IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
ISSN: 2278-1684, PP: 60-66
www.iosrjournals.org

GEOTECHNICAL CHARACTERIZATION CEMENT - FLY ASH –FIBERS MIX

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ABSTRACT*:* *The fly ash is a waste produced mostly from the burning of coal in thermal power station which contributes to environmental pollution. It is naturally-cementitious coal combustion by-product. Many studies have been reported in the literature on the performance evaluation of soil – fly ash system as well soil-fly ash-fiber system. Although ample studies have been reported with randomly distributed fibers, relatively less amount of work is found in respect of polypropylene fibers and cement. In view of this, an experimental investigation being undertaken for the performance evaluation of polypropylene fiber-cement-fly ash system is proposed to be reported in Dissertation report. The objective of present investigation is to quantify the optimum quantity of randomly distributed fibers and cement on the performance in terms of unconfined compressive strength especially when it is planned to be used as sub base for foundation and also in highways The results obtained so far reveals that there is significant improvement in the compressive strength with inclusion of randomly distributed fibers. Further it is observed that the optimum moisture content increases and maximum dry density decreases with increase in percentage of polypropylene fibers with stabilized Fly ash.*

Keywords - *Fly ash, cement, polypropylene fibers, unconfined compressive stress, indirect tensile strength*

I. INTRODUCTION

Industrialization and urbanization are the two processes that are going on unabated all over the world. Apart from the advantages realized due to these processes, one has to look into their negative impact on the global environment and on social life. Most important ill effects due to these global processes are:

(i) Production of huge quantum of industrial waste by products and the problems relate with their safe storage and disposal.

(ii) Scarcity of good land and materials for constructional activities which include infrastructure development.

Any well planned developmental activity undertaken by any public/ private sector must consider these two aspects of the core. Due to their inherent limitations, establishing either the large scale hydro-electric power plants or nuclear power plants is receiving lesser priority. Instead, installing the coal based thermal power plants is being encouraged worldwide. The burning of pulverized coal in thermal power plants results in the production of huge quantum of coal ashes, namely- fly ash and bottom ash.

Fly ash is a naturally – cementious coal combustion by product. It is extracted by the preceipitators in the smokestacks of coal burning power plants to reduce pollution. In the advanced country like United States, about 57 million tons of fly ash is generated per year. Overall, only about 33% of the fly ash produced by the combustion of coal is currently reused or recycled, while the remainder is disposed off in landfills.

Since the fly ash disposal problem emerged with the advent of pollution control systems in the 1960's and 1970's, extensive research has been done to understand how it performs in its orthodox capacity – as a soils stabilizers and structural concrete admixtures. Coal is primary source of energy in many countries such as India (about 70%), China (about 80%) and Pakistan (about 63%). At the global level, coal has a share of about 38% to 40% as a source of energy. India is the forth-largest producer of coal in the world after United States, China and Australia.

The power being considered as engine of growth has always been focused area for most of the developing countries, including India. The power generation in India has increased from 1362 MW in 1947 to 120,000 MW during 2004-05. Further Government of India has planned for enhancement of installed capacity to 200,000 MW by 2012 and to 300,000 MW by 2017. Coal being abundantly available has been major source of energy till date and expected to remain so in near future as well. Indian coal, though deficient in sculpture , contains higher amount of ash (about 35 % to 45 %), hence generation of huge quantity of fly ash in India. The annual generation of ash has increased from about 1.0 million tonne in 1947 to about 40 million tonne in 1994 and 112 tonne during 2005. As per the estimation of Fly Ash Utilization Programme (FAUP) the annual figure of fly ash generation is expected to 170 million tonne in 2012 and 225 million tonne by 2017. The residue, commonly called fly ash, that is being produced annually from different thermal power plants is mainly 80% in the form of fly ash and balanced 20% in the form of bottom ash. This needs thousands of hectares of precious land for its disposal causing severe health and environmental hazards also. The environmentally acceptable disposal of this material has become an increasing concern.

Fly Ash

Fly ash is the finely divided residue from the combustion of pulverized coal. Fly ash is produced by coal – fired electric and steam generating plants. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extract heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash or slag, fall to the bottom of the combustion chamber, while the lighter fine ash particles termed fly ash, and remain suspended in the flue gas. Prior to exhausting the flue gas, fly ash is removed by particulate emission control devices, such as electrostatic precipitators or filter fabric bag houses.

