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Engineering Properties of Basalt Coarse Aggregates in Hamdan Area, NW Sana'a, Yemen

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ABSTRACT

Sana'a city has been growing fast vertically and horizontally to provide housing, business and other facilities to the ever in. This work was undertaken to determine the quality of basalt coarse aggregate in Hamdan area, NW Sana'a. It included field work which consisted of collection of basalt aggregate samples and hand specimens. The study covered coarse aggregates from one of the main crushers in the vicinity of Sana'a city, about 12 km NW of Sana'a, Yemen. The objective of this study is to determine the physical and mechanical properties of basalt coarse aggregates and comparison of the results with the standards. Chemical composition of basalt was determined by the X-ray fluorescence (XRF). The thin sections show that the studied basalt is mainly composed of calcic plagioclase and augite with few olivine. The types of testing required are gradation, specific gravity, water absorption, flakiness and elongation, Los Angeles abrasion value, aggregate impact value, soundness and alkali-silica reactivity. The results showed that, the basalt coarse aggregates in Hamdan area comply with the international standards.

Keywords: *Basalt, Coarse aggregate, Hamdan, Sana'a, Yemen.*

INTRODUCTION

Concrete is of great importance as a structural material and special attention has been paid to the nature of the aggregates employed as it considered one of the most popular construction industry material in the world (Blyth and Freitas, 1977). It is a composite material produced by the homogenous mixing of selected proportions of water, cement and aggregates (fine and coarse). Aggregate is commonly considered inert filler, which accounts for 60 to 80 % of the volume and 70 to 85 % of the weight of concrete (Zerdi, 2015), thus the selection of aggregate is an important factor. To produce a good, strength and high quality concrete the materials used should be in accordance to standard specification.

Infrastructures, like air field pavement construction, roads, bridges and buildings, etc. require huge amounts of aggregates construction materials. Aggregates are the most widely used geomaterials (25 billion tons exploited annually, USGS, 2010).

Aggregate consists of granular material such as sand, gravel and crushed stone. Fine aggregates are considered to be that material passing through sieve No.4 (4.75 mm) and are

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retained on sieve No. 200 (0.075 mm), whereas coarse aggregates are those retained on sieve No. 4. The aggregates are obtained from quarries and pits. A quarry is a place where rock or aggregate materials are separated from their natural beds and processed for use in various construction applications (Krynine and Judd, 1957). The steps of aggregate production starting with ripping at source location followed collection of rock, loading in a truck to transport to crusher location and finally crushing and screening to different size.

Basalt is a dark colored, hard, dense, fine-grained basic volcanic rock. It is very important rock that found in most countries in the world. It is used extensively as engineering materials such as aggregates for cement and asphaltic concrete mix, airfield pavement construction, rock fill for dams and breakwaters, material for railroad ballast and highway base courses (Goodman, 1993).

Prediction of aggregate characteristics before placement and starting the construction activity can indicate the un-expected happening and can prevent the post construction material problems. Therefore, aggregate sampling and testing is a paramount importance to make the construction workable and durability.

The aggregates used in concrete mix have to meet a number of specifications with regard to mechanical performance, durability, chemical stability, gradation, shape, surface texture, and the presence of harmful materials. Several standard tests are employed to ensure aggregates qualify. However, petrographic examination, despite being qualitative in nature, remains the most valuable test for predicting the overall performance of concrete aggregates (Bérubé, 2001). The preliminary need of the aggregates is their inherent durability against natural and man created disturbances. The aggregate provide volume, stability and resistance to weathering. Durable and strong aggregates are normally preferred because they can resist abrasion and disintegration, make an excellent bond with cementing materials, are resistant to rapid impacts and are sound (BS 812). Neville (1981) stated that aggregates are inert materials that are dispersed through-out the cement paste whose strength depends majorly on its shape, surface texture and cleanliness.

The consumption of aggregates is closely related to the economic performance of a country, which is measured as gross domestic product per capita, since various productive sectors depend on quarrying (Menegaki and Kaliampakos, 2010; Balletto and Furcas, 2011; Neves et al., 2015). In the European Union (EU) the aggregates industry is the largest non-energy extractive sector with an output of 2.6 billion tons per year and an annual turnover of 15 billion Euros in the 28 EU members plus European Free Trade Association (EFTA) countries (UEPG, 2016).

Sana'a area has a number of quarries and crushers equipped to crush basaltic rocks into construction size aggregates. Coarse aggregates in Sana'a area are obtained from crushing basaltic rocks. Huge quantities of aggregate are utilized in various construction projects in Sana'a. These are supplied by a number of crushers in the area. At present, there are seven crushers in NW Sana'a are produced coarse basaltic aggregates. The reserves are virtually unlimited. Therefore, it is very important to determine the engineering properties of this aggregate. To my knowledge, no publishes studies and scientific information are available. Hence, this information would help at present or in the future in other engineering projects which may be used this aggregate.

STUDY AREA

The selected quarry for the current study is located in the western part of Yemen at about 12 km NW Sana'a city, the capital of Yemen Republic (Figure 1). It's located between latitude 1702044 and 1707108 N and longitude 401654 and 407648 E (UTM Zone 38N/WGS84/meters) at shown in Figure 1.

Coarse crushing of basaltic rocks to the size of gravel is needed for raw materials for construction materials and there are a number of crushers producing all sizes of aggregates in the study area. Generally, the study area is characterized by hills topography due to the presence of low to moderately hills. The area of basaltic rock outcrops covered an area of about 12 km^2. The highest elevation point is represented by Jabal Kirah (2601 m) (Figure 1). The study area is characterized by arid climate condition and very rare vegetation. The dominant rock for coarse aggregate production in Yemen is generally basalt. Basaltic rocks in Yemen can be found in different areas (Figure 2).

