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Suitability of Class F Flyash for Construction Industry: An Indian Scenario

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Abstract**—**The present study evaluates the properties of class F fly ash as a replacement of natural materials in civil engineering construction industry. The low-lime flash similar to class F is the prime variety generated in India, although it has significantly smaller volumes of high-lime fly ash as compared to class C. The chemical and physical characterization of the sample is carried out with the number of experimental approaches in order to investigate all relevant features present in the samples. For chemical analysis, elementary quantitative results from point analysis and scanning electron microscopy (SEM)/dispersive spectroscopy (EDS) techniques were used to identify the element images of different fractions. The physical properties found very close to the range of common soils. Furthermore, the fly ash-based bricks were prepared by the same sample of class F fly ash and the results of compressive strength similar to that of Standard Clay Brick Grade 1 available in the local market of India.

Keywords**—**Flyash, class F, class C, chemical, physical, SEM, EDS.

I. Introduction

MANY power plants around the world produce electricity by burning coal at their operating facilities. As a result of this process, various types of secondary materials are generated. According to current terminology, any material that results from coal-combustion processes can be referred to as a Coal-Combustion Product (CCP). Among all possible types of CCPs that can be generated at coal-burning power plants worldwide, flyash ranks as one of the most common and widely produced CCP. From the point of view of characterization, flyash can be described as the finely divided fraction of coal ash that exists in the combustion chamber in the flue gas and is captured by an air pollution control equipment at electric power plants [1]. Flyash particles typically solidify while they are still in suspension in exhaust gases and thus are generally spherical in shape. Flyash is composed primarily of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3). Physical and chemical requirements for flyash vary usually depending on its intended use. Accordingly, the specific requirements for the use of flyash in concrete or soil stabilization are described as [2], [3]. According to the classification laid by [2], flyash is classified into two classes viz. Class F and Class C. The chief difference between these classes are the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the flyash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous and lignite). The burning of harder and older anthracite and bituminous coal typically produces class F flyash. This flyash is pozzolanic in nature and contains less than 10% lime, (CaO). Possessing pozzolanic properties, the glassy silica and alumina of class F flyash requires a cementing agent, such as Portland cement, quicklime or hydrated lime, with the presence of water in order to react and produce cementitious compounds. Alternatively, the additions of a chemical activator such as sodium silicate (water glass) to a class F flyash can lead to the formation of a geopolymer. Flyash produced from the burning of younger lignite or sub-bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, class C flyash will harden and gain strength over time. Class C flyash generally contains more than 20% lime (CaO). Unlike class F, self-cementing class C flyash does not require an activator. Alkali and sulfate (SO_4) contents are generally higher in class C flyash. The aim of this investigation is to characterize the various chemical and physical properties of class F flyash which discovers its potential utility. For this purpose; flyash is characterized with respect to its physical and chemical properties to find the utilization of class F flyash as resource material in construction industry.

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II. Current Scenario of Flyash in India

India is the third largest producer of coal and coal-based thermal power plant installations in India which contributes about 70% of the total installed capacity for power generation [4]. However, the bituminous and sub-bituminous coal-use contains over 40% ash content. At present, 120-150 million tons of coal flyash is generated from 120 existing coal-based thermal power plants in India [5]. Flyash, being treated as waste and a source of air and water pollution till recent past, is in fact a resource material and has also proven its worth over a period of time [6].The emerging amount of average generation and utilization data received during the last five years by ENVIS Centre on flyash [7] is 166 million tons and 96 million tons. Flyash Generation and Utilization during the Year 2011-12, 2012-13, 2013-14, and 2014-15 and the first half of 2015-16 are shown in Table I. Flyash generation and utilization data for the First half of 2015-16 (April, 2015 to Sept., 2015) has been received from 132 (One hundred thirty-two) coal/lignite-based thermal power stations of various power utilities in the country. Data received, as on 15th March, 2016, has been analyzed to derive conclusions on the present status of flyash generation and its utilization in the country as a whole [8].

