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Investigation of the Effects of Rock Components for Different Pyroclastic Rocks on Leeb Hardness

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Abstract

The aim of this study is to research the effect of rock components on Leeb hardness (HL), a non-destructive test commonly used in recent periods. With this aim, cube samples of two different pyroclastic rocks containing dominantly pumice (*P*) or volcanic rock fragments (VRF) were prepared. Later, the proportions of different components (*P* and VRF) on the surfaces of the cube samples were determined using the Image Pro Plus 6.0 image processing program. The effect of the variation in these components on HL values was researched with simple regression analysis and strong correlation coefficients were found between these values. According to the data obtained, the HL test was identified not to be suitable for heterogeneous rocks comprising different components.

Keywords

Leeb hardness, image processing program, pumice, volcanic rock fragment, pyroclastic rock

1 Introduction

Leeb hardness (HL) is a non-destructive test used by many disciplines (metallurgy, materials science, civil engineering, geomorphology, restoration work and rock mechanics) in recent times. This test was developed by the Swiss engineer Dietmar Leeb in 1975 with the aim of determining the hardness of metals and polymers [1]. Important advantages in relation to the popularization and use of this test by several disciplines are that the device is mobile and the direction of the hits can be chosen. Its increased use in rock mechanics studies is due to having a broader measurement scale and providing better results compared to Schmidt hardness for weak rocks, in addition to similarity to the Schmidt hammer surface hardness used for indirect estimation of uniaxial compressional strength (UCS) [2]. Pioneering research in this area aims to determine the correlations between physico-mechanical features of rocks (dry density (ρ_d), porosity (n), P-wave velocity (V_p), UCS, etc.) with HL values [1–11]. The area with most focus in previous research was the correlation between HL and UCS and this correlation was researched using simple regression, multiple regression, artificial neural networks and fuzzy approaches [1, 3–17]. These prediction models found correlations with high correlation coefficients. Some researchers determined that the HL test was affected by pores in rocks, grain/crystal size and sample size [1, 5, 6, 12, 18–23]. Researchers determined that the HL values of cube samples should have a side length of at least 7 cm to eliminate the effect of the size factor, while the height/diameter ratio of core samples should be ≥1.5 [1, 20]. In studies, Çelik and Çobanoğlu [21] stated that measurement of HL value was affected by the presence of pores on the sample surface. İnce and Bozdağ [1] determined that large grains or coarse crystals within the components of rocks caused large deviations in HL values. Balcı and İnce [23] found that there was a positive linear and high correlation with HL value with the increase in the percentage of rock fragments (RF) within the composition of pyroclastic rocks. In spite of researching the effect of RFs within the composition of pyroclastic rocks on HL value, the effect of other components (matrix and pumice (P)) was not

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researched. Determining the effect of rock components on HL value is very important for creating HL standards that will be developed for rocks and in terms of the suitability and usability of this test for some rock groups.

In this study, cube samples were prepared from two pyroclastic rocks dominated by different rock components (*P* and volcanic rock fragments (VRF)). Then, the correlation between the variation in *P* and RF proportions on the surfaces of these cube samples with HL value was researched.

2 Material and method

2.1 Material

In this study, samples taken from two different regions in Turkey (Konya and Kayseri) where agglomerate levels are commonly observed were used. Rocks taken from the Kızılören region in Konya were named sample number 1 (rock-1) and rocks taken from the Şahmelik region in Kayseri were named sample number 2 (rock-2).

The macro and micro pictures of components in these pyroclastic rocks are given in Fig. 1. The macro appearance of rock-1 comprises grey matrix phase (MP) containing VRF and phenocrystals (*Pc*) (Fig. 1(a)). Thin section investigation of rock-1 found the main components were RFs, VG, plagioclase (*Pl*), amphibole (*A*) and quartz (*Q*) (Fig. 1(a) and Table 1).

According to Schmid's [24] classification of pyroclastic rocks, rock-1 was named lithic tuff (Fig. 2). The macro appearance of rock number 2 comprised light brown colored MP containing dominantly *P*, *Pc* and small amounts of RFs (Fig. 1(b)). Investigation of rock-2 with polarizing microscope found it comprised *P*, volcanic glass (VG), *Pl*, clinopyroxene (*Cp*) and RFs (Fig. 1(b) and Table 1).

