

# Effect of silica fume and induction furnace slag in the compaction and strength characteristics of black cotton soil

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**Abstract.** The present investigation brings out the experimental outcomes of the influence of two industrial solid wastes on black cotton soil. It evaluates the changes in compaction and strength characteristics of the black cotton soil on addition of these solid wastes. Disturbed soil sampling had been done and as per Indian classification system the soil is classified as CH soil. The virgin soil is mixed with varied percentages of Silica fume and Induction furnace slag independently and its effect on compaction characteristics was ascertained. The proportions identified for silica fume and Induction Furnace slag are in the order of 5 to 20% of dry weight of soil with an incremental increase of 5% . The optimum percentage of silica fume was obtained from the compaction characteristics of the soil. After choosing optimum percentage of silica fume, further the compaction and strength characteristics of the soil was ascertained with optimum percentage of silica fume and varying percentage of induction furnace slag ie 10 to 20% with 5% increase. The results shows that the maximum dry density for BC soil + 10% SF +20% IFS is 1.63 g/cc and UCS for BC Soil + 10% SF +15 % IFS is 138.76 kPa.

**Keywords:** Black cotton soil, Silica fume, Induction furnace slag,

## 1.Introduction

The high volumetric changes of black cotton soil(BC Soil) with respect to moisture content make it unfavorable for foundation. The expansion and shrinkage of BC soil with respect to moisture content causes pressure and settlement to structures founded on it, especially in lightly loaded buildings, canal linings, road pavements etc. It has been found that the loss of property due to damage caused by BC soil is quite immense. Sometimes the cost of retrofitting exceeds even the cost of the construction. Hence it is very essential to control the volumetric changes of the soil (Al-Mukhtar et.al 2010). The process of improving the soil property is known as stabilization and can be done by several techniques such as by mechanical means -soil replacement, mechanical compaction, surcharge loading and moisture control; by using chemical additives-natural, artificial and by addition of solid wastes. The first chemical stabilization in history was done by Mesopotamians and Romans. They mixed weak soil with pulverized lime stone or calcium for the construction of road. Since then usage of lime in soil stabilization has been common. Disposal of industrial wastes to a safer

zone is becoming a burning issue nowadays. The idea of controlling the expansion of soil or improving its properties by adding solid waste is not only economical but also environmental friendly. Solid wastes can be generally classified into three groups namely agricultural waste, municipal waste and industrial waste apart from other categories of wastes. Agricultural wastes like rice husk ash, ground nut shell ash, Coconut fibers, Locust bean ash etc. are very effectively used as soil stabilizers recently. Studies on rice husk ash as stabilizers show improvement in swell and shrinkage property of BC soil. The conclusion of the study was, 10% RHA+10% Silica fume was effective combination in improving the properties of BCsoil. Industrial wastes like quarry dust, marble dust, [Vijayasri (2016)], fly ash and Granulated Blast Furnace Slag [Shenbaga et.al (2004), Guleria1 & Dutta(2011), Mohanty and Patra,(2016), Singh et.al (2008)], Granulated blast furnace slag[Anil Kumar Sharma et al,(2012)], Silica Fume, steel slag, Rice Husk Ash, etc. [Prakash (2013)] are also used widely as soil stabilizers. The inclusion of quarry dust & marble dust on BCsoil shows better results on index properties and CBR values at 40% addition of these additives. Various researches on the combined effect of flyash and GGBS concluded that with 10% FA+20%GGBS gave better performance. Investigation on the effect of silica fume on BCsoil reveals the improvement of swelling and strength characteristics of the soil. It was effective with 10% to 20% SF addition. All research studies projected the improvement of soil properties with the inclusion of solid wastes to the BCsoil. In the present study, Induction Furnace Slag and Silica fume had been selected to study its effect on strength and optimum characteristics of Black cotton soil.

India stands second in the world in castings and also one of the top 10 in terms of average production per plant. A large amount of waste has been generated by ferrous foundries. The Indian foundry produces around 6 million tonnes of castings annually. The annual production of slag is around 1.7 million, it is estimated that around 5000 foundries are functional all over India. During the cast iron production the slag generated is hazardous to the environment. The slag that formed in Induction furnace melting are the results of complex reactions between silica, oxide of iron from steel scrap, other oxidation by products from melting, and reactions with refractory linings. The resulting slag consists of complex liquid phase. Slag contains  $Al_2O_3$ ,  $MgO$ ,  $SiO_2$ ,  $Fe_2O_3$ ,  $CaO$  &  $MnO$  (Sharma and Sivapullaiah, P.V,2012). The large amount of induction furnace slag is considered as waste. The skimmed off slag is often air cooled near production unit. This air cooled slag when powdered and the metal part separated, can be potentially used as stabilizers.

