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Effects of Waste Glass Powder on Subgrade Soil Improvement

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ABSTRACT

The weak soil is largely distributed worldwide and creates problems in constructing pavements, roadways, structures, irrigation systems and foundation works due to low shear strength and bearing capacity. The ways of improving soil is known as soil stabilization. Various soil stabilization techniques are using but none of them are cost effective and environmentally friendly way. The present study aims to effect of soil stabilization with waste glass powder which will reduce the cost and is environmentally friendly. To investigate the effect of glass powder in cohesive soil different types of index and geotechnical engineering tests are conducted and compared with the virgin soil. Glass powder was mixed with the soil samples by 2%, 4%, 6%, 8% and 10% of dry weight of soil to conduct the tests and to determine the optimum percentage of glass powder. The Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) continuously decreased and found 33.9%, 18.4% and 15.5% respectively at 10% of glass powder. Maximum dry density (MDD) was increasing and found constant and Optimum Moisture Content (OMC) was decreasing when added glass powder. The both Unsoaked and Soaked California Bearing Ratio (CBR) was increasing with the addition of glass powder and found maximum value 22.5% and 10.4% respectively. Unconfined compressive strength (UCS) was increasing up to 8% of glass powder and found to 133.5 KN/m^2 and then decreased to 119.7 KN/m^2 when added 10% of glass powder. Shear strength parameter also increases with the increase of glass powder. The study found that the optimum percentage of glass powder is 8% of dry weight of soil.

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***Keywords*:** Waste Glass Powder, Soil Stabilization, Liquid Limit (LL), Plastic Limit (PL), Maximum Dry Density (MDD), Optimum Moisture Content (OMC), California Bearing Ratio (CBR), Unconfined Compression Strength (UCS)

1. INTRODUCTION

Nowadays a huge number of different types of waste are generated in this modern life. Various types of wastes like industrial waste, agricultural waste, hospital waste, residential wastes and tires are becoming a real threat to the environment. It becomes more severe if they are non-biodegradable materials. The civil engineers have used many waste materials to stabilize weak clay and sandy soils. Waste glass, rice husk ash, marble dust, fly ash, stone dust, bagasse ash, hospital waste, shredded tires has been used in different engineering practices in a technique called soil stabilization. These waste products carriages a serious environmental problem if it is not disposed properly. In order to save the cost and reduce environmental pollution this type of recycled waste material can be used. Soil stabilization is defined as an engineering approach used to improve the engineering properties of the soil, as well as to reduce the defects in soil such as settlement, expansion and compressibility.

Many researchers used different types of wastes in soil stabilization. Expansive soil can be used for construction by treating it in the form of stabilization using industrial wastes, Fly ash, Rice husk ash (RHA), Phosphogypsum, Quarry dust, Granulated blast furnace slag etc with or without a binder like cement, bitumen, lime, calcium chloride etc. [1-9]. Many researchers found that fiberreinforced soils are potential composite materials in improving the structural behavior of stabilized and natural soils [10-13]. Expansive soils with fly ash bought a significant reduction in swelling pressure of the soil. Rubber was used with cement to decrease the swelling pressure of clay soil [14]. California bearing ratio and the unconfined compressive strength were increased in clay soil with the addition of Jute fiber [15]. The bearing capacity, dry density, and unconfined shear strength of silty clay soil was increased when aluminum residue and recycled asphalt was added. All the researchers have found varied success in improving the engineering properties of expansive soil.

One of the challenging wastes to the environment is glass waste and is considered on the top of the solid waste list. The volume of global glass production was estimated to be close to 130 million tons in 2005 [16]. In Australia, approximately 850,000 tons of glass are used each year, whereas only 350,000 tons (40%) were recovered for recycling. Therefore, a large number of glass waste is buried in landfills. Normally glass takes 450 years to biodegradation. Thus, it becomes more important to reuse in the form of soil stabilization. The physical properties of the crushed glass are that they reveal high permeability, small strain stiffness, high crushing resistance and these properties could improve its usage in geotechnical engineering works for soil stabilization, embankment constructions etc. A study was carried out on eco-friendly pavement blocks made of waste glass, fly ash and dust and found that compressive strength and flexural strength of the pavement block is increased by 37% and 50% respectively [17]. The addition of waste glass resulted in the increase of Dry Density and CBR values and the reduction of plasticity index, Optimum Moisture Content [18]. A recent research found that the use of soda lime glass powder waste with clay has a significant effect on the strength of the soil [19]. Another research indicated that using glass powder with clay soil up to 8%, increased the unconfined compressive strength, cohesion and angle of internal friction [20].

