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Improvement of Subgrade Soil by Glass Powder Waste

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ABSTRACT
The weak soil is representing a problem in constructions of roads and building foundations and so forth, the ways of soil improvement containing using of cement, lime or other chemicals are expensive as compared with additives from waste materials. Researchers add Crushed Waste Glass (CWG) to soil to improve plasticity, bearing, consolidation, shear strength and other properties of soil. Waste glass has been used to prepare the additive material that passing through sieve size 75 µm added in 3, 5, 7, and 9 % by dry weight of the soil which it classified as A-7-5 according to AASHTO or ML according to USCS. A series of tests were adopted like sieve analysis, Atterberg limits, California bearing ratio, and unconfined compression strength to study the effect of adding glass powder to the soil for improving its properties. It was found that the additive had a positive impact on soil and had improved the soil properties, liquid limit, plastic limit and plasticity index was decreased with the increasing of glass powder, unconfined compression and shear strength behave like curve increasing with the increase of glass powder till percent 7, then began to decrease making the optimum percent of additive, there is significant increasing in the CBR values with the increasing of glass powder over than 4%, these increasing were at 2.5, 3.3, 5.2, 9.4 times when added 3, 5, 7, 9 % glass powder respectively more than CBR value of untreated soil.

KEYWORDS: *subgrade soil; soil improvement; Crushed Waste Glass (CWG); Waste Glass Powder (WGP); Unconfined Compression Strength (UCS); California Bearing Ratio (CBR %).*

I. INTRODUCTION

Pavement system consists of various layers prepared and construct above the natural soil to carry loads which exceed soil strength, the weak soil is representing a problem in constructions of roads and building foundations and so forth, improvement of the bearing capacity of the subgrade soil reduces pavement thickness. Some of pavement distresses and structural failure are attributed to subgrade layer problems due to undesirable engineering properties that's followed by maintenance costs [1, 2]. In some cases, replacing weak soil isn't best economical choice or useless and the ways of soil improvement by using cement, lime or other chemicals as additives are expensive [3] as compared with additives from waste materials, the improvement by wastes represent the sustainable development [2] and environmental benefit, glass Recycling is a way to reduce waste, lower construction costs and eco-friendly [3]. Many researchers used Crushed Waste Glass (CWG) as additives to the soil to improve plasticity, bearing, consolidation, shear strength and some properties of the weak soil will be mentioned in the following review. Waste glass are widely available in Iraq and the process of recycling it in crushed form is simple [3].

II. LITERATURE REVIEW

Davidović, et al. [4] used 20% crushed glass with 80 % clayey material, they found an increasing in CBR value to an average 10%. Fauzi, et al. [1] studied adding CWG and Waste Plastic in percent's up to 12% to two kind of soils (classified according to AASHTO as A-7-6 and A-6), they found that the Plasticity index and cohesion were decreased while the CBR (was increased to 5%) and friction angle was increased as increasing in additives. When the CWG added in percent's up to 8% as graded as soil such used which was cohesive low plasticity clay (CL) (according to USCS system) as shown in Al-Neami, et al research [3], their results showed that 4% is suitable one, and the liquid limit, compressibility, cohesion between soil particles, unconfined compressive strength, and swelling was decreased while plastic limit and friction angle was increased. Nirmala and Shanmugapriya [5,18] concluded in their study that replacing 40% of the soil sample by glass had high CBR value and also high shear strength compared to the field sample and its represents the optimum percentage of mix proportion of soil and glass.

The using of waste bottled pieces to improve soft soils as worked by Abd Al-Ha'aly in percent's up to 9% added as a powder to the soil, his work results showed the ability of waste bottle powder to increase the shear strength and bearing capacity of soil such used [3]. Nuruzzaman and hossain [6] concluded that adding crushed soda-lime glass dust finer than 300 µm size has improved the clay soil (CL) properties, also found that

unconfined strength of soil decreases with the addition of glass dust with no curing, all the relationship following a linear variation as the regression; so no optimum amount had found in their work of glass dust.

Adding waste soda lime glass powder (passing through sieve 75 μm) make a significant effect on (CL or A-7) soil and the suitable percent of addition was 6% (among percent's reached to 12%) from UCS test, and there is increasing in strength with the age, the density and CBR (not soaked) was increased, while the plasticity and OMC decreased with increasing of the glass [7]. Mosa [2] investigate of using of two categories of WGP with poor subgrade soils classification of (A-7-6), these categories includes particles between 425μm and 75μm and another is particles finer than 75μm with percent in 20% was added**,** the results showed that the glass powder content increases the strength of soil and revealed using powder finer than 75 μm is the best, resilient modulus, and CBR values increased whereas the liquid limit, plasticity index, and swelling ratio decreased.