Silica fume (SF) is obtained as the bi-product in the reduction of high-purity quartz with coal in electric furnaces in the production of silicon and ferrosilicon alloys. SF is also obtained as a by-product in the production of other silicon alloys such as ferrochromium, ferromanganese, ferro-magnesium, and calcium silicon. When the high-purity quartz is reduced to silicon at temperatures up to  $2000^{\circ}C$ , it produces  $SiO_2$  vapours, which oxidizes and condense in the low temperature zone to fine particles containing silica. It consists of very fine transparent particles with high surface area.

Because of its extreme fineness and high silica content, Silica Fume can be effectively used as pozzolanic material. This acts as a bonding agent and hence can be effectively used in soil for stabilization.

## 2 Materials Used

### 2.1 Black cotton soil

Black cotton soil was obtained from Bhalki, Karnataka (INDIA). According to Indian classification system this soil was classified as Inorganic Clay of High plasticity (CH) and the properties of BCsoil are given in Table 1.

Index Properties of Black Cotton Soil	
Field Moisture	34.5%
Liquid Limit	65.4%
Plastic Limit	20.3%
Shrinkage Limit	14%
Plasticity Index	45.1 %
Specific Gravity	2.6
Free Swell Index	40%
I.S. Classification	CH
MDD	1.56g/cc
OMC	25
UCS	95.36kPa

### 2.2 Silica Fume

Silica fume is also known as micro silica, condensed silica fume, volatilized silica or silica dust. Silica fume is a very fine non- crystalline product available in wet or dry form. The physical properties and chemical composition of Silica fume as obtained from the manufacturer is listed in Table 2.

Physical Properties of Silica Fume	
Particle Size (Typical)	< 1 micron
Bulk Density	
(as produced)	130 to 430 kg/m <sup>2</sup>
(densified)	480 to 720 kg/m <sup>2</sup>
Specific gravity	2.2

Specific Surface	15,000 to 30,000 m <sup>3</sup> /kg
Chemical composition of micro silica fume (%)	
Silica (SiO <sub>2</sub> )	98.84
Alumina (Al <sub>2</sub> O <sub>3</sub> )	0.04
Calcium Oxide (CaO)	0.63
Iron Oxide (Fe <sub>2</sub> O <sub>3</sub> )	0.03
Potassium Oxide(K <sub>2</sub> O)	0.07
Magnesium Oxide(MgO)	0.01



*Fig 1 Silica Fume as obtained from manufacture.*

### **2.3 Induction Furnace Slag**

Induction Furnace Slag is a non-metallic co-product produced in the process of recycling of scrap iron. They are air cooled naturally and therefore crystalline. The crystallization takes place slowly and hence they are very hard. The induction furnace slag is powdered; metallic part separated and made it pass through 850 micron IS sieve. This slag was procured from Pathencheru Industrial Park in Hyderabad.



**Fig 2** Induction Furnace Slag



**Fig 3** Powdered Slag

**Table 3** Physical Properties of Induction Furnace Slag

Colour	Black
Structure	Crystalline
Specific Gravity	2.78

**Table 4** General Chemical Composition of Slag

Na <sub>2</sub> O	6.07
MgO	1.31
Al <sub>2</sub> O <sub>3</sub>	12.76
SiO <sub>2</sub>	45.82
P <sub>2</sub> O <sub>3</sub>	0.09
SO <sub>3</sub>	0.59
Cl	0.03
K <sub>2</sub> O	0.27
CaO	4.19
TiO <sub>2</sub>	0.55
MnO	1.79
Fe <sub>2</sub> O <sub>3</sub>	8.59
LOI	18.2

In the present investigation, the effect of silica fume, induction furnace slag and their combinations on black cotton soil is being investigated. Optimum percentage of these combinations was obtained.

### 3 Methodologies

#### 3.1 Sample Preparation

Soil samples were collected from an excavation at a depth 1m below the ground level. The organic matter, like tree roots and pieces of bark were removed from the sample. Then it is pulverized properly to make it drying faster. For different proportion of mixes, the additives were taken according to certain percentages by dry weight of soil as shown in Table 5. After preparation of sample and Compaction test and unconfined compression test were conducted on virgin soil and soil mixed with additives and the results were obtained.