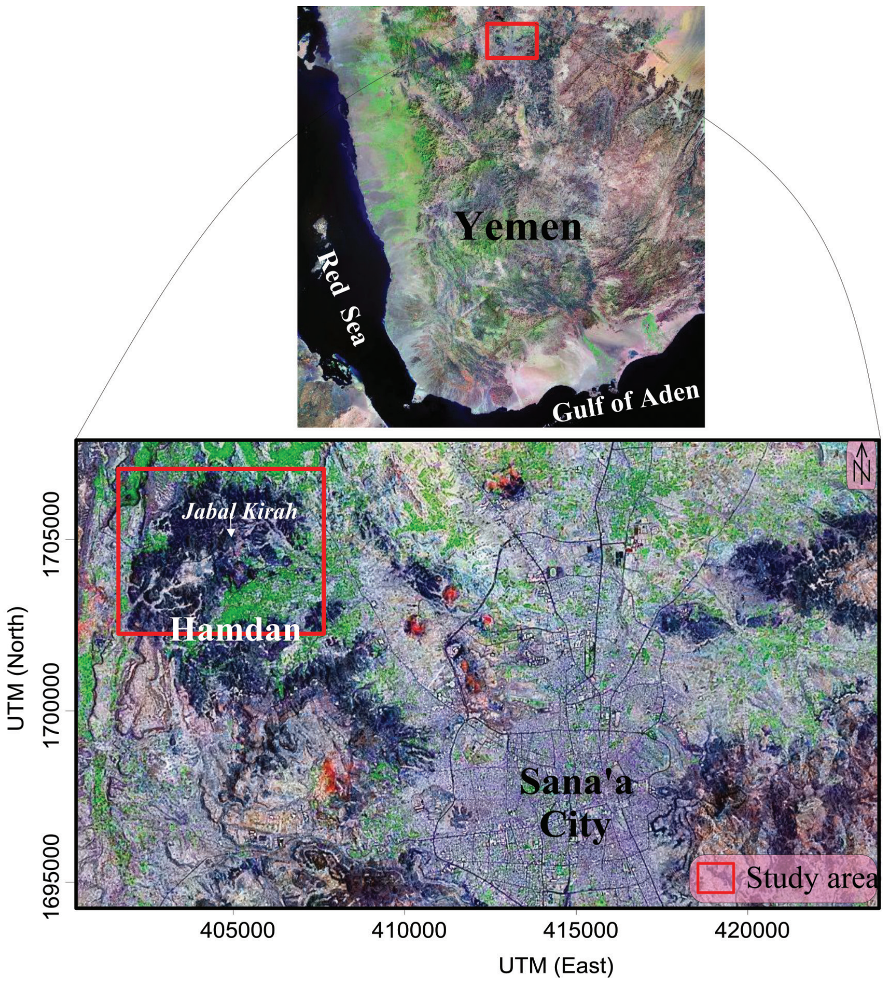

Figure 1. Location map of study area.

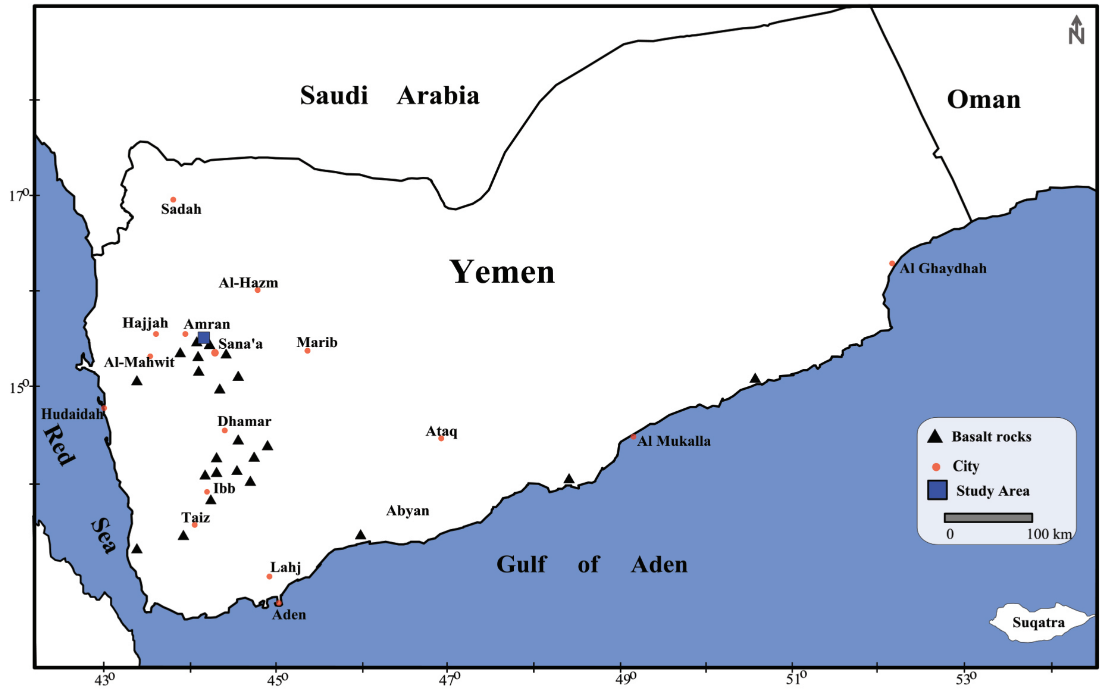

Figure 2. Distribution of basaltic rocks in Yemen.

