International Journal of Rock Mechanics & Mining Sciences 46 (2009) 725–730

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

The effect of sample size on Schmidt rebound hardness value of rocks

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ARTICLE INFO

Article history:
Received 6 May 2008
Received in revised form
13 June 2008
Accepted 13 September 2008
Available online 23 October 2008

Keywords:
Schmidt hardness
Sample size
Rock
Rebound number

ABSTRACT

The Schmidt hammer has been commonly used device for hardness determination and for predicting the unconfined compressive strength and other mechanical properties of rocks, due to the fact that it is a quick, easy, inexpensive and non-destructive testing method. Testing is most commonly performed following the ISRM and ASTM standards. The effect of sample size for a consistent hardness value has not been well defined in previous works. ISRM [Rock characterization testing and monitoring ISRM suggested methods, suggested methods for determining hardness and abrasiveness of rocks, Part 3. Oxford: Pergamon; 1981. p. 101–3] suggested that block edge length should have at least 6 cm, while ASTM [Standard test method for determination of rock hardness by Rebound Hammer Method, D5873-05, 2005] indicated at least 15 cm. In this study, in order to analyze the effect of sample size on Schmidt rebound hardness (SRH) property of rocks, rock samples were collected from eight locations. Cubic samples having different edge dimensions of 6, 7, 8, 10, 12 and 15 cm were prepared. In the laboratory, Schmidt hammer tests were conducted according to the suggested procedure by ISRM (1981) together with different methods of recording SRH. By evaluating the measured data, it is showed that the size of the cubic samples significantly affects the SRH values. Edge dimension of the cubic block should be at least 11 cm for determining a consistent hardness value. An equation predicting the consistent hardness value from samples smaller than 11 cm was also suggested.

1. Introduction

Hardness is one of the characteristics of rocks showing its resistance to permanent deformation. Several factors control the hardness of rock materials, e.g. mineral composition, cementing material and density. Various methods are employed to assess the surface hardness of rocks in engineering applications such as Shore hardness, Mohs and Schmidt rebound hardness (SRH). SRH is the most commonly used one for over half a century. The SRH was originally developed to test the surface rebound hardness of concrete [1], effectively an engineered material and lately it has since been adopted for rock, a natural material [2]. Schmidt rebound measurement device, having a scale between 0 and 100, is a most practically used device for quickly determining the in-situ and laboratory hardness of rocks, used in natural stone industry [3]. Schmidt hammer measures the distance of rebound of a controlled impact on a rock surface. There are different versions of the hammer available in the market. Among them [4], L-type Schmidt hammer is commonly used for testing rocks while N-type Scmidt hammer is used for testing concrete. The 'L' type hammer has an impact three times lower than the 'N' type (0.735 N m compared to 2.207 N m). The L-type is more appropriate for weak rocks and those with thin weathering crusts [4]. Unconfined compressive strength and Young's modulus properties of rocks can also be estimated from the SRH method.

There is a huge amount of work related to SRH. Most of these studies establish relations between hardness and the other parameters for rocks. One of the reasons behind equations developed for predicting the rock strength parameters from SRH measurement is the dimensions of the rock samples. Therefore, this study investigates how important the size of sample on the consistent hardness value determination.

2. Previous SRH studies

The Schmidt hammer has been used in rock mechanics practice since the early 1960s as an index test [5] for a quick rock strength and deformability characterization due to its rapidity and easiness in execution, simplicity, portability, low cost and nondestructiveness [6]. Therefore, the methodology of the Schmidt hammer test is expected to ensure reliable data acquisition and analysis on site or in the laboratory [7]. Moreover, in 1999, Amaral et al. [8] indicated that the Schmidt hammer methodology provides an accurate and consistent index for hardness characterization of different types of granite used as

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doi:10.1016/j.ijrmms.2008.09.004

flooring tiles. In the mining industries, it is used to determine the quality of rock, which is common practice when constructing rock structures such as those found in longwall mining, room and pillar mining, open-pit mining, gate roadways, tunnels, dams, etc [9].

SRH method has been used for a variety of specific applications. Among these, as explained by Goktan and Gunes [10]: state of weathering [11,12], assessment of rock discontinuities [13], mine-roof control [14], roadheader and tunnel boring machine performance [15–21], drilling machine penetration rate [22–24], joint wall strength [25], rock rippability [26], rock deformation coefficient [27], rock abrasivity [28], abrasion resistance of rock aggregates [29], as a classification parameter for rock excavation [30] and estimation of large-scale in-situ strength in a gallery [31]. Since early 1960s, a large number of investigations were carried out for predicting the strength properties of rocks from SRH. They obtained high correlations between Schmidt hardness and unconfined compressive strength and suggested different empirical equations [6,10,32–45]. The reason behind differences in the equations suggested by researchers is due to some limitations as experienced in other index tests. The general factors causing limitations and differences in the results are as follows: accepting the data showing a normal distribution, evaluating the data obtained with different methods of recording SRH, analysis of data not reflecting different rock type characteristics, neglecting the internal properties of the rocks such as cracks, fissures and texture, performing the test on the different surface roughness conditions and moisture content of samples and neglecting the sample dimensions [4,6,40,43,44,46]. Moreover, a number of factors are associated with the obtained Schmidt hammer rebound values, among which are: calibration and improper functioning of the instrument, weathering state of the tested rock, spacing between the impacts, orientation of the hammer, the adopted test procedure and type of hammer and available impact energy [44].

