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EFFECT OF GROUND GRANULATED BLAST FURNACE SLAG ON STABILIZED EMBANKMENT SOILS UNDER TRIAXIAL LOADING

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Abstract*—Industrial waste materials like Ground Granulated Blast Furnace Slag (GGBS), Granulated Blast Furnace Slag(GBFS), which are by products of Iron and steel industry are increased day to day and have similar properties as that of cement. So utilizing these by-products for stabilization benefits both environmental and economic aspects. The main objective of the present study is to Utilization of GGBS for improving various engineering properties of the soil as an alternative to lime or cement. In this study, usage of GGBS with different proportions in sub grade was analysed under static and dynamic loads. Soil sample was collected from pond in NIT Trichy, Tamil Nadu, India. The Index and Engineering properties (Standard proctor compaction, Unconfined compression test, California bearing ratio test) of soil with and without GGBS was determined for different combinations of GGBS with soil and optimized at 16% based on strength performance tests. It is observed that the improved soil strength depends on the amount of GGBS. The work is further extended to know the variation in strength of soil with and without GGBS under dynamic loads by conducting cyclic triaxial tests. Dynamic properties of soil (i.e., Shear modulus and damping ratio) are found out using strain controlled unconfined cyclic triaxial tests carried out as per ASTM D3999 and results are presented accordingly. The effect of GGBS inclusion is evaluated as a function of shearing-strain amplitude, confining stress, cycle number and GGBS content. It was found that the effect of GGBS content is significant on both shear modulus and damping ratio particularly at high shear strain amplitude. Thus effect of fibres in the improvement of dynamic properties of pond sand is investigated and feasibility of GGBS for ground improvement is explored.

***Keywords*— Pond Sand, Ground Granulated Blast Furnace Slag, CBR, Standard Proctor, Unconfined compression test, Cyclic triaxial test.**

I. INTRODUCTION

Utilization of industrial waste materials in the improvement of problematic soils is a cost efficient and also environmental friendly method in the sense that it helps in reducing disposal problems caused by the various industrial wastes. In developing countries like India, the main problem is to provide a complete network of road system with the limited resources. Therefore there is a need to go for low cost road construction to meet the growing needs of road traffic. The cost of construction can be considerably decreased by selecting local materials including local soils for the construction of the lower layers of the pavement such as the sub-base course and subgrade soil. If the stability of the locally available soil is not having adequate bearing capacity, the strength of soil is improved by soil stabilization techniques. The soil stabilization means improving the bearing capacity of soil by adding suitable admixtures. Stabilization of soils with cement and lime is well known and it is very costly which led to focus on the use of the other industrial waste materials like fly ash, rice husk ash and GGBS.

ErdalCokca et al. (2009) studied the effect of stabilizers Granulated Blast Furnace Slag (GBFS) and GBFS-Cement in stabilization of expansive clays by preparing an artificial expansive soil by mixing 85% Kaolinite and 15% Na-Bentonite by dry mass. GBFS and GBFSC were shown to successfully decreasing the total amount of swell while increasing the rate of swell.Anil K.S et al. (2011) studied the effectiveness of fly ash with ground granulated blast furnace slag in the soil and it was found that the UCS of fly ash- GGBS mixture increases with the increase in the GGBS content. And also it was observed that the strength increases with the curing period.
Obuzor et al. (2012) studied the flooding effects on road structural layers/embankments constructed on flood plains stabilized with lime-activated-GGBS. The results show that road structural layers/embankments constructed on floodplains could be durable with the application of industrial by-product material (GGBS) activated by lime. EceCelik et al. (2013) studied the effect of ground granulated blast furnace slag (GGBS) on the swelling properties of lime-stabilized sulphate-bearing soils. The test results revealed that slag treatment eliminated the detrimental effect of sulphate in the lime-treated soils.
LaxmikantYadu et al. (2013) studied the effect of granulated blast furnace slag in the engineering behaviour of stabilised soil. The results show that inclusion of GGBS increases the strength of soft soils. Similarly, significant improvement has been observed for unsoaked and soaked CBR value of soils.

This paper presents work in utilising industrial by-products as suitable admixture to enhance the geotechnical properties of soft soils. Hence an attempt has been made to improve the strength and swell behaviour of expansive black cotton soil using GGBS in this work.