GEOLOGICAL SETTING

The geology of the study area and its surroundings is shown in Figure 3. One of the main exposed rock units in the investigated area is basaltic rocks. These rocks are a part of the Yemen Trap Series (YTS). The YTS represent the lowest part of the Cenozoic Yemen volcanic province, and mainly overly the Cretaceous Tawilah Group (sandstone). They had been developed during the Oligocene Early Miocene. The YTS consists of thick bimodal volcanic (acidic and basic). Thickness of the YTS varies from >2000 m in the western part to tens of meters in the east (Mattash et al., 2013). Ages for the YTS volcanism range from 31 to 16 Ma (Bosworth et al., 2005). The YTV is uncomfortably overlain by the younger Yemen Volcanic Series (YVS) which represent the start of the younger phase of volcanicity (Mattash and Balogh, 1994).

The basaltic rocks in the study area have dark gray color, fine grains, high compressive strength, the weathering range from fresh to slightly weathered on the surface outcrops only and show irregularly oriented columnar joint sets are observed. Most of the joints are unfilled and closed, however, in some cases open joints with iron-oxide staining are observed. The joints are planar, curved, mostly non persistent and closely spaced and closed.

Basaltic rocks are usually fine grained due to rapid cooling as exposed to the earth's surface. Relatively larger-sizes basaltic blocks are commonly used in Yemen as foundations and/or building blocks. Fresh, very strong to strong basalt is found in sufficient quantity and good quality for crushed aggregate production. Several active basalt quarries are found in the various parts of the studied area. According to field observation, the basaltic samples have shown no alterations and weathering evidence in hand specimen. The rock is easily workable due to systematic four/five sets of columnar joints. There are three main uses of aggregate in Sana'a area. They are in construction of structural concrete, road pavement and as fill materials.

made on the aggregates, representative samples of source basaltic rocks and aggregates were collected from one of the main crushers in Hamdan area, about 12 km NW Sana'a, Yemen.

From the source rock of aggregate, hand specimens were collected for preliminary

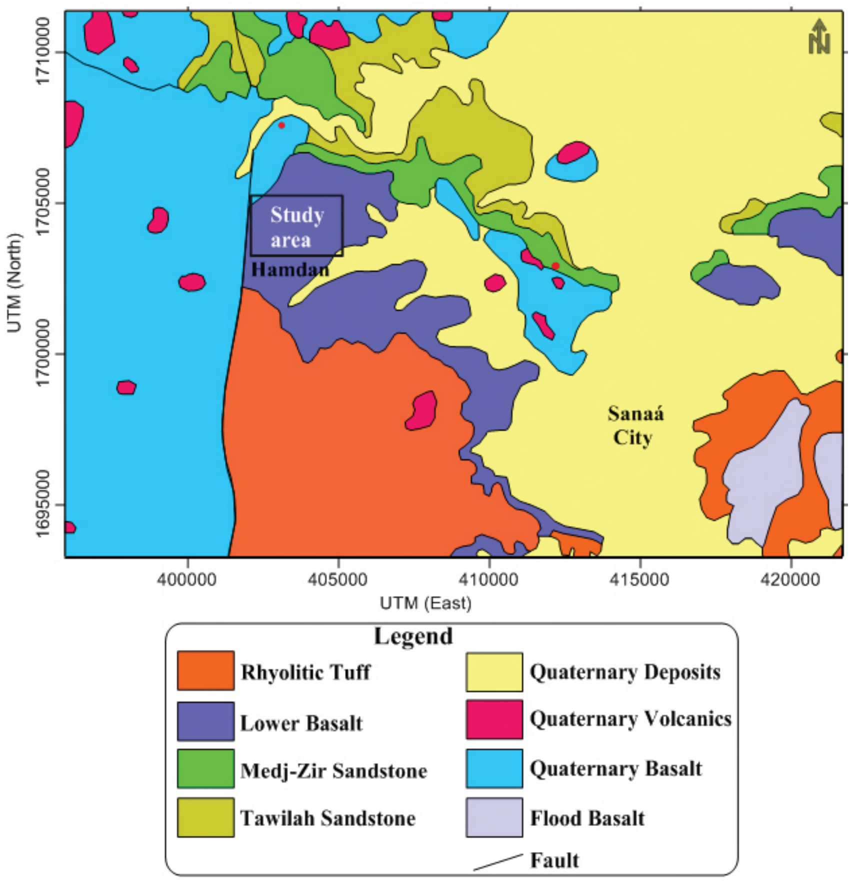

Figure 3. Geological map of the study area and its surroundings (Kruck and Schäffer, 1991).

MATERIALS AND METHODS

Basalt aggregates, which are the most frequently, used as aggregate in concrete and road construction by local companies in Sana'a region. To determine the quality of basalt coarse aggregates physical and mechanical tests were

field identification, chemical composition and for microscopic examination of thin section. Chemical analysis of the collected samples of basalt was carried out by unit model ARL 9800 XP SIM-SEQ XRF of Quality Laboratory in Amran Cement Plant (Amran, Yemen).

The physical and mechanical properties of aggregates were investigated in Materials Testing Laboratory, Civil Engineering Department, Faculty of Engineering, Sana'a University. The main physical and mechanical tests were: gradation, specific gravity, water absorption, flakiness index, elongation index, Los Angeles abrasion value, impact value and soundness. The alkali-silica reactivity test was carried out using Mielenz quick chemical test (ASTM C 289-01). These tests were performed in accordance with BS, ASTM and EN standards. Each test was performed at least six times.

The evaluation has been made by testing these samples in laboratory and comparing the results with the international standards.

RESULTS AND DISCUSSION

Mineralogical and Chemical Composition

The mineralogy of basaltic rocks is characterized by a presence mainly of calcic-plagioclase feldspar and augite. Olivine can also be a few constituent (Figure 4).

