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# Performance of Cement Mortar Made with Fine Aggregates of Dune Sand, Kharga Oasis, Western Desert, Egypt: An Experimental Study

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## ABSTRACT

Fine aggregates of sand dunes cover an area of more than 16.6% of the total area of Egypt, especially in the Western Desert. In Kharga Oasis, about 400 $km^2$ are covered by sand dunes. Sustainable development in the Western Desert of Egypt can be impaired by hazards due to movements of dunes causing desertification which impacts farm lands and infrastructure such as asphaltic roads. The fine aggregates of these dunes are considered as an important natural source of fine aggregate making them a major component in concrete and mortar mixes. The dune sands in Kharga Oasis are composed mainly of quartz, feldspars and trace amounts of other minerals. The silt and clay contents are negligible. Using the USCS-classification, the studied dune sands are poorly graded sand (SP). Texturally, these dune sands are consisting of rounded spherical grains with less abundant angular components. The specific gravity varies in a very narrow range. The TDS-values ranged from 512 to 523 ppm. Calcium Carbonates $(CaCO_3)^{2-}$, Sulphates $(SO_4)^{2-}$ and Chlorides $(Cl)^-$ are present with scarce amounts. Based on the grain-size, textural, mineralogical and chemical results obtained in this study, dune sands in Kharga Oasis can be used as fine aggregates in cement mortar.

**KEYWORDS:** Kharga dune sands, Fine aggregates, Cement mortar.

## INTRODUCTION

Fine aggregates (sands) make up the main bulk of masonry mortar; therefore having a significant effect upon the properties of the product in both fresh and hardened state. The selection of suitable aggregates, which are capable of producing a product with the optimum properties, is very important. Mortar is one of the constituents of the composite anisotropic material denominated masonry. Mortar is responsible for creating a uniform stress distribution correcting the irregularities of blocks and accommodating deformations associated to thermal expansion and shrinkage. Mortar is the material responsible for the distribution of stresses in masonry structures. The knowledge about the fresh and hardened properties of mortar is fundamental to ensure a good performance of masonry walls (Vladimir et al., 2011).

The sand type has a very significant influence on the mortar properties (De Schutter and Poppe, 2004). In desert regions, there is an abundance of natural fine aggregates known as dune sands. In Egypt, nearly 16.6% of the total area of the country is covered with dune sand, especially in the Western Desert. The Western Desert covers approximately 700,000 $km^2$, which is more than two-thirds of the total area of Egypt. In Kharga Oasis, about 400 $km^2$ are covered by dune sands which occur in the form of sand sheets, sand dunes and drifts. Sand dunes in Kharga Oasis are a part Abu El-Maharek sand dune field which is the

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biggest sand dune field (750 km length) in the Western Desert of Egypt. It extends from the NE of the Baharia Oases and runs in a southeastern direction to the Egypt-Sudan borders (El Gammal and Cherif, 2006; Salman, et al., 2010).

Significant works have been reported in the literature regarding the geological origin of these sands and deserts, with results related to their physical, chemical, morphological and mineralogical properties (Beadnell, 1909, 1910, 1933; Bagnold, 1941; Ashri, 1970; El Baz and Wolfe, 1981; El Baz and Hassan, 1986; Issawi and Henawi, 1990; Embabi, 2004; El Gammal and Cherif, 2006). However, very rare studies (Abu Seif, 2011) have been conducted for utilization of these sands as a construction material.

In desert regions, the construction activities require a lot of aggregates. Because of the remoteness of the construction sites in these areas from aggregate production quarries, transporting the aggregates becomes expensive and uneconomical. In addition, engineers are faced with a more restricted choice of materials in these regions as dune sand is finer than normal sand used in construction and does not meet the standard requirements for fine aggregate grading (Al-Harthy et al., 2007). This paper presents the results of an extensive field and laboratory testing carried out to assess dune sands in respect of their use as mortar fine aggregates.

## LOCATION AND GEOLOGICAL SETTING

El-Kharga City is the capital of Al-Wadi Al-Gadid Governorate. Kharga Oasis is located in the Western Desert of Egypt between longitudes 30° 20́ and 30° 40́ E and latitudes 25° 05' and 25° 30' N. It lies at 140km to the east of Dakhla Oasis and 220km southwestward of Assiut City (Fig. 1). It is bounded by the Eocene limestone plateau from the east and north, where steep cliffs form a sharp boundary to the depression floor (El-Sankary, 2002). This limestone plateau stretches along Middle and Upper Egypt with an elevation of up to 550 m above the sea level. However, towards the south and west, the depression floor merges gradually into Taref Sandstone open desert. Kharga Oasis is the largest oasis in the Western Desert of Egypt and consists of a depression about 160km long and from 20km to 80km wide.

The exposed sedimentary sequence in Kharga Oasis is ranging in age from the Lower Cretaceous to the Quaternary. This sedimentary sequence comprises (from older to younger) the following:

1- Sabaya Formation (Barthel and Boettcher, 1978) is the oldest formation in the study area and assigned to Albian-Early Cenomanian age (Schrank, 1987). It is composed mainly of hard to moderately hard, cross-bedded and medium to fine sandstone.
2- Maghrabi Formation (Barthel and Herrmann-Degen, 1981) consists of moderately hard claystone with iron oxide streaks, siltstone and fine sandstone.
3- Taref Formation (Awad and Ghobrial, 1965) is hard cross-bedded coarse to medium-grained sandstone with few interbeds of sandy silt.
4- Quseir Shale (Campanian) consists of an alternation of claystone, siltstone and sandstone beds. It was also named the Variegated Shale (Said, 1962).
5- Duwi Formation (Late Campanian–Early Maastrichtian) is a phosphorite bearing bed intercalated with limestone, sandy limestone, marl, calcareous shales and calcareous sandstone.
6- Dakhla Shale (Maastrichtian-Lower Paleocene) is composed mainly of shale and mudstone in rhythmic manner of glauconite-rich facies.
7- Tarawan Formation (Upper Paleocene) overlies Dakhla Formation and consists of chalky limestone generally with shale at the top.
8- Quaternary deposits are represented by the playa and sand dunes, semi friable to moderately hard sandstone where they are concentrated in the northern portion of Kharga Oasis.

