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Effect of fly ash and different lengths of polypropylene fibers content on the soft soils

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Abstract

The total coal and lignite consumption of the thermic power plants in Turkey is approximately 55 million tons and nearly 15 million tons of fly ash is produced. The remarkable increase in the production of fly ash and its disposal in an environmentally friendly manner is increasingly becoming a matter of global concern. Studies for the utilization of fly ash in Turkey are necessary to reduce environmental problems and avoid economical loss caused by the disposal of fly ash. Efforts are underway to improve the use of fly ash in several ways, with the geotechnical utilization also forming an important aspect of these efforts. An experimental program was undertaken to investigate the effects of Multifilament (MF19average) and Fibrillated (F19average) polypropylene fiber on the compaction and strength behavior of CH class soil with fly ash in different proportions. The soil samples were prepared at three different percentages of fiber content (i.e. 0.5%, 1% and 1.5% by weight of soil) and two different percentages of fly ash (i.e. 10% and 15% by weight of soil). A series of tests were prepared in optimum moisture content and laboratory unconfined compression strength tests, compaction tests and Atterberg limits test were carried out. The fiber inclusions increased the strength of the fly ash specimens and changed their brittle behavior into ductile behavior.

Keywords: *Fly ash-reinforced soil, Fiber-reinforced soil, Polypropylene fibers.*

1. Introduction

Fly ash is one of the most extensive waste materials from the manufacturing industry and is continuously being created due to the increase in energy, utilities and infrastructure in urban areas. Coal burning electric utilities worldwide annually produce millions of tons of fly ash as a waste/by-product and the environmentally acceptable disposal of this material has become an increasing concern. Fly ash is waste material imposing hazardous effect on environment and human health. Also, it cannot be disposed of properly and its disposal is not economically viable but if it is blended with other construction materials like clayey soil then it can be used best for various construction purposes like subgrade, foundation base and embankments.

Also quality construction materials are not readily available in many locations and are costly to transport over long distances. Hence, over the last few years, environmental and economic issues have stimulated interest in development of alternative materials that can fulfill design specifications.

The established techniques of soil / fly ash stabilization by adding cement, lime and reinforcement in form of discrete fibers cause significant modification and improvement in engineering behavior of soils/ fly ash. Fibers are simply added and mixed randomly with soil and fly ash [1]. Due to the high volume of material it requires, the construction industry is often looked upon as a potential consumer of fly ash and studies on the utilization of fly ash and lime for soil stabilization have been undertaken by many investigators, e.g. Mitchell and Katti [2], Maher et al. [3], Consoli et al. [4].

The physical and chemical mechanisms of both the short- and long-term reactions involved in the lime stabilization of soils or soil–fly ash mixtures have been extensively described by Ingles and Metcalf [5] and Brown [6] Edil et al. [7] indicated the effectiveness of fly ash for the stabilization of fine grained soils.

Maher and Ho [8] indicated that an increase in the strength and toughness of kaolinite fibre composite was a function of fibre length and content, and water content. They suggested the contribution of fibres to peak compressive strength was reduced and ductility increased with increasing fibre length. Consoli et al. [9] reported that inclusion of fibre glass in silty sand effectively improves peak strength and Consoli et al. [10] indicated that the inclusion of polyethylene terephthalate fibre in fine sand improves both peak and ultimate strengths, which are dependent on fibre content. Kumar and Tabor [11] studied

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the strength behavior of silty clay with nylon fibre for varying degrees of compaction. Soil reinforcement is the process of improving the engineering properties of the soil and thus making it more stable. The effect of the inclusion of polymer fibre in plain fly ash was studied by Chakraborty and Dasgupta [12] who conducted tri-axial tests and found an increase in friction angle for fibre contents ranging from 0 to 4% by weight of fly ash with a constant fibre aspect ratio of 30. Kaniraj and Havanagi [13] conducted a study on a soil–fly ash mixture reinforced with 1% polyester fibres (20 mm length) and demonstrated the combined effect of fly ash and fibre on the soil and indicated that the fiber inclusion s increase the strench of raw fly ash-soil speciments as well as that of the cement-stabilized speciments and change brittle behavior to ductile behavior. Kaniraj and Gayatri [14] indicated that 1% polyester fibres (6 mm length and 313aspect ratio) increased the strength of raw fly ash and changed the mode of failure from brittle to ductile. Dhariwal [15] carried out performance studies on the California bearing ratio values of fly ash reinforced with jüte and non-woven geo fibres. Bearing in mind the gaps in the available literature and the limited studies on behavior of fibre reinforced soil–fly ash mixtures, the study was undertaken to identify and quantify the influence of fibre variables on the engineering behavior of soil–fly ash mixtures.

Fibre inclusions cause significant modification and improvement in the engineering behavior of soils. A number of research studies on fibre-reinforced soils have recently been carried out using tri-axial, unconfined compression, CBR, direct shear and tensile and flexural strength tests [16], [17], [18], [19], [20], [21], [22], [9], [10], [16], [17].

Jadhao and Nagarnaik [18] studied the influence of polypropylene fibers on the engineering behavior of soil fly ash mixtures by using different fiber lengths in the range of 0-1.5% by dry wet of soil and observed that maximum improvement in strength was achieved at a fiber length of 12 mm with fiber content of 1%. Consoli et al. [9] carried out drained triaxial compression tests to study the individual and combined effects of cement stabilization and randomly oriented fibre inclusions on the behavior of silty sand. Consoli et al. [9] conducted unconfined compression tests, splitting tensile tests, and saturated drained triaxial compression tests to evaluate the benefit of utilizing randomly distributed polyethylene fibres obtained from plastic wastes, alone and combined with rapid hardening portland cement, to improve the engineering behavior of uniform sand. Kumar et al. [17] found that the unconfined compressive strength of highly compressible clay increases with the addition of fibres and further increases when fibres are mixed in clay sand mixtures.