The results of geochemical analyses are summarized in Table 1. Chemical analysis indicates that basalt rock is mainly composed of SiO_2 (48.70 %), followed by aluminum (16.15 %) and iron oxides (11.55 %), a composition that reflects the basic rock quality.

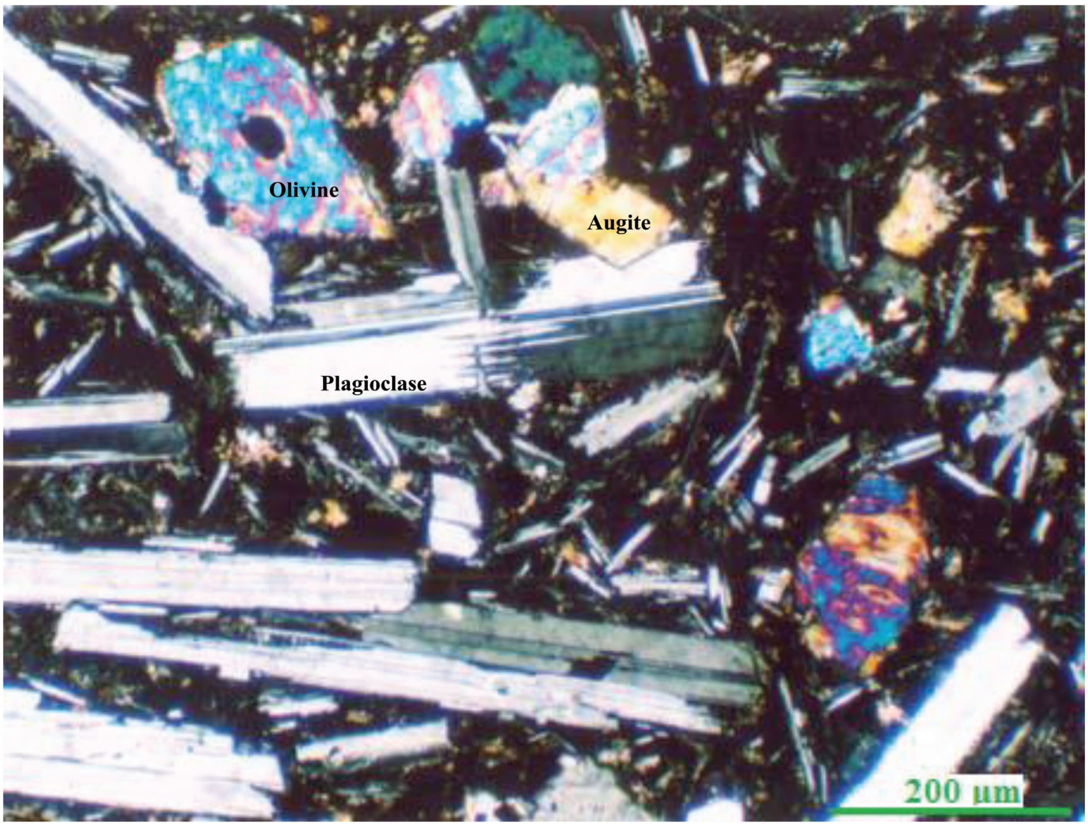

Figure 4. Microphotograph of Hamdan basaltic rock.

Table 1. Chemical composition of Hamdan basaltic rocks.

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	P_2O_3	TiO_2	LOI	Total
%	48.70	16.15	11.55	8.29	6.22	1.07	4.39	0.30	0.46	1.81	0.89	99.84

Engineering Properties of Aggregates

The performance of aggregates in concrete depends on their mineralogical and petrographic characteristics (Harrison and Bloodworth, 1994). Before concrete is produced and through its service life, aggregates may be exposed to physical, mechanical and chemical changes, which they must resist. They have then to satisfy a number of specifications, with standard tests used to control compliance (Engidasew, 2013).

The performance of natural aggregates depends on different characteristics (BS 812) and published literature indicates that a wide range of tests have been devised to describe the materials and determine their suitability as construction materials (Smith and Collis, 1993; Neville, 2000; Korkanç and Tuğrul, 2004). These tests are designed to estimate the future aggregates behavior. As a result, the related physical and mechanical properties and chemical characteristics that reflect the aggregate quality must be determined (BS 812).

The results of engineering properties of basaltic aggregates are summarized in Table 2.

Table 2. Some engineering properties of crushed coarse basaltic aggregates.

Property	**Min.**	**Max.**	**Average**	**Standard deviation**	**No. of tested samples**	**Acceptance limits [Standard used for evaluation]**
Bulk specific gravity	2.58	2.78	2.72	0.04	24	> 2.6 [BS 812: Part 2]
Bulk specific gravity *(saturated surface dry)*	2.64	2.84	2.78	0.04	24	
Apparent specific gravity	2.75	2.92	2.87	0.05	24	
Water absorption (%)	0.73	2.10	1.68	0.32	24	< 2 [ASTM 33-01] < 2.5 [ASTM C 127-01]
Flaky index (%)	10.30	19.77	15.19	2.98	11	< 25 % [BS 812: Part 105.1]
Elongation index (%)	12.37	23.06	18.15	4.02	11	< 25 % [BS 812: Part 105.2]
Los Angeles abrasion value (%)	11.10	18.98	14.56	3.01	6	< 35 % [EN 12620]
Aggregate impact value (%)	7.56	15.65	10.09	3.12	6	< 25 % [BS 812: Part 112; ASTM C 131-96]
Soundness, (Na_2SO_4) (%)	0.30	1.31	0.50	0.40	7	< 10 [ASTM C 33-01; ASTM C 88-99]

Physical Properties of Aggregates

The physical properties of aggregates stem from the inherent properties of the source rock and predict as to how an aggregate would perform in construction. The commonly measured physical and mechanical aggregate properties (BS 812) are particle shape, surface texture, gradation, specific gravity, water absorption, flakiness index and elongation index.

