Open Journal of Civil Engineering, 2022, 12, 463-475
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Characterization of the Physical and Mechanical Properties of the Harrat Ash Shaam Basalt (HASB)/Northeast Jordan

Khaled Tarawneh[1*], Mazen Amaireh[2], Nafeth Abdelhadi[3], Awaad Titi[1], Mohammad Dweirj[1]

[1]Mining Department, Engineering Faculty, Al Hussein Bin Talal University, Ma'an, Jordan
[2]Mining Department, Engineering Faculty, Tafila Technical University, Tafila, Jordan
[3]Civil Engineering, Faculty of Engineering Technology, Balqa Applied University, Zarqa, Jordan
Email: *khtarawneh62@yahoo.com

How to cite this paper: Tarawneh, K., Amaireh, M., Abdelhadi, N., Titi, A. and Dweirj, M. (2022) Characterization of the Physical and Mechanical Properties of the Harrat Ash Shaam Basalt (HASB)/Northeast Jordan. *Open Journal of Civil Engineering*, **12**, 463-475.
https://doi.org/10.4236/ojce.2022.124026

Received: September 30, 2022
Accepted: December 2, 2022
Published: December 5, 2022

Abstract

Due to the mass demand for excellent construction materials for infrared and super structures in Jordan, intensive field and laboratory works were carried out to determine the quality of basalt as a source for construction uses or as aggregate materials. Representative basaltic samples were collected from four quarries in Harrat Ash Shaam Basalt (HASB), northeast Jordan (Al-Azraq, Tel-Hassan, Q'a-Khanna and Al-Aritayin). Necessary and accentual quality control tests were carried out on 17 samples of basalt to determine the physical and mechanical properties of target samples, whereas petrographic and chemical analysis for some representative samples have been carried out using a polarizing microscope and X-ray fluorescence (XRF). This study aims to focus on the main engineering characteristics of the basalt rocks and to shed some light on their properties. This work represents the results of petrographic and chemical analysis, tests of abrasion, absorption, specific gravity, unit weight and void ratio, sieve analysis (gradation), soundness, flakiness and elongation indices, pulse velocity and compressive strength. Petrographic studies show that the basalt is characterized by a presence mainly of calcic-plagioclase feldspar, pyroxene-augite and olivine. The composition of the basaltic samples reflects ultrabasic-basic (Basanite-Tholeiitic basalt type). The basalt is characterized by higher specific gravity, lower absorption and medium abrasion loss values, and resistance to corrosion, with medium to high compressive strength. The results of the studied physical and mechanical properties of the basalt that have been tested comply with the standard requirements. In most of the studies, basalt has good physical and mechanical properties that can be used for engineering applications.

Keywords

Jordan, Basalt, Aggregate, Physical Properties, Mechanical Properties

1. Introduction

Basalt is a fine-grained dark basic igneous rock consisting of plagioclase feldspar, pyroxene, and olivine. Basalt makes up most of the ocean floor and is the most common type of lava. It sometimes cools into characteristic hexagonal columns. It is a very important rock that has a wide distribution in many provinces in Jordan. It is used extensively as engineering materials in rock wall industry, aggregates for cement and asphaltic concrete mixes and pavement construction, rock fill for dams and breakwaters, material for railroad ballast and highway base courses [1].

The basalt of northeast Jordan is part of a 45,000 km^2 lava plateau stretching over about 700 km in a NW-SE direction, from Syria through Jordan to Saudi Arabia. Basalt covers an area of 12,000 km^2 in HASB in northeast Jordan (**Figure 1**). The lava varies in thickness from 100 m up to 1000 m. The outcrops expose basaltic lava as well as pyroclastic materials, which contain abundant mineral xenoliths of mantle from the crustal origin [2]. The regional trend of the volcanic province is NW-SE, parallel to the local Sirhan Fault System and the Red Sea axis [3]. A series of geological and geochemical studies have been performed during

