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# Uses of Sand Dunes as Building Materials

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**Abstract**

During the past forty years, and due to the global climate changes, Iraq had and still suffering from the spreading and expansion of large dune fields in which many new generations have been accumulated, and older ones have expanded leading to the desertification of huge agricultural and urban areas and causing vast environmental problems that have a drastic effect on the life style of the population. To tackle such a problem, many methods have been suggested and even more are applied to fix the dunes or at least to limit their spreading so that to lessen the environmental impact. Such efforts were tried in many dune areas in Iraq, but it was in vain due to the classical nature of remedy that deals only with temporary and limited results, and in many cases worsening the problem. This is evidenced from the increased nature of dune fields in both area and problems.

In this study four major dune fields expanding along four governorates in middle and southern Iraq were studied minerallogically, texturally, and chemically to attest their suitability as fine aggregate for concrete mixtures. These sands are composed of major quartz, feldspars, and calcite minerals, and are devoid of fines (clays), organic matters, and salts. Explicit dune sands of the studied area are not suitable as fine aggregate due to their poor grading, trial on mixing these sands with well-graded river sand (Dibhdiba Formation Sand) in different proportions show that the 35% is optimal for normal load works. Al-Muthana dune sands show the highest evaluations. Missan dune sands were further tested for producing pavement interlock bricks, the results confirmed their aptness for exploitation both economically and environmentally.

**Keywords:** Sand Dunes, Barchans Dunes, Fine Aggregate, Compressive Strength.

# استعمال رمال الكثبان الرملية كمواد بناء

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**الخلاصة**

خلال الأربعين سنة الماضية وبسبب التغيرات المناخية العالمية ، يعاني العراق من تكون وتوسع في حقول الكثبان الرملية حيث تولدت العديد من حقول الكثبان الرملية الجديدة فضلا عن ذلك فان حقول الكثبان الرملية القديمة توسعت رقعتها الجغرافية كثيرا وهذا سبب حصول تصحر شديد للكثير من الأراضي الزراعية مما سبب مشاكل بيئية كبيرة أثرت على نمط الحياة وسببت تلوثا بيئا خطرا. ولغرض معالجة هذه المشاكل الخطرة تم استعمال العديد من الطرق لغرض الحد من توسع رقعة الكثبان الرملية ومحاولة تثبيت هذه الكثبان لمنع زحفها وتقليل مخاطرها البيئية. مثل هذه المعالجات طبقت في العديد من حقول الكثبان الرملية في العراق،

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لكنها لم تكن ناجحة في القضاء على هذه المشاكل البيئية، والتي كانت في الغالب معالجات مؤقتة، وفي الغالب كانت حقول الكثبان الرملية مستمرة في التولد والتوسع وتفاقم المشاكل البيئية .

في هذه الدراسة تم اختيار أربعة حقول كثبان رملية رئيسية تقع في أربعة محافظات في وسط وجنوبي العراق، حيث تم دراستها من ناحية تركيبها المعدني ، طبيعة رمالها نسيجيا ، تركيبها الكيميائي وذلك لبيان مدى ملائمتها كركام ناعم في الخلطات الكونكريتية ، هذه الرمال تتألف بصورة أساسية من معادن الكوارتز ، الفلدسبارات ، الكالسايت ، وهي خالية الى حد ما من الاطيان والاملاح والمواد العضوية.

ان استعمال رمال الكثبان الرملية لوحدها في خلطة الكونكريت يعد أمرا غير ناجحا وذلك بسبب انعدام التدرج الحجمي ، لكن عملية خلطها مع الرمال النهرية (كرمال تكوين الدبدبة) اظهر أن عملية خلط نسبة 35% من رمال الكثبان الرملية مع رمال تكوين الدبدبة وبنسب مقبولة وناجحة في خلطات الكونكريت المستخدمة في الاحمال المعتدلة، اظهرت رمال كثبان محافظة المثنى اعلى نسبة ناجحة يمكن اعتمادها في هذا الجانب.

تم استعمال رمال كثبان محافظة ميسان في صنع مقرنص الأرضيات ، وقد اظهرت النتائج نجاح هذا التطبيق ، ان استعمال رمال الكثبان الرملية في تطبيقات الكونكريت يجعل من هذه الرمال ذات أهمية اقتصادية كبيرة فضلا عن ذلك فان استعمالها في الكونكريت يعد من الحلول الناجحة لمعالجة المشاكل البيئية لتوسع الكثبان الرملية.

## Introduction

Iraq for the past four decades has been and still suffering from desertification, in which vast agricultural areas are transformed into sand dune fields. This environmental depreciation can be attributed to several factors such as climate change that leads temperatures to increase and rainfall to decrease, besides reduction in surface water resources, non-systematic farming techniques, and intensive grazing. These factors cumulatively caused the vegetation cover to be disintegrated into barren land that is vulnerable to be areas of sand dune accumulations, or act as a direct and major source for wind-blown sands. The mode and area of distribution of sand dunes in Iraq is restricted within specific areas that are characterized and influenced by geological and geographical controls.

The past ten years additional sand fields and areas were shaped within new expanses thus increasing the spatial distribution of dune regions into new belts and secondary grounds that were not classified as dune areas before. Many methods have been employed to restrict the sand movement and thus to control the distribution of sand dunes, such methods include the usage of heavy oil, digging trenches, and plant coverings, however such remedies proved to be inadequate as permanent solutions, such cases indicate the complexity and uncontrollable nature of the processes that instigate the sand dune parts [1]. The purpose of this study is dual in nature, on one hand the sands of these dunes may be considered as natural resources suitable for construction purposes, such as fine aggregates resource for concrete, which can be directly applied for developing the area and on the second hand an approach for dismantling the hazardous nature of these dunes on the nearby urban and cultivated regions, thus leading to infrastructure development by environmentally friendly manner.

Many studies have been directed on aeolian sands to inaugurate their identification, quantification and geotechnical properties in order to evaluate their suitability as a construction material. [2] presented a comprehensive literature review on the characteristics, and performance of the aeolian sands, and provided different possibilities and suggestions for their treatment and widespread usage. The earliest efforts goes to Khan [3] who conversed various aspects about the construction of highways in arid zones after analyzing chemical and geotechnical properties of samples of dune sands collected from Sahara desert in Libya. Al-Sanad and Bindra [4] published a book taking into account the construction of roads and highways on dune sands in the Arabian Peninsula. [5] conducted detailed laboratory investigations on dune sands of four sites in Kuwait for determining their geotechnical properties. Recent studies have been directed towards examining the engineering properties of aeolian sands and investigating the ability of using them in construction [6-9].In the last years, substantial research has been directed to examine different types of additives and their potentiality as stabilizing agents for aeolian sands. Different methods of stabilization have been reported in the literature including the use of cement [10-13], cement kiln dust [14-17], bentonite and lime [18-19], bitumen emulsions [20-21],polymer emulsions [22-25], polypropylene fibers [26-27] and even, waste [28-30] Other researchers have accumulated the results of field and laboratory analyses to evaluate dune sands with respect to their use as fine aggregates in cement mortar or concrete, concluding that their use in civil engineering is viable [31-35].

**Location and Geological Setting**

The distribution of sand dunes in Iraq is concentrated along three major belts with a general northwestern to southeastern trend that represent the most effective wind direction on formation and transport of the dunes. These belts lie within the floodplain zone in the middle and southern parts of Iraq (Figure-1). The area of investigation covers four governorates: Missan، Al-Qadesiyah, Thi-Qar, and Al-Muthana. The studied sand dune fields show discrepancies in both character and distribution among and even within each governorate. Missan area include Chailat dune field, which is situated within the eastern belt to the east of Ali Al-Gharbi town 80 km northwest of Amara City, and margining the Iranian borders.