Chakraborty and Dasgupta [12] studied the strength characteristics of fibre-reinforced fly ash by carrying out laboratory triaxial shear tests. The fly ash was collected from the Kolaghat thermal power station in India. Kaniraj and Havanagi [13] studied the behavior of cement-stabilized fibre-reinforced fly ash–soil mixtures. They mixed Indian fly ash with silt and sand in different proportions. The study showed that cement stabilization increases the strength of raw fly ash-soil specimens. The fibre inclusions increased the strength of raw fly ash–soil specimens as well as that of cement-stabilized specimens and changed their brittle behavior to ductile behavior. They further concluded that the combined action of cement and fibres is either more than or nearly equal to the sum of the increase caused by them individually [17].

The behavior of fiber reinforced sand has been studied by a number of researchers in recent years (Ahmad et al. [19], Diambra et al. [20], Ibrahim et al. [21], Lovisa et al. [22], Sadeket al. [23], Falorca and Pinto [24], Liu et al. [25], Gao and Zhao [26], Ibrahim et al. [27], Li and Zornberg [28], Najjar et al. [29], Plé and Lê [30], Tang et al. [31]). These studies showed that adding fiber to sandy soil results in greater peak shear strength and more ductile behavior.

The studies investigating the performance of sand–fiber mixture or sand- plastic waste includes that by; Chauhan et al. [32], Consoli et al [33], Sadek et al. [34]. Chore et al. [35] used sand in conjunction with fly ash. While the investigation reported by Consoli et al. [33] used plastic waste as the reinforcing material, polythyelene terephathalate fibers were used in the investigation reported by Consoli et al. [33]. Researchers such as Park [36], and Consoli et al. [37] [38] also studied the behavior of cemented sandy soil with and without fiber reinforcement, and concluded that inclusion of fibers causes an increase in the strength of samples.

Dos Santos et al. [39] performed high pressure isotropic compression tests on cement-fiber reinforced sand and investigated the hydrostatic compression behavior of this type of geomaterial. Further studies have been performed on fibere cement stabilized sands (Onishi et al. [40], Consoli et al. [38] [41], Estabragh et al. [42]).

A number of research studies have demonstrated that the inclusion of fibre results in significant modifications and improvement in the engineering behaviour of soils. Typically, multifilament (MF19average) and fibrillated (F19average) polypropylene fibre are added and mixed with soil or fly ash. One of the primary advantages of fibres is the absence of potential planes of weakness that can develop parallel to oriented reinforcement.

In this study, samples which are mixed with fly ash, multifilament with average length of MF19 average (6, 12, 24 and 34 mm) and fibrillated polypropylene with average length of F19 average (6, 12, 24 and 34 mm) were prepared to improve on unfavorable properties of the soil such as low strength, bearing ratio and compaction. The paper examines the effect of multifilament (MF19 average) and fibrillated (F19 average) polypropylene fibre content on the geotechnical behaviour of clayey soil–fly ash mixtures. The purpose of this investigation was to identify and quantify the influence of fibre variables on the performance of fibre-reinforced soil–fly ash specimens. The paper discusses the geotechnical laboratory tests carried out with varying polypropylene fibre content.

2. Materials and Experimental Program

The soil samples used in the present experimental tests were obtained from Suşehri-Koyulhisar, northeast of Sivas, where there is a high risk of landslides (Figure 1). The soil was air dried and broken into pieces in the laboratory.

Fig. 1 Location map of the calyyey soils used

A characteristic X-ray diffraction plot of the soil shown in Figure 2 indicates that the soil was predominantly illite (with swelling potential) and lesser amounts of kaolin, quartz and feldspar. The physical properties of the soil used in the investigation are summarized in Table 1. The soils were classified as belonging to the high plasticity CH group (USCS classification). The grain size distribution of the fly ashes and soil samples is given in Figure 3.

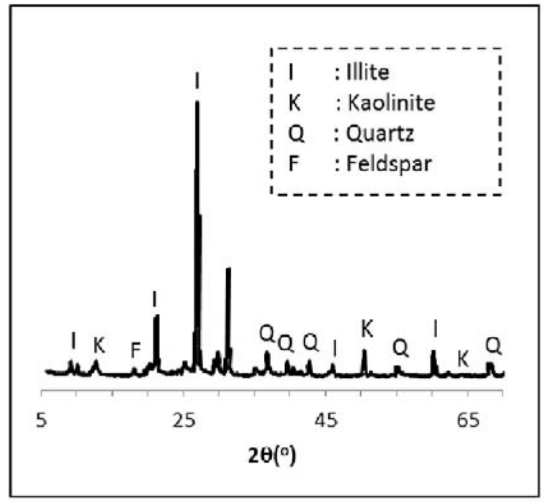


Fig. 2 Characteristic XRD graph of clayey soil used.

Table 1 Engineering properties of clayey soil used in the study

Property	Clayey soil
Gravity	2.81
MDUW*	1320 kg/m^3
OWC*	35.80 %
USCS	CH
AASHTO	A-7-6
Gravel	2 %
Sand	8 %
Silt	11 %
Clay	79 %
Liquid limit	81.95 %
Plastic limit	26.55 %
Plasticity index	55.40 %
Specific surface area, A_c	0.71