Mobile and active sand dunes cause an environmental hazard during strong winds and sand origin storms, particularly in the summer months.

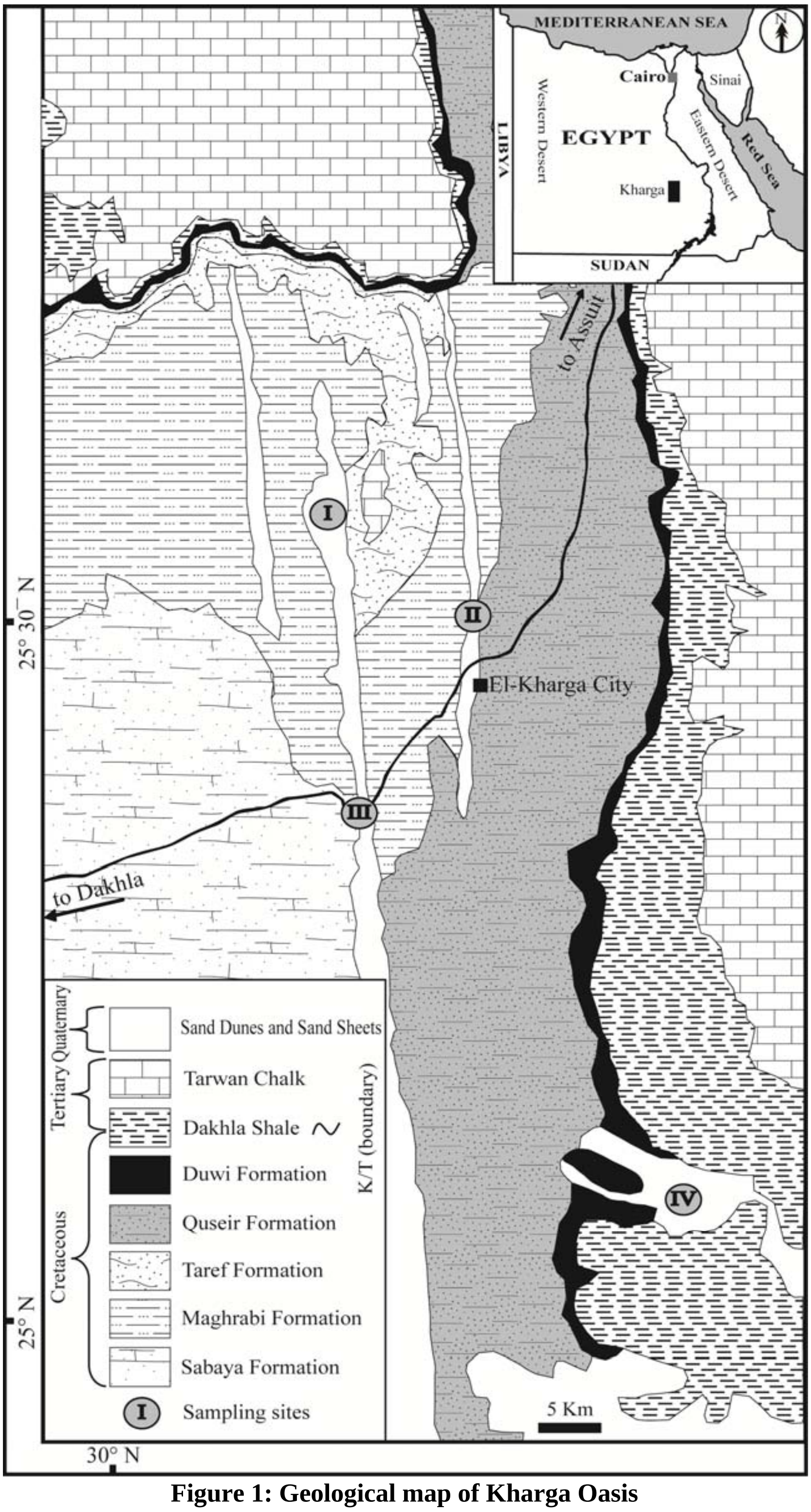


**Figure 1: Geological map of Kharga Oasis**

Sustainable development in the Western Desert of Egypt can be impaired by hazards due to movements of dunes causing desertification which impacts farm lands and infrastructure such as asphaltic roads, railways and monumental sites (Salman et al., 2010). These roads are considered as the most important ways which connect Kharga Oasis with Nile Valley Governorates and other oases in the Western Desert (Figure 2).

