JJEES

JJEES (2020) 11 (4): 253-259
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

Geotechnical Evaluation of South Jordan Basaltic Rocks for Engineering Uses

Suhail Sharadqah[1], Reyad A. Al Dwairi[1*], Mazen Amaireh[1], Hani Nawafleh[2], Omar Khashman[3], Aiman E. Al-Rawajfeh[1],Soraya M. Perez[1]

[1]Tafila Technical University, Faculty of Engineering, Natural Resources and Chemical Engineering Department, Jordan.
[2]Al-Hussein Bin Talal University, Faculty of Engineering, Mining and Minerals Engineering Department, Ma'an, Jordan.
[3]Al-Hussein Bin Talal University, Faculty of Engineering, Environmental Engineering Department, Ma'an, Jordan.

Received 30 July 2019; Accepted 26 May 2020

Abstract

Jordanian basaltic rocks (JB) are highly distributed and available in huge quantities in northeastern, central, and southern Jordan. The objective of this study is to determine the geotechnical properties and those relevant to engineering of JB from southern Jordan, which is related to the Tertiary- Quaternary continental basaltic flows and to conduct a comparison of the results with the standard specifications. Ten random samples of southern Jordan basalt (SJB), were collected representing ten locations.

The laboratory investigation included measurements of point load strength, splitting tensile strength (MPa), Los Angeles, abrasion value (%), slake durability, abrasion, porosity, and saturation degree. In addition, the chemical and mineralogical composition of the basalt was identified utilizing X-ray fluorescence (XRF), and X Ray Diffraction respectively.

The X- Rays show that the studied basalt is mainly composed of clinopyroxene, plagioclase and feldspar; also, olivine is available in significant amounts. Iron oxides (magnetite and ilmenite), iron-titanium oxides (Titanium-augite, sphene) and spinel are present in relatively minor amounts

In terms of the SiO_2 contents, the samples from the SJB range from about 41.08% to 46.2%, while the Al_2O_3% values range from about 11.95% to 14.25%. The Fe_2O_3% values range from 2.3% to 5.22 % and FeO% from about 0.12 % to 0.16 %. MnO% values range from 0.12 % to 0.16%, MgO% from 8.71 % to 10.1%, CaO%, from 9.95 % to 12.05%, Na_2O% from 2.18% to 3.9%, K_2O% from 0.1% to 1.16%, and TiO_2% from 2.35 % to 2.9%. In general, SiO_2 contents are relatively low (< 50%); accordingly, the potential for alkali silica reaction (ASR) is very low.

The results of properties related to engineering indicate that SJB has compressive strength values ranging from 96 to 154 Mpa. Los Angles Abrasion ranges between 3.68% and 4.85%, and splitting tensile strength (MPa) is between 2.345 and 3.291 Mpa. Slake durability (Id1) ranges between 99.14 and 99.42, while slake durability (Id2) falls between (99.05 and 99.34).. The rest of the results were as follows: Voids (0.0112 to 0.029); porosity (1.11 to 2.82)%; water content% (0.16- 0.34)%; saturation % (28 to 55)%, while average dry specific gravity was 2.82.

The results show that the basalt of the southern Jordan area (SJB) complies with the international standards, and the standards used for classifying the decorative and building stones. Therefore, this study recommends the use of SJB as a promising raw material to produce building aggregates.

Keywords: Basalt, South Jordan, Geotechnical, Building stones, Engineering properties.

1. Introduction

Basalt is one of the most common igneous rocks in the world. It is a crystalline basic igneous volcanic black rock which is sometimes glassy. Basalt is widespread in seafloor crust, oceanic islands, continental volcanoes, and flood plateau lavas. It is primarily recognized by its dark color. Mineralogically, it is composed of the following main primary rock forming minerals: Plagioclase, Feldspar, Pyroxene, and Olivine.

Basalt-based materials are environmentally friendly and not hazardous and can be utilized in many industrial applications. The applications are based on the basic quality properties such as high abrasion resistance, compressive strength, and chemical resistance.

Basaltic rocks are used extensively as engineering materials including aggregates for Portland cement concrete and asphaltic concrete, and rock fill for dams and breakwaters. It can be utilized also as material for railroad ballast and highway base courses (Goodman, 1993).

The main objective of the present study is to assess the general suitability of the basalt as a coarse aggregate for concrete mixes and/or as a cut stone for industrial uses.

