

**Assessment of the Use of Steel Slag and/or Air  
Pollution Control Devices Dust in the  
Manufacturing of Fly Ash Bricks/Blocks**

**A Dissertation**

Submitted in partial fulfilment of the requirements for the award of degree  
of

**Master of Technology**

In

**Environmental Science and Technology**

Submitted

By

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Under the guidance of

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**July 2015**

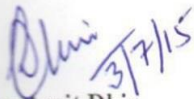
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## CERTIFICATE

This is to certify that work embodied in thesis entitled “**Assessment of the Use of Steel Slag and/or Air Pollution Control Devices Dust in the Manufacturing of Fly Ash Bricks/Blocks**” submitted by **Mr. Shivang Sharma** in partial fulfilment of the requirements for the award of **Master of Technology** degree in **Environmental Science and Technology** at **Thapar University, Patiala** is an authentic work carried out by him under our supervision and guidance.

To the best of our knowledge, the matter presented in this thesis has not been submitted in part or full, to this or any other University / Institute for award of any degree or diploma.



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## DECLARATION

I, the undersigned, hereby declare that the research work presented in thesis entitled **“Assessment of the Use of Steel Slag and/or Air Pollution Control Devices Dust in the Manufacturing of Fly Ash Bricks/Blocks”** has been carried out under the supervision of Dr. Amit Dhir, Assistant Professor, School of Energy and Environment, Thapar University, Patiala.

Further, I declare that no part of this Dissertation been submitted for a degree or any other qualification of any other University or examining body in India/elsewhere.



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**Shivang Sharma**

## **ABSTRACT**

In today's era, all energy planners are aiming to increase the use of oil, gas, nuclear and renewable energy sources to meet the electricity need of India, but till now the major source of electricity generation is coal-based thermal power plants and they will continue to rule till next few decades too. The major problem with coal-based thermal power plant is the disposal of fly ash produced as the waste product from the power plant. Similarly, steel slag & air pollution control devices (APCD) dust are the industrial waste with high polluting tendencies. In past, fly ash was treated as the waste product as well as a source of air and water pollution, but in the recent past, it has been considered as resourceful material in different sectors, especially in construction sector. Steel slag & APCD dust also possess similar properties as that of conventional natural aggregates and can be used as filler in fly ash bricks/blocks. In the recent studies, the properties of fly ash & steel slag revealed that their properties are comparable with natural aggregates. The properties of concrete incorporated with steel slag shows better results when compared to conventional concrete. The use of steel slag and APCD dust as a filler in fly ash bricks is yet to be explored. The present proposal aims at the assessment of use of steel melting furnace slag/APCD dust as filler in the manufacture of fly ash bricks and the evaluation of the properties of synthesized bricks/blocks as well as its associated environmental impacts.

In the present study, effect of the replacement of conventional aggregates with different proportions of fly ash, steel slag and APCD dust in fly ash brick/blocks of size 230x110x75mm/300x200x150mm was evaluated in terms of water absorption and compressive strength test, as per Indian Standard Code IS-3495 (Part- I & II):1976. With the variation of fly ash from 35-70% & steel slag from 21-45%, better results were obtained for C-10 (fly ash-70%, steel slag-21% & cement- 9%). The compressive strength of 11.21 N/mm<sup>2</sup> and water absorption 18.51% were observed for this composition. APCD dust was also varied from 5-20% but due to its very fine size, it was unable to bond strongly enough with rest of the mixture, resulting in higher water absorption rate of 24.53%. The variation of steel slag and fly ash in blocks showed good compressive strength. The composition C-13 (fly ash 45%, steel slag 45% & cement 10%) gave the good results for both compressive strength 8.37 N/mm<sup>2</sup> and water absorption 17.68%. In the investigation of the effect of pH on bricks/blocks, pH of water used in absorption test was varied from pH 5.0-9.0. The results were insignificant on the compressive strength or the water absorption with the change in pH and even during the physical examination of bricks after

water absorption test with different values of pH, the condition of bricks were good. The effluent from the water absorption was also tested for the presence of heavy metals (Fe, Pb & Zn) and the results showed that the metals were under permissible range and can be discharged in the environment. The results depicted that the use of steel slag and APCD dust as a filler in fly ash bricks/blocks proved beneficial for construction purposes as they are also cost effective and environmental friendly materials.

**Keywords: Fly ash, Steel Slag, Air Pollution Control Devices (APCD) dust, Bricks/Blocks.**

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# CHAPTER 1

## INTRODUCTION

### **1.0 Background**

In India the major source of power generation is coal-based thermal power plants where about 57% of power is obtained. The projections made by Planning Commission as well as Ministry of Power up-to 2031-2032 indicate that 2/3<sup>rd</sup> of power generation in the country would continue to depend on coal. The installed power generation capacity in India is about 1, 92,792 MW as on 29.03.2012 and now more than 75,000 MW is planned for 12<sup>th</sup> Five Year Plan. The fast growing power sector with target of adding 1, 00,000 MW every Five Year Plan, would have higher and higher demand of coal, resulting in generation of large volumes of Fly Ash. Fly Ash is a by-product being generated by thermal power plants from the combustion of coal. The amount of Fly Ash produced depends upon the quality of coal used and the conditions under which the thermal power plant is operated. Presently, the annual production of Fly Ash in India from 141 thermal power plants is about 160 million tonnes and it is expected to cross 300 million tonnes by the year 2017 and 900 million tonnes by 2031-32. This would require more than 40, 000 acres of land for the construction of ash ponds. In India, more than 70,000 acres of land are occupied by the ash ponds. (*Loya et al., 2014*)

Indian coal has high ash content (35-45%) and low calorific value (3500kcal/kg – 4500 kcal/kg) which results in huge amount of Fly Ash generation. Such large quantity of Fly Ash pose challenging problems, such as land usage, environmental dangers and health hazards. When is coal is burned to produce heat, 80% of the residue is Fly Ash and 20% is Bottom ash. Fly Ash has particle size ranging from 0.5-300 microns in equivalent diameter; they are light in weight and have potential to air borne easily. They can create nuisance in environment if not managed properly, improper disposal in rivers, seas, ponds, etc. can cause damage to aquatic life also and can become a beading ground for mosquitoes and bacteria. Due to the presence of toxic heavy metals in Fly Ash, it can also contaminate ground water resources. Fly Ash can be used eco-friendly in agriculture, road/ embankments, as etc. It can be used as a resource that can be used in creating wealth, prosperity, innovative products and opportunity of employment.

## 1.1 Chemical Composition & Physical Properties of Fly Ash

Composition of Fly Ash primarily depends upon the geographical conditions related to coal deposits, combustion conditions and the type of collection devices used for the collection of Fly Ash. The major constituents of Fly Ash are oxides of Mg, Al, Ca Si & F which constitutes about 95-99% of total constituents and other minor constituents are Na, S, K & Ti comprising 0.5-3.5%. The characteristic chemical composition & physical properties are given in Tables 1.1 & 1.2 respectively (*Feng et al., 2011 & Ahmad et al., 2010*)

**TABLE 1.1: Typical chemical composition of Fly Ash**

<u>Contents</u>	<u>Percentage by Mass</u>
Calcium oxide, Ca O	0.37-27.68
Silicon dioxide, SiO <sub>2</sub>	27.88-59.40
Aluminium oxide, Al <sub>2</sub> O <sub>3</sub>	5.23-33.99
Iron oxide, Fe <sub>2</sub> O <sub>3</sub>	1.21-29.63
Magnesium oxide, Mg O	0.42-8.79
Sulphur Trioxide, SO <sub>3</sub>	0.04-4.71
Sodium carbonate, Na <sub>2</sub> O	0.20-6.90
Potassium oxide, K <sub>2</sub> O	0.64-6.68
Titanium dioxide, TiO <sub>2</sub>	0.24-1.73
Other alkaline & unidentified	4.0-6.0
LOI, (Loss-on-ignition)	0.21-28.37

**TABLE 1.2: Physical properties of Fly Ash**

<u>Parameters</u>	<u>Fly Ash</u>
Density	2017 g/cm <sup>3</sup>
Bulk density	1.26 g/cm <sup>3</sup>
Moisture content	2%
Particle shape	Spherical/Irregular
Colour	Grey
pH	6.0-10.0
Specific gravity	1.66-2.55
Grain size distribution	Sand silt to silty loam
Water holding capacity	45%-60%
Porosity	45%-55%
Electrical conductivity (dS/m)	0.15-.45

## **1.2 Types of Fly Ash**

Generally fly ash is classified on the basis of coal used in combustion and the amount of lime content present in it. On the basis of that fly ash is usually classified as

- **Class F**

Class F Fly Ash is produced by the burning of harder, older anthracite and bituminous coal typically. This Fly Ash contains less than 20% lime (Ca O) and has pozzolanic nature. Due to pozzolanic properties, the glassy silica and alumina of Class F Fly Ash 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 addition of a chemical activator such as sodium silicate (water glass) to a Class F ash can lead to the formation of a geo-polymer.

- **Class C**

Class C Fly Ash produced from the burning of younger lignite or subbituminous coal. In addition to having pozzolanic properties, it also has some self-cementing properties. Class C Fly Ash will harden and gain strength over time in the presence of water. Class C Fly Ash generally contains more than 20% lime (Ca O). Unlike Class F, self-cementing Class C Fly Ash does not require an activator. Alkali and sulphate (SO<sub>4</sub>) contents are generally higher in Class C Fly Ash.

### **1.3 Environmental Problems Caused by Fly Ash**

Due to increase in demand of power, more thermal plants are established which results in producing huge amount of fly ash. Its disposal is of a serious environmental concern due to its hazardous properties, impact on agriculture and long term risks to ecosystem and human beings both. Some of the problems are:

- **Groundwater contamination**

Since coal contains trace levels of arsenic, beryllium, cadmium, barium, chromium, copper, lead, mercury, molybdenum, nickel, radium, selenium, thorium, uranium, vanadium, and zinc, its ash will continue to contain these traces. Therefore fly ash cannot be dumped or stored where rainwater can leach the metals and move them to aquifers, thus deteriorating the ground water quality.

- **Spills of bulk storage**

Where Fly Ash is stored in bulk, it is usually stored wet rather than dry so that fugitive dust is minimized. The resulting impoundments (ponds) are typically large and stable for long periods, but any breach of their dams or bunding will be rapid and on a massive scale.

- **Exposure concerns**

Crystalline silica and lime along with toxic chemicals are among the exposure concerns. Although industry has claimed that fly ash is "neither toxic nor poisonous," this is disputed. Exposure to fly ash through skin contact, inhalation of fine particle dust and drinking water may well present health risks. Fine crystalline silica present in fly ash has been linked with lung damage, in particular silicosis. Another fly ash component of some concern is lime (CaO). This chemical reacts with water (H<sub>2</sub>O) to form calcium hydroxide [Ca (OH)<sub>2</sub>], giving fly ash a pH somewhere between 10 and 12, a medium to strong base. This can also cause lung damage if present in sufficient quantities.

## **1.4 Utilization of Fly Ash**

Utilization of Fly Ash sustainably is one of the concern of Indian Government, it became an essential need now because of its large generation amount. Today's quantum of production and disposal methods do not lead to sustainability, but may instead lead to a series of disasters. As we know the demand of energy will grow with time therefore the production of Fly Ash will also increase at the same pace, since India has no alternative but to use its poor quality coal which further catalysis the negative impact on environment, therefore Fly Ash with its entire problem is here to stay, so we have to utilise its maximum amount to minimise its negative impacts.

In developed countries like USA, Germany, France, etc. the use of Fly Ash is more than 80% for the manufacture of bricks, cellular concrete blocks, road construction, agriculture, recovery of metals, landfill application, etc. While in India only 40-45% is used for different segments including cement, land development, bricks, road embankments, etc. In India, Fly Ash Mission of Government of India is the nodal agency which put some efforts & taking responsibility for safe disposal and gainful utilization of Fly Ash on sustainable basis. (*Nawaz, 2013*). The different uses of fly ash in various sectors are listed below:

- **Building Materials**

Fly Ash could be used as a key component for variety of construction materials. Since it a pozzolanic material containing silica in good proportion, so it has high potential to be used as

an alternative material for building construction. Some areas of building construction where Fly Ash can be used effectively:

- ✓ Ready-Mixed Fly Ash Concrete
- ✓ Cement
- ✓ Clay Fly Ash Bricks
- ✓ Precast Fly Ash Concrete Units
- ✓ Lime Fly Ash Cellular Concrete
- ✓ Fly Ash sand lime Bricks
- ✓ Lime Fly Ash Bricks

- **Road Construction Material**

Utilization of Fly Ash for road works depending on the intersection between Coal ash and sub-grade soil. Fly Ash can be used for constructing different layers of the road pavement.

- **Agriculture**

Fly Ash has a potential in agriculture and related applications. The Indian Fly Ash is alkaline and as such improves soil quality. Fly Ash improves the pH value of soil when used in low pH acidic soil. It can also be used as insecticide and if used along with bio-waste, it significantly supplements the utility of chemical fertilizers.

