Impact of Silica fume on the properties of Asphalt pavement base course

Farag Khodary
Civil Engineering Department, Qena Faculty of Engineering, South Valley University, Qena, Egypt

Abstract:-

Major road projects needs special limits of specification for the base course material. These limits of specifications may not be available in the local materials used in the project area. So researcher starts to look for additives that can be used to improve the properties of the used materials to reach the required limit of specifications for base course in highway construction. The aim of this work is to study the effect of silica fumes on the soil properties that used for base course in terms of maximum dry density and California Bearing Ratio (CBR). Silica fumes resulting from the reduction of high-purity quartz with coal in electric arc furnaces in the manufacture of ferro-silicon. Morphology and structural of the Silica fume were investigated by transmission electron microscopy (TEM) and scan electron microscope (SEM). A series of laboratory experiments have been implemented for varieties of samples with different modification levels of silica fume namely 2%, 4%, 6%, 8% and 10 % by weight added to the base course soil. The result shows that adding silica fumes improve both strength and stability of the modified soil. The optimum water content increase from 6.2% for unmodified soil to 7.4% for soil modified with 10% silica fume. The maximum dry density for modified soil with 2%,4%,6%,8% and 10% silica fume increased by 2.2%, 3.8%, 5.7%, 9.5% and 11.0% respectively. The California Bearing Ratio (CBR) for modified soil with 2%,4%,6%,8% and 10% silica fume increased by 13.9%, 25.7%, 48.9%, 61.9% and 75.0% . From the hole test result and evaluation of the modified soil in the lab silica fume can improve both strength and stability for the tested soil to be used as base course layer in highway projects.

Keywords: - Silica *fume, highway construction, transmission electron microscopy (TEM), scan electron microscope (SEM), California Bearing Ratio (CBR).*

I. INTRODUCTION

A pavement structure that maintains and distributes loads to the subgrade and depends on aggregate interlock, particle friction, and cohesion for stability[1]. Asphalt pavements are designed to resist rutting, fatigue, low temperatures cracking and other distresses. These distresses reduce the services life of the pavement and increase the maintenance costs. But to build roads to resist pavement distresses and increase the pavement services life span, pavement engineers need to look for new materials. Base course an unbound mixture of coarse and fine crushed stone, as well as crushed sand, to achieve the desired load-bearing capacity and absorb traffic loads so that the underlying subgrade is not deformed [2,3]. Different materials used as soil stabilizer such as lime, cement, and fly ash. Base course aggregate mixed with 2-10% by weight lime improve the mechanical properties of the modified soil [4]. Lime-fly ash-aggregate stabilized base ware used in highway construction. Such a base consists of a mixture of proper quantities of lime, fly ash, and graded aggregate at optimum moisture content. The stability of the resulting mixtures was greatly enhanced and Lime-fly ash stabilized aggregates are observed to shrink more than cement-fly ash stabilized aggregate [5]. Significant efforts have been made to use fly ashes in stabilization of highways base structures, unpaved roads and soil stabilization. From 6–11 and 34–57 times increase in CBR and resilient modulus of road surface gravel when stabilized with 10 and 15% fly ash[5]. Silica fume is a byproduct of silicon alloy manufacturing. The average particle size of silica fume is a few hundred nanometers and the surface area ranges from 15,000 to 30,000 m2 /kg. Addition of silica fume to this mixture will reduce expansion to below detection limit, but will increase the cost of stabilization by 50 percent compared to the blended cement mixtures .California Bearing Ratio (CBR) is the major input parameter used to characterize the strength of the unbound materials and subgrade soils [7,8].

II. MATERIALS

A. Base course soil

The tested Soil for base course was taken from qena quarry that is usually used in road project. Sieve analysis for the tested soil is presented in figure (1) according to "ASTM D422 – Standard Method for Particle- Size Analysis of Soils". The objective of this test is to establish the distribution of particle sizes representing the soil and also useful for classification of soils [9-11]. From figure (1) it can be seen that the soil is uniformly graded because of particle sizes distributed over a wide range sieves.