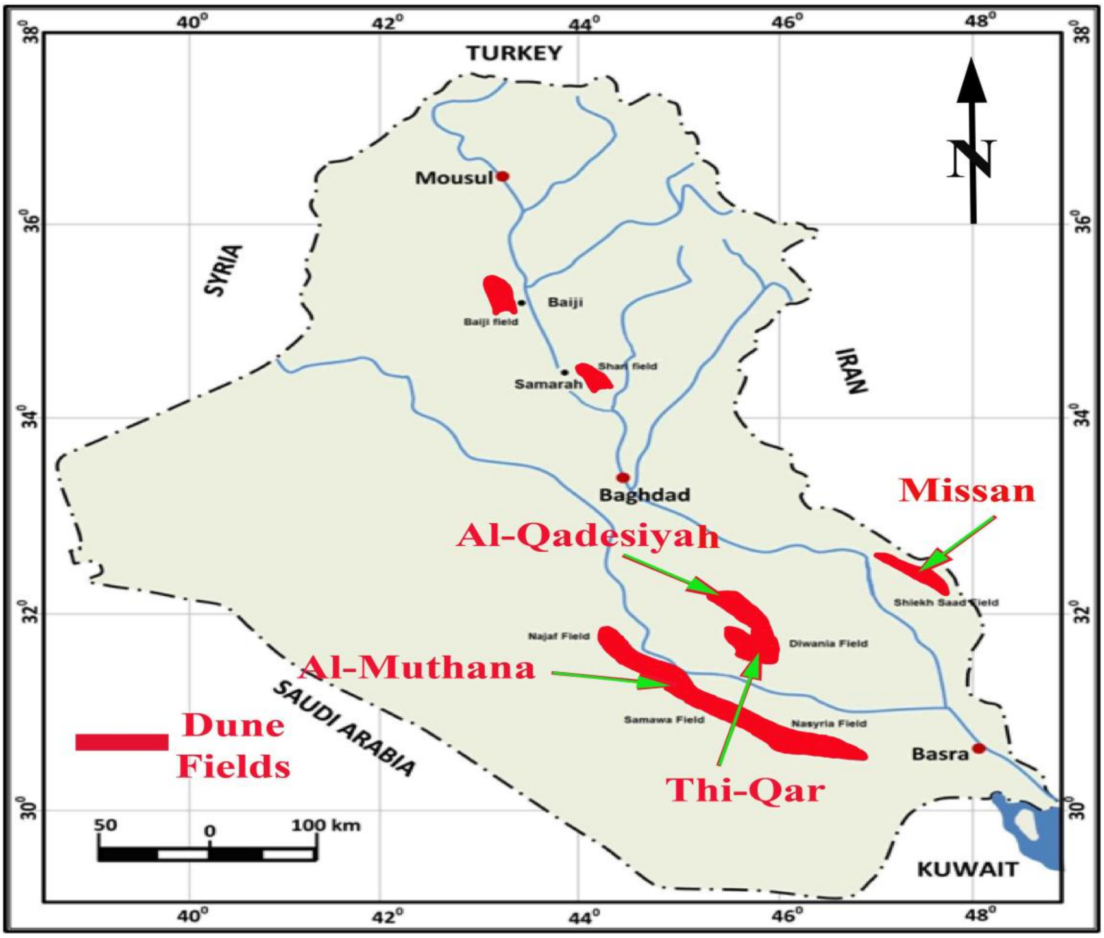


**Figure 1-** Location Map of the studied dune fields show the major three belts of sand dunes in Iraq [36].

Geologically, the area lies within the Floodplain Zone that consists of Quaternary Sediments of alluvial fan, alluvial, lacustrine, and aeolian origins. Exposed geological formations of the Upper Miocene-Pliocene cycle including Injana, Maqdadiya، and Bia-Hassan Formations occupy an eastern narrow rim in the study area, which represents the southeastern limb of Himreen asymmetrical anticline (Figure- 2). The clastic exposures of these formations represent a plentiful source for the coarse aggregates fraction larger than 19 mm.

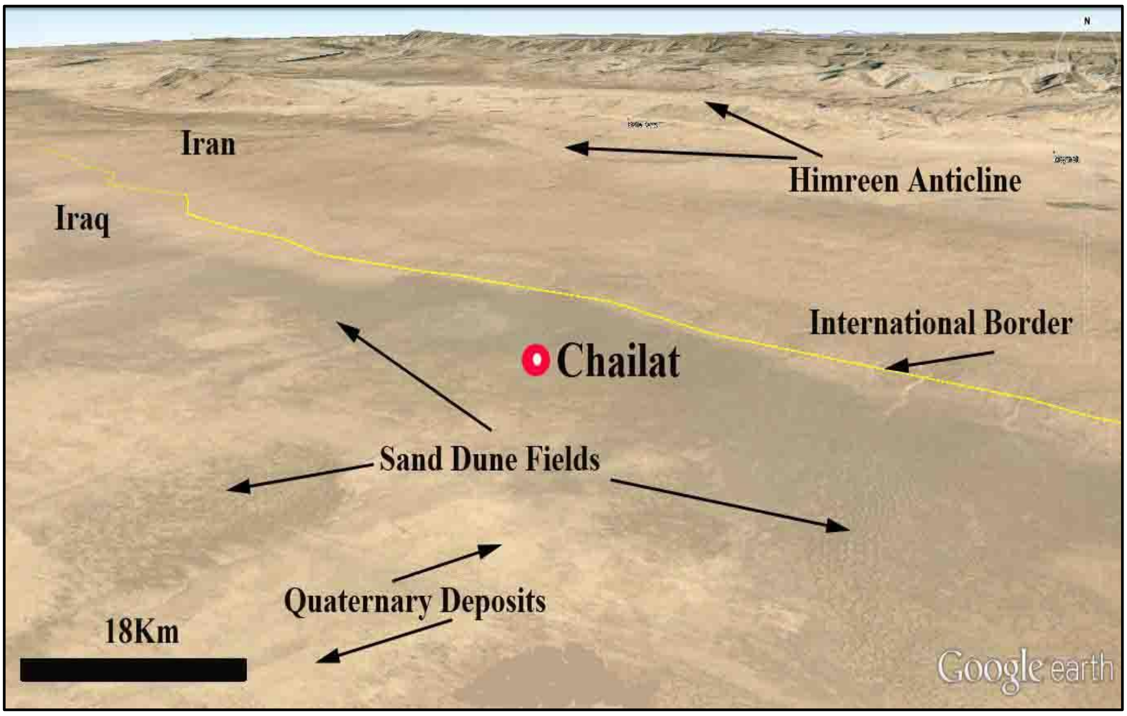


**Figure 2-** Inclined satellite view showing the Missan dune fields [37].

Missan sand dune field represents one of the major dune fields in Iraq; it outcrops over an area of 60 km2. Al-Qadesiyah (Diwaniya), and Thi-Qar dune fields occupy the central belt, they lie within alluvial, channel while levee sand and silt, and marsh sediments, the two fields are intermingled، and spread across 100 Km2. Al-Muthana dune field lies within the western belt, it occupies an area of 100 km2 the northern, eastern and western surrounding areas are characterized by the presence of alluvial depression filling and marsh sediments, while the southern area have a pronounced salt covered alluvial plain deposits, further to the west the nearly horizontal old formations of Dammam and Euphrates carbonates rest nearby (Figure- 3).

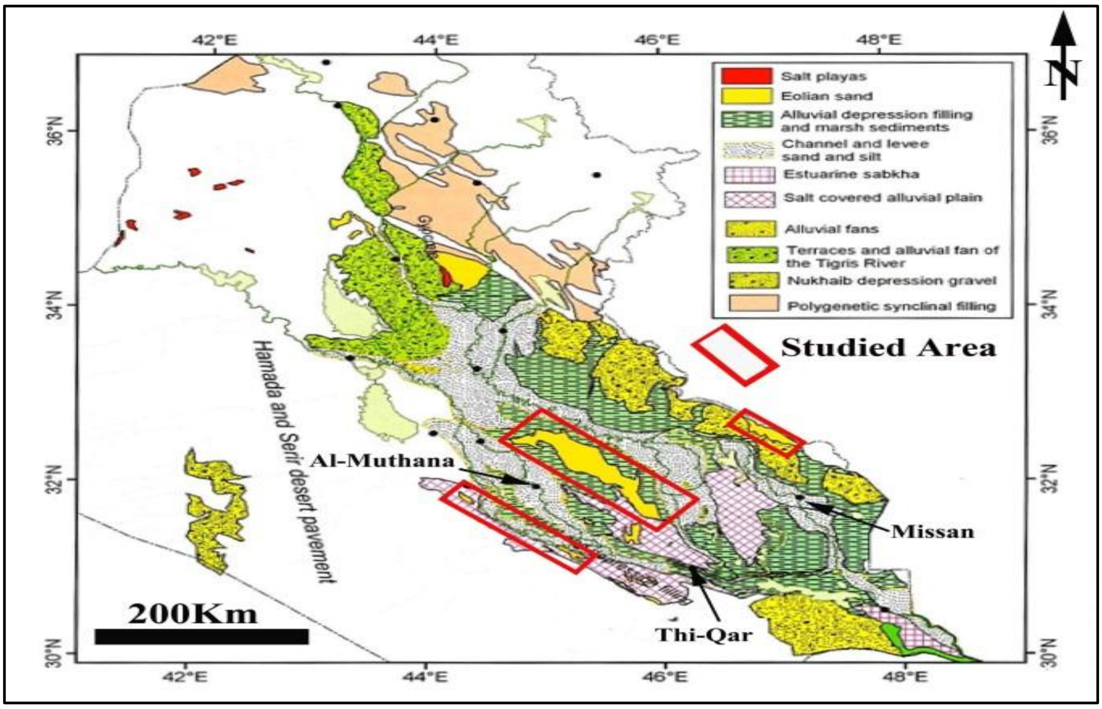


**Figure 3-** Distribution of major Quaternary units and older formations, [38].

Types such as barchans، barchanoids, and nabkhes occur in bulk in all dune fields, in addition to sand sheets, and drifts Figures- (4, 5, and 6) the former two types represent promised targets as fine aggregates.