II. MATERIALS

Soil sample was collected from pond in NIT Trichy, Tamil Nadu, India. The slag produced at blast furnace during pig iron manufacturing is called blast furnace slag. Depending upon the cooling process, three types of slags are generated; namely, air-cooled slag, granulated slag and expanded slag. Granulated slag is produced by quenching the molten slag by means of high-pressure water jets. This slag is crushed, pulverised and screened for use in various applications. Blast furnace slag has a glassy, disordered, crystalline structure which can be seen by microscopic examination which is responsible for producing a cementing effect. The GGBS used in this study was collected from Salem Steel Plant in Tamil Nadu, India.

III. PROPERTIES OF SAND AND GGBS

The laboratory tests carried out on the natural soil include Sieve analysis, Atterberg limits, Specific gravity, Standard Proctor test, Unconfined Compressive strength test and California Bearing Ratio test and the results are shown in **Table 2.1**. The laboratory tests carried out on Ground Granulated Blast Furnace Slag are shown in **Table 2.2**.

Table 2.1. Index properties of soil

S.No	Particulars	Value
1	Indian Standard Soil Classification	Poorly Graded Sand (SP)
2	Uniformity Co-efficient (C_u)	
3	Co-efficient of Curvature (C_c)	
4	Specific gravity	2.64
5	Liquid limit (%)	18
6	Plastic limit (%)	NP
7	Plasticity index	NP
8	Maximum dry density (g/cc)	1.81
9	Optimum moisture content (%)	14
10	Unconfined compressive strength (Kg/cm²)	1.57
11	Poisson ratio	0.35

Table 2.2. Index properties of GGBS

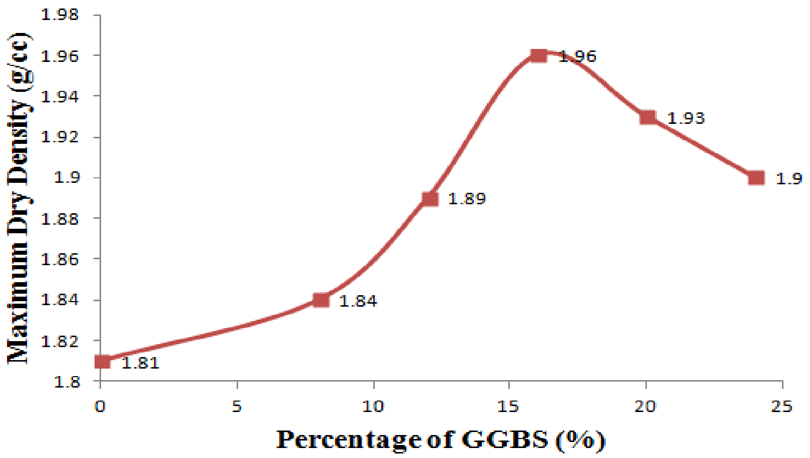
1	Specific gravity	2.65
2	Liquid limit (%)	15
3	Plastic limit (%)	NP
4	Plasticity index	NP
5	Maximum dry density (g/cc)	1.82
6	Optimum moisture content (%)	16

IV. RESULTS AND DISCUSSION

4.1 Standard Proctor Compaction

For performing the standard proctor tests, the soils were prepared by adding the admixture at varying percentages of GGBS. The variation in the strength was observed in **Fig. 3.1**. The standard proctor values for different percentages of GGBS are given in **Table 3.1**.

Fig. 3.1 Effect of GGBS on MDD

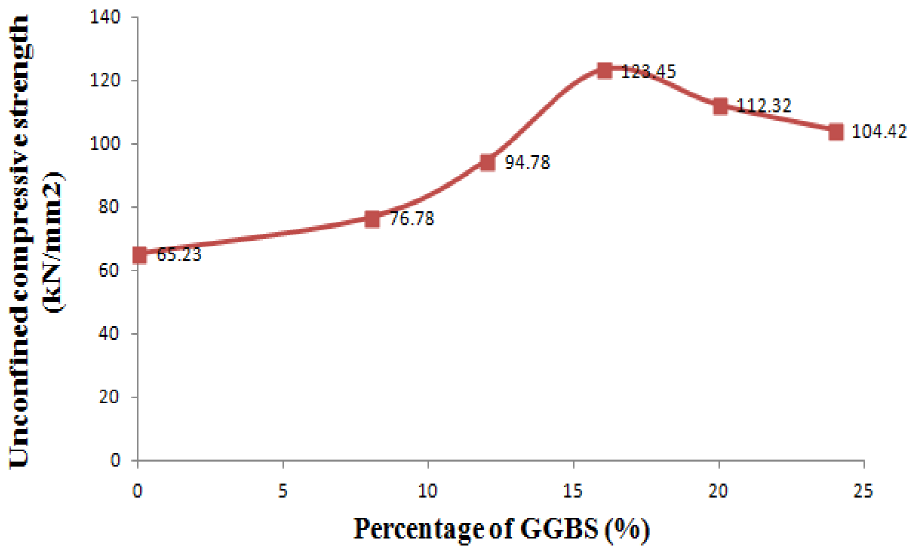


From the results, the OMC values are decreasing with increase in amount of GGBS added to soil. The MDD values are increased with addition of GGBS upto 16% and have shown slight decrease with further increase in GGBS.