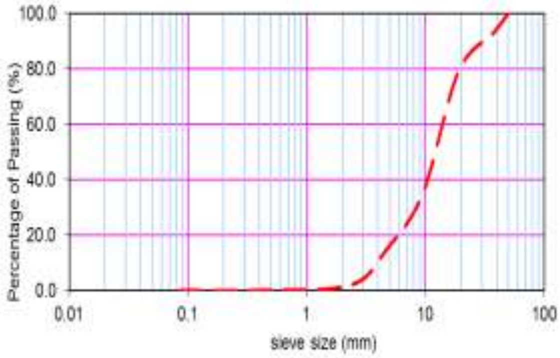

Figure (1) Particle- Size Analysis of Soils

B. Silica fume

Silica fume; it is produced by EFACO (Egyptian Ferro-Alloys Company) which resulting from the reduction of high-purity quartz with coal in electric arc furnaces in the manufacture of ferro-silicon. The fume which contains between 92 and 97 percent silicon dioxide (sio2), and consists of extremely fine spherical glassy particles, is collected by filtering the gases escaping from the furnaces. The average particle size is 0.1 mm, the specific surface area is ranging between 12 and 15 m2/g, and the specific gravity is 2.15. The physical and chemical properties of the silica fume supplies from Egyptian Ferro-Alloys Company.

Morphology and structural of the base course soil were investigated by transmission electron microscopy (TEM, JEOL JEM-1230 with accelerating voltage of 120 kV) and EDX detector unit attached to the system. Figure (2) present the size of silica fumes which in range between 10 -50 nm. This small size help fill the voids in the modified soil and to be more resistance to deformation due to effect of loads. High density of the modified soil is important in terms of density and base course requirement for highway. Also scan electron microscope (SEM) was used to evaluate the soil particle shape and surface [12]. Figure (3) present the shape and surface it can be seen that silica fumes have rough fractured faces which allows a better bond between modified soil particles.

Table (1) shows the physical and chemical properties of the silica fume

Property	Measured values	Limitations
Physical properties :		
Color	Light gray	--
Specific gravity	2.15	--
Bulk density	340	250-450 kg/m^3
Chemical properties :		
SiO_2	97 %	90 % min
C	0.5 %	1 % max
Fe_2O_3	0.5 %	1.5 % max
Al_2O_3	0.2 %	1 % max
CaO	0.2 %	1 % max
MgO	0.5 %	1.5 % max
K_2O	0.5 %	1.5 % max
Na_2O	0.2 %	0.5 % max
SO_3	0.15 %	0.2 % max
Cl	< 0.01 %	0.05 % max
H_2O	0.5 %	0.8 % max
PH	6 %	± 1 % max

* From the Egyptian Ferroalloys Company (EFACO)

Figure (2) TEM micrograph for Silica fume

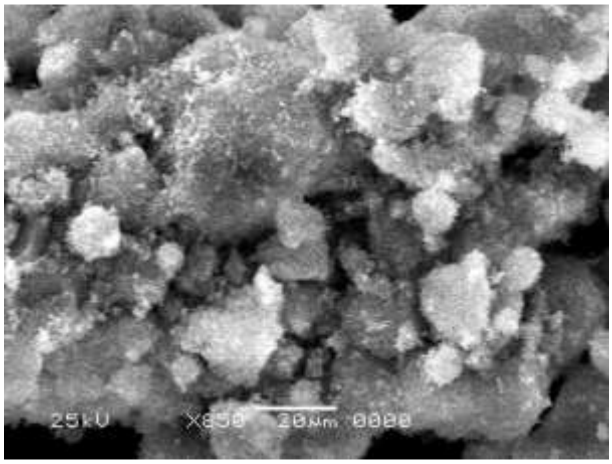

Figure (3) SEM micrograph for Silica fume

III. RESULT AND DISCUSSION

1) Proctor test:-

To attain satisfactory engineering properties soil should be compact to dense state and this process is very important for base course in highway construction. By driving out air from the compacted soil the bulk density of the soil increased. Optimum water content exists at which it will achieve its maximum density. To determine the maximum dry density Standard Proctor (ASTM D698) was used. The tested soil was placed in mold in three layers and 25 blows per layer using Standard rammer [13, 14]. Table (2) presents the result for proctor test for unmodified soil. Figure (4) present the maximum dry density and optimum water content for unmodified soil. Table (3) present both maximum dry density and optimum water content for all modified soil. It is clear from table (3) that with increase of silica fume modification levels the maximum dry density increase and also optimum water content. The optimum water content increase from 6.2% for unmodified soil to 7.4% for soil modified with 10% silica fume. The maximum dry density for modified soil with 2%,4%,6%,8% and 10% silica fume increased by 2.2%, 3.8%, 5.7%, 9.5% and 11.0% respectively.

Table (2) proctor test result for unmodified soil.