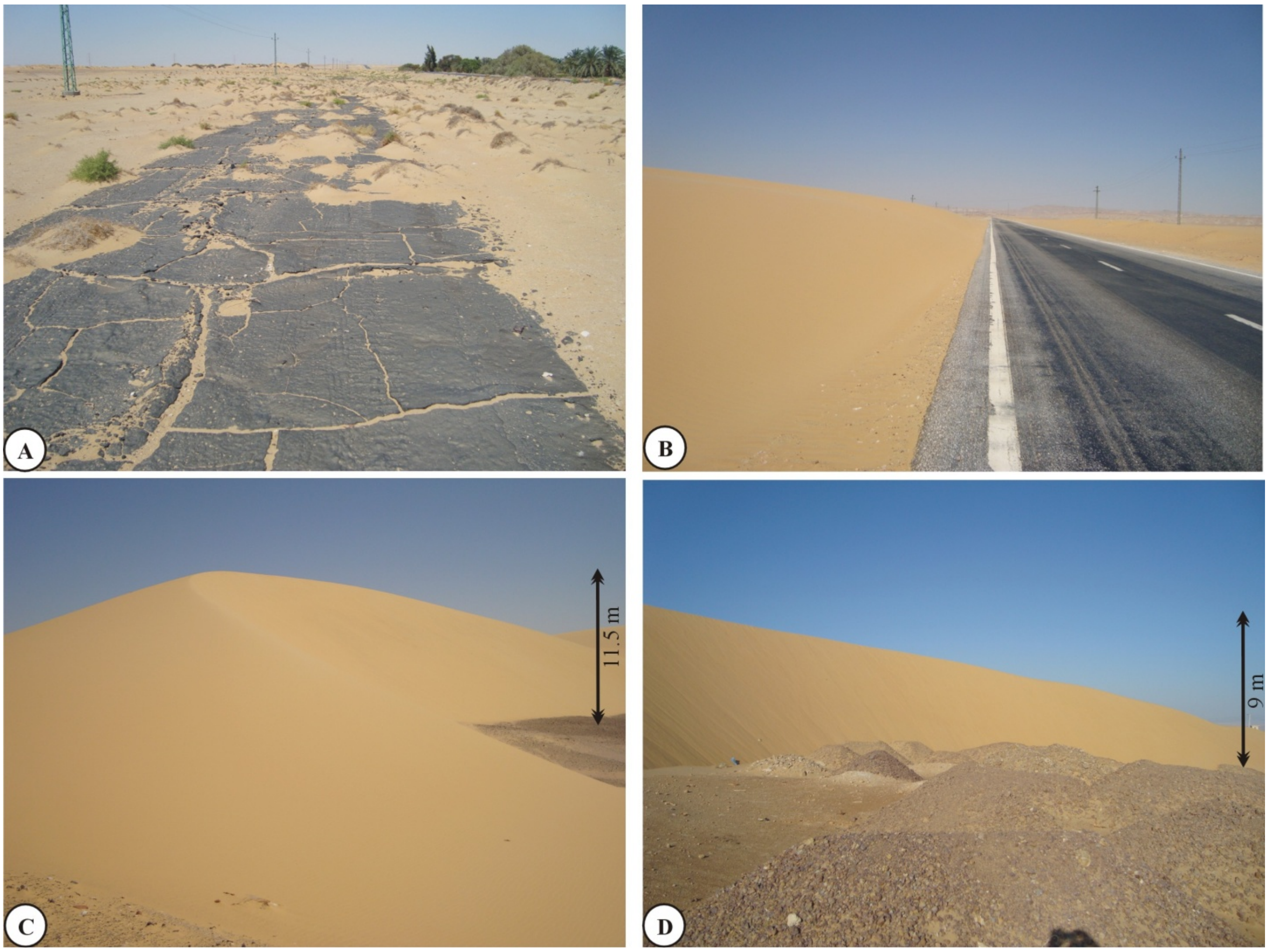


**Figure 2: Field photographs of sand dunes showing; (A): destructive effect of sand dunes along old Kharga-Assuit asphaltic road; (B): destructive effect of sand dunes along present Kharga-Assuit asphaltic road; (C): barchan sand dune to the east of El-Bagawat Cemetery (site II); and (D): barchan sand dune along Kharga-Dakhla asphaltic road (site III)**

## MATERIALS USED

The cement used in this study was Assiut Ordinary Portland Cement (Egyptian CEM I (32.5 N)) (Egyptian Standard Specifications ES. 1- 4756, 2007). The crushed fine aggregates (Taref Sandstone, local material) were taken from a nearby crusher in Kharga Oasis. These crushed aggregates are consisting mainly of quartz (~ 97%) and feldspars (~ 2%). The dune sands used in the cement mortar mixtures were taken from four sites in Kharga Oasis (Fig. 1). The mixes of mortar were prepared keeping the ratio of cement: aggregate: water constant at 1:3:2 (by weight at dry condition). First of all, the total cement and aggregates were dryly mixed for 10 s. Then the total amount of water was added and mixed for 1 min.

## TESTING PROGRAM

Twenty representative dune samples were collected from four sites in Kharga Oasis. To evaluate physical, chemical, mineralogical and mechanical quality of the studied dune sand mortar, the following tests were conducted on the dune sands: sieve analysis; specific gravity; absorption; fineness modulus; sand equivalency. Table 1 presents physical properties of these dune sands. The specific gravity and absorption tests were carried out in accordance with ASTM C128 (1993). Sieve analysis and fineness modulus tests were conducted in accordance with ASTM C33 (1999). The sand equivalent value test of these samples was conducted in accordance with ASTM D2419-95 (1998). Also, the textural characteristics (form and roundness) were counted for both dune sands and crushed aggregate grains and listed in Table 2. The different forms of the studied aggregates (dune and crushed aggregates) were counted using binocular microscope, whereas roundness degree was determined for 100 quartz grains using the visual chart by Powers (1953). The chemical analysis of the bulk sample was performed to determine the chemical compounds of the dune sand samples (Table 3). The mineralogical composition of dune sands was tested using XRD analysis. In addition, to evaluate the effect of dune sands on the mortar properties, various dune sand mixes varying from 0.0% to 100% of the total content of aggregates were used instead of crushed sand of Taref Formation (local material). The slump and compressive strength tests, $f_{cu}$ (7 and 28 days), were carried out on 100-mm cube specimens, in accordance with ASTM C469 (1994). All tests used two duplicate samples.

## RESULTS AND DISCUSSION

Grain size distribution, toughness, form, surface texture, chemical impurities and mineralogical composition of fine aggregate are properties which controlled the behaviour of fresh and hardened mortar. These factors will be discussed in the following section.

