EFFECT OF PARTIAL REPLACEMENT OF CEMENT BY FLY ASH AND LIME SLUDGE ON STRENGTH CHARACTERISTICS OF CONCRETE

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in partial fulfillment of the requirements for
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DECLARATION

The author hereby declares that this thesis entitled "**Effect of Partial Replacement of Cement by Fly ash and Lime sludge on Strength Characteristics of Concrete**", in whole or part, has not been used to obtain any degree in this, or any other, institute. Except where references have been given in text, it is entirely the authors own work.

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CERTIFICATE

This is to certify that the work presented in thesis entitled **"EFFECT OF PARTIAL REPLACEMENT OF CEMENT BY FLY ASH AND LIME SLUDGE ON STRENGTH CHARACTERISTICS OF CONCRETE"** *submitted by* ***Mr. Ravindra Kumar*** *in partial fulfillment of the requirements for the award of degree of* ***Master of Engineering*** *in Structural Engineering at* ***Thapar University, Patiala,*** *is a bonafide work carried out by him under our supervision and guidance. The matter embodied in this thesis has not been submitted anywhere for the award of any other degree.*

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ABSTRACT

Due to growing environmental awareness, as well as stricter regulations on managing industrial waste, the world is increasingly turning to researching properties of industrial wastes and finding solutions on using their valuable component parts so that those might be used as secondary raw material for other industrial applications.

Lime sludge production is a by-product of paper making in the Paper Mill Industries and Fly ash is by-product of coal thermal power plants. To date, these by-products are being used in other industrial branches and in the field of civil constructions, such as in cement manufacturing along with clinker and in masonry work for civil works. Considering the specificity of physical and chemical properties of fly ash and lime sludge and a series of possibilities for their use in concrete, this research work demonstrates the possibilities of using fly ash and Lime sludge together as partial replacements of cement in concrete.

This research work presents an investigation of compressive strength, split tensile strength and abrasion resistance of concrete by adding Lime sludge and Fly ash as partial replacement of cement in various percentages. In this work 30% cement has been replaced by four proportions of Fly ash & Lime sludge keeping Silica fume fixed as 5%. The four proportions are (25% Fly ash +5% Silica fume + 0% Lime sludge), (20% Fly ash +5% Silica fume + 5% Lime sludge), (15% Fly ash + 5% Silica fume + 10% Lime sludge) &(10% Fly ash + 5% Silica fume + 15 % Lime sludge).

It has been observed from the 7 & 28 days tests of compressive strength, Split tensile strength and abrasion resistance of concrete that compressive strength decreases as the percentage of Lime sludge increases in the mix when compared with controlled concrete. Split tensile strength decreases up to 5% replacement with Lime sludge and after that it starts increasing. In abrasion resistance test there is no abrasion observed in the concrete mixes made with partial replacement of cement with Fly ash and Lime sludge

The compressive strength, split tensile strength and abrasion resistance analysis carried out in this work gives a deeper insight into the cementitious properties and pozzolanic behavior of such by-products when used for construction purposes. The results show that the strength properties of concrete vary significantly when cement is partially replaced by Lime sludge and Fly ash.

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INTRODUCTION

1.0 GENERAL

The disposal of industrial wastes is a problem of increasing importance throughout the world. Sludge from paper mills and fly ash from the combustion of coal in thermal power plants are produced in large quantities in most industrial nations of the world today due to the large usage of paper, and electrical energy requirements constitute one of our most serious environmental problems. Paper mill sludge has substantially little usage as a material that can be employed in other industrial applications. Because of its non-utility, the paper mill sludge is merely discarded, along with other waste cellulosic fiber, creating a tremendous disposal problem. Whereas fly ash has been found a numerous use in cement and building material as in bricks, light weight aggregates embankments filling and in soil stabilization.

The characteristics of bio-solids are variable and directly related to the technology used to pulp, the wood and manufacture the paper and to the type of effluent treatment that is employed and the type and source of coal and method of collection ash.

Solid wastes generated from industrial sources are heterogeneous in composition, ranging from inert inorganic (such as produced in mining and collieries) to organic (in industries producing basic consumer products) and may include even hazardous constituents (as in pesticide industry). It was predicted that a global shift in paper and paperboard production would result in the Asia-Pacific region emerging as a major producer of paper mill sludge. Global production of paper mill sludge was predicted to rise over the next 50 years by between 48 and 86% over current levels.

The nature of waste generated from parental industries is mainly depends on the raw materials used in different unit processes. These wastes generated from the industrial sources contain a large number of ingredients, some of which are toxic.

Solid waste is generated from the both large and small categories of Plants. Solid waste from paper industries is generated usually in various stages of paper production viz., (the raw material handling and preparation sections as sludge from the effluent treatment plants, causticizing section in the chemical recovery unit in the form of lime sludge. Solid waste disposal is usually to landfill, although incineration is becoming increasingly widespread. Prior to any land application of solid residues, the levels of chemicals of concern need to be routinely demonstrated to fall below realistic regulatory levels.

The purpose of this research was to study the application and utility of these industrial wastes as a cementitious/pozzolanic material in construction Industry.

1.1 INDUSTRIAL WASTE GENERATION AND THEIR UTILIZATION

Industrial and mineral wastes from mineral processing industries, such as metallurgy, petrochemicals, chemicals, thermal power plants, paper and pulp account for nearly 150 million tons per annum. The more important wastes from these industries from the view point of building materials are fly ash from thermal power plants, slag from steel industry, press mud from sugar industry, paper sludge from pulp and paper industry, phospho- chalk and phospho-gypsum from fertilizer industry, carbide sludge from the acetylene industry, calcium carbonate sludge from soda ash and chrome sludge from sodium chromate industry, red mud from aluminium industry and metallurgical slags from non-ferrous industry.

1.2 CATAGORISATION OF LIME SLUDGE

The various industrial wastes can be catagorised as under.

- ***Paper Sludge***
  Investigations carried out the utilization of lime sludge from paper industry have indicated that the paper sludge can be utilized upto 74 percent (dry basis) as a component of raw mix for the manufacture of Portland cement clinker and this clinker can result in OPC conforming to Indian Standard Specifications IS:269-1989 and IS:8112-1989.
- ***Carbide sludge*** The results of R&D work have revealed that carbide sludge can be used as a source of calcareous component in the raw mix for manufacture of cement clinker. Taking into account of the tolerance limit of chloride content in the cement raw mix, the carbide sludge can be used as high as upto 30 percent in the raw mix for the manufacture of clinker, which yields OPC conforming to all the three National Standard Specifications on cement.
- ***Phospho-chalk***
  R&D investigations have established that Phospho-chalk can be used as a raw mix component for the manufacture of cement clinker. Presence of impurities viz P_2O_5, and SO_3 restricts its level of utilization to ≤ 8 percent only.
- ***Sugar Sludge***
  Preliminary investigations carried out have revealed that sugar sludge can be used as a source of calcareous component in the raw mix for manufacture of cement clinker. Detailed study is needed to establish the role of impurities present in sugar sludge on the performance of the cement (OPC) prepared from it.
- ***Chrome Sludge***
  It has been found that chrome sludge can be used upto 5 percent as mineralizer. Presence of chromium oxide as impurity upto 10 percent restricts its bulk utilization.

1.3 CHARACTERISATION OF LIME SLUDGE

The particle size distribution and physical properties of some of the sludge’s is given in Table 1.1(a) and (b). The slurries from the various industries have different dewatering and sedimentation characteristics depending upon the fineness and particles size distribution and to some extent on their chemical contaminants.

Table1.1 (a) :Particle Size Distribution of Indian Lime sludge (*J.M Mauskar2006*)

Particle Size (Microns)	%Paper Sludge	%Fertilizer Sludge	%Carbide Sludge	%Sugar Sludge	%Chrome Sludge	% Soda Ash Sludge
+ 90μ	2	2	-	6	4	6
– 90μ + 45μ	8	60	8	8	12	16
– 45μ + 30μ	10	20	62	40	12	42
– 30μ + 10μ	72	12	20	24	60	26
– 10μ + 5μ	8	4	6	16	8	6
–5μ	-	2	4	6	4	4

Table1.1 (b): Physical Properties of Lime Sludge (*J.M Mauskar2006*)

S. No.	Sludge Source	Physical State	Moisture Content (%)
1	Paper Sludge	Cake	40-50
2	Phospho Chalk	Cake/ Slurry	20-65
3	Carbide Sludge	Slurry	60-80
4	Sugar Sludge	Cake	40-50
5	Chromium Sludge	Cake	35-45
6	Soda Ash Sludge	Slurry	80-90

The Chemical composition of the lime sludge's from various industries has been presented in Table 1.2. From the Table it is clear that

1. All the sludge have essentially lime as a major constituent and its content varies from 35-70% on dry basis. All the sludge other than from carbide industry contain lime as calcium carbonate. The sludge from carbide industry essentially contains calcium hydroxide.
2. Lime bearing sludge also contain MgO, Al_2O_3, Fe_2O_3 and SiO_2 as associated constituents and their contents vary considerably depending upon the occurrence of these constituents in the limestone used in the parent process.
3. These sludge also contain specific contaminants associated with the process through which they are generated. Most of the problems regarding the utilization of these sludge are attributed to the presence of these contaminants. Sludge from the carbide and the soda ash industry contaminant chloride, most of it is in the soluble form as a major content. Phospho-chalk contains 5-9% of SO_3, upto 1.5% of P_2O_5 and upto 2% of fluoride as major contaminants. Paper, Sugar and chromium sludge contain free alkalies up to 2%. The chromium sludge in addition, contains chromium upto 10 percent.

Table 1.2 : Chemical Composition of Indian Lime sludge (J.M Mauskar2006)

Constituents Determined	**%Paper Sludge**	**%Phos-pho Chalk**	**%Carbide Sludge**	**%Sugar Sludge**	**%Chrome Sludge**	% **Soda Ash Sludge**
LOI	35-40	34-38	25-30	40-50	20-35	34-38
CaO	45-50	45-50	60-70	42-50	35-40	44-48
Al_2O_3	2-5	0.3-0.5	1-3	2-2.5	3-5	1.5-3.0
Fe_2O_3	1-1.5	0.3-0.5	0.1-0.25	2-2.5	-	1-2
SiO_2	4-6	3-5	4-6	1.5-	4-6	4-7
SO_3	-	5-9	0.2-0.3	4.5	-	-
P_2O_5	-	1-1.5	Trace	1-2	-	-
F^-	-	1-2	-	-	-	-
Cl^-	-	-	0.2	-	-	6-10
MgO	1.5-2.0	-	0.2-0.5	4-10	3-6	1-2
Na_2O/ K_2O	0.5-1.5	-	0.02-0.2	1-2	1-1.8	-
Cr_2O_3	-	-	-	-	8-10	-

1.3.1 Comparison of sludge formation processes

Wastewater and consequently solid wastes are the main environmental problem of the pulp and paper mills because this industry has a very water intensive production processes ***(Cabral et al., 1998; Thompson et al., 2001)***. Solid wastes from pulp and paper industries are mainly treatment sludge, lime mud, lime slaker grits, green liquor dregs, boiler and furnace ash, scrubber sludge, and wood processing residuals. Wastewater treatment sludge have a significant concern for the environment because of including chlorinated compounds (EPA,2002). The characteristics of all solid waste generated from the pulp and paper mills are organic exception of boiler and furnace ash. The chemicals of the solid wastes are varied depends on the process type. Solid wastes, sources and qualities are given in Table 1.3

Table1.3 : Solid waste types and sources from pulp and paper mills *(EPA, 2002; Nurmesniemi et al., 2007)*

Source	Waste Type	Waste Characteristic
Waste water treatment plant	Sludge	Organic fractions consists wood fibres and bio sludge. Inorganic fraction consists clay , calcium carbonate and other materials. 20-60% solid content, PH~7.
Caustic Process	Dregs, Muds	Green liquor dregs consisting of non reactive metals and insoluble materials, lime mud.
Power Boiler	Ash	Inorganic compounds
Paper Mill	Sludge	Colour waste and fibre clay including slowly biodegradable organics as cellulos, wood fibres and lignin

1.4 PAPER MILL LIME SLUDGE DEFINED

These days there is an increasing emphasis on a cleaner environment and maintaining the balance of the eco-system of the biosphere. It is generally believed that environmental protection with zero risk and economic growth do not go hand in hand, but at the same time it is also true that sustainable growth with environmental quality is not an unattainable goal. The problem is multi dimensional and multifaceted and calls for integrated efforts by the industry, Govt. policy makers, environmental managers and development agencies to look into generation, disposal and utilization aspects.