Particle shape and surface texture

Particle shape affects the performance of an aggregate during construction and service. The surface texture of aggregates considerably influences the adhesion between aggregate and cement. In general, a rough surface texture gives good adhesion, whereas a glassy surface result in poor adhesion (Harrison and Bloodworth, 1994). Particle shape and surface texture of basalt coarse aggregate has been described on the basis of visual examination according to ASTM D 3398-00 and BS 812: Part 1. Particles shape is angular and irregular and surface texture is rough. Bonding between aggregate and cement paste depends on the surface of the aggregate. Since the rough surface requires more bonding than the smooth surface, the texture of studied basalt aggregate comply the requirement of BS standard specification.

Gradation

Grading of aggregates affects the compaction capacity, permeability and strength of concrete aggregate and road base. It's one of the most important characteristics affecting the stability and workability properties of a mix. This was determined by using the procedure of BS 1973. The results have been used determine compliance for the particle size distribution with applicable specification requirements. The results of tests are shown in Figure 5. It is observed that all samples comply with the specification limits.

The grain size distribution performed according to ASTM C 136-01 indicated that the aggregate is well-graded (GW).

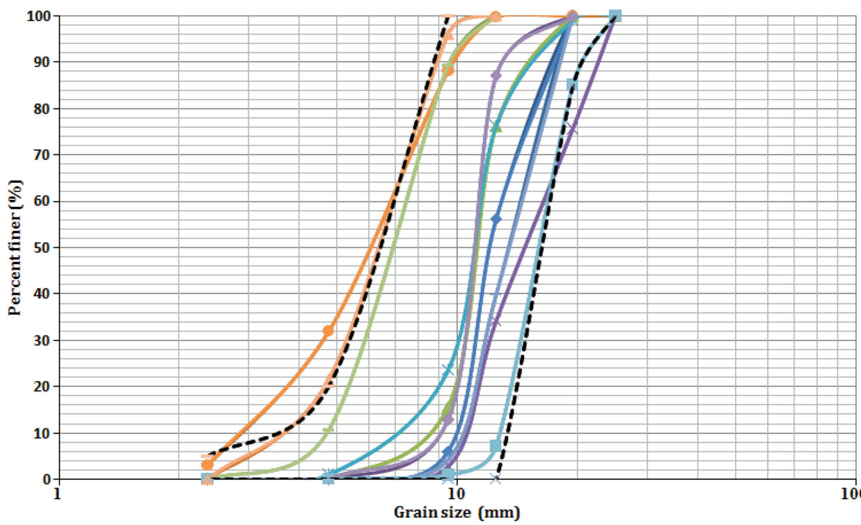

Figure 5. Grain size distribution curves of basaltic coarse aggregates (solid lines). Dashed lines show ASTM-required upper and lower limits for coarse aggregate.

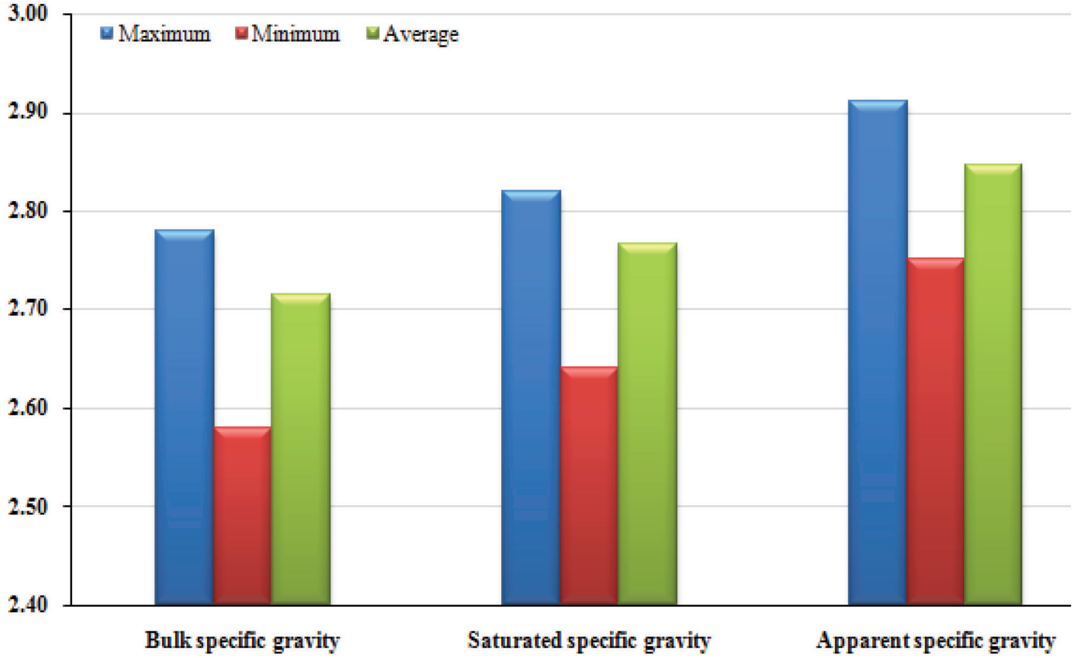

Figure 6. Specific gravity of basalt coarse aggregate.

