Effect of Materials and Stabilizers Type on the Strength of Base Layer

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Abstract

Pavement is defined as multiple layers system and the strength of each layer is reflected on the pavement as whole. Two type of materials used as base layer, conventional granular materials and reclaimed concrete aggregate (RCA) materials. This study presents test results and discusses the effect of lime-silica fume on strength of base layer as stabilizer. Also, a comparison is made between the changes that occur in treated base layer and untreated base layer. Combination of lime - silica fume is used as stabilizer with (1, 3, 5, 7) % and also cement stabilizer is used with (0.5, 1.5) %. Comparison between treated and untreated base layer is made in terms of strength. The material of base layer is conventional base material taken from Al-Nibaee quarry. Samples with three replicates of each possible combination are performed. A total of (68) samples is prepared and subjected to compressive strength test. The obtained results indicate an increase in the strength of base material by factor of increment about (2.56) when Reclaimed Concrete Aggregate (RCA) is used. Also, at (5%) lime -silica fume stabilizer, the factor of increment increases in the strength by about (42.248) more than the untreated samples.

Keywords: Compressive Strength test, Factor of increment in the strength, Silica fume, Conventional base material, Reclaimed Concrete Aggregate (RCA).

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تأثير نوع المواد والمضافات على قوة طبقة الأساس

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الخلاصة :

يعرف التبليط كنظام متعدد الطبقات وقوة كل طبقة تؤثر على ألتبليط ككل. نوعان من المواد استخدمت كطبقة أساس، مواد الركام التقليدية والركام المعاد تدويره من الخرسانة الكونكريتية. تقدم هذه الدراسة نتائج الاختبار، ويناقش تأثير النورة - غبار السيليكا على قوة طبقة الأساس كمثبت. أيضا، يتم إجراء مقارنة بين التغيرات التي تحدث في طبقة الأساس المثبتة وغير المثبتة. كل من النورة – غبار السيليكا أستخدمت كمثبتات بالنسب (1، 3، 5، 7) ٪ وكذلك تم استخدام الأسمنت كمثبت بالنسب (0,5 ، 1,5)٪. يتم المقارنة بين طبقة الأساس المعالجة وغير المعالجة من حيث القوة. المواد المستعملة كطبقة الأساس هي المادة الأساسية التقليدية التي أخذت من مقلع النباعي. تم تحضير نماذج بمعدل ثلاثة لكل نسبة قدر الامكان. (68) المجموع الكلي للنماذج التي أعدت لفحص قوة الانضغاط. النتائج المستحصلة أظهرت زيادة في قوة طبقة ألاساس بواسطة عامل الازدياد بمقدار (2,56) عند استخدام ركام الكونكريت المعاد تدويره. كذلك مثبت النورة - غبار السيليكا بنسبة (5 %)، عامل الازدياد في القوة ازداد بحوالي(42,248) أكثر من العينة الغير المثبتة.

1. Introduction

Pavement design is a process intended to find the most economical combination of layer thicknesses and material types for the pavement, taking into account the properties of the subsoil, the traffic to be carried during the service life of the road and the climatic conditions [1]. Stabilization of granular materials and their behavior against the climatic conditions as well as the durability of treatment with time are the major considerations taken into account by engineers in the latest years. The use of silica-fumes becomes much trading in road works.

In ***1994, McKennon, et.al.*** [2] found that, the addition of silica fume plays a very important role in the improvement of chemical properties of lime treated soils. Silica Fume when reacted with lime, will form a bonded gel [Ca (SiO3)]. Over the recent years, the recycling of industrial wastes and byproducts for use in construction applications have been a priority area of research at a global level.

Although base layer is an intermediary element of the pavement structure, its correct functioning in the road pavement layers is vitally important. To ensure durability and long-term adequate performance of chemically stabilized materials. A common 7-day strength requirement is 300 psi. In some DOT's, 7-day strengths between 200 and 250 psi have been used with success [3].