Until a decade back, the fly ash would be considered a 'polluting industrial waste' and most of it was being dumped in the ash ponds. Very few utilization areas of fly ash were known and perception of the people about it was negative. Over the period of last 15 year, lot of work has been undertaken with the focused thrust provided by the Fly Ash Mission (FAM), Technology Information, Forecasting and Assessment Council (TIFAC), Department of Science and Technology (DST), Government of India along with other stake holder agencies including various Ministries / Departments of Government of India and States, Public Sector Undertakings, Industry, Research and Development, Academia User agencies etc.

Potential of Fly Ash Utilization

The potential of the fly ash has been understood and brought to the fore, the utilization areas are known earlier have been further strengthened by way of undertaking Technology Demonstration Projects and facilitating multiplier effects, awareness has been created among user agencies through dissemination of information and many more new areas of fly ash utilization have been developed. The fly ashes and its products generated at various locations in the country have been analyzed extensively for various technical parameter s and possible harmful effects. All these efforts have yielded good results and the utilization of fly ash increased from 1.00 million tonne per year to 170 tonne per year in 2012.

Most of the thermal power plants in India are coal based and it is estimated that the generation of fly ash from the coal-fired generation units is expected to reach 170 million tonne per annum by the year 2012. The report of the Fly Ash Utilization Programme (FAUP) reveals that out of the huge quantity of fly ash produced, only about 35% finds its use in commercial applications such as mass concrete, asphalt paving filler, light weight aggregate, stabilizer to road bases, raw material for concrete, additive to soil, construction of bricks, mining stowing etc. The remainder is a waste requiring large disposal areas. This cause a huge capital loss to power plants and simultaneously causing an ecological imbalance and related environmental problems.

Further, quality construction materials are not readily available in many locations and, are difficult to transport over long distances which renders the construction costly. On this backdrop, over last few years environmental and economic issues have stimulated interest in development of many alternative material are used that can fulfill design specifications. In order to utilize fly ash in bulk quantities, ways and means are being explored all over the world to use it for the construction of embankments and roads as fly ash satisfies major design requirements of strength and compressibility except for its susceptibility to erosion and possible liquefaction under extreme conditions. The well established technique of fly ash stabilization by adding cementous materials and reinforcement in the form of discrete fibers caused significant modification and improvement in engineering behavior of fly ash. Fibers are simply added and mixed randomly with soil and fly ash.

One of the most promising approaches in this area is the large scale utilization of fly ash in geotechnical construction like embankments, road sub bases, structural land fill, as a use of fly ash as replacement to the conventional weak earth material and fiber as reinforcement would solve two problems with one effort - elimination of solid waste problem on one hand and provision of a needed construction material on other. Also, this will help in achieving sustainable development of natural resources. Both these problems are becoming acute in urban environment because most of coal fired generating plants are located there and the supply of natural construction material is also becoming scarce.

II. REVIEW OF LITERATURE

There have been many studies reporting to the utilization of fly ash and lime in the stabilization of soil. Some of the prominent investigation available in the literature includes that by Ingles and Metcalf [1], Mitchell and Katti [2], Maher et al. [3], Brown [4] and Edil *et al.* [5].In the nineteen eighties, the researchers started using various types of fibers in the utilization of the waste material in conjunction with the different types of soils in order to improve the strength and /or enhance certain properties thereof. Gray and Ohashi [6] indicated that with the inclusion of discrete fiber, shear strength and ductility increases and post peak strength loss reduces. Along similar lines, many researchers worked on this aspect (Gray and Al-Refeai, [7]; Gray and Maher [8]; Al-Refeai, [9]; Michaowski and Zhao [10]; Ranjan *et al*., [11]; Michaowski and Cermak[12]).Maher and Ho [13] reported consolidated drained triaxial tests in respect of lime- fly ash – fibres mixture.

The studies investigating the performance of sand – fiber mixture or sand- plastic waste includes that by; Chauhan *et al.* [14], Consoli *et al* [15], Sadek *et al.* [16]. Chore *et al*. [17] used sand in conjunction with fly ash. While the investigation reported by Consoli *et al.* [15] used plastic waste as the reinforcing material, polythyelene terephathalate fibers were used in the investigation reported by Consoli *et al*. [15]. Polypropylene fibers were used by Chore *et al.* [17]. Most of the fibers were randomly distributed and in discrete fashion.The performance evaluation of clay- fiber system was reported by Kumar and Tabor [18], Kumar *et al*. [19], Tang *et al.* [20] investigated the performance of clay soil- lime- polypropylene fibers. Apart from the polypropylene fibers, nilon fibers and waste polymer fibers were also used.