The quality properties of the basaltic rocks vary from

* Corresponding author e-mail: reyadn@hotmail.com

place to another depending on their origin and weathering state and more significantly on the geological occurrence.

The basaltic rocks in Jordan (JB) are distributed in three main regions based on their mode of occurrence: NE-Jordanian, within the Jordan rift and in central Jordan (Bender, 1974; Al Malabeh, 1993). The age of JB is mainly of Tertiary-Quaternary (Bender, 1974).

During Cenozoic times, basaltic lava poured from vertical fissures and local vents along the Jordan rift, and mountain ridges in central and northeastern Jordan (Fediuk and Al-Fugha, 1999).

Al Dwairi (2007) studied the zeolites associated with these eruptions and classified them into three areas: North east, Central and south Jordan. South Jordan basalt (SJB) is located within the basaltic eruptions along the arched eastern rim of Jordan graben south of Jordan (Bender, 1974). The south Jordan volcanic eruptions belong to volcanic eruptions in northeastern Jordan (Harrat Ash Shaam) (Ibrahim, 1987 and Ibrahim et al., 2003). In southern Jordan, the basaltic rocks are distributed as isolated eruptions associated with volcanic cones. Basalt in southern Jordan is found representatively in ten areas, the most important are Tell Burma, Jabel uneiza and wadi Hisa (MEMR, 2015).

The SJB eruptions occur either as local flows or as individual volcanic bodies, i.e. cones, plugs, sills, and dikes (MEMR, 2015). The studied area is located within the Tafila District as isolated basalt effusions, tectonically controlled by the Arabian plate movement, which moved northwards along the Dead Sea Transform fault (Barberi et al., 1979).

Many researches dealt with basalt frequently focusing on the geneses, geology, mineralogy, petrology, and the distribution of basalts flows in Jordan (Bender, 1974; Ibrahiem, 1987; Al-Malabeh, 1993; Al Dwairi and Shardqah, 2014; Al Dwairi, 2019). Also, many researches rendered special care to the natural zeolite which is normally related to basaltic eruptions in Jordan (Al Dwairi, 2007; Al Dwairi, 2009; Al Dwairi, et al., 2009; Sharadqah and Al Dwairi, 2010; Al Dwairi and Al-Rawajfeh, 2012; Al Dwairi et al., 2014; Al Dwairi et al., 2015; Khoury et al., 2015; Al Dwairi, 2017). However, only little work and few studies have paid attention to the engineering and geotechnical characteristics of Jordanian basalts (Abu-Mahfouz et al., 2016; Al Dwairi et al., 2018).

This research deals with the investigation of the engineering and geotechnical properties of SJB which will be evaluated to determine their engineering applications. Therefore, this study was carried out to investigate and evaluate the main physical and mechanical properties of south Jordan basalt and its suitability as a construction material.

2. Study Area

The study area is located in southern Jordan, and included ten locations as presented by the geological map in Figure 1

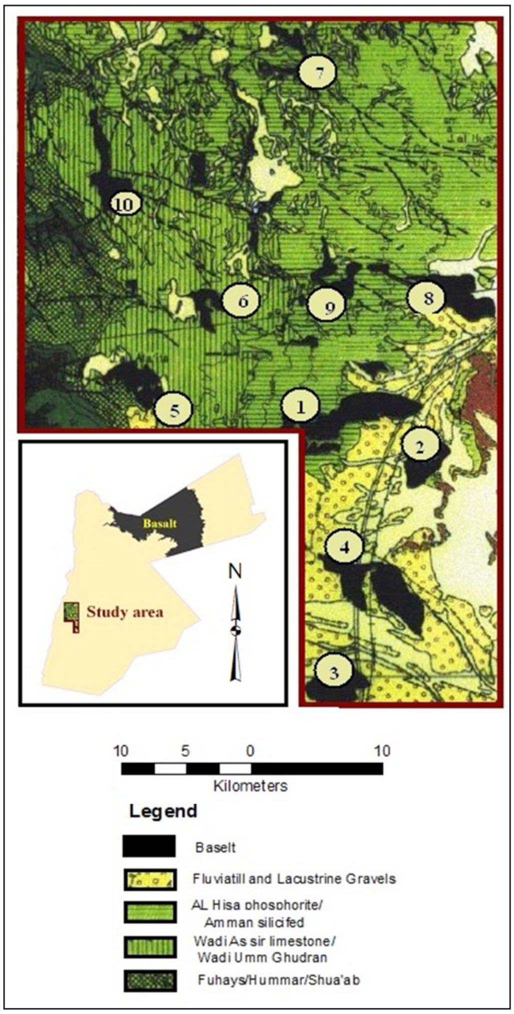

Figure 1. Location map of the southern Jordan basaltic tuff (moderfied after Mehyar and Madanat, 2015).

