Journal of Engineering Research **Vol. 6 No. (2) June 2018 pp.** *46-63*

Properties and behavior of the dust fallout in the State of Kuwait

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ABSTRACT

Sand storms occur frequently in Kuwait, the gulf states, and other arid climate countries. Most storms occur in the spring and summer months, where dry conditions and high speed winds prevail. While the fine particles in suspension in the air have received attention due to their health hazards associated with inhalation, the material deposited on the ground, cars, roads, windows, and plants has not been examined or investigated. Moreover, the geotechnical properties of the dust fallout have not been examined.

The dust fallout deposited at one site in Kuwait City, following four sandstorms, was examined by laboratory testing. Tests included basic properties, strength, and consolidation. Moreover, chemical and environmental tests were performed to determine the material mineral composition and characteristics. The results indicated that the material is a light weight compressible silt, or silt with sand. The average percent of fines including silt and clay is 87%. The mineral composition indicates that the principal components are calcite and quartz with an average of 36% and 33%, respectively. The dust is heavily contaminated with arsenic, cadmium, and iron. These harmful compounds are due to traffic emissions, and other human activities.

Keywords: dust fallout; soil properties; chemical analysis; soil composition; arid areas, health hazards.

INTRODUCTION

Dust storms and rising sand in Kuwait are mostly associated with the strong south-easterly winds that commonly develop in winter and spring during the passage of the Mediterranean depressions. In April (the season of *Sarryat*), thunder clouds usually appear in the afternoon and during the night and are occasionally accompanied by severe dust storms during which the visibility may drop to zero. Spring dust storms, which are usually generated by the south-easterly wind, tend to be of short duration, severe, and followed by rain. The dry and hot north-westerly winds (*Simoom*) that prevail in early summer, due to the monsoon, are also associated with dust storms. During this season, dust storms are particularly frequent, especially in June and July (Al-Awadhi, 2005; Al-Dousari et al., 2012). Such frequent occurrence of the sand and dust storms is mostly attributed to the interaction of the prevailing climatic conditions and the sediment-morphological settings of the local and regional area (Al-Hurban et al., 2010).

The northern Arabian Gulf region including Kuwait is located to the south of the Mesopotamian flood plain, which is covered with muddy and silty sediments. This area is susceptible to dust storms because of its low topographic relief, scanty vegetative cover, light-textured top soils, and recurring strong and turbulent winds. Summer's strong north-westerly wind, the Shamal, exerts enough traction on the bare, dry soil surface along its course to lift thousands of tons of fine sediment particles into the air, carrying them great distances as thick dust clouds.

Surface sediments in the desert of Kuwait reached a stage of maturity where their mobility has been decreased due to the development of lag pavements and a flourishing desert flora (Khalaf and Al-Ajmi, 1993; Al-Hellal and Al-Awadhi, 2006; Al-Enezi et al., 2008). However, due to recent substantial anthropogenic activities, the desert of Kuwait witnessed a significant environmental deterioration (Al-Awadhi, 2013; Al-awadhi et al., 2014). The latter is manifested by the decline in the density of its vegetation cover and therefore, the increase in the aeolian activities and its surface sediments became amenable to contribute to the occurrence of dust and sand storms (Al-Dousari and Al-awadhi, 2012).

While the geotechnical properties of the dune sands were previously determined (Al-Sanad et al., 1993), the properties of the dust fallout have not been examined. The average dust deposition rate in Kuwait City is high (0.6 kg/m^2/year). It ranked the first out of 56 dust deposition rates observed throughout the world (Al-Awadi, J., and Al-Shuaibi, A., 2013). Most of the research carried out so far on the dust fallout has dealt with the deposition rates and the mineral composition (Al-Awadi, J. 2005), sources, and characteristics (Al-Dousari, A. and Al-Awadi, 2012; Al-Hurban, A. and Al-Ostad, A., 2010). Several researchers have examined the chemical composition of the particles in suspension because of its hazardous effect on human health (Alolayan, M. et al. 2013; Brown, K.W. et al., 2008; Draxler, R.R. et al., 2001; Hahnenberger, M. and Perry, K., 2015).

This paper examines the geotechnical properties of the dust fallout at one site in Kaifan, Kuwait City, Kuwait, by laboratory testing. Four samples were taken from the material deposited on the ground following four sandstorms and tested in the laboratory for basic properties, strength, and compressibility. Other chemical and environmental tests were performed to determine the mineral composition of the samples, and the concentration of heavy metals. Based on the comprehensive test results, the properties of the dust fallout were determined and their effects on human health are discussed. Several recommendations are made to deal with their effects on Kuwait, the gulf states, and other countries where frequent sand storms occur.

SAMPLING OF THE DUST FALLOUT

The dust fallout from four dust storms that passed over a suburb of Kuwait City called Kaifan was collected from one site, shown in Figure 1. This site was chosen to represent the urbanized areas of the State of Kuwait. A 152 m^2 area fenced with a 2 m high solid fence was chosen to receive the fallout. This area was surfaced with a smooth solid surface and was cleaned before each storm, and the samples were collected after these four storms for characterization and testing. Details of the four storms were as follows.

Figure 1. Site location plan.

Sample 1
The storm started 7 pm on 10/2/2009. The lowest visibility was between 11 am and 4 pm of 11/2/2009. After 11/2/2009 midnight dust suspension started to decrease until it almost totally cleared by 5 pm on 12/2/2009. The sample was collected at 7 pm on 12/2/2009. The average dust fallout was 0.087 $kg/m^2/day$. The wind speed was 57 km/hr (NW).

Sample 2
The storm started at 5:30 pm on 25/3/2011 with a very visible front, which made visibility less than 10 m. By 5:30 pm on 26/3/2011, the storm almost totally cleared. The sample collected at 5:30 pm on 26/3/2011 indicated a fallout of 0.219 $kg/m^2/day$. The wind speed was 50 km/hr (NW).

Sample 3
Fallout was collected from a storm, which lasted almost 24 hours. The fallout that occurred between midday 30/6/2011 and midday 1/7/2011 was 0.042 $kg/m^2/day$. The wind speed was 49 km/hr (NW).

