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Evolution of the Geotechnical Properties of Fly Ash Stabilized Silty Soil Activated by Graphene Oxide (GO)

A. Pateriya, D. Kishan and S.S. Kushwaha

***Abstract**: At present time, there are vastly available of various nanomaterials, by using this material it plays an important role in various applications along with geotechnical soil stabilization/strengthen techniques. In the present investigation the addition of Graphene Oxide (GO) solution as nanomaterial into the low cemented fly ash (Class F – fly ash) to improving various properties of a local available silty soil. The various tests such as light compaction test, unconfined compression test, direct shear test, liquid limit, and plastic limit test were performed on the newly formed matrix to check their respective behavior to stimulated actual site condition on the given matrix in the laboratory. Also Scanning Electron Microscopy (SEM) analysis was performed to study the structure of the newly formed matrix. The addition of small proportion GO in original soil-fly ash matrix decrease the plasticity index and at the same time increase the maximum dry density, unconfined compression strength, and cohesion value help to use newly soil matrix effectively.*

***Index Terms:** Atterberg's limit, Black cotton soil, Fly ash, Plasticity index, Stabilization*

I. INTRODUCTION

There are various methods and techniques are available to increase different properties of soil. To alter the strength, settlement, and hydraulic conductivity properties the treatment of soil was done [1] [2]. The cement, lime and fly ash have been widely used as cementitious additives to change the geotechnical properties of various soil types in various proportions [3]. Recently, SiO_2, TiO_2, Al_2O_3, Graphene Oxide (GO) and carbon nano-tubes (CNTs) are vast examples to most commonly used as nano-material in the various application [4] [5]. The nano-materials due to the high specific surface area and fine pores may significantly improve the physical and chemical properties of soil. Chemical stabilization of soil by adding the nano-materials into the soil is one of the best techniques that improve the mechanical behavior of cementitious materials-treated soil effectively gives new stronger and stiffer matrix forms by chemical stabilization compared with the original soil [6].

The GO found a protective barrier to reduce the movement of chemicals ingredients [7]. Addition of GO in cemented silty soil results decreasing the pores of the soil matrix and enhancement in GO content led to increasing in dry density and decrease in the optimum moisture content of treated soil samples conclude improved mechanical properties of soft soil effectively [8]. Straight GO–cement composite led to increasing compressive strength by 15–33% and the flexural strength by 41–59%, respectively [9].

However, the change in properties of soil by incorporation of GO directly into the soft soil due to the inherent characteristics of soil is very difficult to obtain. So, the stabilization of cementitious materials-treated soil can improve by treatment of cementitious materials with GO. Fly ash is nothing but industrial waste having pozzolanic properties hence as substitute of cement used to make more eco-friendly mean of stabilization of given soil matrix we can introduce fly ash as cementitious matrix in place of cement its imparted solution of better disposal of given fly ash in a fruitful manner [8]. In the present study, the GO solution was added to the fly ash solution and this fly ash with GO solution as the main ingredient responsible for soil stabilization was introduced into the silty soil original matrix. It should be noted that only 0, 0.01, 0.05 and 0.1% GO by weight of modified fly ash matrix respectively added into the original soil samples led to an increase in effective increase in compressive strength. The mechanical behavior of the new composite materials was deeply studied by consistency, compaction, unconfined compression, and direct shear tests.

II. MATERIALS AND METHODOLOGY

A. Silty Soil

The silty soil sample was collected from near under constructed site of Hostel number 11, MANIT, Bhopal. The soil sample was collected at the depth of 1.5 m and was make homogenous in the geotechnical laboratory to perform respective required tests according to guidelines given in each respective IS codes. The Chemical and geotechnical properties of untreated soil obtained shown in Table I and Table II respectively.

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I Chemical Compositions of Raw Silty Soils

S. No.	Constituents	Percentage
1	SiO_2	24.25%
2	Al_2O_3	1.25%
3	$CaCO_3$	11.5%
4	$CaSO_4.2H2O$	27%
5	$NaALSi_3O_8$	33%
6	$(MG Fe)_6$	2.5%
7	Organic Content	0.5%
8	pH Value	7.2

B. Graphene Oxide

Graphene oxide is easily synthesized from pure graphite powder via modified Hummers method [10]. Based on this synthesis it may alter the final properties of GO, since it totally based on raw chemicals and method of construction of this GO solution at laboratory level. In given research we directly use graphene oxide solution available in market by trade name "Graphene Supermarket".