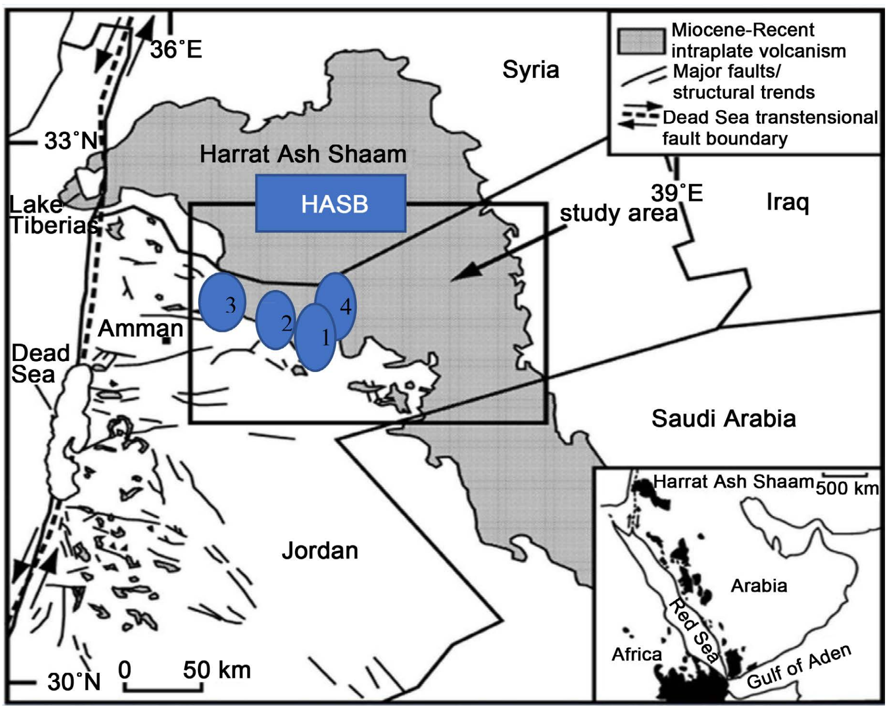

Figure 1. Simplified geological map of the HASB at northeast Jordan, showing sample sites of the study basalt (1-Al Azraq, 2-Tell Hassan; 3-Q'a Khanna; 4-Al Aritayin).

the last few years in the study area [4] [5]. Bibliographies of early work in the North Arabian Volcanic Province including the HAB can be found in many publications [6] [7] [8]. The outcrops expose aa and pahoehoe lavas as well as pyroclastics which contain abundant accidental xenoliths of mantle and crustal origin [9] [10].

[11] subdivided the basaltic flows in the northeast Jordan into five volcanic groups belonging to the HASB. These groups comprise the Wisad, Safawi, Asfar, Rimah and Bishriyya (**Figure 1**). Basaltic flows comprise the majority of the study area. The exposed basalts of northeast Jordan were considered on the geological maps produced by the Natural Resources Authority as the Harrat Ash Shaam Basaltic Super-Group (HASB).

Age dating of the basalt in northeast Jordan was carried out during the last years. Based on new K-Ar dating of the basalt [12] subdivided the HASB into three major phases. The first phase is of Oligocene age 22.0 - 26.0 Ma, the second phase is of late Miocene (12 - 8 Ma) and the third phase is mostly of Pliocene – Quaternary (6 - <0.5 Ma). Geochemical, mineralogical and petrographic studies can be found in many publications, among them [2] [6] [10] [13] [14]. The maximum recorded thickness of the basaltic succession in boreholes as recorded in the study area is about 478 m [15].

Studies on geology and some physical and mechanical properties of basalt in Jordan can be found in unpublished reports distributed by the Natural Resources Authority during the last twenty years for industrial uses such as rock wall industry, aggregates, and application of zeolite minerals for agricultural uses as fertilizers. The published studies on physical and mechanical properties of HASB basalt in northeast Jordan are very limited. The most recent studies of basalt in Jordan can be found in work of [16]. The authors studied the geo-engineering evaluation of basaltic rocks in the Harrat Irbid area. [17] studied thermo physical and mechanical properties of Al Hashimiyya Basalt in Jordan. [18] investigated the relationships between point load index and the uniaxial compressive strength for basaltic rock derived from different regions in Jordan and examinined potential relationships between basalt physical properties and ultrasonic pulse value. [19] studied the geotechnical properties of the basaltic rocks in south Jordan for engineering uses.

This research focuses with an aim to shed light on the main engineering properties of the basaltic rocks in HASB in northeast Jordan. Representative 17 basaltic samples were collected from four quarries (Al-Azraq area, Tell-Hassan, Q'a-Khanna and Al-Aritayin). The most important tests which were carried out are including petrographic and chemical analysis, abrasion, absorption, specific gravity, unit weight and void ratio, sieve analysis (gradation), soundness, flakiness and elongation indices, pulse velocity and compressive strength.

Hence, this research would help at present or in the future in other engineering projects which may use the basaltic rocks in many applications such as in rock wall industry or as aggregate materials. Besides, the basalt now plays an important role in construction materials such as building stone, tiles, or as a decorative stone in infrared and super structures in Jordan.