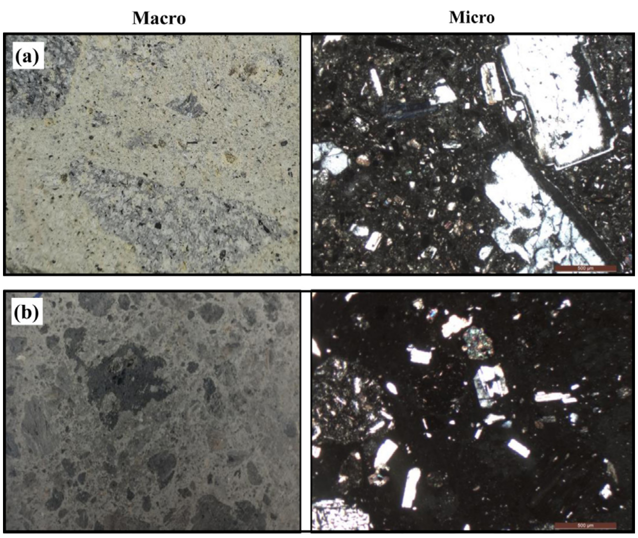

Fig. 1 Macro and micro view of pyroclastic rocks (a) rock-1, (b) rock-2

Table 1 Textural features and mineralogical composition of pyroclastic rocks

Rock properties		Sample No. 1	Sample No. 2
Macro	Color	Grey	Light brown
	Particle size	Fine-coarse grained	Fine-coarse grained
	Components	30–40% VG, 40-55% RF, 15 l–25% PC	35–55% *P*, 15–33% VG, 5% RF, 27% *Pc*
Micro	Texture	Vitrophyric porphyric	Vitrophyric porphyric
	Components	50% RF, 25% VG, 15% *Pl*, 4% *A*, 3% *Plm*, 3% *Q*	40% *P*, 27% VG, 21% *Pl*, 7% *Cp*, 5% RF

VG: volcanic glass, RF: rock fragment, *Pc*: phenocrystals, *P*: pumice, *Pl*: plagioclase, *Plm*: plagioclase microlite, *Q*: quartz, *A*: amphibole, *Cp*: clinopyroxene

According to Schmid classification [24] based on pyroclastic rock components, rock-2 was named vitric tuff (Fig. 2). Both rocks had vitrophyric porphyritic texture (Fig. 1).

2.2 Method

With the aim of determining the physico-mechanical features and HL of pyroclastic rocks, block samples with 30 cm × 30 cm × 30 cm dimensions were obtained from different locations (Kızılören-Konya and Şahmelik-Kayseri) in the Central Anatolia region. From these block samples brought to the laboratory, 6 cube samples with 7 cm × 7 cm × 7 cm dimensions were prepared for each rock group in accordance with the standards given in TS EN 1936 [25]. (Fig. 3(a)). The ρ_d and n values for the rocks were identified in accordance with the method given in TS EN 1936 [25] using these prepared cube samples. To determine the ρ_d of rocks, the volume of samples was first calculated by taking the mean of several caliper readings (Fig. 3(b)). Then the ρ_d of the rocks was determined

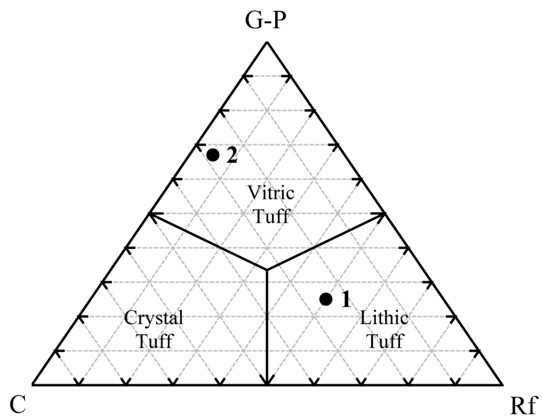

Fig. 2 Classification of pyroclastic samples according to Schmid [24]

