Engineering properties of concrete made with crushed aggregates of diorite, Jeddah, Saudi Arabia

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The aggregate characteristics play an effective role in both fresh and hardened concrete properties. The western parts of Saudi Arabia characterized by rareness of natural aggregates resources so that the Precambrian rocks of the Arabian Shield considered as very important source of crushed aggregates. The studied Precambrian diorite is a hard and dense coarse-grained plutonic igneous rock that represents a local source of crushed aggregates of concrete, mortar and pavement materials. It composes mainly of plagioclase feldspar (andesine), biotite, hornblende and pyroxene. Sometimes, diorite contains small amounts of quartz. The studied samples were plotted in the field of diorite and quartz diorite of discrimination diagram. Its absorption values indicated that the studied crushed diorite aggregates have standard limits for aggregates absorption in the specified standards. The studied crushed aggregates are consisting mainly of equi-dimensional or cubical grains, that means these crushed grains are enough resist shear strength. The studied crushed aggregates have standard limits for aggregates absorption. The Los Angles abrasion values indicate relatively high resistance to wear. The compressive strength values of the studied concrete mix were ranging from 34.43 MPa to 38.32 MPa and having a strong direct proportional relationship with very angular grains content of coarse aggregates (R^2 value = 0.96).

Key words*: Diorite; Quartz diorite; Crushed aggregates: Textural characteristics; Workability; Concrete strength.*

1. Introduction

Aggregates are the major and effective component of concrete and it represents about 80 % of the total volume of concrete. The properties of both green and hardened concrete are generally controlled the overall the aggregates characteristics (ACI, 2001; Abu Seif, 2014). The coarse and fine concrete aggregate characteristics (e.g. size gradation, texture, and volume fraction) play a vital role on concrete rheology (Powers, 1968; Kosmatka et al., 2002; Mehta and Monteiro, 2006). This effect is owing to the inter-particle forces of aggregate and the particle movement in the liquid phases of green concrete (Tattersall and Banfill, 1983; Tattersall, 1991; Ferraris, 1999). The friction among aggregate has a significant contribution to concrete rheology (Kurokawa et al., 1996).

Jeddah, Saudi Arabia considers a part of Arabian shield which covered mostly with igneous and metamorphic rocks with rareness of natural aggregates resources. In the same time, the populated areas of Jeddah extended rapidly owing to its strategic location position so that it is expected in future a lot of new population centers, roads, railways will be done. These constructions need huge qualities of aggregates. The Precambrian igneous and metamorphic rocks of the Arabian Shield considered as local source of crushed aggregates of concrete, mortar and pavement materials.

Diorite is a hard and dense coarse-grained plutonic igneous rock that can be used as an important source of crushed construction aggregates in cement concrete, asphaltic concrete, pavement layers, fill etc. The mineral constitutes of diorite having higher specific gravity, nearly equi-dimensional grains and are non-absorptive so that the crushed forms have high shear strength as well as high resistance of abrasion and lower absorption values. In the present experimental work, engineering properties of cement concrete made with diorite crushed aggregates will be evaluated.

2. Geological setting of the studied area

The study area represents a part of the Arabian Shield in the western of Saudi Arabia and extends between latitudes 39.00° and 39° 30¯ E and longitudes 21°30¯ and 21°55¯ N (Fig. 1). Geologically, this area has been subjected to many previous geological studies (Brown et al., 1963; Al-Shanti, 1966; Laurent et al. ,1973; Nebert et al., 1974; Alqahtani, 1979; Schmidt et al., 1982; Moore and Al-Reaili, 1989; Qari et al., 2001). Generally, the geology the study area can be summarized from old to young as follows:

1. Qattanah Complex is composed mainly of biotite monzogranite and hornblende granodiorite. The granodiorite of Qattanah complex is characterized by medium to coarse grained equi-granular, gray to pink and uniform in composition.

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2. Daghbij Complex is represented by massive to weakly foliated, fine to coarse grained dioritic rocks.
3. Madrakah Formation consists predominantly of andesitic to basalt lava, subordinate andesite and volcaniclastic rocks.
4. Daf Formation is characterized by its red colour. It subdivided into a lower part composed of siltstone, fine-grained sandstones and subordinate volcaniclastic rocks and lava.
5. Bathan Formation consists mainly of clayey rich shale beds. Bathan Formation was first described by Brown et al. (1963). It was accumulated within a major tectonic rifting phase,
6. Ubhur Formation is composed of green sandy clays, siltstones and soft white bioclastic limestone (Spincer and Vincent, 1984). The limestone beds are composed of microfossils and bivalves (Andreieff, 1983).
7. Hammah Basalt consists mainly of olivine basalt and minor pyroclastic deposits. Its age is late Miocene to Pliocene (Camp and Roobol, 1987).
8. Reefal Limestone is exposed in a discontinuous belt along the Red Sea coast. It forms a flat reef platform at low tide. It is massive, cavernous and very porous. It composed mainly of corals and mollusks.
9. Wadi Deposits consist of unconsolidated moderately to poorly sorted sands and gravels of braided channels (Smith, 1980).
10. Sabkha forms low-lying saline mud flats closed to the Red Sea coast and composed of moist brown terriginous sands and clays with interstitial gypsum.