2. Methodology and Materials

To determine the quality of basalt, physical and mechanical tests were made on representative 17 samples of basaltic rocks that were collected from four main localities and quarries in northeast Jordan: (Al-Azraq (31˚51.930'N, 36˚49.372'E; Tell-Hassan (31˚57.160'N, 36˚54.400'E; Q'a-Khanna (32˚01.764'N, 36˚30.408'E; and Al-Aritayin, 32˚08.125'N, 36˚52.008'E) (**Figure 1**). Hand specimens were collected for preliminary field identification, petrographic examination and chemical composition. All tests of basalt were investigated in the laboratory of the Natural Resources Authority, Jordan. The conducted physical and mechanical tests on the basalt samples include petrographic and chemical analysis (XRF), abrasion test, impact and crushing value, absorption, specific gravity for coarse and fine aggregate, bulk specific gravity, unit weight and void ratio, sieve analysis (gradation), soundness, flakiness and elongation indices, pulse velocity and compressive strength. All these tests were conducted in accordance with both American Society for Testing and Materials (ASTM) [20] and International Society for Rock Mechanics (ISRM) [21]. The evaluations have been carried out by testing these samples in laboratory and comparing the results with the international standards.

3. Results and Discussion

Petrographic studies indicate that the basalt is very fine-grained rock with crypto-crystalline texture. The petrography of basaltic rocks is characterized by a presence mainly of calcic-plagioclase feldspar and pyroxene-augite. Olivine present as phenocrysts or as xenocrysts in the groundmass of the basalt, sometime is mostly altered to iddengsite due to the chemical weathering [2]. Iron oxides as magnetite and ilmenite also are present in minor amount, in addition to the presence of iron-titanium oxides and spinel (**Figure 2**).

The chemical analyses of the basalt were carried out by unit model ARL 9800 XP SIM-SEQ XRF. The results of seven representative samples of basalt rocks are summarized in **Table 1**. Chemical analysis indicates that the basalt rock is mainly composed of SiO_2 (44.65% - 48.66%), with an average of 45.85%, followed by Al_2O_3 (average 15.15%), Fe_2O_3 (average 11.92%), CaO (average 11.33%), MgO (average 8.45%), Na_2O (average 1.88%) and TiO_2 (average 1.22%), respectively. This composition reflects the basic rock quality. According to TAS classification [22], the composition of the basaltic samples reflects ultrabasic-basic (Basanite-Theoleiitic-Basalt type) (**Figure 3**).

Table 2 shows the results that have been conducted on 17 basaltic samples to measure the aggregate hardness utilizing Loss Angles abrasion test, specific gravity (Gs), absorption, crushing and impact values. The abrasion test results varies from 17% to 28%. The highest value 28% was recorded in Tell Hassan

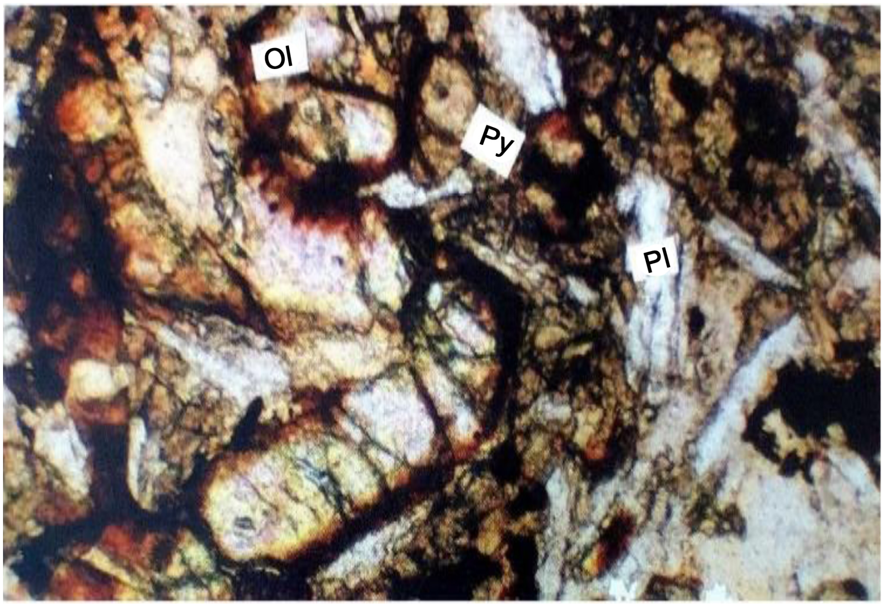

Figure 2. Photomicrograph showing olivine (Ol) xenocrysts, partly altered to iddengsite, calcic-plagioclase laths (Pl) and pyroxene (Py)-augite type.