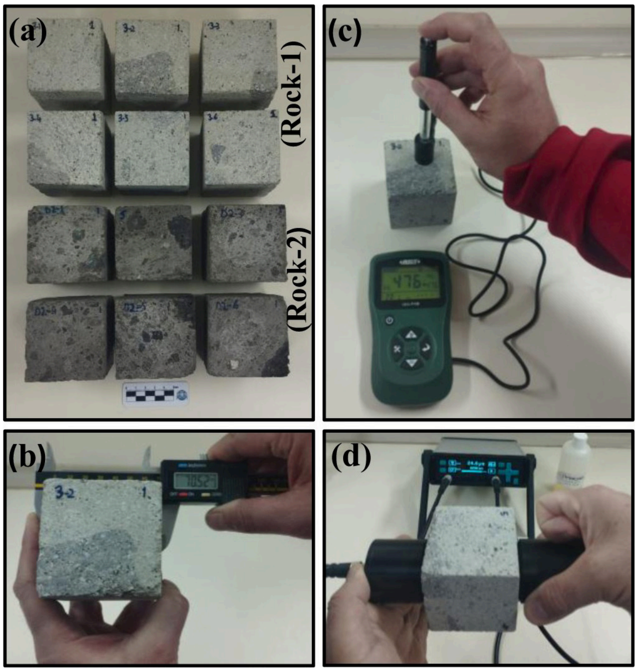

Fig. 3 Test samples and measurement of some physical properties (a) cube samples, (b) dimension measurements, (c) HL test device, (d) V_p test

using the mass per unit volume of the rock sample. The n values for the rocks were found by applying the saturation and caliper procedures [25].

Though there is a standard developed for the HL test applied to metal products (ASTM A956-06 [26]), there is no standard test method recommended for rocks. Measurement of HL values for rocks used an Insize ISH-PHB brand test device and a D-probe with 11 Nmm pulse energy. This device can perform measurements from 0 to 999 HL with ±6 HL accuracy. The device was calibrated before determining the HL value (Fig. 3(c)). For determination of the V_p of the samples, attention was paid to standards given in ASTM E494-10 [27]. The V_p of rocks was measured through direct conduction on the samples using PUNDIT, measuring the speed of propagation of ultrasonic pulses with 0.1 µs accuracy (Fig. 3(d)). For each sample, the average of measurements was taken to determine the values for physical properties of the rocks.

In this study, the approaches recommended by İnce and Bozdağ [1] and Balcı and İnce [23] were used with averages taken for values measured at 20 different points on the surface of the sample. When investigating the effect of the percentage of rock components (P and RFs) on the surface of the samples on HL values, the HL value was identified for each surface of the cube samples. When measuring the HL value for each surface of the sample, measurements were made at 20 different random points on that surface. The arithmetic mean of these measurements was taken to calculate the HL value for the surface. In this stage, measurements were performed on a total of 36 surfaces for each rock (6 cube samples × 6 surfaces).

To determine the proportion of components on the surfaces of the cube samples prepared from the rocks, high resolution images were obtained for the 6 surfaces of the cubes using a Canon EOS 450 camera. Then the total proportion of rock components (P and RF) larger than 5 mm^2 on each surface was determined. The Image Pro Plus 6.0 software [28] was used for this purpose. In this program, the areas of P and RFs were manually identified using appropriate 'smooth' and 'range' values. This process assisted in manually identifying each rock component. To be able to better observe the distribution of rock components in the investigation area, the masking procedure was applied to the images.

Then, areas of rock components on each surface of the cube samples were identified. In the final stage, the area of components was proportioned to the total rock surface. In this study, rock components with area less than 5 mm^2 were not included in the assessment.

With the aim of determining the petrographic features of the rocks used in the study, thin sections were prepared according to the method recommended in EN 12407:2019 [29] and investigated with a Leica brand DM 2700 P model polarizing microscope.