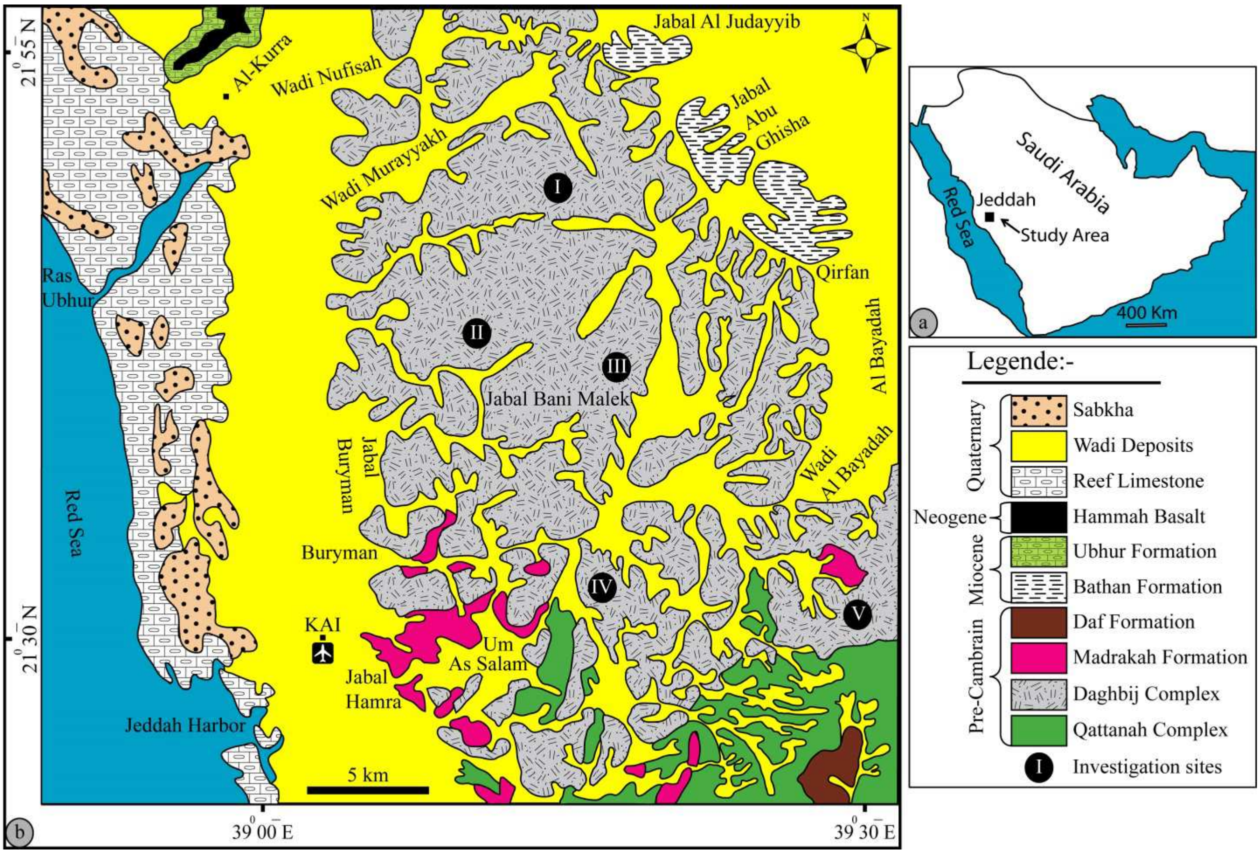

Fig. 1. Geological map of the studied area after Moore and Al-Reaili (1989).

3. Materials and experimental program

To evaluate the geotechnical quality of diorite crushed aggregates for concrete mix, representative aggregates samples were obtained from diorite crusher near Breman Bridge north Jeddah. Then the studied aggregates were subjected to three types of evaluation tests (physical, mineralogical, geochemical and mechanical). The mineralogical composition was done for representative fives bulk samples of diorite sources (Fig. 1). Then these samples were investigated microscopically using petrographic analysis of thin section and then supported by geochemical analysis which done at the ACME Analytical Laboratories Ltd., Canada.

The physical characteristics of the studied aggregates were done by: sieve analysis (ASTM C136, 2004), the specific gravity as well as absorption of both coarse and fine aggregates (ASTM C127, 1999; ASTM C128, 1993), fineness modulus (ASTM C33, 2003), sand equivalent (ASTM D2419-95, 1998) and flakiness index and elongation index of coarse aggregate (CEN, 1997; ASTM D4791, 2005). Los Angeles abrasion value test and particle index were done for coarse and fine aggregates samples according to (ASTM C131,, 1989) and (ASTM D3398, 2000) respectively. Finally, the weight-design of concrete mix was done using mix ratio 1:2:4:6 (water: cement: fine aggregates: coarse aggregates). The cement which used in this work was Ordinary Portland Cement (OPC) of Qassim Cement Company (Saudi Arabian Standards Organization through its standard No. SSA-143/1979). The workability degree (slump test) and compressive strength values (f_{cu}, 28 days), were done using 15cmx30cm specimens according to ASTM C469, 1994). The concrete samples are free steel types.

4. Results and discussion

The followings are the descriptions and interpretations of the physical, mineralogical and mechanical properties of the studied crushed aggregates.

4.1. Mineralogical composition

Generally, diorite and quartz diorite are characterized by coarse-grained intermediate intrusive igneous rocks with phaneritic texture. The studied samples are characterized by grey to dark grey and mineralogical composed mainly of plagioclase feldspar (andesine), biotite, hornblende and pyroxene. Sometimes, diorite contains small amounts of quartz (Blatt et. al., 2005).