Paper and pulp industry in India is generating nearly 0.8 million ton of lime sludge that too only in organized sector. The beginning of the modern paper Industry in India dates back to 1832 when the first paper machine was established, however, the actual production was taken up at the end of century. Currently installed capacity for paper manufacture in India is about 4.6 MT out of its 380 paper mills scattered throughout the country. Out of 380 plants 32 plants are in the large scale sector and the rest in medium and small scale sector. The production capacity of large scale sector ranges above 100 tpd of paper production and of medium and small scale sector is below 100 tpd. The raw material base for these plants are wood, bamboo, straw and agricultural waste. Most of the large paper mills are based on wood and bamboo. However, in the last couple of years 5 - 6 number of agro based mills have increased their production capacity more than 100 tpd and have installed a chemical recovery system. The type of paper manufactured depends upon the raw material and pulping process adopted. Flowchart of Paper Mill Sludge generation is shown on Figure 1.

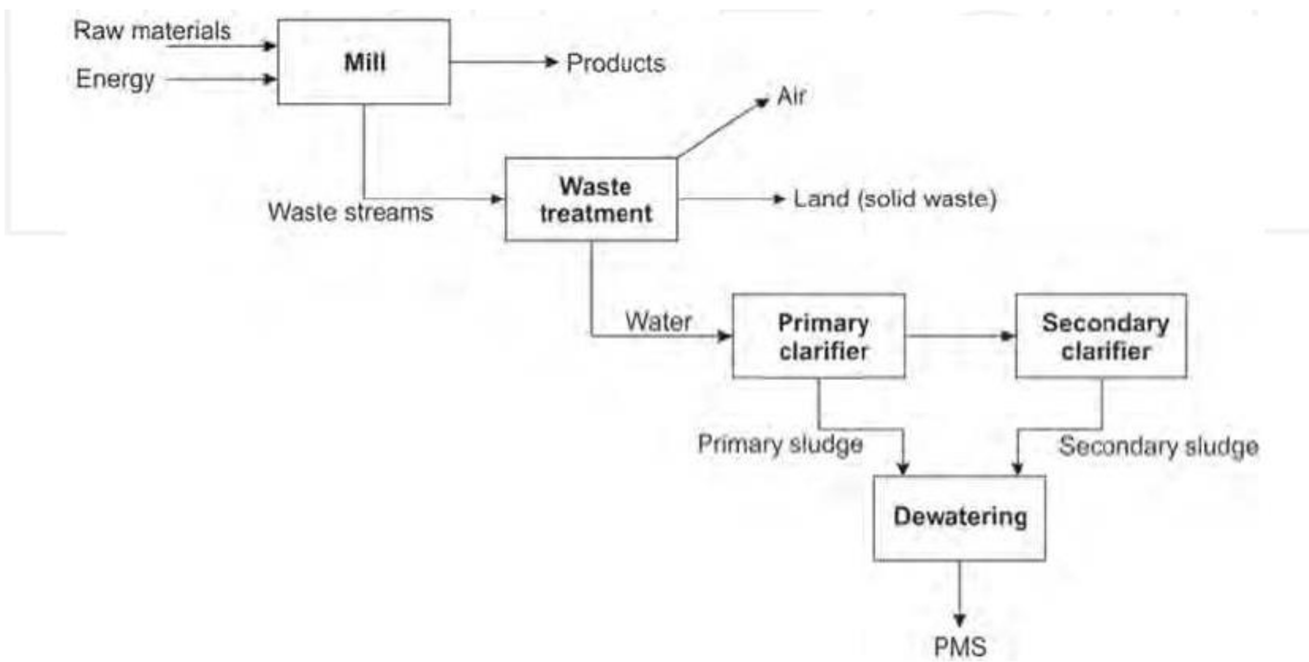

Figure 1.1 : Lime sludge formation process

All the large scale plants are equipped with chemical recovery system i.e. conversion of green liquor to white liquor by causticizing process. In this process calcined lime is used for regeneration of caustic soda by conversion of soda ash generating calcium carbonate sludge as a waste:

$$CaO + H_20 + 80\text{-}90°C = Ca(OH)_2$$

$$Na_2C0_3 + Ca(OH)_2 = \underset{\text{(White liquor)}}{2\,NaOH} + \underset{\text{(Lime Sludge)}}{CaC0_3}$$

The recausticizing reaction occurs at a solid-liquid interface within the solid particle. The green liquor containing dissolved Na_2C0_3 reacts with solid $Ca(OH)_2$, forming solid $CaC0_3$ and NaOH. The solid $CaC0_3$ remains as the interface and NaOH leaves in the dissolved form. Principally $CaC0_3$, which is generated as a by-product during recausticizing process of green liquor to white liquor is commonly known as Lime Sludge which is a solid waste generated from paper industry. Calcium carbonate thus produced is washed with water and filtered to recover alkalies and disposed off either as cake or mixed with water and flown out in settling tanks or disposed off by dumping in low lying areas, open fields thus make them unfertile. Many a times it is spread in a mill yard where is takes the shape of a big mountain due to accumulation of so many years. The rough estimate of this solid waste as mountain is about 7-10 million ton.

1.4.1 Characteristics of Lime sludge/mud

Lime sludge is a very fine precipitated $CaC0_3$ particles along with unsettled dregs carried over from green liquor clarifier. The average Physico-Chemical properties of Lime Sludge waste are given in Table1.4 & Table 1.5.

Table1.4: Chemical properties of Lime sludge (*CRI-ENG-SP 965March 2000*)

MC%	SiO_2%	Al_2O_3%	Fe_2O_3%	CaO%	MgO%	LOI%	SO3	Na_2O %
40-60	2-8	0.8-1.2	0.8-1.2	48-53	0.2-3.0	37-42	0.1-0.3	0.8-2.0

Major impurities associated with lime mud (sludge) are Silica and Magnisium. Silica enters mainly via raw materials or through purchased lime and goes to chemical recovery loop. During the causticizing operation $Si0_2$ forms Ca $Si0_3$ which is geletinous in nature. This geletinous nature hinders the setting property of lime mud (sludge). It has been observed that high percentage of silica in lime mud entraps higher moisture content .

$Ca\,(OH)_2 + Si0_2 + Na_2\,C0_3 = NaOH + CaC0_3 + Ca\,Si0_3$
(Green liquor) (Slow setting lime mud)

Table 1.5 : Particle Size distribution of Lime Sludge *(CRI-ENG-SP 965March 2000)*

Size range in micron	%age
+90	Nil
-90 to +50	8
-50 to +30	11
-30 to +10	78
-10	3

Attention is required to use this solid waste either as recycling product to be used for the paper manufacturing process or in some other value added products. Some Paper Industries are already recycling Lime Sludge and converting it to quick lime which can be further reused in paper manufacturing process. Only few mills are having lime reburning calciner to convert

Lime Sludge to quick lime for reuse in the causticizing process. The high temperature process which drives the $C0_2$ out of $CaC0_3$ to produce CaO is called calcination.

Mineralogical Studies

Mineral analysis of representative Limes Sludge carried out using X-ray diffraction analysis technique are given in figure 1.2. The results indicated the presence of only calcite as major and brucite as minor mineral in the sample. The diffractogram of lime sludge sample is shown in Figure below.

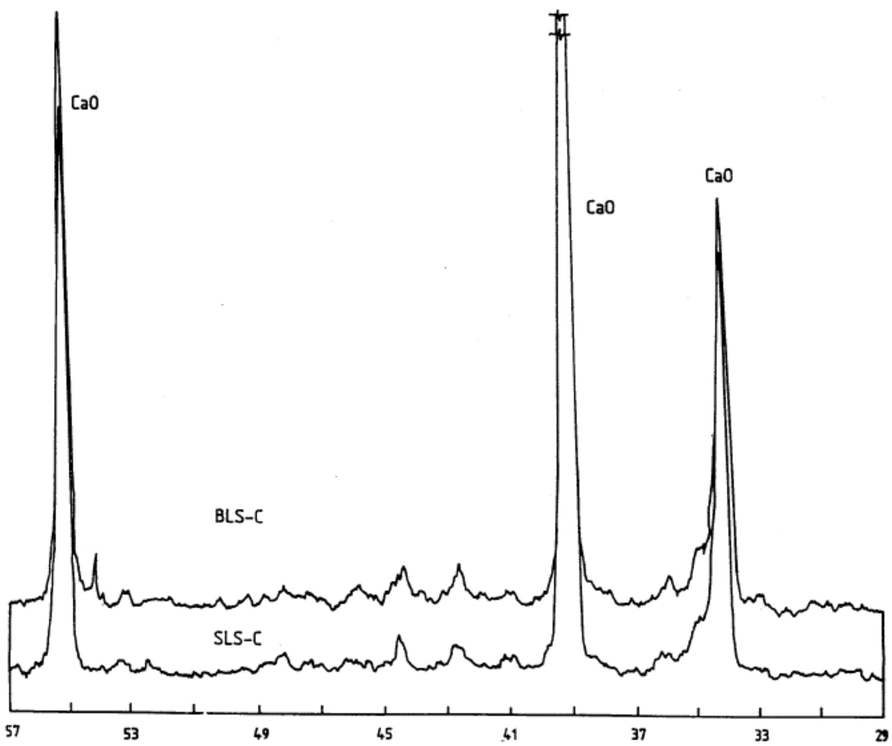

Figure 1.2 : XRD of calcined Lime mud (CRI-ENG-SP 965March 2000)

1.4.2 Theory of calcination

Manufacture of lime involves thermal decomposition of calcium carbonate under certain conditions of temperature and pressure. The dissociation of CaC03,the main chemical compound in lime sludge takes places as per reaction:

$$CaC0_3 \;=\; CaO + CO_2 \;-\; 42.52 \text{ Kcal}$$

The reaction indicates that for one gram molecule of $CaC0_3$, it is necessary to spend 42.53 Kcal heat. Accordingly for obtaining one kg of lime (CaO) from $CaC0_3$, the heat energy required will be about 750 Kcal which includes energy for dissociation as well as that needed to bring to the threshold state of dissociation. The mechanism of calcium carbonate decomposition is as follows:

a) When heating a cube of calcium carbonate from room temperature to calcining temperature, it first expands prior to dissociation.

b) Surface calcination, starts, the pore volume increase, the sample volume remains constant.

c) When calcination is complete, the sample has the maximum pore volume and simple volume is still largely unchanged.

d) With further temperature increase and longer calcination limes, crystals grow and sintering begins, both pore volume and sample volume decrease. The dissociation temperature of $CaC0_3$ can vary from 800-1000°C.

Parameters affecting Calcination

The factors affecting calcination are:

a) When heating a cube of calcium carbonate from room temperature to calcining temperature, it first expands prior to dissociation.

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d) With further temperature increase and longer calcination limes, crystals grow and sintering begins, both pore volume and sample volume decrease.The dissociation temperature of $CaC0_3$ can vary from 800-1000°C

1.4.3 Utilization of Lime sludge in Construction Industry

Lime sludge is generated from paper, acetylene, sugar, fertilizer, sodium chromate and soda ash industries. Approximately 4.5 million tons of sludge in total are generated annually from these industries.