**Figure 4-** Barchan dunes in Missan dune field.


**Figure 5-** Barchanoid ridges in Thi-Qar dune fields [37].

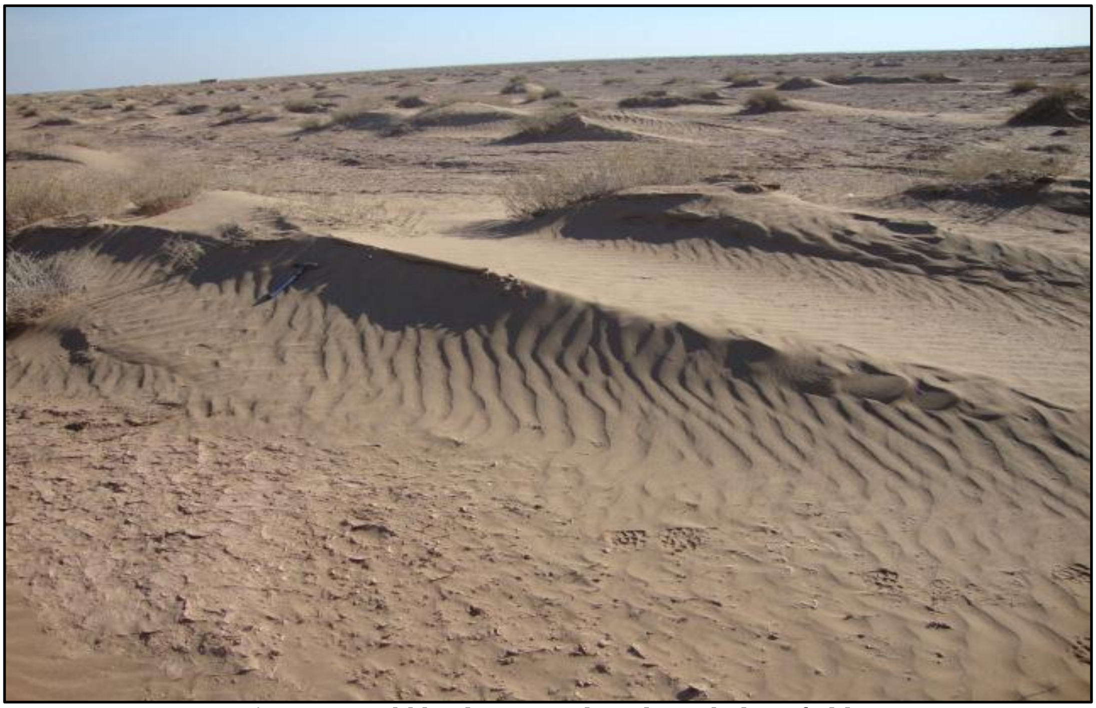

**Figure 6-** Nabkha dunes in Al-Qadesiyah dune fields.

**Methodology and Sampling**

Detailed fieldwork was conducted on the types, morphology, and distribution of the four sand dunes fields in the studied area. Twenty samples from each dune field were collected along a profile across the movement direction of each sand dune using topographic maps and a GPS instrument. The collected samples were investigated from the mineralogical, textural, and chemical aspects. Minerals were identified using Leitz polarizing petrographic microscope and D2-PHASER Bruker XRD instrument. Size analysis was performed by a set of standard sieves and an electrical shaker. Chemical analysis was done by XEPOS-SPECTRO ED XRF; these tests were performed in the Iraqi-German Laboratory at Geology Department-University of Baghdad. Shape analysis was conducted using binocular microscope and INSPECT-550 SEM, analysis was completed at College of Science-University of Kufa. The engineering tests were conducted at the Central Baghdad Laboratory / National Center for Construction Laboratories / Ministry of Construction and Housing

**Materials**

**Cement**

In this study ordinary portland cement that is available in the Iraqi market was used is this study. This cement is of Al-Mas Brand which is produced by Tasluga Cement Factory in Sulamania Governorate. The physical and chemical properties of this cement is found well conformed with the Iraqi specification ICS/5/1984 (Table- 1).

**Table 1-** Physical analyses and chemical composition of OPC (Al- Mass), [39].

| Properties | | The Results | I .Q .S No.5 /1984 limits |
|---|---|---|---|
| Setting time | Initial | 132 | ≥ 45 min |
| | Final | 270 min | ≤ 10 hours (600min) |
| Compressive strength (MPa) | 3 days | 22.52 | ≥ 15 |
| | 7 days | 30.24 | ≥ 23 |
| Fineness ($cm^2$/gm) | | 3160 | ≥ 2300 |
| Soundness | | conform | < 0.8 |
| Chemical Composition | CaO | 62.21 | - |
| | $SiO_2$ | 20.76 | - |
| | $Al2O_3$ | 4.10 | |
| | $Fe_2O_3$ | 3.30 | |
| | MgO | 2.46 | < 5.0 |
| | $K_2O$ | - | |
| | $Na_2O$ | - | |
| | $SO_3$ | 2.76 | < 2.8 |
| | L.O.I | 2.75 | < 4.0 |
| | L.S.F | o.94 | 0.66 – 1.02 |
| | I.R | 0.94 | < 1.5% |
| | F .L | 1.12 | - |
| | $C_3S$ | 57.15 | - |
| | $C_2S$ | 16.65 | - |
| | $C_3A$ | 5.28 | - |
| | $C_4AF$ | 10.03 | |

**Fine aggregates**

Two types of natural sands, namely dune sand (DS), and Dibdiba sand (DB) were used as fine aggregate. The latter belongs to Dhibdiba Formation, a clastic formation of alluvial origin of Miocene age, it is widespread in central and southwestern areas of Iraq, and considered a prime source of fine aggregates for most construction projects in Iraq.

**Chemical and Mineral Components**

Chemical analysis, heavy mineral and light mineral fractions of the studied sands in Tables- (2, 3 and 4) respectively show that the percentages of oxides and their corresponding minerals varies with each dune area. Silica represents the major constituent in all samples, Dhibdiba formation sands have the highest value (83.22%), followed by Al-Muthana dune (67.2%-65.9%), and the other dune fields have percentages lower than 50%. Silica is the sole component of quartz, and cryptocrystalline silica (chalcedony, and chert ) Figure- 7(A), and 7(B), and subordinate in feldspars Figure- 7(C), 7(D), and 7(E). Lime percentage is the second among the studied samples, Missan, Thi-Qar, and Al-Qadesiyah dunes have their lime between 16%-20.2%, Al-Muthana sands has 12.2%, while Dhibdiba sand has the lowest value (6.7%). Lime contributes to the minerals calcite and gypsum Figure- 7(F), and 7(G). Alumina is the third common oxide, Missan, Thi-Qar, and Al-Qadesiyah dunes have ranges between 6.1%-7.8%, Al- Muthana sand has 1.0%-2.15%, while Dhibdiba sand has less than 1.0%. Alumina is a major constituent of feldspars and phyllosilicates (mica, and chlorites) Figure- 8(B). Iron oxides show more than 3% in Missan, Thi-Qar, and Al-Qadesiyah dunes, Al-Muthana sand has less than 0.5%, while Dhibdiba sand has more than 0.56%. Magnetite, hematite, goethite, and many other heavy minerals (Figure 8-A) relates directly to iron oxides presence. The presence of gypsum is correlated to the presence of the sulfite radicle. Dhibdiba formation sand have the highest percentages (3.7%), Al-Muthana dune have values ranges between 1.85% -2.1% while Missan, Thi-Qar, and Al-Qadesiyah dunes show traces as indicated by the lack of gypsum in their samples (Figure- 9). The other oxides such as magnesia, titania, and the others show low concentrations that have little affect on the overall chemical and mineralogical components that are considered as potentially harmful due to their chemical reactivity with portland cement concrete.

**Table 2-** Chemical analysis of the selected samples.

| Oxides % | Samples Number | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dibdibba | Missan | | | Thi-Qar | | | Al-Qadesiyah | | | Al-Muthana | | |
| | DB | Ch1 | Ch2 | Ch3 | T1 | T2 | T3 | Q1 | Q2 | Q3 | S1 | S2 | S3 |
| MgO | 1.7 | 1.7 | 1.6 | 1.8 | 2.9 | 2.7 | 2.8 | 2.6 | 2.7 | 2.6 | 0.05 | 0.06 | 0.07 |
| Al2O3 | 0.85 | 6.4 | 6.1 | 6.07 | 6.2 | 7.8 | 7.8 | 6.8 | 7.3 | 6.5 | 2.15 | 1.2 | 1.0 |
| SiO2 | 83.22 | 53.4 | 52.53 | 55.3 | 52.0 | 48.6 | 47.2 | 46.4 | 47.9 | 49.4 | 67.2 | 65.2 | 65.9 |
| P2O5 | 0.37 | 0.49 | 0.48 | 0.52 | 0.5 | 0.6 | 0.6 | 0.5 | 0.4 | 0.5 | 0.53 | 0.52 | 0.51 |
| SO3 | 3.70 | 0.01 | 0.03 | 0.04 | 0.05 | 0.07 | 0.06 | 3.08 | 2.07 | 2.09 | 2.1 | 1.85 | 1.90 |
| Cl | 0.03 | 0.02 | 0.04 | 0.03 | 0.04 | 0.05 | 0.04 | 0.05 | 0.04 | 0.06 | 0.03 | 0.04 | 0.04 |
| K2O | 0.18 | 1.25 | 1.17 | 1.28 | 1.0 | 1.13 | 1.09 | 1.1 | 1.2 | 1.2 | 0.81 | 0.9 | 1.0 |
| CaO | 6.70 | 17.2 | 17.0 | 16.0 | 17.0 | 20.2 | 18.9 | 20.0 | 19.1 | 18.4 | 12.2 | 13.8 | 14.8 |
| TiO2 | 0.13 | 0.57 | 0.57 | 0.56 | 0.5 | 0.47 | 0.53 | 0.48 | 0.46 | 0.5 | 0.15 | 0.2 | 0.3 |
| Fe2O3 | 0.56 | 3.29 | 3.31 | 3.11 | 3.14 | 3.6 | 3.43 | 2.90 | 3.1 | 3.2 | 0.42 | 0.48 | 0.46 |
| MnO | 0.52 | 0.06 | 0.06 | 0.05 | 0.07 | 0.07 | 0.06 | 0.05 | 0.06 | 0.06 | 0.01 | 0.01 | 0.01 |
| Others | 2.04 | 16.61 | 17.11 | 15.24 | 16.6 | 14.71 | 17.49 | 16.04 | 16.19 | 15.49 | 14.35 | 15.74 | 14.01 |