3. Materials and Methods

3.1. Material Source

To carry out the research, ten basaltic samples were selected from southern Jordan. From each selected site, more than 100kg fresh bulk samples have been collected; the coordinates of the sampling sites are given by Table 1.

Table 1. Coordinates of the sampling sites.

Sample #	Location	Sample Name	Longitude(N)	Latitude(E)	Elevation(m)
1	Tall Juhira	SJB 1	30° 38’47”	35°49’37”	1355
2	Tall Burma	SJB 2	30° 37’23”	35°49’43”	1077
3	Uneiza	SJB 3	30°29’42”	35°47’30”	1144
4	Tall Amir	SJB 4	30°33’05”	35°47’58”	1049
5	Al Taata	SJB 5	30°42’34”	35°42’03”	1462
6	Al Harer	SJB 6	30°52’09”	35° 41’56”	1579
7	Al Alia	SJB 7	30°55’09”	35°48’ 19”	1058
8	Jurf El Daraweesh	SJB 8	30°42’16”	35°53’09”	1281
9	Huliat El Gran	SJB 9	30° 43’07”	35° 53’34”	1336
10	Al Hala 1	SJB 10	30° 46’19”	35° 38’33”	1525

3.2. Methods and Tests

The suitability for usage as materials for engineering purposes depends principally on the physical and mechanical properties of the basalt; although for some applications, mineralogical or chemical properties are also required. The British Geological Survey, 1994. The American Society for Testing and Materials (ASTM), and the International Society of Rock Mechanics (ISRM), have devised a wide range of tests to assess materials and their value and potential and performance. These properties include specific gravity, density, water content, void ratio, absorption, degree of saturation, Los Angeles Abrasion, slake durability indices, point load index, and ultrasonic velocity. Following is a brief description of some of these properties tested in this study.

The mineralogy of basaltic rocks (SJB), was identified using X Ray Diffraction according to Al Dwairi, 2007, while the chemical composition of SJB was determined using X - Ray Fluorescence (XRF) available at the laboratory of the Mining Engineering Department, at Al-Hussin Bin Talal University (Jordan).

The physical characteristics of basaltic rocks (SJB) were determined in the laboratory. The rock specimens were prepared from rock block samples collected from the investigated representative sites.

The mechanical characteristics include Point load test (PLT), splitting tensile strength, the Los Angeles Abrasion Test. Slake Durability tests were also carried out according to the ASTM or AASHTO standards.

The physical characteristics of SJB, including Void ratio (e), porosity (n), water content, and water saturation, were evaluated utilizing ISRM, X.1979, Specific Gravity ASTM D 854, and Bulk Density Crawford, 2013.

The porosity (n) is defined as the proportion of void volume to total volume (equ. 1), and the void ratio (e) is the proportion of void volume related to that of solid volume (equ. 2). Porosity and void ratios were evaluated by estimating the bulk dry density and the specific gravity of the ground material. The saturation degree refers to the proportion of pores filled by water according to equation 3. The unit weight values are given by equation 4.

$$\textbf{Porosity } (n) = \frac{Vp}{Vt} \quad \textit{Equation 1}$$

Where:

Vp: is the volume of space

Vt: is the total volume

$$\textbf{VoidRario}(e) = \frac{Vp}{Vs} \quad \text{Equation 2}$$

Where:

Vp: is the volume of space

Vs: is the volume of solids

$$\textbf{Sturation Degree } (S) = \frac{Vw}{Vv} X\ 100\% \quad \textit{Equation 3}$$

Where:

Vw: is the volume of water

Vv: is the volume of voids

$$\gamma\ dry = \frac{\gamma\ wet}{1+w} \quad \textit{Equation 4}$$

Where:

γ: is the unit weight

w: is the water content in the rock sample (dry weight bases)

Point Load Test (Is50):

To determine the mechanical strength of the rock, a point-load strength test was performed according to the recommendations of the ASTM D5731 – 16, for blocks of irregular geometry. The value for Is (50) (Point load strength index for 50 mm diameter core) is determined with the equivalent core diameter of the specimens. Early studies (Broch and Franklin, 1972), and Miller, 1965, were conducted on hard strong rocks, and found that the relationship between UCS and the point load strength could be expressed as follows.