MDUW: Maximum. Dry Unit Weight

OWC: Optimum Water Content

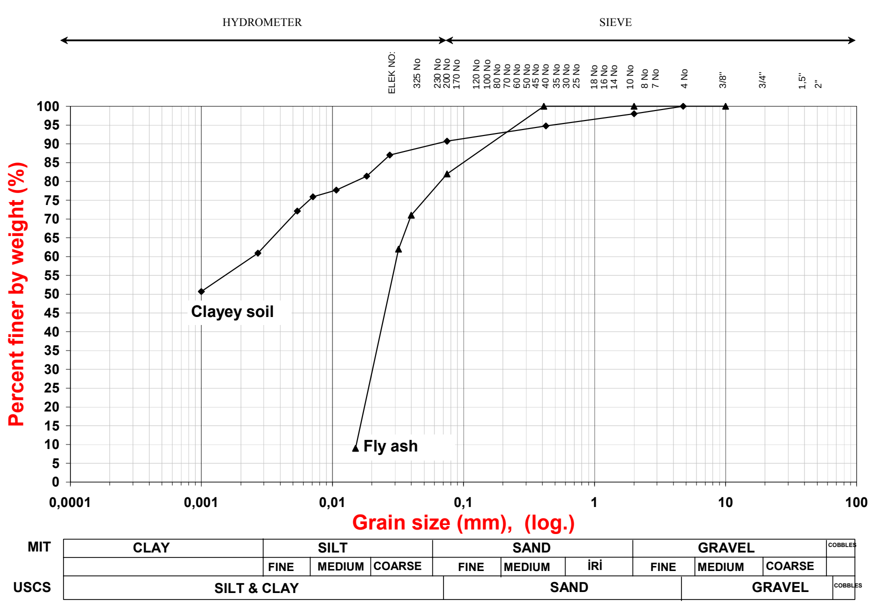


Fig. 3 Grain size distribution curves of fly ash, clayyey on the base of sieve and hydrometer analysis.

Fly ash is defined as the mineral matter extracted from the flue gases of a furnace fired with coal. Fly ash consists of often hollow spheres of silicon, aluminum and iron oxides, and unoxidized carbon. It can be regarded as non-plastic fine silt according to the Unified Soil Classification System. The composition of fly ash varies considerably depending on the nature of the coal burned and the characteristics of the power plant [43]. As fly ash is a pozzolanic material (siliceous or siliceous and aluminous) its engineering behavior can be improved by the addition of cement or lime [17]. In the study, the fly ash was obtained from the industrial waste from the Kangal thermal power station in Turkey which produces some 4 million tons of fly ash from lignite coal each year.

The physical and chemical properties of the Kangal fly ash are given in Table 2. It is a high calcium fly ash with a lime content of 16% which which is classified as Class C according to ASTM C618. Its self cementing characteristics make it an inexpensive source of high quality soil stabilizing agent. Selected examples of X-ray diffraction traces of feed coal, fly ash and bottom ash and SEM microphotographs of minerals and amorphous components in the fly ashes are given in Figure 4-5.

Table 2 The physical and chemical properties of fly ash

Composition	Kangal fly ash	Composition	Kangal fly ash
Type	Class C or high lime fly ash	Loss of ignition	2.15
SiO_2 (S)	33.14	Free CaO	6.35
Al_2O_3 (A)	14.70	Reactive silicous	28.85
Fe_2O_3 (F)	4.32	Reactive CaO	25.60
S+A+F	52.16	Density (g/cm^3)	2.24
CaO	35.18	Dry loose unit weight (g/cm^3)	0.81
MgO	1.18	Amount retained on 90 μm sieve (%)	28
SO_3	7.85	Amount retained on 45 μm sieve (%)	52
		Pozzolanic activity (TS EN 450, 1998)	
K_2O	0.92	(%) 7D	72
Na_2O	0.58	(%) 28D	78
Na_2O equiv.	1.19		

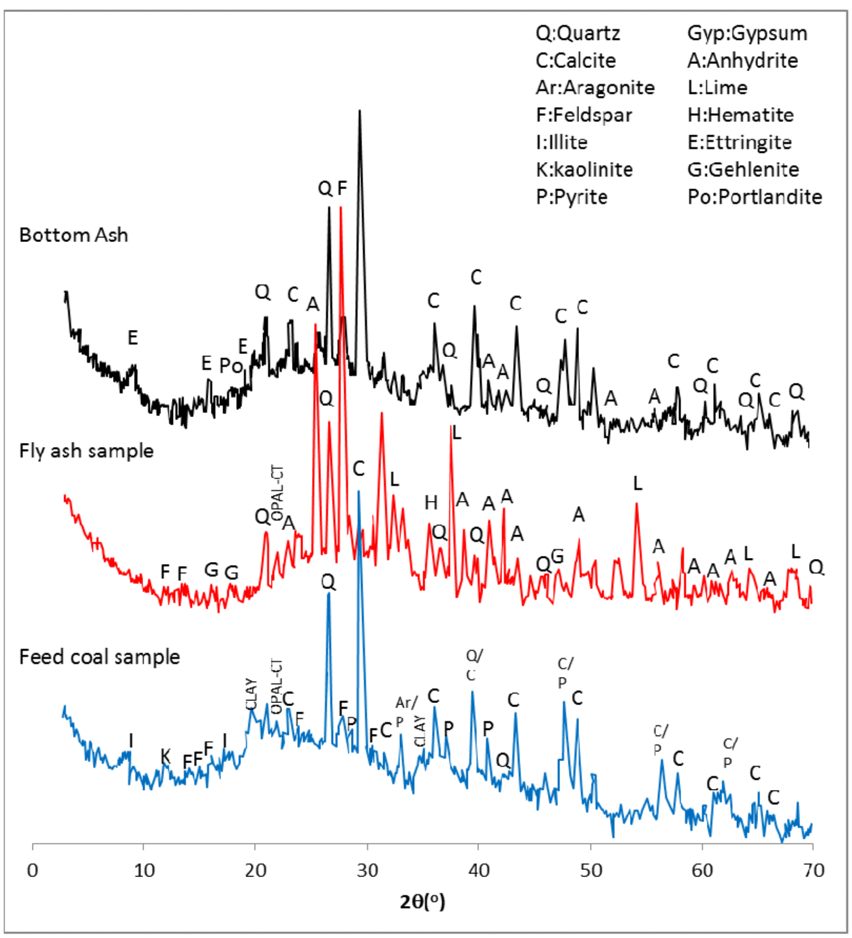


Fig. 4 Selected examples of X-ray diffraction traces of feed coal , fly ash and bottom ash from the Kangal power plant, Turkey.