Increasing of the resilient modulus of subgrade lead to decrease the pavement layers thicknesses and reducing the initial and maintenance costs due to reducing damage, increasing service life, and the performance of pavement [2].

This study focused on using the WGP finer than 75 μm with cohesive soil to assess the mix properties (in consistency and strength) and determining the suitable percent of additive. This study helps also in provide reference may add to literatures that's useful in future studies.

III. MATERIALS AND METHODS

The used materials were the cohesive soil and crushed glass powder, series of tests was achieved on soil to investigate of its original engineering properties and on soil/ and glass mixes to assess the effect of glass addition:

Soil

A poor cohesive soil was brought from site located in Al-Seniyah town nearby Al-Diwaniyah city at Al-Qadisiyah governorate (180 Km southern Baghdad), figure (1) shows the grain size analysis achieved according to ASTM D 422 standard, it classified as low plasticity silt according to USCS and fair to poor subgrade, clay (A-7-5) according to AASHTO. Table (1) shows the properties, soil appears that it has not good quality performance according to the group index which was (4) and the activity of soil was (0.72), It tends to kaolinite (descriptions of Das and Sobhan (base on specific gravity) [8], and Mitchell [8] and Skempton [8] base on activity and Atterberg limits).

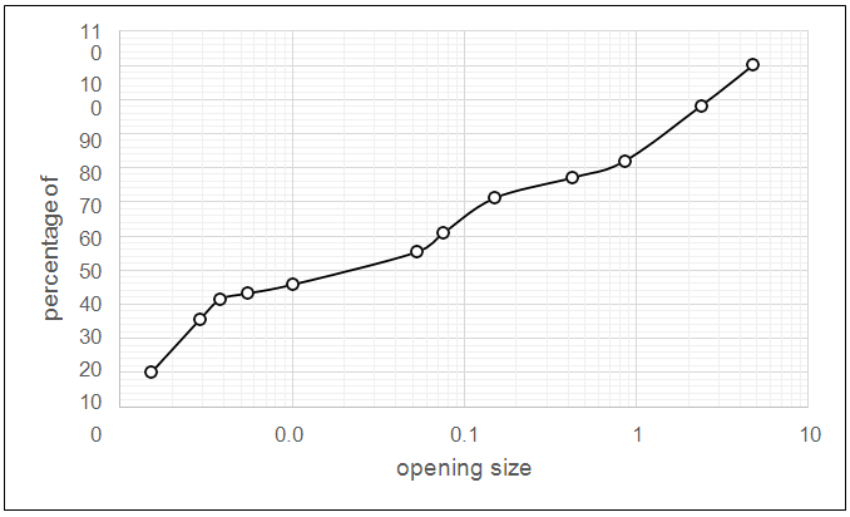

Figure 1 the grain size distribution of soil

Table 1 the soil properties

Components	**Percentages**	
Sand	49.17	
Silts	25.23	
Clays	25.6	
Property	Results	Standard
maximum dry density Optimum moisture content	1.77 gm/cm3 15 %	ASTM D 1557

Plastic limit Liquid limit Plasticity index	30 % 41.66 % 11.66 %	ASTM D 4318
specific gravity	2.6	ASTM D 854
California Bearing Ratio (CBR) (4 days soaked in water)	1.46 %	ASTM D 1883
Unconfined Compression Strength And shear strength (3 days cured in its humidity)	25 Kpa 13 Kpa	ASTM D 2166

Glass

Waste glass has been used to prepare the additive material was from the empty glass bottles, Cleaned from the dusts and other material then broke cautiously into small pieces by using a hammer and covering the glass with piece of cloth (to avoid raveling the glass). After crushing the glass to suitable pieces, it put in a grinding machine to transform it to powder as shown in figure (2) and screen it by using sieve size 75 μm then to obtain the powder, the passing through such that sieve had been taken.

Figure 2 illustrate the glass powder such used

The synthetic glass which bottles made from in general is composed of high percentage of silica which is sand form with some modifiers oxides like soda and lime. The soda-lime glass is the most familiar type used for drinking vessels, the chemical composition in the table (2). The crushed glass used in soil stabilization due to its high permeability and high crushing resistance [9], its non-plastic mater.