Feldspars were represented as plagioclase type (oligoclase and andesine). Potassium feldspars were not recorded. Plagioclase crystals are the main constituents and represented by coarse-grained subhedral and euhedral crystal with of lamellar twinning. Quartz represents less than 10 % of quartz diorite samples (Fig. 2).

The major elements of representative samples were analyzed in Canada (ACME Analytical Laboratories Ltd.). The concentrations of major elements as well as and Sc, Ba, and Ni were determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES) by fusing 0.2 g of the studied powder sample using $LiBO_2$ (Tab. 1). The studied samples were plotted on SiO_2 and (Na_2O + K_2O) TAS discrimination diagram (Fig. 3). These samples were plotted in the field of diorite and quartz diorite.

Tab. 1. Chemical analysis data of the studied samples.

Major Elements [%]	**Site No.**				
	I	**II**	**III**	**IV**	**V**
SiO_2	63.52	62.36	63.22	64.22	64.12
Al_2O_3	17.04	17.01	17.07	16.13	16.22
Fe_2O_3	4.56	5.54	4.56	5.31	4.76
CaO	5.48	5.51	5.46	5.23	5.48
MgO	2.28	2.54	2.58	2.24	2.28
Na_2O	4.54	4.36	4.58	4.36	4.54
K_2O	0.65	0.61	0.64	0.68	0.65
MnO	0.06	0.08	0.06	0.08	0.06
TiO_2	0.53	0.52	0.53	0.51	0.53
P_2O_5	0.18	0.20	0.18	0.20	0.18
Cr_2O_3	0.01	0.01	0.01	0.01	0.01
Ba	0.02	0.03	0.02	0.03	0.02
LOI	0.93	1.02	0.93	0.91	0.92
Sum	99.80	99.79	99.84	99.91	99.77

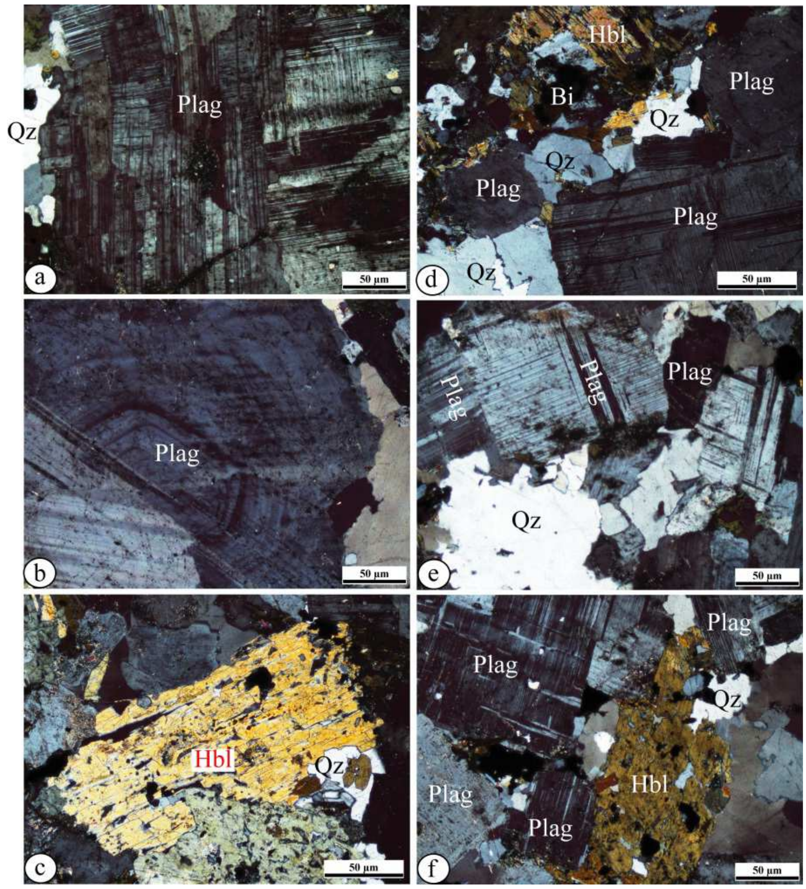

Fig. 2. Photomicrographs of coarse-grained diorite (a, b and c) and quartz diorite (d, e and f) under cross-nicoles showing plagioclase (Plag), hornblende (Hbl), quartz (Qz) and biotite (Bi).

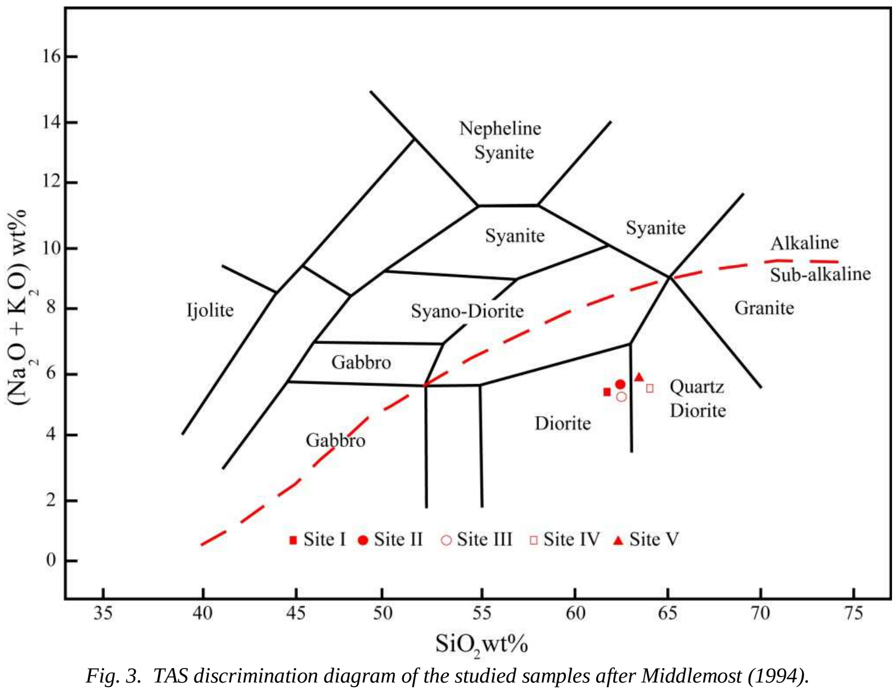

Fig. 3. TAS discrimination diagram of the studied samples after Middlemost (1994).