2. Study Objective

The main objective of this study is laboratory tests to study the effect materials and stabilizer types on strength of base layer. Both conventional granular base material and reclaimed concrete aggregate (RCA) material is used. In addition, the stabilizers used in this study are combination of lime - silica fume with (1, 3, 5, 7) % and cement stabilizer with (0.5, 1.5) % to show the effect of lime-silica fume stabilizer on strength of conventional granular base layer.

3. Silica Fume

Silica fume, also known as microsilica, is a byproduct of producing silicon metal or ferrosilicon alloys. It consists primarily of amorphous (non-crystalline) silicon dioxide (SiO2). Because of its fine particles, large surface area, and the high SiO2 content, Microsilica is a very reactive pozzolan when used in presence of the calcium compounds [4]. It is usually a gray colored powder, somewhat similar to Portland cement or some fly ashes.

Nearly 100000 tons of silica fume are produced each year on the world. Silica fume is used in concrete, ceramics and rubber. When added to concrete, silica fume acts as both a filler, improving the physical structure by an occupying the space between the cement particles and as a pozzolan reacting chemically to important far greater strength and durability to concrete [5].

Before mid-1970s, nearly all Silica Fume was discharged into the atmosphere. After environmental concerns necessitated the collection and landfilling of Silica Fume, it became economically justified to be used in various applications. It is used in applications where a high degree of impermeability is needed. In concrete containing silica fume, water demand increases with the increase in amounts of silica fume [6].

Silica Fume is produced in conformance with the ASTM C 1240 specifications. Silica Fume in contact with water goes into solution within an hour. The silica in solution forms an amorphous silica rich, Ca poor, gel on the surface of the silica fume particles and agglomerates. After time, the silica rich, Ca poor, coating dissolves and the agglomerates of silica fume reacts with free lime (CaOH2) to form calcium silicate hydrates (CSH). This reaction is called the pozzolanic reaction [7].

3.1 Availability and Handling

Silica Fume is available in two conditions: dry and wet, see **Figure (1).** Dry silica can be provided as produced or densified with or without dry admixtures and can be stored in silos and hoppers. Silica Fume slurry with low or high dosages of chemical admixtures are available. Slurried products are stored in tanks with capacities ranging from a few thousand to 400,000 gallons (1,510 m^3) [8].

Fig .(1) Types of Silica Fume, *((http://www.theconcreteportal.com/admix_min.html))* [17].

3.2 Properties

Silica fume is an ultrafine material with spherical particles less than 1μm in diameter, the average is about 0.15 μm. This makes it approximately 100 times smaller than the average cement particle [9]. The bulk density of silica fume depends on the degree of densification in the silo and varies from 130 (undensified) to 600 kg/m^3. The specific gravity of silica fume is generally in the range of 2.2 to 2.3. The specific surface area of silica fume typically ranges from 15to 30m^2/kg [10].

3.3 Advantages of Using Silica Fume

The advantages of using silica fume are shown below, as follows [11]**:**

- High early compressive strength
- High tensile, flexural strength, and modulus of elasticity
- Very low permeability to chloride and water intrusion
- Enhanced durability
- Increased toughness
- Increased abrasion resistance on decks, floors, overlays and marine structures
- Higher bond strength
- High electrical resistivity and low permeability
- Superior resistance to chemical attack from chlorides, acids, nitrates and sulfates and life-cycle cost efficiencies.