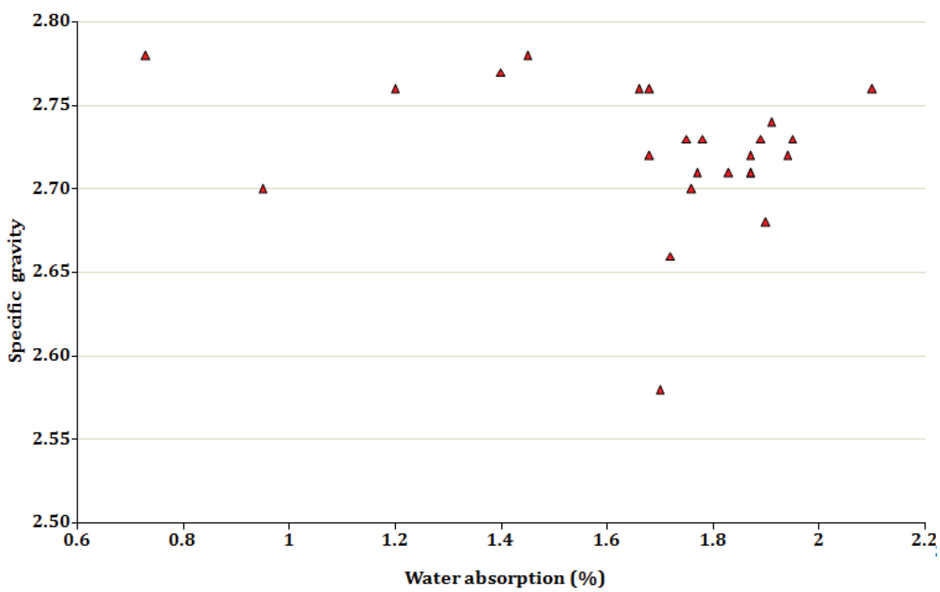

Figure 7. Specific gravity versus water absorption.

Specific gravity and water absorption

Three types of specific gravity were determined according to ASTM C 127-01. The summary results of specific gravity are shown in Table 2 and Figure 6. It is observed that the bulk specific gravity varies from 2.58 to 2.78, with an average of 2.72 ± 0.04, (n=24), bulk specific gravity (saturated surface dry) varies from 2.64 to 2.84, with an average of 2.78 ± 0.04, (n=24) and apparent specific gravity varies from 2.75 to 2.92, with an average of 2.87 ± 0.05, (n=24).

BS 812 and ASTM C 127-01 standards stated the maximum allowable value of water absorption of concrete aggregate is 2 and 2.5, respectively. Hence, the studied samples have shown good quality in term of water absorption (< 2.5).

The specific gravity of an aggregate is an important factor in mix design calculation because it relates the weight of aggregate to its volume. This property, give an idea of strength of rocks. There is generally a direct positive relationship between high specific gravity and high strength of aggregates (Kandhal and Lee, 1970; Neville, 2000).

Water absorption represents the water contained in aggregate in saturated surface dry condition. It was determined according to ASTM C 127-01. It varies from 0.73 to 2.10 %, with an average of 1.68 ± 0.32 %, (n=24) (Table 2, Figure 7).

BS 812 and ASTM C 127-01 standards stated the maximum allowable value of water absorption of concrete aggregate is 2 and 2.5, respectively. Hence, the studied samples have shown good quality in term of water absorption (< 2.5).

The aggregates water absorption is an important property in determining mixing ratios. Therefore, aggregate with low water absorption values are in high demand for quality concrete manufacturing. High strength concrete can be made with rock of low water absorption (< 2 %) (Fookes, 1980). BS 812 and ASTM C 127-01, state that the upper limit for concrete aggregate water absorption should not be greater than 2 and 2.5 %, respectively. The studied basaltic samples are suitable for high strength concrete production considering their water absorption (very low < 2.5 %).

The water absorption affects the specific gravity of the aggregate as well as in service behaviour of concrete. It is considered an indirect measure of permeability of aggregate that affects other physical characteristics such as mechanical strength, soundness and its general durability (Smith and Collis, 1993; Neville, 2000; Korkanç and Tuğrul, 2004). Aggregate having high water absorption are more porous in nature and are generally considered unsuitable (Schmidt and Graf, 1972). In general, less absorptive aggregates often tend to be more resistant to mechanical forces and weathering.

Flakiness index and elongation index

The shape of aggregate is an important characteristic since it affects the workability of concrete. Particle shape and size distribution influence the water content necessary to obtain a mix of suitable resistance, and then by affecting the compressive strength, drying shrinkage and durability of the resulting concrete (Engidasew, 2013).

Regarding aggregate properties, every rock unit has its own properties depending upon its mineralogical and textural characteristics.

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 (Engidasew, 2013).

During aggregate production, the rock breaks into an assemblage of particles of different shapes, of which four categories are identified in BS specifications: cuboidal, elongate, flaky and flaky-elongated. The presence of flaky and elongated aggregate particles beyond specified limits increases the degradation of mixes. Flaky and elongated aggregate particles may break during construction and under traffic load.

Flaky is a term used as a description for the material with small thickness; relative to the other two dimension. A flaky particle is one in which the smallest dimension is a maximum of 0.6 times the mean sieve size (BS 812: Part 105.1). Flakiness index is determined by separating the flaky particles by using a metal thickness gauge (BS 812: Part 105.1). The flakiness index varies from 10.30 to 19.77 %, with an average of 15.19 ± 2.98 %, (n=11).

An elongated particle is one whose maximum dimension is greater than 1.8 times its mean dimension (BS 812: Part 105.2). A particle, of which the length is considerably larger than the other dimension is called elongated. Elongation index is determined by separating the elongated particles by using a special gauge (BS 812: Part 105.2). The elongation index varies from 12.37 to 23.06 %, with an average of 18.15± 4.04 %, (n=11).

