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Influence of Fly Ash on the Properties of Soil: A Review

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Abstract—*Construction materials are the major components of the civil engineering construction which governs overall economy and safety of structure. These materials should be economical and non-hazardous for the user. To provide such materials is one of the major challenges for the researchers working in this civil engineering area. Now-a-days uses of waste materials are becoming popular. These wastes are generally generated by different industrial and agriculture practices in form of ashes. Due to rapid industrialization energy generation is increasing day by day. This energy generation by numerous power plants cause production of industrial waste. Generation of these wastes is a big threat to our society and environment. So we either have to find ways to dump these wastes safely or to use these wastes in a constructive manner. Industrial wastes have been gaining importance as a geotechnical material in the present days. Different research is done on the behaviour of soil mixed with these industrial wastes to understand the potential of these waste in the improvement of engineering behaviour of soil. It is found from the studies that these industrial wastes can be used as admixture for the improvement of weak or poor soil. It is observed that fly ash altered the soil texture, decrease bulk density, increase water holding capacity, soil porosity, pH, electrical conductivity and organic carbon values of the soil. In this paper the review of different studies, where fly ash is used as admixture for the improvement of engineering properties of soil is presented.*

Keywords*: fly ash, porosity, electric conductivity, bulk density*

1. INTRODUCTION

The rapid increase in the demand for power has led to the usage of large coal-based power stations in India. Nearly 80 thermal power stations in India use bituminous coal and produce about 100 million tons of fly ash per year. The annual production of fly ash from thermal power plants in the world is about 1000 million tons. This poses problems in the forms of land use, health hazards, and environmental dangers. Both in disposal and in utilization, utmost care has to be taken to safeguard human life, wildlife, and such other considerations. The quantity of fly ash produced depends on different factors such as the quality of coal, degree of pulverization, furnace design, changes in coal supply, changes in boiler load, and firing conditions [1, 2]. Only a small fraction of fly ash (10%) is used for applications like the manufacture of bricks, pozzolana cement, and other products, while the remaining bulk quantity of fly ash is simply dumped near the thermal power plants as refuse, consuming precious land. Bulk utilization is possible only in geotechnical applications like embankments, dams, fill behind retaining walls, reclamation fills, and in road construction. Its advantages are low unit weight, high shear strength [3], low compressibility, low specific gravity [4], insensitivity to moisture variation, and pozzolanic properties [5]. The present research work was carried out on roads and embankments where bulk utilization of fly ash is possible. Research work and studies [6, 7] have been carried out to improve the soil strength, and have concluded that the strength of the soil can be improved by the addition of fly ash. But proper mixing of bulk quantities of soils and fly ash may not be practical in the field. The pond ash is coarse and less pozzolonic and hence is not being accepted as pozzolona (Sonawane and dwivedi 2013) so fly ash be used more as comparison to pond ash. It is also the social responsibility of researchers to find the ways to efficiently use the industrial by-products in order to preserve our precious resources, conserve energy and reduce or eliminate the need for disposal of industrial waste in landfills. This Paper highlights the potential of Fly ash in the geotechnical field.

1.1 Fly Ash

Fly Ash is industrial waste product from thermal power plants which uses coal as fuel. It is estimated that 170 million tonnes of fly ash is being produced from different thermal power plants in India consuming 70 thousand acres of precious land for its disposal causing severe health and environmental hazards [28]. There are two major classes of fly ash, class C and class F. The former is produced from burning anthracite or bituminous coal and the latter is produced from burning lignite and sub bituminous coal. Both the classes of fly ash are pozzolans, which are defined as siliceous and aluminous materials [29]. The micro sized fly ash mainly consists of silica, alumina and iron and the particles are generally spherical in size which makes them easy to blend and make a suitable mixture. In order to utilize fly ash inbulk quantities, ways and means are being explored all over the world. One of the methods to mitigate these problems is to recycle the fly ash as a safe construction material. Because of the inherent self-hardening characteristics of fly ash, it finds a potential application in different civil engineering applications. The self-hardening characteristics of a fly ash depend on the free lime present in it. Fly ash with a low percentage of lime is produced by a number of thermal power plants throughout the world. Stabilization with a suitable admixture is one of the promising methods to enhance the strength and durability of the fly ash containing low percentages of lime. In spite of continuous efforts made by the government hardly 5-10% of the fly ash is being used for construction purpose like brick making, cement manufacturing, soil stabilization and as filling material. As the properties of fly ashes vary from place to place, there is a need to check the variability of properties for its effective utilization. Hence, before the utilization of fly ash as a construction material, it is necessary to study properties of fly ash from different sources, so that it can be used beneficially. Physical and chemical properties reported in different studies are presented in Table 1 and Table 2 respectively. It can be further seen in Table 2 that silica content in fly ash is very high. Such high content of silica is reason for the pozzolonic activity up to some extent. Fig. 1 shows the SEM picture of the Fly ash and the shape of particle is found out to be Spherical. Fig.2 shows the particle size distribution of different types of fly ashes. Fig. 3 shows the x ray diffraction pattern of fly ash.