All the lime sludge other than carbide sludge contain lime as calcium carbonate. The carbide sludge from acetylene industry mainly contains lime as calcium hydroxide. These sludge essentially contain lime as major constituent, however, their chemical compositions vary considerably depending upon the composition of limestone used in the parent process. All sludge contain some deleterious constituents/ contaminants, which come from the process through which they are generated, e.g. the phospho-chalk from fertilizer industry contains 5-9 percent SO_3, up to 1.5 percent P_2O_5 and upto 2 percent fluoride as major contaminants. Similarly paper, sugar and chromium sludge contain free alkalies upto 2 percent. The chromium sludge and carbide sludge in addition also contain chromium upto 10 percent and chloride upto 2 percent respectively. The presence of these deleterious constituents/ contaminants restricts their bulk utilization in making cement and related building materials.

Detailed investigations were carried out on the utilization of lime sludge from various industries. The study has revealed that sludge from paper industry can be utilized upto 74 percent (dry basis) as a component of raw mix for the manufacture of cement clinker. In addition to it around 30 percent (dry basis) lime sludge can also be utilized for the manufacture of Masonry cement. Due to the presence of deleterious constituents in higher quantities carbide sludge can be used only up to 30 percent whereas level of utilization for other sludge could reach to only 10 percent in the manufacture of cement clinker.
The lime sludge from paper industry has been found suitable as blending material for manufacture of masonry cement in the proportion of up to 30 percent conforming the Indian Standard specification of IS:3466-1988.
Paper Mill Sludge containing a high inorganic fraction can be utilized in the production of building materials (*Černec et al., 2005*). Due to its combustion matrix, it can be used in the brick production industry. The addition of 5-15 % of Paper Mill Sludge as raw materials improves both the final product and the processes. First, since its fiber content increases the porosity of the matrix, it enables the manufacture of lighter bricks; second, it saves fuel in the oven, decreasing firing time and makes the product more resistant against cracking during the drying and firing stages (Monte et al., 2009; Furlani et al., 2011). The same advantages can be used in the production of light aggregates for the building industry. (*Ducman and Mirtic, 2011*). A similar exploitation has been noticed in cement industry. Paper Mill Sludge with high organic content has an energy level that makes it an efficient alternative fuel in the production of Portland cement.
(Dunster, 2009). Including up to 20 % of deinking sludge into mortar improves the mortar mechanical properties (Yan et al., 2011).

1.5 FLY ASH

fly ash is a naturally-cementitious coal combustion by-product. It is extracted by the precipitators in the smokestacks of coal-burning power plants to reduce pollution. About 120 coals based thermal power stations in India are producing about 112 million tonne fly ash per year. With the increasing demand of power and coal being the major source of energy, more and more thermal power stations are expected to be commissioned/augment their capacities in near future. fly ash has been considered as a "Pollution Industrial Waste" till about a decade back and was being disposed off in ash ponds. Indian coal has high ash content (35%-45%) and low calorific value (3500 kcal/kg – 4000 kcal/kg) as a result of which huge quantity of fly ash is generated. It is expected to increase to about 200 MT per year by the year 2012. This would require about 4000 ha of land for the construction of ash ponds. Generally one acre of land is required per megawatt of power generation. Continuous studies have been carried out in India towards management of fly ash (FA), disposal and utilization. Out of total power generated of India, about 70% is produced by thermal power plants (TPPs). The Majority of thermal power plants 84% are run by coal; rest on gas (13%) and oil (3%). Thermal power plants uses 260 million tons (MT) of coal which is about 65%

of annual coal produced in India The quality of fly ash which depends on coal, coal particle fineness, percentage of ash in coal, combustion technique used, air/fuel ratio, burners used, and type of boiler. The Indian Government has taken a target of 31.1 million housing complex as per 2001 Census, out of which 24 million units are in rural area and 7.1 million units in urban areas, for that govt. targeted the year 2010. In 1998, National Housing and Habitat Policy has been announced by the govt. which aims for providing “Houses for All” and facilitating the construction of 20 lakh additional housing units (13 lakh in rural areas and 7 lakh in urban areas) annually, with emphasis on extending benefits to the poor and the deprived. Apart from the above housing needs, nearly 1% of the housing stock in the country is destroyed every year due to natural hazards. Large number of innovative alternate building materials and low cost construction techniques developed through intensive research efforts during last three to four decades satisfies functional as well as specification requirements of conventional materials/ techniques and provide an avenue for bringing down the construction cost. fly ash, an industrial by-product from Thermal Power Plants (TPPs), with current annual generation of approximately 112 million tons and its proven suitability for variety of applications as admixture in cement/concrete/mortar, lime pozzolana mixture (bricks/blocks) etc. Cement and Concrete Industry accounts for 50% fly ash utilization, the total utilization of which at present stands at 30MT (28%). The other areas of application are Low lying area fill (17%), Roads & Embankments (15%), Dyke Raising (4%), Brick manufacturing (2%) and other new areas for safe disposal of fly ash is in paint industry, agriculture etc.

Table 1.6 : Fly ash generation and utilization in different countries ***(J.Alam and M.N Akhtar 2011)***

S. No	Country	Annual ash production, MT	Ash utilization %
1	India	112	38
2	China	100	45
3	USA	75	65
4	Germany	40	85
5	UK	15	50
6	Australia	10	85
7	Canada	6	75
8	France	3	85
9	Denmark	2	100
10	Italy	2	100
11	Netherland	2	100

1.5.1 Classes of fly ash

According to ASTM C-618 fly ash is broadly classified into two major categories: Class F and Class C fly ash. The chief difference between these two classes is the amount of calcium, silica, alumina, and iron content. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous, and lignite).

Class 'F' fly ash

The burning of old anthracite and bituminous coal typically produces Class F fly ash which contains less than 10% lime (CaO). Possessing 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 geopolymer.

Class "C" fly ash

Class „C" fly ash produced from the burning of younger lignite or sub bituminous coal generally contains more than 20% lime (CaO). This type of ash does not require an activator & the contents of Alkali and sulfate (SO4) are generally higher as compare to the Class „F" fly ash.

Figure 1.3 : Typical ash colours (Class "F" & "C" fly ash) ***(J.Alam and M.N Akhtar 2011)***

1.5.2 Properties of fly ash

Physical Properties of fly ash are given in the Table1.7.

Table1.7 : Physical Properties of fly ash*(J.N Akhtar1 J.Alam2 and M.N Akhtar 2002)*

Colour	Whitish Grey
Bulk density (g/cm3)	1.28
Specific gravity	1.86
Average particle size	-

Chemical Properties of fly ash are given in the Table1.8.

Table1.8 : Chemical Properties of fly ash ***(Monita Olivia and Hamid R. Nikraz (2011)***

Compound	% by weight
SiO_2	50.50%
Al_2O_3	26.57
Fe_2O_3	13.77
CaO	2.13
MgO	1.54
SO_3	0.41
K_2O	0.77
(P_2O_5)	1.0
LOI	4.0

1.5.3 Utilization of fly ash in Construction Industry

In the past, fly ash produced from coal combustion was simply entrained in flue gases and dispersed into the atmosphere. This created environmental and health concerns that prompted laws which have reduced fly ash emissions to less than 1% of ash produced. Worldwide, more than 65% of fly ash produced from coal power stations is disposed of in landfills and ash ponds. In India alone, fly ash landfill covers an area of 40,000 acres (160 km2).The recycling of fly ash has become an increasing concern in recent years due to increasing landfill costs and current interest in sustainable development. Some of the innovative and commonly manufactured eco friendly building material utilizing fly ash is covered below.

1)Cellular Light Weight Concrete (CLC) Blocks: These are substitute to bricks and conventional concrete blocks in building with density varying from 800 kg/m3 to 1800 kg/m3. The normal constituents of this Foaming Agent based technology from Germany are cement, fly ash (to the extent 1/4th to 1/3rd of total materials constituent), sand, water and foam (generated from biodegradable foaming agent). Using CLC walling & roofing panels can also be manufacture. Foaming agent and the Foam generator, if used for production of CLC with over 25% fly ash content invites concession on import duty by Govt. of India .

2)Development of fly ash Based Polymer Composites as Wood Substitute: **fly ash** based composites have been developed using fly ash as filler and jute cloth as reinforcement. After treatment, the jute cloth is passed into the matrix for lamination. The laminates are cured at specific temperature and pressure. Number of laminates is used for required thickness. The technology on fly ash Polymer Composite using Jute cloth as reinforcement for wood substitute material can be applied in many applications like door shutters, partition panels, flooring tiles, wall panelling, ceiling, etc. With regard to wood substitute products, it may be noted that the developed components / materials are stronger, more durable, resistant to corrosion and above all cost effective as compared to the conventional material i.e. wood. This technology has been developed by Regional Research Laboratory, Bhopal in collaboration with Building Materials & Technology Promotion Council (BMTPC) and TIFAC. One commercial plant has also been set up based on this technology near Chennai .

3)Portland Pozzolana Cement: Up to 35% of suitable fly ash can directly be substituted for cement as blending material. Addition of fly ash significantly improves the quality & durability characteristics of resulting concrete. In India, present cement production per annum is comparable to the production of fly ash. Hence even without enhancing the production capacity of cement; availability of the cement (fly ash based PPC) can be significantly increased.

4)Ready mixed fly ash concrete: Though Ready Mix concrete is quite popular in developed countries but in India it consumes less than 5 percent of total cement consumption. Only recently its application has started growing at a fast rate. On an average 20% fly ash (of cementitious material) in the country is being used which can easily go very high. In ready mix concrete various ingredients and quality parameters are strictly maintained/controlled which is not possible in the concrete produced at site and hence it can accommodate still higher quantity of fly ash.

5)Fly Ash- Sand-Lime-(Gypsum /Cement) Bricks /Blocks: **fly ash** can be used in the range of 40-70%. The other ingredients are lime, gypsum /cement, sand, stone dust/chips etc. Minimum compressive strength (28 days) of 70 kg/cm2 can easily be achieved and this can go up to 250 Kg/cm2 (in autoclaved type) .

6)Fly Ash in Road Construction: **fly ash** can be used for construction of road and embankment. This utilization has many advantages over conventional methods. Saves top soil which otherwise is conventionally used, avoids creation of low lying areas (by excavation of soil to be used for construction of embankments). Avoids recurring expenditure on excavation of soil from one place for construction and filling up of low lying areas thus created.

7)Asphalt concrete: Asphalt concrete is a composite material consisting of an asphalt binder and mineral aggregate. Both Class F and Class C fly ash can typically be used as a mineral filler to fill the voids and provide contact points between larger aggregate particles in asphalt concrete mixes. This application is used in conjunction or as a replacement for, other binders (such as Portland cement or hydrated lime). For use in asphalt pavement, the fly ash must meet mineral filler specifications outlined in ASTM D242. The hydrophobic nature of fly ash gives pavements better resistance to stripping. fly ash has also been shown to increase the stiffness of the asphalt matrix, improving rutting resistance and increasing mix durability.

1.6 MANAGEMENT AND DISPOSAL OF SOLID WASTES

Integrated solid waste management of pulp and paper mills are through anaerobic digestion, composting, land applications, thermal processes such as Incineration/ combustion, pyrolysis, steam reforming, and wet oxidation.

Anaerobic Digestion: This process type is a cost effective way due to the high-energy recovery (Verstraete and Vandevivere, 1999; Mata-Alvarez *et al.*, 2000). Industrial wastes, which have high organic content and digestable, are suitable for anaerobic digestion like paper sludge and wastewater treatment plant sludge (Kay, 2003; CANMET, 2005).

Composting: This method is suitable for the wastes and sludge, especially paper fibres and organic materials. The wastes are stabilized via microorganisms with minimal carbon loss. The end product of this process, humus-like material, can be used for houseplants, green-house and agriculture (Jokela *et al.*, 1997; Hackett *et al.*, 1999; Christmas, 2002; Gea *et al.*, 2005).

Land Application: This method has been preferred disposal method, especially for the acidic soil due to CaCO3 content of sludge. This application is widely used in the United Kingdom and Northern Europe. Before the application, dewatering and/or incineration treatment are done to the waste/sludge in order to reduce volume (Carr and Gay, 1997; Van Horn, 1997).