Table 2 the chemical composition of glass

Components	Value %	Action in soil
Silica	69.2* 72** 74***	Sand, cohesionless improve consistency**
sodium oxide	8.75* 14.2** 13***	
Lime	15.1* 10** 10.5***	Given strength**
Alumina	2.29* 0.6** 1.3***	
Other	1.57* 1.2***	

*Ikara, et al. [9], **Nuruzzaman and Hossain [6], ***Canakci, et al. [7]

This glass powder was added to soil in percent's (3, 5, 7, and 9 %) by weight of dry soil sample, the dry materials was mixed carefully till be homogeneous well together for period (3-5) minutes.

Experimental Testing Program consisted of two phases, the first was tests achieved on soil to investigate its engineering properties and the second was adopted to study the effect of adding WGP to the soil (sieve analysis, Atterberg limits, CBR%, and unconfined compression strength (UCS)).

IV. RESULTS AND DISCUSSION

Consistency

both liquid and plastic limits were clearly decreased also the plasticity index with the increasing of glass powder content as shown in figure (3) this is attributed to reduction in characteristic of soil keeping water or soil-water attraction [2] due to action of silica in glass work as sand, cohesionless [6] and doesn't absorb of water, and the presence of lime in glass works in reducing plasticity and moisture holding capacity [10, 11]; whereas the low action of lime in early age, absorbing water and mineralogy of soil not revealed increasing in plastic limit [12].

The results of liquid limit and plasticity index agreed with other researches mentioned in literature but disagreed in plastic limit with Neami, et al. [3] when they used various sizes of glass and few content of powder such they used of as additive in their work, and didn't affected till 8% by glass finer 0.075mm in Mosa [2] research that is may related with type or mineralogy composition of soil. The reduction in liquid limit was more than plastic limit reduction (which plastic may be affected by lime binder action) resulting in a significant decreasing in plasticity index as shown in figure (4) and at 5% produced an equal decreasing in both plastic and liquid limits.

As shown in table (4) the soil was altered from clay to silt (A-4) and from medium to slight plasticity, there is a significant enhancement in quality performance (according to the group index) and the Activity due to plasticity reduction and action of lime in glass which reaction with clays. In light of Iraqi specifications, the results tends to make soil accepted as roads subbase layer.