- **Mines Fills**

Utilization of Fly Ash in mine fills has potential to consume large quantity of Fly Ash. This single application of Fly Ash can utilise about 1/4<sup>th</sup> of total amount of Fly Ash. It will not only save scarce river sand but also enable to enhance coal recovery from the mines.

- **Environmental Applications**

- ✓ **Absorbent**

The absorbents are prepared by hydrothermal conversion of glass residue of Fly Ash with aqueous alkaline earth matter. These absorbents are suitable for purification of waste gases, drinking water purification, waste water treatment and even include NH<sub>3</sub> removal from waste water.

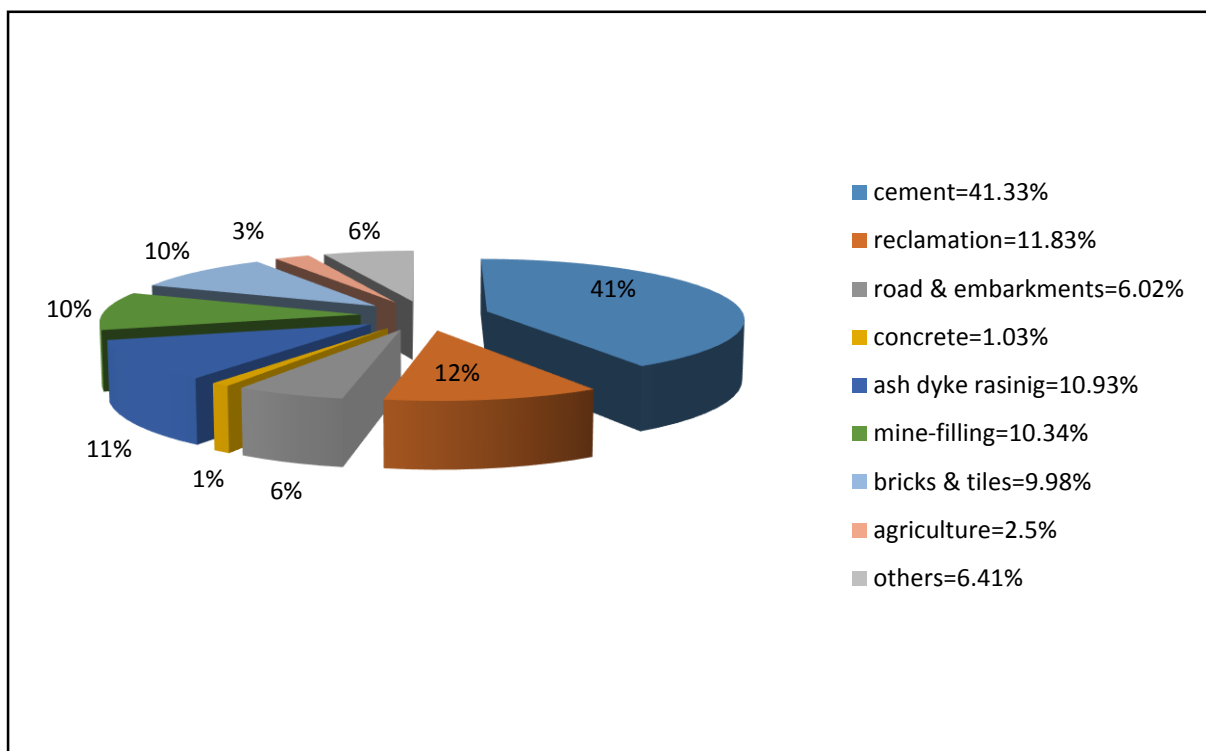
✓ **Silage**

Organic silicon synthesised from Fly Ash had been tried to clean the sea water from oil pollution in UK. The products prepared by treating Fly Ash with upstream of air flow cottoning silanes or organic silicon, so as to absorb the oil agglomerates and precipitate would finally settle at sea bottom together with the pollutants.

✓ **Alkaline resistant fibres**

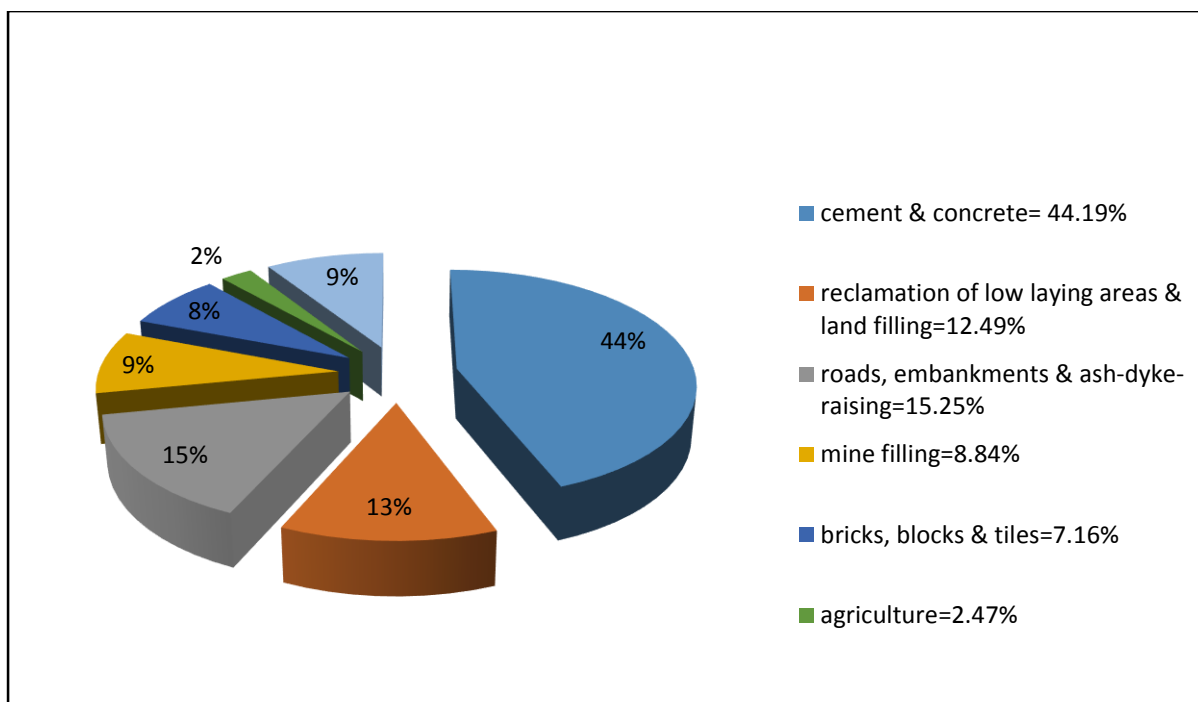
Fly Ash can be utilized as a raw material for making various structural materials and alkaline resistant fibres useful infiltration of aggressive chemicals

As discussed above the various sectors where fly ash can be utilised effectively, the figure 1.1 illustrates us some of the major areas where fly ash was effectively used during the financial year 2012-13 in India and Figure 1.2 illustrates the forecasted use of fly ash in some of the major areas.



**Fig 1.1: Modes of Fly Ash utilization during financial year 2012-13**

(Source: CEA, Report on Fly Ash Generation at Coal/Lignite Based Thermal Power Stations and its Utilization in the Country for the Year 2011-12 and 2012-13, Central Electricity Authority, Ministry of Power, Government of India, New Delhi, India, 2014.)



**Fig. 1.2: Forecast of modes of Fly Ash utilization during financial year 2020-21**

*(Source: Loya et al., 2014)*

## 1.5 Fly Ash Bricks/Blocks

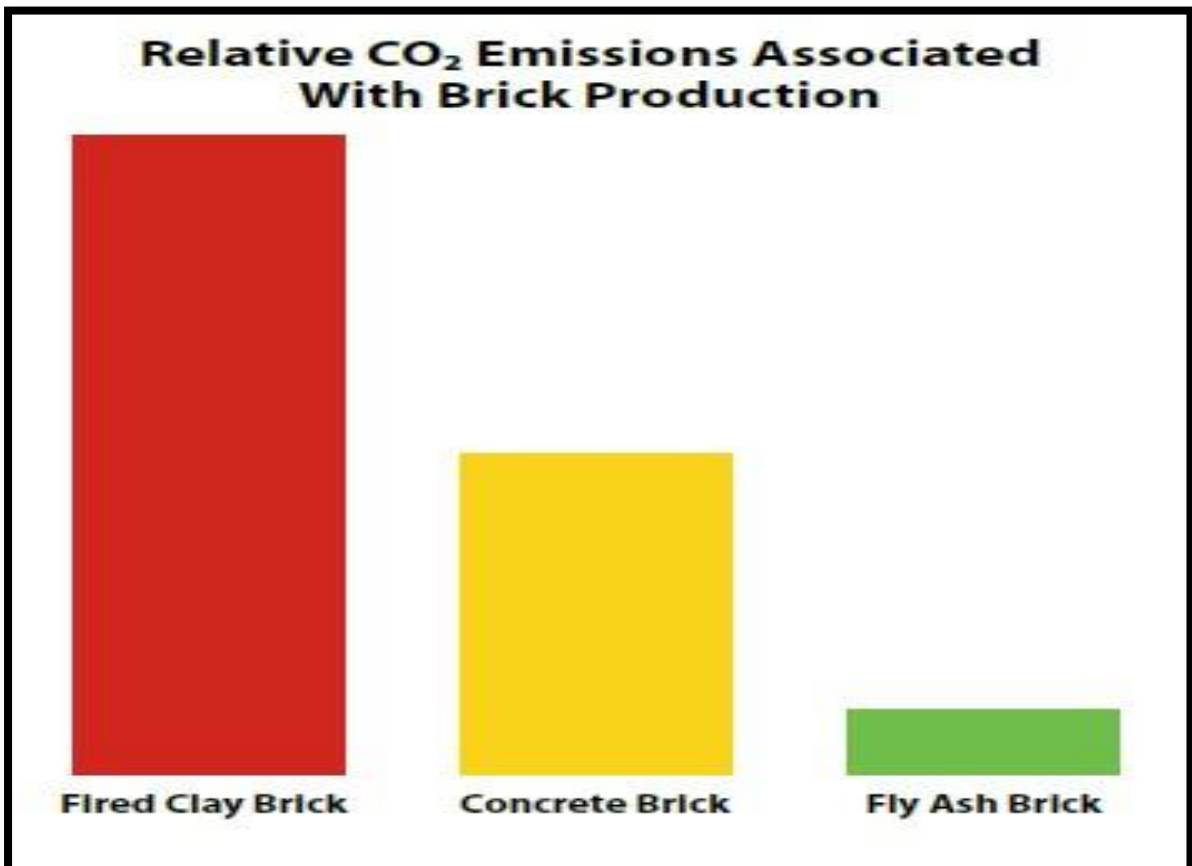
The utilisation of Fly Ash as main raw material in the manufacture of bricks will not only create ample opportunities for its proper and useful disposal but also help in environmental pollution control to a greater extent in the surrounding areas of power plants. The manufacture of Fly Ash bricks is a commercially and technically established technology. Fly Ash bricks can be extensively used in all building constructional activities similar to that of common burnt clay bricks. The Fly Ash bricks are comparatively lighter in weight and stronger than common clay bricks. Fly Ash bricks can be made by using different composition of raw materials like lime, gypsum, steel slag / APCD dust, cement, etc.

## 1.6 Potential benefits of Fly Ash Bricks/Blocks

There are numerous advantages of Fly Ash bricks/blocks some of them are follows:

- The bricks are uniform in shape and size, therefore, require less mortar in brick work.

- Plaster thickness required will be less compared to clay bricks, this saving of cement mortar.
- These bricks are environment friendly as:
  - ✓ It uses Fly Ash which is a by-product of thermal power plant.
  - ✓ Saves agriculture land which is used for the manufacturing clay bricks.
  - ✓ Saves scare of natural resources.
  - ✓ Less energy intensive compared to clay bricks and helps us in keeping clean environment.
  - ✓ Can be manufactured at construction site also.
  - ✓ Protection of environment, as in construction it can partly replace cement, production of which entails energy consumption and CO<sub>2</sub> emissions. Figure 1.3 illustrates the comparison between the CO<sub>2</sub> emission from the manufacturing of different types of bricks and it clearly shows very low CO<sub>2</sub> emission while manufacturing fly ash bricks.



**Fig. 1.3: Carbon dioxide emission due to Brick Production**

(Source: <http://breakingenergy.com/wp-content/uploads/sites/2/2014/02/coal3.jpg>)

## 1.7 Methods of Fly Ash Bricks Production

Based on the availability of raw materials Fly Ash bricks can be produced on large scale with different methods. These methods are:

- **Burnt clay Fly Ash bricks.**

In this method, Fly Ash mixed with local soil can be used to manufacture burnt clay bricks. The manufacturing process is similar to conventional clay brick making process. The compatible physico-chemical & mineralogical properties with soil, capacity to modify the drying behavior of sensitive plastic and saving in fuel requirement make Fly Ash conducive to use in burnt clay bricks.