Incineration (Combustion): Combination of incineration with power and steam generation is one of the most applied methods in Europe, especially for wastewater treatment plant sludge. However, water and ash content of most sludge cause the energy deficiency. Fluidized bed boiler technology is becoming the one of the best solution for the final disposal of paper mill wastes in order to provide successful thermal oxidation of high ash, high moisture wastes (Busbin, 1995; Fitzpatrick and Seiler, 1995; Davis *et al.*, 1995; Albertson,1999; Porteous, 2005; Oral *et al.*, 2005).

Pyrolysis: In this process, organic wastes are converted to gaseous and liquid phase under high temperature and in the absence of oxygen. This is an alternative technology to incineration and landfill. This method is suitable for organic content high wastes such as wood, petroleum, plastic waste. However this technology is not sufficient for pulp and paper mill waste. Some investigations have been continue to adapt this technology to pulp and paper mills (Fio Rito, 1995; Frederik *et al.*, 1996; Kay, 2002; Fytili and Zabaniotou, 2008).

Steam Reforming: This technology is used for sludge treatment, however it is still considered as an emerging technology for paper sludge. Steam reforming is a novel combustion technology, which carries out in a steam reforming reaction system (Durai-Swamy *et al.*, 1991; Aghamohammadi and Durai-Swamy, 1995; Demirbas, 2007).

Wet Oxidation: The principle of wet oxidation is that organic compound as solid or liquid form is firstly transferred to water where it contacts with an oxidant under high temperature and pressure. During wet oxidation, waste pulped with water is carbonized and its fuel value increases to the equivalent of medium-grade coal. The waste does not cause any air emission in order to combust without flame or smoke (Kay, 2002). This technology is also considered as an emerging technology like steam reforming.

1.7 CONSTRAINTS IN UTILIZATION OF INDUSTRIAL WASTES

In spite of extensive R&D work having been done in the country even upto the stage of pilot plant trials, the level of waste utilization in India continues to be very low, only approximately 15 percent. Most of Coal fly ash is being used for the manufacture of PPC and some of the fly ash from other thermal power plants is also being used for the manufacture of PPC and making building blocks and bricks. A small percentage of fly ash generated in thermal power plants close to big cities finds use in building industry. However, it is estimated that only 28 percent of the total fly ash generated in the country finds use one way or the other in building industry.

Lime sludge from paper industry has been partly used by the paper industry itself but still the remaining portion is creating environmental problems and occupying large tracts of cultivable land. Phospho gypsum is also similarly used partly.

The lower rate of utilization of industrial wastes in India may be attributed to one or more of the following factors:

i) Since bulk of wastes is being disposed off in wet state, arrangements have to be made for extraction and supply of these wastes in dry state, which involves lot of expenditure.
ii) Transportation waste in dry form in open wagons results in huge transit losses.
iii) Provision of marketing of standard quality fly ash/ other wastes in bags or any other packing including drums.
iv) Plant engineering of commercial size plants for manufacturing new materials based on industrial wastes.
v) Need for modifications of existing standards and codes consequent upon the acceptance of different uses of fly ash and formulation of new standards wherever necessary.
vi) Limitation in distance over which the wastes can be economically transported.
vii) Variation in the quality of wastes is one of the major problems related to its bulk utilization.
viii) Unawareness of consumers towards quality of waste based products along with confidence of builders in the use of building materials from unconventional materials.

1.8 RECOMMENDED MEASURES TO PROMOTE UTILIZATION OF INDUSTRIAL WASTES

The following actions will go a long way in the promotion of utilization of wastes in national interest.

i) Arrangement should be made for availability of wastes in dry state.
ii) Efforts should be made for minimizing quality variation.
iii) The industrial wastes should be beneficiated to remove impurities, if possible, which deteriorate the quality of the clinker.
iv) Wide publicity regarding advantages of products based on industrial wastes.
v) Land adjoining the waste generating industry may be acquired, ear marked and offered on lease for setting up of waste based industries.

vi) Ban through a legislation on the use of precious top soil for burnt clay brick manufacture within 50 kms radius of fly ash brick plant.

vii) Arrangements to provide industrial waste to the user pneumatically.

viii) A legislation banning use of cement without fly ash as an ingredient except where technically it is not advisable.

ix) Industrial waste based products should be exempted from excise duty.

1.9 OBJECTIVE OF THE RESEARCH WORK

The objectives of the present work is to study the effect of partial replacement of cement by Lime sludge viz. Lime mud/Sludge as Paper Mill Industrial Waste and fly ash as Coal thermal power plant based Industrial waste. It has been proposed to partially replace cement with Lime Mud/Sludge and fly ash and find its effect on the compressive strength, split tensile strength and abrasion resistance of concrete. Five percentage levels of replacement i.e. 0%, 5%, 10%, 15% and 20 % are considered for partially replacing cement with Lime sludge and fly ash. M-20, M-25 & M-30 concrete grade is initially designed without replacement and subsequently cement is partially replaced with Lime sludge and fly ash keeping Silica fume constant in the following proportions.

S.No	% Cement	% Silica fume	% fly ash	% Lime sludge
1	100	0	0	0
2	70	5	25	0
3	70	5	20	5
4	70	5	15	10
5	70	5	10	15

CHAPTER- 2
LITERATURE REVIEW

2.0 GENERAL

Lime mud/sludge and fly ash is used as substitute to clinker. The Lime sludge and fly ash otherwise would have been a waste and used as a filler material, if used properly, will conserve valuable limestone deposits required for production of cement. Lime sludge and fly ash can be used in cement/masonary and construction industry as a raw material which has advantages of better performance, durability and optimal production cost, besides being eco-friendly. Various researchers have worked on use of lime sludge and fly ash in concrete as a reliable cementitious material and practical in use. A brief review of the work carried out by various researchers on use of these two industrial wastes in concrete is presented below.

The mechanical strength and durability of concrete vary with the use of lime sludge and fly ash from industrial waste. The use of these industrial waste as a partially cement replacement is acceptable to a reasonably large extent.

A detailed review of the literature regarding the mechanical properties and durability aspect of various concrete mix is presented in succeeding section.

2.1 LIME SLUDGE

2.1.1 Compressive and Split Tensile Strength

Pitroda et al (2013) conducted an experimental study for the innovative use of hypo sludge in concrete formulations as a supplementary cementitious material was tested as an alternative to traditional concrete. The cement has been replaced by waste paper sludge accordingly in the range of 0% (without Hypo sludge), 10%, 20%, 30% & 40% by weight for M-25 and M-40 mix. Concrete mixtures were produced, tested and compared in terms of strength with the conventional concrete. These tests were carried out to evaluate the mechanical properties like compressive strength up to 28 days and split strength for 56 days are taken. As a result, the compressive strength increased up to 10% addition of hypo sludge and further increased in hypo sludge reduces the strengths gradually. This research work is concerned with experimental investigation on strength of concrete and optimum percentage of the partial replacement by replacing cement via 10%, 20%, 30%, and 40% of Hypo Sludge. Keeping all this view, the aim of investigation is the behavior of concrete while adding of waste with different proportions of Hypo sludge in concrete by using tests like compression strength and split strength. The chemical property of Hypo sludge used in the study is shown in Table 2.1

Table 2.1 : Properties of Raw Hypo Sludge *(Pitroda et al, 2013)*

S. No.	Constituent	Present in Hypo Sludge (%)
1.	Moisture	56.8
2.	Magnesium oxide (MgO)	3.3
3.	Calcium Oxide (CaO)	46.2
4.	Loss on Ignition	27
5.	Acid Insoluble	11.1
6.	Silica (SiO_2)	9

Mixes of M25 & M40 grade were designed as per IS 10262:2009 and the same was used to prepare the test samples. The design mix proportion are shown in Table 2.2

Table 2.2 : Concrete Design Mix Proportions *(Pitroda et al, 2013)*

S. No.	Concrete Type	Concrete Design Mix Proportion (By Weight)				Cement Replacement By Hypo sludge
		W/C Ratio	C	F.A	C.A	
1	A1-M25	0.4	1.0	1.01	2.5	-
2	C1-M25	0.4	0.9	1.01	2.5	0.1
3	C2-M25	0.4	0.8	1.01	2.5	0.2
4	C3-M25	0.4	0.7	1.01	2.5	0.3
5	C4-M25	0.4	0.6	1.01	2.5	0.4
6	A2-M40	0.3	1.0	0.44	2.17	-
7	C5-M40	0.3	0.9	0.44	2.17	0.1
8	C6-M40	0.3	0.8	0.44	2.17	0.2
9	C7-M40	0.3	0.7	0.44	2.17	0.3
10	C8-M40	0.3	0.6	0.44	2.17	0.4

The compressive strength results are compiled in Table 2.3 and split strength in Table 2.4. The compressive strength vs % replacements of cement results are graphically shown in Fig. 2.1 and 2.2. The same for split strength is in figure 2.3.

Based on limited experimental investigation concerning the compressive & split strength of concrete, the following conclusions had been drawn:

- Compressive strength reduces when cement replaced hypo sludge. As hypo sludge percentage increases compressive strength and split strength decreases.
- Use of hypo sludge in concrete can save the paper industry disposal costs and produces a 'greener' concrete for construction.
- The cost analysis indicates that percent cement reduction decreases cost of concrete, but at the same time strength also decreases.
- This research concludes that hypo sludge can be innovative supplementary cementitious Construction Material but judicious decisions are to be taken by engineers.

Table 2.3 : Compressive Strength and % Change of Strength at 7, 14, 28 days for M25 &M40 *(Pitroda et al, 2013)*

Concrete Grade	Concrete Type	Average Ultimate Compressive strength N/mm² at			% Change in Compressive Strength at		
		7 days	14 days	28 days	7 days	14 days	28 days
M25	A1-M25	28.77	32.00	44.59	0	0	0
	C1-M25	20.15	23.56	29.63	-29.96	-26.37	-33.55
	C2-M25	13.93	13.93	17.78	-51-58	-56-46	-60.14
	C3-M25	5.93	9.04	10.07	-79.38	-71.75	-77.41
	C4-M25	4.44	5.78	8.15	-84.56	-81.93	-81.72
M40	A2-M40	34.81	49.04	52.74	0	0	0
	C5-M40	18.52	23.56	26.22	-46.79	-51.95	-50.28
	C6-M40	14.22	17.78	18.67	-59.14	-63.74	-64.59
	C7-M40	5.33	10.22	13.63	-84.68	-79.15	-74.15
	C8-M40	4.3	7.26	7.56	-87.64	-85.19	-85.66

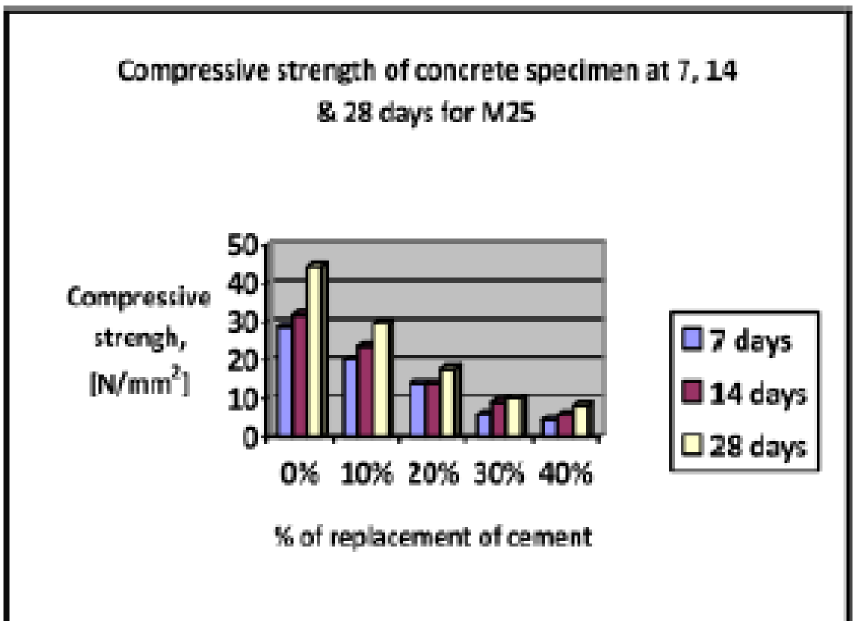

Figure 2.1 : Compressive Strength of Cubes at 7, 14 & 28 Days for M25 (*Pitroda et al, 2013)*