4. Experimental Work

4.1 Materials

The material tested in this study are locally available in Iraq and used in road working. The coarse aggregate is brought from the hot mix plant of Al-Nibaee quarry at Al-Taji. The fine aggregate refers to a combination of natural sand (river sand) brought from Kerbala and the crushed sand brought from the hot mix plant of Al-Nibaee quarry. The physical properties and chemical composition of the aggregate are shown in **Tables (1) and (2)** respectively. The State Corporation for Roads & Bridges in Iraq [12] established standard specifications for base course. The gradation used in this study is shown in **Table (3)** and **Figure (2).**

Table .(1) Physical Properties of Nibaee Aggregates

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C127 and C128).	2.681	2.6303
Apparent Specific Gravity (ASTM C127 and C128).	2.602	2.46
Percent Water Absorption (ASTM C127 and C128).	0.45	0.53
Percent Wear (Los-Angeles Abrasion) (ASTM C131).	20.12	……

Table .(2) Chemical Composition of Nibaee Aggregates

Chemical Compound	% Content
Silica,SiO_2	82.52
Lime, CaO	5.37
Magnesia, MgO	0.78
Sulfuric Anhydride, SO3	2.71
Alumina, Al2O3	0.48
Ferric Oxide, Fe2O3	0.69
Loss on Ignition	6.55
TSS(total soluble salts)%	1.9
Organic matter (%)	0.5
Gypsum content (%)	0.45
Mineral Composition	
Quartz	80.3
Calcite	10.92

The test was done in cooperation with National Center for Construction Laboratories and Researches (Baghdad).

Table .(3) Gradation of the Aggregate for Base Course (SCRB, 2003).

Sieve Size	Sieve Opening (mm)	Percentage Passing by Weight of total Aggregate	
		Base Course	
		Specification Limit (S.C.R.B)	Selected gradation of Aggregate
1 1/2"	37.5	100	100
1″	25.0	80-100	95
1/2"	12.5	50-80	70
No.4	4.75	30-60	47
No.40	0.425	10-30	22
No.200	0.075	5-15	10

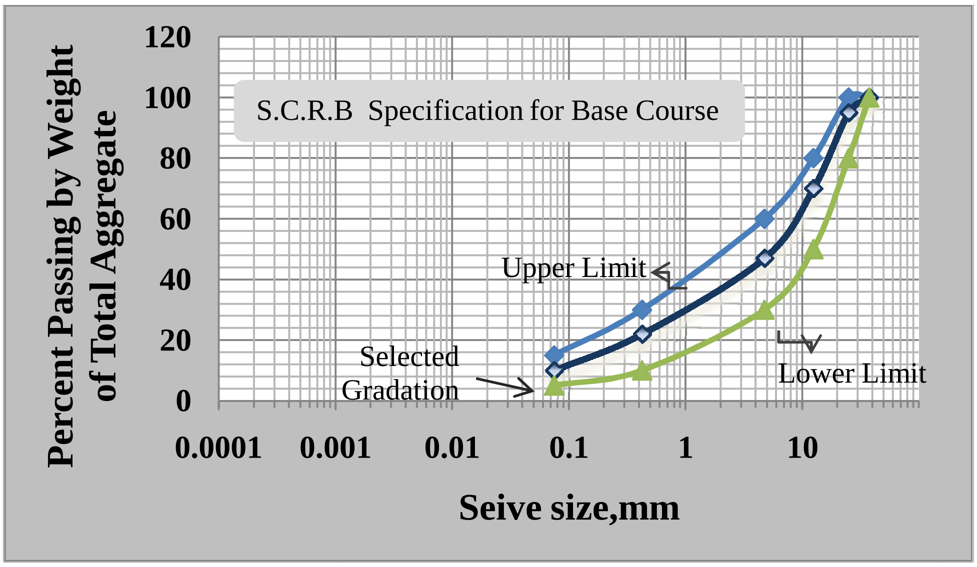

Fig .(2) Specification Limits and Gradation for Base Course (SCRB, 2003).

4.2 Mineral Filler

In this study the mineral filler used, is brought from Kerbala. Mineral filler is thoroughly dry and free from lumps or aggregations of fine particles.