### Grain Size Distribution

Grain size distribution affects significantly some characteristics of mortar like packing density, voids content, and, consequently, workability, segregation and durability. Many authors (Johansson, 1979; Johansen and Andersen, 1989; Glavind et al., 1993; Golterman et al., 1997) claim that uniformly distributed mixtures produce better workability than gap-graded mixtures.

The studied fine aggregates of sand dunes show unimodal distribution (Fig. 3). These samples are predominantly fine sand with no gravel and little amount of coarse sand whatsoever a trace of fines. The components of coarse fraction (4.72-2.0 mm) vary from 0.2% to 0.6%. Medium fraction (2.0-0.42 mm) range from 29% to 36%. Fine fraction (0.42-0.075 mm) range from 63.4% to 70.8%. Silt + clay fractions (<0.075m) are 0.1% to 0.6% (Table 1). The values of coefficient of uniformity ($C_u$) vary from 2.11% to 2.18%, while the values of coefficient of curvature ($C_c$) range from 1.2% to 1.3%. All samples were classified as poorly graded sand (SP) according to the Unified Soil Classification System (USCS).

The Fineness Modulus (FM) is the most commonly computed factor for fine aggregates, which is used to determine the degree of uniformity of the aggregate gradation. Fineness modulus (FM) values of the studied dune sand samples range from 0.9 to 0.99 (Table 1). These results indicate that the studied dune sands do not meet the limits for fine aggregate gradations in the specified standards. So, it is necessary to improve gradation of these dune sands by mixing them with well graded crushed fine aggregates of Taref Sandstone (local material) to produce an acceptable level of gradation.

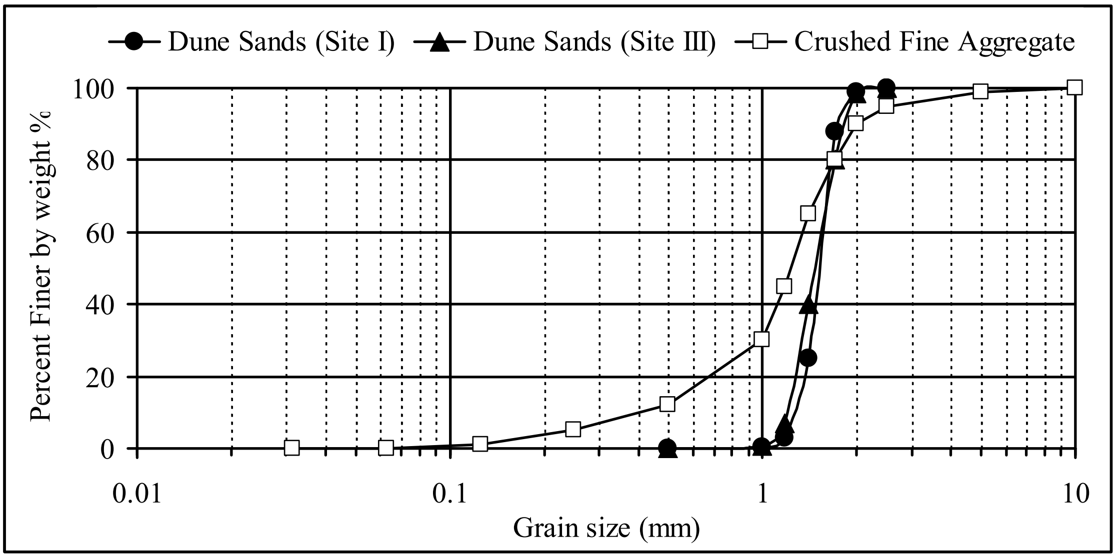


**Figure 3: Grain size distribution of the studied aggregates**

**Clay Content (Sand Equivalent)**

In natural fine aggregates (sands), the presence of deleterious particles like clay minerals and organic matter mostly present in the minus 75μm portion, may cause several problems such as: (1) lower strength and durability and (2) affecting the bond between the binder and the aggregate and increasing significantly the demand for water (Yool et al., 1998; Dumitru et al., 1999; Hudson, 1999). Consequently, some specifications limit the amount of minus 75μm to avoid these negative effects. The sand equivalent values of the studied fine aggregates vary from 95% to 97% (Table 1). This means that the studied fine aggregate contains negligible amounts of mud (silt and clay).

**Specific Gravity ($G_S$)**

Specific gravity of an aggregate is essential during the design stage of structural elements. It is used as a useful indicator of the suitability of an aggregate and helps in determining the amount of cement needed in the mortar mix (Roberts et al., 1996). Very low specific gravity frequently indicates an aggregate that is porous, weak or absorptive (Langer, 1993). The specific gravity value of the studied fine aggregates of dune sands varies from 2.44 to 2.48 (gm/cm$^3$) (Table 1). The narrow variation in specific gravity of the studied dune sands is a very good property in mortar applications (Nichols, 1991). These results mean that the studied aggregates meet the limits for fine aggregates specific gravity in the specified standards and hence substantiate their utilization in various civil engineering related applications.

**Absorption**

Fine aggregates with very low absorption generally develop lower strength bonds and produce less durable mortars than those with a slightly higher absorption (Ahn, 2000). Aggregates with a high absorption value will absorb greater amounts of the cement into the aggregate and thus increase costs. Absorption value for the studied dune sand aggregates range from 0.94 to 0.96 (Table 1). These results indicate that the studied fine aggregates have standard limits for fine aggregates absorption in the specified standards.

**Textural Characteristics**

The textural characteristics of fine aggregates have an important effect on both fresh mortar (workability) and hardened mortar (strength and durability). There is a clear relationship between shape, texture and grading of aggregates and the voids content of aggregates.