The CBR value increases to an average 10% when 20% crushed glass mixed with 80 % clayey material [21]. Crushed waste glass and waste plastic was mixed up to 12% with two kinds of soil and found that CBR (was increased to 5%) and friction angle was increased as increasing in additives while, Plasticity index and cohesion were decreased [22]. The frictional strength of the fine-grained soils considerably improved with the addition of crushed glass and recommended that this concept could be used to improve the engineering properties [23]. A research showed that the mixture consist of 80% clay material and 20% crushed waste glass can be used in subgrade and embankment of read pavements construction [24].

The main objective of the investigation is to determine the optimum percentage of glass with cohesive soil. The optimum percentage was determined by the investigation of different index and engineering characteristics of the soil. The waste glass was taken as 2%, 4%, 6%, 8% and 10% by dry weight of soil and mixed with the soil and examine the effects on LL, PL, PI, OMC, MDD, CBR, UCS and shear strength of the soil.

2. MATERIALS

The materials used for the investigation were the cohesive soil and crushed glass powder. A series of tests was conducted to achieve original engineering properties of soil and waste glass powder.

2. 1. Soil

The poor cohesive soil sample was collected from a site in Ganakbari area at 1.5m depth from the ground level. The geotechnical properties of the expansive soil are shown in Table 1.

Table 1. Geotechnical Properties of Soil

Item	Property	Value
1.	Sand	21%
2.	Silt + Clay	79%
3.	Specific Gravity	2.64
4.	Liquid limit (LL)	49.52%
5.	Plastic Limit (PL)	28%
6.	Plasticity index (PI)	21.52%
7.	Shrinkage Limit (SL)	9.6%
8.	Optimum Moisture Content (OMC)	17.53%
9.	Maximum Dry Density (MDD)	1.83 (gm/cm^3)

10.	Unconfined Compressive Strength (UCS)	63.2 (KN/m^2)
11.	California bearing ratio (CBR) Unsoaked	2.32%
12	California bearing ratio (CBR) Soaked	1.56%

2. 2. Glass

Waste glasses were taken from the nearest glass processing plant in Dhaka, Bangladesh. The waste glasses were washed, dried and then broken down into a powder by using a hammer and covering it with a piece of cloth to avoid raveling. The glass powder was passed through the sieve number 200. The passing through such that sieve had been taken. The properties of the glass and chemical composition of the glass are shown in Table 2 and Table 3 respectively.

Table 2. Properties of glass.

Item	Properties	Values
1.	Specific gravity	2.62
2.	Compression resistance	860-1020 Mpa
3.	Hardness	5.3 mohs Hardness
4.	Density	2.45 g/cm^3
5.	Bending strength	52 Mpa
6.	Softening point	950°C

Table 3. Chemical Composition of glass.

Item	Components	Composition (%)
1.	Silica	71
2.	Sodium oxide	11.25
3.	Lime	10.25
4.	Alumina	1.5
5.	Other	6

3. EXPERIMENTAL PROGRAM

In this study, various proportions such as 2%, 4%, 6%, 8% and 10% (by dry weight of soil) of waste glass powder was mixed with natural soil to investigate the geotechnical propersties of the sample soil. The laboratory tests were carried out to determine the LL, PL, PI, MDD, OMC, UCS and CBR. The LL and PL test was performed according to specifications ASTM D4318 [11]. The MDD and OMC were determined by the specifications of ASTM D698 [12] and ASTM D1557 [13], respectively.

The CBR was conducted according to the specification of ASTM D1883 – 99 [14]. The UCS was performed regarding the specification ASTM D2166 [15]. The direct shear test was conducted according to ASTM D 3080.

4. TEST RESULTS AND DISCUSSIONS

4. 1. Liquid Limit, Plastic Limit and Plasticity Index

The effect of Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) with applying different percentage (2%, 4%, 6%, 8% and 10%) of glass powder is presented in Table 4. It is found that with the addition of glass powder, the LL was continuously decreased from 49.52% to 33.9% and PL was continuously decreased from 28% to 18.4%. This reduction is due to the characteristic of soil keeping water which occours because of the silica presence in glass works as sand which does not absorb water.