$$USC = K(\ Is50) = 24.5\ (\ Is50) \quad \textbf{Equation 5}$$

Where:

UCS: Unconfined Compressive Strength (Mpa)

K: conversion factor

Is50: point load strength corrected to a diameter of 50mm

A recent study by Sharo and Tawaha, 2019 conducted on thirty samples of Jordan basalt investigated the relationship between the uniaxial compressive strength (UCS) and the point load index (PLI, indicated for K= 23.52

$$UCS = 23.52\ (Is\ 50) \quad \textbf{Equation 6}$$

In general, the results agreed well with earlier studies. The obtained measurements of (Is 50), were converted to UCS utilizing equation 5.

Splitting Tensile Test was conducted according to ASTM D3967-016, by extracted core samples, 50 mm diameter and 25mm length. The splitting tensile strength (σt) of each sample was calculated by equation 7 for each sample.

$$\delta t = \frac{2P}{\pi LD} \textbf{Equation 7}$$

Where:

σt = splitting tensile strength, MPa

P = maximum applied load indicated by the testing machine in

L = length of the core sample, in (mm)

D = Sample diameter in (mm)

Slake Durability Test (SDT): the test was performed in accordance with ASTM D4644; two cycle testes have been elaborated; each for ten minutes and at a speed of thirty revolutions/minute in a water bath. The percentage of dry mass, which remained in the drum of the original mass after one cycle, is reported as Id1, and the percentage of dry mass, which remained in the drum after two cycles, is reported as Id2.

Los Angeles Abrasion test: the test was carried out according to AASHTO 96 T. For each basaltic source, the samples were prepared for A- grade, while considering the sample weight of 5kg. The prepared samples were subjected to 500 hundred revolutions at a speed of 30 revolutions/minute. The reported value of Los Angles Abrasion is the result of equation 8.

$$Av = \frac{m1-m2}{m1x100\%} \textbf{Equation 8}$$

Where:

Av: is Abrasion Value

m1: original sample mass (g)

m2: final sample mass (g)

4. Materials and Methods

4.1. Mineralogical and Chemical Composition

The mineralogical investigation indicates that the studied basaltic rocks were mainly composed of clinopyroxene, plagioclase and feldspar; also, olivine is available in significant amounts. Iron oxides (magnetite and ilmenite), iron-titanium oxides (Titanium-augite, sphene) and spinel were present in relatively minor amounts as indicated in the XRD results (Figure 2).

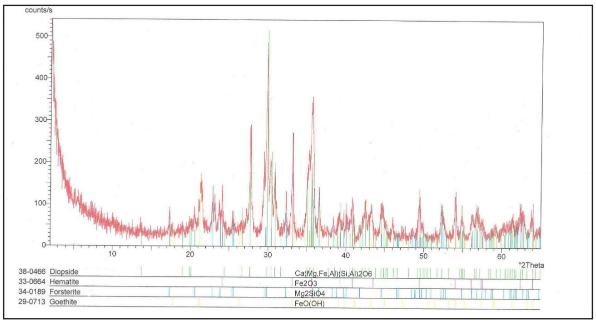

Figure 2. X ray diffraction pattern example for SJB.

The mineralogical investigation indicates that the studied basaltic rocks were mainly composed of clinopyroxene, plagioclase and feldspar; also, olivine is available in significant amounts. Iron oxides (magnetite and ilmenite), iron-titanium oxides (Titanium-augite, sphene) and spinel were present in relatively minor amounts as indicated in the XRD results (Figure 2).

Table 2. Chemical composition of the samples from SJB

Sample Name	SiO_2%	Al_2O_3%	Fe_2O_3%	FeO%	MnO%	MgO%	CaO%	Na_2O%	K_2O%	TiO2%
SJB 1	43.5	13.98	3.50	7.67	0.13	8.75	10.30	2.75	0.98	2.40
SJB 2	44.15	14.25	4.10	8.34	0.14	8.90	9.95	2.60	1.08	2.57
SJB 3	42.35	13.70	2.30	9.20	0.12	8.71	10.60	3.10	0.95	2.90
SJB 4	42.80	14.00	5.22	8.50	0.16	9.21	11.53	2.30	0.90	2.60
SJB 5	45.20	13.01	3.89	7.98	0.15	10.10	10.50	3.20	1.15	2.75
SJB 6	41.08	13.00	3.20	8.20	0.15	9.57	11.09	2.18	0.85	2.58
SJB 7	42.07	14.15	4.60	6.85	0.14	8.90	11.90	3.50	1.05	2.59
SJB 8	43.61	11.95	4.00	6.95	0.15	8.95	12.05	3.90	1.16	2.35
SJB 9	41.24	12.77	3.80	7.23	0.14	9.21	11.80	2.90	0.96	2.45
SJB 10	46.20	13.77	4.45	8.45	0.14	9.05	10.87	2.85	0.10	2.40
Average (%)	43.22	13.458	3.906	7.937	0.142	9.135	11.059	2.928	0.918	2.559