4.2 Unconfined Compressive Strength

For performing the UCS tests the soils were prepared by adding the optimum moisture content obtained by conducting the standard proctor test. The admixture was added at varying percentages of GGBS. The variation in the strength was observed in **Fig. 3.2**.

Fig. 3.2 Effect of GGBS on UCS

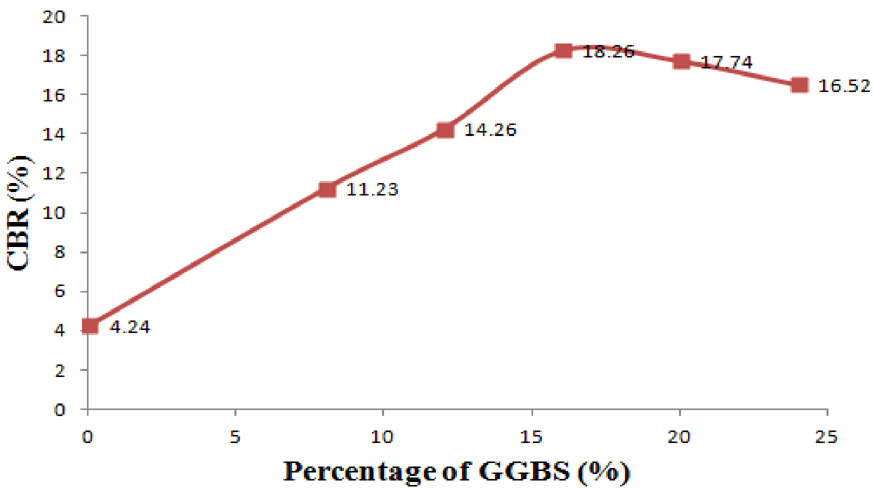


The UCS values are increased with addition of GGBS for Calcium Bentonite Clay upto 16% and have shown slight decrease with further increase in GGBS.

4.3 California Bearing Ratio

For performing CBR tests the soils were prepared by adding the optimum moisture content obtained by conducting the standard proctor test. The admixture was added at varying percentages of GGBS. The variation in the strength was observed in **Fig. 3.3**.

Fig. 3.3 Effect of GGBS on CBR



The CBR values are increased with addition of GGBS for Black Cotton Soil upto 24% and have shown slight decrease with further increase in GGBS. The same trend was observed for Organic Clayey Soil showing maximum CBR values at 25% of GGBS respectively.

4.4 Optimum content of GGBS

Combinations of soil and GGBS	MDD (gm/cc)	OMC (%)	UCS (kN/mm^2)	CBR (%)
Soil	1.81	16	65.23	04.24
Soil+08%GGBS	1.84	15	76.78	11.23
Soil+12%GGBS	1.89	14	94.78	14.26
Soil+16%GGBS	1.96	12	123.45	18.26
Soil+20%GGBS	1.93	11	112.32	17.74
Soil+24%GGBS	1.90	10	104.42	16.52

V. UNCONFINED CYCLIC TRIAXIAL TESTS

5.1 Sample preparation and tests conducted

Cyclic triaxial tests were conducted on cylindrical samples prepared soil with 0%, 8%, 16% and 24% GGBS contents at three different shear strain levels i.e.07.85%, 12.25%, 16.80% at loading frequency of 1Hz and calculations were carried out as per ASTM D3999 (2011). Reinforced and un-reinforced Cylindrical samples of dimensions 38 mm diameter and 76 mm height were used. The combinations were given in Table 5.1, a total of 12 samples were tested.

5.2. Formulation Used

The shear modulus is evaluated as the slope of a secant line that connects the extreme points on a hysteresis loop at a given shear strain, as shown in Fig. 5.1. As the cyclic strain amplitude increases, the shear modulus decreases.