Sample 4
Fallout was collected from a storm, which lasted six days between 2/11/2014 and 7/11/2014 and resulted in dust fallout of about 0.035 $kg/m^2/day$.

The dust fallout during these four storms ranged between 0.035 and 0.219 $kg/m^2/day$. When the second storm is excluded, the average fallout was 0.055 $kg/m^2/day$. The deposition of dust as a result of storm No. 2 (0.219 $kg/m^2/day$) was also detected by Al Awadhi and Al Shuaibi (2013). This one-day dust deposition constitutes one-third of the average annual deposition.

THE TESTING PROGRAM

The following laboratory tests were performed:

1. Mechanical and hydrometer analysis to determine the grain size distribution curves.

2. Direct shear tests on samples prepared at 95% relative compaction. The samples were of 63 mm diameter and 20 mm thickness.
3. Falling head permeability tests on sample 3. The samples were of 100 mm diameter and 130 mm height and were compacted to a 95% relative compaction.
4. Consolidation tests on samples compacted to 95% relative compaction. The samples were of 75 mm diameter and 20 mm thickness.
5. Other tests were carried out at the National Unit for Environmental Research and Services (NUERS), Kuwait University. They included alkalinity analysis, carbon, hydrogen, nitrogen, sulfur CHNS analysis, conductivity analysis, determination of petroleum hydrocarbon compounds (PHCs), and hexane extractable material (HEM), metal analysis, and ph analysis.

Inductively coupled plasma optical emission spectrometry (ICPOES) was employed for the determination of metals in the collected dust samples. For ICPOES analysis, it was necessary to digest the samples and add an acid mixture containing 2 ml HNO_3, 6 ml HCl, and 1 ml HF. The mixture was left overnight and then heated on a hot plate at 100 °C to almost dryness. The residue was then dissolved in 15 ml of deionized water. The solution was filtered and transferred into a 25 ml volumetric flask and diluted to the mark. To assess that the digestion procedure was adopted, and to check the accuracy, aliquots of two certified reference materials (CRMs), namely, SRM 2709 San Joaquin soil (NIST,USA) and SRM 2711 Montana soil (NIST, USA), were subjected to the same treatment and included in the over-all analytical process. For metal analysis, the extraction and analysis of heavy metals were carried out as per the US EPA method IO-3.2 (USEPA, 1999).

Total petroleum hydrocarbons (TPHs) and petroleum hydrocarbon compounds (PHCs) in the dust fallout samples were measured using the US-EPA 8015C method (GC analysis) and US-EPA 3540C (extraction) procedure. The filter samples containing dust fallout sediments were extracted on Soxhlet Extraction unit (7890A GC system with flame Ionization Detector–Agilent) for 4 hours with 60 ml dichloromethane, filtered with hexane, concentrated to 1 ml, and analyzed on GC system equipped with fused silica capillary column, operated in split mode using carrier gas, helium. Then, the samples were heated at 50ºC and gradually increased through 3 ramps up to 330 ºC. The GC system was calibrated using C8-C40 standards from 175 to 1750 μg/ml, and the samples were quantitated against the curve generated through calibration.

Mineralogical analyses of the whole dust sample including its silt and clay fractions were carried out using a Siemens D5000 Diffractometer (XRD), equipped with a position sensitive detector. The computer program FIFFRAC^{plus} (BRUKER AXS, INC, 2004) with ICDD library was used to identify the minerals.

Morphological and elemental analyses were also performed using a scanning electron microscope (SEM) equipped with energy dispersive x-ray spectrometer (EDS). This was carried out by the Nanotechnology Research Facility, College of Engineering and Petroleum, Kuwait University.

SAMPLE PREPARATION

Samples for direct shear tests, permeability, and consolidation tests were prepared in four layers by tamping to reach 95% of the maximum density as determined from the compaction test. All tests were carried out according to the ASTM standards.

TEST RESULTS

Table 1 is a summary of the test results. Figure 2 shows the grain size distribution curves of the four samples. From Table 1 and Figure 2, it is noted that silt (< 0.075 mm – 0.002 mm) is the principal component with an average value of 72% and the average clay size (smaller than 0.002 mm) is 14.75%. The average percent of fines (passing #200 sieve or smaller than 0.075 mm), which include both the silt and clay size, is 87%, with sample 1 having the largest fines content of 93.8% and sample 2 having the minimum value of 82.3%. All samples were classified as ML according to the Unified Soil Classification System. The group name is silt for samples 1, 3 and silt with sand for samples 2, 4.