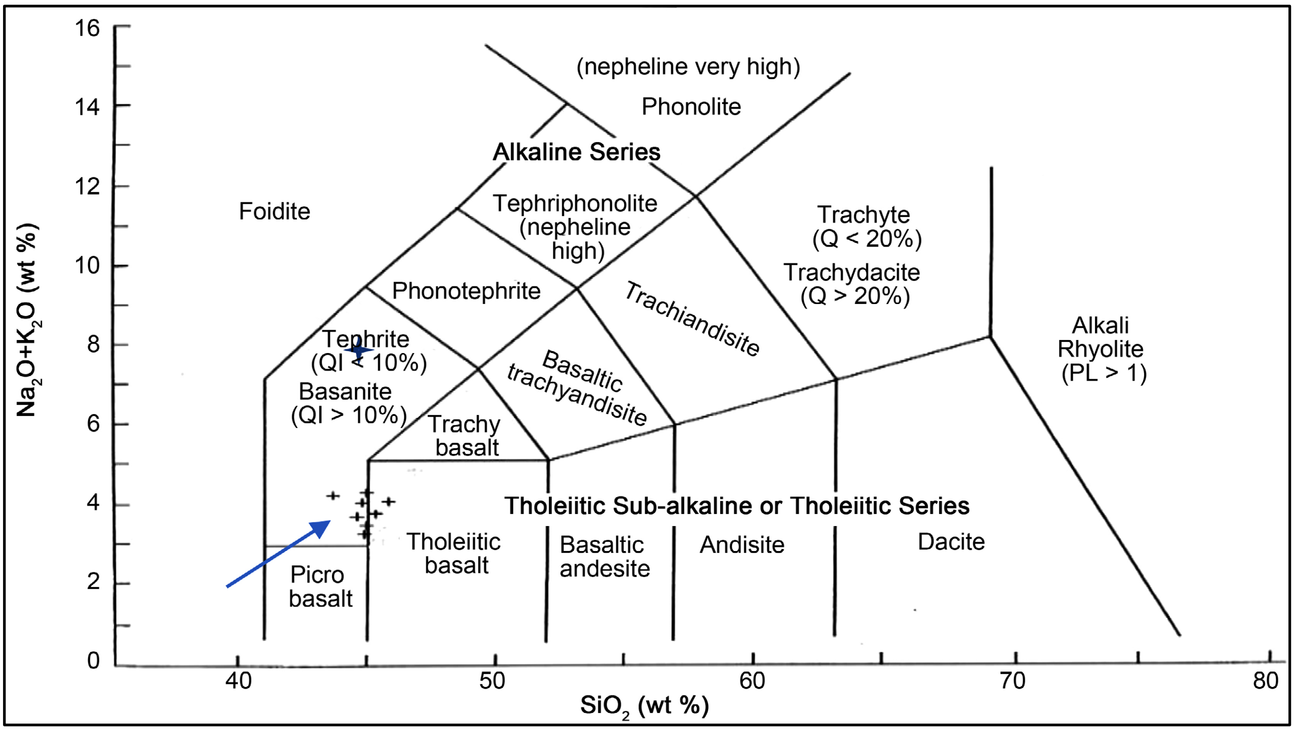

Figure 3. Classification of volcanic rocks based on the total alkali-silica diagram (TAS) [22]. The arrow shows the location of the study samples regarding the chemical test.

area, while the lowest value 17% was recorded in Qa'-Khanna area.

Gs vary from 1.59 to 2.81, with an average of 2.46. The highest value 2.81 was recorded in Qa' Khanna, while the lowest value 1.59 was recorded in Al-Aritayin area. It can be noticed that the Gs of the studied samples show a limited range of

Table 1. XRF results of the study basalt samples.

Oxide %	B1	B8	B10	B14	B15	B16	B5
K_2O	1.13	0.78	0.71	0.53	0.86	0.98	1.10
P_2O_5	0.25	0.34	0.11	0.36	0.22	0.17	0.21
SiO_2	45.19	47.22	48.66	44.65	45.18	45.19	44.86
CaO	15.34	11.44	10.36	12.31	10.08	9.86	9.93
MgO	8.12	9.05	10.25	7.50	8.09	8.54	7.64
Fe_2O_3	10.11	10.04	10.35	12.29	13.98	14.54	12.18
Al_2O_3	13.6	14.93	13.87	15.22	15.97	15.78	16.73
TiO_2	1.5	1.4	1.25	1.89	0.93	0.78	0.83
MnO	0.12	0.11	0.14	0.25	0.21	0.23	0.18
Na_2O	2.32	2.41	2.20	0.78	1.08	1.29	3.14
LOI	2.15	2.18	1.74	3.23	1.28	1.69	2.87

Table 2. Results of the abrasion test, specific gravity (Gs), absorption, crushing and impact values.