Table 4. Effect of glass powder on LL (%), PL (%) and PI (%).

Additional material (%)	LL	PL	PI
0%	49.52	28	21.52
2%	44.9	26.4	18.5
4%	40.6	23.2	17.4
6%	38.1	21.6	16.5
8%	35.6	19.3	16.3
10%	33.9	18.4	15.5

The variation of LL, PL and PI of the soil with increasing percentage of glass powder is shown in Figure 1. The percentage decrease in LL is 31.5%, PL is 34.3% and PI is 28%. The compressibility and swelling characteristics of soil changes with the changing in LL. Therefore, the compressibility and swelling characteristics of the soil was reduced due to reduction in LL and which will tend to improve the sub grade soil.

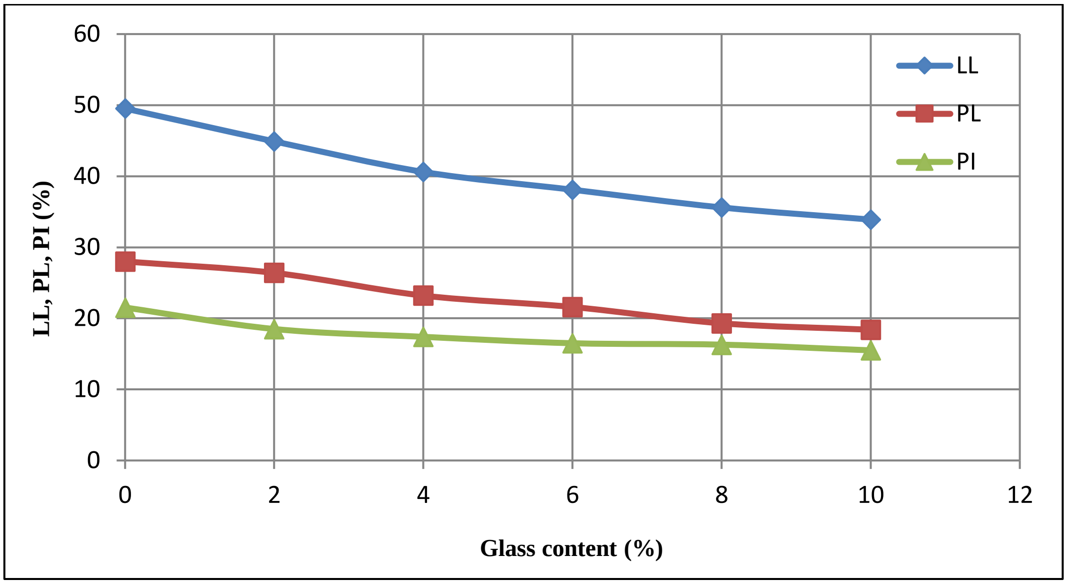

Figure 1. Variation of LL, PL and PI value for different glass powder content.

4. 2. Maximum Dry Density and Optimum Moisture Content

The effect on Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of different percentage (2%, 4%, 6%, 8% and 10%) of glass powder is tabulated in Table 5. The MDD of the pure soil was 1.83 gm/cm^3 and increased to 2.03 gm/cm^3 when added 8% of glass powder and remain constant after further increase the glass powder to 10%. On the contrary, OMC was decreased from 17.53% to 10.5% for adding up to 10% glass powder. The increase in MDD was due to the increased specific gravity of glass powder and the decrease of OMC was due to the fact that the addition of glass powder with soil diminishes the attraction to water particles. Figure 2 and Figure 3 reveal the variation of compaction characteristics with different percentage glass powder.

Table 5. Effect of glass powder on MDD (gm/cm^3) and OMC (%).