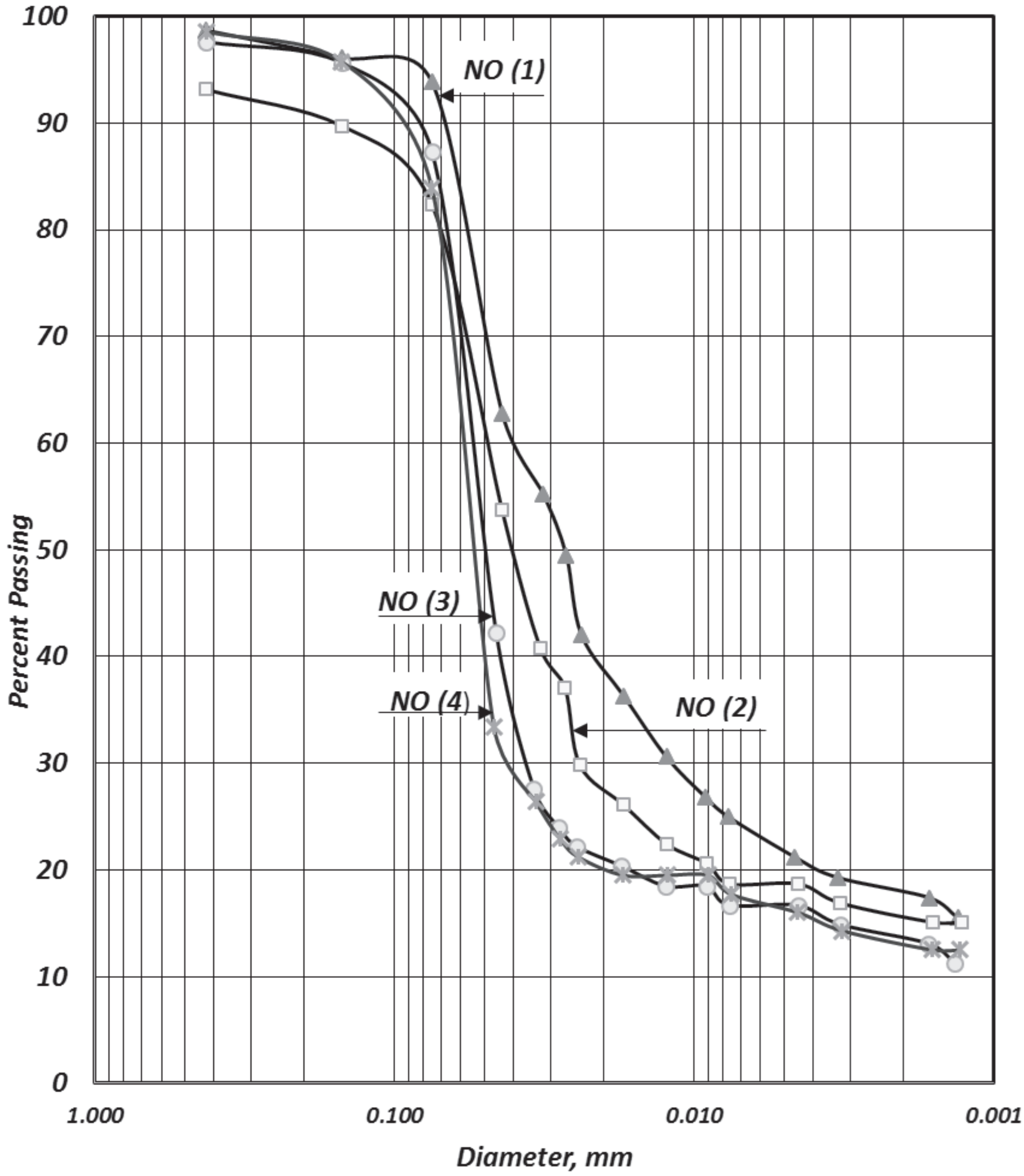

Figure 2. Grain size distribution curves of dust fallout sampled.

Table 1. Summary of the test results on the dust samples.

	Sample 1	Sample 2	Sample 3	Sample 4
% finer than # 200	93.8	82.3	87.3	83.9
*Finer than 10 μm	26	20	18	20
+Finer than 2.5 μm	18	16	13	12
Fine sand (%)	6	18	13	16
Silt (between 2 & 75 μm) (%)	76	66	74	72
Clay (< 2 μm) (%)	18	16	13	12
Permeability (cm/sec)	-	-	3.5×10^{-5}	-
ϕ (degrees)	33.7	36.1	34.1	-
C (kPa)	6.73	7.52	15.43	-
LL	26	-	-	-
PL	22	-	-	-
PI	8	NP	NP	NP
Soil classification	ML	ML	ML	ML
Sulfate SO_4^- (%) BS 1744	0.19	0.17	0.18	0.20
Chloride CL^- (%) BS 1744	588	-	-	-
Organic matter (%) BS 1377-3	3670	-	-	-
Water content (%)	2.42	2.07	1.44	1.41
Maximum density (gm/cm^3)	1.39	1.38	1.45	1.43
Minimum density (gm/cm^3)	1.01	0.98	1.08	1.07
Compression index C_c	0.249	0.200	0.159	-
Swelling index C_s	0.026	0.019	0.016	-
Specific gravity	2.56	2.63	2.67	2.66

- not measured

* Percentage of soil with diameter < 10 μm

+ Percentage of soil with diameter < 2.5 μm

The weight of particulate matter of sizes less than 10 μm and 2.5 μm in 1 m^3 of air (i.e., PM_{10} and $PM_{2.5}$) has significance when health hazard is concerned. In our samples, the grain size distribution curves and Table 1 indicate the average percentage of these sizes that are approximately 21% and 15%, respectively.

Table 1 shows that the dust is a light weight material with the average minimum density 1.035 g/cm^3, which is slightly higher than the density of water. The average maximum density is 1.41 g/cm^3, which is substantially smaller than other soils. As such, the material is easily moved and transported by wind forces.

The results of the direct shear tests on samples 1, 2, and 3 are shown in Figures 3 and 4. Figure 3 shows the shear stress vs. relative displacement for the three samples tested at normal pressures of 31.5 kPa, 63 kPa, and 94.4kPa. As shown, there is no peak or