Fig. 1: The Original Picture and SEM Picture of Fly Ash [8].

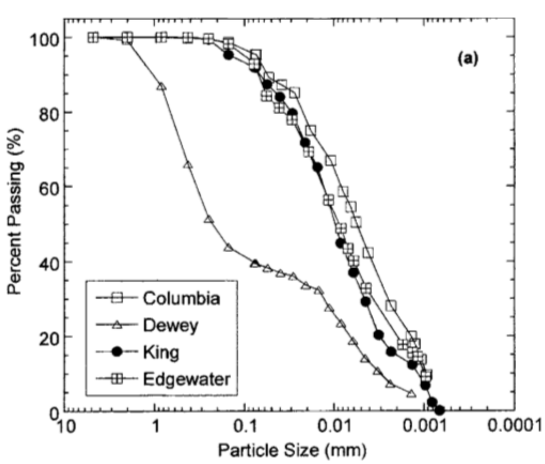

Fig. 2: Particle Size Distributions of the Different Samples of Fly Ashes [9]

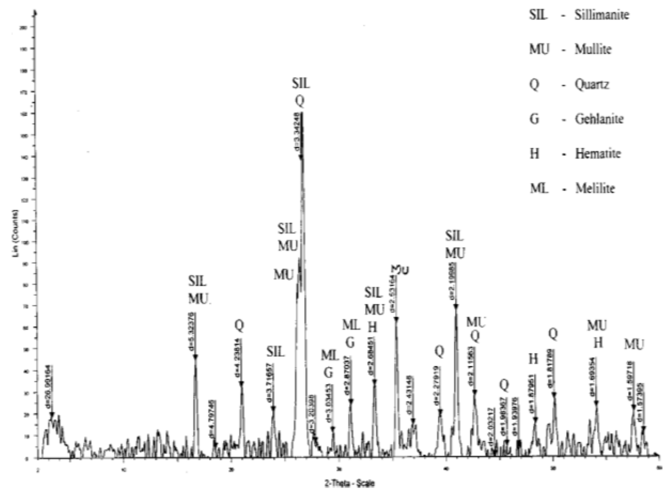

Fig. 3: X-ray Diffraction Pattern of Fly Ash [10]

Table 1: Physical property of Fly Ash [11,12,13]

Property	**Range of Values**
Colour Grey Odour Odourless	
Consistency	
Liquid limit (%) Shrinkage Limit (%)	40-50 38
Plastic limit (%)	Non Plastic
IS Classification	SM
Specific Gravity Specific Surface Area (cm2/g)	2.18-2.64 4020

Table 2: Chemical Property of Fly Ash [12,13]

Constituent	Value (%)
Silica Dioxide (SiO2)	56.7-57.5
Alumina Oxide (Al2O3)	26.10-33
Ferric Oxide (Fe2O3)	4.8-6.2
Calcium Oxide (CaO)	0.5-3.8
Magnesium Oxide (MgO)	0.2-2.3
Sulphur Trioxide(SO3) Titanium oxide (TiO) Pottasium Oxide (KO2) Sodium Oxide (Na2O)	1.6 1.4-2.1 0.4-0.82 0.2-0.68
Loss on Ignition(LOI) Moisture	1.5-1.9 0.3

2. EFFECT OF FLY ASH ON THE SOIL PROPERTIES

Many researchers have conducted different type of experiments to find out the properties of soil mixed with fly ash. Table 3 shows the Geotechnical behaviour of fly ash. The effect of mixing of fly ash on the engineering properties and index properties of soil is explained in the sections presented below.