Test Number	1	2	3	4	5
Volume of Mold	0.000942	0.000942	0.000942	0.000942	0.000942
Wt. Mold	6.630	6.630	6.630	6.630	6.630
Wt. Soil + Mold	8.401	8.551	8.694	8.695	8.630
Wt. Soil	1.771	1.921	2.064	2.065	2.000
Wet Density	1880	2039	2191	2192	2123
Water Content	2.0	4.0	6.0	8.0	10.0
Dry Density	1843	1961	2067	2030	1930

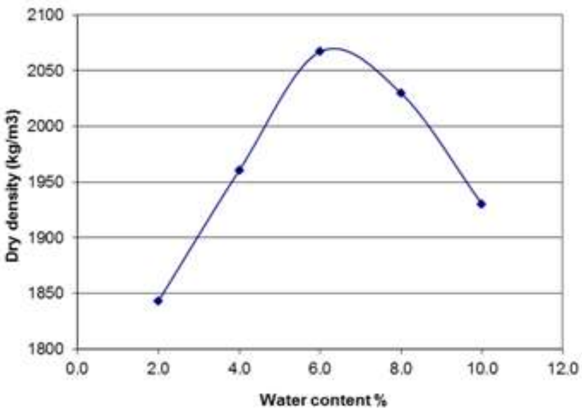

Figure (4) Proctor Compaction Curve

Table (3) proctor test result for all modified and unmodified soil.

Type of soil	Maximum Dry density (Kg/m3)	Optimum water content
Unmodified soil	2070	6.2
Soil + 2% silica fume	2115	6.4
Soil + 4% silica fume	2149	6.7
Soil + 6% silica fume	2189	7
Soil + 8% silica fume	2267	7.2
Soil + 10% silica fume	2298	7.4

2) California Bearing Ratio

California Bearing Ratio (CBR) test is conducted for evaluating the suitability of the subgrade and the materials used in sub-base and base of flexible pavement. The California bearing ratio (CBR) is a penetration test for evaluation of the mechanical strength of road foundation. The test is performed by measuring the pressure required to penetrate a soil sample with a plunger of standard area. The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard crushed rock material [16, 17]. Figure (5) and tables (3, 4, 5) presents all result and procedure for California bearing ratio test. From the test result it can be seen that the CBR for modified soil with 2%,4%,6%,8% and 10% silica fume increased by 13.9%, 25.7%, 48.9%, 61.9% and 75.0% . CBR-value is used as an index of soil strength and bearing capacity. Using silica fumes as soil modifier improve the strength and bearing capacity for all tested samples.

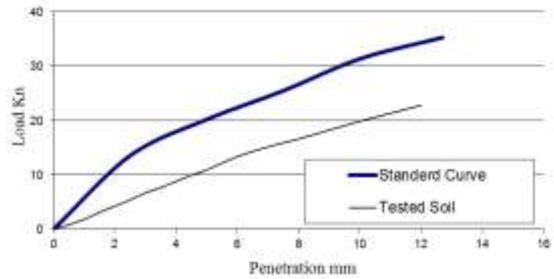

Figure (5) Standard curve to break stones

Table (3) Standard test result for break stones.

Standard curve to break stones	
Load (Kn)	Penetration (mm)
0	0
13.52	2.5
20.19	5
25.48	7.5
31.36	10
35.28	12.7

Table (4) CBR Test Result for unmodified soil

CBR Test Result			
Load (Kn)	dial gauge (mm)	Penetration (mm)	CBR %
0	0	0	
0.814	0.05	0.5	
1.791	0.11	1	
3.093	0.19	1.5	
4.233	0.26	2	
5.372	0.33	2.5	39.7
6.674	0.41	3	
7.651	0.47	3.5	
8.791	0.54	4	
9.930	0.61	4.5	
10.907	0.67	5	54.0
13.349	0.82	6	
15.140	0.93	7	
16.605	1.02	8	
18.233	1.12	9	
19.861	1.22	10	
21.326	1.31	11	
22.791	1.4	12	

Table (5) CBR test result for all modified and unmodified soil.