4.3 Reclaimed Concrete Aggregate (RCA)

The use of reclaimed concrete aggregate promised to be a technically-viable solution that offers economic and environmental advantages. Reclaimed concrete aggregate, collected from waste materials, results from the waste concrete blocks of laboratory in the College of Engineering Al-Mustansiriya University. Reclaimed concrete aggregate is generated through broken large parts of concrete blocks materials. Breaking process is made after cleaning recycled Portland cement concrete materials from unwanted materials. Then, from crushing process, reclaimed grains are produced with different gradients. These different gradients have been separated by sieve analysis and then prepared to be used. **Figure (3)** shows reclaimed concrete aggregate materials. The gradation used in this study according to SCRB specification for base course [12], as shown in **Table (3)** and **Figure (2).**

Fig .(3) Reclaimed Concrete Aggregate Materials (RCA).

4.4 Additives

There are many types of additives available in the local market and used for many jobs in road works. Additives used in this study are described below:

4.4.1 Silica Fume

Silica fume is available in the local market (50$ for 10 Kg). The color of the material is dark gray. It has a very smooth texture, as texture, as shown in **Figure (4).** Usage of silica fume has become widespread in the field of engineering. In the field of civil engineering is most often used with concrete where part of the amount of cement is replaced to increase its strength and develop its properties. Silica fume is used either singly or mixed with other additives such as lime, asphalt and cement. Chemical and physical properties of silica fume are shown in **Tables (4), (5)** and **(6)** respectively.

Fig .(4): Silica Fume Material.

Table .(4) Composition and Properties of Silica Fume.*

Composition (%) - property	Silica fume
SiO_2	98.87
Al_2O_3	0.01
Fe_2O_3	0.01
CaO	0.23
MgO	0.01
K_2O	0.08
Na_2O	0.00
Blaine fineness (m^2/kg)	200000

***Manufacturer Properties**

Table .(5) Chemical Properties of Silica Fume (SF), (ASTM C1240-03).

Oxide Composition	S.F.	Limit of Specification Requirement ASTM C 1240
SiO2, min. Percent	90.0	>85.o
Moisture Content, Max. Percent	0.68	<3.0
Loss on Ignition, Max. Percent	2.86	<6.0

Table .(6) Physical Properties of Silica Fume, (ASTMC1240-03).

Physical Properties	S.F.	Limit of Specification Requirement ASTM C 1240
Percent Retained on 45-µm (No.325) Sieve, Max.	7	<10
Accelerated Pozzolanic Strength Activity Index with Portland Cement at 7 days, Min. Percent of Control	128.6	>105
Specific Surface, Min, m2/Kg	21	>15
Specific Gravity	2.231	>2.2

4.4.2 Lime

Chemically pure hydrated lime (Ca (OH) 2) is used in this study. This material is obtained from local market. Physical properties and chemical composition of Hydrated Lime are shown in **Tables (7) and (8)** respectively.

Table .(7) Physical Properties of Hydrated Lime*.

Properties	Lime
Form	Fine dry white powder
Color	white
Specific Gravity	2.3
pH (25ºC)	12.93
Finess (m^2/Kg)	657

Table .(8) Chemical Composition of Hydrated Lime*

The Composition	Percent by Weight
CaO	71
Al_2O_3	0.5
SiO_2	4
Fe_2O_3	0.4
MgO	2.5
SO_3	0.3
Active CaO	52

(*) Tests are carried out by NCCL

4.4.3 Cement

Portland cement is used as stabilizer. The chemical composition and physical properties of Portland cement are shown in **Table (9).**

Table .(9) Chemical Composition & Physical Properties of Cement Types Used.