Table 2.4 : Split Strength and % Change of Strength at 56 days for M25 & M40, *(Pitroda et al, 2013)*

Concrete Type	Average split Strength for cubes at 56 days N/mm²	% Change in Split strength at 56 days

A1-M25	3.44	0
C1-M25	3.26	-5.23
C2-M25	2.43	-29.36
C3-M25	1.72	-50.00
C4-M25	1.28	-62.79
A2-M40	3.96	0
C5-M40	3.59	-9.34
C6-M40	2.51	-36.61
C7-M40	1.60	-59.59
C8-M40	1.33	-66.41

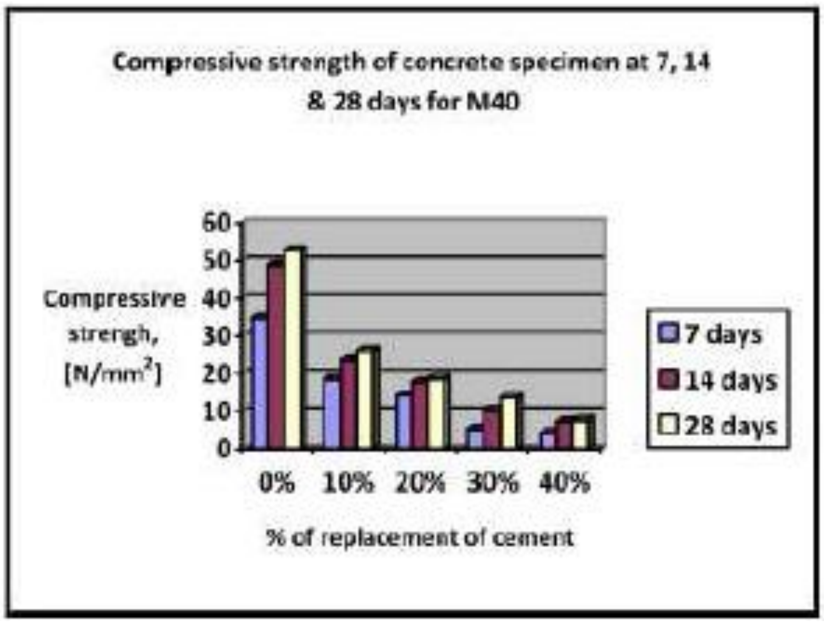

Figure 2.2 : Compressive Strength of Cubes at 7, 14 & 28 Days for M40, ***(Pitroda et al, 2013)***

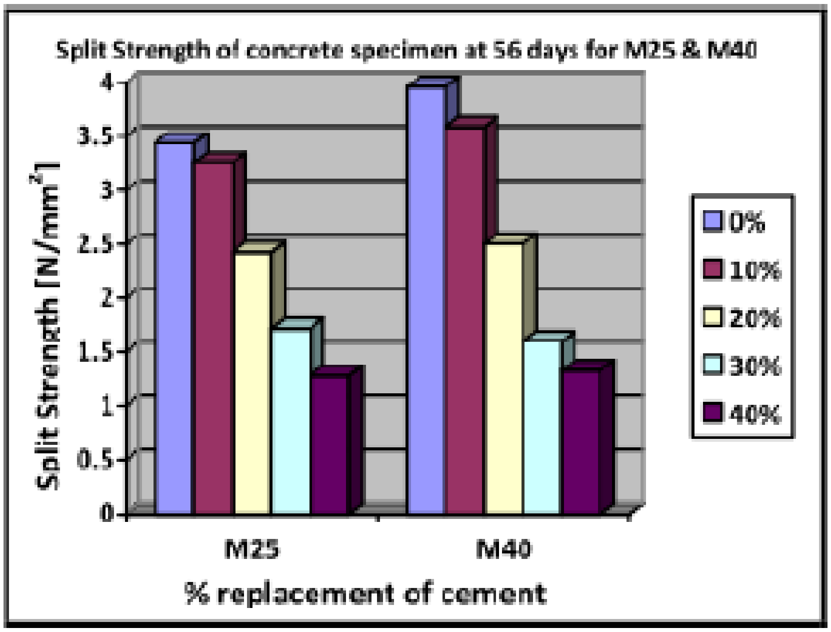

Figure 2.3 : Split strength of cubes (150X150X150) at 56 Days for M25 & 40, ***(Pitroda et al, 2013)***

Srinivasan *et al* (2010) experimentally investigated the strength of concrete and optimum percentage of the partial replacement by replacing cement *via* 10%, 20%, 30%, 40%, 50%, 60% and 70% of Hypo Sludge. A mix M25 grade was designed as per Indian Standard method and the same was used to prepare the test samples. The design mix proportion is done in Table 2.5

Table 2.5 : ***Design Mix Proportion, (Srinivasan et al, 2010)***

	Water	Cement	Fine aggregate	Coarse aggregate
By weight, [kg]	191.6	547.42	456.96	1255.475
By volume	0.35	1	0.834	2.29

The concrete mix proportions with hypo sludge replacement are provided as below:
10% replacement 0.90: 0.834: 2.29; 20% replacement 0.80:0.834:2.29
30% replacement 0.70:0.834:2.29; 40% replacement 0.60:0.834:2.29
50% replacement 0.50: 0.834: 2.29; 60% replacement 0.40: 0.834: 2.29
70% replacement 0.30: 0.834: 2.29

150 mm × 150 mm × 150 mm concrete cubes were casting using M25 grade concrete. Specimens with ordinary Portland cement (OPC) and OPC replaced with hypo sludge at 10%, 20%, 30%, 40%, 50%, 60% and 70% levels were cast. During casting the cubes were

mechanically vibrated by using a table vibrator. After 24 h the specimens were removed from the mould and subjected to water curing for 14 and 28 days. After curing, the specimens were tested for compressive strength using a calibrated compression testing machine of 2,000 kN capacity.

Split tensile strength of concrete is usually found by testing plain concrete cylinders. Cylinders of size 150 mm × 300 mm were casting using M25 grade concrete. Specimen with OPC and OPC replaced by hypo sludge at 10%, 20%, 30%, 40%, 50%, 60% and 70% replacement levels were cast. During moulding, the cylinders were mechanically vibrated using a table vibrator. After 24 h the specimens were removed from the mould and subjected to water curing for 28 days. After curing, the specimens were tested for split tensile strength. The obtained results are given in Tables 2.6, 2.7, 2.8 and Figs. 2.4, 2.5, 2.6

Table 2.6 : *Compressive Strength of Cubes at 14 Days (Srinivasan et al, 2010)*

Partial replacement %	Number of specimen	Initial crack load, [kN]	Ultimate load, [kN]	Ultimate compressive strength, [N/mm^2]
0	3	193.000	400.725	17.81
10	3	23.850	577.575	25.67
20	3	328.650	764.100	33.96
30	3	360.550	798.750	35.5
40	3	215.950	499.500	22.2
50	3	173.250	348.750	15.5
60	3	128.650	279.000	12.4
70	3	92.550	193.500	8.6

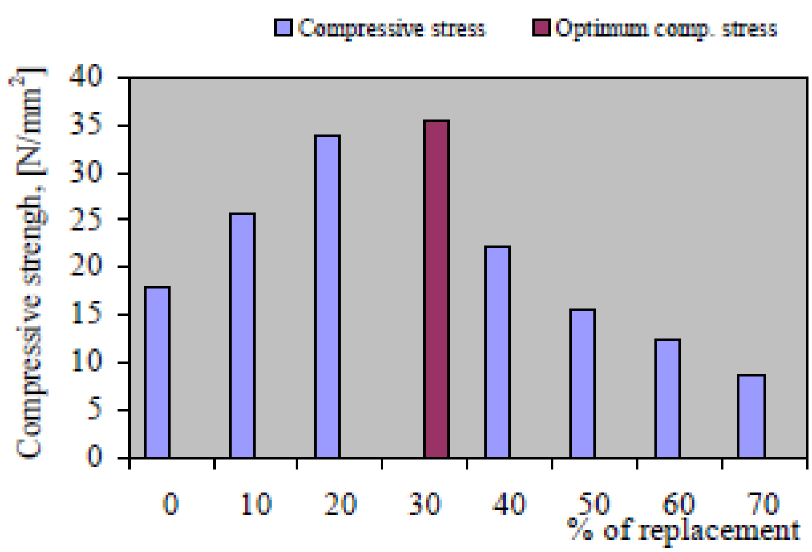

Figure: 2.4 : Compressive strength of concrete specimen at 14 days. *(Srinivasan et al, 2010)*

Table 2.7: Compressive Strength on Cubes at 28 Days *(Srinivasan et al, 2010)*

Partial replacement %	Number of specimen	Initial crack load, [kN]	Ultimate load, [Kn]	Ultimate compressive strength, [N/mm^2]
0	3	697.100	839.925	37.33
10	3	810.300	908.325	40.37
20	3	948.250	1,253.025	55.69
30	3	925.950	1,262.475	56.11
40	3	720.00	898.875	39.95
50	3	308.350	412.537	18.335
60	3	175.650	357.075	15.87
70	3	115.850	291.150	12.94

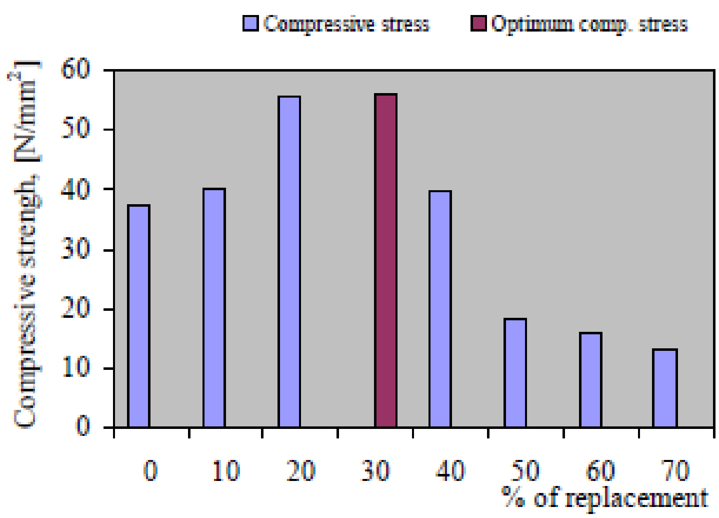

Figure 2.5: Compressive strength of concrete specimen at 28 days. ***(Srinivasan et al, 2010)***

Table 2.8: Split Tensile Strength of Cylinder at 28 Days ***(Srinivasan et al, 2010)***

Partial replacement %	Number of specimen	Ultimate load, kN	Split tensile strength, [N/mm^2]
0	3	130.061	1.84
10	3	110.269	1.56
20	3	104.615	1.48
30	3	100.373	1.42
40	3	98.253	1.39
50	3	97.546	1.38
60	3	101.080	1.43
70	3	102.494	1.45

Based on limited experimental investigation concerning the compressive and split tensile strength of concrete, the following observations are made regarding the resistance of partially replaced hypo sludge:

- Compressive strength of the concrete increased when the percentage of replacement is increased up to 40% and as the replacement increased compressive strength decreased.
- The split tensile strength decreased when the percentage of the replacement is increased.
- From this level, replacement of cement with this waste of hyposludge material provides maximum compressive strength at 30% replacement.
- We find the glory to E.W.S. group people by get the 28 days curing test. When government implement the projects for temporary shelters for who those affected by tsunami, E.Q., etc., this material can be used for economic feasibility.
- Cost of cement should become low from this project.
- Environment effects from wastes and maximum amount of cement manufacturing is reduced through this project,
- A better measure by a *New Construction Material* is formed out through this project.