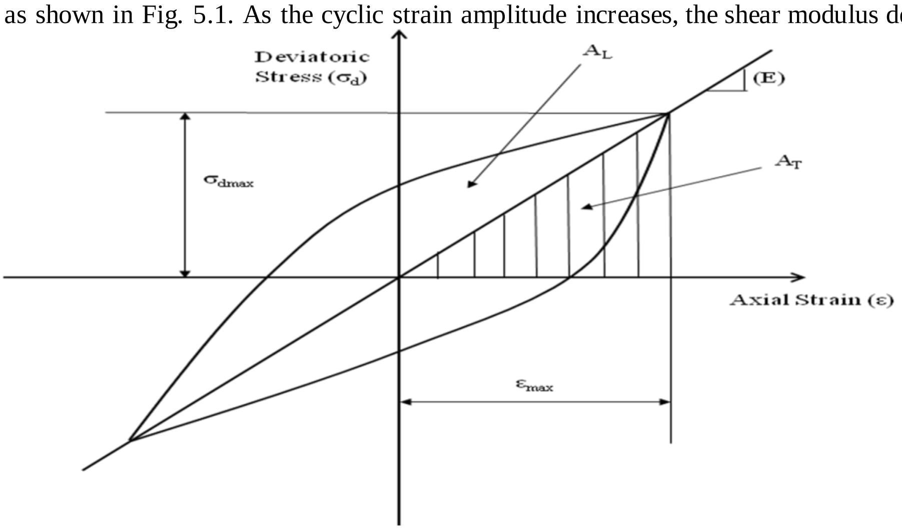


Figure 5.1. Hysteretic stress-strain relationship

From cyclic triaxial test results, a hysteresis loop similar to Fig. 5.1 will be obtained by plotting the deviator stress (σ_d) versus axial strain (ε). The slope of the secant line connecting the extreme points on the hysteresis loop is the young modulus (E) (as per Towhata 2008).

$$\lambda = (1+\mu)\varepsilon$$

$$E = \frac{\sigma_{d\max}}{\varepsilon_{\max}}$$

$$E = 2G(1+\mu)$$

where, G is the shear modulus, λ is the shear strain and μ is the Poisson's ratio that may be taken as 0.5 for saturated undrained specimen (Towhata, 2008). The damping ratio D, is a measure of dissipated energy versus elastic strain energy and is computed by

$$D = \frac{1}{4\pi}\frac{A_L}{A_T}$$

where A_L = Area enclosed by the hysteresis loop and A_T = Area of the shaded triangle

Shear modulus and damping ratio for sand at different % GGBS content and at 3 different shear strains are given in Table 5.1.

Table 5.1. Shear Modulus and Damping Ratio for Sand at 3 Different Shear Strain levels

S.No	GGBS content (%)	Shear strain(%)	Shear modulus (MPa)	Damping ratio (%)
1	0	07.85	0.642	0.012
2		12.25	0.426	0.032
3		16.80	0.212	0.058
4	8	07.85	0.960	0.164
5		12.25	0.612	0.696
6		16.80	0.251	1.246
7	16	07.85	1.201	0.508
8		12.25	0.768	1.665
9		16.80	0.368	2.821
10	24	07.85	1.320	0.179
11		12.25	0.853	0.825
12		16.80	0.456	1.477

Figs 5.2 and 5.3 shows the variation of shear modulus and damping ratio with GGBS content for different shear strain levels. Variation of GGBS content had a significant effect on both shear modulus (G) and damping ratio (D). As GGBS content increases shear modulus increases upto optimum content of GGBS and further increase in GGBS content also shear modulus increases. Due to inclusion of 16% GGBS content in sand there is an increase in shear modulus which further increases with percentage increase of GGBS content. As GGBS content increases the damping ratio also increases upto optimum content of GGBS and with further increase in GGBS content the damping ratio value decreases.