Chemical Compound	% Content
Silica,Sio_2	21.54
Lime, CaO	62.2
SiO_3	………
Sulfuric Anhydride, SO_3	1.5
Alumina, Al2O3	4.4
Magnesia (MgO)	3.7
Ferric Oxide, Fe2O3	5.3
K_2O	0.58
Na_2O	
Loss on Ignition (L.O.I)	0.3
I.R	0.48
$Ca(OH)_2$	………
Total	100
Physical properties	
%Passing Sieve No. 200	98
Apparent Specific Gravity	3.4

From Local Market

5. Sample Preparation

Preparation of sample is a general term that includes the following:

5.1 Preparation of Aggregate

The aggregates and filler for conventional materials (Al-Nibaee aggregate) and non conventional materials (reclaimed concrete aggregate (RCA)) are prepared using the same procedure, except a washed sieve analysis is done for Al-Nibaee material only. For both types of materials, the aggregates are first dried to a constant weight, separated to the desired sizes by sieving and recombined with the mineral filler to conform to the selected gradation requirements of SCRB specification for base course [12]. The weight of each aggregate size and filler is determined by multiplying its percent by the desired weight of final mix.

5.2 Preparation of Stabilizer

To remove unwanted particles from stabilizers materials (which include silica fume, lime and cement), all these stabilizers are sieved on sieve No.200. Although no standard procedures for samples treated with silica fume and lime have been created, but ASTM C 593 is usually used as a guide. Silica fume and lime concentrations are generally determined as a percentage of the weight of dry aggregate. The amount of cementitious material in a stabilized base mix usually ranges from 5 to 10 percent by weight of the mix, but may in some cases comprise as much as up to 20 percent by weight if a lighter weight aggregate is used [13]. Stabilizers are used in this study as the following percentages are adopted below:

- Lime-silica fume with (1, 3, 5, 7) %.
- Lime to- silica fume ratio of 1:4 [14].
- Cement with (0.5, 1.5) %.

5.3 The Process of Mixing

The total weight of the batch was approximately 5500 gm to produce a sample intended for testing of 4.58in. (116.43mm) in height by 6in. (152.4mm) in diameter. Once gradations are established, four to six samples with varying moisture contents are prepared for moisture-density testing. The final mixture has been compacted into the mold using modified Proctor compaction effort in accordance with ***(ASTM D 1557 – 02e1)*** [15].

The modified Proctor procedure requires compaction of the samples in five lifts; each lift consists of 56 blows. Extruder device made from frame and jack by a researcher shown in **Figure (5)** is used to extrude the samples from the mold, and its weight is measured. The moisture content determinations are performed in accordance with ***(ASTM D 2216 – 05)*** [15].

Fig .(5) Extruded Sample.

Once moisture contents and dry densities are computed and plotted, the OMC and MDD are determined for each untreated and treated materials. Additional samples are prepared at the corresponding OMCs, cured for a 7-day period for lime-silica fume and cement. Finally they are tested for compressive strength test.

Three replicate samples are tested at each percent of additives. For this study a 7-day cure is selected. Curing of samples treated with Portland cement occurs at room temperature in a fog room, where they are subjected to 100 percent relative humidity during the 7-day curing period. Afterwards, samples are soaked underwater for 4 hours following PCA guidelines [16].

For lime-silica fume, a 7-day cure is selected, as the basis for equivalency in accordance with ***ASTM C 593***[15]. Samples are sealed in airtight plastic bags following extrusion to prevent moisture loss during the curing period. Curing occurs in an oven at 38 °C (100°F) for 7 days. After this period, the samples are removed from the container, and allowed to cool to room temperature, as depicted in **Figure (6).**

Fig .(6) Curing Condition for Samples Treated with Lime-silica fume.

Then, the samples are submerged for compressive strength testing in water for 4 hours, removed, and allowed to drain on a nonabsorbent surface. Then, test within 1 hour of the time of removal from the water in accordance with **ASTM C 593**. After the curing period, samples are subjected to compressive strength test. Values for OMC, MDD, and compressive strength are obtained for each type of stabilizer.