4.2. Gradation analysis

In concrete mix aggregates geotechnical studies, the gradation curves of both fine and coarse aggregates play an effective role in both properties of green and hardened concrete. The needed amount of cement paste depends mainly on the amount of inter-aggregate void space which must be completely filled (Mehta and

Monteiro, 1993). Furthermore, the aggregate grading influences directly green concrete properties (consistency and segregation) and extended to the hardened concrete properties (Baker and Scholer, 1973).

Fig. 4 shows grain size analysis of both crushed aggregates of the studied samples. It shows nearly smooth well-graded curves. From aggregate size gradation and aggregate packing points of view, well graded crushed aggregates usually have less void spaces among particles than poor graded natural non-crushed aggregates, and are requiring less cement paste to fill the inter-particle voids. Consequently, the studied crushed aggregates will give an acceptable degree of aggregate packing and require a lesser amount of paste to attain a given consistency since less cement paste will be needed to fill the voids between the aggregate particles (Struble et. al., 1998; Smith and Collis, 2001; Jamkar and Rao, 2004; ACI- E-701, 2007).

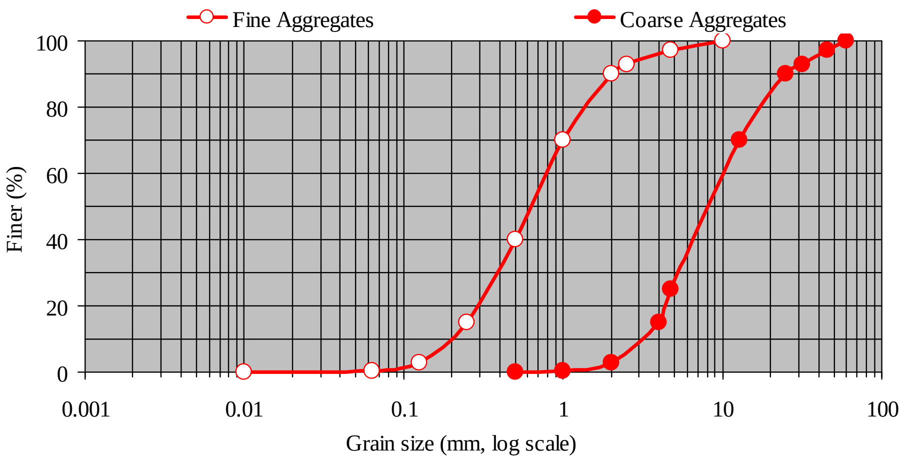

Fig. 4. Grain size distribution curves of the studied crushed aggregates.

4.3. The Fineness Modulus (FM)

Fineness modulus (FM) is one of the most used computed factors in aggregate classification processes. Usually, it uses to verify the uniformity degree of aggregate gradation. In other words, smaller variations in FM-values of fine aggregate grading can affect the aggregate workability owing to the higher surface area. The FM value of an aggregate usually proportional to its average particles size that means the higher the FM, the coarser the aggregate is. FM-value of the studied crushed aggregates samples ranges from 5.1 to 5.5 and from 3.1 to 3.3 for coarse and fine aggregates respectively (Tab. 2). This means the studied aggregates will produce concrete mix with an acceptable workability degree and have a highest compressive strength (ASTM C469, 1994).

4.4. Specific gravity

The determination of specific gravity of concrete aggregates considered as very important test that was done during the concrete design stage and used as an indicator of the concrete aggregate suitability. Furthermore, the low values of specific gravity point to aggregates are porous, weak, or absorptive. The specific gravity values of both studied course and fine aggregates vary from 2.83 gm/cm^3 to 2.85 gm/cm^3 and from 2.81 gm/cm^3 to 2.83 gm/cm^3 respectively (Tab. 2). The narrow variation in specific gravity of the studied aggregates is a very good property in concrete mix applications (Nichols, 1991). This means that, the studied crushed aggregates were met the standard limits for both coarse and fine aggregate specific gravity.

4.5. Absorption

The concrete aggregates absorption test must be done to assess the effective water/cement ratio which depends upon available free water of hardened concrete (Newman, 1959). During concrete mix, aggregates with a high absorption value will absorb greater amounts of water and cement and thus increases costs. From concrete durable point of view, the aggregates of very low absorption values will profuse lower strength bonds and lesser durable concrete (Ahn, 2000). The absorption value of the studied crushed aggregates varies from 0.64 to 0.68 and from 0.54 to 0.66 for both coarse and fine aggregates respectively (Tab. 2). This indicated that the studied crushed aggregates have standard limits for aggregates absorption in the specified standards.