- **High ash content burnt clay Fly Ash bricks.**

In this method, Fly Ash up to 60% can be used to manufacture burnt clay Fly Ash bricks. The technology is conducive where soil is having very high clay content like black cotton soil, clay. In this method required quantity of Fly Ash and high clayey soil are mixed manually or by mechanized means and then water is added and mixed thoroughly. The wet mix is kept for about 12 hours for its soaking and then hand moulded into bricks.

- **Flux bonded burnt clay Fly Ash bricks.**

In this technology, Fly Ash (about 80%) along with good quality clayey soil (about 10%), flux making additive and small quantity of water are properly mixed and then molded into brick shape through compaction machine. The bricks are air dried and fired in kiln at about 800° - 1000°C. The flux bonding technique is based on addition of certain ceramic glass formers to Fly Ash which will form liquid phase in the temperature of 800-1000°C and bind the Fly Ash particles thus provide strength, brick-red color and the desired properties.

- **Fly Ash lime gypsum bricks.**

In this method, Fly Ash in presence of moisture reacts with lime & gypsum to forms compounds having cementitious properties. This property is used for making Fly Ash lime gypsum bricks. In this method, about 50-65% Fly Ash, 20-30% sand or stone dust, hydrated lime 8-12% and gypsum about 5% are thoroughly mixed in pan mixer. Sufficient quantity of water is added in

this mix to make it semi dry mix. This semi dry mix is fed into vibro/hydraulic press machine for molding into bricks.

- **Fly Ash cements bricks /Fly ash cement-gypsum bricks.**

In this method, Fly Ash bricks can also be made using cement in place of hydrated/sludge lime and gypsum. Raw material mix composition can be 50-60% Fly Ash, 30-40% sand/stone dusts and about 8-10% Ordinary Portland cement. Raw materials in required proportion is thoroughly mixed in pan mixer and made in semi dry mix by adding sufficient amount of water. This mix is fed in vibro/hydraulic press and molded in to bricks.

- **High Fly Ash content bricks (Through Mineral Polymerization).**

In this technique, Fly Ash (about 90-94%), liquid caustic soda lye, additive and water are mixed in required proportion and fed into vibro press for molding into brick shape. Bricks are then kept in air for air curing for about 28 days to gain the strength.

## **1.8 Steel Slag**

The steel-making industry places great emphasis on sustainable development and a general target is the production of steel in a waste-free process. This implies an optimal extent of utilization of the co-products arising from steel-making. Slags, which are an integral part of iron and steel-making processes, comprising more than 80 per cent of all coproducts, are of crucial significance when environmental matters are to be taken into account, (*Hiltunen, et al., 2004*). Steel slag exist as solid waste during melting of steel scrap from the impurities and fluxing agents, which form the liquid slag floating over the liquid crude iron or steel in arc or induction electrical furnaces, or other melting units. The use of such materials not only result in conservation of natural resources but also helps in maintaining good environmental conditions by effective utilization of these wastes material.

However, Iron & Steel Slag is non-metallic in nature and does not contain hazardous materials. Slag is an alternative construction material with superior environment friendly qualities and better product features (*FICCI, 2014*). The slag generated from this process is referred to as Blast Furnace Slag (BFS). The hot metal is then converted to steel in a basic oxygen furnace where the carbon percentage is controlled to obtain desired properties such as

high strength. Another type of slag results from this process and is called Basic Oxygen Furnace Slag (BOFS). This production process is known as the integrated production method. In mini-mills, steel scrap is melted in an electrical arc furnace. The slag generated from the mini-mills is called the Electrical Arc Furnace Slag (EAFS). The characteristic chemical composition & physical properties of Steel Slag is given in Table 1.3 & 1.4: (Korany et al., 2001 & Pajgade et al., 2013)

**Table 1.3: Chemical Composition of Steel Slag (BFS, BOFS and EAFS)**

<b>Chemical Analysis (%)</b>	<b>BFS</b>	<b>BOFS</b>	<b>EAFS</b>
Silicon Dioxide (SiO <sub>2</sub> )	34.05	9.68	22.56
Aluminium Oxide (Al <sub>2</sub> O <sub>3</sub> )	13.35	0.41	3.52
Iron (Fe)	0.83	21.00	20.20
Ferric Oxide (Fe <sub>2</sub> O <sub>3</sub> )	-	7.52	-
Calcium Oxide (Ca O)	37.20	44.29	37.00
Magnesium Oxide (Mg O)	4.54	4.45	3.08
Sulphur (S)	1.44	0.18	-
Sulphur Trioxide (SO <sub>3</sub> )	-	-	0.24
Manganese Oxide (Mn O)	-	8.50	10.20
Phosphorous Oxide (P <sub>2</sub> O)	2.92	-	-
Phosphorous Pentoxide (P <sub>2</sub> O <sub>5</sub> )	-	3.47	0.68
Potassium Oxide (K <sub>2</sub> O)	-	-	0.03
Chromium Oxide (Cr <sub>2</sub> O <sub>3</sub> )	-	-	2.04
Titanium Oxide (TiO <sub>2</sub> )	-	-	0.45
Sodium Oxide (NaO <sub>2</sub> )	1.45	-	-
Barium Oxide (Ba O)	3.95	-	-
Potassium Oxide (K <sub>2</sub> O)	0.27	-	-
Basicity Index	1.09	4.57	1.64

**Table 1.4: Physical Properties of Steel Slag**

<u>Aggregates</u>	<u>Absorption (%)</u>	<u>Specific Gravity</u>	<u>LA Abrasion (%)</u>
Steel Slag	2.5	2.91	27

## **1.9 Environmental Problems Caused by Steel Slag**

The problem of such slag generated from the iron and steel industry is not only hindering the use of millions of square meters of land for more useful purposes, but also contaminating it. Many slag types contain some heavy metals such as barium, titanium and lead. Also, it is well known that toxic substances tend to concentrate in slag. Furthermore, due to the likely leaching, ground water is susceptible to serious pollution problems.

## **1.10 Utilization of Steel Slag**

- Steel slag can be utilised as a filler in Fly Ash bricks and concrete.
- Steel slag used in making safer roads by offering better skid-resistance and improves safety when used in the asphalt layer. The use of steel slag also provides economies of scale when used in the road construction process, addressing India's growing infrastructure needs.
- Steel slag can be used as a soil neutralizer for highly acidic soils.
- Steel slag has a longer life and durability than natural aggregates when used as rail ballast, thus helping save maintenance costs.

## **1.11 Air Pollution Control Devices (APCD) Dust**

APCD dust is made up of solid particles predominantly larger than those found in colloids and capable of temporary suspension in air or other gases. They don't tend to flocculate expect under electrostatic forces, they also don't diffuse but settle under the influence of gravity.

It is produced by crushing grinding or burning of organic or inorganic materials. Generally they are over 20  $\mu$  in diameter, although some are smaller. Fly Ash from chimneys varies from 80-3  $\mu$ ; cement from 150-10  $\mu$ ; foundry dust from 200-1  $\mu$ . Most of the APCD dust particles settle to the ground as dust fall, but particles 5  $\mu$  or smaller tend to form stable suspensions.

## **1.12 Types of APCD Dust Collection Unit**

There are some collection equipment which are installed in industries for the collection of APCD dust as per their requirement. Some of them are

- Settling chambers
- Cyclone separators
- Electrostatic precipitators
- Inertial separators (other than cyclone)
- Filters
- Scrubbers or wet collectors.

As we came to know about the Fly Ash, Fly Ash bricks, steel slag and APCD dust, now we can utilize the Steel slag / APCD dust as filler in manufacturing of Fly Ash bricks by varying their proportions to obtain the best combination. This not only give the environmental benefits but also helps in reducing the cost of raw material to great extent because we're using the waste products and more over with their generation rate is also very high in today's energy demanding world.

## CHAPTER 2

### REVIEW OF LITERATURE

#### **2.0 Overview**

In recent past fly ash and steel slag was treated as the waste product as well as a source of air and water pollution. But now, it is considered as a resourceful material in different sectors. In general, if a 1000 MW power station is using coal of 3500 kilo calories per kg and ash content range is 40-50 per cent, then there would be need of about 500 hectares for disposal of fly ash for about 30 years of operation. Therefore, it is necessary that fly ash should be utilised effectively to minimize environmental degradation.

#### **2.1 International Scenario**

##### **2.1.1 Fly Ash**

Globally, the production of fly ash in India is at the top with 112 MT/yr. followed by china 100 MT/yr., USA 75MT/yr., Germany 40 MT/yr., UK 15 MT/yr., Australia 10 MT/yr., Canada 6 MT/yr., France 3 MT/yr., Denmark 2 MT/yr., Italy 2 MT/yr. and Netherlands 2 MT/yr. But, the utilization rate the trends get reversed with 100% utilization by Netherlands, Italy and Denmark, 85% utilization by France, Australia and Germany followed by Canada 75%, USA 65%, UK 50%, China 45% and India at the last spot with only 38% utilization. (*Dwivedi et al., 2014*).

*Cultrone et al., 2004*, studied the porosity of the brick that depends directly on the mineralogical composition of the raw material and the firing temperature and reported that the fly ash bricks are as durable as clay bricks and in fact in certain aggressive environments perform better than clay bricks.

Bricks whose solid ingredient of 100% fly ash are 28% lighter than clay bricks and possessed compressive strength higher than 40 MPa. The other important characteristics of fly ash bricks like absorption capacity, initial absorption rate, bond strength and durability were evaluated and the results of these characteristics of fly ash bricks were superior to clay bricks. (*Kayali, 2005*). Fly ash might improve the compressive strength of bricks and make them more

resistant to frost. Fly Ash can be used in the range of 40-70%. The other ingredients are lime, gypsum /cement, sand, stone dust/chips etc. (*Lingling et al., 2005*).

High performance fly ash bricks were produced, using fly ash, water & chemical additives such as plasticiser, Carboxymethyl Cellulose (CMC) and  $\text{CaCl}_2$  in small quantities. Addition of  $\text{CaCl}_2$  as an admixture would help to accelerate the curing process significantly. However, there was a disadvantage that it would increase corrosion of any metallic object which may be in contact with these bricks. (*Kayali, 2005*)

*Liu et al., 2005*, reported the manufacture of Class C fly ash, water and air entraining agent. These bricks have improved freezing and thawing properties, as well as achieved greater durability. However, the cost was 20% less than the traditional clay bricks. The stabilisation of Class C fly ash with calcium activators like hydrated lime and Cement Kiln Dust (CKD) in the construction of a structural pavement base layer. He found that the strength and freeze-thaw durability of the stabilised mix increased. Hydrated fly ash has been used in pavement and sub-grade because of its ease of compaction, high strength, low unit weight, economical benefits and abundant supply. (*White, 2006*)

*Lin, 2006*, explored the reuse of different waste products in order to manufacture better quality bricks. Fly ash bricks weigh one-third less than that of conventional clay-fired bricks, enabling a truck to carry more bricks per load, thus reducing shipping costs and improving profit margins. The second economic reason is an abundance of low-cost fly ash available to make the bricks, yielding an excellent product. (*Reidelbach, 1970*)

The positive effect of the addition of fly ash, sand and hydrated lime in the compressive strength of the bricks. In the field of Architectural Heritage, there is almost no research about fly ash addition in the manufacture of replacement bricks for use in restoration work. An essential criterion in this case is that the bricks must have the same physical and mechanical parameters (colour, porosity, hydraulic properties, etc.) as the original bricks used in the building being restored. (*Cicek et al., 2007*)

The technical quality of compositionally different groups of solid bricks fired between 800 and 1000 °C. The textures of the bricks with fly ash were very similar to the textures of those without fly ash, except that the samples with the additive contained spherical fly ash particles with diameters ranging from 0.1 to 10 mm. These particles led to a reduction in the density of the bricks and a substantial improvement in their durability. Use of this additive

could have practical implications as a means of recycling and for achieving cost savings in brick production. (*Cultrone et al., 2009*)

*Gamage et al., 2011*, recommended the use of around 25% of fly ash instead of cement in order to gain effective resultant end products in terms of durability, workability, permeability and density. It has been analysed that black coal fly ash was mainly used in research studies as it contains less impurities than brown coal fly ash.

The compressive strength of 28 days cured clay bricks prisms and fly ash bricks prisms were increased significantly than the 7 days cured clay bricks prisms and fly ash bricks prisms. Further, the compressive strength of 28 days cured fly ash bricks prisms of CM ratio 1:4, 1:5 and 1:6 increased significantly as compared to 28 days cured clay bricks prisms. (*Palanisamy et al., 2012*)

### **2.1.2 Steel Slag**

Steel Slag is being used extensively for various applications in many countries across the world including USA, the European Union, Brazil, Australia and China. Australia utilizes more than 60 to 70 % the steel slag that it generates. On an average, China use 40-50% Europe use 80%, US and other developed countries use 70-80 % of steel slag. (*FICCI, 2014*)

*Korany et al., 2001* deduced that all masonry brick units made by utilizing steel slag showed higher bulk density values than the commercial bricks. Water absorption values for all masonry brick groups were either comparable to or slightly higher than those of the commercial bricks. All groups showed absorption percentages well below the limit and the compressive strength results for all masonry groups at 28-day age were also higher than commercial bricks.