Sample No.	Abrasion (500 revolution) %	Specific Gravity (Gs)	Absorption %	Crushing value %	Impact value %
B1	39	2.56	2.53	17	15.66
B2	13	2.81	3.21	16	13.88
B3	19	2.72	2.20	18	14.11
B4	21.5	2.72	1.94	20	15.21
B5	23.16	2.72	1.80	22.90	16.33
B6	21.40	2.73	1.60	21.40	12.65
B7	29.18	1.87	2.22	18.5	15.88
B8	32.38	1.74	1.40	15.98	16.78
B9	19.64	2.73	1.60	21.72	14.21
B10	17	2.78	1.60	13.7	13.33
B11	21	2.72	1.40	14.2	17.23
B12	23	2.75	1.80	13.33	13.50
B13	33.4	1.80	1.29	22.2	14.72
B14	43.2	1.59	2.33	25.3	14.91
B15	15	2.64	3.04	21.9	13.50
B16	24	2.54	2.32	22.31	11.70
B17	26	2.33	3.56	21.43	12.23

variation and the Gs do not exceed the minimum value of basalt specific gravity (2.04 - 2.21).

Reported by [23], similar conclusion also were reported on the Gs of the basalt in Harrat Irbid Basaltic rocks Irbid [16], and is comparable with Al-Hashimiyya basalt that is reported by [17], which gives a specific gravity average of 2.59. The relationship between specific gravity (Gs) and absorption is shown in **Figure 4**.

Absorption test is used to describe the rock texture. In this study, absorption test ranges from 1.29% to 3.56%. The highest value 3.56% was recorded in Tell-Hassan area, while the lowest value 1.29 was recorded in Al-Azraq area. High values of absorption are related to the samples that are rich in cracks, voids and vesicles in their texture. Most of the basaltic samples have an absorption similar to the values of a crystalline basaltic type [23].

Crushing strength is only a compression load applied vertically on the tested samples. Crushing test helps to determine the aggregate crushing value of coarse aggregates as per IS: 2386. The crushing value ranges from 13.33% to 25.3%. The highest value 25.3% was recorded in Al-Azraq area, while the lowest value 13.33% was recorded in Al-Aritayin area.

Impact load is sudden loads, this test is normally using in road or railway works due to vehicle loads. The impact value of the studied samples ranges from 11.70% to 17.23%. The highest value 17.23% was recorded in Al-Azraq area, while the lowest value 11.75% was recorded in Al-Aritayin area. The relationship between impact value and Los Angeles Abrasion Value (LAAV) shown in **Figure 5**. It can be noticed a positive correlation between these values. The European standards (EN) state the maximum allowable value is 35%. Therefore, the studied samples have shown good quality in terms of LAAV test results (<35%, EN 12,620).

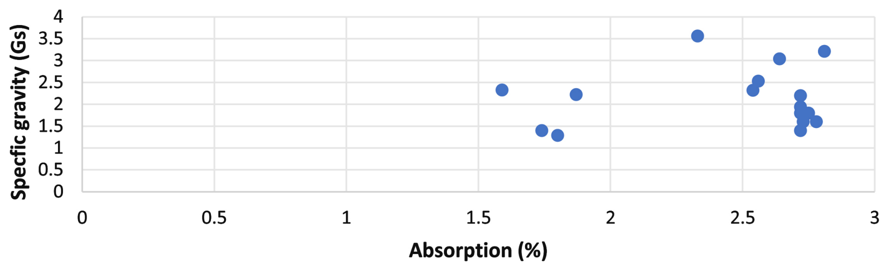

Figure 4. The relationship between specific gravity (Gs) and absorption.

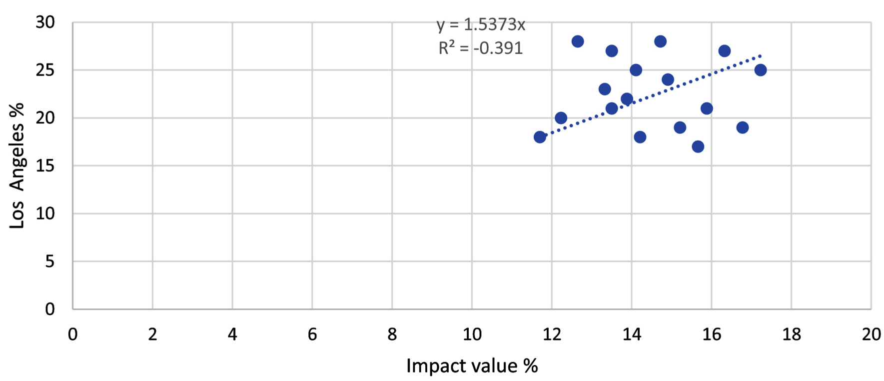

Figure 5. The relationship between impact value and Los Angeles abrasion value.