TABLE I
FLYASH GENERATION AND UTILIZATION CURRENT SCENARIO IN INDIA

Description	2011- 12	2012-13	2013-14	2014-15	1st Half of 2015-16
Nos. of Thermal Power Stations	124	138	143	145	132
Coal Consumed (million tons)	437.41	482.97	523.52	549.72	251.69
Average Ash Content (%)	33.24	33.87	33.02	33.50	33.23
Flyash Generation (million tons)	145.42	163.56	172.87	184.14	83.64
Flyash Utilisation (million tons)	85.05	100.37	99.62	102.54	46.87
Percentage Utilization	58.48	61.37	57.63	55.69	56.04

III. PUBLISHED STUDIES ON CLASS F FLYASH

The production of High Performance Concrete (HPC) needs to incorporate the supplementary cementations materials such as flyash and kaolin in the concrete mix [9]. The combination of fibre reinforced flyash lime stone dust brick (10FRFALSDB3') was found to have the highest compressive strength (9.155 MPa) with 10% stone dust, sand combination at 10% cement [10]. Reference [11] Conducted a series of tests on flyash-based brick tiles of class F type. After experimental investigation it is found that the tiles failed on the lower compressive strength as compared to the conventional clay roof tiles. The highest compressive strength reached 6.896 MPa for the combination of 15TFASDBT. The experimental study [12] reveals that the lower permeability values were obtained when increasing the percentage of Cement (C) at the fixed percentage of Treated Flyash (T.F.A) and Radish Stone Dust (R.S.D). Though permeability (k) dropped sharply with the variation of Coarse Sand (C.S) with C, the k has been found in the range of 10^{-7} which is much closer to the value of clay available in the market for making bricks and roof tiles. New set of experiments conducted by [13], its compressive strength has been increased by 30.65% as compared to the past study carried out by [11].

IV. MATERIALS AND METHODS

The flyash is obtained from Harduaganj Thermal Power Station Aligarh, U.P India. The flyash is dried for 2 hours at 110 °C in an electric oven and stored in a zip locked bag and placed in desiccators for performing chemical and physical studies. For the comparison of physical properties the sample of common soil was taken from the construction site of Sharda Mall Aligarh, India. The class F flyash sample is used after pretreatment by finely ground calcium hydroxide, a laboratory reagent which is used to augment the cementitious properties of the sample. The surface morphology of the sample was monitored using JEOL JSM-6510LV Scanning Electron Microscope (SEM), equipped with Energy-Dispersive X-ray spectroscopy (EDX) analyzer. Backscattered electron imaging (BSE), secondary electron imaging (SEI) and EDS are the basic standard modes of operations in SEM analysis.. In this study, EDS was used to characterize the samples. The elemental analysis was performed in a “spot mode” in which the beam is localized in a single area manually chosen with the field in view. SEM technique was used for determining the morphology and shape of ash particles. For physical properties, Indian (IS) and (ASTM) Standard Test Methods were used.

V. RESULTS AND DISCUSSION

A. Chemical Analysis of Class F Flyash

Locally available samples were examined in the present study. Scanning Electron Microscopy (SEM) with Energy Dispersive Spectroscopy (EDS) provide detailed imaging information about the morphology and surface texture of individual particles as well as elemental composition of samples. SEM is one of the best and most widely used techniques for the chemical characterization of ash using a focused electron beam to scan the surface of sample. Exact chemical composition is then summarized in Table II. The identified elements in the ash samples were found to be C, O, Al, Si, K, Ca and Ti in various compound forms (Al_2O_3, SiO_2, K_2O, CaO, TiO_2 etc.). The Quantitative result from point analysis of Class F flyash used in the study is shown in Fig. 1. Physicochemical characteristics of class F flyash are important parameters for deciding economic utilization of flyash which are analyzed in Table II.