In the utilization of waste steel slag for making bricks the appropriate amount of steel slag (less than 10%) was added to the mixture, the firing temperature could be reduced. The compressive strength and shrinkage reduced and the water absorption increased with increasing the slag content. (*Shih et al., 2004*)

*Weiguo et al., 2007* analysed that the maximum dry of the material increases with the increase in the contents of steel slag and the fly ash while the optimum water content decreases with the increase of the proportion. They also concluded that with the passage of time the strength of the bricks increases.

*Kourounis et al., 2007* reported that cement replacement using steel slag developed lower strength at all ages compared to Portland cement, and the strength of the cementitious pastes decreased with increasing slag content. The slag-cements required less water to give the same workability with the same binder content and had increased setting times. During the investigation of the optimisation the compressive strength of Basic Oxygen Slag-cement Bypass Dust - Plasterboard Gypsum combinations and developed a semi dry mix with the strength of 11 MPa (w/c =0.3) and 31 MPa (w/c=0.13) at 28 days. (*Karami et al., 2012*)

*Hisahiro et al., 2008* analysed a new environmental friendly block "Ferroform" which mainly consist of steel making slag (aggregate) and granulated blast furnace slag (binder). They concluded that ferroform have same strength and durability as concrete and can be used as a substitute for concrete blocks, natural stones and fresh concrete.

According to (*Jegendan et al., 2010*) Ground Granulated Blast-furnace Slag (GGBS) is used throughout the UK and approx. 2 million tonnes are used per annum. It is commonly used as an additive in cement mixes and lime can used to activate the reaction rather than PC. Better durability is expected with higher GGBS content but it also slows the curing time (*Oti et al., 2009*).

The experimental study on performance of concrete containing steel slag aggregate after high temperature exposure and studied that the properties of four steel slag based concrete mixtures with different types of cement pastes. The percentage replacement of fine aggregate using steel slag was adopted to be 60%. The compressive strength and modulus of elasticity of steel slag concrete was comparable with dolomite based mixture up to a temperature of 600°C, beyond which it decreases. (*Netinger et al., 2012*)

*John et al., 2013* concluded that the slag fines can be used as fine aggregate in concrete. The replacement ratio of the fine slag shall be limited to 30%. During the studies on properties of super-fine steel slag prepared by mechanical grinding. The cementitious properties of super-fine steel slag were compared with ordinary steel slag, cement & fly ash. The results obtained shows its replacement tends to weaken the cementitious properties of composite binders. On comparing with fly ash, the super-fine steel slag contributes more towards hardening at early stages than later stage and the use of super fine steel slag was reported to be expensive. (*Wang et al., 2013*)

The concrete with mixed construction and demolition waste as fine aggregate and steel slag as coarse aggregate reached 30 MPa 28-day compressive strength and showed adequate

durability for low grade applications. Also, 50% cement replacement with high calcium fly ash and use only of steel slag and recycled aggregates resulted in concrete of adequate strength and considerable environmental gains. (*Anastasiou et al., 2014*)

*Pang et al., 2015* investigate the possibility of replacement of common natural aggregate with carbonated granulated steel slag aggregate are the results showed significant improvement in the compressive strength and volume stability with drop in water absorption, porosity and free calcium oxides.

## **2.2 National Scenario**

### **2.2.1 Fly Ash**

The use of cement in the manufacture of construction products can be reduced by substitution with fly ash. While the use of cement cannot be completely avoided, for certain products like tiles, the substitution can go up to 50 per cent. These products are known to be stronger and more cost-effective because of substantial savings on raw material. Full utilization of generated fly ash in India, will provide employment potential for 3000 people. (*Patil et al., 2013*)

Several studies show that fly ash brick is a far superior building material than burnt clay brick. The use of fly ash brick provides a stronger, more durable construction that is better protected from efflorescence and salinity with meaningful savings in construction costs. But the greater benefit lies in controlling two major ecological problems of fly ash disposal and the reduction of cultivable land that is needed for the production of burnt clay brick. In addition to brick products, fly ash has been utilized in the manufacture of lightweight roofing products such as rigid roofing tiles. (*Ahmaruzzaman, 2010*)

According to *Advanced Materials and Processes Research Institute Council of Scientific & Industrial Research (ASIR)*, Fly Ash can be used for production of bricks. This is due to the fact that both clay and Fly Ash are not much different in respect of their chemical composition. Further, the residual carbon content in Fly Ash brings about an economy in fuel consumption during firing of bricks. When Fly Ash is used for construction of bricks, about 0.25 to 0.80 times of clay can be replaced by Fly Ash. The bricks produced using Fly Ash has the advantage of being lighter in weight as the density of Fly Ash is about one half of the clay. (*Nawaz, 2013*).

*Alam et al., 2010* used fly ash type 'C' as a raw material in Fly ash bricks and also treated the fly ash with 10% cement or 5% coarse sand or 15% sand or different combination of sand and lime stone dust with or without 0.2% geo fibre. He observed that treated fly ash is superior in strength and the best result is found when the brick is made of 50% of fly ash and 25% admixture of sand and max tenth part by weight of lime stone dust. They found that the brick so made achieved the compressive strength that is close to the value of standard first class brick in India.

The Central Fuel Research Institute (CFRI), Dhanbad has developed a technology for fly ash utilization for the manufacture of building bricks in which Fly Ash can be used in the range of 40-70%. (*Senapati et al., 2011*)

*Patil et al., 2013* reported that Fly ash from coal-fired thermal power stations is an excellent potential raw material for the manufacture of construction material like blended cement, fly ash bricks, mosaic tiles and hollow blocks. It also has other, high volume applications and can be used for paving roads, building embankments, and mine fills. Fly ash products have several advantages over conventional products.

In India the current production of clay brick exceeds 100 billion bricks a year. Under such circumstances fly ash brick is technically acceptable, economically viable and environment friendly solution and it may not be wrong to target to produce at least 2 billion fly ash bricks per year. It would consume about 5 million tonne of fly ash /year, yielding a net saving of around Rs. 20 crores per annum. (*Dwivedi et al., 2014*)

### **2.2.2 Steel Slag**

In India, the current production of steel slag is around 12 million tonnes per annum and its use is less. However, with steel production on the rise, slag production is also expected to increase manifold. In contrast with other nations, most slag produced in India, especially steel slag, is discarded, however, this is increasingly becoming a problem due to paucity of land; utilization of slag is in the trial phase. Right now, there is no statutory regulation or norm for controlling the slag generation or for utilization of slag. However, in 2003 the MoEF came up with Corporate Responsibility on Environmental Production (CREP), the initiative aimed at waste minimization through 100% utilization of slag by recycling or reuse by 2008. However, the country has not been able to achieve this target due to the voluntary nature of

the initiative and as well due to lack of interest by end-user segments. In India, slag utilisation is less than 20%. (FICCI, 2014)

*Singh et al., 1995* reported that the compressive strength of the gypsum anhydrite- slag pastes increased with curing time. The results also showed the combination of gypsum and slag with a small amount of other chemical activators achieved higher compressive strength.

Steel melting through electric arc furnace used to the extent of 30–40 wt.% with other conventional raw materials for developing vitreous ceramic tiles, The fired products showed relatively higher density with shorter firing range and good strength properties. (*Sarkar et al., 2010*)

*Nadeem et al., 2012* analysed that full substitution of slag aggregate with normal crushed coarse aggregate improved the flexure and split tensile strength by 6% to 8% at all replacements and in case of replacing fine aggregate & both the aggregates( Fine & coarse) with slag, the strength improvement was at 30% to 50% replacements.

*Yadu et al., 2013* evaluated the potential of granulated blast furnace slag in stabilizing the soft and tested the performance of granulated blast furnace slag stabilized soil California bearing ratio test swelling pressure and unconfined compressive strength tests.

*Pajgade et al., 2013* evaluated the durability of concrete made with steel slag aggregates and carried out experimental investigations to evaluate effects of replacing aggregate (coarse and fine) with that of slag on various type of concrete grade. From the results it was analysed that as the percentage of steel slag has increased, the strength of aggregate increases. After 75% replacement of sand as steel slag slight decrease in strength was observed but still it is higher than 0% replacement without any adverse effect on the strength of concrete.

The utilization of steel slag as the partial replacement of fine aggregate in M20 concrete and found that the partial substitution of natural aggregates permits a gain in compressive, tensile and flexural strength of concrete. He also talked about cost reduction of concrete. (*Kothai et al., 2014*)

From the reviewing of literature we came across many benefits of using the fly ash and steel slag in brick manufacturing. The physical, chemical and mechanical properties of steel slag and steel slag concrete were studies by researchers revealed that, their properties are

comparable with those of natural aggregates. The mechanical properties of hardened concrete incorporated with steel slag shows better results compared to conventional concrete, therefore steel slag can be used as a filler in fly ash bricks. It makes bricks more strong against loads by increasing its compressive strength and reducing the water absorption capacity. Moreover these have uniform shape and size which reduces the consumption of mortar during wall making. It also seems to be very beneficial to environment because of the utilization of the waste products which have detrimental effects on environment including human and animal life. It is also very cost effective as the raw material is a waste product only.

## **CHAPTER 3**

### **LACUNAE & OBJECTIVES**

#### **3.1 Lacunae**

From the reviewing of literature, we came to know about that most of the research was in the field of fly ash bricks with natural aggregates as filler materials. There was limited research in the utilization of steel slag or APCD dust as filler in fly ash bricks/blocks. Following are some gaps were found in reviewing of literature:

- Some reports discussed the utilization of fly ash in bricks but it is very low in comparison to global trends this may be because of the unawareness among the people about the fly ash bricks in India.
- The utilization of steel slag in construction sector is very low, as there is no interest shown by industries in taking initiative toward this area.
- More durability studies are to be conducted for the evaluation of performance of concrete containing fine induction furnace slag.
- The use of steel slag as filler in the manufacture of fly ash bricks needs to be explored.
- Steel slag is being extensively used in landfills across the world, and is a viable alternative for use in India.
- In the field of APCD dust utilization in fly ash bricks, no research are available. Thus, its use needs to be assessed.

#### **3.2 Objectives of Present Study**

The main goal of this study is to find the feasibility of using steel slag/APCD dust in fly ash bricks/blocks. The study was carried out with following objectives:

- 1) Assessment of use of steel melting furnace slag/APCD dust as filler in the manufacture of fly ash bricks; and
- 2) Evaluation of the properties of synthesized bricks/blocks and its associated environmental impacts.

## **CHAPTER 4**

### **MATERIALS AND METHODS**

This chapter describes the materials, manufacturing and methods used during the study and experimentation. It includes the instruments and methods used during the testing of bricks/blocks.

#### **4.1 Materials**

##### **4.1.1 Fly Ash**

Fly ash is a by-product from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse in suspension and float out of the combustion chamber with the exhaust gases. As the fused material rises, it cools and solidifies into spherical glassy particles called fly ash. Fly ash is collected from the exhaust gases by electrostatic precipitators or bag filters. The fine powder does resemble portland cement but it is chemically different. The fly ash used in our bricks was collected from Thermal Power Plant, Roopnagar.

##### **4.1.2 Steel Slag**

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. The steel slag used in bricks was collected from steel furnaces, located in Mandi Gobindgarh.

##### **4.1.3 APCD Dust**

It is produced by crushing grinding or burning of organic or inorganic materials. Generally they are over 20  $\mu$  in diameter, although some are smaller. Most of the APCD dust particles settle to the ground as dust fall, but particles 5  $\mu$  or smaller tend to form stable suspensions. The APCD dust used in bricks was collected from industries, located in Ludhiana.

##### **4.1.4 Cement**

Cement is a fine mineral powder manufactured with very precise processes. Mixed with water,

this powder transforms into a paste that binds and hardens when submerged in water. Because the composition and fineness of the powder may vary, cement has different properties depending upon its makeup. Ordinary Portland cement of grade 53 is used as binder. Lime has same properties as cement, it can be used as cement replacement

## 4.2 Instruments and Equipment

### 4.2.1 Fly Ash Bricks, Blocks Making Machine & Related Equipment

A semi-manual stationary Welcon model S-3 Fly ash based bricks/blocks making machine is used. It manufacture bircks/blocks by vibro-compaction technique. It includes a bricks/ blocks manufacturing unit, Welcon made conveyor belt, materials mixing discharge & storage hopper and manual shifting trolley. The following table shows its production capacity:

**Table 4.1: Production Capacity of Bricks/Blocks Making Machine**

<u>Product</u>	<u>Size(mm)</u>	<u>No. of Products per Stroke</u>
Bricks	230x110x75	10
Blocks	400x200x150	2
Blocks	300x200x150	2 or 4

Average production 1000 to 1200 no bricks/hrs.



**Figure 4.1: Brick/Block making machine**

#### 4.2.2 Oven

An automatic oven from Oven universal Company (NWS 143) was used for drying of bricks before water absorption test. The maximum temperature of oven was 250 °C and the capacity of oven was 336 litres.



**Figure 4.2: Oven**

#### 4.2.3 Water Absorption Container

A normal size tub with high walls made of plastic was used for water absorption test of bricks/blocks. The capacity of container was 175 litres.