The results of porosity and void ratio of 17 selected samples from four locations are shown in **Table 3**. The porosity ranges from 0.041 (Al-Azraq area) to 5.95 (Tell-Hassan area). The void ratio is range between 0.011 and 0.091. The high values of porosity and void ratio are related to the type of basaltic materials and degree of weathering. Generally, scoria materials have high values than the dense basalt as was noticed from the tests. This due to presence of pore spaces (voids, vesicles and cracks) in the matrix of the volcanic-clastic materials, which are very dominant. Dense basalt and well crystalline textures show low porosity and low void ratio. This support the idea of [23] that such type of basalt can be considered as crystalline basalt and matching with this value range. Regarding [24], the porosity of scoria and tuff can be reach up to 41%, while in basalt reach up to 17%.

The results of Ultrasonic velocity technique are shown in **Table 4**. The pulse velocity for core m/sec ranges between 3333 m/s (Tell Hassan) to 5323 m/s (Al-Azraq. According to the IAEG, the basalt samples can be classified as high ultrasonic wave velocity of class 4. [17] reported the ultrasonic wave velocity in Al-Hashimiyya basalt as 5067 m/s, which is slightly less than those of Harrat Ash Shaam basalt, with averages about 4308 m/s. This is due to the weak texture of

Table 3. Results of the porosity and void ratio.

Sample No.	Porosity %	Void ratio %
B1	5.95	0.091
B2	1.02	0.021
B3	1.02	0.032
B4	0.98	0.011
B5	1.14	0.022
B6	1.20	0.025
B7	1.05	0.033
B8	0.88	0.034
B9	1.22	0.044
B10	1.02	0.043
A11	0.98	0.021
B12	0.78	0.048
B13	0.41	0.04
B14	3.56	0.045
B15	4.55	0.065
B16	3.22	0.044
B17	3.55	0.087

the volcanic clastic materials and presence of internal micro cracks, which support the idea that the ultrasonic traveling velocities are high in homogenous rock masses with good mechanical properties and can be used to identify the quality of the rock structure [25]. This is consistent with the ultrasonic test results from northeast Jordan (HASB) rocks, which have a high quality and desirable properties due to the moderate to high density and well crystalline structure.

In this study, soundness test utilizing sodium sulphate (Na_2SO_4) was used. All the samples have shown very good results ranging from 3% to 3.2% with an average of 2.78. These results are quite good according to the ASTM C 88 - 99 [26] and BS 812 specifications (<10%) [27].

Flakiness and elongation indices are generally considered to be an inherent property of the rock itself, depending mainly upon its mineralogy, texture and structure; and partly on the crushing methodology/techniques [28]. Flakiness index is determined by separating the flaky particles by using a metal thickness gauge (BS 812: Part 105.1) [29]. The flakiness index varies from 12.30 (Al-Azraq) to 23.52% (Al-Arityain), with an average of 17.91% (**Table 5**). The elongation index varies from 5.9% (Q'a-Khanna) to 22.83% (Al-Arityain), with an average of 14.36%. The flakiness and elongation indexes of the tested basaltic samples comply the BS 812: Part 105.2-specifications and can be used for concrete aggregate <25% (BS 812: Part 105.1) [29].

The results of compressive strength for 17 basalt samples are presented in **Table 6**. Unconfined compressive strength (UCS) ranges from 109.3 to 145.1 MPa. The lose Angeles abrasion value range between 17% and 28%. Regarding [30], the compressive strength basalt can be varies from 100 to 300 MPa. Using the classification system proposed by [31], the examined basalt rocks can be considered as a (C-B) classification having a medium to high strength rock.

Table 4. Results of ultrasonic pulse velocity.

Location	Pulse velocity for core m/sec
Tell-Hassan	3334
Q'a-khanna	5012
Al-Aritayin	3564
Al-Azraq	5323

Table 5. Results of elongation index and flakiness index tests %.

Location	Q'a-Khanna	Al-Azraq	Tell-Hassan	Al-Aritayin	Rock wall quarry
Sample No	B4	B5	B7	B13	B16
Elongation %	5.9	14.5	11.09	22.83	17.3
Flakiness %	19.5	12.5	22.59	23.52	23.7

Table 6. Unconfined compressive strength of basalt samples.