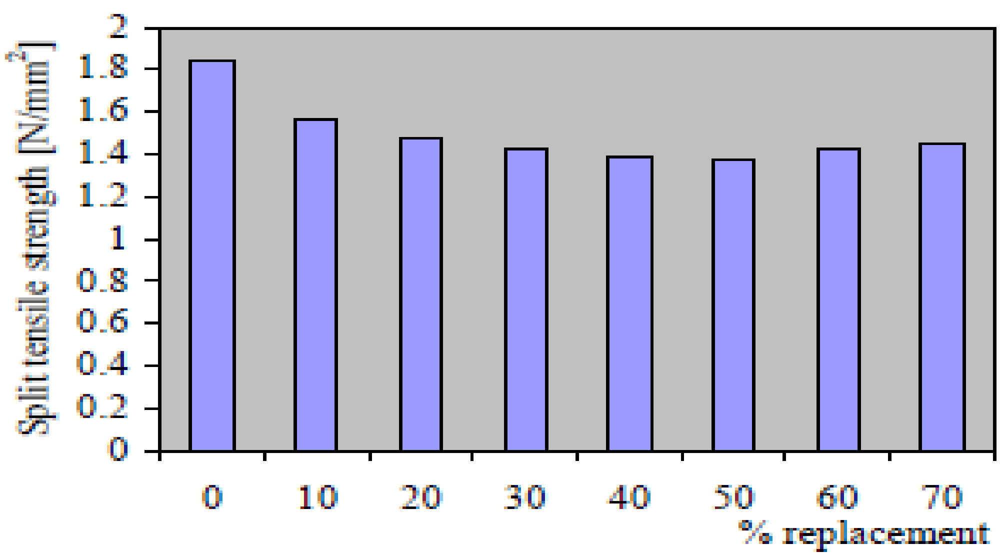

Figure 2.6: Split tensile strength of concrete specimen at 28 days. *(Srinivasan et al, 2010)*

Solanki & Pitroda (2013) studied the flexural strength of beams by partial replacement of cement with fly ash and hypo sludge in concrete. Designed M20 grade mixes, the design mix proportion for which are tabulated in Table 2.9 and 2.10. Concrete specimen of size 500mm*100 mm*100mm is cast in metal mould. Test specimens are stored in water before testing. The bearing surface of support and rollers are wiped, cleared and any loose sand or other material is removed. The specimen is placed in machine for testing as shown in fig 2.7.

Table 2.9 : Design Mix Proportions *(Solanki & Pitroda, 2013)*

	Water	Cement	Fine aggregate	Coarse aggregate
By weight, (kg)	186	385	727.6	1201.84
By volume, (m^3)	0.48	1	1.89	3.12

Table 2.10 : Concrete Design Mix Proportions *(Solanki & Pitroda, 2013)*

Sr.No.	**Concrete Design Mix proportion for M-20 Grade of Concrete**					
	W/C ratio	**Cement**	**F.A**	**C.A**	**Fly ash**	**Hypo sluge**
1	0.48	1.0	1.89	3.12	0.0	
2	0.48	0.9	1.89	3.12	0.1	
3	0.48	0.8	1.89	3.12	0.2	
4	0.48	0.7	1.89	3.12	0.3	
5	0.48	0.6	1.89	3.12	0.4	
6	0.48	1.0	1.89	3.12		0.0
7	0.48	0.9	1.89	3.12		0.1
8	0.48	0.8	1.89	3.12		0.2
9	0.48	0.7	1.89	3.12		0.3
10	0.48	0.6	1.89	3.12		0.4

Figure 2.7 : Flexural strength test *(Solanki & Pitroda, 2013)*

The results of flexure testing of specimens are provided in Table 2.11 and figures 2.8 and figures 2.9

Table 2.11 : Flexural Strength of Beam for M20 at 28 Days, *(Solanki & Pitroda, 2013)*

Partial replacement of	Partial replacement in %	Average flexural strength of Beam (N/mm²)	% change of flexural strength of Beam (N/mm²)
Fly ash	0%	5.05	0
	10%	4.48	-11.28
	20%	5.61	11.08
	30%	4.46	-11.68
Hypo sludge	0%	5.05	0
	10%	5.50	8.91
	20%	4.17	-17.42
	30%	4.18	-17.22

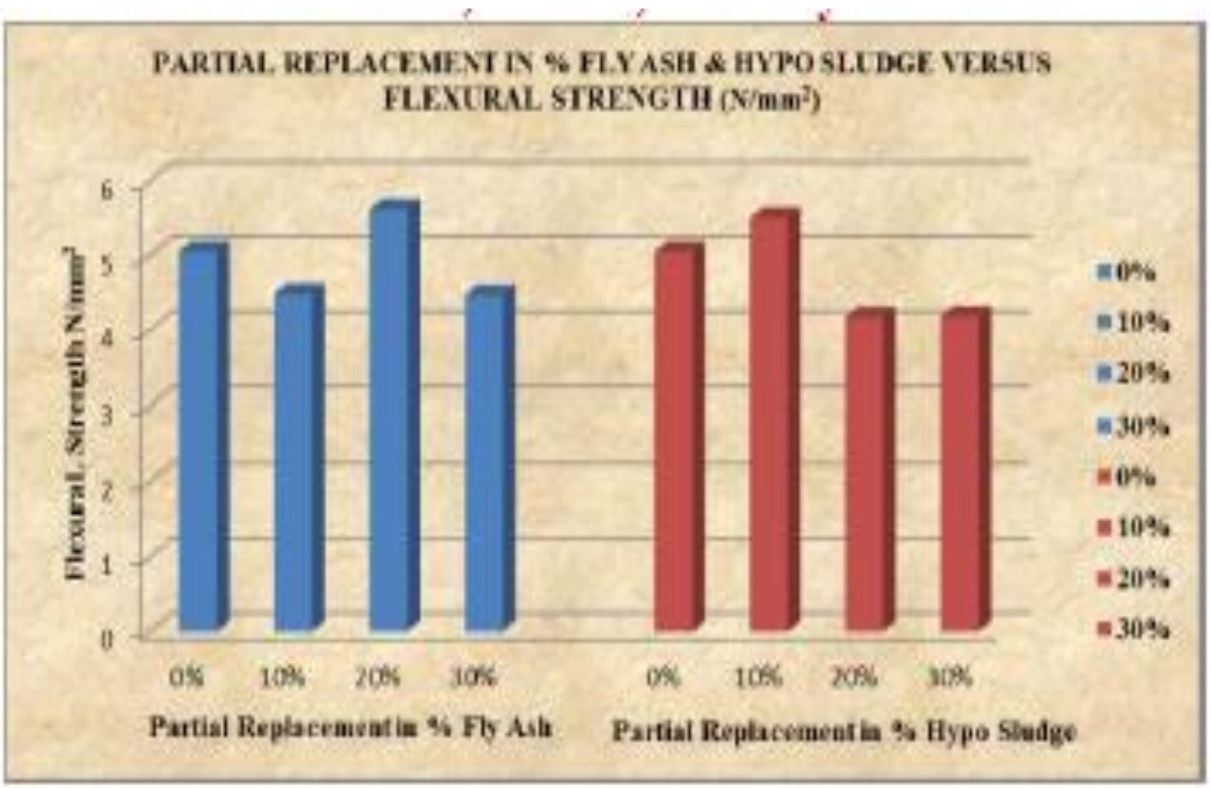

Figure 2.8 : Partial Replacement in % fly ash & Hypo Sludge versus Flexural Strength (N/mm²) at 28 days, *(Solanki & Pitroda, 2013)*

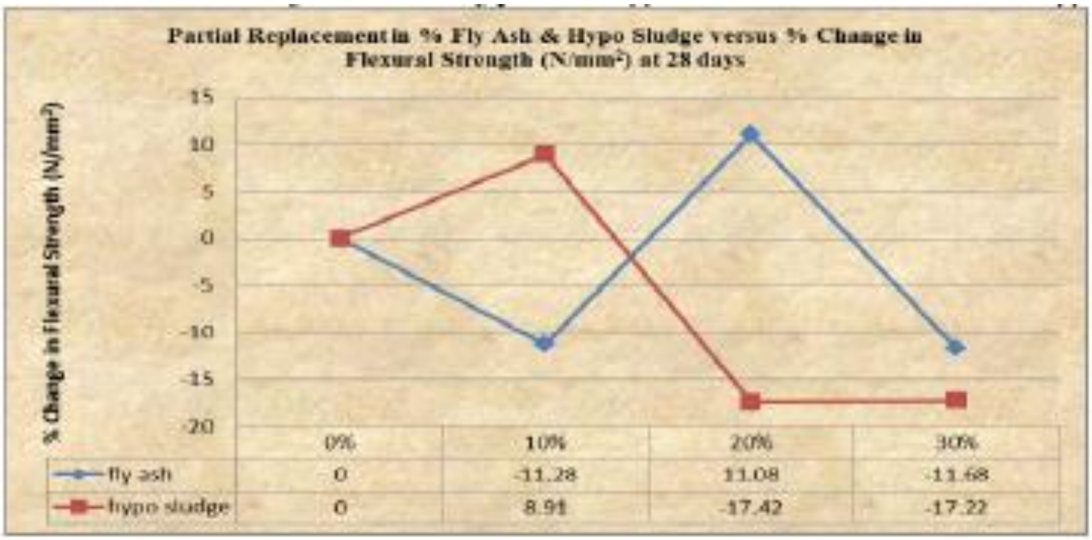

Figure 2.9 : Partial Replacement in % fly ash & Hypo Sludge versus % Change in Flexural Strength (N/mm^2) at 28 days, *(Solanki & Pitroda, 2013)*

Based on limited experimental investigation concerning the flexural strength of concrete, the following observations are made regarding the resistance of partially replaced fly ash and hypo sludge:

- Flexural strength of the concrete increases when the 20% replacement of cement by fly ash is increased up to 11.08 %.
- Flexural strength of the concrete increases when the 10% replacement of cement by hypo sludge is increased up to 8.91%.
- Environmental effects from wastes and residual amount of cement manufacturing can be reduced through this project.

Moisés Frías & Iñigo Vegas, (2009)

Figure 2.10 illustrates the evolution of relative compressive strength determined for standardized mortars with partial additions of 0%, 10% and 20% of thermally activated paper sludge. Up until 14 days of curing, an increase is observed in the relative compressive strength, as the incorporation of calcined paper sludge is increased. The acceleration of cement hydration and the pozzolanic reaction constitute the principal effects that explain the evolution of these strengths. The relative maximum is achieved after 7 days of curing. Likewise, replacement of 20% of the cement by calcined sludge provides greater relative compressive strength during the first fortnight of curing. This discussion coincides with the findings of other authors (Wild et al., 1996) when studying this mechanical property in cement mortars or concretes prepared with pure metakaoline. The lower the content of metakaolinite in the added sludge (10%), the further the values of relative compressive strength will fall for curing periods of over 14 days. The pioneering studies of Pera (Pera & Ambroise, 2003) demonstrated that the most influential parameter in pozzolanic activity at 28 days is the quantity of metakaolinite present in the sludges, regardless of other parameters, such as specific surface area, numbers of particles under 10 micrometers or the average diameter of the distribution of particle sizes.