**Table 3-** Percentages of light minerals in studied dune sands.

| Light Components | Samples Number | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Missan | | | Thi-Qar | | | Al-Qadesiyah | | | Al-Muthana | | |
| | Ch1 | Ch2 | Ch3 | T1 | T2 | T3 | D1 | D2 | D3 | S1 | S2 | S3 |
| Quartz | 53.9 | 54.4 | 52.5 | 47.5 | 44.7 | 44.3 | 40.9 | 42.9 | 45.4 | 60.5 | 61.3 | 63.4 |
| Potash Feldspar | 5.7 | 4.1 | 5.1 | 2.4 | 2.9 | 3.6 | 3.6 | 4.7 | 3.8 | 6.8 | 7.1 | 6.9 |
| Plagioclase Feldspar | 3.7 | 4.5 | 4.7 | 2.1 | 2.7 | 2.9 | 2.7 | 2.4 | 2.5 | 2.1 | 1.8 | 1.6 |
| Carbonate R. Fragments | 18.2 | 18.0 | 17.8 | 26.4 | 28.1 | 29.7 | 28.7 | 27.9 | 25.4 | 13.4 | 12.8 | 12.3 |
| Chert R. Fragments | 14.3 | 15.0 | 15.6 | 17.5 | 17.8 | 16.5 | 14.6 | 13.7 | 14.8 | 6.3 | 6.5 | 5.2 |
| Evaporites | 0.8 | 1.0 | 1.3 | 1.0 | 0.9 | 0.7 | 6.5 | 5.3 | 4.2 | 5.9 | 5.8 | 6.0 |
| Igneous R. Fragments | 2.0 | 1.7 | 1.8 | 1.9 | 2.0 | 1.9 | 1.8 | 1.9 | 2.0 | 2.9 | 2.8 | 2.6 |
| Metamorphic R. Fragments | 1.4 | 1.3 | 1.2 | 1.2 | 0.9 | 0.4 | 1.2 | 1.2 | 1.9 | 2.1 | 1.9 | 2.0 |

**Table 4-** Percentages of heavy minerals in dune sands.

| Heavy Minerals | Samples Number | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Missan | | | Thi-Qar | | | Al-Qadesiyah | | | Al-Muthana | | |
| | Ch1 | Ch2 | Ch3 | T1 | T2 | T3 | D1 | D2 | D3 | S1 | S2 | S3 |
| Opaques | 56.3 | 57.7 | 54.9 | 42.2 | 40.7 | 42.6 | 44.7 | 46.6 | 47.7 | 31.7 | 30.6 | 30.1 |
| Chlorite | 10.2 | 9.6 | 10.3 | 8.8 | 9.2 | 7.4 | 4.2 | 5.0 | 4.8 | 6.5 | 5.9 | 5.5 |
| Pyroxene | 4.5 | 3.9 | 3.8 | 7.2 | 7.7 | 8.2 | 5.4 | 5.0 | 5.2 | 6.0 | 6.5 | 6.0 |
| Amphibole | 4.3 | 4.4 | 4.3 | 5.3 | 5.8 | 5.6 | 5.1 | 5.3 | 5.0 | 6.9 | 7.2 | 7.0 |
| Muscovite | 3.0 | 4.0 | 3.9 | 4.9 | 5.3 | 5.1 | 4.5 | 4.6 | 5.2 | 5.2 | 4.9 | 4.8 |
| Biotite | 2.6 | 2.5 | 2.2 | 5.3 | 5.0 | 4.7 | 5.2 | 4.6 | 4.8 | 3.5 | 3.2 | 3.0 |
| Epidote | 5.6 | 4.9 | 5.0 | 5.0 | 4.6 | 4.2 | 4.6 | 4.5 | 4.3 | 5.0 | 5.6 | 5.5 |
| Zircon | 2.6 | 2.5 | 2.9 | 6.8 | 7.2 | 7.7 | 7.7 | 7.5 | 7.0 | 11.8 | 13.7 | 12.5 |
| Garnet | 4.7 | 4.8 | 5.1 | 4.1 | 3.9 | 3.7 | 4.3 | 4.2 | 3.8 | 4.8 | 4.6 | 4.5 |
| Tourmaline | 2.2 | 2.7 | 2.6 | 4.5 | 4.2 | 4.6 | 6.5 | 6.4 | 6.2 | 13.4 | 12.6 | 14.5 |
| Rutile | 1.2 | 0.8 | 1.3 | 1.5 | 1.8 | 1.7 | 3.8 | 3.7 | 3.2 | 3.2 | 3.6 | 4.5 |
| Staurolite | 0.8 | 1.0 | 1.3 | 1.4 | 1.2 | 0.9 | 1.3 | 1.6 | 1.5 | - | 0.8 | 0.9 |
| Kyanite | 0.8 | - | 0.6 | 1.0 | 1.1 | 0.9 | 1.4 | - | - | 1.0 | - | - |
| Unidentified | 1.2 | 1.2 | 1.8 | 2.0 | 2.3 | 2.7 | 1.3 | 1.0 | 1.3 | 1.0 | 0.8 | 1.2 |

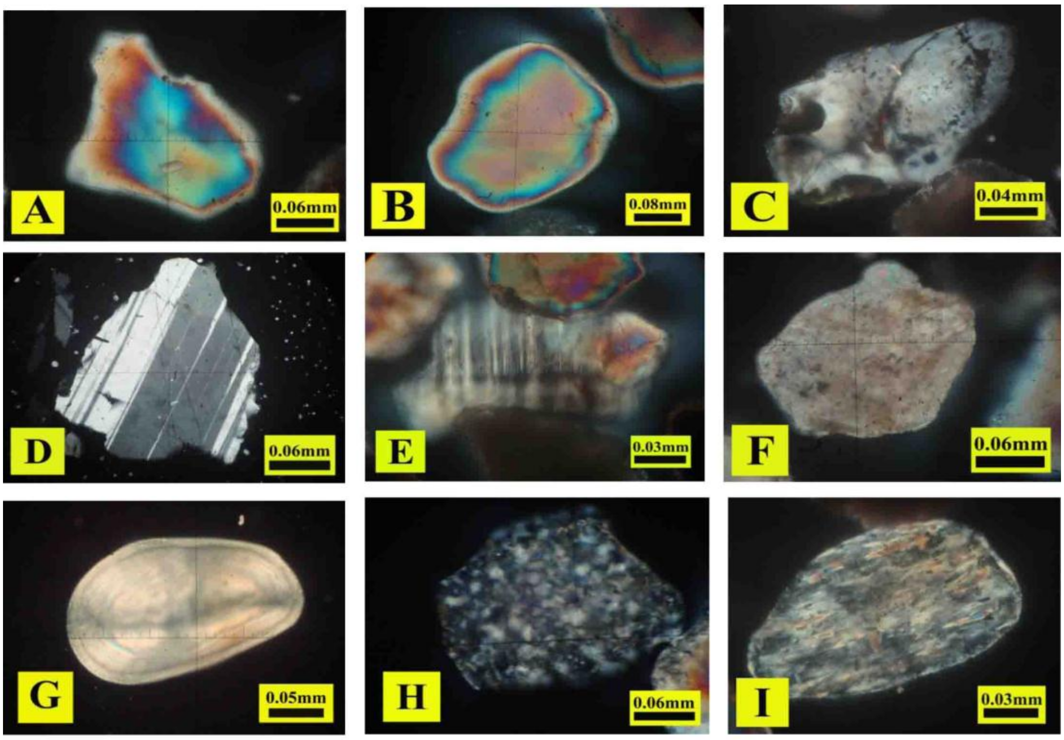


**Figure 7-** Light minerals and components of selected dune sand samples, A and B: Monocrystalline quartz, C: Potash feldspar orthoclase, D: Plagioclase feldspar, E: Potash feldspar microcline, F and G: Carbonate rock fragment, H: Chert rock fragment, I: metamorphic rock fragment.

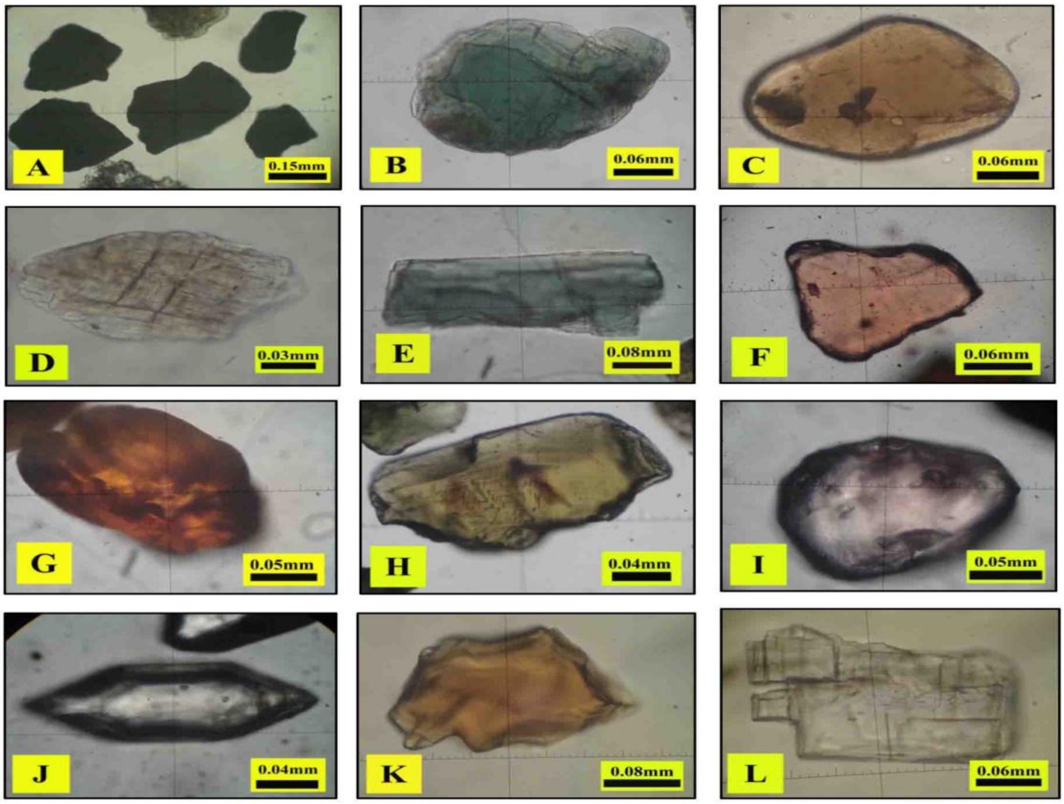


**Figure 8-** Heavy minerals of selected dune sand samples, A: Opaqures, B: Chlorite, C: Tourmaline, D: Hornblende, E: Pyroxene, F: Garnet, G: Rutile, H: Epidote, I and J: Biotite, K: Staurolite, L: Kyanite.