Sample No	Unconfined compressive strength (MPa)	Los Angeles Abrasion Value (%)
B1	109.3	17
B2	115.6	22
B3	135.5	25
B4	122.4	19
B5	124.7	27
B6	112.5	28
B7	137.4	21
B8	118.8	19
B9	120.6	18
B10	127.1	23
B11	137.0	25
B12	135.2	27
B13	142.6	28
B14	145.1	24
B15	143.7	21
B16	115.0	18
B17	124.2	20

4. Conclusions and Recommendations

The use of basalt and its aggregate in civil structures and industrial applications depends upon the physical and mechanical properties that will be consistent with the quality products to the customer standard requirements, and should satisfy the standard requirements for engineering purposes. Basaltic rocks and basalt that aggregates from HASB in northeast Jordan area are widely distributed and covered a huge area with unlimited reserves. The most important mining method for exploitation of the basalt is quarrying. Several quarries are used for extraction and exploitation of the basalt and aggregates. Petrographic studies show that the basalt is characterized by a presence mainly of calcic-plagioclase feldspar, pyroxene-augite and olivine. The composition of the basaltic samples reflects ultrabasic-basic (Basanite-Tholeiitic-Basalt type).

Basalt is used as blocks or as fine-coarse aggregates in many applications in Jordan (rock wall industry, decoration stones, pavement, roads, asphaltic concrete mix, etc). This is due to the quality of the study basalt to be used as aggregates that are characterized by higher specific gravity, lower absorption and good abrasion loss values, resistance to corrosion, and medium to high compressive strength. Most of the studied physical and mechanical properties of the basalt have been tested to comply with the standard requirements. In most of the studies, basalt has good physical and mechanical properties that can be used for engineering applications.

Further studies should be focused on selected areas that will be recommended for producing the basalt and aggregates depending on the type of application in building as decoration, rock wall industry, pavement, decoration and asphalt concrete mix. This needs further studies that help the investors and engineers to select the suitable materials that will be directly applied and used.

Acknowledgements

The authors would like to thank all staff at the laboratory of the Natural Resources Authority. The authors also would like to thank anonymous reviewers for valuable comments and suggestions to improve the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Goodman, R.E. (1993) Rock in Engineering Construction, Engineering Geology. Wiley, New York.

[2] Tarawneh, K. (2020) Mineralogical Studies on Some Selected Semi-Precious Stones from Different Localities at Northeast Jordan. *Natural Resources Journal*, **11**, 168-183. https://doi.org/10.4236/nr.2020.114011

[3] Camp, V. and Roobol, M. (1992) Upwelling Asthenosphere beneath Western Arabia and Its Regional Implications. *Journal of Geophysical Research*, **97**, 15255-15271. https://doi.org/10.1029/92JB00943

[4] Tarawneh, K. (1999) The Geology of the Al Hamiddiya Area (Al Hababiyya Area). Bulletin No. 35, NRA, Amman.

[5] Tarawneh, K. (1999) The Geology of the Wadi El Abid Area. Bulletin No. 44, NRA, Amman.

[6] Tarawneh, K., Ibrahim, K. and Rabba, I. (2002) Petrography, Geochemistry and K-Ar Geochronology of the Dike Systems (NW-SE) of the Harrat Ash Shaam in Northeast Jordan. *Mu'tah Lil-Buhuth wad-Dirasat*, **17**, 69-87.

[7] Shimon, I., Harlavan, Y., Tarawneh, K., *et al.* (2001) New K-Ar Ages of Basalts from the Harrat Ash Shaam Volcanic Field in Jordan: Implications for the Span and Duration of the Upper-Mantle Upwelling beneath the Western Arabian Plate. *Geology*, **29**, 171-174. https://doi.org/10.1130/0091-7613(2001)029<0171:NKAAOB>2.0.CO;2

[8] Guba, I. and Mustafa, H. (1988) Structural Control of Young Basaltic Fissure Eruption in the Plateau Basalt Area of the Arabian Plate, Northeastern Jordan. *Journal of Volcanology and Geothermal Research*, **35**, 319-334. https://doi.org/10.1016/0377-0273(88)90026-1

[9] Ibrahim, K., Rabba, I. and Tarawneh, K. (2000) Geology and Mineral Occurrences Map of the Harrat Ash Shaam/NE Jordan Scale 1:250,000. NRA, Amman.

[10] Ibrahim, K.M., Shaw, J., Baker, J., Khoury, H., Rabba, I. and Tarawneh, K. (2006)

Pliocene-Pleistocene Volcanism in Northwestern Arabian Plate (Jordan): I. Geology and Geochemistry of the Asfar Volcanic Group. *Neues Jahrbuch für Geologie und Paläontologie*, **242**, 145-170. https://doi.org/10.1127/njgpa/242/2006/145

[11] Ibrahim, K. (1993) The Geological Framework for the Harrat Ash Shaam Basaltic Super Group and Its Volcano Tectonic Evolution. Natural Resources Authority, Geo-Logical Division, Bulletin 25, Amman.