4.6. Textural characteristics

4.6.1. Roundness degree and shape

The textural characteristics of aggregates play a very effective function on the workability and strength of the green and hardened concrete mix. Angular particles of crushed aggregates tend to be more interlocked than rounded particles of natural aggregates when compacted. The rough cubical aggregates will give well aggregates particles interlock (Kuo and Freeman, 1998; Maerz, 2004).

Figure 5 shows detailed investigations of roundness and shape of the studied crushed aggregates. The result data of roundness degree shows that the studied coarse crushed aggregates are composed mainly of very angular (65.82 %), angular (24.70 %), Sub-angular (6.11 %) and Sub-rounded (3.36 %). whereas fine aggregates are consisting of very angular (58.28 %), angular (22.60), sub- angular (13.37 %) and sub-rounded (5.75 %, Tab. 2 and Fig. 5a).

The dominance of angular grains within both coarse and fine crushed aggregates is having higher ratios of angular grains makes more grain-to-grain contact with lock tightly within concrete mix. Consequently, the higher ratio of angular grains of the studied crushed aggregates will give high surface area and good link characteristics but necessitate more cement amount to generate more workable concrete mix (Mehta and Monteiro, 1993; Kosmatka and Panarese, 1998).

It is well known that, the shape of aggregates has more effective role in the fresh concrete properties than hardened concrete. In fact, the shape of aggregates controls green concrete workability as well as compactability and thereby concrete strength and durability of hardened concrete (Willis, 1967; Jing and Stroeven, 2006). From surveying the shape data of both fine and coarse aggregates, it was found that, both of them constitute mainly of equant grains (Fig. 5b). That means, the studied aggregates will produce concrete mixture characterized by good strength as well as acceptable degree of workability.

4.6.2. Elongation and flakiness index

To make a qualified concrete mixture, the flaky and elongated coarse aggregates must be avoided that due to the occurrence of elongated and flaky coarse aggregates further than a certain limit will increase the degradation of the concrete mixes as well as the presence of high percentage of elongated and flaky coarse aggregates considered as one of the undesirable properties of concrete aggregates. Furthermore, elongated and flaky coarse aggregates will make the concrete mixture more harsh and difficult to work with (Shetty, 2008). Also, it has been established that, the shape of concrete aggregate plays a very effective character in the concrete mix properties (Al Harthi and Abo Saada, 1997). As well as the flaky and elongated coarse aggregates are not desirable and they tend to break easily under stress (Ali and Sengoz, 2005).

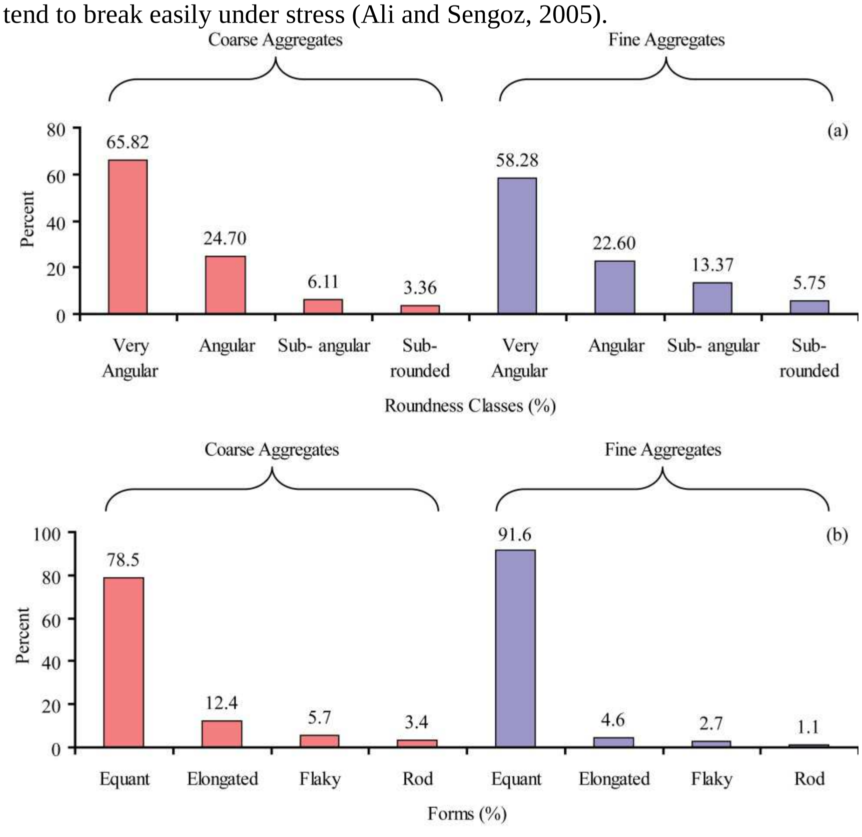

Fig. 5. Relative frequency of different roundness classes shape of the studied crushed aggregates (average values).

Both flakiness (FI) and elongated (EI) index of the studied crushed coarse aggregates were calculated by using flakiness and elongated index gauges. The FI-value ranges from 4.21 % to 4.82 %, whereas the EI-value varies from 5.94 % to 6.91 % (Tab. 2). That means that the studied crushed coarse aggregates are consisting mainly of equi-dimensional or cubical grains, that means these crushed grains are enough resist shear strength. This agrees with the results given by Li and Kett (1967).