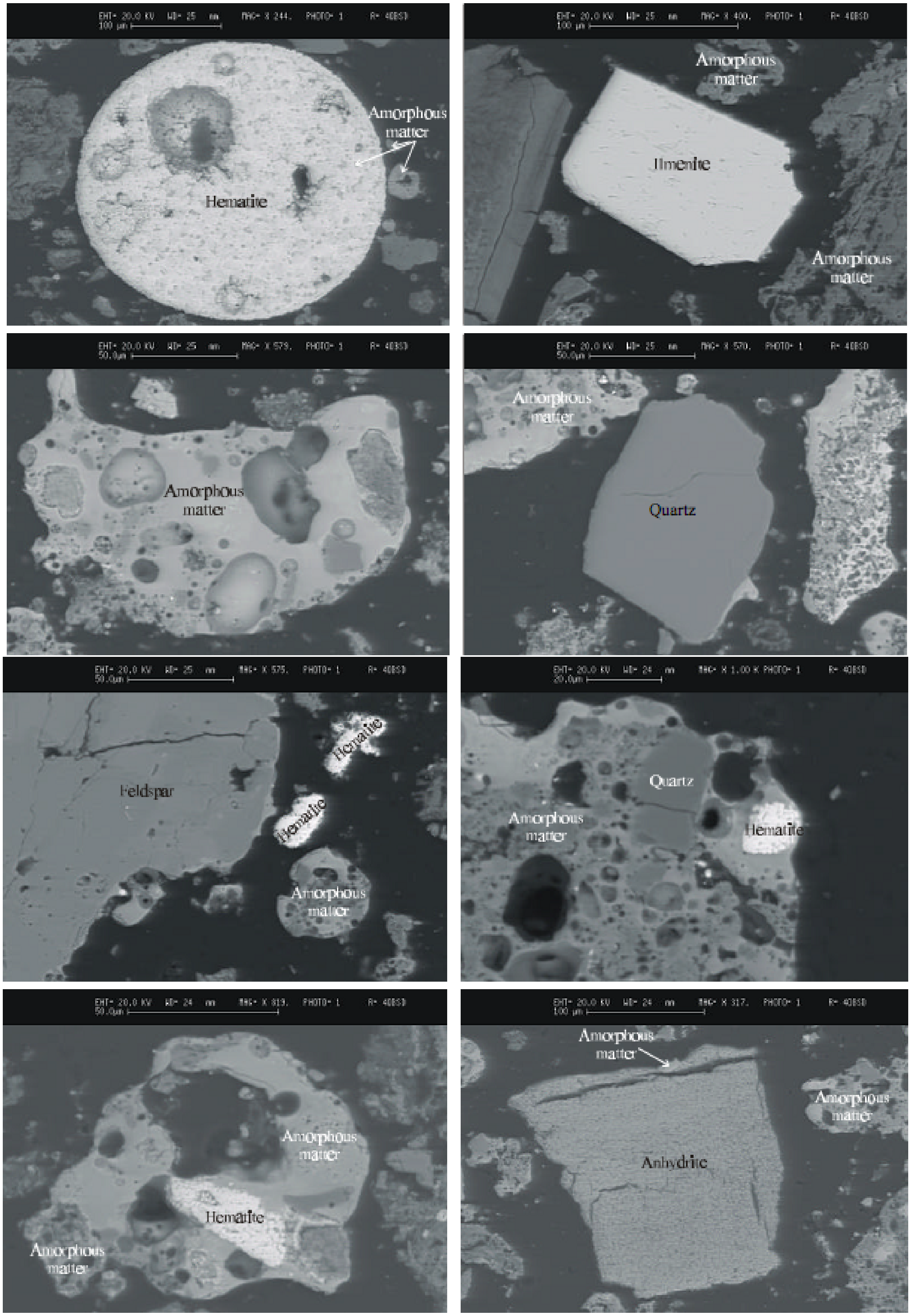


Fig. 5 Selected SEM images of fly ash from the Kangal power plant, Turkey [27]

Polypropylene fibre is the most common synthetic material used to reinforce concrete and soil. The primary attraction is that of low cost [45] and ease of mixing with soil. There are different kinds of synthetic fibers, for example, nylon, polyester, multifilament polypropylene, and aramid fibers are very soft and fine, whereas monofilament and fibrillated film polypropylene fibers are coarse, stiff, and usually brightly colored. In this study, two types of fibres including fibrillated polypropylene fibre (F19average) and multifilament fibre (MF19average) were used to evaluate their potential to enhance the CBR characteristics of clayey soil. The fibres were supplied by Polypropylene Fibre Industry in Istanbul, Northwest Turkey. Photographs are presented in Figure 6 and their properties in Table 3. The fibre content used was 0.5 %, 1% and 1.5%, by dry weight of soil.

Fig. 6 Multifilament fibers and fibrillated polypropylene fibers used in this study (as supplied by the manufacturer)

Table 3 Table Properties of polypropylene fibers used (as supplied by the manufacturer)

Type and Composition	Polypropylene Fiber	
Fiber Type	Multifilament (MF)	Fibrile (F)
Standard	ASTM C-1116-1997 Type III	ASTM C-1116-1997 Type III
Length	6-12-24-34 mm	6-12-24-34 mm
Tenacity	7.0 grams/denier	6.0 grams/denier
Tensile Strength	700 N/mm^2	400 N/mm^2
Young's (Elasticity) Modulus	3.500 N/mm^2	2.600 N/mm^2
Breaking elongation	% 20	% 15
Density	0.91 grams/cm^3	0.91 grams/cm^3
Color	Transparent	Transparent
Softening Point	150 Celcius	150 Celcius
Melting Point	160 Celcius	160 Celcius
Acid Resistance	Stable	Stable
Alcali Resistant	Stable	Stable
Ultraviolet Resistance	Optional	Optional

3. Scope of Present Study

The geotechnical characteristics of fly ash-soil specimens mixed with as 0.5 %, 1% and 1,5%, by dry weight of soil oriented fibres were investigated. The mix proportions can be from the following equations:

$$\rho_u = \frac{W_{fly\,ash}}{W_{mix.}}, \quad \rho_f = \frac{W_{fibrilated\,fiber}}{W_{mix.}}, \quad \rho_{mf} = \frac{W_{multiflament\,fiber}}{W_{mix.}} \qquad (1)$$