Equant or spherical particles have less specific surface area than flat and elongated particles, and consequently require less cement paste and less water for workability (Shilstone, 1999). Flaky and elongated particles negatively affect workability, producing very harsh mixtures. Spherical particles lead also to better workability and finishability (De Larrard et al., 1997; Shilstone, 1999). Angular and rough particles tend to increase the demand for water as they have higher void content than round particles; these particles tend to increase the water demand for a given workability. Surface texture affects particle-packing efficiency; the impact of surface texture on cement mortar behavior becomes more important as particles get smaller (Hudson, 1999). Aeolian sand grains are generally more rounded because air-transported grains are intensively subjected to pitting and become round faster than those transported in aqueous media (El-Sayed, 1999).

**Table 1. Physical properties of the studied dune sands**

| Site | Sample No. | Coarse 4.72- 2.0 mm | Medium 2.0-0.42 mm | Fine 0.42-0.075 mm | Silt+Clay (<0.075) mm | $C_U$ | $C_C$ | USCS Classification | Fineness modulus (FM) | Sand equivalent % | Specific gravity (gm/cm$^3$) | Absorption |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 0.6 | 32 | 67 | 0.4 | 2.15 | 1.2 | SP | 0.95 | 97 | 2.45 | 0.94 |
| | 2 | 0.4 | 31 | 68 | 0.6 | 2.16 | 1.21 | SP | 0.95 | 96 | 2.44 | 0.95 |
| I | 3 | 0.5 | 33 | 66 | 0.5 | 2.14 | 1.2 | SP | 0.97 | 95 | 2.46 | 0.96 |
| | 4 | 0 | 31 | 68.6 | 0.4 | 2.18 | 1.25 | SP | 0.95 | 97 | 2.45 | 0.95 |
| | 5 | 0.2 | 29 | 70.8 | 0 | 2.15 | 1.3 | SP | 0.93 | 97 | 2.46 | 0.96 |
| | 6 | 0.5 | 31 | 68.3 | 0.2 | 2.14 | 1.22 | SP | 0.9 | 96 | 2.47 | 0.95 |
| | 7 | 0.3 | 34 | 65.4 | 0.3 | 2.14 | 1.24 | SP | 0.92 | 96 | 2.45 | 0.94 |
| II | 8 | 0.5 | 33 | 66.5 | 0 | 2.16 | 1.25 | SP | 0.98 | 95 | 2.45 | 0.96 |
| | 9 | 0.4 | 35 | 64.1 | 0.5 | 2.18 | 1.26 | SP | 0.98 | 95 | 2.44 | 0.96 |
| | 10 | 0.5 | 34 | 65.1 | 0.4 | 2.16 | 1.25 | SP | 0.99 | 95 | 2.46 | 0.95 |
| | 11 | 0.4 | 32 | 67.1 | 0.5 | 2.11 | 1.24 | SP | 0.98 | 96 | 2.45 | 0.95 |
| | 12 | 0.3 | 35 | 64.1 | 0.6 | 2.14 | 1.25 | SP | 0.98 | 95 | 2.45 | 0.94 |
| III | 13 | 0.2 | 36 | 63.4 | 0.4 | 2.13 | 1.24 | SP | 0.91 | 95 | 2.46 | 0.95 |
| | 14 | 0.4 | 35 | 64.1 | 0.5 | 2.14 | 1.3 | SP | 0.91 | 95 | 2.46 | 0.95 |
| | 15 | 0 | 34 | 65.6 | 0.4 | 2.11 | 1.26 | SP | 0.93 | 95 | 2.47 | 0.95 |
| | 16 | 0.4 | 33 | 66.1 | 0.5 | 2.14 | 1.25 | SP | 0.94 | 95 | 2.45 | 0.95 |
| | 17 | 0.3 | 32 | 67.2 | 0.5 | 2.13 | 1.3 | SP | 0.95 | 95 | 2.45 | 0.96 |
| IV | 18 | 0.5 | 35 | 64.5 | 0 | 2.15 | 1.3 | SP | 0.95 | 95 | 2.46 | 0.94 |
| | 19 | 0.6 | 33 | 66.3 | 0.1 | 2.14 | 1.31 | SP | 0.94 | 96 | 2.48 | 0.95 |
| | 20 | 0.4 | 34 | 65.1 | 0.5 | 2.16 | 1.28 | SP | 0.92 | 95 | 2.45 | 0.95 |
| Average Value | | 0.4 | 33.1 | 66.2 | 0.3 | 2.14 | 1.26 | SP | 0.94 | 95 | 2.46 | 0.95 |

SP: Poorly graded sand; USCS: Unified Soil Classification System; $C_U$: Coefficient of uniformity and $C_C$: Coefficient of curvature

The relative frequency percentages of different forms and roundness classes of the studied dune sands as well as crushed fine aggregates of Taref Sandstone are listed in Table 2 and displayed in Figure 4. The dune sands are dominantly spherical form grains (74%) and about 80% of the total grains are rounded grains (well rounded grains = 23%, rounded grains = 35% and sub-rounded grains =22%). This means that the studied dune sands alone will need considerable amounts of cement and water to produce good workable and less strong mortar. It is clear that dune sands must be mixed with crushed fine aggregates (rough texturally crushed fine aggregates of Taref Sandstone) to improve their textural characteristics; thus mortar strength will be increased.