TABLE II
LIST OF ELEMENTS WITH THEIR WEIGHT (%) AND ATOMIC (%) PRESENT IN CLASS F FLYASH

Element	Weight %	Weight %
C	14.42	21.05
O	54.59	59.83
Al	11.96	7.77
Si	16.47	10.29
K	0.73	0.33
Ca	0.94	0.41
Ti	0.88	0.32

The percentage of CaO was found in the given sample 1.31% has fallen into class F defined by [2]. The Compounds SiO_2 and Al_2O_3 are major constituents of flyash which were measured at their highest concentration i.e. 35.23% and 22.59% respectively. It is also obvious that different constituents in flyash show great variation in their chemical composition. This is due to the variable quality of Indian coal and also due to the lack of control and standardization in the plant machinery. A descending order of fixed carbon is followed with increase in densities of the fractions. This may be assigned to a higher mineral matter content of the fractions with smaller particle size. Fractions having larger particle size obviously contain larger agglomerates of carbonaceous matter, thereby increasing the fixed carbon content and lowering the densities. Whereas fractions having smaller particle sizes contain lower amount of these agglomerates and they are low in fixed carbon content.

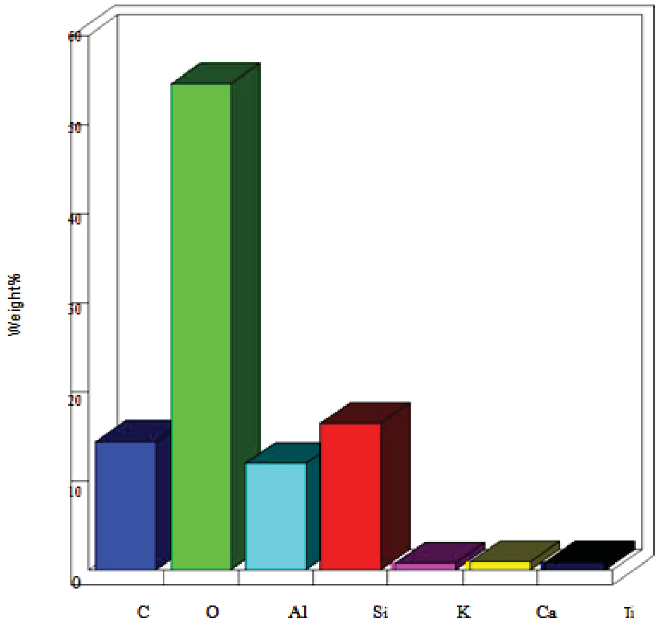


Fig. 1 Quantitative results from point analysis of Class F Flyash

B. SEM/ EDS Analysis

The characterization of surface morphology has a vital role in understanding the physical and chemical behavior of the material. The significance of the physical nature of the surfaces of solids can be observed in the fields of material science and surface chemistry. SEM is a useful technique to study modes of particle association or for detection of surface irregularities. The surface morphology of the sample was investigated by Scanning Electron Microscopy (SEM). SEM is used to investigate the surface morphology of the sample. Fig. 2 shows SEM images recorded on sample class F, flyash surface at x2000, x5000 and x6000 magnifications. As, it can be seen in Figs. 2 (a) and (b) which clearly indicates the presence of irregular shaped particles of variable size, covered with relatively smooth grains of quartz. The micrographs in Figs. 2 (c) and (d) also designated dark areas as organic materials, light areas as mineral matter and gray as mixture of coal and ash. Solid and porous part indicated the presence of mineral matter most likely quartz. Partially burnt coal particles were shown by irregular black porous parts. Particles size 10µm at WD 13mm appeared to be spherical with small bulging of siliceous and aluminous glass in Fig. 2 (e). The EDS of flyash sample suggested the presence of Carbon, Oxygen, Aluminum, Silicon, Potassium, Calcium and Titanium as the primary elements. Thus, it is clear from the discussion given above that SEM/EDS are useful tools to study morphology and surface texture of individual particles as well as elemental composition of samples. Hence, SEM/EDS are one of the important and widely used techniques for physicochemical analysis of flyash samples.