4.7. Los Angeles abrasion (LAA)

The main aim of LAA-test test was to evaluate abrasion resistance of the studied crushed coarse aggregates which can be used in both cement concrete and asphaltic concrete mix. Consequently, the obtained data will be very important in assessment the durability performance of the studied aggregates. Los Angles abrasion (LAA) values of the studied coarse crushed aggregates (larger than 2.36 mm) vary from 11.52 % to 13.2 % (Tab. 2). These results indicate strong resistance of the studied aggregates for abrasion (ASTM C131, 1989). The relative higher conflict to wear, as evaluated by a low abrasion loss percent, is desirable characteristics of aggregates to be used in cement concrete and asphaltic concrete mix. It was found that, there are strong correlations among LAA-values and flakiness index, elongation index and very angular grains content of the studied coarse crushed aggregates (Tab. 2 and Fig. 6).

4.8. Particle index

The particle shape, angularity, and surface texture considered as important and critical properties in evaluation processes of fine aggregate quality for both cement concrete and asphalt concrete mix. The geometrical irregularities of an aggregate particle are of great importance for the behavior of the aggregates. This test depends mainly on the conception that the voids of an aggregate was characterized the compacted of one-sized aggregate within a standardized mold and correlated with grain shape, grain angularity and textural characteristics of an aggregate.

The particle index is determined according to (ASTM D3398, 2000); it is computed from the following equation:

$$I_a = 1.25(V_{10}) - 0.25(V_{50}) - 32.0 \qquad (1)$$

Where Ia = particle index,
V_{10} = voids in aggregate compacted at ten drops per layer and
V_{50} = voids in aggregate compacted at 50 drops per layer.

The value of particle index of the studied fine crushed aggregates fluctuates from 5.37 to 6.11 (Tab. 1), that means this type of crushed fine aggregate has a considerable amount of angular and rough texture, well interlocking, high packing, better performance, and high rutting resistance (Boutilier, 1967; McLeod and Davidson, 1981; Winford, 1991; Neville, 1997; Lee et al., 2000). Consequently, it was indicated that a strong correlation between the particle index values and very angular grains content of fine aggregates (Tab. 2).

4.9. Workability of fresh concrete

The workability measures the flow ability of fresh cement concrete and it considers as one of the most important characteristics of green cement concrete components (aggregates, cement and water). The workability degree depends mainly on some aggregate characteristics (e.g. gradation, shape, and surface textures) and aggregate: cement: water ratio. The concrete components as well as mix ratio effect on its flow ability, segregation resistance, and compact ability of concrete (Smith and Collis, 2001).

Texturally, the natural aggregates characterized by smooth gain surface and spherical grain shape that provides more workability of concrete mix require less water for cement concrete mixing. Consequently, crushed fine aggregates have acute and rough surfaces so that, the fresh concrete are having less workability degree.

The slump test results of the studied diorite crushed aggregates values are ranging from 88 mm to 95 mm (Tab. 3). These results mean that, the workability of the studied crushed aggregates is medium and acceptable for standard reinforced works without any vibration (Wilby, 1991). Furthermore, the workability degree of the studied crushed aggregates has a strong positive correlation with very angular grain percent of fine aggregates (R^2 value =0.8, Fig. 7).

Tab. 2. Basic physical and mechanical properties of the studied diorite crushed aggregates (*).

Coarse Aggregates

Sample No.	**FM**	**Specific Gravity** [gm/cm^3]	**Abs.** [%]	**Textural Characteristics**						**LAA** [%]
				FI [%]	**EI** [%]	**Roundness Classes** [%]				
						Very Angular	**Angular**	**Sub-angular**	**Sub-rounded**	
1	5.3	2.83	0.64	4.36	6.18	63.2	25.72	7.41	3.67	11.89
2	5.4	2.83	0.65	4.61	6.74	66.87	24.75	6.84	1.54	12.6
3	5.5	2.83	0.67	4.37	6.24	63.21	26.45	5.74	4.6	11.92
4	5.4	2.83	0.68	4.65	6.82	67.42	26.47	4.82	1.29	12.71
5	5.3	2.85	0.64	4.82	6.88	69.78	19.47	7.11	3.64	13.2
6	5.2	2.83	0.65	4.32	6.1	62.57	27.84	6.22	3.37	11.8
7	5.2	2.83	0.67	4.21	5.94	62.85	24.76	8.21	4.18	11.52
8	5.3	2.85	0.66	4.56	6.52	66.11	25.41	5.42	3.06	12.46
9	5.1	2.83	0.64	4.71	6.71	67.48	25.42	5.98	1.12	12.87
10	5.2	2.84	0.67	4.78	6.91	67.94	24.13	4.75	3.18	13.07
11	5.3	2.83	0.67	4.61	6.57	66.17	24.15	4.98	4.7	12.59
12	5.2	2.83	0.68	4.56	6.47	66.12	24.11	6.22	3.55	12.46
13	5.3	2.83	0.64	4.6	6.49	66.47	25.31	6.78	1.44	12.57
14	5.3	2.84	0.65	4.75	6.87	68.74	25.41	5.78	0.07	13
15	5.2	2.83	0.67	4.71	6.91	68.22	24.27	6.11	1.4	12.87
16	5.2	2.83	0.68	4.39	6.23	63.74	25.32	6.14	4.8	11.99
17	5.3	2.85	0.65	4.41	6.19	63.45	24.55	6.13	5.87	12.03
18	5.3	2.84	0.66	4.62	6.49	65.82	22.98	6.42	4.78	12.62
19	5.4	2.83	0.64	4.59	6.37	66.42	23.45	5.73	4.4	12.54
20	5.3	2.83	0.67	4.44	6.46	63.91	24.11	5.47	6.51	12.13