II Geotechnical Properties of Untreated Soil

S. No.	Laboratory Tests	Numerical Value
1	Specific Gravity	2.55
2	Gravel (%)	0
3	Sand (%)	6
4	Silt (%)	77
5	Clay (%)	17
6	Colour	Brown
7	Liquid Limit (LL), %	42.55
8	Plastic Limit (PL), %	28.33
9	Plasticity Index (PI), %	14.22
10	Shrinkage Limit (SL), (%)	8.75
11	Indian Standard Soil Classification (ISSCS)	MI
12	Maximum Dry Density (MDD) (kN/m^3)	16.27
14	Optimum Moisture Content (OMC, %)	7.54
16	Angle of Internal Friction (ϕ)	28.25º
17	Cohesion (kPa)	2.54

C. Modified Fly Ash

There are two thermal power plants close to Bhopal. Kota Thermal Power Plant, Kota, Rajasthan and Sarni Thermal Power Plant, Sarni, Madhya Pradesh. Both of them use coal as fuel to generate thermal power, and fly as combustion product. These power plants face the problems related to fly ash as discussed in earlier chapters. To address these problems, there is always a need for the maximum utilization the fly ash in civil engineering projects. For the present research work, low lime fly ashes (class F) are used and these were collected from Kota Thermal Power Plant, Kota, Rajasthan. The raw fly ash was collected in dry state from electrostatic precipitator and generally called as raw fly ash at the plant which has low pozzolanic reaction. To make it fit to use as civil engineering material it requires some additives such as lime and gypsum in order to modify given raw fly ash 12% lime and 0.4% gypsum respectively by weight of raw fly ash added into original raw fly ash in order to make it modified fly ash assembly.

D. Raw Fly Ash

Particle size distribution of raw fly ash has been determined through the hydrometer analysis [11]. Fig. 1 shows the particle size distribution curve. It can be said that raw fly-ash have particles of uniform silt size. The chemical composition of raw fly ash directly available from Kota Thermal Power Plant data specification chart the different ingredients composition is presented in Table III.

The Specific gravity of the fly ash was determined according to density bottle method. The compilation of result is presented in Table IV. Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of fly ash were determined by standard Proctor compaction test [12]. The result is tabulated in Table IV. Fig. 2 shows moisture content and dry density of raw fly ash. Atterberg's limits of raw fly ash were determined by Casagrande apparatus [13]. The plastic limit has not been determined, as the fly ash is found to be non-plastic in nature.

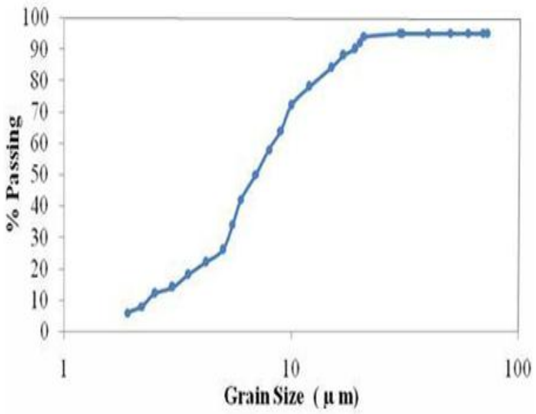

Fig. 1: Particle size distribution curve of raw fly ash

III Chemical Compositions of Raw Fly Ash

S. No.	Constituents	Percentage
1	Al_2O_3	32.70
2	SiO_2	49.60
3	Fe_2O_3	4.77
4	CaO	2.40
5	MgO	0.19
6	Loss in ignition	6.84
7	Others	3.59
8.	pH	7.89

IV Geotechnical Properties of Raw Fly Ash

Properties	Specific Gravity	OMC (%)	MDD (g/cc)	LL (%)	PL (%)
Results	1.95	18.45	1.278	29.50	Non-Plastic

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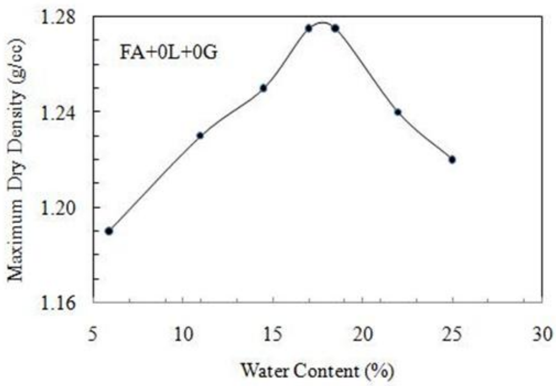

Fig 2: Compaction test result of raw fly ash

E. Lime

To stabilize the low lime-fly ash, hydrated lime is used for the following reason.