Some investigations reported work carried out on soft soil in conjunction with different fibers. Prabhakar and Shridhar [21] worked on soft soil reinforced with bio-organic materials such as sisal fibers. The studies concerning the stabilization of expansive soil such as black cotton soil using lime and/ or fly ash in conjunction with various types of fibers include that by Gosavi *et al*. [22], Ramesh *et al.* [23]. Phani Kumar *et al.* [24] reported investigation on expansive soil stabilized with fly ash. Ravi Shankar and Raghavan [25] reported the investigations on lateritic soils reinforeced with coir fibers.

The studies concerning the utilization of only fly ash along with the fibers are reported by Dhariwal [26], Kaniraj and Gayatri [27]. Apart from this, some of the significant studies that dealt with the system of soil- fly ash- fibers include those by Kaniraj and Havanagi [28], Jadhav and Nagarnaik [29], Day et al. [30] reported the performance evaluation of soil and randomly distributed coir fibers. Kalantri et al. [31] worked on cement stabilized peat samples.

Fly ash is not only the waste material but it is hazardous to human health, too. It is found from above cited literature that the significant amount of work have been reported on the performance evaluation of soil-fly system and soil - fly ash – fiber, cement- fly ash system as well as cement- fly ash- fiber system. Although many studies have been reported with randomly distributed fibers, relatively less amount of work reported in respect of the system of cement- fly ash- polypropylene fibers. Keeping in view some of the gaps in the available literature, an experimental study was undertaken to bring out the strength parameters of fly- ash stabilized with different percentages of cement and polypropylene fibers for different curing periods in respect of soaked and un-soaked conditions.

III. OBJECTIVES AND SCOPE OF THE STUDY

The investigation aimed at quantifying the optimum quantity of fibers and cement on strength parameters which may find potential applications in the diverse field of civil engineering. The specific objective was evaluate the performance of the composite system comprising cement- fly ash- fiber system for the optimum performance in terms of the unconfined compressive strength (UCS) and indirect (Brazilian) tensile strength through an experimental study by using cement as a replacement material for fly ash and varying its (cement) contents along with that of fibers in respect of un-soaked and soaked conditions.In the investigation, the fly ash was replaced by 5%, 10%, 15% and 20% cement. Further, for each of these combinations, fibers contents such as 0.5%, 1% and 1.5% are varied by weight of fly ash. In view of the above, one sample was prepared comprising fly ash only. Further, 16 samples were prepared for curing periods such as 7 and 14 days for both- soaked and unsoaked condition. The soaking period was kept as 10 Hours.

IV. PROPERTIES OF THE MATERIALS

The fresh fly ash to be used in the experimental investigation was provided by *Dirk India Limited, Eklehara, Nasik*, who in turn had obtained it from Nasik Thermal Power Station. The chemical composition and physical properties of the fly ash as supplied by the Suppliers are shown in Table 1.The polypropylene fibers used in investigation were modified virgin polypropylene. The polypropylene fibers are hydrophobic, non-corrosive and resistant to alkalis, chemicals and chlorides. The characteristic of the polypropylene fibers were provided by the suppliers and are given in the Table 2. The cement used in the said investigation comprised of Ordinary Portland

Cement (ACC Cement of 53 Grade) which was made available by *RMC Readymix (India) Pvt. Ltd*. The characteristic of the cement was tested in RMC Readymix laboratory and given in Table 3.

V. EXPERIMENTAL PROGRAMME

The experimental programme comprised of conducting the preliminary tests to arrive upon the index properties of fly ash and unconfined compressive and Brazilian tensile strength tests on stabilized fly ash. Subsequently, the standard proctor tests along with the unconfined compression test and indirect tensile strengths were conducted in the laboratory.

While the liquid limit of the fly ash was found to be 21, it was found to be non-plastic. Before preparation of sample, optimum moisture content (OMC) and maximum dry density (MDD) was determined for sixteen mixes of fly ash, cement and polypropylene fibers using standard proctor test. The quantity of cement and polypropylene fibers were varied for each type mix. It is observed that in respect of un-reinforced fly ash – cement mixture, maximum dry density (MDD) is 1.424 gm/cc. for mix of fly ash and 20% cement while for same mix reinforced with 0.5%, 1.0%, and 1.5% polypropylene fibers the MDD observed as 1.416 gm/cc, 1.432 gm/cc, 1.401 gm/cc. From this it is seen that MDD is less in case of un-reinforced fly ash-cement mixture as compare to reinforced fly ash-cement mixture. Further, the MDD is found to decrease with increase in fiber content.