Figure 5.2. Influence of GGBS content on shear modulus

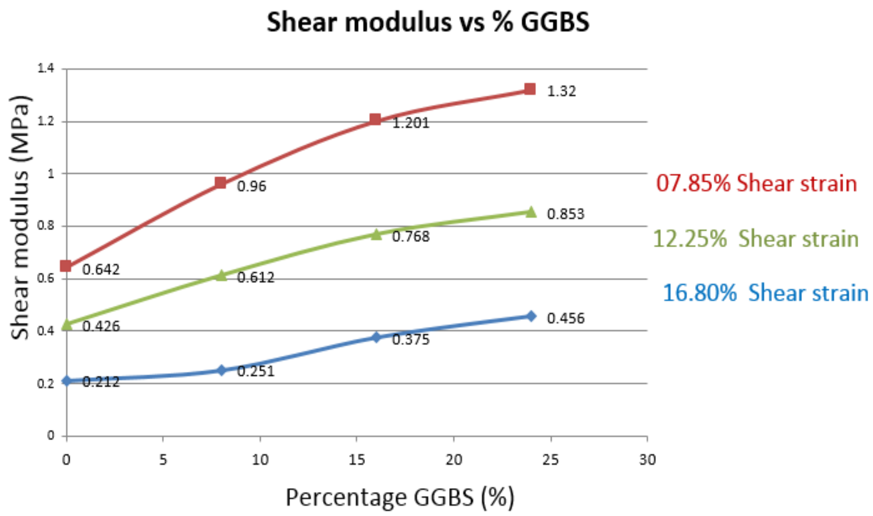
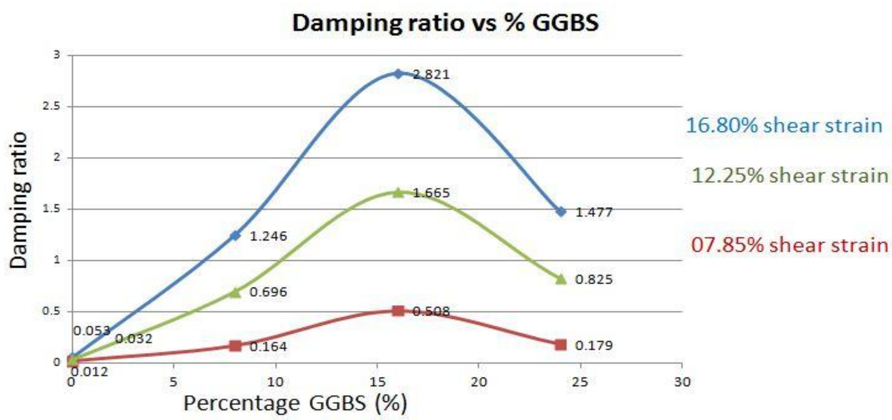


Figure 5.3. Influence of GGBS content on damping ratio



Figs 5.3 and 5.4 shows the variation of shear modulus and damping ratio with shear strain for different GGBS contents. It can be observed that as the shear strain increases, the shear modulus decreases and damping ratio increases. The trend of results of Shear modulus with shear strain is similar to that for unreinforced sand observed by Kokusho (1980) and Kramer (1996). The trend of the results of damping ratio with shear strain is similar to that observed by Maher and Woods (1990). They suggested that for dynamic loads as GGBS content increases the rigidity of the composite material increases. This increase in rigidity translates into a higher shear modulus at low as well as at high shear strain amplitude.