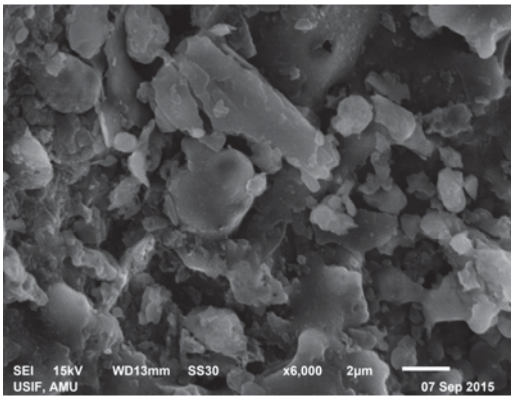
C. Physical Analysis of Class F Flyash

Physical analysis is one of the important parameter for selection and consideration of material in civil engineering construction industry. Its geo-technical property makes it a good substitute of soil and the required percentage provide the general range of physical geo-technical properties available in the flyash sample. As determined in the present study the physical properties of class F flyash are listed in Table III.

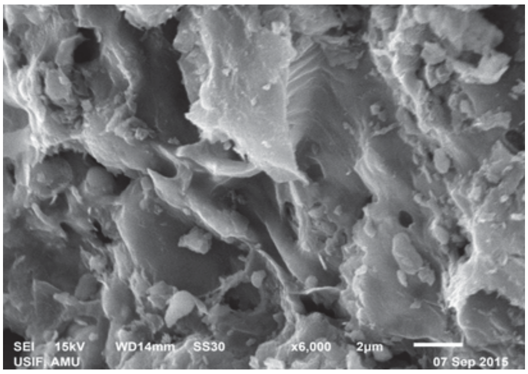
TABLE III
SUMMARY OF TEST RESULTS FOR DIFFERENT EXPERIMENTS ON CLASS F FLYASH

Parameter	Ranges	
	Experiment Present Study	**CBRI (2016)**
	Class F Flyash	**Common soil**
Bulk Density (gm/cc)	1.25	1.3–1.7
Specific Gravity	2.12	2.5-2.8
Plasticity	Lower or non-plastic	Lower or non-plastic
Maximum Dry Density (gm/cc)	1.2875	1.3-2.4
Optimum Moisture Content (%)	18	5.0-30.0
Angle of InternalFriction(degrees)	28	30-40
Cohesion (kN/m^2)	2.1	Negligible
Permeability (m/sec)	1.650×10^{-5}	$8{\times}10^{-6}$ - $7{\times}10^{-4}$
Shrinkage Limit (Vol stability)	Higher	Low - high
Grain size	Major fine sand range / and very small per cent of clay size particles	Major sand size fraction / silt and clay fraction and small per cent of gravel size fraction
Clay (percent)	Negligible	Low- medium
Free Swell Index	Very low	very low
Classification (Texture)	Sandy silt to silty loam	sandy clay, silty clay, clay loam and silt loam
Water Holding Capacity (WHC) (per cent)	40-60	10-70
Porosity (per cent)	30-65	15-75

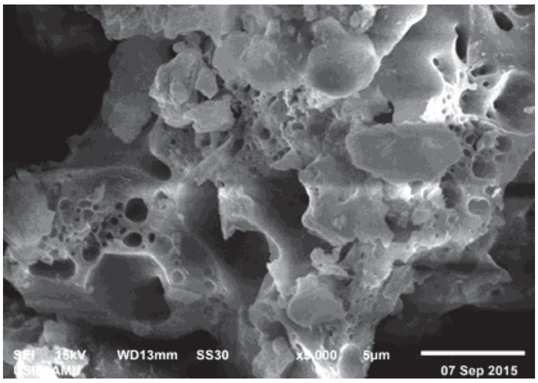
The strength and durability are two important factors to replace any material in construction industry. For a material to be considered as building material, it requires engineering properties suitable for construction works. These properties of building materials are responsible for its quality and capacity and help to decide their applications. A series of experiments conducted by [14] the addition of flyash has also shown improvement in the soil properties viz. texture, structure and bulk density. Permeability of clay loam soil increased from 0.54cm/hr to 2.14cm/hr by the addition of 50% flyash whereas it decreased from 23.80 cm/hr to 9.67 cm/hr in sandy soil by 50% flyash addition.