Addition of lime increase the pH value of the pore fluid resulting in precipitation of most of the metals and initiate the pozzolanic reaction by dissolving silica and alumina of fly ash. Stabilization of the low lime-fly ash will reduce the dusting problems. It is easily available at a reasonable cost. The chemical composition of lime was directly taken from manufacturer's specification chart. The different ingredients composition is presented in Table V.

F. Gypsum

Analytical quality, anhydrous gypsum is being used. Gypsum is used to accelerate the pozzolanic reaction between low lime-fly ash and hydrated lime. The analytical quality was chosen to avoid the interference of impurities which may retard the initial hydration process.

Table 4: Chemical Composition of Lime

III. METHODOLOGY

S. No.	Constituents	Percentage
1	SiO_2	1
2	AlO_3	5.4
3	FeO_3	0.69
4	CaO	69.1
5	MgO	0.4
6	Loss of ignition	22.7
7	Others	0.71

Preparation of the soil modified fly ash and grapheme oxide composites:

Modified fly ash (class-F fly ash + lime +gypsum) was used in this study whose proportion already disuse before. The amount of modified fly ash used for the stabilization of the soil was 200 kg per cubic meter of soil. The GO solution was added in the amounts of 0, 0.01, 0.05 and 0.1% by weight of modified fly ash. The respective calculated amounts of GO solution were added into the flasks containing 150 mL of water. The GO aqueous suspensions were stirred continuously for 10 min to obtain the homogeneous solutions. The prepared GO suspensions were added into the modified fly ash solutions, mixed it to prepared homogenous matrix. Then the prepared mixture was put into the mixing bowl containing soil. The mixing was continued for 5 to 8 min to till homogenous composite matrix was obtained. In order to investigate the compression strength, the prepared mixtures were compacted into a split mould in four layers with inner diameter of 38-mm and height of 76-mm. For this, the soil samples were formed at optimum moisture contain for which we get maximum dry density wrapped into the cylindrical moulds which further completely covered at top and bottom by mean of plastic sheets for 28 days at room temperature. Compression strength test was conducted to get the effect of the GO nano-sheets on the mechanical behaviour of newly formed soil matrix using modified lightly fly ash material.

Mainly in order to effective utilization of fly ash for disposal in soil in which manner it impart improvement in engineering properties to untreated soil sample light compaction test was first performed on each newly formed matrix of variable proportion of graphene oxide in order to get maximum dry density at optimum moisture content [14]. Then for each such optimum moisture content, cylindrical newly soil matrix at variable proportion sample were prepared of size 38mm diameter and 76 mm in height is allowed to cure for 28 days at room temperature and then it subjected to unconfined compression [14]. The tests were repeated for each respective proportioning samples three times and the average values were noted down. Deformation values were recorded during the test for each respective sample.

The direct shear test was also performed on each respective specimen after prepared sample and cure for 28 days at room temperature of each specified proportion of newly soil matrixes in order to obtain respective values of cohesion and internal friction angle of this newly formed soil matrixes [15].

The impression of GO concentration (0, 0.01, 0.05 and 0.1% of GO by weight of modified fly ash) on plasticity characteristic of soil plus modified fly ash samples were evaluated for each respective sample whole procedure conducted for three different sample and average value were noted [13].

The surface morphology of GO at 0.05% proportion in modified fly ash-soil sample was obtained using a scanning electron microscopy (JSM-6390A).

IV. RESULTS AND DISCUSSIONS

A. The Morphology of GO, soil and modified Class F Fly ash:

Fig. 3 shows the SEM image of the GO nanomaterial (0.05% by weight of modified fly ash) within soil plus modified fly ash matrix at 28 days cure, from this image it is clear that GO act as binder material which forms binding action for both soil and fly ash and it act as binder material in order to fill the internal micro crack which helps to increase both strength and durability of newly formed soil matrix.

This is because GO adsorbed cations of fly ash and formed calcium silicate hydrated gel same function for GO react with cement composite [9]. Pozzolanic material binding action is done due to cationic action of GO and fly ash material. From this SEM image, it clears all GO, fly ash and soil formed perfectly bind newly soil matrix which ready to use in various project based on the requirement of their improved mechanical properties.