Table 1: Properties and composition of fly ash

Chemical composition			
Property	**Value**	**Property**	**Value**
Silica (SiO_2)	58.040	Titanium Oxide (TiO_2)	1.30
Alumina (Al_2O_3)	25.71	Magnesium Oxide (MgO)	1.589
Ferric Oxide (Fe_2O_3)	5.31	Sodium Oxide (Na_2O)	0.601
Sulphur Tri Oxide (SO_3)	0.677	Potassium Oxide (K_2O)	0.60
Physical Properties			
Specific Gravity	2.13		
Liquid limit	-		
Shrinkage limit	30.42		
Loss of ignition	1.071		
Moisture (%)	0.267		

Table 2: Characteristics of polypropylene fibers.

Property	Value	Property	Value
Length (mm)	06	Water absorbing capacity	Nil
Specific Gravity	0.91	Tensile Strength	450 Mpa
Elongation	15%	Melting Point (^{0}C)	165
Nature	Inert	Heat Resistance (^{0}C)	<130

Table 3: Characteristics of cement.

Normal Consistency (IS:4031 Part IV)	
Required water for Normal Consistency	110 ml
% of Normal Consistency	27.5 %
Setting Time (IS:4031 Part V)	
Initial Setting Time	150 Min (Minimum 30 Min)
Final Setting Time	225 Min (Maximum 600 Min)
Specific Gravity (IS:4031 Part II)	3.03
Specific Surface (Fineness) (IS: 4031 Part II)	310.83 (Minimum 225 cm^2/gm)
Compressive Strength	
3 Days	27 MPa
7 Days	37 MPa
28 Days	53 MPa

Three identical samples were prepared for unconfined compression strength test (UCS) in UCS cylindrical split mould having diameter 38.1 mm and height 76.2 mm. for each type of mix at their respective OMC and MDD. The samples were kept in desiccators for 7 and 14 days. Thereafter, they were tested for compressive strength. Along similar lines, a cylindrical sample of 60 mm length (diameter) and 30 mm thickness (length) was used for preparation of the samples. The specimens were cured for 7 and 14 days. The cement stabilized fly ash may be subjected to inundation in the field to access the effect of soaking. The Brazilian (indirect) tensile strengths (BTS) were carried out along lines similar to that of UCS. The values of UCS and BTS are given in Table 5.

Table 5: Values of Compressive and Tensile Strengths in kg/cm^2 for different curing periods

S. N.	Cement (%)	Fibers (%)	UCS				BTS			
			7 Days		14 days		7 Days		14 Days	
			US	S	US	S	US	S	US	S
01	05	-	5.50	3.41	11.07	10.05	1.54	0.82	1.80	1.74
02	10	-	17.82	16.48	28.48	26.61	3.29	2.88	3.84	3.49
03	15	-	26.19	22.22	47.44	45.39	6.80	5.75	7.16	6.80
04	20	-	32.06	27.28	65.40	59.21	9.46	7.70	12.91	11.87
05	05	0.5	6.97	4.26	14.46	12.99	2.36	1.81	3.21	2.27
06	05	1.0	13.83	10.06	19.88	16.68	4.32	2.37	4.63	2.80
07	05	1.5	9.77	8.50	12.05	11.06	2.15	1.43	2.97	1.92
08	10	0.5	18.09	16.72	39.05	34.35	5.85	4.54	8.02	6.98
09	10	1.0	19.05	18.03	39.88	34.90	6.32	4.61	8.20	7.16
10	10	1.5	17.98	16.16	36.81	33.40	5.81	4.19	5.76	4.89
11	15	0.5	30.93	25.19	49.28	42.94	7.07	6.63	8.64	6.45
12	15	1.0	31.41	25.78	52.08	50.27	7.21	6.70	9.77	7.68
13	15	1.5	25.96	21.03	48.87	45.34	5.85	4.54	7.33	5.76
14	20	0.5	38.49	36.16	65.60	61.13	12.34	9.08	14.92	11.34
15	20	1.0	39.71	36.65	70.32	68.39	12.48	9.25	15.27	12.04
16	20	1.5	32.99	28.37	63.45	59.02	9.44	7.51	12.65	10.12

VI. DISCUSSION OF THE RESULTS

From the values of the unconfined compressive strength (UCS) obtained in case of 7 and 14 days', it is observed that the both- UCS and BTS, of Fly Ash increases with increase in percentage of the cement. Further, little addition of polypropylene fibers to the cement stabilized fly ash shows an adequate increase in compressive strength. The results indicate that the soaking reduces the compressive strength of fly ash. As the percentage of cement increases the reduction in strength due to soaking reduces. Further, the strength of stabilized fly ash increases as the curing period increases. As regards the effect of fibers, with the increase in percentage of fibers up to 1%, the compressive strength of the fiber also increases. However, when the fiber increases up to 1.5%, the strength is found to reduce.