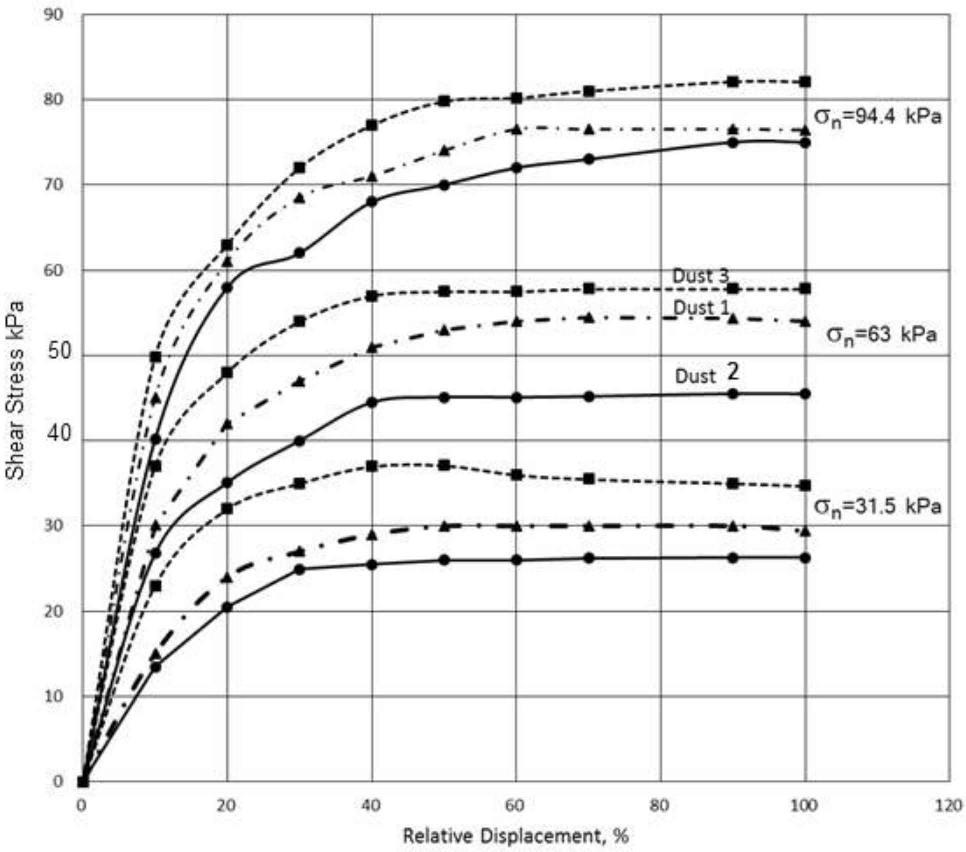

Figure 3. Shear stress vs. relative displacement for the dust samples 1, 2, and 3.

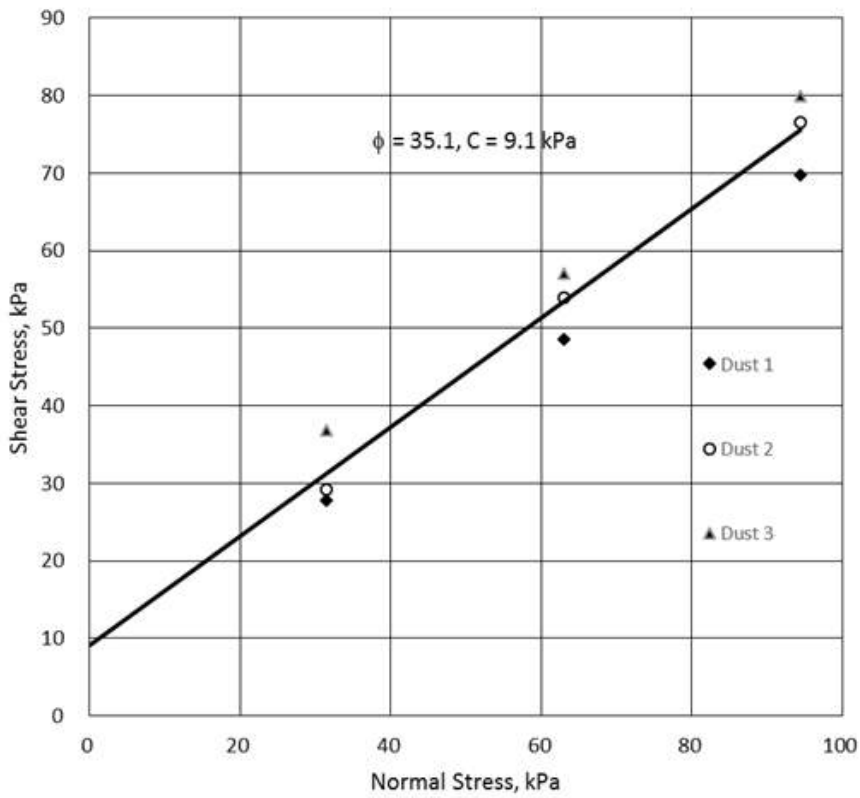

Figure 4. Failure envelop for the dust samples.

well defined maximum shear stress indicating soft or compressible material. Sample 3 is the stiffest or incompressible with lower relative displacement at any shear stress compared to samples 1, 2. This may be due to the lower clay content of 13% for sample 3 compared with 16%, 18% for samples 2 and 1, respectively.

The shear strength parameters for each dust samples, at 95% relative compaction, are given in Table 1. Figure 4 shows the shear stress vs. normal stress for all three samples and the average failure envelope. The average cohesion c′ and angle of friction ϕ′ are 9.1 kPa and 35.1°, respectively.

The consolidation test results are given in Table 1 and Figures 5, 6. Figure 5 shows the void ratio vs. effective pressure (e-log σ′) curves for samples 1, 2, and 3. Figure 6 shows the test points and the average e-log σ′ curve. The compression index C_c and the swelling index C_s were determined from these curves as shown in Table 1. From Figure 6, the average compression and swelling index are 0.2 and 0.0203, respectively.

Table 2 shows the coefficient of consolidation C_v with applied pressure for samples 1, 2, and 3. It is clear that this coefficient is not constant, and it changes with the applied pressure. The average value of C_v for the range of pressure 50 – 400 kPa is 2354.5, 2254.75, and 2613 mm^2/min for samples 1, 2, and 3, respectively. The larger value for sample 3 indicates that the time required to achieve a given degree of consolidation will be smaller compared to samples 1 and 2. This is logical and within expectations considering that sample 3 has the lowest clay content of 13% as shown in Table 1.

Falling head permeability tests were carried out on sample 3 only at 95% relative compaction, yielding a coefficient of permeability $k = 3.5 \times 10^{-5}$ cm/sec.