Type of soil	CBR % @ Penetration 2.5 mm	CBR % @ Penetration 5 mm
Unmodified soil	39.7	54.0
Soil + 2% silica fume	42.9	61.5
Soil + 4% silica fume	56.7	67.9
Soil + 6% silica fume	59.4	80.4
Soil + 8% silica fume	63.6	87.4
Soil + 10% silica fume	65.7	94.5

CONCLUSIONS

High limits of specification need high quality soil and this not all time available in the local area of highway project. Researchers look for effective solution to this problem. One of the proposed Options is to use silica fume as soil modifier in order to improve the soil properties. The result of the tested modified soil can be summarized as:-

- Transmission electron microscopy (TEM) and scan electron microscope (SEM) is used in this study to evaluate the surface texture and size of silica fumes.
- The dimension of sialic fumes is about 10-50 nm and it have rough surface.
- Small size of silica fumes help to fill the voids in the soil and produce soil more resistance to deformation.
- Rough of the surface texture of silica fumes increase the bond between soil particles and affect directly the soil strength.
- Standard proctor test was used in this study in order to determine the optimum water content and maximum dry density for all tested soil.
- Additional of sialic fumes to the soil increase the density of soil from 2070 kg/m3 to 2298 kg/m3.
- California bearing ratio was used in this study in order to evaluate mechanical strength of the tested soil for using as base course layer in pavement construction.
- Additional of sialic fumes to the soil increase CBR from 54% to 94.5%

Finally using silica fumes as soil modifier sounds to be good from the point of strength and stability.

Acknowledgement

The author sincerely thank Qena faculty of engineering -south valley university for providing all needed research facilities. Also author sincerely thank central Lab., South Valley University, Qena, Egypt for TEM and SEM measurements.

References

1. Abaza, Khaled A. "Optimum flexible pavement life-cycle analysis model."*Journal of Transportation Engineering* 128.6 (2002): 542-549.
2. Pasetto, Marco, and Nicola Baldo. "Experimental evaluation of high performance base course and road base asphalt concrete with electric arc furnace steel slags." *Journal of hazardous materials* 181.1 (2010): 938-948.
3. Kim, Woosung, Joseph Labuz, and Shongtao Dai. "Resilient modulus of base course containing recycled asphalt pavement." *Transportation Research Record: Journal of the Transportation Research Board* (2007).
4. Gnaedinger, John P. "Lime or lime: fly ash pretreated pavement construction material and method." U.S. Patent No. 4,496,267. 29 Jan. 1985.
5. Nicholson, J. Patrick. "Mixture for pavement bases and the like." U.S. Patent No. 4,018,617. 19 Apr. 1977.
6. Cetin, Bora, Ahmet H. Aydilek, and Yucel Guney. "Stabilization of recycled base materials with high carbon fly ash." *Resources, Conservation and Recycling* 54.11 (2010): 878-892.
7. Malhotra, V. M.; Ramachandran, V. S.; Feldman, R. F.;Aitcin, P.-C.Condensed Silica Fume in Concrete CRC Press, Inc., Boca Raton, Florida, 1987.
8. Taskiran, T. "Prediction of California bearing ratio (CBR) of fine grained soils by AI methods." *Advances in Engineering Software* 41.6 (2010): 886-892.
9. Kettler, T. A., John W. Doran, and T. L. Gilbert. "Simplified method for soil particle-size determination to accompany soil-quality analyses." *Soil Science Society of America Journal* 65.3 (2001): 849-852.

10. Blott, Simon J., and Kenneth Pye. "GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments." *Earth surface processes and Landforms* 26.11 (2001): 1237-1248.
11. Rawls, Walter J. "ESTIMATING SOIL BULK DENSITY FROM PARTICLE SIZE ANALYSIS AND ORGANIC MATTER CONTENT1." *Soil Science* 135.2 (1983): 123-125.
12. FitzPatrick, Ewart Adsil, and Ewart Adsil Fitzpatrick. *Soil microscopy and micromorphology*. No. 631.43 F5. Chichester: John Wiley & Sons, 1993.
13. Bahar, R., M. Benazzoug, and S. Kenai. "Performance of compacted cement-stabilised soil." *Cement and concrete composites* 26.7 (2004): 811-820.
14. Puppala, Anand, and Chisha Musenda. "Effects of fiber reinforcement on strength and volume change in expansive soils." *Transportation research record: Journal of the transportation research board* 1736 (2000): 134-140.
15. Fletcher, C. Scott, and W. Kenneth Humphries. "California bearing ratio improvement of remolded soils by the addition of polypropylene fiber reinforcement." *Transportation Research Record* 1295 (1991).
16. Clegg, B. "An impact soil test as alternative to California bearing ratio." *Third Australia-New Zealand conference on Geomechanics: Wellington, May 12-16, 1980*. Institution of Professional Engineers New Zealand, 1980.
17. Taskiran, T. "Prediction of California bearing ratio (CBR) of fine grained soils by AI methods." *Advances in Engineering Software* 41.6 (2010): 886-892.