Where; ρ_u, ρ_f, ρ_{mf}; proportions of fly ash and Polypropylene fibre by dry weight of soil (respectively M19 average and F19 average) $w_{fly\ ash}$, $w_{fibrilated\ fibre}$, $w_{multiflament\ fibre}$; dry weight, w_{mix} ; total weight

Combination of fibre and fly ash in clayey soil as follows;

a) Fly ash is added to the clayey soil in the proportion 0, 10 and 15% by dry weight of soil.

b) Fibrillated fibre is added to the soil/fly ash mix in

the proportions 0.5, 1.0 and 1.5% by total weight
c) Multifilament fibre is added to the soil/fly ash mix in the proportions 0.5, 1.0 and 1.5% by total weight
More detail can be seen in the Table 4.

Table 4 Detail of Fly Ash-Soil-Fiber Mixtures for Tests Conducted

Combination		Soil (%)	Fly Ash (%)	Fiber (%)	MDUW (kg/m^3)	OWC (%)	CBR average	CBR rate of increase
SO	SOIL	100	0	0	1320.00	35.80	0,47	1
SOFA10	SOIL+ FLY ASH 10 %	90	10	0	1281.35	38.63	6,16	13,11
SOFA15	SOIL+ FLY ASH 15 %	85	15	0	1238.05	40.85	13,47	28,65
SOFAFB1.5	SOIL+ FLY ASH 0 % + FB 1.5 %	98,5	0	1,5	1265,97	34,45	2,7657	5,88
SOFAFB1	SOIL+ FLY ASH 0 % + FB 1 %	99	0	1	1288,1	35,3	3,2372	6,89
SOFAFB0.5	SOIL+ FLY ASH 0 % + FB 0.5 %	99,5	0	0,5	1287,7	34,88	3,2947	7,01
SOFAMF1.5	SOIL+ FLY ASH 0 % + MF 1.5 %	98,5	0	1,5	1271,4	34,8	1,978	4,21
SOFAMF1	SOIL+ FLY ASH 0 % + MF 1 %	99	0	1	1292,5	36,31	2,3172	4,93
SOFAMF0.5	SOIL+ FLY ASH 0 % + MF 0.5 %	99,5	0	0,5	1286,29	35,79	2,2195	4,72
SOFA10FB1.5	SOIL+ FLY ASH 10 % +FB 1.5 %	88,5	10	1,5	1248	37,55	15,116	32,16
SOFA10FB1	SOIL+ FLY ASH 10 % +FB 1 %	89	10	1	1268,81	38,09	18,078	38,46
SOFA10FB0.5	SOIL+ FLY ASH 10 % +FB 0.5	89,5	10	0,5	1283,14	37,91	22,298	47,44
SOFA10MF1.5	SOIL+ FLY ASH 10% +MF 1.5 %	88,5	10	1,5	1245,12	37,11	18,434	39,22
SOFA10MF1	SOIL+ FLY ASH 10 % +MF 1 %	89	10	1	1262,63	37,67	21,717	46,21
SOFA10MF0.5	SOIL+ FLY ASH 10 % +MF 0.5	89,5	10	0,5	1272,42	37,83	23,925	50,91
SOFA15FB1.5	SOIL+ FLY ASH 15% +FB 1.5 %	83,5	15	1,5	1243,29	37,62	27,651	58,83
SOFA15FB1	SOIL+ FLY ASH 15% +FB 1 %	84	15	1	1245,65	38,91	27,513	58,54
SOFA15FB0.5	SOIL+ FLY ASH 15% +FB 0.5 %	84,5	15	0,5	1251,4	39,24	29,307	62,36
SOFA15MF1.5	SOIL+ FLY ASH 15% +MF 1.5 %	83,5	15	1,5	1229,47	38,67	23,327	49,63
SOFA15MF1	SOIL+ FLY ASH 15% +MF 1 %	84	15	1	1248,15	39,36	27,933	59,43
SOFA15MF0.5	SOIL+ FLY ASH 15% +MF 0.5 %	84,5	15	0,5	1256,05	39,21	29,980	63,79

$CBR_{\text{rate of increase}} = CBR_{\text{average}} / CBR_{\text{unreinforced}}$
FB:Fibrillated polypropylene fiber, MF: Multiflament polypropylene fiber

4. Test Results and Discussion

4.1. Compaction tests

The soils were compacted using the standard 2.5 kg Proctor and the 4.5 kg heavy rammer (ASTM D698). Optimum water content (OWC) and maximum dry unit weight (MDUW) of clayey soils are shown in Table 4. Figures 7 and 8 show the variation in maximum dry density and optimum moisture content for the different proportions of fly ash-soil-fibre mixtures.