**Table 2. Relative frequency percentages of different forms and roundness classes of the studied aggregates**

| | Type | Dune sands | Crushed fine aggregates |
|---|---|---|---|
| Form | Equant | 76 | 57 |
| | Elongated | 15 | 25 |
| | Flaky | 9 | 18 |
| Roundness Degree | Very angular | 6 | 13 |
| | Angular | 13 | 23 |
| | Sub-angular | 22 | 37 |
| | Sub-rounded | 34 | 20 |
| | Rounded | 9 | 4.5 |
| | Well-rounded | 16 | 2.5 |

**Table 3. Basic geochemical characteristics of the studied dune sands (average values)**

| Site | pH | TDS (ppm) | $(CaCO_3)^{2-}$ (ppm) | $(SO_4)^{2-}$ (ppm) | $(Cl)^-$ (ppm) | $SiO_2$ % | FeO % | $Al_2O_3$ % | CaO % | MgO % | $K_2O$ % | $Na_2O$ % | Loss on ignition |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | 7.5 | 512 | 69 | 21 | 14 | 86.15 | 1.05 | 9.75 | 0.95 | 1.61 | 0.12 | 0.03 | 1.12 |
| II | 7.6 | 523 | 71 | 19 | 11 | 86.52 | 0.98 | 9.66 | 0.98 | 1.55 | 0.13 | 0.04 | 1.21 |
| III | 7.5 | 516 | 74 | 23 | 12 | 86.45 | 1.02 | 9.45 | 0.97 | 1.57 | 0.11 | 0.03 | 1.18 |
| IV | 7.5 | 518 | 68 | 18 | 14 | 86.54 | 1.04 | 9.52 | 0.94 | 1.62 | 0.13 | 0.03 | 1.14 |

**Mineralogical and Chemical Characteristics**

The strength and permanence of the bond between the cement and aggregate of cement mortar are functions not only of the surface texture, but also of the chemical characteristics of the aggregate. The integrity of bond will be lost if chemical reactions, such as that between high-alkali cement and reactive aggregates, subsequently take place. On the other hand, some types of chemical superficial interaction between the aggregate and the cement paste may be beneficial in producing a more intimate and stronger union (Hudson, 1999).

Aggregates sometimes contain certain constituents that can react with alkali hydroxides in cement mortar. The reactivity is potentially harmful only when it produces significant expansion (Mather, 1975).

The alkali-aggregates reaction (AAR) forms a gel that swells as it draws water from the surrounding cement paste. The gel has a tendency to swell by absorbing water from the surrounding paste. Highswelling gel may cause pressures exceeding the tensile strength of mortar, which results in cracking of the mortar (Lerch, 1955; Neville, 1973; Smith, 1979; Diamond, et al., 1981; Chatterji et al., 1989; St. John and Poole, 1995). When sodium chloride is present in the aggregates or mix water, the tricalcium aluminate in Portland cement may react with the chloride, taking some of the chloride out of the solution with the separation of sodium ions in the solution.

The sulphate ions, if contained in the aggregate mortar, react with unhydrated components of the hardened cement paste. This chemical reaction may lead to expansive reaction products such as ettringite. In turn, ettringite may cause the overall expansion of a structural element and its extensive damage progressing from the outer surface towards the specimen inner core (Skalny et al., 2002). This process may result in a gradual loss of mortar strength accompanied by surface spalling and exfoliation (Biczok, 1972).