According to Le Bas et al. (1986), diagram (Figure 3), the composition of the samples reflects Ultra Basic – Basic (Basanite and Basalt)

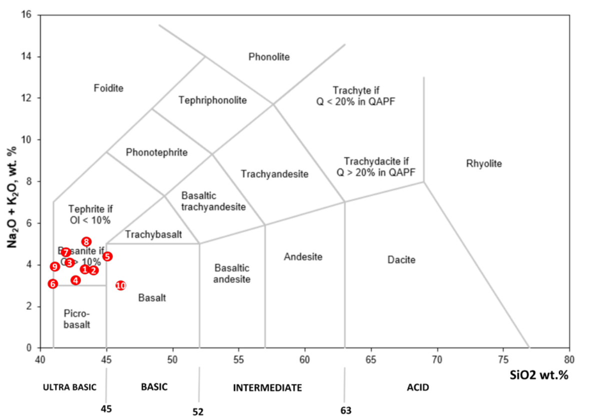

Figure 3. Classification of the Basalt according to Le Bas et al. (1986).

Katayama et al. (1989) pointed out that where the silica content of bulk composition exceeds 50%, basalt may have a potential for alkali silica reaction (ASR). According to the chemical analysis, all the samples have less than 50% SiO_2; accordingly, their potential for alkali silica reaction (ASR) is very low.

4.2. Geotechnical Characteristics

The results of geotechnical properties of the collected samples are listed in Table 3. The values reported in the tables are the averages of several replicate tests, compressive strength values

Unconfined compressive strength (UCS) ranges from 96 to 154 Mpa, with an average of 125.6 Mpa, Using the classification system proposed by Deere and Miller (1966), the examined basalt rocks of the studied areas can be considered as a (C) classification having a medium strength rock (55-110) Mpa.

Slake Durability was reported after the first cycle (Id1) between 99.14 and 99.42, and for the second cycle (Id2) between (99.05 and 99.34). Following Gamble (1971), the classification index for durability after the first cycle (Id1) was more than 99 % and after the second Sycle (Id2), it was more than 98 %, which indicates a very durable basalt.

Los Angeles Abrasion Value (%): The Los Angeles abrasion values (after 500 cycles) range between 3.68% and 4.85% with an average of 4.03%, which indicates a high resistance to abrasion According to IS: 2386 (Part 4), the aggregate impact value should not exceed 45% for aggregate used for concrete other than for wearing surface, while the aggregate impact value should not exceed 35% for concrete used for wearing surfaces such as runways, roads, pavements, floors etc.

Splitting Tensile Strength (MPa): The results of Splitting Tensile Strength (MPa) range between 2.345 and 3.291 Mpa, with an average of 2.94 Mpa.

Table 3. Average of geotechnical characteristics of the basalt samples

Location #	Unconfined compressive strength (MPa)	Splitting Tensile Strength (MPa)	Los Angeles Abrasion Value (%)*	Slake durability	
				I_{d1}	I_{d2}
JB 1	143	2.345	3.73	99.31	99.26
JB 2	135	3.127	3.68	99.28	99.17
JB 3	117	2.813	3.84	99.30	99.23
JB 4	136	2.919	3.97	99.19	99.05
JB 5	128	3.158	4.2	99.14	99.11
JB 6	154	3.291	4.27	99.16	99.10
JB 7	96	2.871	4.85	99.42	99.31
JB 8	124	3.189	3.68	99.41	99.34
JB 9	116	2.910	3.87	99.39	99.33
JB 10	107	2.781	4.18	99.17	99.10
Average	125.6	2.94	4.03	99.28	99.2

4.3 Physical Characteristics

The analysis of the physical characteristics of the basaltic samples shown in Table 4 revealed the following results:

Bulk density range was (2.73- 2.92) g/cm^3, with an average of 2.82 g/cm. Based on the IAEG 1982 criteria, the basalt rock samples from two locations (SB-8 &SB-9) were classified as class -4, high density (2.5-2.75) g/cm. As for the samples from the other locations, they are classified as class -4 very high density (Over 2.75) g/cm^3.