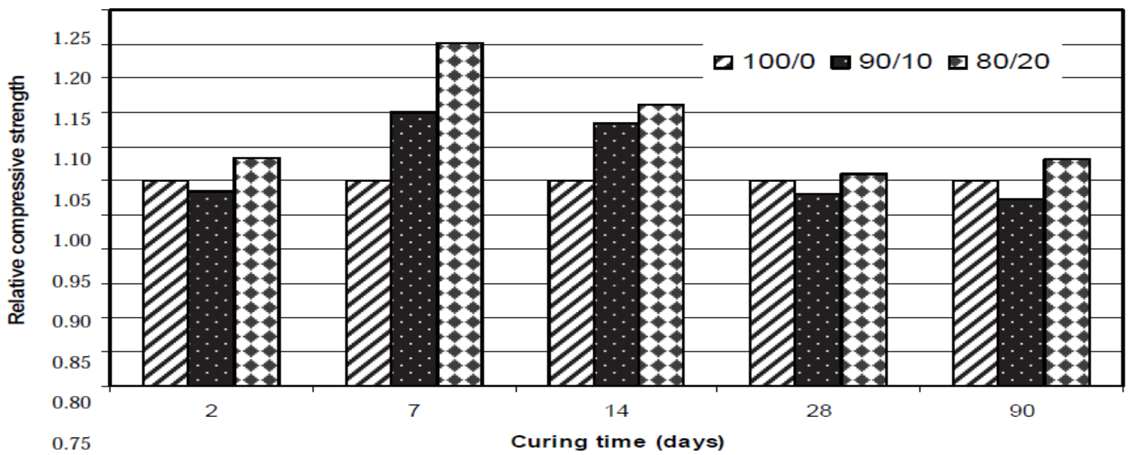

Figure 2.10 : Relative compressive strength of blended cements with paper sludge calcined at 700deg.C. ***(Moisés Frías & Iñigo Vegas, 2009)***

Figure2.11 illustrates the evolution of relative compressive strength determined from standardized cement mortars with partial additions of 0%, 6%, 21%, 35% and 50% of the mineral additions under study. The ternary cements 79/21, 65/35 and 50/50, with a thermally activated paper sludge content of over 10% in weight, display lower mechanical strength than the reference cement sample, although the decrease in their strength is lower than the total percentage of cement that is replaced. At 90 days, a recovery of mechanical resistance is observed in the ternary cements as a consequence of the activity developed by the fly ash.

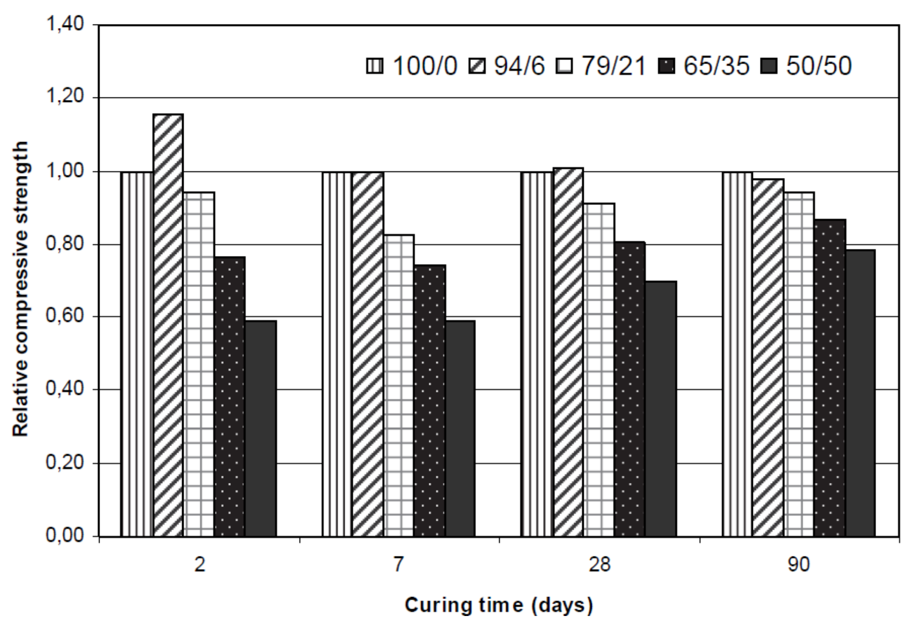

Figure 2.11 : Relative compressive strength in relation to ternary cement mixtures with paper sludge calcined at 700ºC and fly ash, ***(Moisés Frías & Iñigo Vegas, 2009)***

Sumit A Balwaik, S P Raut (2011)

The use of paper-mill pulp in concrete formulations was investigated as an alternative to landfill disposal. The cement has been replaced by waste paper sludge accordingly in the range of 5% to 20% by weight for M-20 and M-30 mix. By using adequate amount of the waste paper pulp and water, concrete mixtures were produced and compared in terms of slump and strength with the conventional concrete. The concrete specimens were tested in three series of test as compression test, splitting tensile test and flexural test. These tests were carried out to evaluate the mechanical properties for up to 28 days. As a result, the compressive, splitting tensile and flexural strength increased up to 10% addition of waste paper pulp and further increased in waste paper pulp reduces the strengths gradually The compressive strength, splitting tensile strength and flexural strength test results are given in Table2.12.

Table 2.12 : Compressive strength, splitting tensile-strength and flexural strength test results, *(Sumit A Balwaik, S P Raut, 2011)*

Mix	Waste Paper Pulp in %	Cube compressive strength (N/mm^2)		28-days strength (N/mm^2)	
		14 days	28 days	Splitting	Flexural
M-20	0	22.04	31.63	2.74	12.30
	5	25.62	33.93	2.90	14.17
	10	23.53	32.33	2.76	12.75
	15	18.85	25.43	2.33	10.75
	20	16.72	21.62	2.20	9.19
M-30	0	24.37	40.70	3.4	14.71
	5	26.85	42.37	3.70	15.78
	10	25.63	41.86	3.60	14.92
	15	22.77	38.41	3.20	12.51
	20	19.91	34.87	2.80	10.24

Shiqin Yan, and Kwesi Sagoe–Crentsil (2012) Investigated the use of recycled paper sludge in geopolymer mortar . This study evaluates the hardened geopolymer mortar properties of samples incorporating dry waste paper sludge. It was observed that The average 91-day compressive strengths of mortar samples incorporating 2.5 wt% and 10 wt% waste paper sludge respectively retained 92% and 52% of the reference strength.as shown in figure: 2.12.

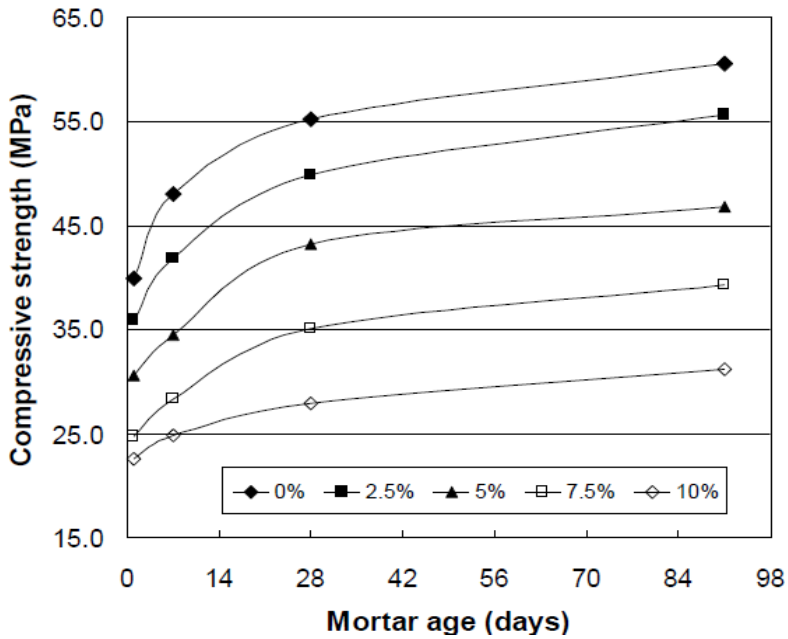

Figure 2.12 : Compressive strength development with curing time *(Shiqin Yan, and Kwesi Sagoe–Crentsil, 2012)*

2.1.2 *Durability Properties*

According to **Zala & Umrigar (2013),** durable concrete is one that performs satisfactorily under the exposed environmental condition during its service life span. Concrete requires to little or zero maintenance and normal environment. Main characteristic influencing the durability of concrete is its permeability to the ingress of water. When excess water in concrete evaporates, it leaves voids inside the concrete element creating capillaries which are directly related to the concrete porosity and permeability. The pores in cement paste consist of gel pores and capillary pores. The pores in concrete as a result of incomplete compaction are voids of larger size which give a honeycomb structure leading to concrete of low strength. Permeability is a measure of flow of water under pressure in a saturated porous medium while Sorptivity is materials ability to absorb and transmit water through it by capillary suction.

There is a need for another type of test rather than the absorption test and permeability tests to measure the response of concrete to pressure. This test should measure the rate of absorption of water by capillary suction, "sorptivity" of unsaturated concrete.

Sorptivity, or capillary suction, is the transport of liquids in porous solids due to surface tension acting in capillaries and is a function of the viscosity, density and surface tension of the liquid and also the pore structure (radius, tortuosity and continuity of capillaries) of the porous solid. It is measured as the rate of uptake of water.

Sorptivity (S) is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity.

Table 2.13 : Acceptance limits for durability indexes, *(Zala & Umrigar 2013)*

Acceptance Criteria		OPI (log scale)	Sorptivity (mm/h)
Laboratory concrete		>10	< 6
As-built Structures	Full acceptance	> 9,4	< 9
	Conditional acceptance	9,0 to 9,4	9 to 12
	Remedial measures	8,75 to 9,0	12 to 15
	Rejection	< 8,75	>15

Table 2.14 : Average % water absorption at 90 days for M25 and M40, *(Zala & Umrigar, 2013)*

Concrete grade	Concrete Type	Dry wt in grams (W1)	Wet wt in grams(W2)	% water absorption
M25	A1-M25	929.67	934.67	0.54
	C1-M25	1005.67	1017.00	1.13
	C2-M25	919.67	933.33	1.49
	C3-M25	869.00	899.67	3.52
	C4-M25	850.67	887.33	4.31
M 40	A2-M40	968.67	972.67	0.41
	C5-M40	956.67	971.33	1.53
	C6-M40	920.67	936.00	1.67
	C7-M40	905.00	932.00	2.99
	C8-M40	773.33	813.00	5.12

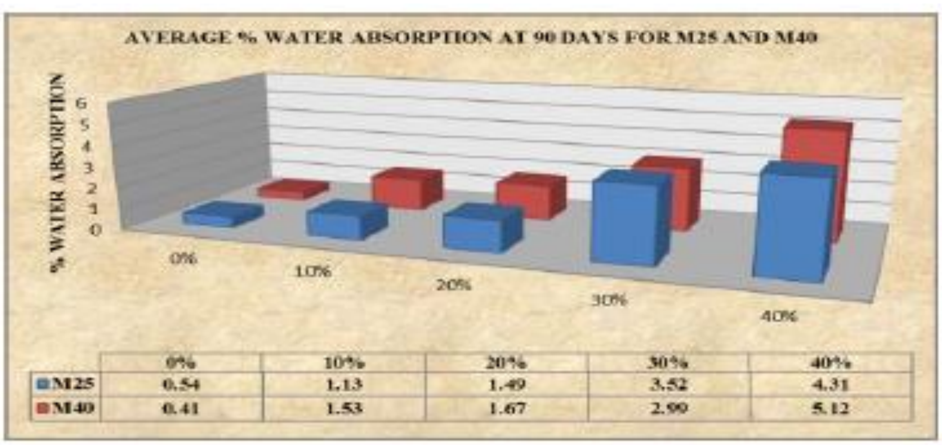

Figure 2.13 : % Replacement of cement versus % water absorption, *(Zala & Umrigar, 2013)*

Table 2.15: Sorptivity at 90 days for M25 & M40, *(Zala & Umrigar, 2013)*

Concrete grade	Concrete Type	Dry wt in grams (W1)	Wet wt in grams (W2)	Sorptivity value in 10^{-5} mm/min$^{0.5}$
M25	A1-M25	979.00	980.00	2.32
	C1-M25	1012.50	1013.50	2.32
	C2-M25	917.50	919.50	4.65
	C3-M25	884.00	890.00	13.95
	C4-M25	866.50	873.50	16.28
M 40	A2-M40	979.00	979.50	1.16
	C5-M40	959.00	961.00	4.65
	C6-M40	928.50	931.00	5.81
	C7-M40	920.50	927.00	15.11
	C8-M40	769.50	780.00	24.42