**Figure 4.3: Water absorption container**

#### 4.2.4 Weighing Machine

An electronic light duty weighing scale from Avery Company (1112A) with capacity upto 60 kg was use for measuring the weight of bricks & blocks before and after water absorption test. It was calibrated from time to time for accurate results.



**Figure 4.4: Weighing machine**

#### 4.2.5 pH Meter

A digital pH Meter (PH3) from Hach sensION+ company was used to monitor the pH of water before and after water absorption test and the pH was adjusted with the help of NaOH (0.1 N) and HCl (0.1 N). Freshly prepared buffer solutions (of pH 4 and 9) were used to calibrate the instrument from time to time throughout the research.



**Figure 4.5: pH meter**

#### **4.2.6 Mortar Mixing Pan and Masonry Trowel**

Before compressive strength test of there is a need to fill the frog of bricks for that a desired proportion of cement, sand and water mix was used and this mix was prepared in mortar mixing pan with the help of masonry trowel. Masonry trowel was also used in filling & levelling of frog fill in accordance of brick surface.



**Figure 4.6: Mortar mixing pan & Masonry trowel**

#### 4.2.7 Jute Bags

Bags made of jute were used for cutting of bricks and blocks.



**Figure 4.7: Jute bags**

#### 4.2.8 Compressive Testing Machine

Advance compressive testing machine (ACTM) from Aimil Company with capacity up to 5000 KN was used for compressive test on bricks/blocks and it was calibrated with an accuracy of  $\pm 1\%$ .



**Figure 4.8: Advance compressive testing machine**

## 4.3 Methodology

### 4.3.1 Brick/Block Synthesis

The manufacturing process of Fly ash bricks/blocks requires fly ash, steel slag, APCD dust, lime/ cement to be mixed in a suitable proportion according to the desired composition. Steps involved in manufacturing were:

- **Pan Mixing**

The raw materials were brought by wheel barrow/pull carts to the pan mixer and the raw materials in desired quantities were poured in the pan mixer. Pan mixer have rotatory grinders which helps in making the mixture smooth and free from lumps, once the dry mixing is done then desired amount of water was added to make mixture wet and ready for moulding.

- **Conveyor**

Once the mixing is done and the desired mix is prepared, then the mix was shifted to the conveyor system which carry the mix to the moulding system.

- **Moulding**

The conveyor drops the mix in the filling box above the moulds. The filling movement made by cylinder can be controlled over desired section of the mould to assure equal filling. After filling the moulding machine compacted the mixture in the moulds through vibro-compression.

- **Drying & Curing**

Once the bricks were taken out of the mould, they were air dried for about 1-2 days. After drying water curing was subsequently done for about 14 days to allow required strength to be achieved.

- **Product**

The manufactured bricks and blocks were of size 230x110x75mm and 300x200x150mm respectively. Different ranges of Fly Ash 35-70%, steel slag 21-45% APCD dust 5-20% were used in the manufacturing of bricks/blocks.

### 4.3.2 Testing of Bricks/Blocks

Synthesised bricks were tested for water absorption, compressive strength & effluents were tested for heavy metals (lead, iron & zinc).

#### I. Water Absorption Test (24-hours Immersion Cold Water Test)

The purpose of conducting this test is to check the water absorption capacity of bricks and blocks and testing was done according to Indian Standard Code IS-3495 (Part-II):1976.

- **Procedure**

Dry the specimen in a ventilated oven at temperature of 105 to 115°C till it attains substantially constant mass. Cool the specimen to room temperature and obtain its weight ( $M_1$ ). Specimen warm to touch shall not be used for the purpose. Immerse completely dried specimen in the clean water at a temperature of  $27 \pm 2^\circ\text{C}$  for 24 hours. Remove the specimen and wipe out any traces of water with damp cloth and weigh the specimen. Complete the weighing 3 minutes after the specimen has been removed from water and obtain its weight ( $M_2$ ). Water absorption, percent by mass, after 24 hours immersion in cold water is given by the following formula:

$$\frac{M_2 - M_1}{M_1} \times 100$$

Usually the water absorption should not be less than 20%.

#### II. Compressive Strength Test

The purpose of conducting this test is to check the load at which the brick/block fails. The testing was done according to Indian Standard Code IS-3495 (Part-I):1976

- **Procedure**

Remove unevenness observed in the bed faces to provide two smooth and parallel faces by grinding. Immerse the samples in water at room temperature for 24 hours. Remove the specimen and drain out any surplus moisture at room temperature. Prepare cement mortar (1:3) and fill the frog and all voids in the bed faces with it. Store the sample prepared under jute bags for 3 days. Remove and wipe out any traces of moisture. Measure the area of 2 horizontal faces.

Place the specimen with flat faces horizontal and mortar facing upward between two plywood sheets and centre carefully between plates of testing machine. Apply load axially at a uniform rate of 14 N/mm<sup>2</sup> per minute till the failure occurs and note the maximum load at failure.

$$\text{Compressive strength (N/Mm}^2\text{)} = \frac{\text{Maximum load at failure in N}}{\text{Average area of the bed in mm}^2}$$

### III. Effluent Test

This test was conducted to check the presence of heavy metals (iron, lead, zinc, etc.) in effluent from water absorption test of bricks. If the range of these exceeds the permissible range than the bricks are not good for construction. Testing of the waters sample was done by SAI Labs, Patiala by APHA 22<sup>nd</sup>. Edn.3111B, Atomic Absorption Spectrometer (AAS) & Microwave Plasma Atomic Emission Spectrometer (MP-AES).

- **Procedure**

- ✓ Digest the sample required amount of sample with concentrated HNO<sub>3</sub> (2 ml in 50 ml sample).
- ✓ Run the samples for metals with Atomic Absorption Spectrometer (AAS) or Microwave Plasma Atomic Emission Spectrometer (MP-AES).

## **CHAPTER 5**

### **RESULTS AND DISCUSSIONS**

In the manufacturing of fly ash bricks and blocks of size 230x110x75mm and 300x200x150mm respectively, the replacement of conventional filler materials has been explored with steel slag and APCD dust. This chapter presents the results of water absorption and compressive strength of bricks especially manufactured from fly ash, steel slag and APCD dust. Water absorption Test (24-hours Immersion Cold Water Test) & compressive strength test were performed on bricks having different compositions of fly ash, steel slag & APCD dust. All the results of testing are categorised according to the different composition of the bricks/blocks. Table 5.1 shows all the compositions used for bricks/blocks manufacturing. After 14 - 21 days of curing of bricks/blocks, the tests mentioned in Chapter 4 were performed on the manufactured bricks/blocks.

**Table 5.1: Different composition of Bricks/Blocks**

<b><u>Sample Code</u></b>	<b><u>Materials Used (%)</u></b>
Composition-1 (C-1, Brick)	FA*-50%, AD*-20%, SS*-25%, C*-5%
Composition-2 (C-2, Brick)	FA*-50%, AD*-20%, SS*-23%, C*-7%
Composition-3 (C-3, Brick)	FA*-50%, AD*-20%, SS*-21%, C*-9%
Composition-4 (C-4, Brick)	FA*-55%, AD*-15%, SS*-21%, C*-9%
Composition-5 (C-5, Brick)	FA*-55%, AD*-15%, SS*-23%, C*-7%
Composition-6 (C-6, Brick)	FA*-60%, AD*-10%, SS*-22%, C*-8%
Composition-7 (C-7, Brick)	FA*-60%, AD*-10%, SS*-21%, C*-9%
Composition-8 (C-8, Brick)	FA*-65%, AD*-5%, SS*-21% ,C*-9%
Composition-9 (C-9, Brick)	FA*-45%, SS*-45%, C*-10%
Composition-10 (C-10, Brick)	FA*-70%, SS*-21%, C*- 9%
Composition-11 (C-11, Brick)	FA*-35%, WL*-16%, SS*-30%, S*-15%, C*-4%
Composition-12 (C-12, Block)	FA*-70%, SS*-21%, C*-9%
Composition-13 (C-13, Block)	FA*-45%, SS*-45%, C*-10%
Composition-14 (C-14, Block)	FA*-35%, WL*-10%, SS*-34%, S*-15%, C*-6%

*FA\*- Fly Ash, SS\*- Steel Slag, AD\*- APCD dust, WL\*- Wet Lime, S\*- Sand & C\*- Cement*

Each composition was tested in batch of four bricks of same composition and average result was considered. For assessing the effect of pH on bricks, pH of water during water absorption test was also varied. In addition, effluent from water absorption was also tested for heavy metals like Fe, Zn and Pb.

## 5.1 Variation of Fly Ash in Bricks

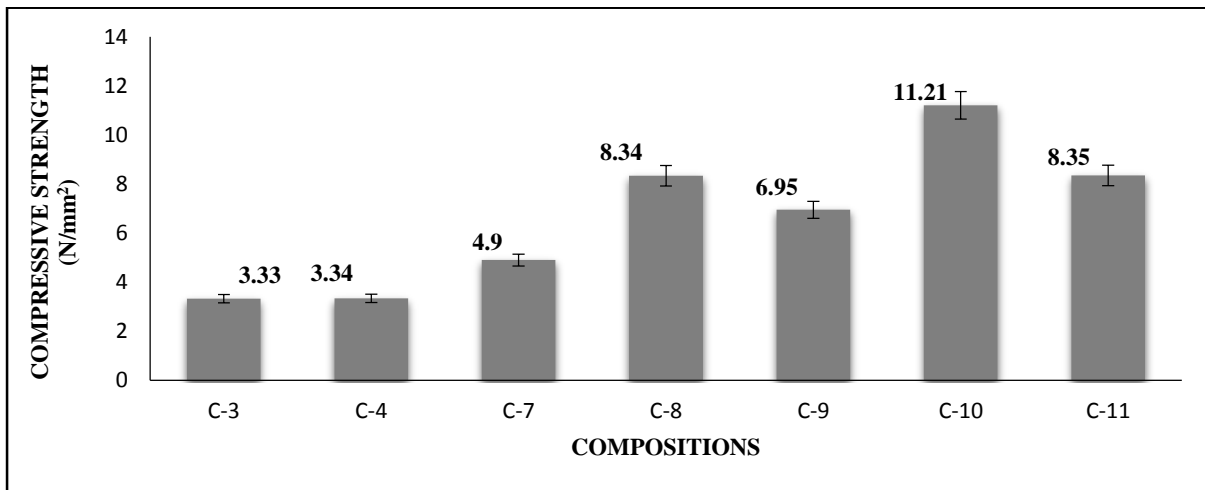
Utilization of fly ash in construction sector is one of the most explored area. Fly ash is pozzolanic in nature, which help fly ash to attain cementing properties. Due to this fly ash can replace large amount of cement products form different construction sectors. As far as bricks are concerned, fly ash have the potential of replacing conventional clay bricks because fly ash bricks are much more superior to conventional clay bricks. In the present study, the fly ash proportion was varied from 35 to 70% in different compositions to see the effects on manufactured bricks. Table 5.2 shows the test results of variations of fly ash on water absorption and compressive strength test.

**Table 5.2: Variations of Fly Ash in Fly Ash Bricks**

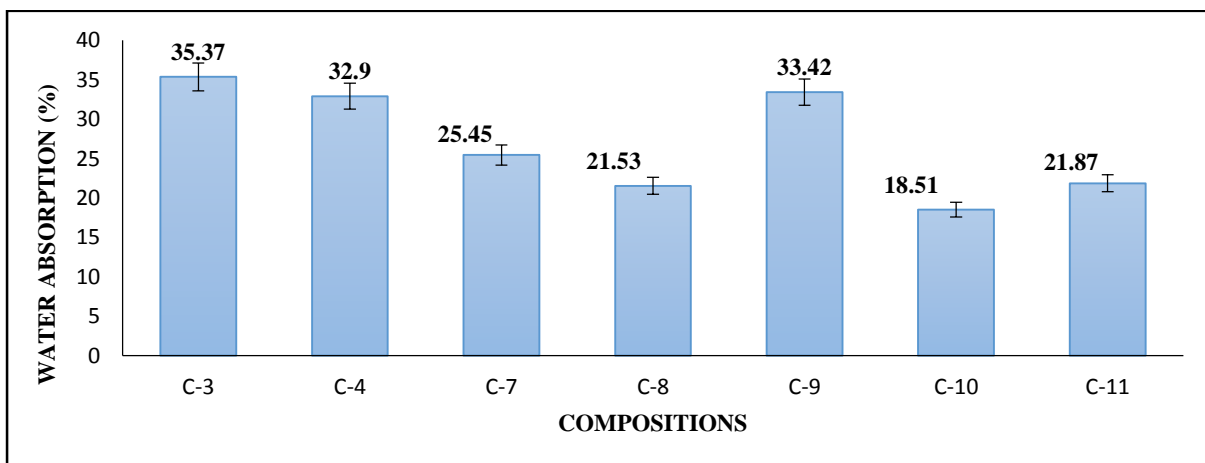
<u>Samples</u>	<u>Composition</u>	<u>Water Absorption (%)</u>	<u>Compressive Strength (N/mm<sup>2</sup>)</u>
C-3	FA*-50%, AD*-20%, SS*-21%, C*-9%	35.37	3.33
C-4	FA*-55%, AD*-15%, SS*-21%, C*-9%	32.90	3.34
C-7	FA*-60%, AD*-10%, SS*-21%, C*-9%	25.45	4.90
C-8	FA*-65%, AD*-5%, SS*-21% ,C*-9%	21.53	8.34
C-9	FA*-45%, SS*-45%, C*-10%	33.42	6.95
C-10	FA*-70%, SS*-21%, C*- 9%	18.51	11.21
C-11	FA*-35%, WL*-10%, SS*-34%, S*-15%, C*-6%	21.87	8.35

Results in Fig. 5.1 (a) & 5.2 (b) depict that, as the percentage of fly ash was increased there was a significant improvement in the compressive strength and decrease in water absorption. The composition C-10 with fly ash 70%, furnished the best result with compressive strength of 11.21 N/mm<sup>2</sup> when compared to 3.5 to 5 N/mm<sup>2</sup> of conventional clay bricks. The values of water absorption for the composition C-10 was 18.51% which is well below 20% required for a good brick.