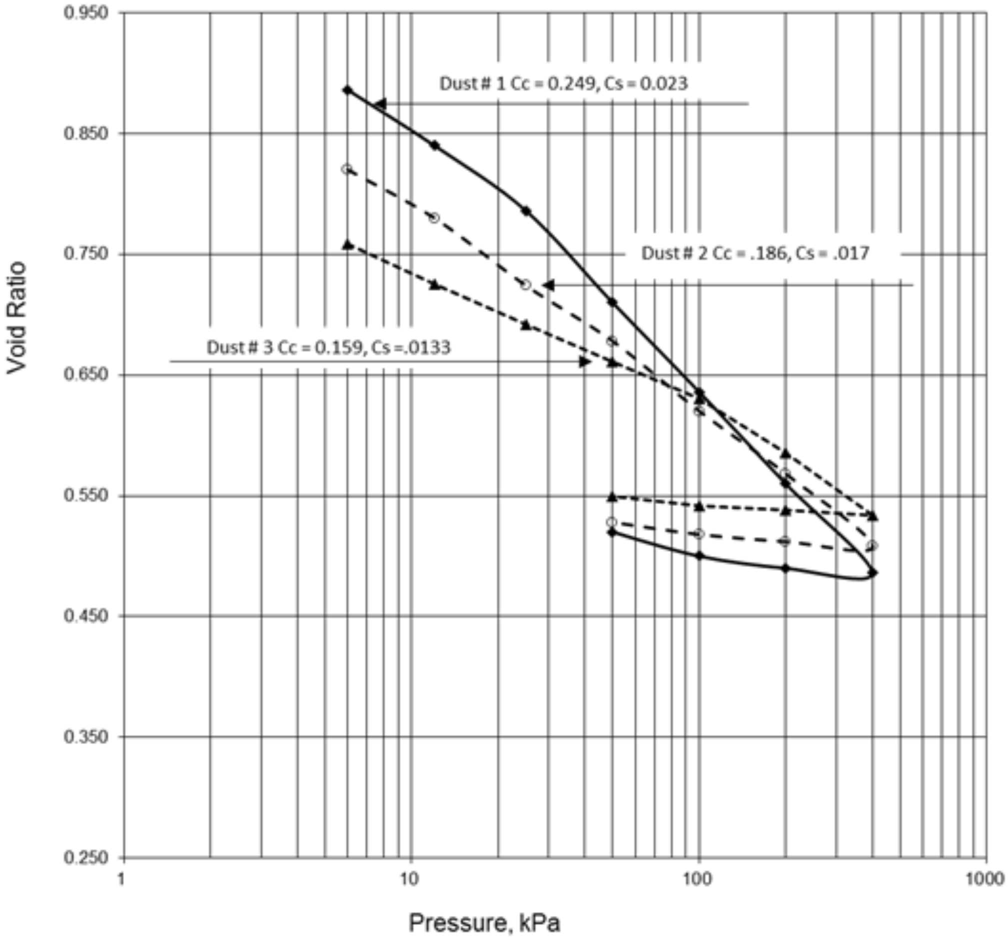

Figure 5. e – Log s curves for dust samples.

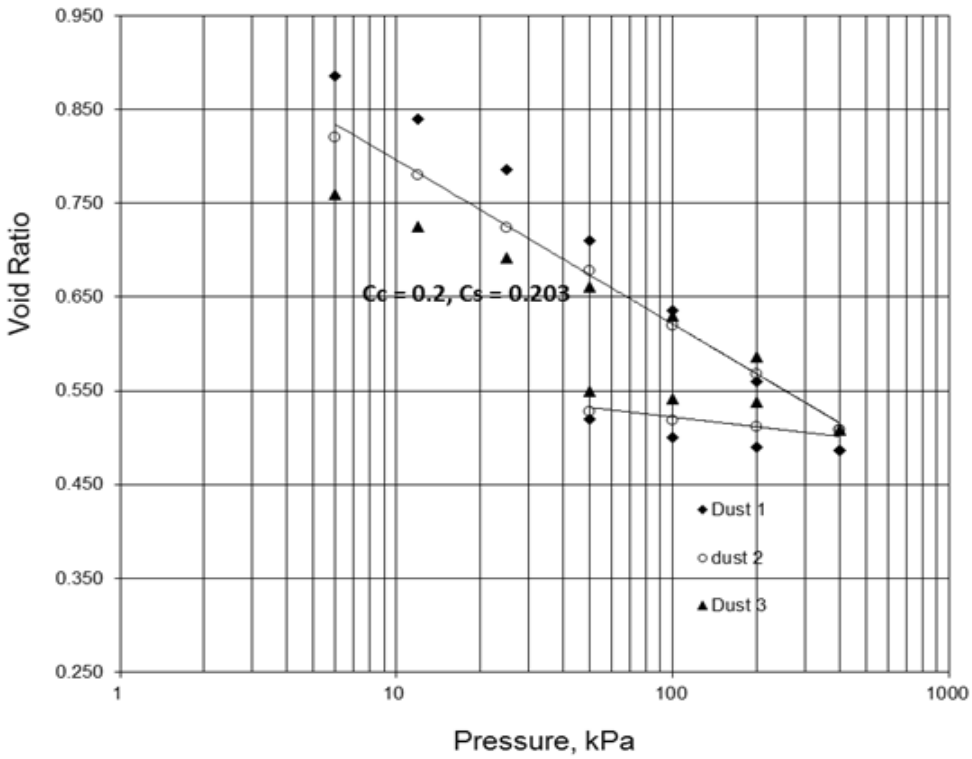

Figure 6. Average e-log σ curves for samples 1, 2, and 3.

Table 2. Coefficient of consolidation - C_v values.

Pressure kPa	C_v mm²/min		
	S_1	S_2	S_3
12	3194	-	3561
25	2925	4015	3163
50	2892	2869	3135
100	2932	2194	2275
200	2038	2251	2445
400	1556	1705	2597

The results of tests carried out at the "NUERS" are summarized in Tables 3 and 4. Table 3 shows the pH, alkalinity, conductivity, sulfur, hydrogen, and carbon values for each sample. The total petroleum hydrocarbons (TPHs) measured as gravimetric determination of hexane extractable material (HEM) by using microwave extraction were done according to EPA method 3546. It measures both petrogenic (from petroleum) and biogenic (from biomaterials) hydrocarbons. Results are shown in Table 4.

The petroleum hydrocarbon compounds (PHCs) were measured using ultraviolet fluorescence detector (UVF) according to EPA method 3540 C. It measures only the aromatic fraction of petrogenic hydrocarbon. Results are shown in Table 4.