Effect of cement contents

It is found that the compressive as well as tensile strength of the stabilized mixes of fly ash and cement is found to increase with the addition of cement contents. This is attributed to the increase in the availability of alkali (which is by-product of hydration of cement) for pozzolanic reaction. Further, the rate of gain in the strength is found to be high for higher cement contents. The strength of the cement stabilized fly ash is found on the lower side in respect of the soaking of the samples.

The difference between the UCS in respect of un soaked and soaked specimen when cured for 7 days is observed to be 37% , 7.5% ,15.15% , 16.6% for the samples having 5%, 10%, 15% and 20% cement contents. For 14 days curing period, the corresponding difference is 9.21%, 6.57%, 4.32% and 9.46%, respectively. The corresponding difference for BTS in the context of 7 day's curing is observed to be 47%, 12.5%,15.5% and 18.6% and that in the context of 14 days' curing, 3.33%, 9%, 5% and 6.7%.

Effect of fiber content

The compressive strength of stabilized fly ash-cement mixture varies with addition of randomly distributed polypropylene fibers. In respect of all the mixes cured for 7 and 14 days, the generalized trend that is observed is that the compressive strength is found to increase considerably with the addition of fibers up to 1%. However, thereafter, it is found to decrease when the fiber contents are increased to 1.5%, barring few exceptions. Similar trend holds good for tensile strength as well barring certain exceptions in respect of the mix containing 15% and 20% cement mix for the soaked samples.

Effect of curing period

The effect of curing period on various cement stabilized fly ash mixes with different combinations of cement and fibers fiber contents is examined on the unconfined compressive strengths (UCS) and Brazilian tensile strengths (BTS) of such mixes. The values of the either strengths of all mixes is found to increase in with increase in curing period. The strength is found to be gained rapidly in the beginning; but thereafter, it decreases with further increase in the curing period. However, there are some exceptions. The pozzolanic reaction accelerates during first stage of curing. The higher curing period enhances the compressive as well as tensile strengths of cement stabilized mix of fly ash-fibers.

Effect of soaking

It is observed that there is reduction in either strength of stabilized specimens due to soaking irrespective of mix proportion and curing period. For un-soaked specimen, there is a possibility of suction development in the pore fluid which gives rise to high strength. Soaking the specimens may fill the voids to certain extent and reduces the chances of development of suction in the pore fluid. While soaking, softening of specimens may take reducing the strength. In this investigation, it is observed that the strength is reduced on soaking for 10 hours which implies that the two mechanisms i.e. probability of low suction development in soaked specimens and softening of the specimens have dominated the gain of strength due to pozzolanic reaction in presence of sufficient moisture. Test results of saturated specimens may be used in practice to avoid the assessment of development of suction in partially saturated specimens. The low hydraulic conductivity of the stabilized mix is also beneficial to minimize the loss of strength due to inundation in the field.

IV. CONCLUSIONS

Some of the broad conclusions deduced from the present study are as follows.

i. The stabilization of the fly ash with cement alone or in conjunction with polypropylene fibers is effective in order to enhance the either strength parameter-compression as well as tensile strength.

ii. The strengths (UCS as well as BTS) increase up to 1% fiber in all the mixes and thereafter, it decreases.

iii. The value of the strengths (UCS and BTS) increases with increase in curing period. The rate of gaining the strength in most of the cases are rapid during initial phase of curing, i. e., up to 14 days curing.

iv. The value of strengths (UCS as well as BTS) in respect of un- soaked sample is higher than that in case of soaked sample.

v. At higher curing period such as 14 days considered in the present study, the durability of stabilized fly ash gets improved due to formation of Pozzolanic reaction with the addition of cement.

vi. Both the strengths- compressive as well as tensile- is found to be higher in case of 20% cement contents and corresponding to 1% fiber in case of either samples, i.e., un soaked and soaked, indicating the optimum performance of the mix with 20% cement contents and 1% fibers.

It can be concluded that the waste material such as fly ash can be used effectively in the civil engineering construction. Further, slight addition of the cement in such waste material enhances its performance. Reinforcement of such composite materials with fibers further increases the strength and durability of the fly ash.

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