The high compressive strength of C-10 bricks may be attributed to the cementing properties of fly ash used in manufacturing bricks. Improvement in the compressive strength features the well build matrix in the manufactured bricks, which help other materials to make strong bonds with each other. The water absorption rate was also low, as there were less voids because of the compact matrix results in less permeability in the bricks. Previous studies also indicated that fly ash used in range of 40 to 70% might improve the compressive strength of bricks. (*Linging et al., 2005*).



**Figure 5.1 (a): Variation of Compressive Strength with Different Composition of Fly Ash**



**Figure 5.1 (b): Variation of Water Absorption with Different Composition of Fly Ash**

## 5.2 Variation of Steel Slag in Bricks

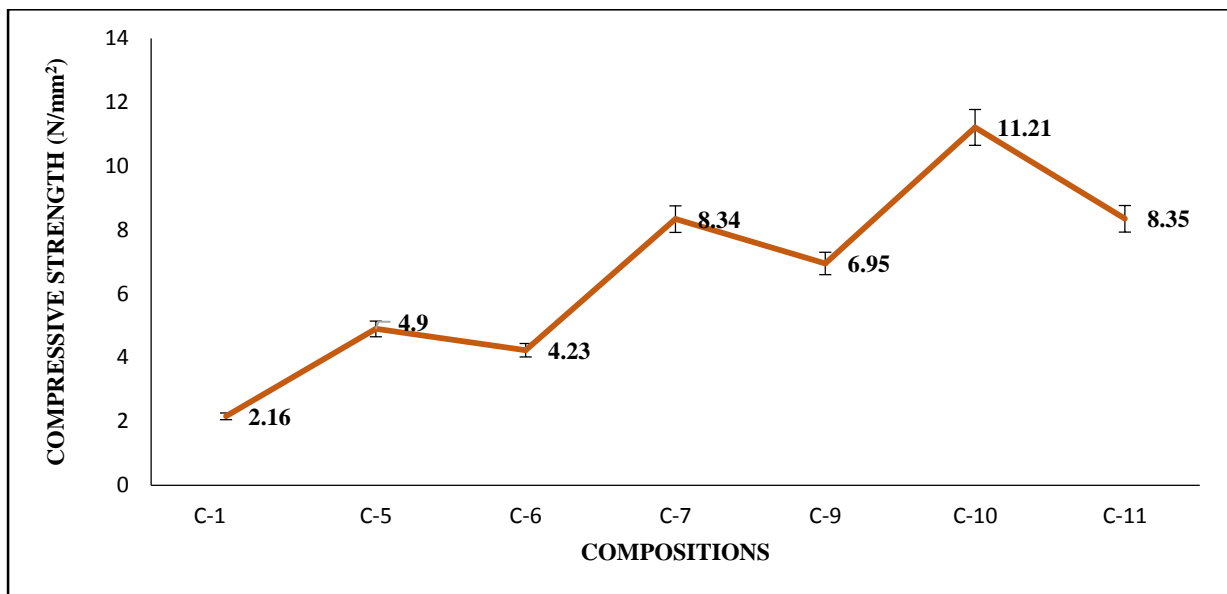
The studies on the use of steel slag in fly ash bricks open new gateways for its utilization in construction sector and provide steel slag a new platform for replacing the conventional aggregates. In the present study, the steel slag proportion was varied in range from 21 to 45% in different compositions to assess the effect on manufactured bricks in terms of compressive strength and water absorption. Table 5.3 shows the test results of variations of steel slag on water absorption and compressive strength test.

**Table 5.3: Variations of Steel Slag in Fly Ash Bricks**

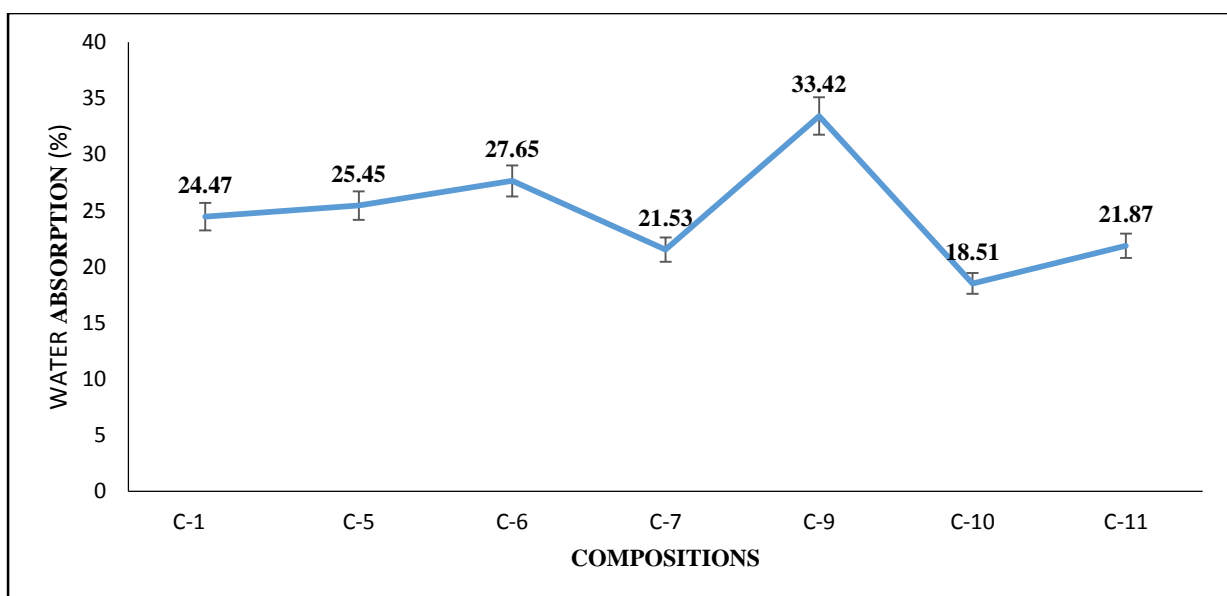
<u>Samples</u>	<u>Composition</u>	<u>Water Absorption (%)</u>	<u>Compressive Strength (N/mm<sup>2</sup>)</u>
C-1	FA*-50%, AD*-20%, <b>SS*-25%</b> , C*-5%	24.47	2.16
C-5	FA*-55%, AD*-15%, <b>SS*-23%</b> , C*-7%	25.45	4.90
C-6	FA*-60%, AD*-10%, <b>SS*-22%</b> , C*-8%	27.65	4.23
C-7	FA*-60%, AD*-10%, <b>SS*-21%</b> , C*-9%	21.53	8.34
C-9	FA*-45%, <b>SS*-45%</b> , C*-10%	33.42	6.95
C-10	FA*-70%, <b>SS*-21%</b> , C*- 9%	18.51	11.21
C-11	FA*-35%, WL*-16%, <b>SS*-30%</b> , S*-15%, C*-4%	21.87	8.35

Results in Fig. 5.2 (a) & 5.2 (b) shows that, with the increase in the amount of steel slag in the mix for bricks manufacturing, there was a decrease in the water absorption and increase in the compressive strength. The composition C-10 with steel slag 21%, furnished good compressive strength of 11.21 N/mm<sup>2</sup> when compared to 3 to 5 N/mm<sup>2</sup> of conventional bricks. The water absorption of composition C-10 was 18.51% which is well below 20% required for a good brick.

As steel slag aggregates expected to have dense structure with minimum voids, so there was decrease in the permeability in bricks that results in decrease in water absorption. As, steel slag aggregates have similar properties in comparison to conventional aggregates, hence it bonded strongly with the other materials resulting in less voids and compacted bricks, thus favouring higher compressive strength too. Previous studies also indicated that there is a useful possibility of replacement of conventional natural aggregates with granulated steel slag aggregates which results in improvement in compressive strength by 15-20%. (Bo Pang *et al.*, 2015)



**Figure 5.2 (a): Variation of Compressive Strength with Different Composition of Steel Slag**



**Figure 5.2 (b): Variation of Water Absorption with Different Composition of Steel Slag**

### 5.3 Variation of APCD Dust in Bricks

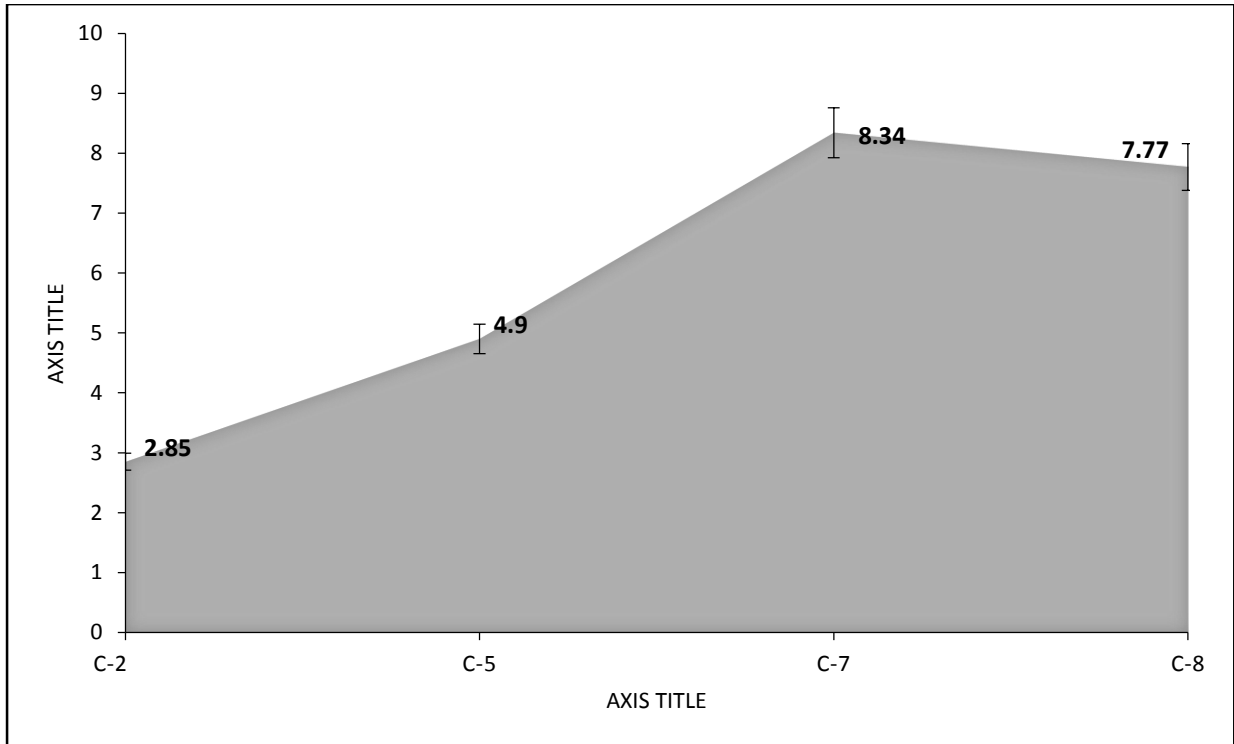
Air Pollution Control Devices (APCD) dust is a mixture of solid particles larger than colloidal particles. APCD dust is usually collected with the help of electrostatic precipitators, it is very fine in nature and get airborne very easily. The field of effective utilization of APCD Dust is yet to be explored. They can be used as fillers in construction industries where there is a need for fine aggregates. In this study, the APCD dust was varied from 5 to 20% in different compositions to evaluate the effects on compressive strength & water absorption of the manufactured bricks. Table 5.4 shows the test results of variations of steel slag on water absorption and compressive strength test.