6. Compaction Test Methods

The moisture – density relation for aggregate is determined by using modified compaction. A mechanical compaction apparatus and a mold having an internal diameter of 6 in. The compaction is carried out according to ***(ASTM D1557)*** [15]. **44 samples** made to find OMC&MDD for each ratio and type of stabilizer as well as the untreated samples. Other **24 samples** are prepared and compacted at OMC for each stabilizer for compressive strength test [18], **Table (10).**

Table .(10) Results of Compaction Test for Al-Nibaee Aggregate Materials.

Stabilizer Type	Stabilizer Concentration (%)	Moisture Content (%)	Dry Density (gm/cm3)	OMC (%)	MDD (gm/cm3)
Untreated	-	2.58	2.07	6.2	2.14
		3.1	2.08		
		4.6	2.11		
		6.2	2.14		
		7.6	2.12		
Lime-Silica Fume	1%	3.55	2.2	6.8	2.32
		5.83	2.3		
		6.96	2.32		
		8.87	2.26		
		9.98	2.22		
	3%	4.16	2.19	7.2	2.30
		6.02	2.25		
		7.19	2.3		
		8.5	2.25		
		9.2	2.22		
	5%	3.76	2.108	7.1	2.216
		6.08	2.21		
		7.97	2.213		
		9.52	2.186		
		11.17	2.107		
	7%	4.27	2.1	8.2	2.22
		6.4	2.175		
		8.2	2.22		
		9.4	2.16		
		9.98	2.12		
Cement	0.5%	3.58	2.07	7	2.16
		4.1	2.08		
		5.6	2.11		
		7.1	2.16		
		8.6	2.12		
		9.32	2.096		
	1.5%	2.8	2.223	7.6	2.28
		4.2	2.25		
		7.5	2.28		
		9.4	2.24		
		10.55	2.1		
		11.56	2.04		

Reclaimed Concrete Aggregate (RCA)	-	**1.44**	**2.1**	**6.50**	**2.215**
		3.32	**2.15**		
		6.2	**2.215**		
		8.8	**2.175**		
		11	**2.1**		
		12.4	**2.05**		
		13.54	**2.013**		

7. Effect of Stabilizer on OMC and MDD

Table (11) summarizes the values of Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for reclaimed concrete aggregate materials, Al-Nibaee aggregate materials and stabilized Al-Nibaee aggregate with lime-silica fume and cement. Stabilizer concentrations are reported as percentages of the weight of dry aggregate, while OMC is reported in each case as the percentage of the total weight of the dry aggregate and stabilizer.

Table .(11) Results of OMC and MDD

Stabilizer Type	Stabilizer Concentration (%)	OMC (%)	MDD (gm/cm^3)
Untreated	-	**6.2**	**2.14**
RCA	-	**6.5**	**2.22**
Lime-Silica Fume	**1**	**6.8**	**2.32**
	3	**7.2**	**2.30**
	5	**7.1**	**2.22**
	7	**8.2**	**2.22**
Cement	**0.5**	**7**	**2.16**
	1.5	**7.6**	**2.28**

8. Effect of lime-silica fume on Compressive Strength

The comparison between samples in terms of compressive strength for samples treated with lime-silica fume at (1, 3, 5, and 7 %) and cement at (0.5 and 1.5%) with untreated samples is explained in **Figure (7).** While **Figure (8)** shown the comparison between Al-Nibaee and reclaimed concrete aggregate (RCA) materials also by compressive strength value.

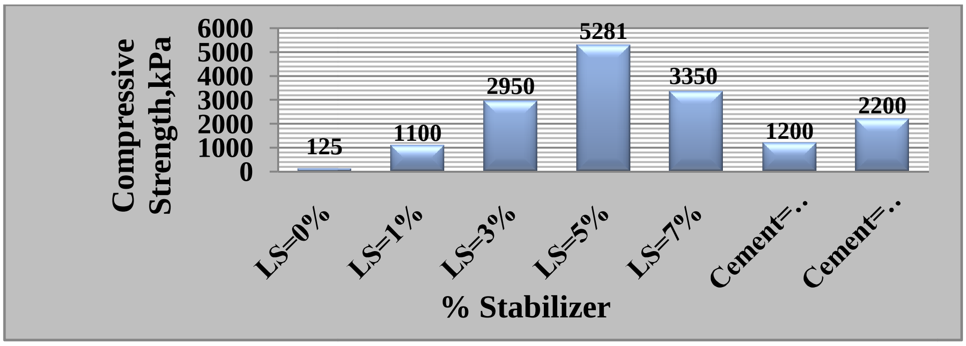

Fig .(7) The Comparison between Untreated Samples with Treated.