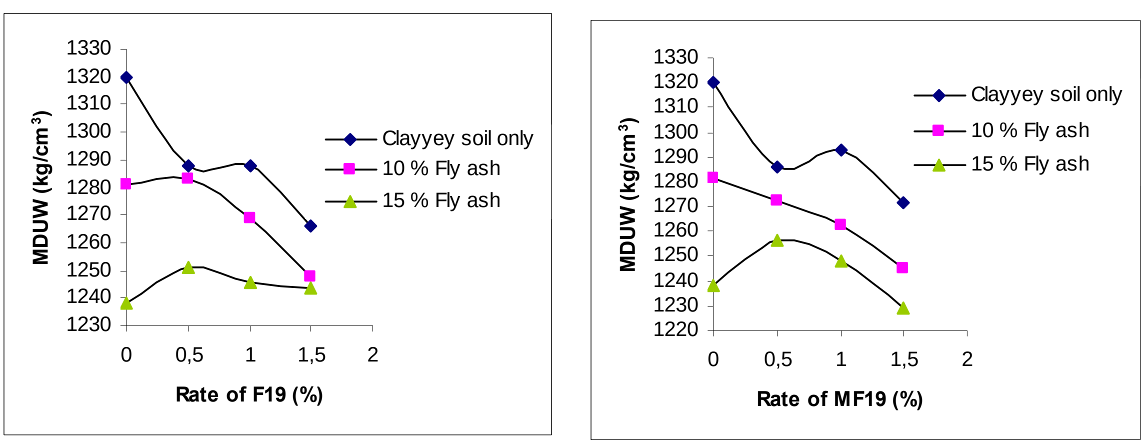


Fig. 7 The variation of maximum dry unit weight

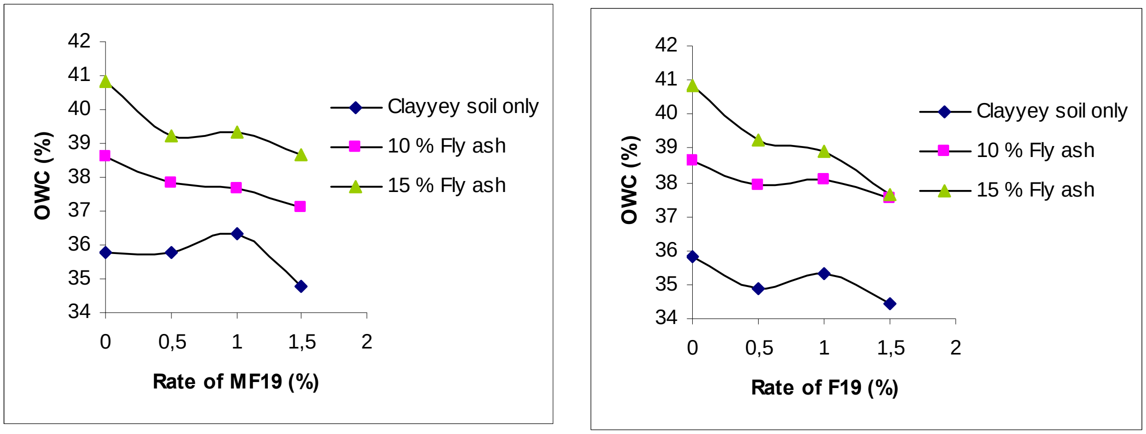


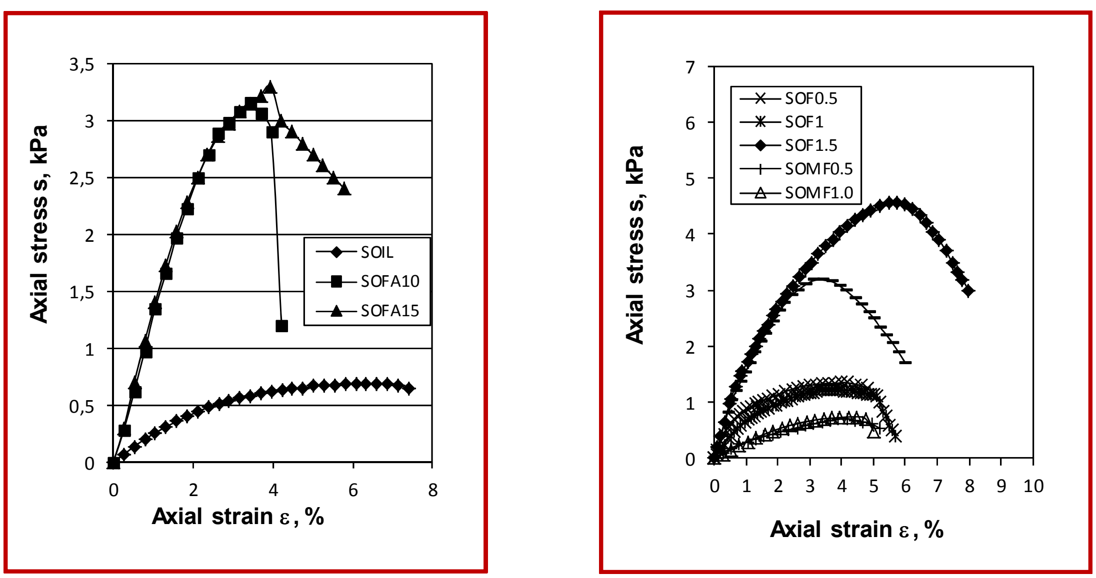
Fig. 8 The variation of optimum water content

The results indicate that with an increase in fly ash, the MDUW of the mixes decreases and the OWC increases. With the addition of fly ash, there is further decrease in MDUW and increase in OWC. The presence of fly ash having a relatively low specific gravity may be the cause of this reduced dry density. The increase in OWC can be attributed to the increasing amount of fines which require more water content because of their larger surface area. The results of compaction tests showed that fibres had a lowering effect on the MDUW and OWC of fly ash–soil–fibre mixtures. This is somewhat different from the trend observed by Setty and Rao [46] who reported that both MDUW and OWC increase with increase in fibre content in silty sand mixed with polypropylene fibres.