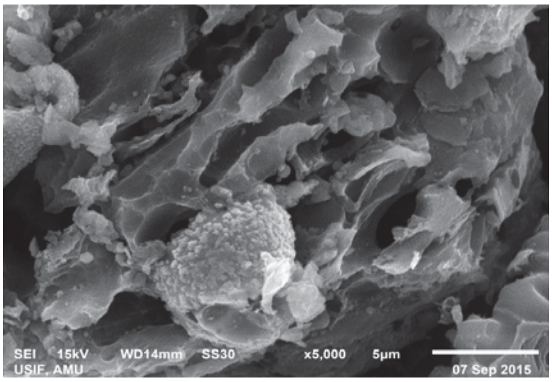
(a) SEM image of class F fly ash sample (size: 2µm) at WD 13mm



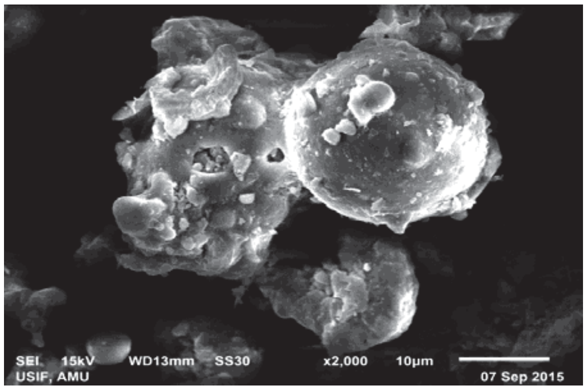
(b) SEM image of class F fly ash sample (size: 2µm) at WD 14mm



(c) SEM image of class F fly ash sample (size: 5µm) at WD 13mm



(d) SEM image of class F fly ash sample (size: 5µm) at WD 14mm



(e) SEM image of class F Fly ash sample (size: 10µm) at WD 13mm

Fig. 2 SEM micrograph of class F Flyash with different particles size a) 2µm at WD 13 mm b) 2µm at WD 14mm c) 5µm at WD 13 mm d) 5µm at WD 14 mm and e) 10µm at WD 1

Water holding capacity of sandy soil also increased from 0.38 cm/cm to 0.53 cm/cm at 50% level. Many researchers have conducted characterization studies in order to evaluate the suitability of flyash for several fields of applications. The Indian flyash is alkaline in nature. Hence, its application for agricultural soils could increase the soil pH and thereby neutralize acidic soils [15]. The specific gravity of flyash is 2.12 as determined by Density Bottle Method. The sample of flyash is analyzed by using different sieve sizes. The % finer was found to be 99% by hydrometer analysis. It was found that the diameter of the flyash particles ranges from 0.005mm to 0.6 mm as shown in Fig. 3.

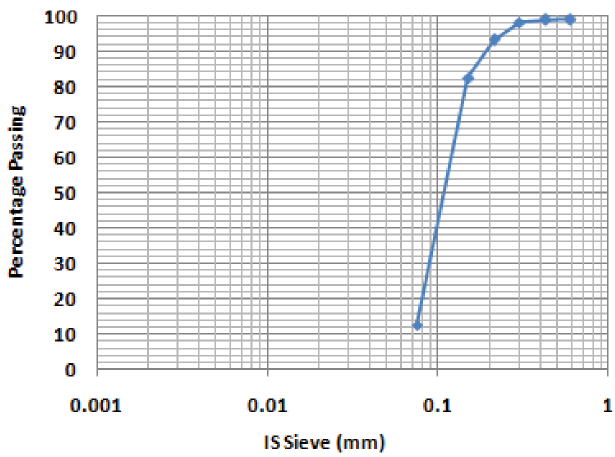


Fig. 3 Particle size distribution characteristics for Class F flyash sample

The locally available common soil sieve analysis results plotted in Fig. 4 clearly shows, about 65 % particles passing 0.075 mm fall in clay and silt range by the above discussion if has been figure out that the class F flyash particles coarser than common soil. The Optimum Moisture Content (O.M.C) and Maximum Dry Density (γd) of the class F flyash is determined by the Proctor's Compaction Test. The main aim of this test is to arrive at a standard which may serve as a guide and a basis of comparison for the field compaction.