The flakiness index and elongation index comply the BS 812: Part 105 specifications as concrete aggregate.

Mechanical Properties of Aggregates

The mechanical tests provide parameters for strength and durability of rock aggregates (Aitcin and Mehta, 1990; Neville, 2000). The available standards (BS, ASTM and EN) require that the rock aggregate should not disintegrate during mixing or compaction. In this study, strength and durability of the basaltic coarse aggregates were tested through the procedures and limits defined by the parameter such as aggregate impact value (AIV) and Los Angeles abrasion value (LAAV).

Toughness is the property of aggregates to resist impact against moving loads. These tests are included in BS for measurement of the mechanical properties of crushed rock aggregates, including the AIV and LAAV tests (BS 812: Part 112 and BS 812: Part 113), respectively.

AIV indicates relative measure of mechanical resistance of an aggregate to sudden shock (Smith and Collis, 2001). The AIV test was stated to have the following advantages: it requires a small sample; it requires less expensive portable equipment; and samples may be tested in a wet condition (Kandhal et al., 1998). AIV and LAAV are the basic strength parameters to evaluate the strength and durability of the aggregate.

As it has been seen in Figure 8, LAAV and AIV show a linear relationship (with R^2=0.86) indicating these properties are important mechanical properties of the aggregate characterization as far as this study is concerned.

Apart from testing aggregate with respect to its LAAV and AIV, testing the aggregate with respect to its resistance to wear is an important test for aggregate to be used for road constructions, building floors and pavement constructions. In the current study, the AIV value ranges from 7.56 % to 15.65 %, with an average of 10.09 ± 3.12 % (n=6). BS and ASTM standards stated that AIV should be less than 25 % of its weight (BS 812 Part 110:1990; ASTM C 131-96). All studied samples meet the mentioned specification. The results obtained for AIV test is mainly affected by inherent geological factors (petrology and fabric) (Ramsay et al., 1974).

The LAAV of the studied samples ranges from 11.1 to 18.98 %, with an average of 14.56 ± 3.01 % (n=6). The EN standards state the maximum allowable value is 35 %. Therefore, the studied samples have shown good quality in terms of LAAV test results (< 35 %, EN 12620).

Soundness of Aggregates

Soundness test (ASTM C 88-99) evaluates the resistance of aggregate to disintegrate when subjected to attacks by salts and freeze and thaw action during extreme weathering conditions (Wu et al., 1998). Freezing and thawing cycles are simulated by immersing the aggregate in a sulphate solution, drying the aggregate, and then reimmersing the aggregate in the sulphate solution. Expansive forces are created when the sulphate crystals in the aggregate pores are re-hydrated. The salt expansion simulates the forces

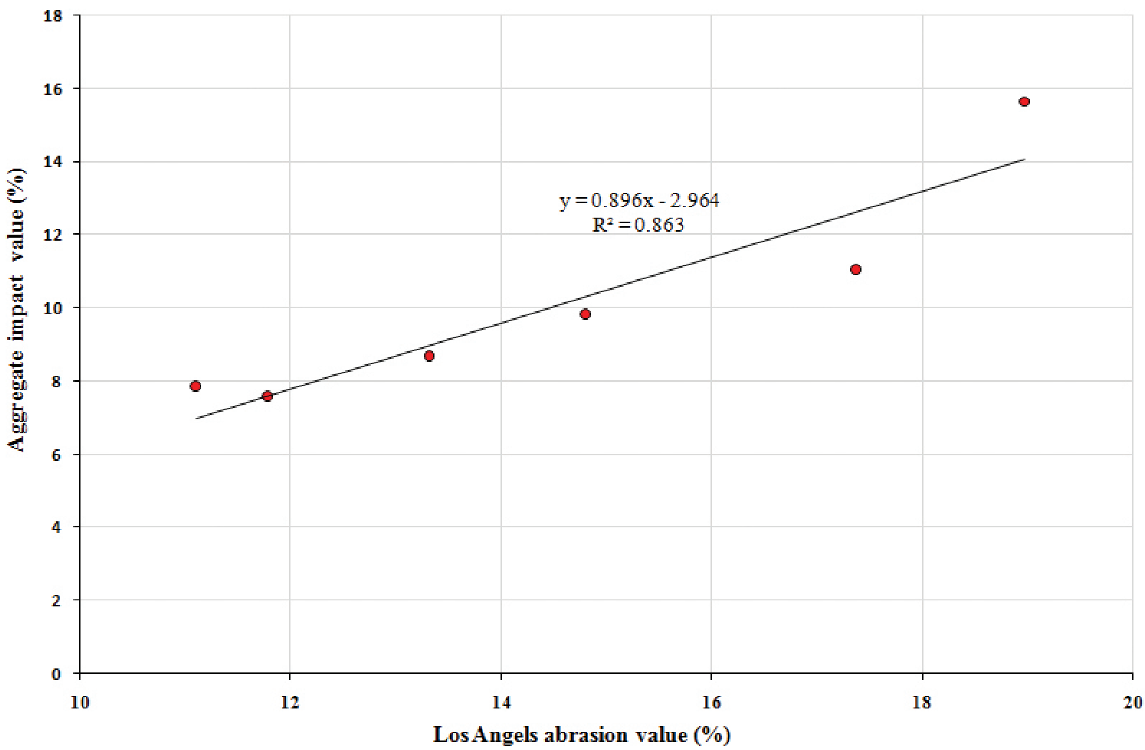

Figure 8. Los Angeles abrasion values versus aggregate impact values.

that are created when water freezes in aggregate pores. The ranges of mass loss allowed in specifications vary from agency to agency with the type of sulfate used. Typical limits are 10 and 18 % loss for sodium and magnesium sulphate, respectively.