[12] Tarawneh, K., Shimon, I., Harlavan, Y., *et al*. (2000) Dating of the Harrat Ash Shaam Basalts Northeast Jordan: Phase 1. Geological Survey of Israel and the Natural Resources Authority of Jordan.

[13] Ibrahim, K., Tarawneh, K. and Rabba, I. (2003) Phases of Activity and Geochemistry of Basaltic Dike Systems in Northeast Jordan Parallel to the Red Sea. *Journal of Asian Earth Science*, **21**, 467-472. https://doi.org/10.1016/S1367-9120(02)00075-5

[14] Al-Malabeh, A. (1993) The Volcanology, Mineralogy and Geochemistry of Selected Pyroclastic Cones from NE-Jordan and Their Evolution for Possible Industrial Applications. PhD Thesis, Erlangen University, Erlangen.

[15] Tarawneh, K. (2003) Geological Map of Wadi Al Jathum and Q'a El Abed Area. Map Sheet No. 3455-III, Scale 1:50,000, NRA, Amman.

[16] Abu-Mahfouz, I., Al-Malabeh, A. and Rababeh, S. (2016) Geoengineering Evaluation of Harrat Irbid Basaltic Rocks, Irbid District—North Jordan. *Arab Journal of Geoscience*, **9**, 28-40. https://doi.org/10.1007/s12517-016-2428-4

[17] Al-Zyoud, S. (2019) Thermo-Physical and Mechanical Properties of Al Hashimiyya Basaltic Rocks, Jordan. *International Journal of Geosciences*, **10**, 193-208. https://doi.org/10.4236/ijg.2019.102012

[18] Sharo, A. and Al Tawaha, M. (2019) Prediction of Engineering Properties of Basaltic Rocks in Jordan. *International Journal of Civil Engineering and Technology*, **10**, 1731-1739. https://doi.org/10.15866/irece.v10i3.17767

[19] Sharadqah, S., Al Dwairi, R.A., Amaireh, M., *et al*. (2020) Geotechnical Evaluation of South Jordan Basaltic Rocks for Engineering Uses. *Jordan Journal of Earth and Environmental Sciences*, **11**, 253-259.

[20] ASTM (American Society for Testing and Materials) (1989) Soils and Rocks (1, 2)-D 4543-85. Annual Book of ASTM Standards, Philadelphia.

[21] ISRM (1994) Suggested Methods for Rock Characterization Testing and Monitoring ISRM Commission on Testing Methods, E. T. Brown Edition. Pergamon Press Oxford 211p. 1981. ASTM. Annual Book of ASTM Standard Construction Soil and Rocks. *ASTM Publication*, **4**, 975.

[22] Le Maitre, R., Bateman, P., Dudek, A. and Keller (1989) A Classification of Igneous Rocks and Glossary of Terms. Blackwell Scientific Publication, London, 193 p.

[23] Jumikis, A.R. (1983) Rock Mechanics. 2nd Edition, Trans Tech Publications, 37-40.

[24] Morris, D.A. and Johnson, A.I. (1967) Summary of Hydrologic and Physical Properties of Rock and Soil Materials, as Analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, 1948-1960. USGS Water Supply Paper 1839-D. https://doi.org/10.3133/70197603

[25] Onur, A.H., Bakraç, S. and Karakus, D. (2012) Ultrasonic Waves in Mining Application. In: Santos Jr., A., Ed., Ultrasonic Waves.

[26] ASTM C 88-99. Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate. Annual Book of ASTM Standards.

[27] BS 812: Part 105.2 (1989) Determination of Aggregate Particle Shape (Elongation

Index). British Standards Institution, London.

[28] Engidasew, T.A. (2013) Engineering Geological Characterization of Volcanic Rocks of Ethiopian and Sardinian Highlands to Be Used as Construction Materials. PhD Thesis, Università degli Studi di Cagliari, Cagliari. (unpublished)

[29] BS 812: Part 105.1 (1989) Determination of Aggregate Particle Shape (Flakiness Index). British Standards Institution, London.

[30] Attewell, P.B. and Farmer, I.W. (1976) Principles of Engineering Geology. Chapman and Hall, London. https://doi.org/10.1007/978-94-009-5707-7

[31] Deere, D. and Miller, R. (1966) Engineering Classification and Index Properties of Intact Rock. Tech Report No. AFWL-Tr-65-116, USAF Weapons Lab, Kirtland Air Force Base.