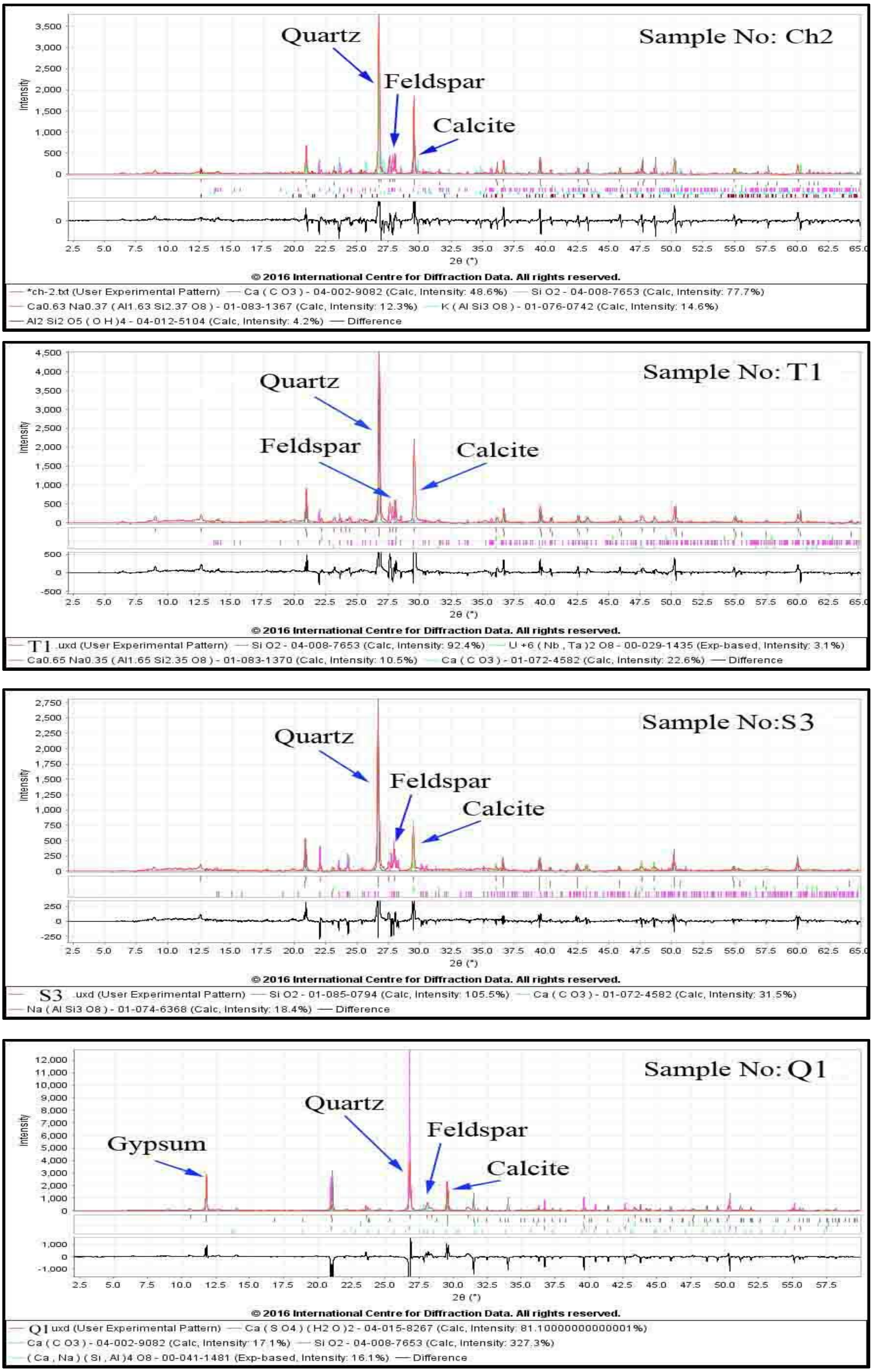


**Figure 9-** X-ray difractograms of selected dune sand samples in the studied areas.Texture (Shape and Size) of Particles

Texture, which includes both size and shape of the sand grains show discriminate results among the studied samples. The size and shape of particles in the fine aggregate affect the workability.

The use of very fine sand requires that more water (This may be due to increasing in the specific surface area activity) to be added to achieve workability. Angular fine aggregate particles interlock and reduce the freedom of movement of particles in the fresh concrete [40]. Aeolian sand grains are generally more rounded because air-transported grains are intensively subjected to collision and become round faster than those transported in aqueous media [41].

**Size - Fineness Modulus-FM**

FM is an index of the fineness of an aggregate, the higher the FM , the coarser the aggregate. Different aggregate grading may have the same FM. FM of fine aggregates is useful in estimating proportions of fine and coarse aggregates in concrete mixtures [42]. Size analysis of the studied samples (Figure- 10) show different grading scales (FM) as compared with the [38], (Table- 5). Grading is the particle size distribution of an aggregate as determined by sieve analysis [42]. Dhibdiba sand has a well-conformed match with the limits of the standard method. However, the four studied dune areas lack the very coarse, and coarse fractions and have an excess of the very fine fraction, these samples show unimodal distributions. All dune samples are classified as poorly graded sand (SP). Thus, using these sands solely as fine aggregates is not passable.