The values of TPHs and PHCs are low from soil contamination perspective; however, for fine particles it may cause irritation to the respiratory system.

Table 3. Summary of the chemical test results.

	Sample 1	Sample 2	Sample 3	Sample 4
pH	7.82	7.56	7.68	8.59
Alkalinity mg/kg	766	286	379	663
Conductivity (μmho/cm)	6130	7800	6700	22300
Sulphur (%)	0.372	0.426	0.803	1.300
Hydrogen (%)	0.347	0.308	0.294	0.302
Carbon (%)	4.667	4.242	3.657	3.974

Table 4. Petroleum compounds in the dust samples.

Sample #	TPHs (mg/kg)	PHCs (μg/g)
1	703	4.239
2	300	2.496
3	563	1.733
4	633	8.366

TPHs – total petroleum hydrocarbons
PHCs – petroleum hydrocarbon compounds

Mineralogical analysis

Mineralogical analysis of the dust samples, using XRD, indicated that they are mainly composed of calcite and quartz and subordinate amounts of albite, montmorillonite, microcline, dolomite, and gypsum (Table 5). Calcite grains are the most abundant; they vary between 27.1% and 45.8% with an average of 36.35%. Quartz is the second most dominant mineral grain; it ranges from 22.8% and 40.2% with an average of 33.15%. Albite, montmorillonite, microcline, and dolomite grains occur with an average of 10.83%, 6.65%, 5.67%, and 4.65%, respectively. Few gypsum, orthoclase, and halite grains were recorded in some samples; their average frequency is less than 1%.

Table 5. Relative frequency % of the various mineral grains.

Sample #	Calcite	Quartz	Albite	Montmo-rillonite	Microcline	Dolomite	Orthoclase	Gypsum	Halite
1	33.7	37.2	5.3	8.4	0.0	11.1	3.8	0.0	0.0
2	45.8	22.8	9.1	7.6	8.6	5.2	0.0	0.0	0.0
3	38.8	32.4	12.7	4.9	9.7	0.0	0.0	1.6	0.0
4	27.1	40.2	16.2	5.7	4.4	2.3	0.0	1.6	2.6
Average	36.35	33.15	10.83	6.65	5.67	4.65	0.95	0.8	0.65
Max.	45.8	40.2	16.2	8.4	9.7	11.1	3.8	1.6	2.6
Min.	27.1	22.8	5.3	4.9	0	0	0	0	0

The size and morphological characteristics of the collected dust particles observed by the scanning electron microscope (SEM) are illustrated in Figure 7. The SEM shows clearly different grain morphological structures and sizes. In general, quartz grains are mostly subrounded to angular; few are flaky. They display several surface features such as triangular pits and dissolution cavities and are crusted with minute calcite and dolomite rhombs of micron or less than a micron in size.

Feldspar grains are subhedral; some are cracked. Montmorillonite commonly occurs as minute pellets of agglomerated flakes. Gypsum occurs as clusters of micron size monoclinic crystals. Calcite is mostly represented by clustered micritic crystals forming grains of irregular shape. Discrete dolomite rhombs are recognized; they are commonly of few microns in size. The dust fallout samples include considerable amounts of dry plants debris; sample 4 contains few pollen grains.

Potential Source

The mineralogical composition of the studied dust fallout samples indicates that they are composed mainly of quartzitic calcareous silt and clay. It is suggested that they are mostly derived from surface soil rich in carbonates and quartz. The northern surface of Kuwait is mostly carved in calcrete. The latter consists of siliciclastic grains (quartz and feldspars) cemented by micritic calcite. This kind of deposits can be easily weathered and develops a thin blanket of loose fine grained soil formed of quartz, feldspars, and silt and clay size calcite grains. This loose soil may provide significant amount of windblown dust during dry windy climate. Therefore, it is suggested that the studied dust fallout sediments may have been locally derived; however, the potential contribution of the surface sediments at the southern Mesopotamian flood plain located at the northwest of Kuwait should not be ignored.

DETERMINATION OF THE DUST CONTAMINATION

Elemental Concentration

Table 6 shows the average distribution of seventeen elements measured in the collected dust samples. The average concentrations ranged from 4.3 (Cd) to 149020.6 mg/kg (Ca). The average concentrations of direct or indirect related pollutants to traffic emission decrease in the order of Mn, Ni, As, Cr, Zn, Cu, Pb; that is, the Pb concentrations were the lowest among these measured elements in the sample collected from the sites (6.52 mg/kg). Comparing the average results in Table 6 with acceptable levels for same heavy metals given in Table 7 used by Faiz et al. (2009), all element concentrations were found to be below the acceptable level, except the concentrations of Cd, Ni, and As, which were found to be 1.4, 2.4, and 5.2 times above the acceptable levels, respectively.

Table 6. Elemental contents in dust samples (mg/kg) and results of the index geoaccumulation (I_{geo}) compared to element contents in sediment collected in Kuwait. (Background)

Metal	Dust	Background Value	I_{geo}	Ratio: Mean metal Conc. in dust/Mean metal Conc. in Kuwait sediment
Al–Aluminium	23980.75	5469.19	1.55	4.38
As-Arsenic	105.34	4.31	4.03	24.44
Ba-Barium	131.51	51.55	0.77	2.55
Ca-Calcium	149020.60	30344.91	1.71	4.91
Cd-Cadmium	4.30	0.42	2.77	10.22
Co-Cobalt	13.51	3.66	1.30	3.70
Cr-Chromium	55.69	25.63	0.53	2.17
Cu-Copper	27.95	21.96	-0.24	1.27
Fe-Iron	29300.87	4162.24	2.23	7.04
K-Potassium	6230.01	4162.24	0.00	1.50
Mg-Magnesium	29979.15	4983.45	2.00	6.02
Mn-Manganese	604.80	121.14	1.73	4.99
Na-Sodium	2890.52	915.12	1.07	3.16
Ni-Nickel	118.24	25.64	1.62	4.61
Pb-Lead	6.52	4.56	-0.07	1.43
Ti-Thalium	20.36	177.60	-3.71	0.11
Zn-Zinc	49.08	18.36	0.83	2.67
Min	4.30	0.42	-3.71	0.11
Max	149020.60	30344.91	4.03	24.44

Table 6 shows that the average concentrations for all elements analyzed in the dust samples (except Ti) were 2.17 (Cr) to 24.44 (As) times higher than their soil background values, that is, soils from desert and coast of Kuwait as determined by Al-Awadhi and AlShuaibi (2013). This indicates that most pollutants in the dust samples came from anthropogenic sources.