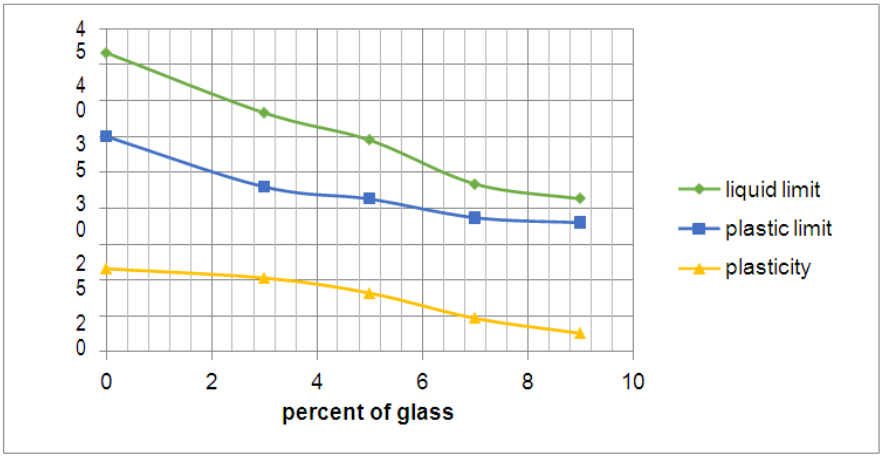

Figure 3 Atterberg limits for all mixes

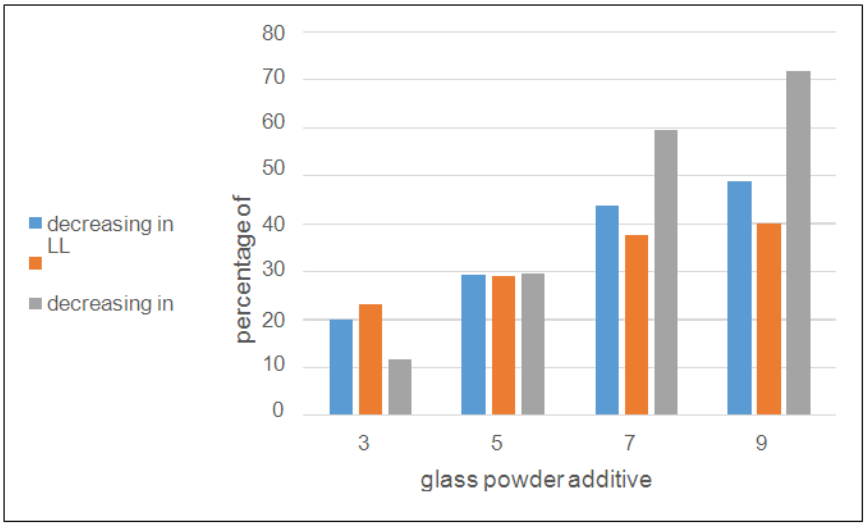

Figure 4 decreasing in percent in Atterberg limits for all mixes

Table 4 descriptions for all soil- glass mixes

Features	**Percent of glass added**				
	0%	3%	5%	7%	9%
Soil classification base on AASHTO	A-7-5 clay	A-4 Silts	A-4 Silts	A-4 Silts	A-4 Silts
Soil classification base on USCS	ML Low plasticity Silt	CL Low plasticity clay	CL Low plasticity clay	CL-ML Low plasticity clay-silt	ML Low plasticity silt
Group index	4	3	2	0	0
Activity (A)	0.72	0.6	0.45	0.24	0.16
Plasticity*	Medium	Medium	Low	Slight	Slight
Soil description **	Silts medium compressibility	Clay medium plasticity	Clay low plasticity	Clay low plasticity	Clay low plasticity

* According to Burmister (1949) [8], ** According to Casagrande (1932) [8]

Soil Strength

Due to reaction between the lime (in glass) and clays working as binder after hydration and increase bonds and cohesive, lime causes an improvement in soil texture providing pozzolanic strength and reducing plasticity [12-15], figure (5) exhibit the stress-strain relationship of soil mixed with glass powder and cured to 3 days in their humidity, there is increasing in the compression strength with the increasing in glass powder percent at all samples, and these relationships were curve behavior as shown in the figure (6) with the best result when added the 7% glass powder. The soil is reactive with lime and the strength increased with lime increasing up to an optimum content of lime which revealed by UCS [16]. The higher value of UCS was 47 Kpa at addition 7% glass then decreased to 44 Kpa at percent of 9% glass, the improvement in the UCS and shear may be due to reduction in plasticity when adding glass powder till a specific limit (when soil became between clay and silt) then began to falling back by increasing the glass more than 7% (action of sand or silica) due to reduction in cohesive and increasing in the angle of friction which cause local shear failure as the sample behave similar to sandy soils [2], [3], or decrease in adhesive between the surface of the glass and soil [17].

There is convergence of results with the Canakci, et al. [7], and Mosa [2] research which the relation was as curve shape with optimum value at percent's of glass about 6, 5% respectively, but disagreed with Nuruzzaman and Hossain [6] and Neami et al. [3], they were observed that the UCS is decreased with increasing in crushed glass when they using graded glass containing granules not but powder.

Unconfined compression strength test used to evaluate soil in unconfined situations, because the high percent of glass producing sandy soils, on the other hand the sandy soil mixture is very stiff under confined conditions [2].