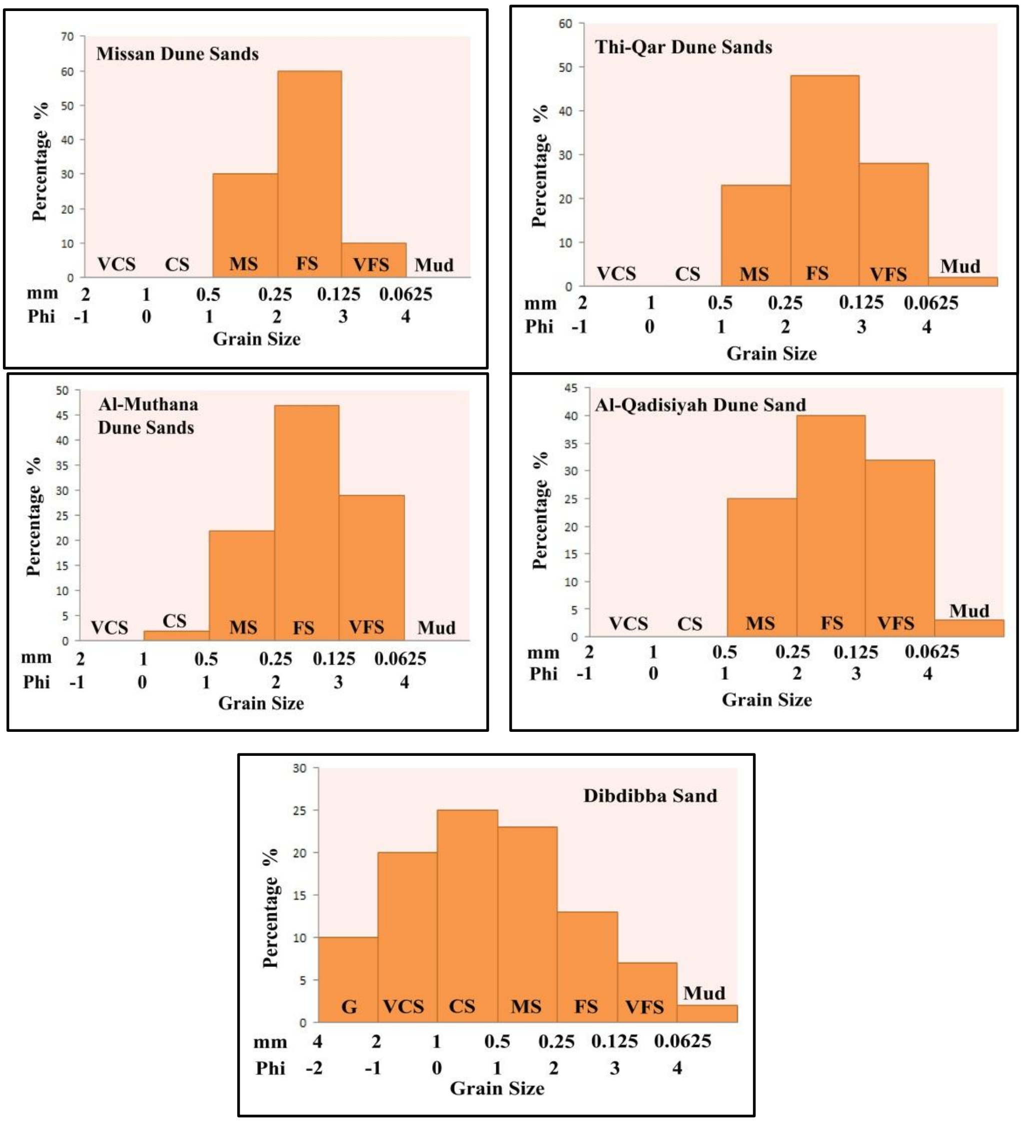


**Figure 10-** Average Grain size distribution of the studied dune fields.

**Table 5-** Average Grain size distribution of the studied dune fields with their Fineness Modulus values (FM).

| Sieve Size (mm) | Dibdibba | Missan | Thi_Qar | Al-Qadesiyah | Al-Muthana | IQS Limit No. 45/1984 |
|---|---|---|---|---|---|---|
| 10 | 0 | 0 | 0 | 0 | 0 | 100 |
| 5 | 0 | 0 | 0 | 0 | 0 | 90-100 |
| 2.36 | 10 | 0 | 0 | 0 | 0 | 75-100 |
| 1.18 | 20 | 0 | 0 | 0 | 0 | 55-90 |
| 0.6 | 25 | 0 | 0 | 0 | 3 | 35-59 |
| 0.3 | 23 | 30 | 23 | 25 | 22 | 8-30 |
| 0.15 | 22 | 70 | 77 | 75 | 75 | 0-10 |
| Fineness Modulus (FM) | 2.73 | 1.30 | 1.23 | 1.25 | 1.28 | |

**Shape – Roundness and Surface Texture**

The particle shape and surface texture of an aggregate influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured, angular, elongated particles require more water to produce workable concrete than do smooth, rounded, compact aggregates. Hence, aggregate particles that are angular require more cement to maintain the same water-cement ratio. Flat and elongated aggregate particles should be avoided or at least limited to about 15% by mass of the total aggregate [43].

Shape of the studied dune sands as examined by both the SEM and binocular microscopes shows a rounded to subrounded shape Figures- (11 and 12). Quartz is the standard mineral for grain shape analysis [44-46] In order to estimate the roundness, 200 quartz grains were point counted in each sample using the visual chart by [47].

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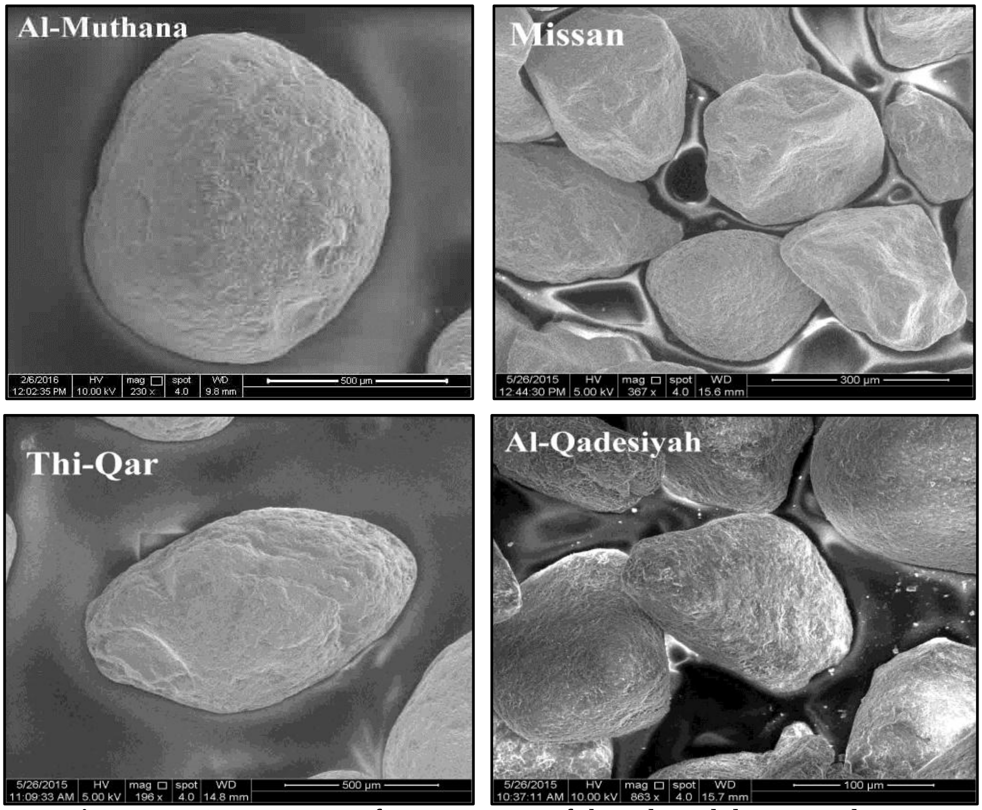



**Figure 11-** SEM images of quartz grains of the selected dune samples.

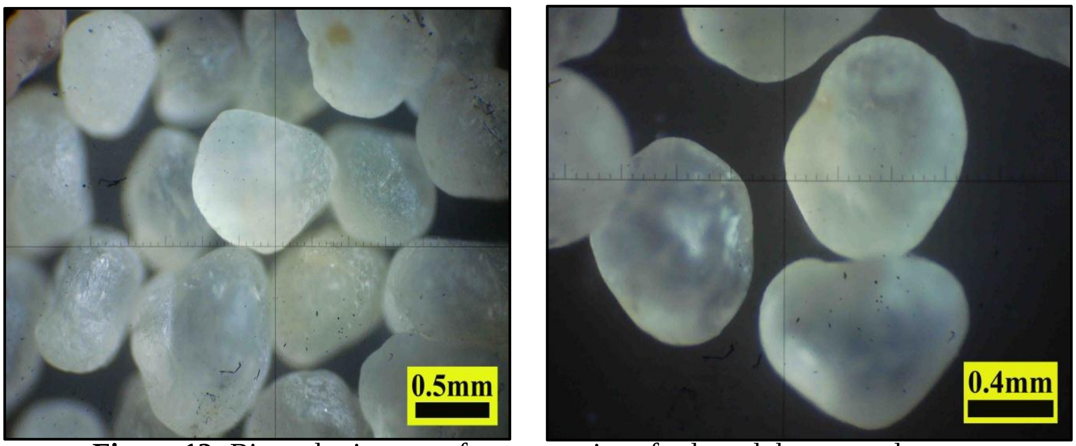



**Figure 12-** Binocular images of quartz grains of selected dune samples.

**Coarse Aggregates**

The source of the coarse aggregate is furnished from outcrops of Maqdadiyah Formation of Pliocene in age in Missan Governorate to the east of the sand dune field. These clastic rocks are being trenched for manufactured aggregates. 2660 samples (5mm-20mm) from five sites were collected (Figure-13), the specimens were examined visually by using hand specimen procedures such as hardness, color, HCL reaction, and by preparation of thin sections and examination under the polarizing microscope (Table-6). Size grading as based on the [39] designed for normal-strength aggregates stressed on the 10mm, and 20mm sizes. The grading of given maximum-size for coarse aggregate can be varied over a moderate range without appreciable effect on cement and water requirement of a mixture if the proportion of fine aggregate to total aggregate produces concrete of good workability [48].

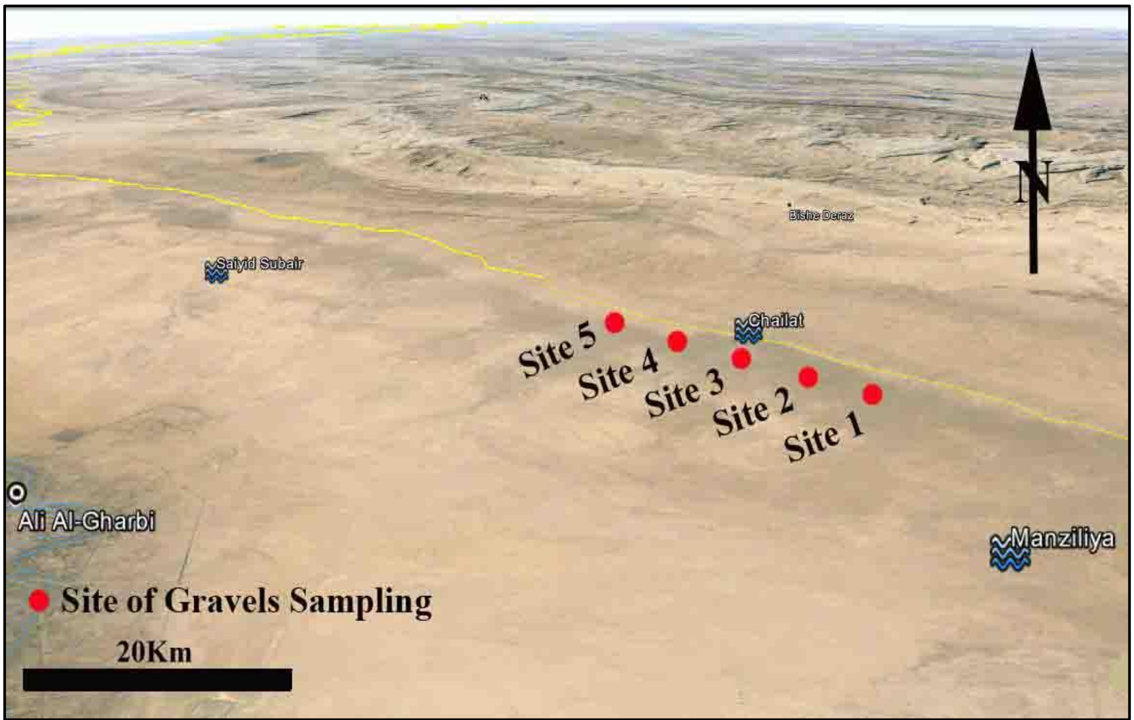



**Figure 13-** Inclined satellite view showing the sites of gravels sampling, Missan Governorate [37]

**Table 6-** The average composition of gravels from Missan quarries of gravels.

| Number of Samples | Site of Sampling | Number of Samples | Composition | | | | |
|---|---|---|---|---|---|---|---|
| | | | Carbonates | Chert | Igneous | Metamorphic | Quartz |
| 2660 Gravels | Site 1 | 400 | 65 | 15 | 7 | 5 | 8 |
| | Site 2 | 500 | 68 | 14 | 6 | 5 | 7 |
| | Site 3 | 650 | 63 | 16 | 8 | 6 | 7 |
| | Site 4 | 540 | 64 | 14 | 9 | 5 | 8 |
| | Site 5 | 570 | 69 | 12 | 7 | 7 | 5 |
| Average | | | 65.8 | 14.2 | 7.4 | 5.6 | 7 |