Table 3: Geotechnical behaviour of Fly ash

Properties	Value
Optimum moisture content (OMC) (%)	31.0-38.2
Maximum dry density (MDD) (g/cc)	11.5-12.6
Co. eff. of uniformity , Cu	1.4-6.3
Co. eff. of curvature, Cc	0.9-1.1
Free Swell Ratio	0.75-1.2
Angle of internal friction	300 – 400
Coefficient of Permeability (cm/s)	8 x 10-6 – 7 x 10-4

2.1 Plasticity Behaviour and Hydraulic Conductivity of Soil

Plasticity of soil depends upon the minerals and the properties of the soil. By mixing of Fly Ash, plasticity behaviour of soil changes with amount of Fly Ash. So when it is mixed, liquid limit (LL), plastic limit (PL), shrinkage limit of clay changes [14,15]. Plasticity index of soil reduces with increase in the content of the fly ash. The index properties of soil are significantly improved for better by the addition of fly ash. Shrinkage limit is increased significantly with the addition of fly ash. This is highly desirable from the view point of volume stability [12]. Change in the liquid limit or plastic limit depends upon the type, particle size distribution and pozolanic reactivity of fly ash and soil [16]. Table 4 shows the variation of the liquid limit and plastic limit of the soil mixed with the Fly Ash content given by different researchers. In Fly Ash particle distribution is dominated by silt content. So, when Fly Ash is mixed with the clay it changes the particle size distribution of the mixture of Fly Ash and clay. The new distribution affects the overall plastic behaviour of soil. Hydraulic conductivity or permeability property of soil is an important criterion for the structures like liners [17]. Hydraulic conductivity of soil depends upon the types of soil and particle size distribution of soil. For clay or fine grained soil hydraulic conductivity is less, while for coarse grained soil it is greater. Well graded soil or the soils with different sizes of particles have less permeability and for poorly graded soil permeability is greater. When Fly Ash is mixed with the soil it changes the distribution of particle sizes of soil, so hydraulic conductivity changes [18].This shows that stabilization of soil with cement and fly ash could lead to better strength and lower permeability thus better durability.

Table 4: Variation of liquid limit and plastic limit with Fly Ash content

Fly Ash content	[12]		[8]		[14]	
	Liquid limit	Plastic limit	Liquid limit	Plastic limit	Liquid limit	Plastic limit
0	84	25.4	170	50	-	-
20	81	33	98	24	-	-
40	76	31.6	73	20	-	-
60	66	32.5	55	18	75.10	51.83
80	56	NP	44	16	45.69	19.83
100	53	NP	40	15	NP	NP

2.2 Compaction behaviour of soil

Compaction behaviour of soil depends upon the type of soil. For coarse grained soil maximum dry density is greater than fine grained soil. While optimum moisture content (OMC) of coarse grained soil is less than OMC of fine grained soil. There is a clear tendency that the maximum dry unit weight increases at 20% fly ash content and then decreases whereas the optimum moisture content decreases gradually with increase in fly ash content [8]. The cause for the reduction in the optimum water content when increasing the fly ash content is because of the cation exchange between additives and expansive soil decreases the thickness of electric double layer and promotes the flocculation. The flocculation of the solid particles implies that the water additives soil mixtures can be compacted with lower water content, and the optimum water content is reduced. The decrease in the optimum water content indicates that expansive soil can be stabilized by adding fly ash even for soils with low water content. The decrease of the maximum dry unit weight with the increase of the percentage of fly ash is mainly due to the lower specific gravity of the fly ash and compared with expansive soil, and the immediate formation of cemented products which reduce the density of the treated soil. Table 5 shows the variation of MDD and OMC with content of RHA. Since specific gravity of fly ash is less, so when it is mixed with the soil, soil changes into lighter material. Because of which MDD of soil decreases with increase in the content of fly ash. Fly ash shows Pozzolonic activity and it has affinity with water. Due to this reason OMC of mixtures increases with increase in the content of fly ash.