#### 3.2 Experimental Procedure

Basic laboratory tests for the identification of the soil, its index properties and strength properties were carried out on virgin Black cotton soil. Then the soil properties were again ascertained by mixing it with Silica fume, Induction Furnace slag and its combinations with varying percentages of two additives. The proportions of additives were taken in the order of 5%, 10%, 15% & 20% for ascertaining its compaction characteristics. Experimental program for compaction and UCS is given in Table 5 and Table 6 respectively.

**Table 5** Experimental program on Compaction Characteristics for Black cotton soil.

Sample Composition
Plain BC soil
BC Soil + 5% Silica Fume
BC Soil + 10% Silica Fume
BC Soil + 15% Silica Fume
BC Soil + 20% Silica Fume
BC Soil + 5% Induction Furnace Slag

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BC Soil +10% Induction Furnace Slag
BC Soil + 15% Induction Furnace Slag
BC Soil + 20% Induction Furnace Slag
BC Soil + 10% Silica Fume+5% IFS
BC Soil + 10% Silica Fume+10% IFS
BC Soil + 10% Silica Fume+15% IFS
BC Soil + 10% Silica Fume+20% IFS

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**Table 6** Experimental program on UCS for Black cotton soil.

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Sample Composition
BC soil alone
BC Soil +10% SF+10% IFS
BC Soil +10% SF+15% IFS
BC Soil +10% SF+20% IFS

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### 3.3 Test Procedure

All tests were conducted in laboratory as per the Indian Standard Code. The basic properties of the soil like Free swell Index, Specific Gravity, Moisture content, Liquid Limit & Plastic limit, Shrinkage Limit were determined as per IS 2720 Part-1,2,5,6 respectively in the Laboratory. The Compaction characteristics of the soil is determined by Proctor test conducted in the laboratory as per IS: 2720(Part VIII-1980).The

Unconfined Compressive Strength of the soil was determined by conducting Unconfined Compression Test on the soil as per IS 2720 Part –X.

#### **Standard proctor test confirming to IS 2720 Part-VIII-1980**

The prepared soil specimen is mixed with varying percentage (5,10,15,20% of dry weight of soil ) of silica fume, Induction Furnace Slag independently and then with optimum percentage of Silica fume and varying % of Induction furnace slag to ascertain the compaction characteristics in each combinations. The soil is mixed with additives in its dry form, after mixing thoroughly, initially a water content of 10% is added and the corresponding dry density is found out, the procedure is repeated for 15, 20, 25, 30% for obtaining the compaction curve for each mixed proportions. The experimental program is tabulated on table 5.

#### **Unconfined compressive strength Test Confirming to IS 2720 Part-X.**

The unconfined strength of the prepared soil is ascertained by making a cylindrical mould of 35mm diameter and 76mm long. It was then statically compacted to its OMC and MDD. The sample was then kept in a desiccator for about an hour and the sample is subjected to UCS test.

Since the soil didn't show relevant changes in its OMC & MDD characteristics after 10% percentage inclusion of SF in the soil, optimum percentage is considered as 10% for silica fume. And since the compaction characteristics improved after the addition of IFS, the lowest percentage ie 5% had been omitted. With optimum percentage of silica fume as 10% of dry weight of soil as constant the variations of 10%, 15% & 20% percentage of IFS was added to the soil for the determination of UCS characteristics of the soil.

The prepared soil was mixed thoroughly with 10% of SF at first and then added the variation of IFS. Cylindrical soil specimen with dimensions 35mm diameter and 80mm long had been prepared by compacting it to its OMC & MDD. The prepared specimens were kept in a desiccator for 3 days, 5 days, 7 days, 9 days and 12 days as curing period and then UCS strength ascertained for each specified curing day. The procedures were repeated for other combinations of soil and 10% SF with different percentage of 15 % IFS & 20% IFS.