**Mix Proportions**

A two-step mixing procedure was followed. The first step concerns the fine aggregates, and the second is related to the overall raw materials mixture. Dune sands of the studied area are not suitable if used alone as fine aggregates in concrete, so for environmental and economical reasons, a mixture of dune sand and Dhibdiba formation sand was formulated so as to reach an optimum ratio that is suitable for normal-load concretes, the mixing ratio are shown in Table- 7.The amount of dune sand was manipulated by varying its content by 25%, 35%, and 50% with Dhibdiba formation sand. The best mixing ratio is related to the 35% dune sands as evident in the size histogram and FM value (Figure- 14).

**Table 7-** The percentage of mixing of dune sand to Dibdibba formation sand.

| Dune Fields | Mix No. | Percentage of Dune sands | Percentage of Dibdibba Formation Sands |
|---|---|---|---|
| Dibdibba Sand | DB | 0 | 100 |
| Missan | M1 | 25 | 75 |
| | M2 | 35 | 65 |
| | M3 | 50 | 50 |
| Thi-Qar | T1 | 25 | 75 |
| | T2 | 35 | 65 |
| | T3 | 50 | 50 |
| Al-Qadesiya | Q1 | 25 | 75 |
| | Q2 | 35 | 65 |
| | Q3 | 50 | 50 |
| Al-Muthana | S1 | 25 | 75 |
| | S2 | 35 | 65 |
| | S3 | 50 | 50 |

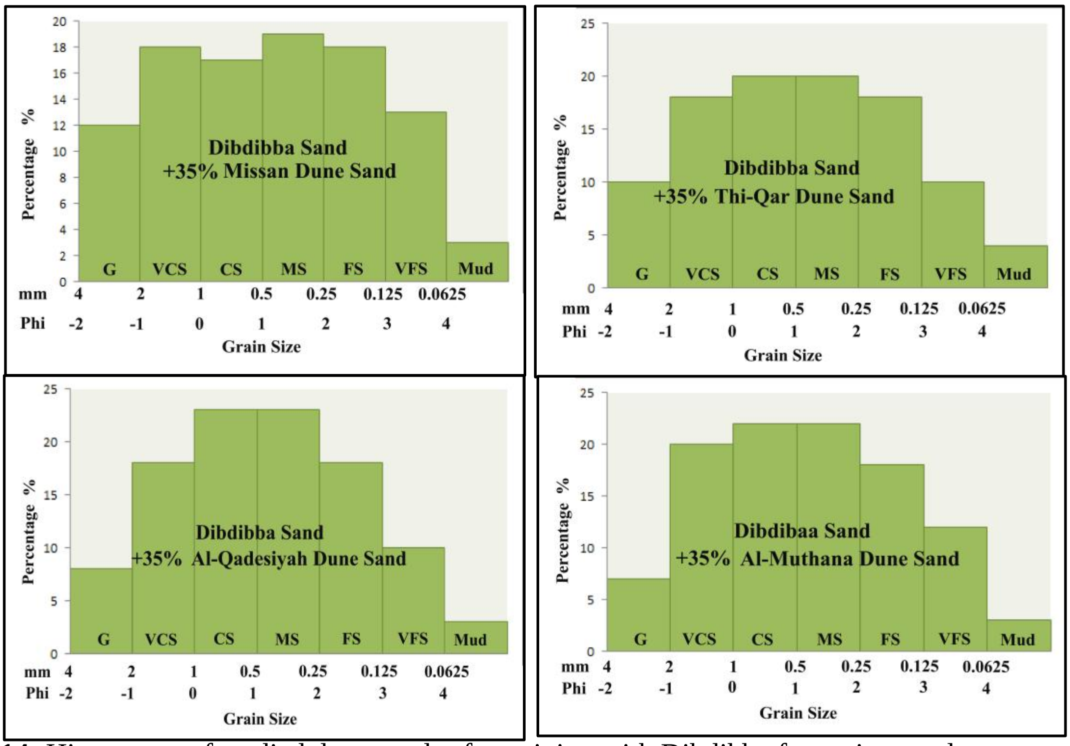



**Figure 14-** Histograms of studied dune sands after mixing with Dibdibba formation sands.

The proportions of the raw materials used in preparation of the concrete paste is fixed for all experiments Table- 8, mixing was performed by a conventional constant-speed mixer، for each mix several cubes of dimension (10cm$^3$) were cast in pre-oiled steel molds Figure- 15. The process was employed in the the Central Baghdad Laboratory / National Center for Construction Laboratories / Ministry of Construction and Housing and done in accordance with the [39]. Specimens were demolded after 24h and cured in water bath Figure- 16. Compressive strength was determined at the age of 7 and 28 days Figure- 17. The results were taken as the average of three measurements.

**Table 8-** Percentages of gravel, sand, cement, and water for normal load concrete mixture [39].

| Percentage for m$^3$ (Kg)<br>Cement: Sand: Gravel: Water | Weight Percent<br>Cement: Sand: Gravels |
|---|---|
| 460: 650: 1035: 205 | 1: 1.41: 2.25 |

**Figure 15-** Cubes of concrete after demolding.

**Figure 16-** Cubes of concrete in the curing bath.


**Figure 17-** compressive strength test of concrete cubes.

## Results and Discussion

### Workability

Slump test was performed to evaluate the workability of fresh concrete. The workability is an assembly of several properties such as consistency, plasticity, and cohesion [49]. The slump test gives an indication of the water content, and thus the hardened strength of concrete [50]. Figure- 18 displays the workability (slump test in mm) results, it is clear that the studied dune sand cement concrete give different workability for the four different sites of dune sands at the same water/cement ratio. The result show two trends, the first as indicated by Thi-Qar and Al-Muthana dune sands in which the slump decreases abruptly at the 35% dune sand content, while the second as shown by Al-Qasesiyah and Missan dune sands in which there is a direct increase in slump with the increase in the dune sand content ratio. This difference in the slump behavior may be attributed to the high roundness and sphericity of the dune sand grains [50].

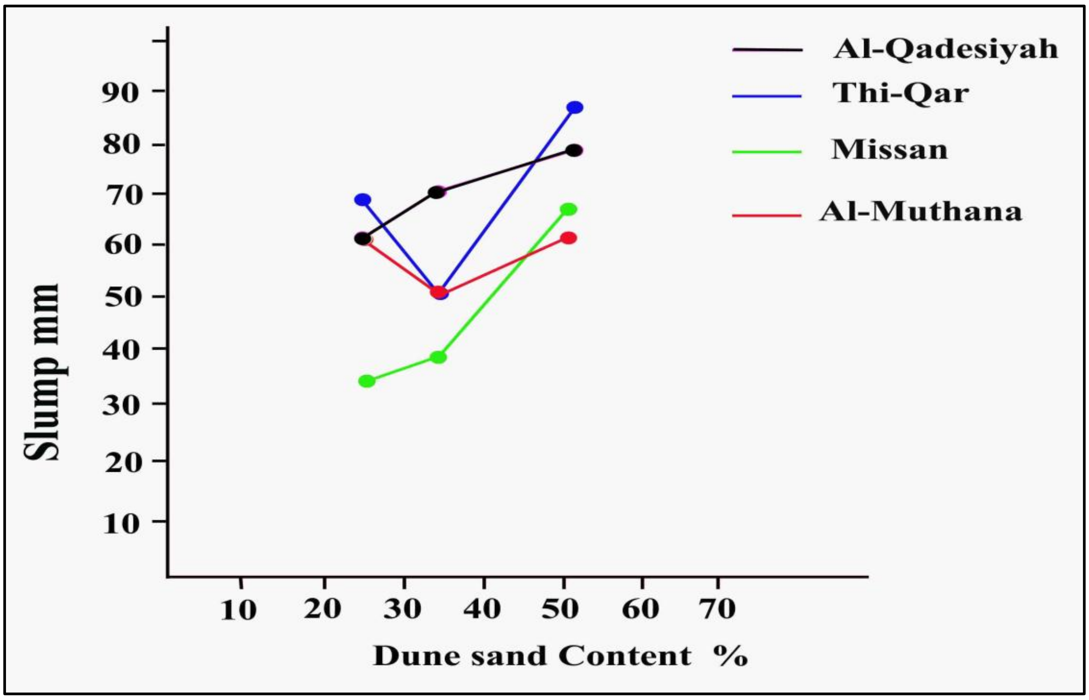



**Figure 18-** Relationship between slump and percentage of the mixed dune sands.

**Compressive Strength**

The type of fine aggregate has a significant influence on both rheological and mechanical properties of concrete [51]. The strength of cement concrete is assumed to depend primarily on three factors: the water-cement ratio, the degree of compaction, and the shape of aggregates [31]. Round, smooth sands require less mixing water, thus producing better strength at the same cement content, because a lower water/cement ratio can be used. On the other hand، surface features has a significance effect on strength, as rough surfaces, especially the distinctive pitted texture of dune sands, enhance the bond between particles and paste, thus increasing strength [51]. 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 N/mm. The compressive strength of the studied samples Table- 9 show a threshold value of 35% mixing ratio of dune sands as the lower and larger values of mixing give lesser compressive strength results (Figure- 19). Missan, Thi-Qar, and Al-Qadesiyah dune sands show lower values than Dhibdiba, and Al-Muthana sands, the compressive result of the latter surpasses the others. The segregation observed in the compressive strength values may be attributed to the increasing of the rounded grains packing of the dune sand grains which are characterized by smooth and rounded surfaces which may lead to increase bleeding and segregation of these grains within the fresh concrete before hardening processes [52].