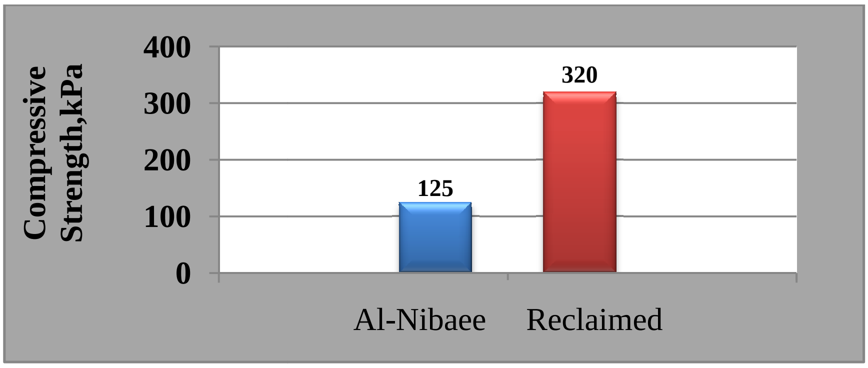

Fig .(8): Comparison between the Al-Nibaee and Reclaimed

The compressive strength values represent average of three samples. From **Figure (7),** for lime-silica fume stabilizer, the values of compressive strength increase with the proportion of stabilizer till 5%, after this ratio the strength value decreases with the proportion of lime-silica fume stabilizer of (7%). For cement stabilizer, the compressive strength value increases with the proportion increment. **Table (12)** summarizes the stabilizer percentage and compressive strength values.

Table (12): Compressive Strength Values.

Stabilizer Type	Stabilizer (%)	Average compressive strength, (kPa)
Untreated	-	125
RCA	-	320
Lime-Silica Fume	1	1100
	3	2950
	5	5281
	7	3350
Cement	0.5	1200
	1.5	2200

It becomes clear that, for (5%) lime-silica fume, the compressive strength value increases by factor of increment about (42.248) more than untreated samples. For samples treated with cement, the strength keeps increasing with the proportion of increment, the factor of increment value increases by about (9.6) and (17.6) in the strength more than untreated samples for (0.5%) and (1.5%) cement respectively. In addition, an increase of about (2.56) factor of increment in the strength of base material when reclaimed concrete aggregate is used. **Table (13)** shows the effect of different types of stabilizers and materials on the compressive strength.

Table .(13) Effect of Different Stabilizer on Compressive Strength

Stabilizer Type	Stabilizer (%)	Average Compressive Strength, (kPa)	Factor of Increment in the Strength
Untreated	-	125	0
RCA	-	320	2.56
Lime-Silica Fume	1	1100	8.8
	3	2950	23.6
	5	5281	42.248
	7	3350	26.8
Cement	0.5	1200	9.6
	1.5	2200	17.6

9. Conclusions

1. The Compressive Strength increases with the proportion of stabilizer until 5%, after which the strength value decreases with the proportion of lime-silica fume stabilizer of (7%).
2. For (5%) lime-silica fume, the compressive strength value increases by factor of increment about (42.248) more than untreated samples .
3. For cement stabilizer, the compressive strength value increases with the proportion increments. The factor of increment value increases by about (9.6) and (17.6) in the strength more than untreated samples for (0.5%) and (1.5%) cement respectively.
4. An increase in the strength of base material by factor of increment about (2.56) is observed when reclaimed concrete aggregate is used. Unstabilized reclaimed concrete materials (RCA) have higher strength than the untreated (natural) aggregate base materials.