3 Results and discussion

The statistical values for n, ρ_d, V_p and HL of the pyroclastic rocks used in the study are given in Table 2. The mean values for n, ρ_d and V_p of rock-1 were 14.32%, 1.88 g/cm^3 and 3.13 km/s, respectively. For rock-2, the ρ_d was 0.99 g/cm^3,

Table 2 Physical properties and HL values of the rocks

Rock	Sample count	Statistical definition	ρ_d (g/cm^3)	n (%)	V_p (km/s)	HL*
1	6	Average	1.88	14.32	3.13	521.83
		Minimum	1.83	10.95	2.98	356.00
		Maximum	1.92	16.59	3.41	769.00
		Standard deviation	0.04	2.04	0.15	151.88
2	6	Average	0.99	39.16	1.73	208.0
		Minimum	0.89	37.10	1.62	115.0
		Maximum	1.02	40.93	1.81	328.0
		Standard deviation	0.05	1.34	0.07	75.7

ρ_d: dry density, n: porosity, V_p: P-wave velocity, HL: Leeb hardness
* It is the average of the values obtained by making 20 random measurements in each sample without paying attention to the components while performing HL test in rocks.

n 39.16% and V_p was 1.73 km/s. When the statistical values for the physical properties of the rocks are investigated, the standard deviation values appear to be high.

This situation is thought to be related to the variability of components within the rocks. For rock-1 the HL value was 521.83, and the standard deviation was 151.88, while for rock-2, the HL and standard deviation values were 208.0±75.7. The components forming the rock (MP, *P* and VRF) the main reason for the difference in HL values of the pyroclastic samples used in the study is. To better understand this relationship, the HL values for components on each surface of the samples were separately determined (Table 3). For rock-1, the HL values for MP varied from 340 to 450, with mean values of 402.15. The other component of this rock of VRF had minimum, maximum and mean values for HL of 523, 789 and 638.92.

For the *P* component in rock-2, the HL values varied from 93 to 150, while the HL values for MP was measured from 117–340. The standard deviation values for HL measured for components in the rocks are high. As stated by several researchers previously, the dimension factor is important for the HL test [1, 20, 22]. In this study, the high standard deviations for the rock components are related to the different sizes of the rock components within the cube samples. Samples from rock-1 with larger RFs had higher HL values, while smaller values were measured for smaller VRF (Table 3).

This size variation directly affects the variation in HL values for rock-1. For samples of rock-2, the situation is different, with larger *P* fragments having lower HL values, while smaller *P* fragments had larger values (Table 3). This size variation directly affected the variation in HL values for the rock. To better understand this situation, the proportional variation in rock components on the measurement surface, affecting the HL value, were determined with an image processing program (Fig. 4) and statistical data are given in Table 4.

When Table 4 is investigated, the percentage values for VRF on the cube surfaces of rock-1 varied from 3.56% to

Table 3 Statistical features of HL values measured for different components (VG, *P* and RF) comprising pyroclastic rocks

Sample No.	Rock components	Statistical definition			
		Average	Minimum	Maximum	Standard deviation
1	VG	402.15	340.00	455.00	41.66
	RF	638.92	523.00	789.00	77.30
2	VG	260.87	177.00	342.00	45.57
	P	116.18	93.00	150.00	18.29

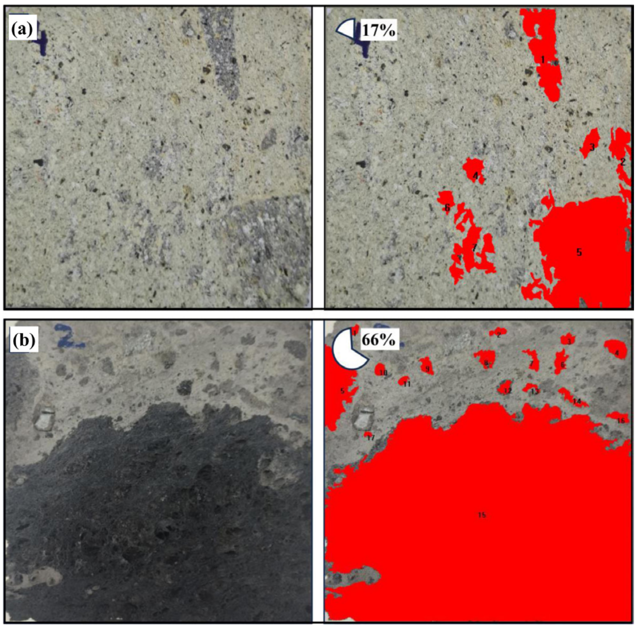

Fig. 4 Determination of percentages for rock components with an image processing program (a) for RFs in rock-1, (b) for *P* in rock-2