Assessment of the Dust Samples Contamination

The dust contamination assessment was performed using the index of geoaccumulation (I_{geo}) calculated from the equation (Muller 1969):

$$I_{geo} = \log_2 [C_n / 1.5 B_n] \quad (1)$$

where C_n is the measured concentration of the heavy of the examined element in dust sample and B_n is the geochemical background concentration of the heavy element in Kuwait surface sediments.

The contents of elements in Kuwait surface sediments were determined by Al-Awadhi and AlShuaibi (2013) by analyzing 184 top surface soil samples collected from different types of aeolian surface sediments (Table 6). Muller (1969) has distinguished six classes of the geoaccumulation index (Table 8). The calculated results of I_{geo} of heavy metals from the dust samples are presented in Table 6, which shows that the mean values of I_{geo} increase in the order As > Cd > Fe > Mg > Ca >Mn> Al> Co> Na> Zn> Ba > Cr. It was observed that the mean I_{geo} values of Cu, K, Pb, and Ti are less than zero, which means that practically the dust samples are not polluted with these elements, but could be uncontaminated to moderately contaminated by Mg, Ca, Mn, Al, Co, Na, Zn, Ba, and Cr, that is, the mean value of $1 < I_{geo} < 2$. The maximum I_{geo} of As was higher than 4 and less than 5, indicating very heavily to extremely contaminated dust samples, while Cd and Fe elements had maximum I_{geo} more than 2 and less than 3, indicating moderately to heavily contamination.

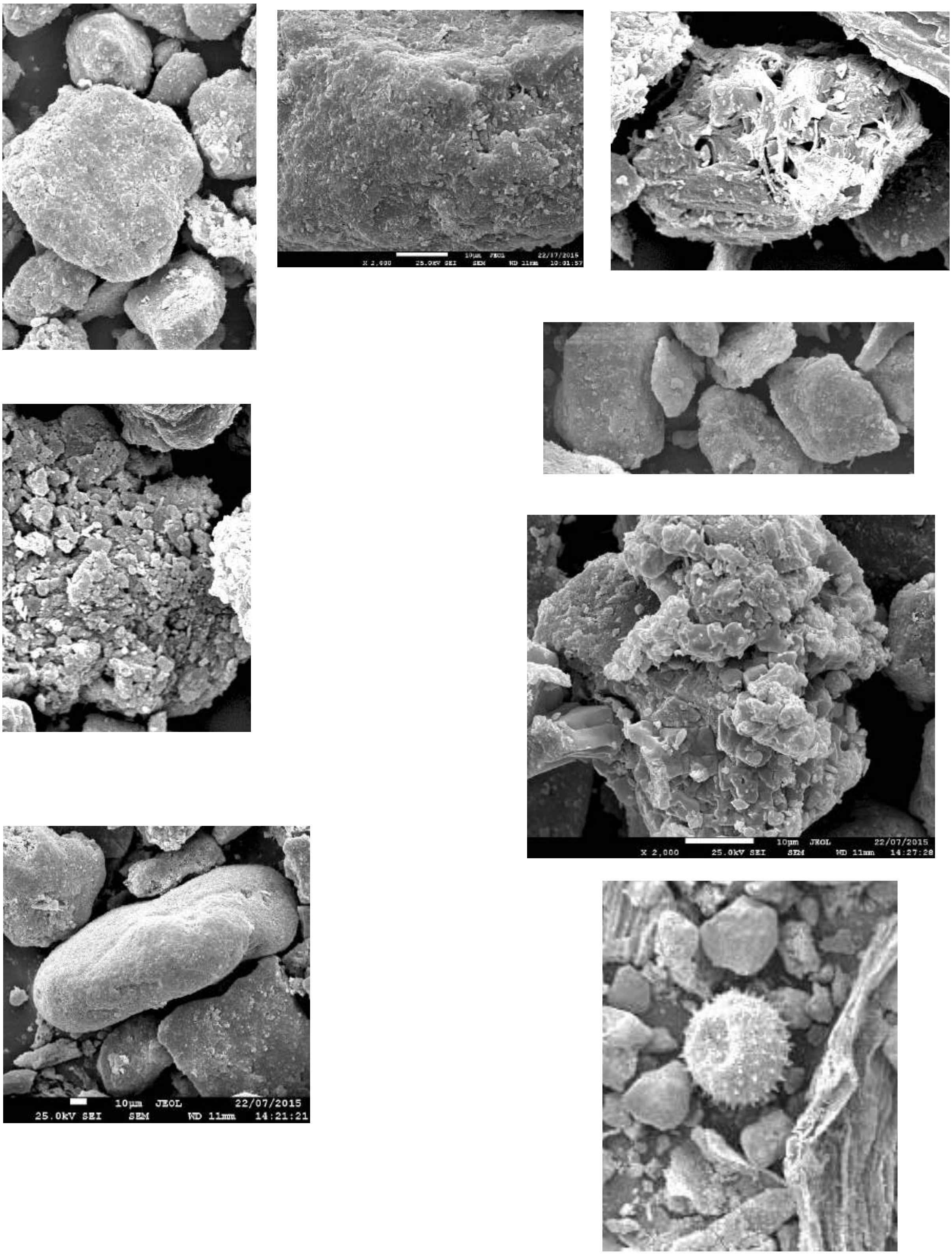

Figure 7. SEM images of dust particles showing the significant changes in both grain sizes and morphology of the dust particle and pollen grain presence.

Table 7. Acceptable values of some heavy metals (Sezgin*et al*., 2003).