Additional material (%)	Glass powder	
	MDD	OMC
0%	1.83	17.53
2%	1.89	16.8
4%	1.95	15.9
6%	2.00	14.6
8%	2.03	12.7
10%	2.03	10.5

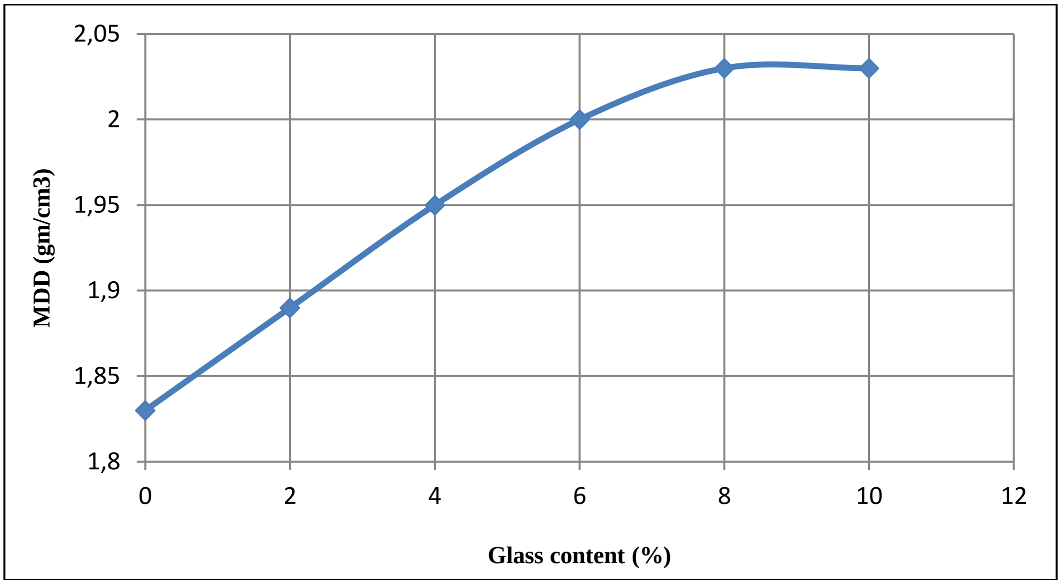

Figure 2. Variation of MDD value for different glass powder content.

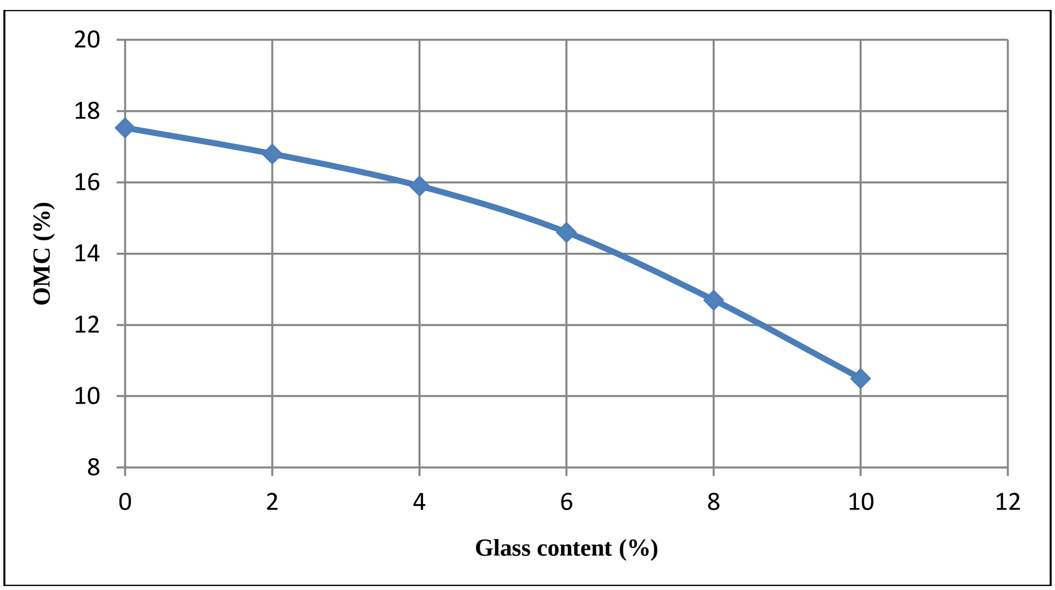

Figure 3. Variation of OMC value for different glass powder content.