Specific Gravity: The Specified gravity values reported for the samples were within the range (2.76-2.98) g/cm^3, with an average of 2.86 g/cm.

Porosity (%) was found within the range of (1.11-2.82) %, with the average 1.6 %. According to the IAEG 1982 criteria, the basaltic rocks from ten locations were located within Class -4 (Low Porosity).

Water content (%) falls within the range of (0.16 to 0.34) %, with an average of 0.24 %. Saturation (%) was reported within the range of (28-55) %, with an average of 39.1%.

Table 4. Average of geotechnical characteristics of the basalt samples

Location #	Specific Gravity (g/cm³)	Bulk Density (g/cm³)	Void ratio (e)	Porosity (n) %	Water content %	Saturation %
JB 1	2.98	2.92	0.017	1.67	0.22	35
JB 2	2.86	2.83	0.0119	1.18	0.17	37
JB 3	2.92	2.86	0.02	1.96	0.21	28
JB 4	2.86	2.85	0.0145	1.43	0.16	29
JB 5	2.87	2.82	0.0164	1.61	0.32	51
JB 6	2.92	2.84	0.029	2.82	0.34	31
JB 7	2.86	2.84	0.0146	1.44	0.27	48
JB 8	2.76	2.73	0.0112	1.11	0.16	36
JB 9	2.79	2.75	0.0156	1.54	0.25	41
JB 10	2.80	2.77	0.0130	1.28	0.28	55

Generally, the values are comparable to those of late tertiary and early quaternary basalt which is the case in this study (Abu-Mahfouz et al., 2016, Mehyar and Madanat 2015). It is notable that results of all samples have the same pattern of variability for all locations and for all tests. A similar wide range of measurement values for different samples from the same location has been reported in (González de Vallejo et al., 2008).

The Porosity is mainly due to vesicles; however, the relatively high saturation may indicate some secondary porosity. Secondary porosity tends to connect parts of these vesicles, which is enabling water to move and fill the vesicles. Figure 4 shows a reverse relationship between saturation degree and UCS, where the R^2 is more than 35%.

Saturation degree also seems to have some relation with the geographical distribution. In the sites toward the east were the desertic conditions are more severe and the precipitation is more limited, the saturation degree tends to be low. In contrast, in the western basaltic flow exposures, the saturation degree is mostly higher. All these relations support the hypothesis that the variation in the physical and geotechnical index properties between different basalt locations in the study area may be attributed to the weathering processes rather than to the basalt geneses. Despite all that has been discussed above, the basalt from all locations in the study area still a high similarity from the geotechnical point of view. Basalts of the study area is of a high quality for common usage, such as aggregates.