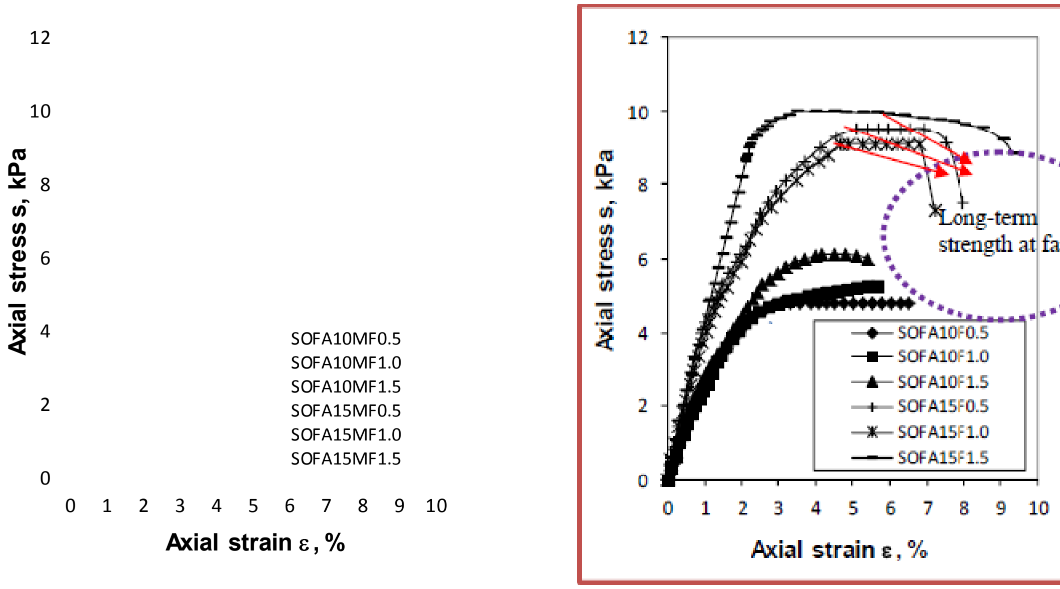
The addition of fly ash to the soil caused a significant reduction in MDUW and an increase in OWC. However, with the addition of fibre both the MDUW and OWC decrease. In the other soil–fly ash mixture, MDUW decreases with increase in the fibres. Typical values of MDUW and OWC for the different soil–fly ash mixtures with various fibre contents are presented in Figs. 7 and 8.

4.2. Unconfined compression tests

As discussed above, a minimum of three specimens were prepared for each combination of variables and tested at a deformation rate of 0.264 mm/min. Figure 9 shows typical stress–strain curves for the fly ash–soil–fibre specimens. The fibre with fly ash inclusions had a significant effect on the stress–strain behavior. The fly ash specimens attained a distinct axial failure stress at an axial strain of about 3.5–4.0% following which they collapsed; but, the fibre reinforced specimens exhibited a highly ductile behavior. The specimens mixed with average of 19 mm fibres attained a peak axial stress at a relatively higher axial strain than the fly ash specimens and then they continued to deform under declining axial stress. Thus, inclusion of the fibres seems to have an important influence on the behavior of the specimens. The unconfined compressive strength was taken as the peak stress or the axial stress corresponding to 15% [47] [48] axial strain if no peak stress was discernible.



(a) (b)



(c) (d)

Fig. 9 Stress–strain curves: (a) stabilized soil with varying fly ash content; (b) fiber-reinforced unstabilized soil with varying fiber content; (c)) fiber-reinforced stabilized soil with 10% ,15 % fly ash and varying fibrillated fibers content; (d) fiber-reinforced stabilized soil with 10% ,15 % fly ash and varying multifilament fibers content

A minimum of three specimens were prepared for each combination of variables and tested according to ASTM D 2166. As seen in Figure 9, fibre inclusion enhanced the peak stress of unstabilized soil, although the proportion was less significant. It can also be seen that fibre-reinforced unstabilized soil exhibits more ductile behavior and smaller loss of post-peak strength than unstabilized soil, with the reduction in the loss of post-peak stress being more pronounced for higher fibre content. Figure 9 also shows that the initial stiffness of the soil appears not to be affected by the addition of fibre, although the effect on the stabilized soil specimens is clear. The peak stress increases dramatically with an increase in fly ash content, and the stabilized soil exhibits a marked stiffness and brittleness. Its failure strain is 0.5–0.75%, which is much smaller than that for the unstabilized soil and fibre-reinforced unstabilized soil. It is also of note that the inclusion of fibres with the stabilized soil reduces the brittleness of the response. The failure strain increased, ranging from 3.5 to 4.5%. The axial stress increases with increase in axial strain until the peak value is reached, followed by a sudden drop to zero in stabilized soil, but the reduction of post-peak stress is gradual when fibres are included. Furthermore, the residual strength of fly ash– fibre–soil specimens increases with increased fibre content. Undoubtedly, one of the main advantages of fibre-reinforcement when applied to soil is the improvement in material ductility see Figure 9. It is shown that some samples are under load after the test, the ‘‘bridge’’ effect of fiber can efficiently impede the further development of tension cracks and the deformation of the soil (Figure 10).

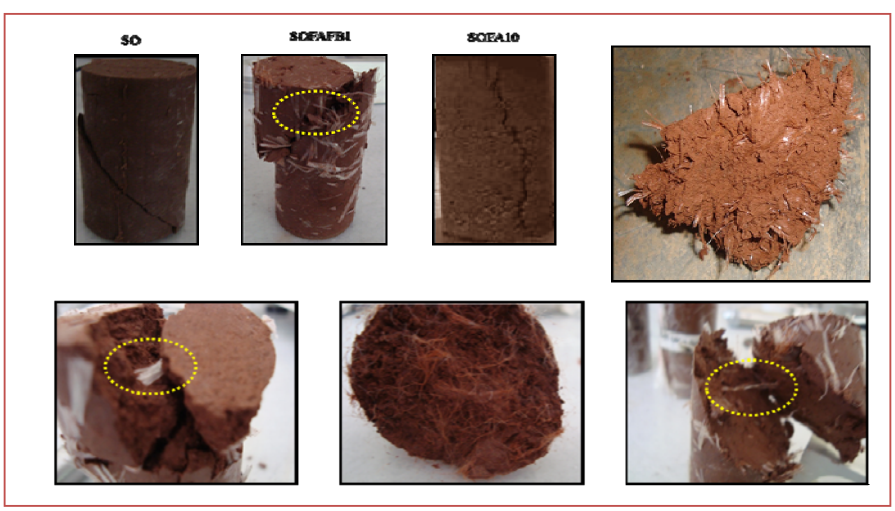


Fig. 10 Some samples after the test

4.3. California bearing ratio tests

California bearing ratio (CBR) tests were conducted using a cylindrical mould on specimens compacted in three layers at maximum dry unit weight and the optimum water content determined by conducting standard Proctor tests. The tests were conducted following AASHTO T193. According to AASHTO T193-63 and ASTM D1883-73, the soaking period for CBR samples for normal soil is 96 h or 4 days [31]. The CBR samples prepared with different proportions of fly ash and polypropylene fibres (0, 10 and 15% fly ash with 0.5, 1.0 and 1.5% of polypropylene fibres) to soil at its optimum water content were compacted and then soaked in water. The CBR values obtained are tabulated in Table 4. It appears that the addition of 0.5% multifilament fibres (MF) gives the maximum percentage increase in CBR value (ratio of obtained CBR value/highest CBR value) after curing for 96 days; see Figure 11.