Fine Aggregates

Sample No.	**FM**	**Specific Gravity** [gm/cm^3]	**Abs.** [%]	**Roundness Classes** [%]				**Particle Index** [%]
				Very Angular	**Angular**	**Sub- angular**	**Sub-rounded**	
1	3.1	2.82	0.55	58.59	22.42	15.88	3.11	5.79
2	3.2	2.82	0.54	56.75	24.46	13.74	5.05	5.81
3	3.1	2.83	0.56	57.61	23.22	14.22	4.95	5.69
4	3.1	2.82	0.57	55.76	24.18	13.47	6.59	5.49
5	3.2	2.83	0.54	56.99	23.31	12.87	6.83	5.56
6	3.1	2.82	0.55	54.91	22.87	13.44	8.78	5.368
7	3.3	2.83	0.56	56.55	21.91	14.74	6.8	5.58
8	3.1	2.83	0.56	57.62	22.24	15.22	4.92	5.69
9	3.2	2.82	0.64	59.15	23.24	13.41	4.2	5.79
10	3.2	2.83	0.66	59.61	22.14	12.44	5.81	5.89
11	3.3	2.83	0.57	58.66	23.22	12.76	5.36	5.79
12	3.2	2.81	0.58	57.62	24.24	11.47	6.67	5.69
13	3.2	2.82	0.59	59.65	25.14	13.44	1.77	5.89
14	3.1	2.83	0.61	60.55	20.22	14.11	5.12	5.97
15	3.2	2.82	0.57	59.61	20.31	12.61	7.47	5.88
16	3.3	2.82	0.59	58.71	19.49	13.44	8.36	5.79
17	3.2	2.82	0.58	57.78	24.47	11.47	6.28	5.67
18	3.2	2.83	0.62	59.78	23.87	11.94	4.41	5.91
19	3.1	2.82	0.59	60.58	19.66	12.71	7.05	6.11
20	3.2	2.83	0.56	59.17	21.43	13.94	5.46	5.79

(*) FM: fineness modulus, SE: Sand equivalent, Abs: Absorption, LAA: Los Angeles abrasion, FI: Flakiness index and EI: Elongation index

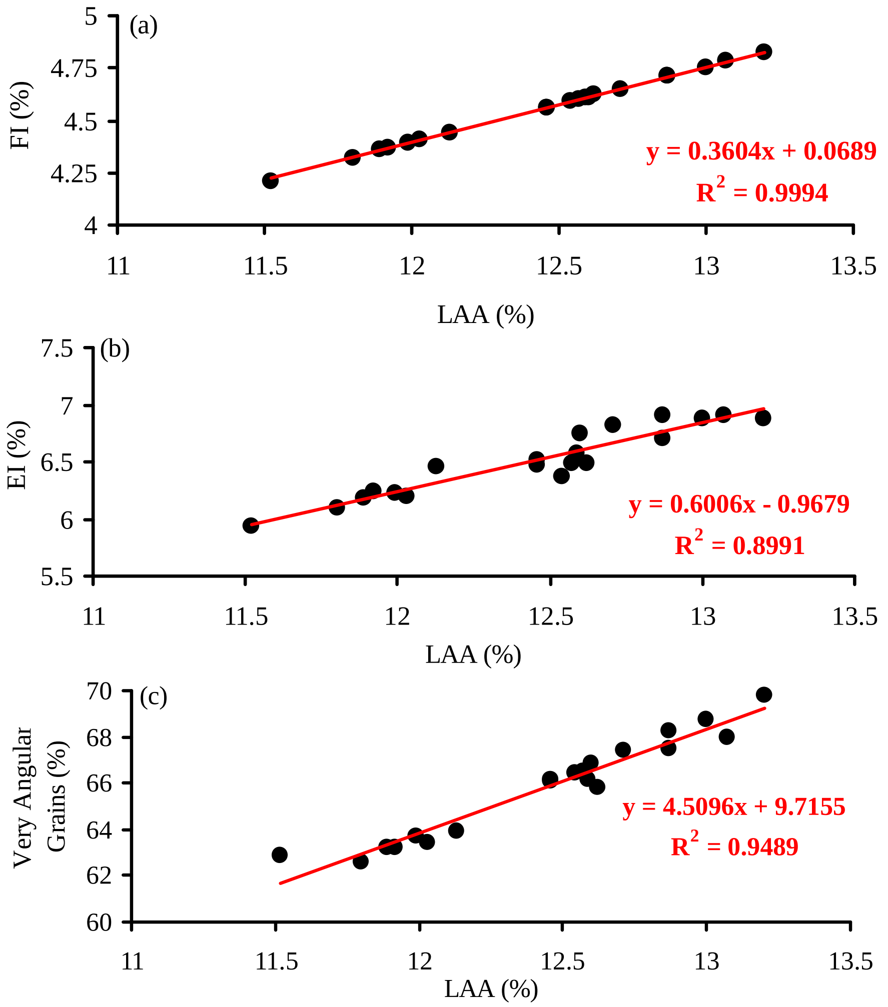

Fig. 6. Los Angles abrasion (LAA) versus flakiness index (a), elongation index (b) and very angular grains content (c) of coarse crushed aggregates.