Acceptable values (mg/ Kg)	Metals
100	Lead
3	Cadmium
100	Chromium
50	Copper
50	Nickel
2	Mercury
300	Zinc
25	Boron
50	Cobalt
5	Molybdenum
3	Selenium
20	Arsenic
500	Titanium
50	Vanadium
5	Uranium

Table 8. Six classes of the geoaccumulation index (Muller, 1969).

Class Value	Soil Quality
Igeo< 0	Practically uncontaminated
$0 < I_{geo} < 1$	Uncontaminated to moderately uncontaminated
$1 < I_{geo} < 2$	Moderately contaminated
$2 < I_{geo} < 3$	Moderately to heavily contaminated
$3 < I_{geo} < 4$	Heavily contaminated
$4 < I_{geo} < 5$	Heavily to extremely contaminated
$5 < I_{geo}$	Extremely contaminated

DISCUSSION

Although Kuwait has the highest dust deposition rate observed throughout the world, no studies were carried out to determine the geotechnical properties and the mineral characteristics of this material. The present study and the test results indicate that the dust fallout consists mainly of very fine light weight silt. Not only is it harmful while in suspension during sand storms due to inhalation and respiratory effects, deposition on the skin, but also after the dust is settled. With wind, the material deposited on the road sides and home windows will infiltrate homes and car components such as air and air conditioning filters, resulting in health problems and environmental pollution. More damage will occur since the dust fallout contains petroleum hydrocarbon compounds resulting from traffic and emissions and contaminated with heavy metals such as arsenic, cadmium, and iron. Therefore, frequent cleaning of roads, cars, and homes even after the sandstorms has subsided is necessary. The green environment resulting from planting grass and more trees, water spraying, and irrigation will help reduce the impact of sandstorms.

It should be noted that the direct and immediate effect of dust is on the respiratory system, eyes, and skin. It can also be absorbed, affecting different body organs. Therefore, it is advisable when exposed to sandstorms to wear masks, glasses, and long cloth to ensure that the skin is not exposed. In case of heavy storms, schools may be closed and construction work halted by government orders.

The dust fallout is very soft light weight and compressible material with about 90% fine silt and clay size particles. It is classified as ML according to the Unified Soil Classification system. As such, it cannot be used as base for secondary roads or for supporting structural loads, even though it has a reasonable angle of friction ϕ when compacted to 95% relative compaction. It is highly compressible with large deformation and lower soil modulus compared with granular sandy soils.

CONCLUSIONS

The properties of the dust fallout at one site in Kuwait were examined by laboratory testing on samples taken after four sandstorms. Based on test results, the following conclusions were reached:

1. The dust fallout consists of light weight predominantly silty size particles and is classified as ML with a group name of silt, or silt with sand, according to the Unified Soil Classification System.
2. Consolidation tests on compacted sample (R = 95%) show that the material is soft and compressible with C_c, C_s equal $\approx$ 0.2, 0.02, respectively.
3. Direct shear test on compacted samples (R=95%) indicates that the average strength parameters c', ϕ' are $\approx$ 9 kPa, 35°, respectively.
4. The index of geoaccumulation indicates the dust is heavily contaminated by As, CD, and Fe with following distribution order As>Zn>Pb>Cu. Similarly, the concentrations of these elements are higher than their local background values in the same distribution order.
5. The dust fallout contains petroleum hydrocarbon compounds resulting from land use and traffic emissions. It requires frequent cleaning of roads, homes, and cars even after the occurrence of sandstorms.

6. Mineralogical analysis of dust samples using XRD indicates that they are mainly composed of calcite and quarts with subordinate amounts of albite, montmorillonite, microcline, and dolomite.
7. SEM images clearly showed different grain morphological structures and sizes. The grain sizes are mostly silty size with small percentages of fine sand and clay.
8. The results of the mineralogical composition of the studied dust fallout samples suggest that it may have been locally derived; however, the potential contributions of the surface sediments at the southern Mesopotamian flood plain located at the northwest of Kuwait should not be ignored.

ACKNOWLEDGMENTS

The authors would like to acknowledge the help of the staff of the following facilities at Kuwait University:

1. The geotechnical engineering laboratory of Civil Engineering Department, Kuwait University.
2. The National Unit for Environmental Research and Services (NUERS), College of Engineering and Petroleum, Project No. SRUL 01/13.
3. The Kuwait University Nanotechnology Research Facility (KUNRF), College of Engineering and Petroleum, Project No. GE01/07.

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Submitted: 01/05/2017
Revised : 31/10/2017
Accepted : 01/11/2017

Journal of Engineering Research **Vol. 6 No. (2) June 2018 pp.** *63*

خواص وتصرف
الترسبات الغبارية في دولة الكويت

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الخلاصة

تتكرر العواصف الرملية والغبارية في الكويت والجزيرة العربية والمناطق الجافة حول العالم وفي الكويت تزيد هذه العواصف خلال فصلي الصيف والربيع . وبالرغم من قيام الكثير من الباحثين بدراسة الآثار البيئية والصحية للحبيبات الدقيقة العالقة والمترسبة نتيجة لهذه الظاهرة إلا أن القليل منهم قد درس خواص هذه المواد الجيوتقنية.

يقدم هذا البحث نتائج دراسة مخبرية شاملة لخواص جميع مكونات المواد المترسبة من أربعة عواصف مرت على الكويت. وقد تم جمع العينات من موضع واحد في ضاحية كيفان وهي أحد ضواحي العاصمة الكويت وتشمل الفحوصات التي أجريت الخواص الأساسية، وفحوصات قوة وانضغاط التربة. بالإضافة إلى المكونات الكيميائية والمعدنية وخواص وطبيعة هذه المواد المترسبة.

أظهرت نتائج هذه الدراسة بأن المكون الرئيسي للمواد المترسبة هو الطمي مع نسبة قليلة من الرمل والطين والمحتوية بشكل أساسي على معادن الكالسيت (36%) والكوارتز (33%) مع نسب متفاوتة من المعادن الثقيلة الضارة بصحة الإنسان. كما أظهرت نتائج الفحوصات الجيوتقنية أن هذه المواد قوية إلا أنها قابلة للانضغاط.