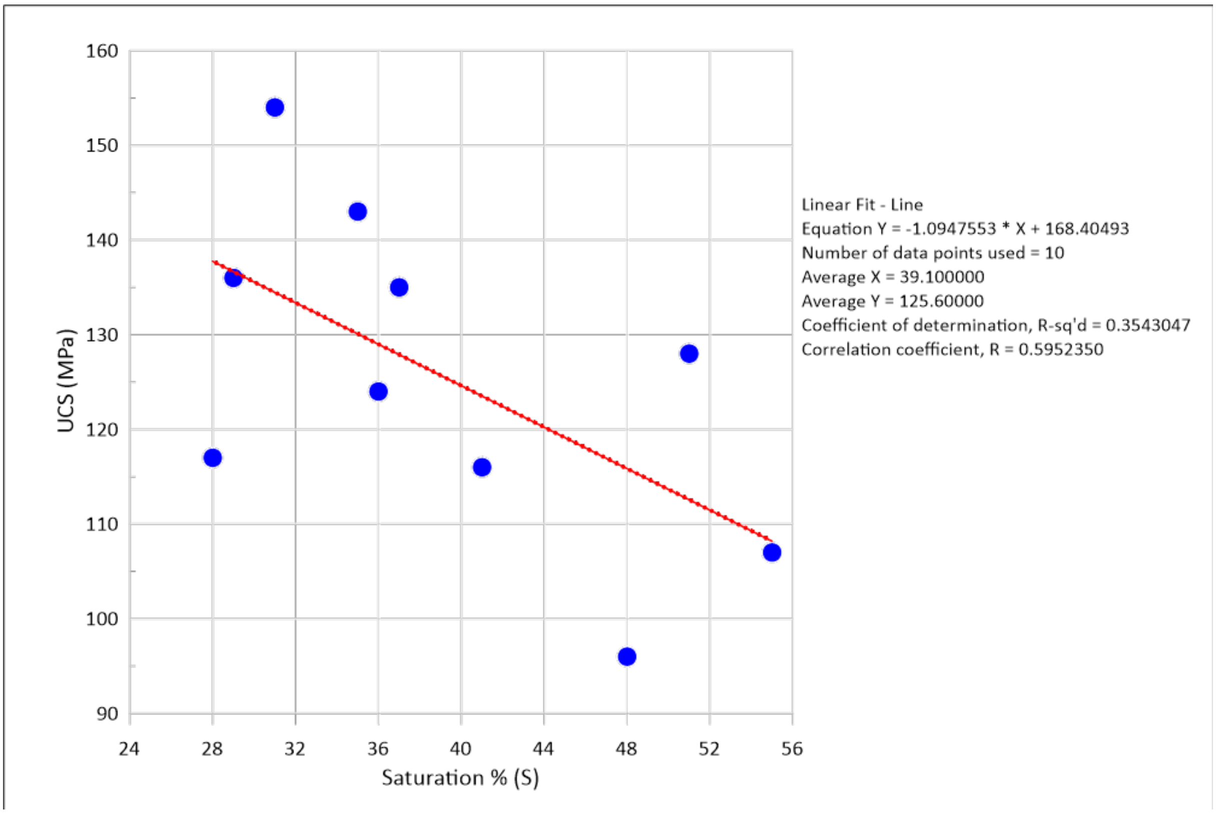

Figure 4. Relationship between the UCS and Saturation degree.

5. Conclusions

Based on the comprehensive analysis of the test results and the chemical analysis, the potential of the Basalt of South Jordan for alkali silica reaction (ASR) is very low. Moreover, based on the review of all the mechanical and physical tests of the samples from the ten locations, the results show that the SJB meets the requirements and specifications of the ASTM or AASHTO standards specified for construction materials; accordingly, SJB can be used as a promising construction material.

References

AASHTO, American Association of State Highway and Transportation.

Abu-Mahfouz, I., Al-Malabeh, A., Rababeh, S. (2016). Geo-engineering 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

Al Dwairi, R. (2017). Modeling of Chromium (VI) Adsorption from Aqueous Solutions Using Jordanian Zeolitic Tuff. Water Science and Technology 75: 2064-2071.

Al Dwairi, R. (2019). Mineralogical and Geochemical Characterization of Jordanian Olivine and Its Ability to Capture CO2 by Mineralization Process Indonesian Journal on Geoscience 6: 175-183.

Al Dwairi, R. (2009). The use of expendable local zeolite deposits for NH4 removal in municipal wastewater. Jordan Journal of Civil Engineering 3: 256–264.

Al Dwairi, R. (2007). Characterization of the Jordanian zeolitic tuff and its potential use in Khirbet es Samra wastewater treatment plant. Unpublished PhD Thesis, The University of Jordan, Amman, Jordan 185 P.

Al Dwairi, R. and Al-Rawajfeh, A. (2012). Recent Patents of Natural Zeolites Applications in Environment, Agriculture and Pharmaceutical Industry. Recent Patents on Chemical Engineering 5: 20-27.

Al Dwairi, R., Ibrahim, K., Khoury, H. (2014). Potential use of faujasite–phillipsite and phillipsite–chabazite tuff in purification of treated effluent from domestic wastewater treatment plants. Environmental Earth Sciences 71: 5071-5078.

Al Dwairi, R., Khoury, H., and Ibrahim, K. (2009). Mineralogy and Authigenesis of Zeolitic Tuff from Tall-Juhira and Tall Amir, South Jordan. Jordan Journal of Earth and Environmental Sciences 2: 81- 88.

Al Dwairi, R., Omar W., Al-Harahsheh, S. (2015). Kinetic modelling for heavy metal adsorption using Jordanian low-cost natural zeolite (fixed bed column study). Journal of Water Reuse and Desalination 5(2): 231-238.

Al Dwairi, R.and Sharadqah, I. (2014). Mineralogy, geochemistry and volcanology of volcanic tuff rocks from Jabal Hulait Al_Gran, South of Jordan (New Occurrence). Jordan Journal of Civil Engineering 8: 187-198.