References

1. ARAYA, A.A., "Characterization of Unbound Granular Materials for Pavements", M.Sc thesis, IHE/TUDelft, the Netherlands geborenteMekelle, Ethiopia، 2011.
2. McKennon, J.T., Hains, Norman L. and Hoffman, D.C., "Method for Stabilizing Clay Bearing Soils by Addition of Silica and Lime", Patent Cooperation Treaty (PCT), Patent Classification: C09K 17/00, Publication Number: WO 94/06884, 1994.
3. Zhou, F., Fernando, E. and Scullion, T., "A Review of Performance Models and Test Procedures with Recommendations for Use in the Texas M-E Design Program", Texas Transportation Institute, the Texas A&M University System, No. FHWA/TX-08/0-5798-1, 2008.
4. Al-Sharify, G.A., "Effect of Microsilica on the Swelling Characteristics of Expansive Soils with and without Lime", Al-Qadisiya Journal for Engineering Sciences, Vol. 4, No. 2, pp: 134-142, 2011.
5. Ganjian, E., "Mechanical and Physical Properties of Iranian Produced Microsilica", Proceeding of the international seminar on the use of microsilica in concrete, Iran, PP: 197-214 9-U, 1997.
6. Kosmatka, S.H., Kerkhoff, B. and Panarese, W.C., "Design and Control ofConcrete Mixtures", 14th ed., PCA R&D Serial Number SN2561, Skokie, Illinois 60077-1083 USA, 2003.
7. From the Internet on the Site "http://conwill.com/silica.html".
8. Admixtures and ground slag for concrete, Transportation research circular no. 365 (December). Washington: Transportation Research Board, National Research Council, 1990.
9. Fleischer W., Sodeikat, C. and Springenschmid, R., "Conclusions from the Long-Time Behaviour of Cement-Bound Road Base", Proc. Seventh International Symposium on Concrete Roads, Vienna, Austria, 1994.
10. Guthrie, W. S., and Hermansson, A., "Frost Heave of Variably Saturated Aggregate Base Materials", Transportation Research Record: Journal of the Transportation Research Board, National Research Council, Washington, DC, No. 1821, pp: 13-19, 2003.
11. Siddique, R. and Khan, M. I., "Supplementary Cementing Materials", Engineering Materials, DOI: 10.1007/978-3-642-17866-5_2, _ Springer-Verlag Berlin Heidelberg, 2011.
12. Iraqi General Specification for Roads and Bridges, "Standard Specification for Roads and Bridges", the state Corporation for Road and Bridges, Revised Edition, 2003.

13. **Federal Highway Administration, FHWA "User Guidelines for Waste and Byproduct Materials in Pavement Construction", No.A-RD-97-148, 1997.**
14. **Harichane, K., Ghrici, M., Khebizi, W. and Missoum, H., "Effect of the Combination of Lime and Natural Pozzolana on the Durability of Clayey Soils ", Electronic Journal of Geotechnical Engineering, EJGE, Vol. 15, pp: 1149-1209, 2010.**
15. **ASTM, "Road and Paving Materials", Annual Book of ASTM Standards, Volume 04.03, American Society for Testing and Materials," West Conshohocken, USA, 2009.**
16. **Soil-Cement Laboratory Handbook, Publication EB052.07S. Portland Cement Association, Skokie, IL, 1992.**
17. **From the Internet on the Site "(http://www.theconcreteportal.com/admix_min.html)".**
18. **Masood, Gh. Gh., (2013): "Experimental and Numerical Investigation of Stabilized Unbound Granular Pavement Materials", M.Sc Thesis, Department of Highway and Transportation Engineering, College of Engineering, Al-Mustansiriya University, Baghdad, Iraq.**