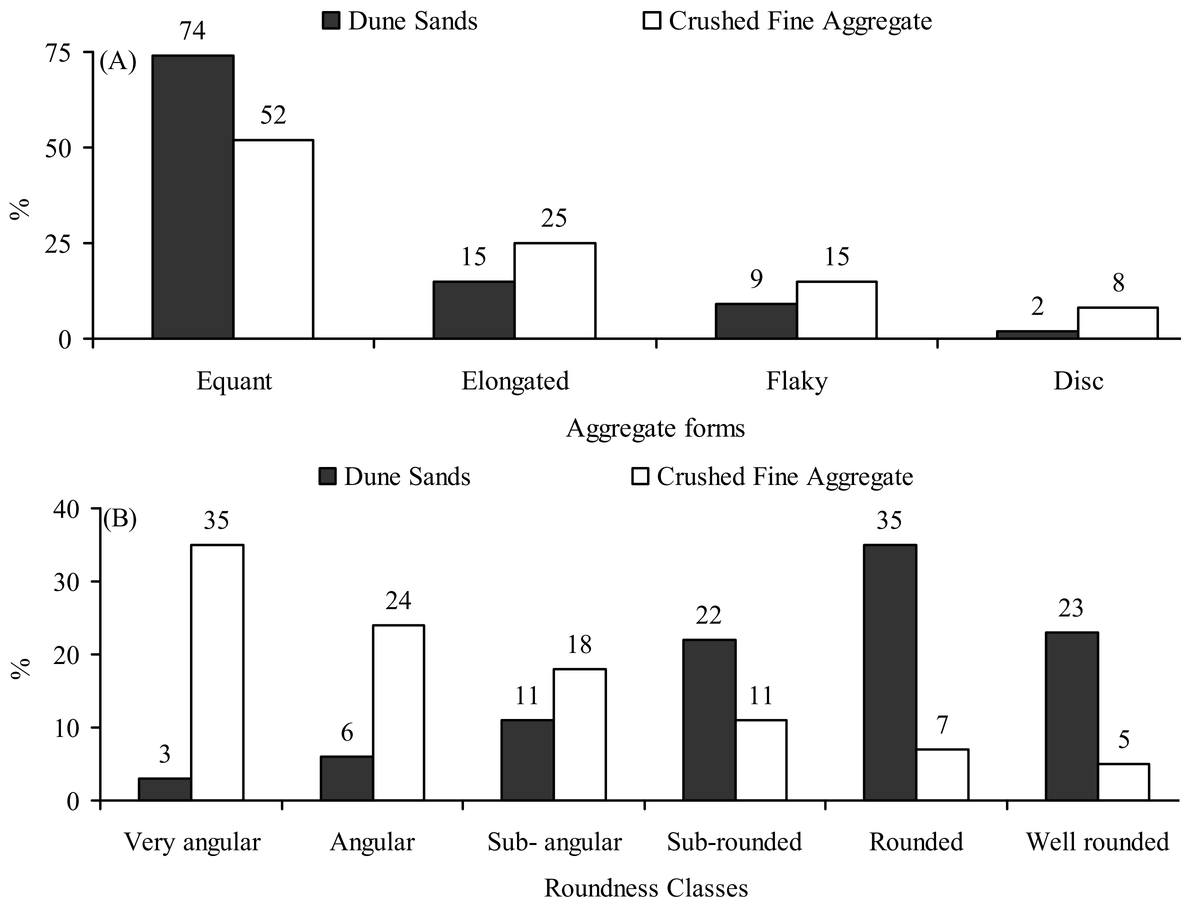


**Figure 4: Relative frequency of different forms and roundness classes of the studied aggregates**

The results of chemical analysis of the studied samples are given in Table 3. The total dissolved salts (TDS) values of the studied samples range from 512 to 523 ppm. The chemical agents which are normally aggressive to mortar are sulfates and chlorides. The values of sulfates and chlorides are very small and nearly negligible, whereas calcium carbonate values are variable with a maximum value of 74 ppm. Accordingly, sulfates, $(SO_4)^{2-}$, were recorded with a maximum value of 18 ppm. Also, magnesium, calcium, potassium and sodium hydroxides were recorded with scarce concentrations (Table 3).

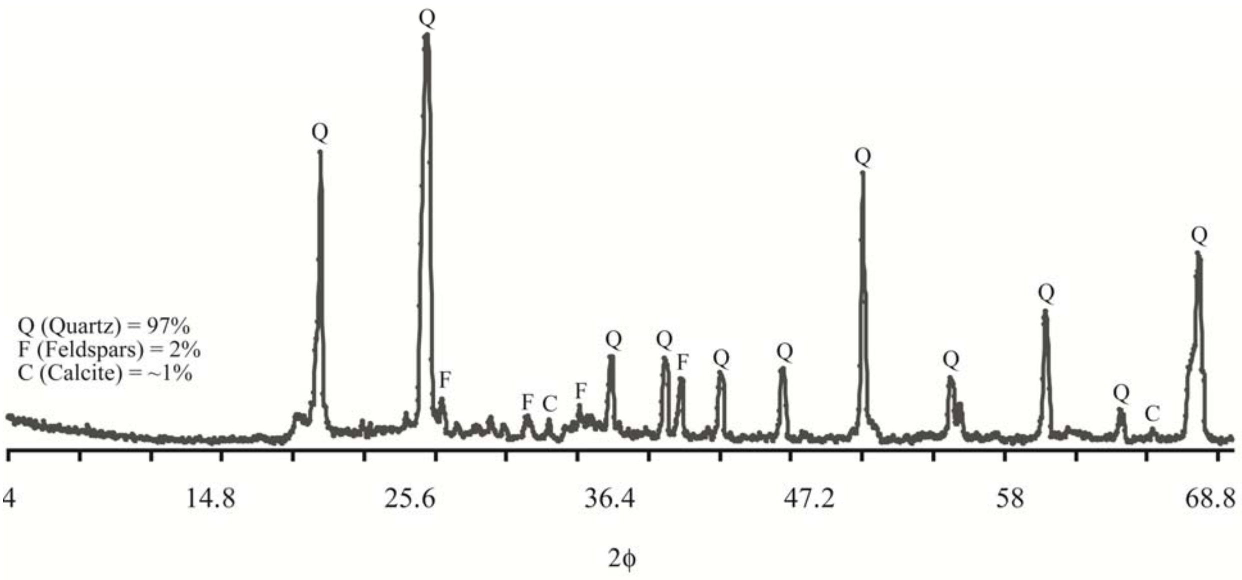


**Figure 5: XRD chart of the studied dune sands**

Figure 5 shows X-ray diffraction of fine aggregates of dune sand in Kharga Oasis. The relative frequency is based on measuring the (001) peak height for the individual mineral considering the total summation of the peak heights of the associated minerals being 100% equal. Thus, it was possible to determine the percentages of mineral composition of the studied fine aggregates. Three types of minerals were identified throughout the studied sequence. Quartz was the predominant mineral present in all samples (97%) with feldspars (2%) and a negligible percent (~1%) of other minerals (e.g. calcite). These fine aggregates are free of active carbonate rock fragments like dolomite or magnesite. Thus, from the alkali-silica reaction point of view, the studied dune sands are compositionally and chemically stable as well as capable of producing mortar without alkali-aggregates reaction (AAR).

From strength and durability point of view, the above-mentioned mineralogical and chemical results indicate no harmful contaminants within the studied dune sand aggregates which react adversely when used as mortar aggregates.

**Workability of Dune Sand Mortars**

Workability of mortars plays an important role in the construction process of masonry structures. Workability may be considered as one of the most important properties of mortar because it influences directly the bricklayer's work (Sabatini, 1984). It is important to mention that the quality of the workmanship can influence considerably the mechanical properties of masonry. The workability is an assembly of several properties such as consistency, plasticity and cohesion (Panarese et al., 1991). The slump test gives an indication of the water content, and thus the hardened strength of mortar (Ferraris, 1998).

Figure 6 displays the workability (slump test in mm) results; it is clear that the studied dune sand cement mortars give similar workability for samples from different four sites at a fixed water/cement ratio.

The results show that when the dune sand content increases, the slump initially increases. This may be due to the high sphericity and roundness of the dune sand grains. However, the slump decreases abruptly at dune sand contents >70%. The degree of workability of the studied dune sands varies from (67mm)-low to (148mm)-medium (Wilby, 1991). Dune sands have rounded or cubical shapes and a relatively smooth surface, while crushed aggregates of Taref Sandstone have an angular shape and rough textured surfaces. The latter types will require a larger percentage of cement and water to provide for proper workability of the mortar (Smith, 1979). From workability point of view, dune sands of Kharga Oasis have good quality to use as fine aggregate in cement mortar manufacturing (>70%).