Al Dwairi, R., Al Saqarat, B., Shaqour, F., Sarireh, M. (2018). Characterization of Jordanian Volcanic Tuff and its potential use as lightweight aggregate. Jordan Journal of Earth and Environmental Sciences 9: 127-133.

Al Malabeh, A. (1993). The Volcanology, Mineralogy, and Geochemistry of Selected Pyroclastic Cones from NE Jordan and Their Evaluation for Possible Industrial Applications. PhD Thesis, Universitat Erlangen. 300 p.

ASTM C 330-89, "Standard Specification for Lightweight Aggregates for Structural Concrete", Annual Book of ASTM Standards, 4.02: 193- 195.

Barberi, F., Capaldi, P., Gasperini, G., Marineli, G., Santacroce, T., Scndone, R., Treuil, M., Varet, J. (1979). Recent basaltic volcanism of Jordan and its implications on the geodynamic history of the Dead Sea Shear Zone. International Symposium Geodynamic Evolution Afro-Arabian Rift System, Rome, 667-682.

Bender, F. (1974). Geology of Jordan. Contributions to the Regional Geology of Earth 7. Gebrüder Borntraeger, Berlin (Supplement pp. 196).

Broch, E. and Franklin, J.A. (1972). The Point-Load Strength Test. International Journal of Rock Mechanics and Mining Sciences 9: 669-697. https://doi.org/10.1016/0148-9062(72)90030-7.

Crawford, K. (2013). Determination of Bulk Density of Rock Core Using Slandered Industry Methods Dissertations, Master's Theses and Master's Reports - Open. Michigan Technological University. P 192.

Deere, D. and Miller, R. (1966). Engineering classification and index properties for intact rock. Tech. Report No AFWL - TR-65-116, Air Force Weapons Lab., Kirtland Air Base, New Mexico.

Fediuk, F. and Alfugha, H. (1999). Dead Sea Region: Fault-controlled chemistry of Cenozoic Volcanics. Geolines 9: 29–34.

Gamble, J. C. (1971). Durability-Plasticity Classification of Shales and Other Argillaceous Rocks, Th. D. Thesis, University of Illinois at Urbana-Champaign.

González de Vallejo, LI., Hijazo, T., Ferrer, M. (2008). Engineering geological properties of the volcanic rocks and soils of the Canary Islands. Soils and Rocks 31: 3–13.

Goodman, RE. (1993). Engineering Geology Rock in Engineering Construction. Wiley, New York.

Ibrahim, K. M. (1987). Geochemistry and petrology for some of the basaltic outcrops in central Jordan. M. Sc. Thesis, University of Jordan, Amman, 164.

Ibrahim, K. M., Tarawneh, K., 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.

Katayama, T., St John, DA., Futagawa, T. (1989). The petrographic comparison of some volcanic rocks from Japan and New Zealand - potential reactivity related to interstitial glass and silica minerals. In: Okada, K, Nishibayashi, S, Kawamura, M (Eds.), Proceedings of the 8th International Conference on Alkali-aggregate Reaction in Concrete (ICAAR), Kyoto, Japan. CRC Press, Boca Raton/FL: 537–542.

Khoury, H. N., Ibrahim, H., Al Dwairi, M., Torrente, R. (2015). Wide spread zeolitization of the Neogene – Quaternary volcanic tuff in Jordan. Journal of African Earth Sciences 101: 420–429.

Le Bas, M.J., Lemaitre, R.W., Streckeisen, A., Zanettin, B. (1986). A Chemical Classification of Volcanic-Rocks Based on the Total Alkali Silica Diagram. Journal of Petrology 27(3): 745-750. https://doi.org/10.1093/petrology/27.3.745.

Mehyar, N. and Madanat, M. (2015). Mineral Status and Future Opportunity: Basalt. Ministry of Energy and Mineral Resources. Amman, Jordan, Pp 11.

Miller, R.P. (1965). Engineering classification and index properties for intact rock, Ph.D. Thesis, University of Illinois. Reported in Richard Goodman, introduction to rock mechanics.

Ministry of Energy and Mineral Resources (MEMR) (2015). Basalt, Mineral Status and Future Opportunity

Sharadqah, S., and Al Dwairi, R., (2010). Control of Odorants Emissions from Poultry Manure Using Jordanian Natural Zeolites. Jordan Journal of Civil Engineering 4: 378-388.