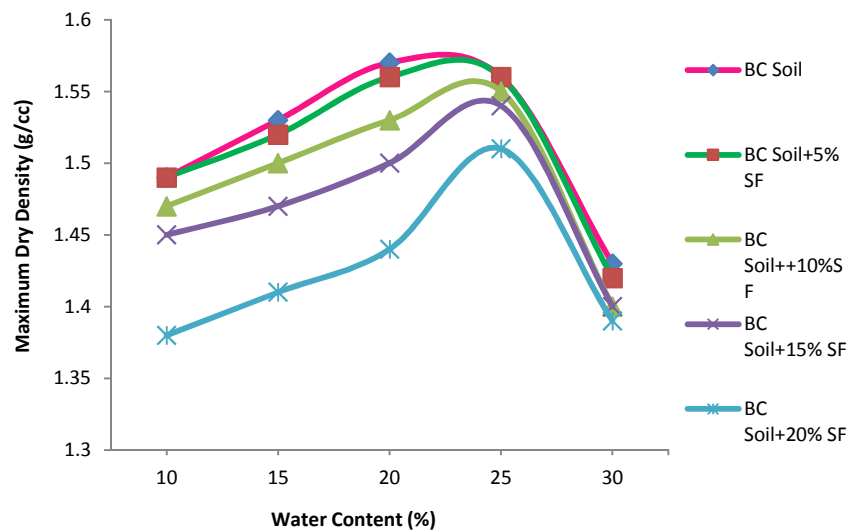
## **4 Results and discussion**



Variation of compaction properties and UCS properties of Black Cotton Soil with the addition of Silica Fume, Induction Furnace Slag and their combination as shown in fig 4,5&6 respectively.

#### 4.1 Effect of Silica Fume on the Compaction Characteristics of Black Cotton soil.

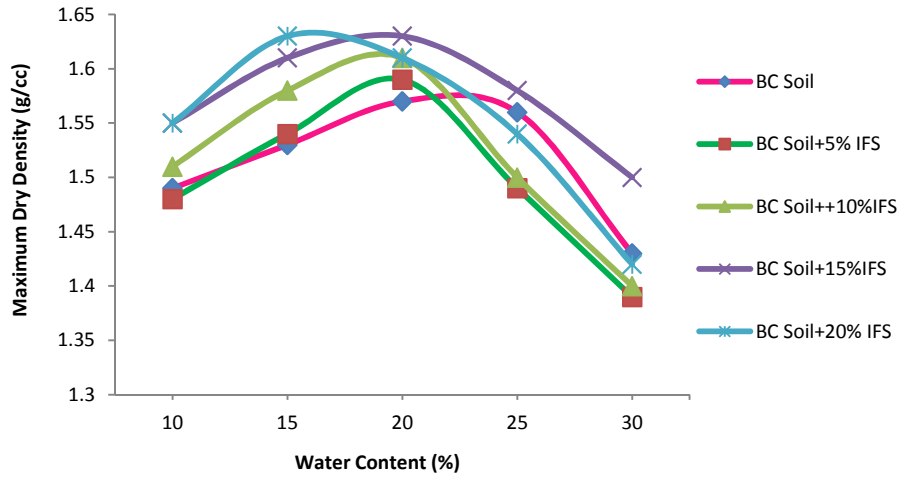
The variation in OMC & MDD is shown in Fig 4. When Silica Fume was treated with Black Cotton Soil, there was a gradual increase in the OMC and decrease in Maximum dry density of soil. When 20% Silica Fume was added to BC Soil, the percentage increase in OMC is about 27% and percentage decrease in MDD is 3.8%. This may be due to the increase in percentage fines in the soil.



*Fig 4 Dry unit weight against Water content of BC soil treated with Silica Fume.*

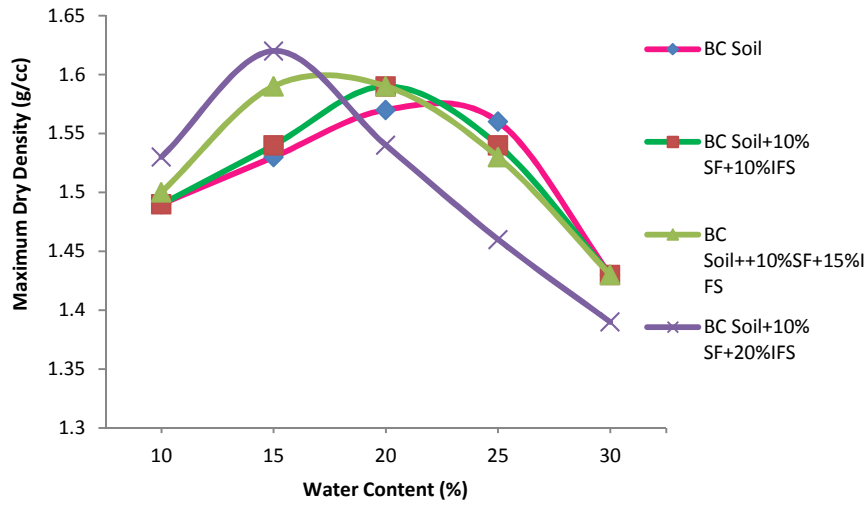
#### 4.2 Effect of Induction Furnace slag on the Compaction Characteristics of Black Cotton soil.