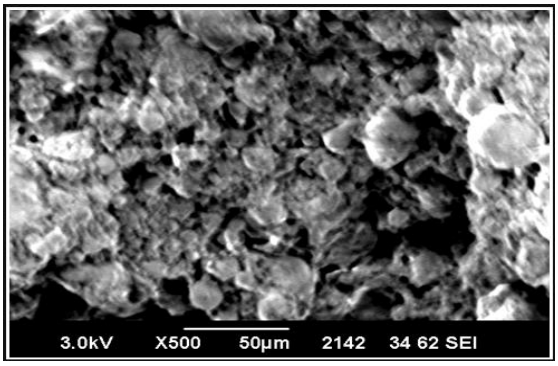

Fig. 3: SEM image (at GO, 0.05%)

B. The responseto GO nano-material on the compaction value:

As there is an increase in GO composition on soil plus modified fly ash composition their response is as shown in the following Fig. 4, It conclude that as GO composition increase it decrease the volume by making it denser assembly also fill the internal pores microcracks and reduce the value of optimum moisture content result to form more compact newly matrix. Such similar trends are reported by previous researchers Pan et al., 2015 and Farzad et al., 2016. From all this work done of present and previous report, we conclude as GO proportion increase it increase the denseness of newly soil matrix with decrease respective value of optimum moisture content for a given assembly.

C. The response to GO material on the plasticity of the soil:

The response of GO material in plasticity index (PI) of the soil plus fly ash assembly was investigated which results are listed in Fig. 5.

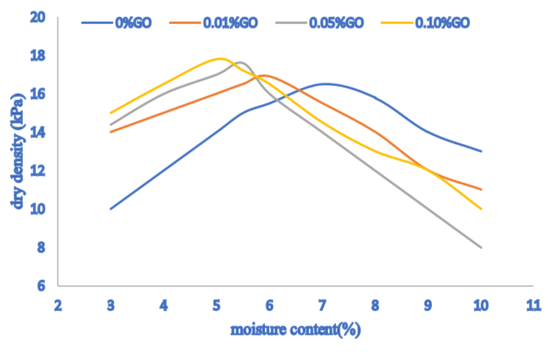

Fig. 4: Compaction test results at different GO%

The response of GO material in Plasticity Index (PI) of the soil plus fly ash assembly was investigated which results are listed in Fig. 5. The Plasticity Index (PI) is defined as the difference between the Liquid Limit (LL) and the Plastic Limit (PL) and indicates the range of moisture contents over which the soil remains plastic. As shown, the increasing content of GO resulted in decreases in all LL, PL and PI values. This is because excess water is utilized by mean of GO solution response in order to form silica hydrated gel to increase bond strength and denser resulted newly soil matrix is resulted to formed.

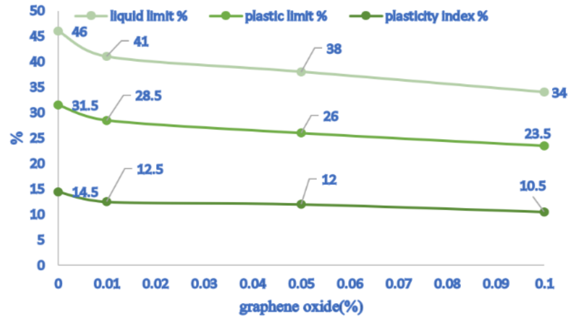

Fig. 5 Liquid and plastic limit test results at different GO%

D. The responseto GO material on the unconfined compression strength (UCS)

As we know that fly ash is pozzolanic material they play a vital role in order to fill the pores gap of any assembly whether it may be cement, concrete, and soil. Hence it reduces the volume and make it more dense structure, When we impart graphene oxide in addition with fly ash in silty soil assembly this graphene oxide helps to fill that gap which may left even after use of fly ash by forming additional internally silica hydrated gel due to chemical reaction between fly ash and graphene oxide solution it also impart more denseness and it also fill internal micro-cracks which initial form during hydration process. In addition to it, graphene oxide may form internally Nano level barrier coating help to retain minerals composition within own newly formed soil matrix and reduce chances of leaching. From the following fig. 6 that graph concludes as we increase the graphene oxide composition even in very small proportion than it imparts unconfined compression strength of soil fly ash matrix in a very fruitful manner.

