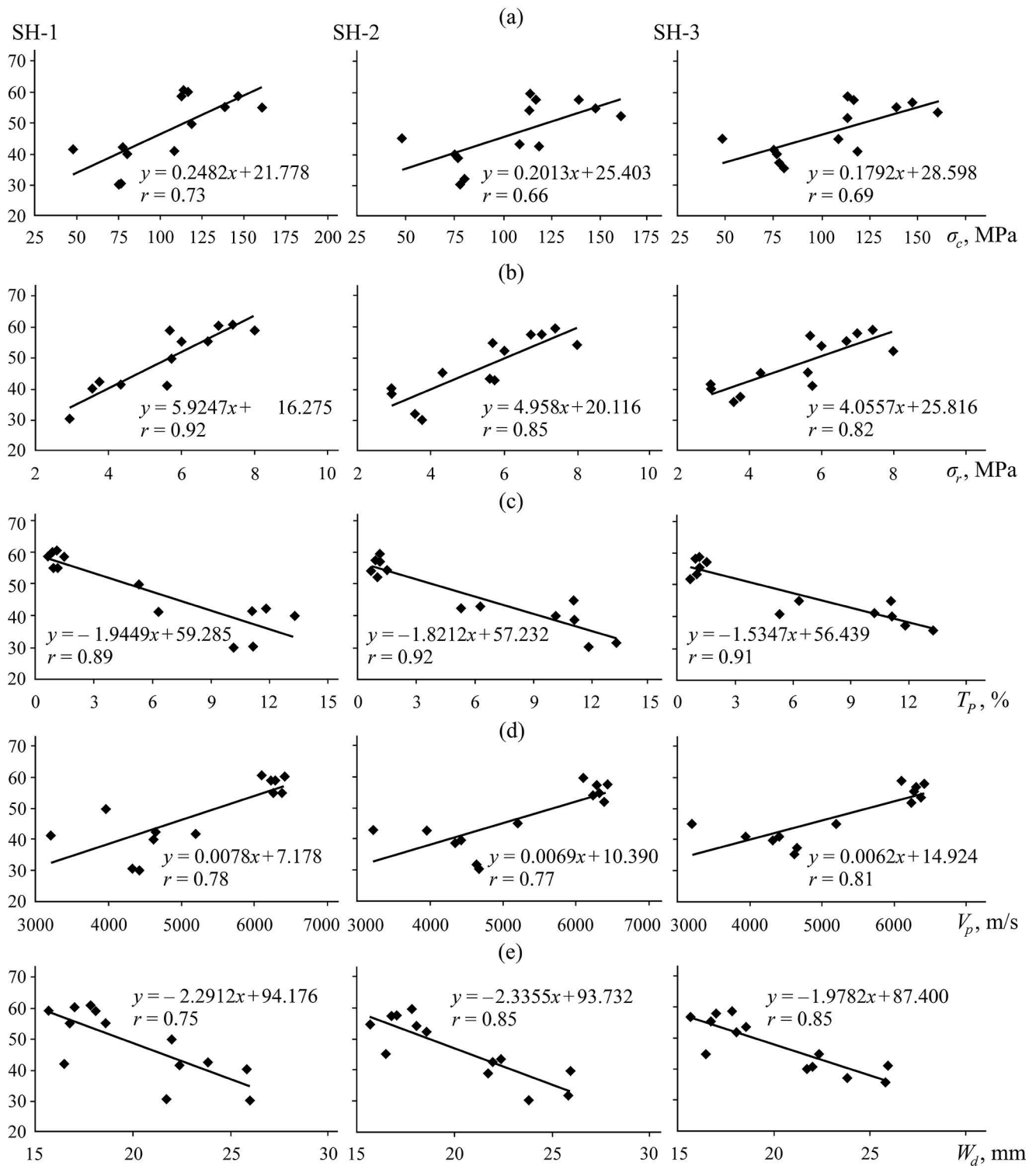


Fig. 4. The relationship between Shore hardness values and (a) uniaxial compressive strength, (b) Brazilian tensile strength, (c) total porosity, (d) sound speed propagation and (e) abrasive strength.

Meaningful relationships were generally found between Shore hardness and physical/mechanical properties of carbonate rocks using each three test device. It was determined that rock properties can be estimated with Shore hardness values obtained from each device.

Linear relationships with meaningful coefficient of correlation were found between Shore hardness values (SH-1, SH-2, SH-3) and UCS σ_c (Fig. 4a). High correlation ($r=0.73$) was observed between SH-1 and σ_c , medium correlation ($r=0.66/0.69$)—between σ_c and SH-2/SH-3, i. e. the correlation between SH-1 and σ_c is higher than between SH-2 and σ_c , SH-3 and σ_c .

Linear strong correlation was found between Shore hardness values and Brazilian tensile strength σ_r (Fig. 4b). The coefficient of correlation between SH-1 and σ_r was 0.92 (very high), between SH-2 and σ_r —0.85 (high) and between SH-3 and σ_r —0.82 (high).

Strong nonlinear correlations were determined between Shore hardness values and total porosity T_p (Fig. 4c). The best correlation is between SH-2 and T_p at $r=0.92$ (very high), between SH-3 and T_p at $r=0.91$ (very high) and between SH-1 and T_p at $r=0.89$ (high).

Linear relationships were found between Shore hardness values and sound speed propagation распространения звуковой волны V_p (Fig. 4d). The coefficients of correlation between SH-1, SH-2, SH-3 and V_p were 0.78, 0.77 and 0.81, respectively.

Meaningful correlations were observed between Shore hardness values and abrasive strength W_d (Fig. 4e). High correlation was determined between SH-2, SH-3 and W_d at $r=0.85$, medium correlation—between SH-1 and W_d at $r=0.75$.

The obtained r values between examined rock properties and Shore hardness values obtained from each three test device were very close to each other. Shore hardness of rocks can be used to predict rock properties. The use of PCE-1000 durometer and Mitech MH310 hardness tester, which are more sensitive and easier to use, can be preferred in estimating the rock properties using Shore hardness.

CONCLUSIONS

The usability of digital new generation Shore hardness test devices used in hardness measurements of rocks instead of C-2 type Shore scleroscope was investigated. In the experiments, devices of two different brands that are economically available on the market were used. Statistical regression between the obtained hardness values and physical/mechanical properties was analyzed. It was found that hardness values obtained using three test devices are close to each other and they can substitute each other.

The relationships between hardness values and uniaxial compressive and Brazilian tensile strengths were obtained, as well as the relations between hardness values and total porosity, sound speed propagation and abrasive strength.

In order to determine the Shore hardness of the rocks more accurately, digital measurement devices should be produced at different impact energy and different tip diameters and studies should be continued to renew the tests and to develop the devices.

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