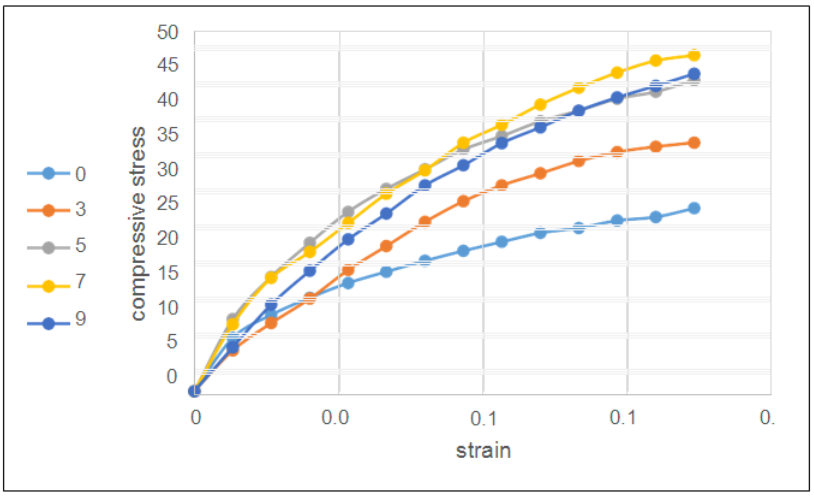

Figure 5 stress-strain graph for all soil-glass mixes

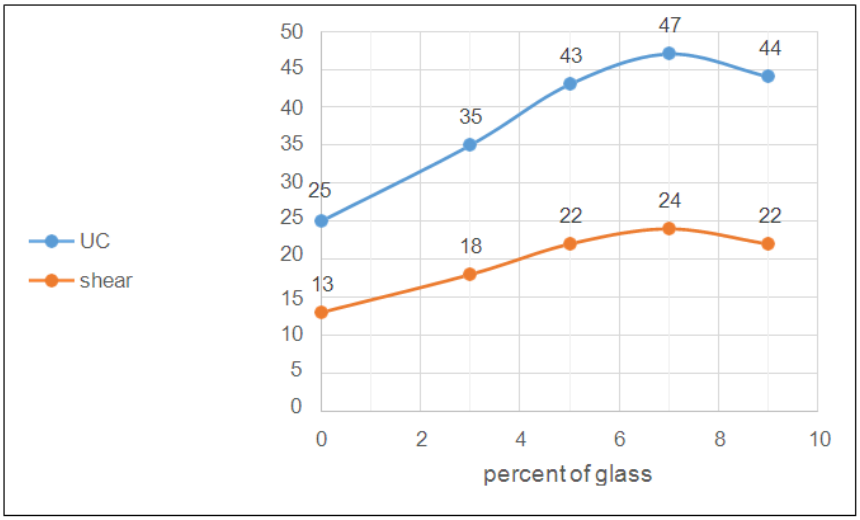

Figure 6 the relationship between percent of glass and both of shear strength and unconfined compression strength

Figure (7) exhibit the 4 days soaked in water CBR results, it was found that there is increasing in the CBR values and a significant increasing with percent of glass powder more than 4%, these increasing values was 2.5, 3.3, 5.2, 9.4 times when added 3, 5, 7, 9 % glass powder respectively more than untreated soil CBR value due to reducing the plasticity when using cohesionless powder, the effect of pozzolanic lime in the glass powder [17], [2] and incompressibility of glass powder and increase in soil toughness due to tight structure formation and increase in friction among the soil particles [3]. The soaked in water samples gave the best results than cured in air like worked in researches, Fauzi et al. [1], Canakci, et al. [7], and Mosa [2].

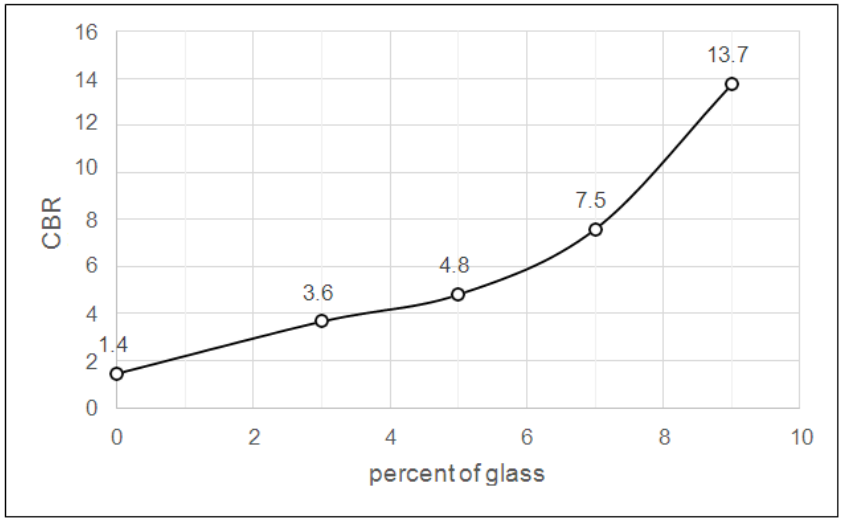

Figure 7 CBR % values for all soil-glass mixes

V. CONCLUSIONS AND RECOMMENDATIONS

It can be concluded from the using of crushed bottle glass passing sieve opening size 0.075mm with cohesive soil in this research the following issues according to the tests results such adopted in this work:

1. The consistency and plasticity of soil such used was improved, the liquid limit, plastic limit and plasticity index was decreased with the increasing of glass powder, which is minimize the subgrade problems causes failure or needs to maintenance and costs.
2. The compression, unconfined compression and shear strength behave like curve increasing with the increase of glass powder to 7% added, then began to decrease making the optimum percent of additive at 7% which was the suitable percent from unconfined compression strength point of view.
3. The CBR results refers to significantly improvement occurs in soil when increasing the glass powder which it is mean raising in layer coefficient (a) used in pavement layers design leads to minimizing the

thickness and initial cost.

4. It's recommended that the percent of glass powder such used must be constrained, high percent makes soil similar to sand; the reduction in soil cohesion with increasing of friction angle will occurs and fail in shear [2], while the low percent may noticeably effect on improvement.

5. It's recommended further studies by adding lime or cement and investigate the feasibility using it in subbase pavement layer.

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