4. 3. California Bearing Ratio

The california bearing ratio (CBR) value of both unsoaked and soaked condition of the pure soil was 2.32% and 1.56% respectively. CBR value of unsoaked condition increased to 22.5% when added 10% glass powder. Soaked CBR value also increased to 10.4% when 10% glass powder was mixed. The effect of change in both conditions with respect to glass powder is given in Table 6. The increase in the CBR value may be due to the shear transfer mechanism between the soil and glass powder and the improvement in the strength might be due to the pozzolanic action of glass powder mix. The graphical representation of the variation of CBR value in both conditions with respect to glass powder is shown in Figure 4.

Table 6. Effect of glass powder on CBR (%).

Additional material (%)	CBR (Unsoaked)	CBR (Soaked)
0%	2.32	1.56
2%	4.6	2.45
4%	7.3	4.2
6%	10.4	6.5
8%	15.7	8.9
10%	22.5	10.4

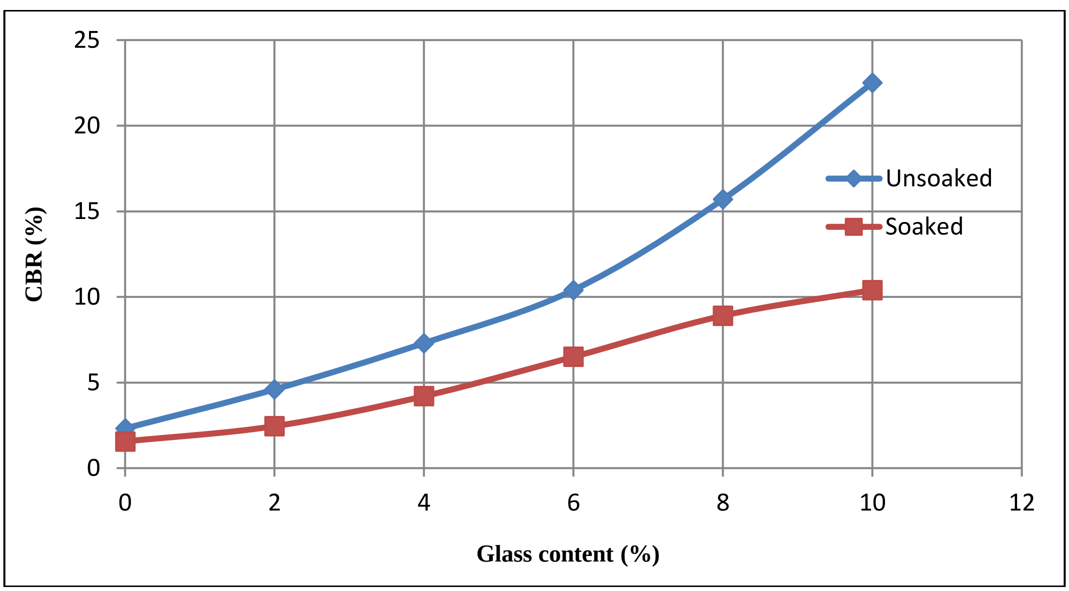

Figure 4. Variation of CBR value for different glass powder content.

4. 4. Unconfined Compressive Strength

It can be seen from Table 7 that, the unconfined compressive strength (UCS) was increased from 63.2 KN/m^2 to 133.5 KN/m^2, with the increase of glass powder up to 8% and then, decreased to 110.7 KN/m^2 when 10% glass powder is added. The increase in the UCS is for the presents of lime in glass powder and working as binder with clays after the hydration and enhance bonds. Lime causes the reduction of plasticity and improve the soil texture by pozzolanic strength. The decrease in the UCS values after the addition of 10% glass powder is may be due to decrease in cohesion of the soil. Figure 5 represents the variation of UCS of a soil with the increasing percentage of glass powder.

Table 7. Effect of glass powder on UCS (KN/m^2).

Additional material (%)	**UCS (KN/m^2)**
0%	63.2
2%	71.4
4%	86.6
6%	105.3
8%	133.5
10%	119.7