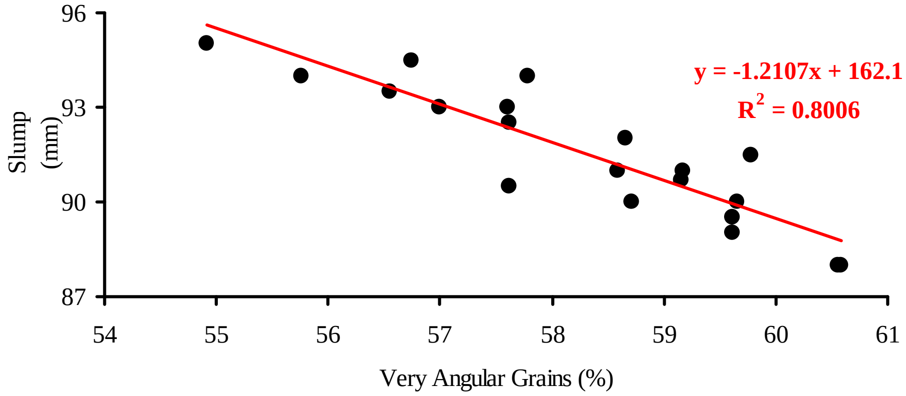

Fig. 7. Slump (mm) versus very angular grains content of fine aggregates.

4.10. Hardened concrete strength

The hardened concrete strength has been understood to depend principally on water: cement: aggregates percentage and the compaction degree. Nevertheless, the textural characteristics of an aggregate will be influenced on the strength of hardened concrete (BS EN 12390:3, 2002; Rocco and Elices, 2009). The natural aggregates of smooth and rounded grains need less amount of water in concrete mix to give good strength degree of hardened concrete at the same content of mixed cement. Consequently, angular and rough crushed aggregates provide hardened concrete with more compacted and more strength resistance. The compressive strength values of the studied concrete mix (28-days) were ranging from 34.43 MPa to 38.32 MPa (Tab. 3).

Figure 8 indicates a strong direct proportional relationship between compressive strength and very angular grains content of coarse aggregates (R^2 value = 0.96, Fig. 8a). Contrarily, it had indicated an indirect weak proportional relationship between compressive strength and workability (R^2 value = 0.16, Fig 8b).

Tab. 3. Workability and compressive strength of the studied diorite crushed aggregates cement concrete.

Sample No.	**Slump** [mm]	**Compressive Strength** [MPa]	**Sample No.**	**Slump** [mm]	**Compressive Strength** [MPa]
1	91	34.73	11	92	36.23
2	94.5	37.43	12	92.5	36.53
3	93	35.03	13	90	36.83
4	94	37.13	14	88	38.32
5	93	38.32	15	89.5	37.72
6	95	34.43	16	90	34.73
7	93.5	34.73	17	94	35.03
8	90.5	36.53	18	91.5	36.53
9	90.7	37.43	19	88	36.83
10	89	38.02	20	91	35.63

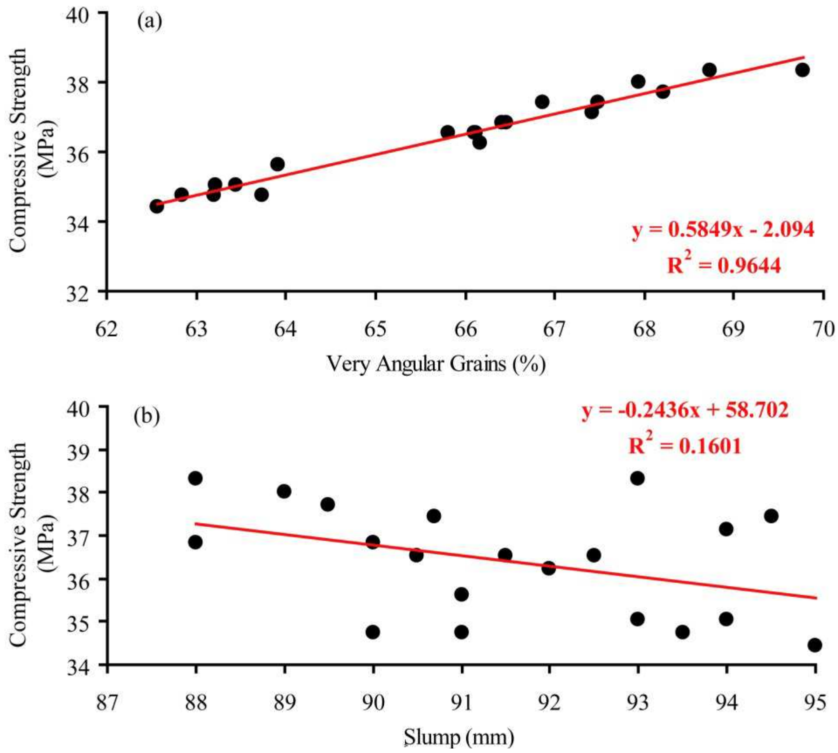

Fig. 8. Compressive strength values of the studied concrete mix (28-days) versus very angular grains content of coarse aggregates and slump [mm] values (a and b respectively).

5. Summary and recommendations

The quality of dioritic crushed aggregates has been evaluated on the basis of detailed experimental geotechnical results; the following conclusions could be drawn:

1. Diorite and quartz diorite are hard and dense enough coarse-grained plutonic igneous rocks that are suitable for using as crushed construction aggregates.
2. The studied crushed aggregates meet the standard gradation limits of concrete aggregates.
3. From textural characteristics point of view, the studied coarse crushed aggregates are composed mainly of equi-dimensional angular and rough grains so that these aggregates will produces more grain-to-grain contact with lock tightly within concrete mix.
4. The results of slump test as well as unconfined compressive strength test of the studied aggregates concrete indicate a suitable degree of workability of fresh concrete and a good mechanical strength of hardened concrete.

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