Table 5: Variation of MDD and OMC with Fly Ash content

Fly Ash (%)	[19]		[8]		[12]	
	MDD	OMC	MDD	OMC	MDD	OMC
20	15.5	22.5	1.45	24	13.9	30
40	14.6	25.0	1.43	22	13.6	31.1
60	13.9	28.0	1.41	19.57	12.7	33
80	-	-	1.39	17.27	11.8	35.4
100	10.9	45.5	1.38	16	10.6	38.2

2.3 Swelling behaviour of soil

Expansive soils or swelling soils are one of the problematic soils. They have tendency to increase in the volume when water is made available and to decrease in the volume if water is removed due to which cracking takes place. Non expansive soil undergoes large compaction at high water content [20]. There are different techniques like replacement of expansive soil, modification of soil and use of foundation like belled piers, under reamed piles are generally adopted by Geotechnical engineers. Use of admixtures of the modification of the property of swelling soil is one of the ground improvement techniques. Fly ash has also potential to suppress the swelling behaviour of soil. The swell pressure is largely decreases due to the effect of fly ash and the reduction factors increases as curing time increases [22, 27]. Due to non-expansive characteristics of fly ash, and the particle size and shape of fly ash, leads to the conclusion that the swelling behaviour of the soil can be effectively controlled by the addition of fly ash[21, 22, 23].

2.4. Strength of soil

Strength of soil increases with increases in the amount of cementious material. Fly Ash have shown the cementaneous properties. Fly Ash has silica contents, which shows the pozzolonic reaction. The pozzolonic reaction increases the cementenious quality in the soil. The results reveal that the proper proportions of soil and fly ash improves the CBR values [24]. CBR value also increases with increase in the Fly Ash amount [24, 25]). Variation of CBR value with Fly Ash content given by [13,8] is presented in Table 6. It shows that load carrying capacity of Fly Ash mixed clay increases. The addition of fly ash to soil results in significant improvement in the CBR due to the pozzolanic effect and fly ash can be used as a base material due to its higher CBR. Curing of (high calcium) fly ash soil mixes results in significant improvement in the CBR and hence soil can be used in bulk in combination with fly ash in pavement construction [24]. The mechanical properties such as strength (compressive, tensile and flexural), modulus of elasticity and CBR are considerably enhanced with addition of fly ash [26].

Table 6: Variation of the CBR with the Fly Ash content

Fly Ash content	[13]		[8]	
	Unsoaked	Soaked	Unsoaked	Soaked
0	7	1.4	7.42	1.54
20	10.3	3.5	16.35	1.75
40	9.3	2.0	4.99	1.13
60	7.4	1.7	6.44	0.99
80	15.6	3.9	10.37	1.19
100	8.8	3.0	7.00	0.65

3. CONCLUSIONS

This Review Paper Briefly discussed the effect of Fly Ash on the behaviour of soil mixed with the Fly Ash. For the sake of protecting the environment and the better utilization of the industrial waste material for geotechnical purposes it is important to understand its impact on the behaviour of soil. It is found out that the shape and size of the Fly Ash, particle size distribution, Physical Properties, chemical constituents etc. are mainly affecting the geotechnical properties of mix. Yet further Research is required to understand the mechanism and potential of fly ash with different type of soil for the improvement of behaviour and properties of soil. Fly ash has good potential for use in geotechnical applications. The relatively low unit weight of fly ash makes it well suited for placement over soft or low bearing strength soils. Its low specific gravity, freely draining nature, ease of compaction, insensitiveness to changes in moisture content, good frictional properties, etc. can be gainfully exploited in the construction of embankments, roads, reclamation of low-lying areas, fill behind retaining structures, etc. The effective utilization of fly ash, on the one hand, proves to be an effective admixture for improving the soil quality and, on the other hand, affords a means of disposal of the industrial by product without adversely affecting the environment.

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