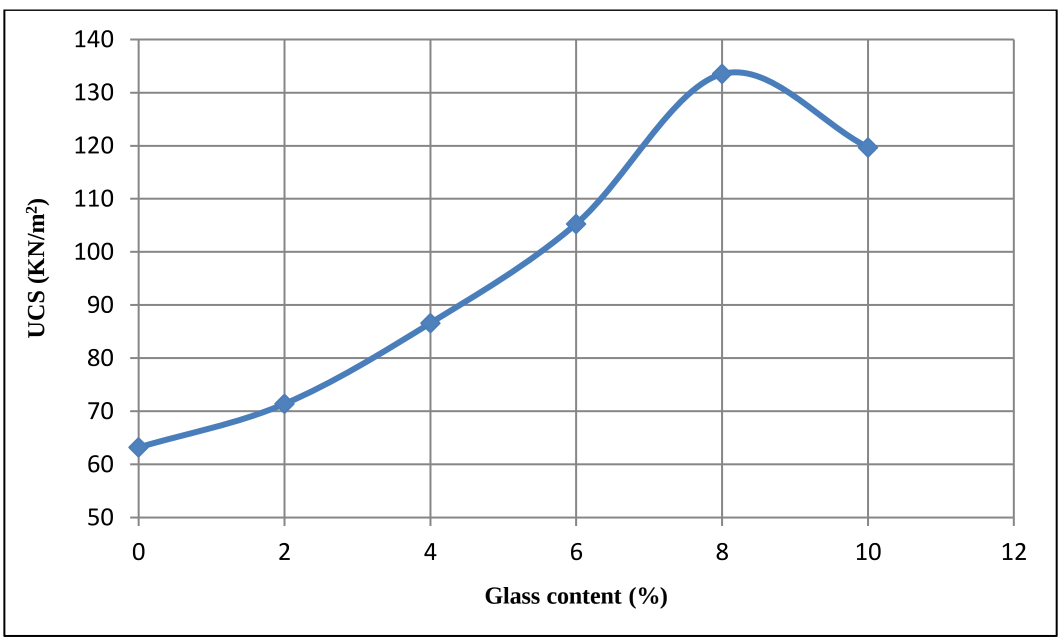

Figure 5. Variation of UCS value for different glass powder content.

4. 5. Direct Shear Test

The effect on shear strength parameters of different samples were tested and is shown in Table 8. The increase of glass powder also provides a positive influence in the development of cohesion and angle of internal friction. The cohesion of the pure soil was 42.7 KN/m^2 and increased to 106.4 KN/m^2 when added 10% of glass powder.

The rate of increasing became to decrease after the addition of 8% glass powder. Likewise, the angle of internal friction was also increasing with the increase of percentage of glass powder. Angle of internal friction was found to 27.4 and increase to 43.5 when added 10% of glass powder. Figure 6 and Figure 7 shows the variation of cohesion and angle of internal friction with different percentage of glass powder.

Table 8. Effect of glass powder on shear strength parameters.

Additional material (%)	**Cohesion (KN/m^2)**	**Angle of internal friction (ϕ)**
0%	42.7	27.4
2%	54.4	31.6
4%	63.8	34.4
6%	76.8	38.5
8%	98.6	41.3
10%	106.4	43.5