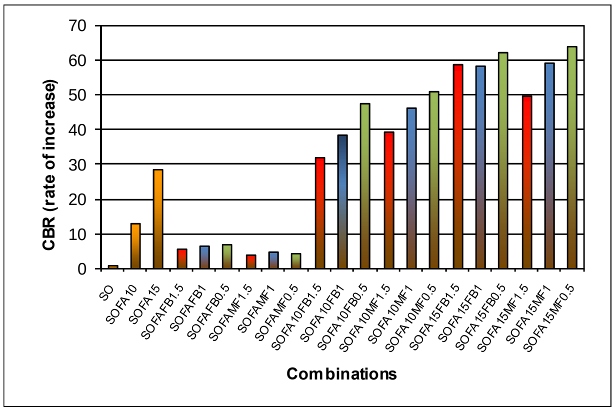


Fig. 11 Different fly ash, fibrillated polypropylene fibers (F19average) and multifilament fibers (MF19average) content increase in CBR values

A minimum of three specimens were prepared for each combination of variables and tested according to AASHTO T193-63 and ASTM D1883-73. The results are shown in Table 4, which indicates.

(a) The addition of polypropylene fibres to the fly ash–soil mixtures resulted in a significant increase in the CBR values.

(b) The clayey soil samples stabilized with fly ash and polypropylene fibres show an increase in CBR values; for the soil +15% fly ash +0.5% MF this was by as much as 63.79 % due to the fly ash acting as a binding agent.

(c) The maximum CBR value of the SOFA15MF0.5 and the SOFA15FB0.5 samples were 29% while the minimum value of 1.97% was obtained for the SOFAMF1.5 group.

(d) The CBR of the multifilament fibres (MF19average) was a little higher than that for the polypropylene fibres (F19average).

All the results indicated that an increase in fly ash resulted in an increase in CBR values which was enhanced by the addition of polypropylene fibres.

5. Conclusion

An experimental program was undertaken to investigate the individual and combined effects of fiber inclusions and fly ash stabilization on the geotechnical characteristics of fly ash-soil mixtures. Experiments were conducted on fly ash-soil specimens of different forms as (1) unstabilized-unreinforced specimens; (2) fly ash-stabilized specimens; (3) fiber-reinforced specimens; and (4) fiber-reinforced fly ash-stabilized specimens. . The results of increase in CBR values and were determined for stabilized specimens with two types of polypropylene fibers of varying dosages and the compaction tests were performed for various combinations of fly ash-soil-fiber mixtures. Effect of fibers treatment on CBR values and compaction properties were investigated. The main conclusions are follows. The following conclusions are drawn from the study:

- The best results were obtained in a group of “SOIL+ FLY ASH 15%”. Results are very close to each other. The different results between in compression test and CBR is estimated that occur during the production of the sample due to the negativities so high-fiber mixture ratio made it difficult to prepare the specimen for the unconfined compression test.
- The polypropylene fibers act a reinforcement to the soil. It appears that it prevents the formation of cracks in the sample and along with fly ash, binds the soil particles together, leading to an increase in CBR values of the stabilized soil.
- The treatment is little more effective on CBR of clayey soil for multifilament fiber (MF19) when compared with fibrillated polypropylene fiber (F19 average). The reason for this result might be texture of fibrillated polypropylene fiber. Fibrillated polypropylene fiber (F19 average) is harder and has only one part. In contrast; the multifilament fiber (MF19 average) has a texture that is softer and spreads out when mixed with fly ash-soil mixtures so that holds fly ash-soil particles together with a less void ratio of the mixture.
- CBR decreased when higher dosages of fibrillated fiber (F19 average) and multifilament fiber (MF19) are used. At the dosage levels higher than 0.5%, there is decreasing on the CBR.
- The fiber inclusions change the behaviour to ductile bahaviour. Polypropylene fibers or the interaction between fly ash and fiber reinforcement which is responsible for the increase in CBR values. The addition of polypropylene fibers imparts the ductility to soil fly ash specimens. The ductile behavior increases with increase in fiber content.
- The inclusion of fiber reinforcement within unstabilized-unreinforced specimens and stabilized-reinforced specimens soil caused an increase in the CBR. Increasing fiber content could increase the peak axial stress and decreases the stiffness and the loss of post-peak strength, weakens the brittle behavior of fly ash stabilized-reinforced specimens. The increase in strength of combined fiber and fly ash inclusions is much more than the sum of the increase caused by them individually.
- The ‘‘bridge’’ effect of fiber can efficiently impede

the further development of tension cracks and deformation of the soil. Bond strength and friction at the interface seem to be the dominant mechanisms controlling the reinforcement benefit.

- In fiber-reinforced fly ash unstabilized soil, interactions occur at the interface between the fiber surface and the clay grains play key roles in the mechanical behavior. However, in fiber-reinforced fly ash stabilized soil, the interactions between the fiber surface and the hydrated products make main contribution to the strength at the interface. The micromechanical behavior of the fiber/matrix interface depends on binding material properties in the soil, normal stress around the fiber body, effective contact area and fiber surface roughness. It is known that the interface roughness plays an important role in reinforced soil systems.
- These conclusions are of significance, both for developing methods of improving the interfacial strength, and for application in engineering projects. It could be concluded from this study that the combination of fiber and fly ash has the virtues of both fiber-reinforced soil and fly ash-stabilized soil, and therefore the addition of fiber–fly ash to soil can be considered as an efficient method for ground improvement.

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