Sumner and Nel [47] observed that Schmidt hardness value of rocks was found to decrease with increasing moisture content and block size should exceed approximately 25 kg for accurate and consistent rebound. Hucka [48] and Katz et al. [49] determined that the degree of surface smoothness and polishing significantly affect the SRH values and improve the quality of field measurements. Ayday and Goktan [50] found good correlations between L-type and N-type Schmidt hammer rebound values. Aydin and Basu [43] found a very good correlation between L and N hammer rebound values that both hammers are fairly sensitive to the physical properties, particularly to dry density though less so to effective and total porosities. The N hammer, producing a lesser scatter in the data, proved to be more efficient than the L hammer in predicting uniaxial compressive strength and Young's modulus [43].

3. Experimental method

In the literature, it was found that the effect of various sample sizes for a consistent SRH value determination has not been investigated. ISRM [51] indicated that block edge length should have at least 6 cm, while ASTM [52] determined at least 15 cm. Both standards specify that core specimens should be at least NX size (54.7 mm) or larger in diameter. Aydin [53] suggested that cores should be of at least NX size ($\geqslant$54.7 mm) for the L-type hammer and preferably T2 size ($\geqslant$84 mm) for the N-type hammer. He [53] emphasized that block specimens should be at least 100 mm thick at the point of impact.

Different methods of recording SRH value have been suggested by ISRM and various researchers. The recommended Schmidt hammer test procedures used in this study are summarized below:

ISRM [51]: Record 20 rebound values from single impacts separated by at least a plunger diameter, and average the upper 10 values.

Hucka [48]: Select the peak rebound value from 10 continuous impacts at a point. Average the peaks of the three sets of tests conducted at three separate points.

Poole and Farmer [54]: Select the peak rebound value from five continuous impacts at a point. Average the peaks of the three sets of tests conducted at three separate points.

Fowell and Smith [27]: Take the mean of the last five values from 10 continuous impacts at a point.

In order to analyze the effect of sample size on the SRH values of rocks, eight different rock types collected from various locations of Turkey were studied. Name, type and origin of the tested rocks are given in Table 1. Cubic samples with edge dimensions of 6, 7, 8, 10, 12 and 15 cm were prepared by cutting with a circular saw. For each rock type, 24 samples were prepared. At least four samples were tested for each rock size. Sample preparation and testing method were carried out in accordance with the specifications of the ISRM [51]. Testing was conducted as follows. (a) Tests were performed with L-type hammer having impact energy of 0.74 N m. (b) All tests were made with the hammer held vertically downwards ($\pm 5^{\circ}$). (c) Each sample surface were smoothened with abrasive of 220 grit size and flat over area covered by the plunger. (d) All samples were free from cracks, other flaws and were air-dried. (e) The testing was carried out on a rigid steel base of minimum weight of 20 kg to adequately secure the specimen against vibration and movement during the test.

Table 1
Details on rocks tested

Rock name	Rock type	Rock class
Andesite	Andesite	Igneous
Burdur Beige	Limestone	Sedimentary
Mugla Yellow	Marble	Metamorphic
Mugla Grey	Marble	Metamorphic
Bucak Travertine	Travertine	Sedimentary
Cappuccino Beige	Limestone	Sedimentary
Lymra	Limestone	Sedimentary
Denizli Travertine	Travertine	Sedimentary

4. Test results

Test methods explained in the previous section, which are ISRM [51], Hucka [48], Poole–Farmer [54] and Fowell–Smith [27] among the different SRH measurement methods, were selected and applied on all rock samples. Each test method was performed on any sample. Average value according to each evaluation procedure was recorded as rebound number.

For presenting the variations in hardness characteristics from Schmidt hammer test results, SRH values against sample size were plotted for all rocks. The average hardness of the rock samples according to different Schmidt hammer rebound techniques are presented in Figs. 1–4. The standard deviation of the SRH values varied from 0.5 to 2.5. When the data given in Figs. 1–4 are examined, it is seen that increase in sample size results with increase in the SRH value. Increase in SRH values is initially very significant and reaching a constant hardness value at a critical sample size. In order to determine the average critical sample size for a consistent SRH value, two lines were fitted to the data; one is an inclined line fitted to SRH data increasing with sample size; the other is a horizontal line fitted to SRH data showing no changes