**Table 9-** The compressive strength values of concrete mixtures of studied dune samples.

| Dune Fields | Mix No. | Compressive Strength | | Water Content W/C | Slump mm |
|---|---|---|---|---|---|
| | | 7 Days (N/mm²) | 28 Days (N/mm²) | | |
| Dibdibba Sand | DB | 24 | 30 | 0.5 | 40 |
| Missan | M1 | 19 | 25 | 0.5 | 37 |
| | M2 | 23 | 30 | 0.5 | 40 |
| | M3 | 20 | 23 | 0.5 | 70 |
| Thi-Qar | T1 | 17 | 24 | 0. 5 | 70 |
| | T2 | 20 | 29 | 0. 5 | 50 |
| | T3 | 18 | 25 | 0. 5 | 90 |
| Al-Qadesiya | Q1 | 20 | 24 | 0. 5 | 60 |
| | Q2 | 21 | 28 | 0. 5 | 70 |
| | Q3 | 19 | 25 | 0. 5 | 80 |
| Al-Muthana | S1 | 25 | 28 | 0. 5 | 60 |
| | S2 | 31 | 34 | 0. 5 | 50 |
| | S3 | 24 | 27 | 0. 5 | 60 |

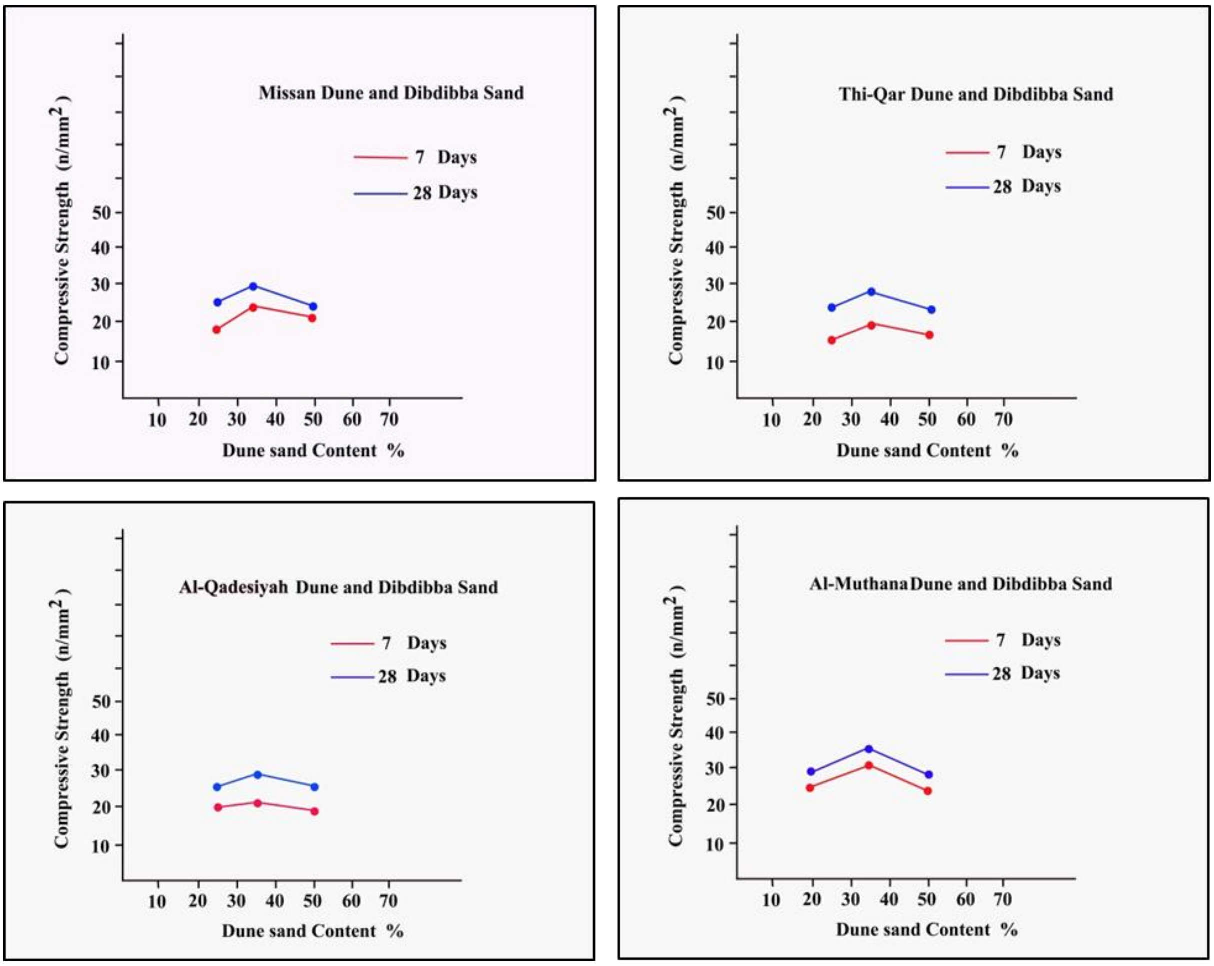



**Figure 19-** Relationship between compressive strength values and the mixed percentages of the studied dune sample.

**Application**

To test the validity and soundness of the above mentioned experiment and procedure, application for producing concrete pavement bricks was implemented. Missan dune sands were chosen as a start, due to the logistic manifestations of the area in regard to the availability of both fine and coarse aggregates from the large number of quarries which lie nearby the dunes. The prepared concrete with the optimum 35% of dune sand of fine aggregate was casted into silicon molds of four different designs of Interlock Pavement Bricks, and following the Iraqi Quality Standard [53], (Table- 10). The products were prepared and manufactured in one of the local construction factories in Al-Kamalia area in Baghdad (Figure- 20). The Interlock Pavement Bricks were then tested in Central Baghdad Laboratory / National Center for Construction Laboratories / Ministry of Construction and Housing and the results are found to be well correlated with the standard bricks (Figure- 21), except for design A, the failure of which may be attributed to the inconsistency in shape and thickness (Table- 11).

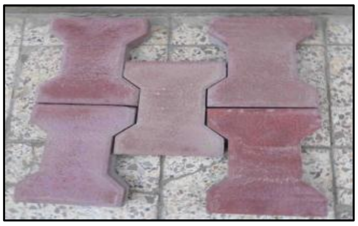
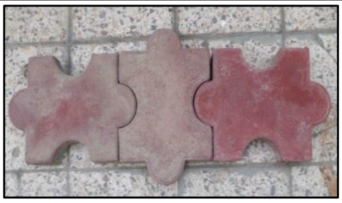
**Table 10-** Iraqi Quality Standard number (IQS: 1606 in 2006) for interlock pavement block.

| Light mm | Width mm | High mm | Surface Area mm² | Water Sorption % | Compressive Strength N/mm² |
|---|---|---|---|---|---|
| 290 | 140 | 60 | - | 10 | 25 |

**Figure 20-** Silicon molds used in interlock pavement application.


**Figure 21-**Test of Compressive strength of interlock pavement block.

**Table 11-**Engineering properties of the different interlock pavement design according to [53].

| Design No. | Water Sorption % | Compressive Strength (28Days), (N/mm²) | Surface Area mm² | Image of Design |
|---|---|---|---|---|
| A | 8.79 | 16.49 | 56600 |  |
| B | 6.9 | 29.42 | 56200 |  |
| C | 8.28 | 38.11 | 41916 |  |
| D | 7.47 | 48.48 | 47973 |  |

**Summary and Conclusions**

Eighty samples were collected from the dune sands of Missan، Al-Qadesiyah, Thi-Qar, and Al-Muthana governorates. These sands displayed different characteristics in regard to their mineralogy, texture, and chemical components. Assessment of these sands was performed for their suitability as fine aggregates in concrete tasks. Mineralogy and chemical analysis of these sands reflect good fitness as fine aggregate; however, size grading presented an obstacle due to their poor nature. Mixing with standard graded sand (Dihbdiba formation sand) by 25%, 35%, and 50% showed that the 35% ratio is satisfactory, and gave promising results. These encouraging outcomes are strengthened by application of the above procedure in producing interlock pavement bricks, which offered successful products that may be a profitable remedy of these areas.

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