**Table 5.4: Variations of APCD Dust in Fly Ash Bricks**

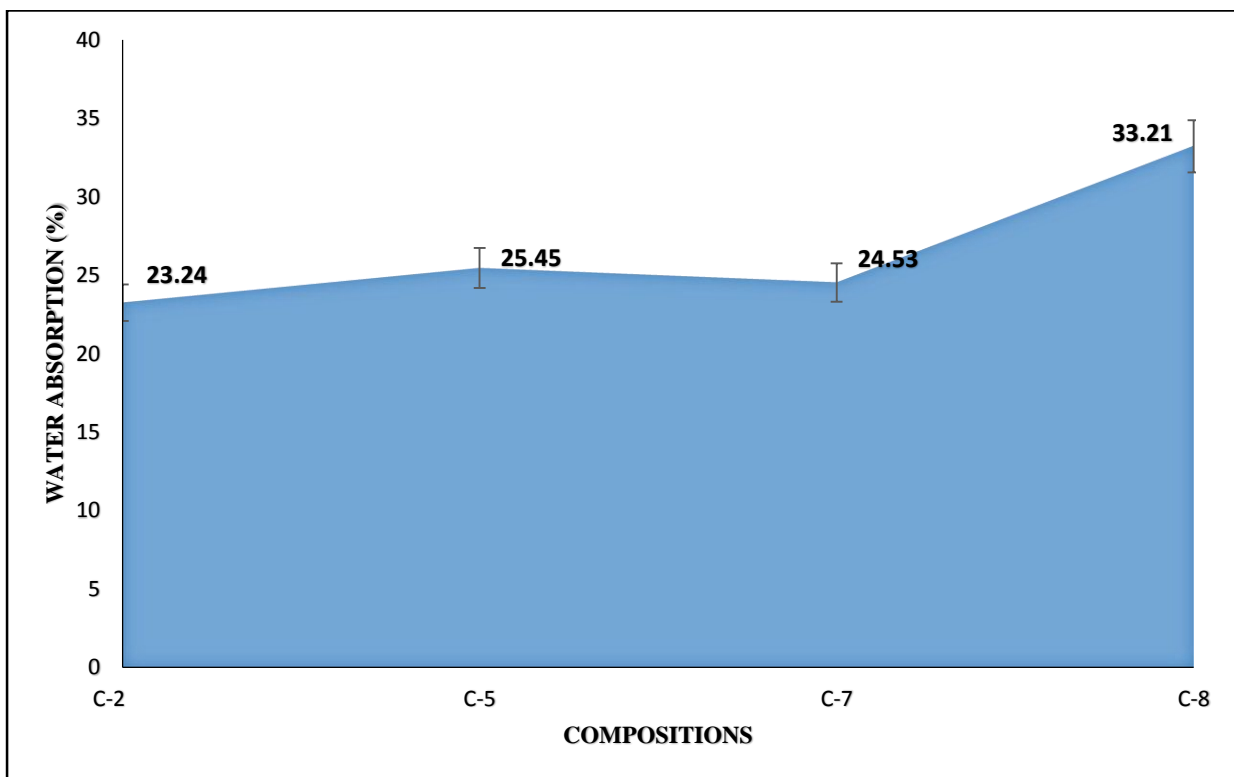
<u>Samples</u>	<u>Composition</u>	<u>Water Absorption (%)</u>	<u>Compressive Strength (N/mm<sup>2</sup>)</u>
C-2	FA*-50%, AD*-20%, SS*-23%, C*-7%	23.24	2.85
C-5	FA*-55%, AD*-15%, SS*-23%, C*-7%	25.45	4.90
C-7	FA*-60%, AD*-10%, SS*-21%, C*-9%	24.53	8.34
C-8	FA*-65%, AD*-5%, SS*-21% ,C*-9%	33.21	7.77

Fig. 5.3 (a) & 5.3 (b) shows that with the increase in the amount of APCD dust there was decrease in the compressive strength and the maximum compressive strength of 8.34 N/mm<sup>2</sup> was observed with 10% APCD dust. The water absorption values of the bricks prepared with APCD dust were on higher side which is not desirable. Hence composition C-7 with APCD dust 10% gives the better results with compressive strength up to 8.34 N/mm<sup>2</sup> and water absorption of 24.53%.

APCD dust have very fine structure which helps in filling the voids present in the bricks that results in increase in compressive strength, but due to very fine size of APCD dust particles, sometimes it was unable to bond strongly enough with rest of the mixture, results in higher water absorption. But if APCD dust is used in small amount with some water repelling materials, then it may prove beneficial.



**Figure 5.3 (a): Variation of Compressive Strength with Different Composition of APCD Dust**



**Figure 5.3 (b): Variation of Water Absorption with Different Composition of APCD Dust**

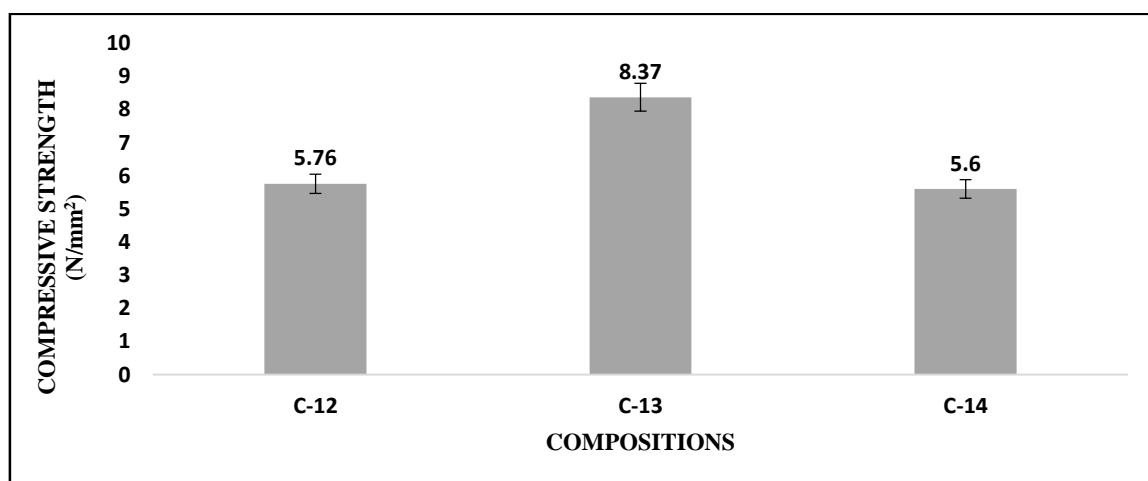
#### 5.4 Variations of Steel Slag & Fly Ash in Blocks

Blocks are different form bricks as they are bigger in size & have more weight. They are usually used in super structures or industries where walls are meant to be thicker as compared to conventional building walls. Blocks have more stability and provide good insulation from outer environment. The blocks were manufactured with different proportions of fly ash ranging from 35-70% and steel slag ranging from 21 to 45%. Table 5.5 shows the test results of variations of steel slag and fly ash on water absorption and compressive strength test of blocks.

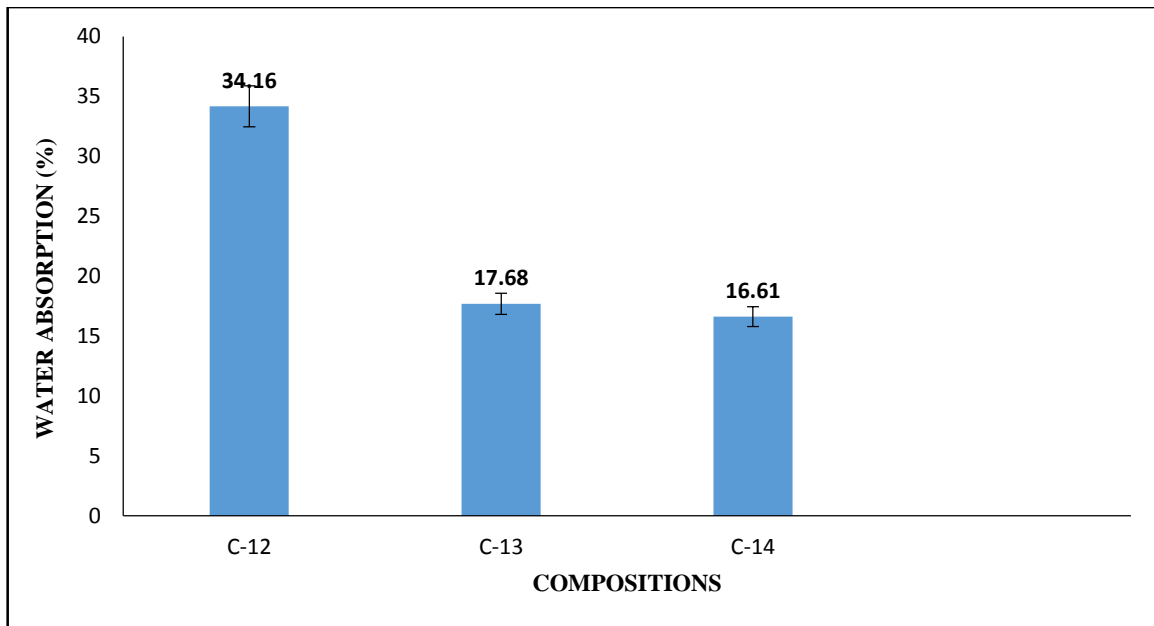
**Table 5.5: Variations of Steel Slag & Fly Ash in Blocks**

<u>Samples</u>	<u>Composition</u>	<u>Water Absorption (%)</u>	<u>Compressive Strength (N/mm<sup>2</sup>)</u>
C-12	FA*-70%, SS*-21%, C*-9%	34.16	5.76
C-13	FA*-45%, SS*-45%, C*-10%	17.68	8.37
C-14	FA*-35%, WL*-16%, SS*-30%, S*-15%, C*-4%	16.61	5.6

In Fig. 5.4 (a) & 5.4 (b), the variation of steel slag and fly ash in blocks showed good compressive strength. The composition C-13 in which the amount of fly ash was 45% and steel slag was 45% gave the good results for both compressive strength (8.37 N/mm<sup>2</sup>) and water absorption (17.68%). “Ferroform” an environmental friendly blocks, mainly consist steel melting slag and granulated blast furnace slag have same strength and durability as that of concrete and can be uses as a replacement of concrete blocks and natural stones (*Hisahiro et al., 2008*)



**Figure 5.4 (a): Variation of Compressive Strength of Blocks with Different Composition**



**Figure 5.4 (b): Variation of Water Absorption with Different Composition of Blocks**

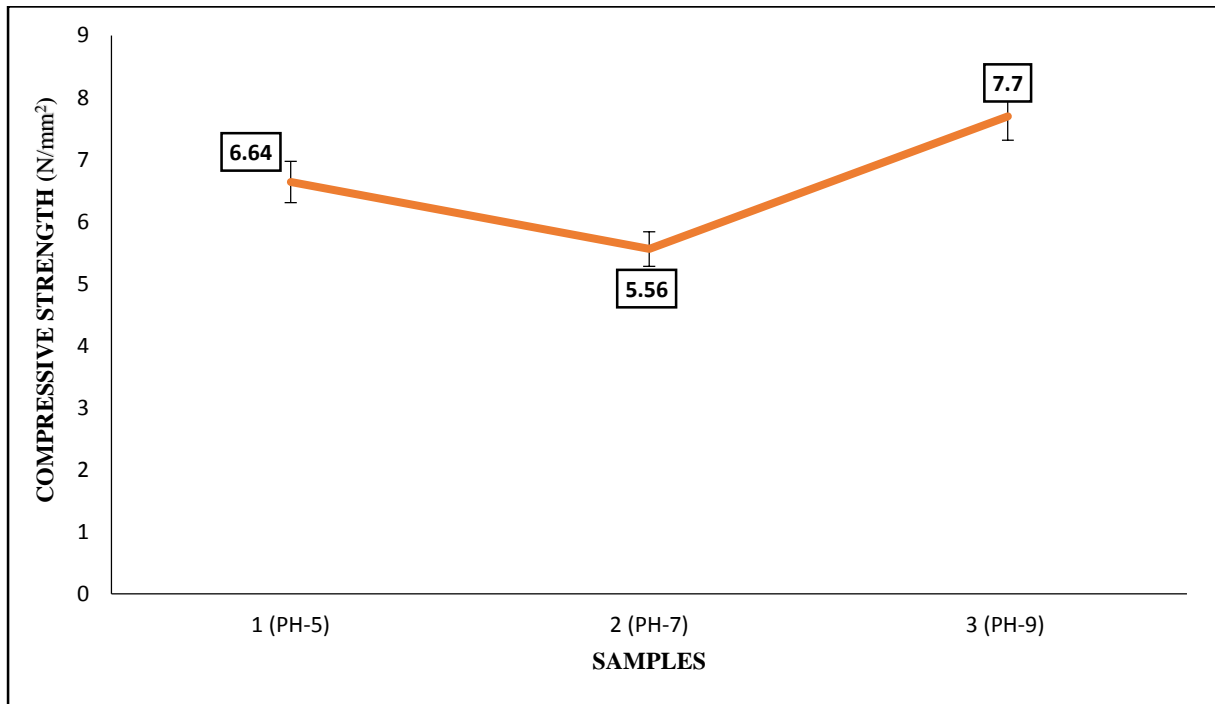
### 5.5 Effect of pH on Bricks/Blocks

Bricks/blocks are the stepping stone of any structure, it has to deal with environmental conditions inside and outside the buildings. Rain water plays a very important role in bricks/blocks, therefore the effect of pH on bricks/blocks must be considered. As acid rain is one of the most common polluting phenomena these days, it can have very detrimental effects on infrastructures. In current study, the pH of water used in water absorption test was varied ranging from pH 5.0 to 9.0. Table 5.6 shows the test results of effect of pH on bricks/blocks.