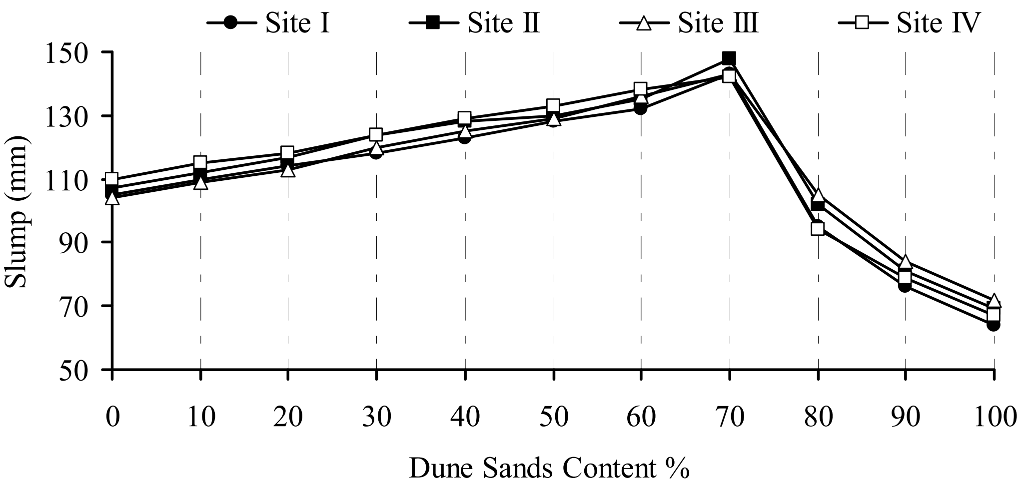


**Figure 6: Effect of dune sand content on workability for cement mortar**

**Strength of Dune Sand Mortars**

According to Neville (1996), the type of fine aggregate has a significant influence on both rheological and mechanical properties of mortars. The mechanical properties of cement mortar are affected by the strength of the cement-aggregate bond and by other factors such as texture and soundness of the rock (Gillott, 1980). The compressive strength of cement mortar is the most common performance measurement used by engineers in designing buildings and other structures. The strength of cement mortar is assumed to depend primarily on two factors: the water-to-cement ratio and the degree of compaction. Even so, the shape of aggregates has an influence on the cement mortar strength (Rocco and Elices, 2009). Round, smooth sands require less mixing water in mortar and thus produce better strength at the same cement content because a lower water/cement ratio can be used. Angular sand grains, in addition to requiring more mixing water, may not be workable enough for applications such as cement mortar (Langer, 1993). The compressive and flexural strengths of mortar seem to depend on angularity: angular particles tend to increase strengths (Kaplan, 1959). On the other hand, surface texture has a significant effect on strength, as rough surfaces enhance the bond between particles and paste, thus increasing strength (Galloway, 1994).

The uniaxial compressive strength was measured by breaking 100-mm cube specimens (7 and 28 days) in a compressive testing machine. The compressive strength was calculated from the failure load divided by the cross-sectional area resisting the load and repeated in units of megapascals.

Figure 7 shows the compressive strength values for the mix within 7 and 28 days. These values show that the strength of cement mortar commonly decreases with increasing dune sand content. It is noticed that, the decreasing in mortar strength was abruptly at dune sand content more than 70%. This decrease in strength may have resulted from increasing rounded grains packing of the dune sand grains which are characterized by smooth and rounded surface (Kaplan, 1959; Galloway, 1994). The higher contents of dune sand aggregates (up 70%) cause the strength of cement mortar to decrease as a result of increasing the smooth surface area of these grains which may lead to increase bleeding and segregation of these grains within the fresh mortar before hardening processes.

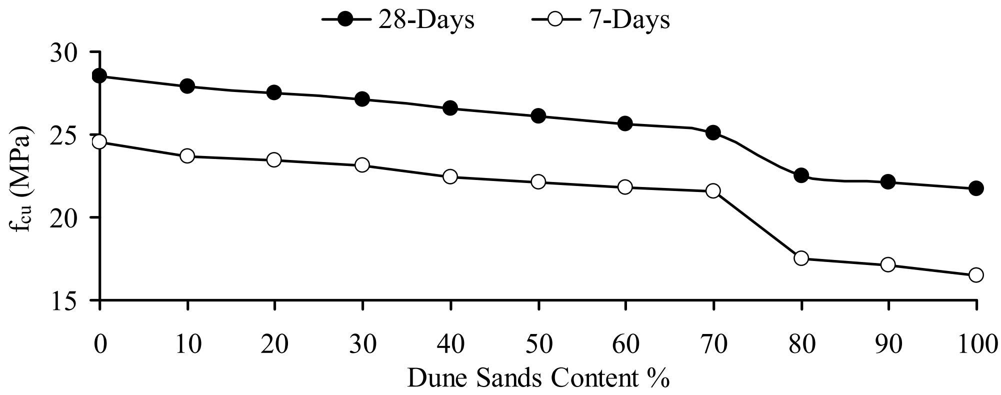


**Figure 7: Effect of dune sands on cement mortar strength**

## SUMMARY

Generally, the studied dune sands are found to exhibit properties similar to aeolian sands from Kuwait, Saudi Arabia, Oman, Algeria, Australia and China. Based on the results obtained in this study, it can be clearly seen that:

1. Dune sands can be used as fine aggregates in cement mortar mixtures whenever suitable sand materials are not economically available.
2. The use of dune sands in constructional activities helps to control sand movement which can cause major geo-environmental hazards.
3. Compositionally and chemically, the studied dune sands are capable of producing mortar without alkalis attack.
4. From grain size and textural point of view, the dune sands must be mixed with crushed fine aggregates to improve their gradation and textural properties.
5. The workability of the dune sand mortar was acceptable when the cement/sand ratio is not smaller than 1:2 and dune sand content did not exceed 70% of the total volume of fine aggregates.
6. The compressive strength of dune sand cement mortar reaches good strength at a constant mix ratio of 1:3:2 (cement: aggregate: water, by weight at dry condition) and dune sand content not exceeding 70% of the total volume of fine aggregates.

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