Figure 5.4. Influence of GGBS content on damping ratio versus shear strain

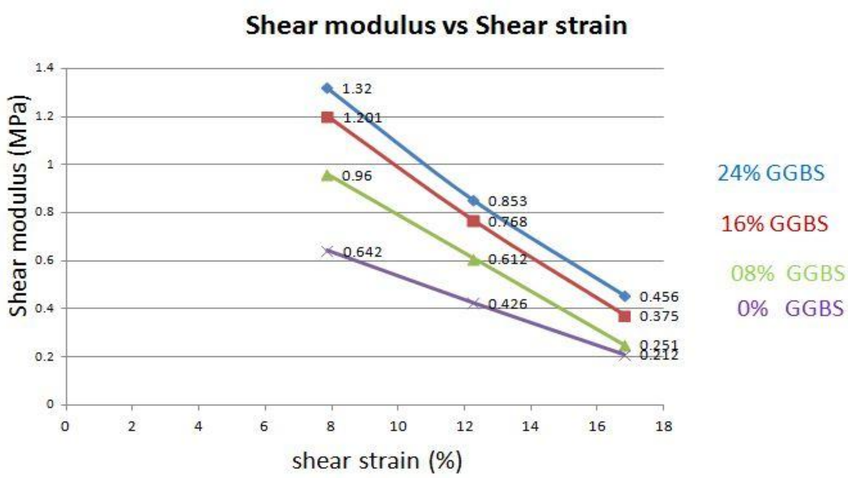


Figure 5.5. Influence of GGBS content on damping ratio versus shear strain

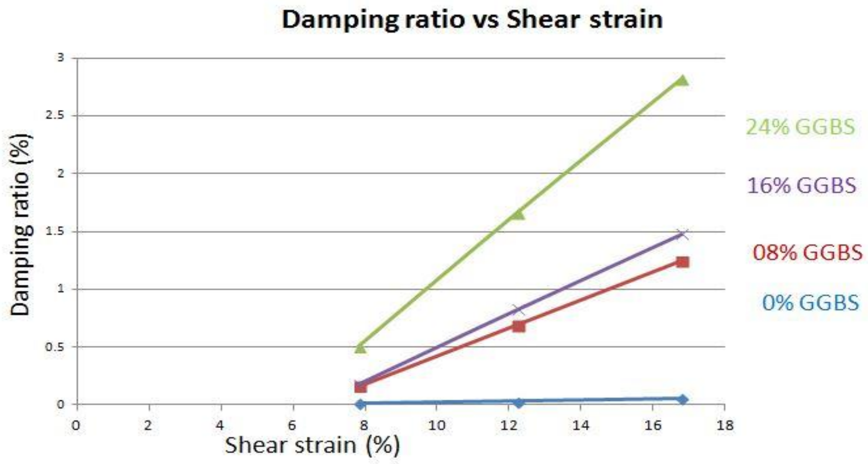
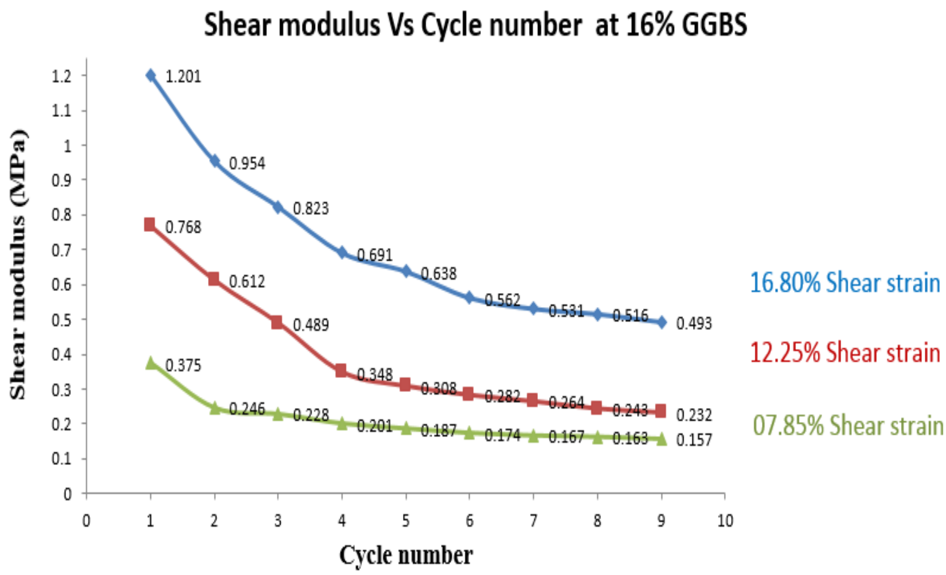


Fig 5.6 shows the variation of shear modulus with respect to number of loading cycles at 16% GGBS content. Shear modulus decreases as number of loading cycles increases at a given shear strain level. Percentage reduction in shear modulus is high at lower cycle number and low at higher cycle number. The curve becomes asymptotic to X-axis as cycle number increases. Similar trend was observed at all other GGBS contents and shear strain levels.

Figure 5.6. Influence of number of loading cycles on shear modulus at 16% GGBS



VI. CONCLUSIONS

- It was found that with the increase in GGBS content the dry density also increases up to optimum content of GGBS and with further increase in GGBS content the dry density decreases gradually.
- It was found that optimum moisture content for Silty Sand sandy soil was decreased with the addition of GGBS from 16% to 12%.
- It was found that with the increase in GGBS content the unconfined compressive strength also increases up to optimum content of GGBS and with further increase in GGBS content UCS value decreases.
- It was found that with the increase in GGBS content the CBR also increases up to optimum content of GGBS and with further increase in GGBS content CBR value decreases.
- It was found that for the Silty Sand sand (both unreinforced and reinforced) as shear strain increases the shear modulus decreases while damping ratio increases. Thus the basic characteristic of sand remains intact with the reinforcement.
- Results also shows that with increase in GGBS content the damping ratio also increases up to optimum content of GGBS, but it is not significant and with further increase in GGBS content the damping ratio value decreases.
- And also results shows that shear modulus increases with increase in GGBS content and decreases with increase in number of loading cycles at a given strain level.

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