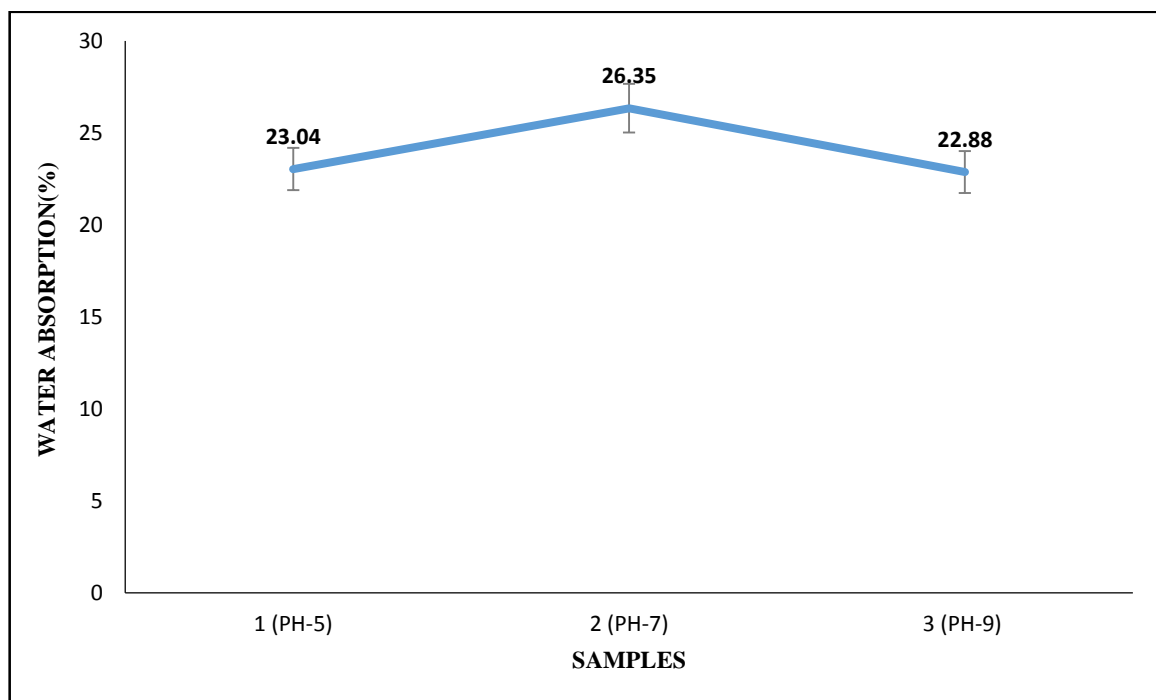
**Table 5.6: Effect of pH on Bricks/Blocks**

<u>Samples</u>	<u>Composition</u>	<u>Water Absorption (%)</u>	<u>Compressive Strength (N/mm<sup>2</sup>)</u>
1 (PH-5)	FA*-45%, SS*-45%, C*-10%	23.04	6.64
2 (PH-7)	FA*-45%, SS*-45%, C*-10%	26.35	5.56
3 (PH-9)	FA*-45%, SS*-45%, C*-10%	22.88	7.70

Results presented in Fig 5.5 (a) & 5.5(b) showed insignificant effect of pH on the compressive strength or the water absorption. During the physical examination of bricks after water absorption test with different values of pH, the condition of bricks were good. So, the effect of pH on the prepared bricks was not detrimental with change in pH thus.



**Figure 5.5 (a): Variation in Compressive Strength Test at Different pH Values**



**Figure 5.5 (b): Variations in Water Absorption Test at Different pH Values**

## 5.6 Effluent from Water Absorption Test

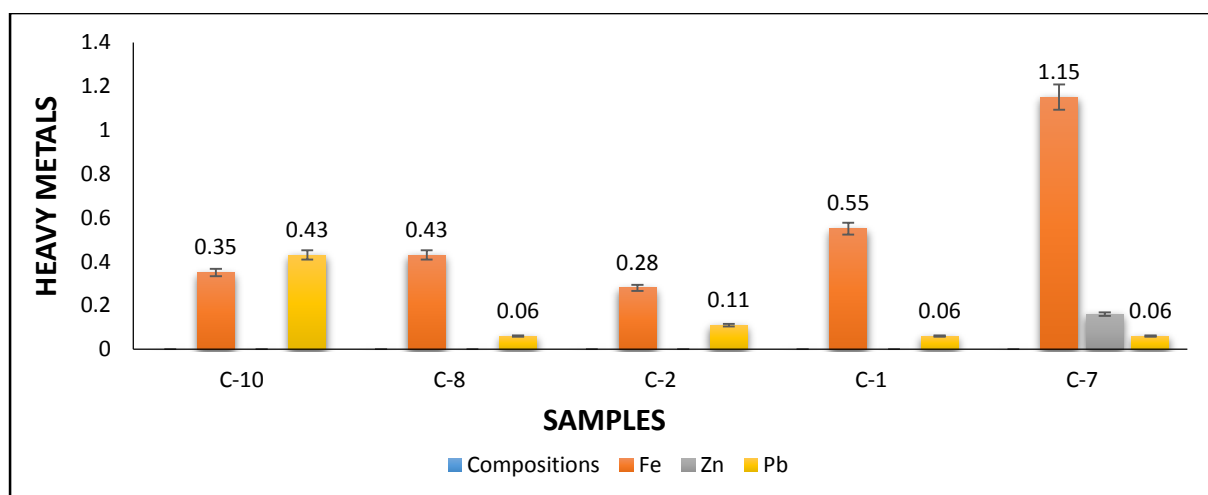
If the presence of heavy metals in the effluent is more, then they can pollute the water streams and may contaminate the ground water. During rainy seasons, bricks/blocks came in contact with water, if they possess traces of heavy metals in them, then they can induce heavy metals in surface run offs. The rain water with traces of heavy metals can pollute the streams and ground water. In the present study, the presence of heavy metals (Zn, Pb & Fe) in the effluent from water absorption test was assessed. Table 5.7 shows the result of presence of heavy metals in the effluent of water absorption test in some samples.

**Table 5.7: Presence of Heavy Metals**

Samples	Compositions	Heavy Metals (mg/l)		
		<u>Fe</u> <u>AR*- 3mg/l</u> <u>(max.)</u>	<u>Zn</u> <u>AR*- 5mg/l</u> <u>(max.)</u>	<u>Pb</u> <u>AR*-0.1mg/l</u> <u>(max.)</u>
C-10	FA*-70%, SS*-21%, C*- 9%	0.35	<0.01	0.43
C-8	FA*-60%, AD*-10%, SS*-21%, C*-9%	0.43	<0.01	0.06
C-2	FA*-50%, AD*-20%, SS*-23%, C*-7%	0.28	<0.05	0.11
C-1	FA*-50%, AD*-20%, SS*-25%, C*-5%	0.55	<0.05	0.06
C-7	FA*-45%, SS*-45%, C*-10%	1.15	0.16	0.06

AR\*- Acceptable Range

It is evident from Fig.5.6 that the presence of heavy metals (Fe, Pb & Zn) are within the acceptable limits (Fe < 3mg/l, Zn < 5mg/l & Pb < 0.1 mg/l) which allows its safe discharge in the environment.

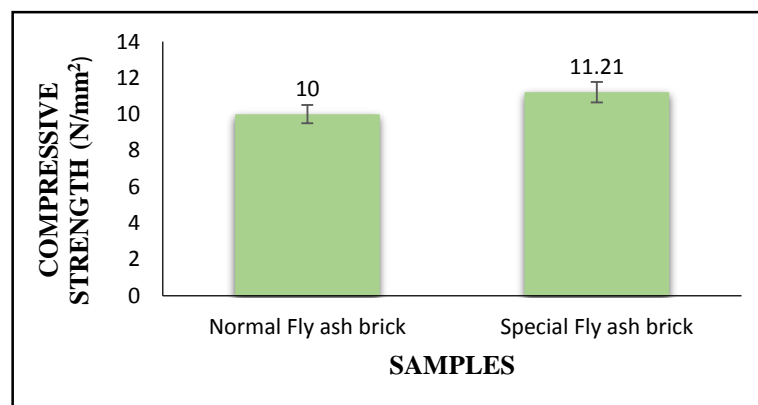


**Figure 5.6: Presence of Heavy Metals in Effluent Samples after Water Absorption Test**

## 5.7 Comparison of Normal Fly Ash Bricks & Fly Ash Bricks Made from Steel Slag/APCD Dust

Normal fly ash bricks usually made up of fly ash, sand/stone dust, lime and gypsum. The bricks made from these material can have various ratios of material that depends on desirable properties of bricks. The only waste material used in normal fly ash bricks is fly ash, rest are the natural or man-made materials. Raw materials like sand are excavated from river beds, stone dust is prepared by crushing & then grinding it until desired size is obtained. Lime and gypsum are natural occurring minerals that are derived from the rocks. These materials are extracted from environment, resulting in their depletion after certain time. Normal fly ash bricks have water absorption less than 20% as desired and the strength of these bricks can vary from 6.5- 10 N/mm<sup>2</sup>.

On the other hand, synthesised fly ash bricks were specially manufactured bricks that utilised the environmental wastes like steel slag/ APCD dust. Steel slag is the most abundant waste product form the steel industries and its disposal is always the key concerning factor, APCD dust is also growing day by day. Due to stringent environmental regulations, air polluting industries like metallurgy industries, thermal power plants, etc. increased the number of APCD devices, results in increase in the collection of APCD dust. In present study, bricks were manufactured from these waste materials by varying their proportions and the effect of compressive strength was assessed.



**Figure 5.7: Comparison of Compressive Strength of Normal Fly Ash Bricks & Special Fly Ash Bricks**

Fig. 5.7 shows the composition of synthesised fly ash bricks with fly ash-70%, steel slag-21% & cement- 9% have compressive strength up to 11.21 N/mm<sup>2</sup> which is more in comparison to normal fly ash bricks 6 -10 N/mm<sup>2</sup> .

## **CHAPTER 6**

### **CONCLUSION**

Use of steel slag and APCD dust as filler in fly ash brick/blocks proved to be an effective alternative for conventional aggregates. In the present study, effect of the replacement of conventional aggregates with different proportions of fly ash, steel slag and APCD dust was evaluated on fly ash brick/blocks. The observations clearly indicated the significant increase in compressive strength when compared to conventional bricks and water absorption rate were also on the lower side. With the increase in the amount of steel slag in the mix for bricks manufacturing, there was a decrease in the water absorption and increase in the compressive strength. The composition C-10 (FA-70%, SS-21% & C- 9%) with steel slag 21%, furnished good compressive strength of 11.21 N/mm<sup>2</sup> when compared to 3-5 N/mm<sup>2</sup> of conventional bricks. The water absorption of composition C-10 was 18.51% which is well below 20% as required for a brick of good quality. With the increase in the amount of APCD dust, there was decrease in the compressive strength and the maximum compressive strength of 8.34 N/mm<sup>2</sup> was observed with 10% APCD dust. The bricks prepared with APCD dust have an average value of 31.80 %water absorption, which is on higher side and is not desirable. Hence composition C-7 with APCD dust 10% gives the better results with compressive strength of 8.34 N/mm<sup>2</sup> and water absorption of 24.53%. The variation of steel slag and fly ash in blocks showed good compressive strength. The composition C-13 in which the amount of fly ash was 45% and steel slag was 45% gave the good results for both compressive strength 8.37 N/mm<sup>2</sup> and water absorption 17.68%. The effect of pH was also investigated on bricks/blocks, by varying pH from 5.0-9.0 and the result revealed no significant reduction in the compressive strength or the water absorption. Even during the physical examination of bricks after water absorption test with different values of pH, the condition of bricks was found to be good. The effluent from the water absorption was also tested for the presence of heavy metal (Fe, Pb & Zn) and the results showed that the metals were found to be present under permissible range (Fe < 3mg/l, Zn < 5mg/l & Pb < 0.1 mg/l) and can be discharged in the environment. Hence, it can be concluded that the use of steel slag and APCD dust as a filler in fly ash bricks/blocks may prone to be beneficial for construction purposes as they are also cost effective and environmental friendly materials.

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## **LIST OF PUBLICATIONS**

1. Sharma S. and Dhir, A.; “Use of Steel Slag and/or Air Pollution Control Devices Dust as Filler in the Manufacture of Fly Ash Bricks”, Taylor & Francis, Civil Engineering and Environmental Systems, (under review).
2. Conference on (2015); “Use of Steel Melting Furnace Slag Dust as Filler in the Manufacture of Fly Ash Bricks”. National Seminar on Environmental Management, Sustainable Development and Human Health, Dr. S.S. Bhatnagar University Institute Of Chemical Engineering & Technology, Punjab University, Chandigarh. March 25, 2015.