The variation in OMC & MDD is shown in Fig 5. It was inferred that there was a gradual decrease in the OMC and increase in Maximum dry density of soil, with increasing percentage of IFS in black cotton soil. The percentage decrease in OMC observed is 27% and increase in MDD is 3.7%, when 20% Induction Furnace Slag was introduced. This may be due to the increase coarse grains in the soil. These may also be due to the soil type, the related interchangeable cations and the relative amount of silicate clay mineral in the samples.



**Fig 5** Dry unit weight against Water content of BC soil treated with Induction Furnace Slag.

**4.3 Effect of Silica Fume and Induction Furnace Slag on the Compaction Characteristics of Black Cotton soil.**

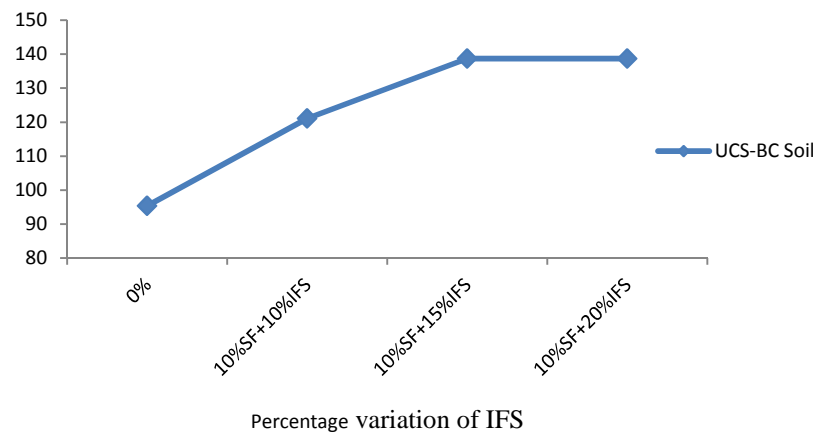


**Fig 6** Dry unit weight against Water content of BC soil treated with Silica Fume and Induction Furnace Slag.

The variation of OMC did not show much variation with percentage increase in Silica Fume from 5 to 15% and there was a constant decrease in MDD with increase in percentage of Silica Fume. Hence 10 % Silica Fume was considered as optimum

percentage. Thereafter the BC soil was treated with 10% SF and varying percentage of IFS to obtain the compaction and strength characteristics. The variation of the combination of additives is shown in Fig6. When the soil was treated with Silica Fume and IFS, OMC of the soil decreased gradually. The MDD shows constant increase with increasing % of SF & IFS in the soil by the combined effect of silica fume and Induction furnace slag.

#### 4.4 Effect of Silica Fume and Induction Furnace Slag on the UCS of Black Cotton soil.



*Fig 7 Variation of UCS (kPa) with different percentages of additives.*

The effect of UCS is shown in Fig 7; there is a constant increase in strength for black cotton soil with percentage of additives and with increase in curing period. There was not significant changes observed after (10% SF+15% IFS) addition. Hence the Optimum percentage of Silica Fume & Induction Furnace Slag in the soil was found to be 10% SF +15 % IFS for UCS. The percentage increase in strength is 45.5% compared to virgin soil.

## 5 Conclusion

1. Due to addition of 20% Silica Fume with BC Soil, the percentage increase in OMC is about 27% and percentage decrease in MDD is 3.8% compared to the BC soil alone. When IFS was used to treat the soil, OMC of the soil decreased and MDD was increased with % increase in IFS.
2. OMC of the soil decreased gradually, When the soil is treated with Silica Fume and IFS. The MDD shown constant ascend with increase in % of SF & IFS in the soil. The maximum dry density for (BC soil + 10% SF +20% IFS) is 1.63 g/cc.

3. The percentage increase in strength for (BC soil + 10% SF +15 % IFS) mix is found to be 45.5% compared to its virgin soil.
4. Optimum value of UCS was observed for (BC Soil + 10% SF +15 % IFS) mix.

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