Table 4 Statistical features of main rock components affecting HL values on the surfaces of cube samples (VRF, *P*)

Rock No.	Rock properties	Statistical definition			
		Average	Minimum	Maximum	Standard deviation
1	RF	41.99	3.56	93.88	26.07
2	*P*	24.20	4.20	66.31	14.73

93.88%. The correlation between the HL values for rock-1 with the RF percentages on the surfaces of the cubes is shown in Fig. 5(a). When the correlation is investigated, there was an increasing linear correlation between HL with VRF and the coefficient of determination (R^2) was 0.9503. This finding is consistent with the results of Balcı and İnce [23], and a higher correlation coefficient was obtained in this study.

For rock-2, the main rock component affecting the variation in HL value was *P*. This component had minimum and maximum distribution of 4.20% and 66.31% on the cube surfaces. The HL and P correlation graph prepared for this rock is given in Fig. 5(b). When this graph is investigated, a reducing linear correlation between HL value and *P* percentage is observed. The correlation coefficient (R^2) between HL and *P* percentage is 0.9242. As understood from the two different situations in Fig. 5, the hardness of the main components comprising the rock were determinative for the HL value. Due to the small surface area where this test is applied, it is not recommended

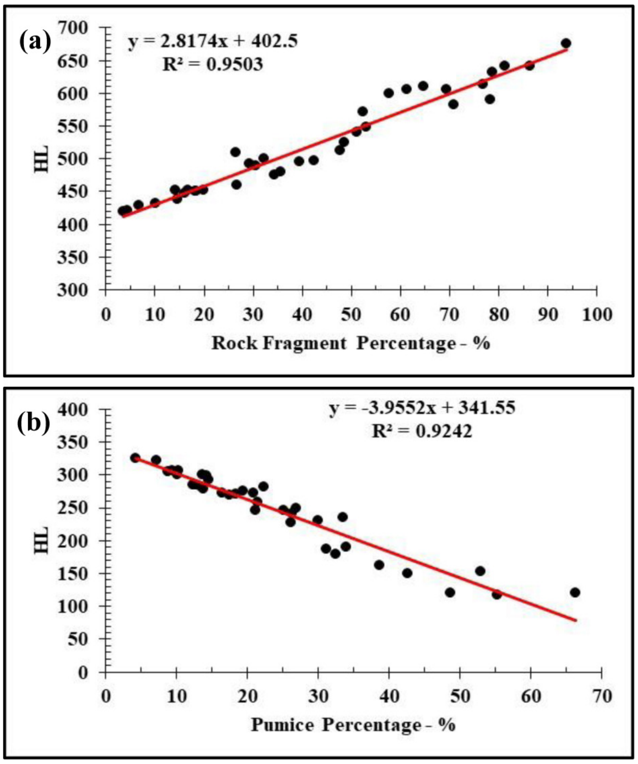

Fig. 5 Correlation of HL with percentage of rock components (a) RFs with HL, (b) *P* with HL

to apply and use this test on rocks containing components with different sizes and hardnesses.

4 Conclusions

This study aimed to determine the effect of pyroclastic rock components on HL value and the results obtained may be summarized as follows:

- The hardness of components in pyroclastic rocks (MP, *P* and VRF) directly affect the HL value.
- Harder components on the measurement surface of the rock increase the HL value, while components with low hardness reduce the HL value.
- There was an increasing linear correlation between VRF percentage on the rock surface with HL with R^2 value 0.95, while there was a reducing linear correlation between *P* percentage with HL with R^2 value of 0.92.
- The size of the components (*P* and VRF) within the rocks was another factor affecting the HL value.

The results of the study show that the HL test is not suitable for heterogeneous rocks comprised of components with different hardnesses.

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