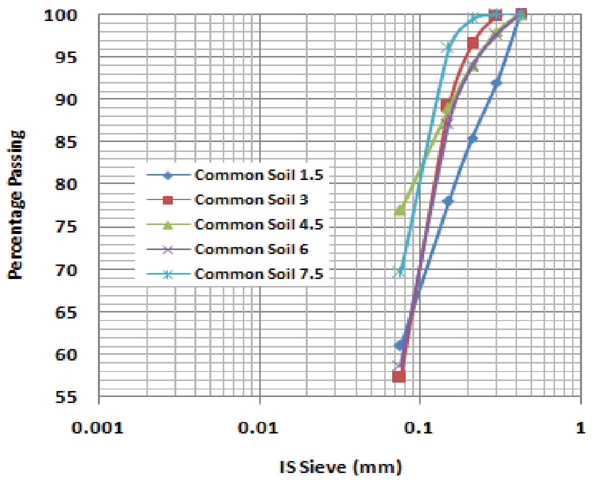


Fig. 4 Particle size distribution characteristics for locally available soil sample

Finally a graph of moisture content vs. dry density is plotted and it has been given in Fig. 5. Locally available soil at 1.5 m, 3 m, 4.5 m, 6m and 7.5 m is shown in Fig. 6. The O.M.C is found to be 18% against the dry density 1.2875 g/cc for class F sample and which is close in the range of common soil found maximum at 6 m depth from the ground 13.68 % against the dry density 2.15 g/cc.

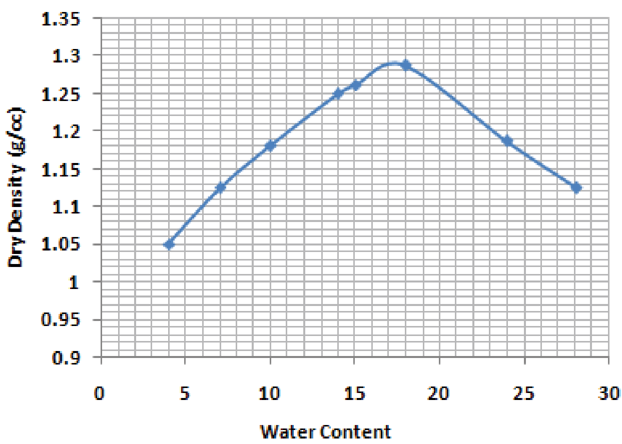


Fig. 5 Variation of OMC and MDD Class F sample

As can be seen in Table III, the permeability of class F sample was found 1.650×10^{-5} m/sec. The lower levels of permeability was found to develop better static stability including lower aggregate segregation and bleeding, together with improved hardened properties such as bonding to embedded reinforcement.

D.Compressive Strength Characteristic of Class F Flyash Sample with Different Materials

To determine the compressive strength characteristics of class F sample 9′′×4.5′′×3′′ size sample were prepared which is similar to standard first-class clay brick in Indian condition. With a suitable mix proportion, even with 50% of mixed materials replaced by class F flyash, the compressive strength of the composite mixed mortar and can reach over about 7.58 MPa at 21-day. Compared to Standard Clay Brick Grade 1, the proposed tested sample shows a reduction in strength as compared to the standard clay bricks of an average compressive 10.55 MPa used in the study. For increasing the strength of the sample Waste Polythene Fibre (WPF) was mixed in the sample. At 20 % cement combination gives the maximum strength at Treated Flyash Stone dust Brick (20 TFASDB). The mix proportion of the sample was Cement (20%), treated flyash (50%), Coarse sand (10%), Stone dust (20%) with varying percentage of waste polythene fibre. With an addition of 1 % WPF at 21-day age designated as (20 TFASDB) the compressive stress increases about 30% of the sample tested without WPF. The summary of test results is shown in the Table IV. The variation of strength is shown in Fig. 7. It was observed on the basis of experimental data that the compressive strength of these bricks increases with increase in bond strength of the composite material along with other factors.