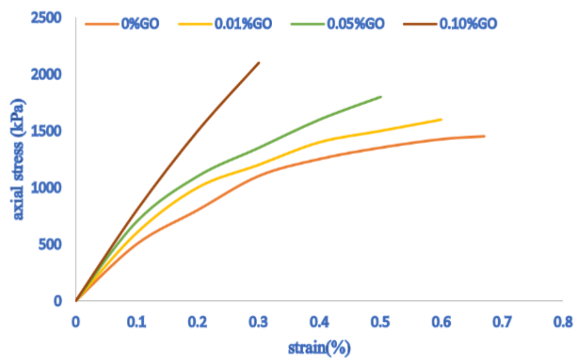

Fig. 6: UCS test results at different GO%

E. The responseto GO material on the shear parameters:

The cohesion (kPa) and internal friction angle (degree) of the soil samples after 28 days curing obtained from linear regression analyses done on the result of each respective already stated proportions of graphene oxide, soil and fly ash for treated soil samples obtained from the direct shear test.

The correlation coefficients are almost equal to unity in the analyses (R^2> 0.98) as shown in figure7. The cohesion and internal friction angle of newly soil matrix increased with increasing graphene oxide content. The increase in cohesion values shown in Fig.8 may be due to the decreasing of voids between the soil and fly ash particles and the formation of denser material. A similar trend is obtained by Farzad et al., 2016. Better filling the gaps between soil-fly ash particles and improved the internal connectivity between silty particles with higher GO content result to provide a more homogenous soil matrix. Therefore, the treated soils response more stiff behavior as compared to untreated soil. A similar trend is obtained by Azzam, 2014.

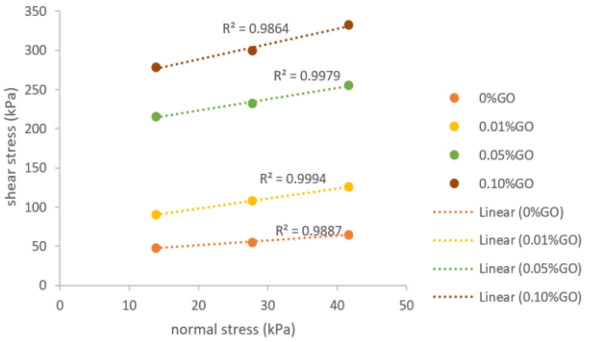

Fig. 7: Direct shear test results at different GO%

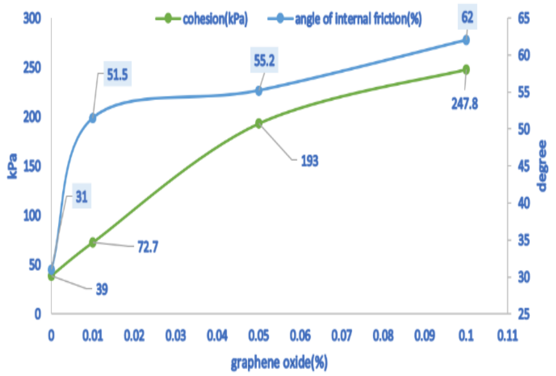

Fig. 8: Shear parameters value at different GO%

V. CONCLUSION

When in original matrix of soil plus modified fly ash we introduce 0.1%GO by weight of modified fly ash, it response the geotechnical properties in the following manner:

- It increases the maximum dry density from 16.5 kPa to 17.8 kPa.
- It decreases the optimum moisture content from 7% to 5%.
- It changes the plasticity index from 14.5 % to 10.5 %.
- It increases the unconfined compression strength after a cure for 28 days at room temperature by approximate 44 % as compared to untreated soil plus modified fly ash matrix.
- It increases the cohesion value after a cure for 28 days at room temperature by approximate 530 % as compared to untreated soil plus modified fly ash matrix.

From SEM image it is clear that there is the formation of dense packing of this newly formed soil matrix due to the filling of residual pores gap in between internal particles of matrix makes it stronger soil matrix used in various projects like road/rail embankment, Dam embankment, airport subgrade foundation treatment etc. effectively. Hence for not only disposing of fly ash in soil but also improve engineering properties of soil very effective manner it required to use such required little proportion of graphene oxide by weight of modified fly ash in raw soil and modified fly ash assembly it gives result in better ways helps to make more eco-friendly mean of execution of civil engineering projects.

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