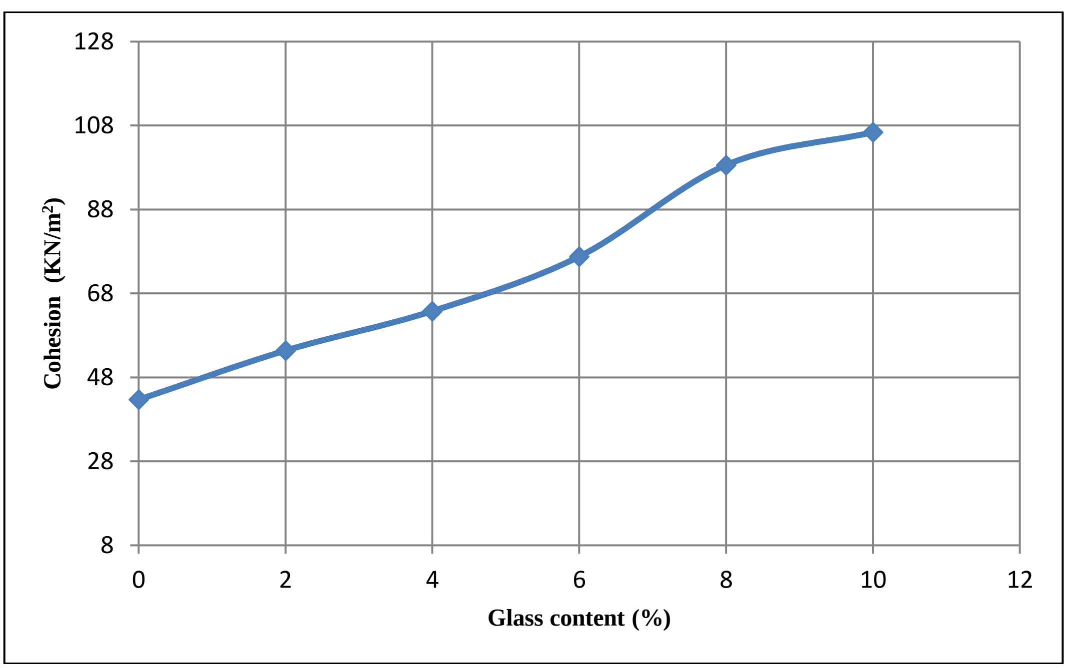

Figure 6. Variation of cohesion value for different glass powder content.

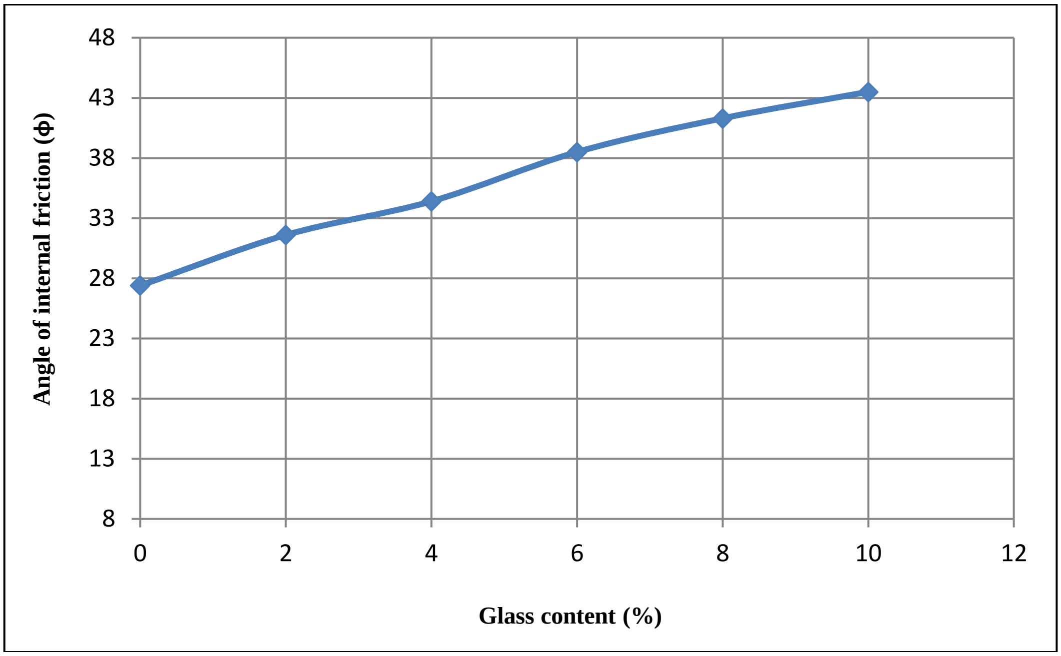

Figure 7. Variation of angle of internal friction value for different glass powder content.

5. CONCLUSIONS

This study concluded that the waste glass powder is useful for improving the clay soil. Using waste glass for stabilization not only help to reduce the environmental effect, but also for economic solutions as this material are locally and cheaply available. Based on the results, it can be said that LL, PL and PI continuously decreased with the increase of the glass powder which will potentially improve the subgrade. The MDD value increased from 1.83% to 2.03% with the addition of waste glass up to 8% of the dry weight of soil and remain constant when added 10%. On the other hand, OMC decreased from 17.53% to 10.5% with the increment of glass powder. The both unsoaked and soaked CBR increased with addition of glass powder and maximum value found to 22.5% and 10.4% respectively. The UCS increased to 133.5 KN/m^2 when added 8% and then decreased to 119.7 KN/m^2 when added 10% glass powder of the dry weight of soil. The shear strength parameters also increase with the increase of the glass powder but the rate of increment was decreasing after the addition of 8% glass powder. Therefore, the optimum percentage of waste glass powder for improvement the soil is found to be 8%.

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