In the current study, we used sodium sulphate (Na_2SO_4) soundness test. All the samples have shown very good results ranging from 0.10 % to 1.31 % with an average of 0.50 ± 0.41 %, (n=7). These results are quite good according to the ASTM and BS specifications (< 10 %).

Alkali Silica Reaction

Alkali-silica reaction (ASR) is a chemical reaction between the reactive silica contained in aggregates and the alkalis in the cement paste (Farny and Kosmatka, 1997). It is caused due to combination of three factors: a significant quantity of reactive silica in aggregates; high alkalinity in the pore solution of concrete and moisture from external source (Fatt and Beng, 2007). The reaction forms a swelling gel which may induce stress, resulting in expansion and cracking which over time can threaten structural integrity (Harrison and Bloodworth, 1994). The reactivity of volcanic rocks is usually associated with the presence of volcanic glass, altered minerals and SiO_2 content of the rock (Wakizaka, 2000; Korkanç and Tuğrul, 2005). The deterioration of concrete by ASR is well known in several countries such as Japan, China, Italy, Australia, New Zealand, Argentina, Brazil, Iceland and Turkey.

The Mielenz quick chemical test (ASTM C 289-01) has been found to be a satisfactory initial method for determining the potential reactivity of aggregates derived from volcanic rocks (Mielenz and Benton, 1958). This test categorizes aggregates as innocuous, potentially deleterious or deleterious (Figure 9). For this test, three different samples from study quarry of basaltic rocks used as aggregate sources were sampled in the studied area and tested. So, according to this test, the aggregate samples collected from study quarry plot in the innocuous field which means non-reactive (Figure 9). Further, the chemical analysis of the basalt (Table 1) demonstrated that the basalt had around 48.70 % SiO_2. According to Katayama et al. (1989) the basalt could be unreactive when its silica content is less than 50 %.

CONCLUSIONS AND RECOMMENDATIONS

The life performance of civil structures mainly depends upon the properties of aggregates. The aggregate strength should satisfy the standard requirements for structural purposes. The selection of suitable aggregates is of prime importance because it forms over three quarters of the volume of the concrete. Concrete is made up of aggregate, cement and water. Through this combination of materials, 75 % of the mix is governed by aggregate.

Basalts aggregates from Hamdan area are widely used as coarse aggregates because the quality for aggregate production is very good and characterized by higher specific gravity, lower absorption and abrasion loss values, resistance to corrosion, high compressive strength and non-reactive ASR.

The quarry sites around Sana'a are not systematically selected. In order to improve further the outcome of a similar work it is recommended in the future to have a close cooperation between an engineer and the geologists. Furthermore the aggregate producers must continuously comply with the standard requirements make sure give proper attention in producing consistent and quality products to the customers' standard requirements.

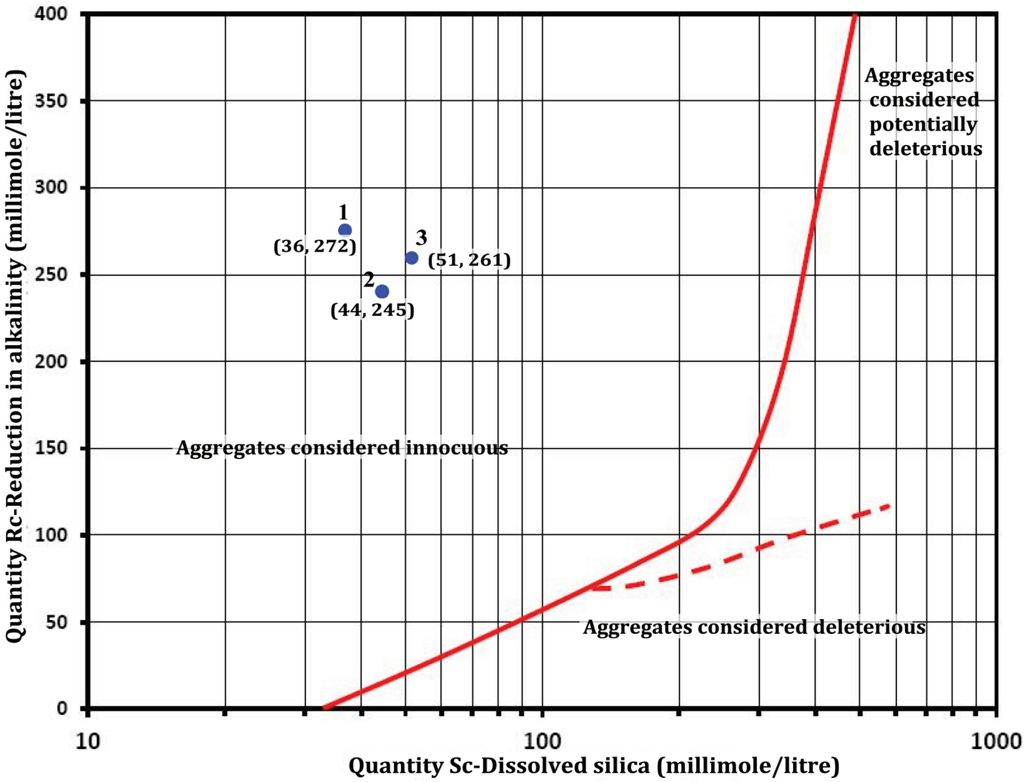

Figure 9. Samples plotted on Mielenz standard graph with illustration of division between innocuous and deleterious aggregates on the basis of reduction in alkalinity test (ASTM C 289-01).

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