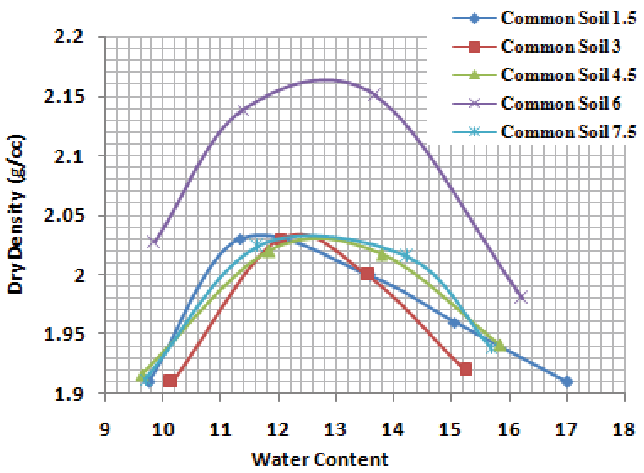


Fig. 6 Variation of OMC and MDD for locally available soil sample

TABLE IV
SUMMARY OF TEST RESULTS OF CLASS F FLYASH BRICKS

Mould Designation	W. P. F (%)	Compressive Strength (MPa)	Sample size
SFCB	-	10.55	(10 specimen)
0.00TFASDB	0.00	7.529	(10 specimen)
0.25TFASDB	0.25	7.906	(10 specimen)
0.50TFASDB	0.50	8.299	(10 specimen)
0.75TFASDB	0.75	8.138	(10 specimen)
1.00TFASDB	1.00	10.05	(10 specimen)

VI. CONCLUSION

ASTM C618 Class F flyash samples have been examined in the present study. Millions of tons of flyash are produced each year due to the massive consumption of coal. The industry is facing problem to develop efficient and economical techniques to recycle these materials. Recycling of flyash will conserve the natural raw materials and reduce the disposal cost. It will also create new revenues and business opportunities while protecting the environment.

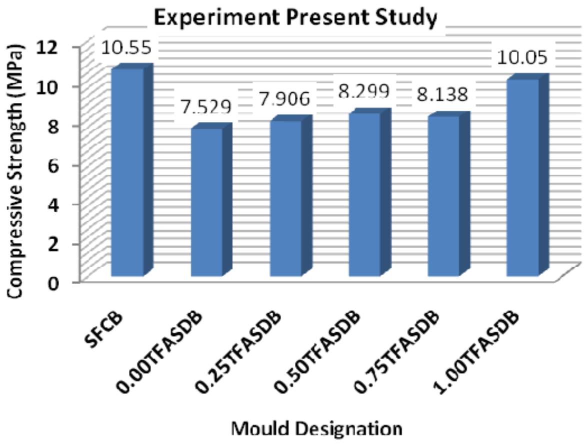


Fig. 7 Compressive Strength Variation

As per Indian scenario, there is a vast difference in the production and utilization of this waste material. In India, the majority of flyash produced fall in class F category. This study shows the chemical and physical suitability of class F flyash in the construction industry. Since flyash ties up free lime which leads to less bleed voids, it leads a considerable reduction of permeability to water and sulfate as aggressive chemical. Moreover, the experimental results on compressive strength on class F flyash shows that use of 20 TFASDB, at 20 % cement combination gives the maximum strength which is slightly different in strength properties of the Standard Clay Brick Grade 1 locally available sample. It also reveals that all physical properties are much closer than available local soil. By using class F flyash we can save the amount of soil used in the production of soil-based construction materials i.e., bricks, roof tiles and blocks etc. Economic benefits can be achieved by using flyash as a pozzolanic addition in the concrete mixture and mixed mortar. In conclusion, the use of such additional, waste materials provide both durable and economic concrete structures and ecological balance.

For Indian condition, it is recommended that the class F flyash can be used as a general fill in construction activities i.e., buildings, roads, embankment and low-lying areas. As flyash is a lightweight material as compared to commonly used fill material (local soils), it causes lesser settlements. India is an agriculture-based country. The overuse and inappropriate use of soil results in nutrient depletion, erosion and other forms of degradation, the soil productivity declines; it reduces the area available for agricultural use. By utilizing flyash as a fill material, an equal volume of top soil which will otherwise be used in filling can be saved.

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