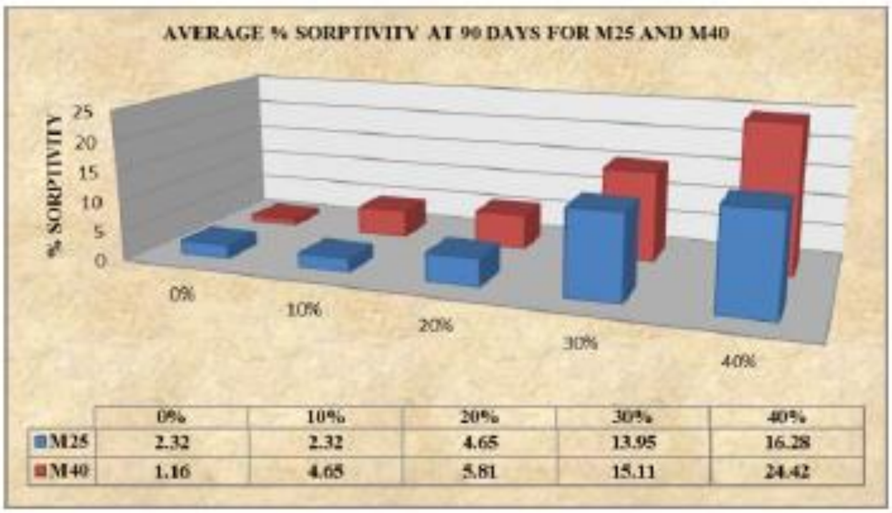

Figure 2.14 : % Replacement of cement versus sorptivity, *(Zala & Umrigar, 2013)*

Tables 2.14 and 2.15 gives the water absorption and Sorptivity test results of % replacement of Paper Industry Waste (Hypo Sludge) in concrete for 90 days curing. The % replacement vs % water absorption and Sorptivity results are graphically shown in figure 2.13 and 2.14. The acceptance limits for durability indexes are provided in Table 2.13. The major conclusions drawn by the authors from the study are as under:

- The water absorption and sorptivity of Paper Industry Waste (Hypo Sludge) concrete shows lower water absorption and sorptivity at 10% replacement with Paper Industry Waste (Hypo Sludge) for M25 and M40 grade concrete. There after the water absorption and sorptivity shows an increasing trend.

- The water absorption and sorptivity of Paper Industry Waste (Hypo Sludge) concrete shows higher water absorption and sorptivity than traditional concrete.
- The water absorption and sorptivity of M25 Paper Industry Waste (Hypo Sludge) concrete is higher than water absorption and sorptivity M40 grade concrete.
- The Paper Industry Waste (Hypo Sludge) can be innovative supplementary cementitious Construction Material but judicious decisions are to be taken by engineers.

Moisés Frías & Iñigo Vegas, ***(2009***) studied durability against Freez thaw and sulphate attacks in Binary cement mortars that include 10% and 20% thermally activated paper sludge present, respectively, two and three times more strength faced with freezing/thawing actions than the standard reference mortar (Figure2.15). As the exposure cycles progress, the increase in total porosity is less for those cements that incorporate thermally activated paper sludge. The higher the percentage substitution of cement by calcined paper sludge, the denser the mortar microstructure throughout a higher number of freezing/thawing cycles. Moreover, the greater the replacement percentage of thermally activated paper sludge, the slower the loss of compressive strength in the mortars exposed to freezing/thawing cycles (Vegas et al., 2009)

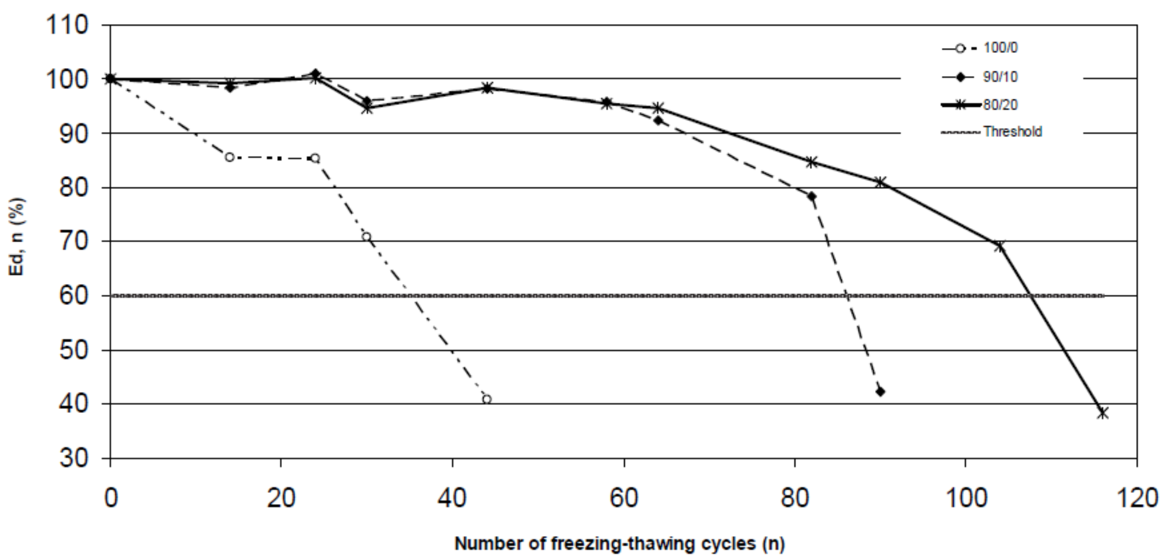

Figure 2.15 : Evolution of the dynamic modulus of binary cement mixtures with paper sludge activated at 700ºC subjected to freezing/thawing cycles, *(*Moisés Frías & Iñigo Vegas,*2009)*

Resistance to sulfates

It is well known that sulfates constitute one of the most aggressive agents against cement based materials, and cause different deterioration mechanisms as a consequence of the direct reaction between sulfate ions and the alumina phases in the cement, giving rise to ettringite, a highly expansive compound. The cements prepared with pozzolans of a siliceous-aluminous nature (fly ash and metakaolinite) can be more susceptible to sulfate attacks, owing to the incorporation of the reactive alumina of the pozzolan (Taylor, 1997; Siddique, 2008). The bibliographic data found on the behavior of normal Portland cements prepared with calcined paper sludge highlights the lower strength in the face of sulfate attacks (external and internal source) with respect to the reference cement sample.

Naik, T. R (2003)Concrete containing residual solids from pulp and paper mills and paper-recycling plants exhibit improved resistance to chloride-ion penetration and freezing and thawing without loss of strength. The addition of recycled materials can improve the quality of concrete while reducing the amount of waste deposited in landfills.

Shiqin Yan and Kwesi Sagoe–Crentsil (2012) studied the water absorption of geo-polymer mortar decrease with increasing paper sludge dosage at ambient temperatures, as shown in figure 2.16, hence providing good prospects of overall potential for waste paper sludge incorporation in production of building and masonry elements. The result indicate that despite its high moisture absorbance due to its organic matter and residual cellulose fibres content, waste paper sludge appears compatible to geopolymer chemistry and hence serves as a potential supplementary additive to cementitious masonry products based on this binder system.

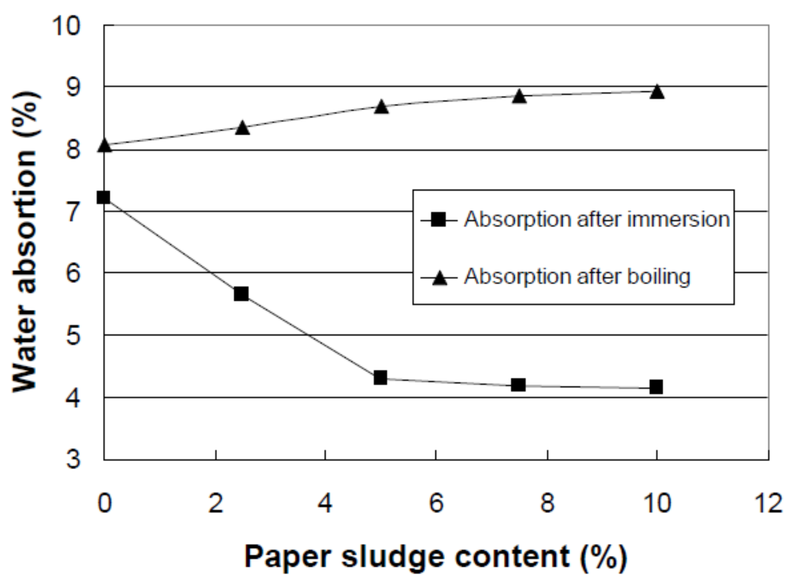

Figure 2.16: Water absorption of mortar specimens after immersion and boiling,
(Shiqin Yan and Kwesi Sagoe–Crentsil ,2012)

Eroglu Habip, H. Hulusi Acar, Ucuncu Osman, Imamoglu Sami (2006)

In this study, lime mud waste obtained from kraft pulp mill recovery unit was investigated on soil stabilization of forest road which is the one of the most important structure for forestry operations. Some chemical and physical characteristics of lime mud waste and soils collected from three different regions around Blaksea territory, in Turkey were initially analysed and then treated with lime mud waste with various ratio. Mechanical properties of treated soils were determined according to standards by realizing atterberg limits, specific weight, triaxial compression and compaction tests. Atterberg limits results indicated that it was possible to increase liquid and plastic limit values of soils with increasing the addition of lime mud in the mixture. Depending on lime mud content, cohesion values of soils were changed depending on the soil types. Addition of lime mud was affected positively to slip strength of soils. In order to obtain maximum dry density, more water content was required on mixtures. As a result, forest roads deformed depending on environmental effects and exceed loading could be stabilised and maintained by using lime mud waste.

2.2 FLYASH

2.2.1 *Compressive and split tensile strength*

Arun Kumar M. B. and R. P. Swamy, 2011 studied Flyash-eglass-Al6061 alloy composites having 2 wt%, 4 wt%, 6wt% and 8wt% of flyash and 2 wt% and 6wt % of e-glass fiber were fabricated by liquid metallurgy (stir cast) method. The casted composite specimens were machined as per test standards. The specimens were tested to know the common casting defects using ultra-sonic flaw detector testing system. Some of the mechanical properties have been evaluated and compared with Al6061 alloy. Significant improvement in tensile properties, compressive strength and hardness are noticeable as the wt % of the flyash increases. The microstructures of the composites were studied to know the dispersion of the flyash and e-glass fiber in matrix. It has been observed that addition of flyash significantly improves ultimate tensile strength along with compressive strength and hardness properties as compared with that of unreinforced matrix as shown in figures: 2.19. The test specimens were prepared by machining from the cylindrical bar castings. Each specimen having 8 mm in diameter X 60 mm gauge length in size for tensile testing and 20 mm diameter X 20 mm length for compression testing were prepared. The specimen surfaces were polished with 1 μm diamond paste. The samples for microscopic examination were etched with Keller's reagents as etchant. The specimens were washed with distilled water followed by acetone and dried thoroughly.

Tensile test: Test specimens were prepared according to ASTM E8-82 standards, each specimen having 8mm in diameter and 60mm gauge length, as shown if Figure: 2.17. The specimen was loaded in Hounsfield Universal Testing Machine until the failure of the specimen occurs. Tests were conducted on composites of different combinations of reinforcing materials and ultimate tensile strength and ductility were measured.

For conducting a standard tensile test, a specimen that has been measured for its cross-sectional area and gauge length is placed in the testing machine and the extensonometer is attached. Simultaneous readings of load and elongation are taken at uniform intervals of load. Uniaxial tensile test is conducted on the fabricated specimen to obtain information regarding the behavior of a given material under gradually increasing stress strain conditions. Figure: 2.18 shows some tensile test specimen after testing.

Tensile strength: Figure: 2.19 shows the effect of fly content and e-glass fiber on ultimate tensile strength of composite material. In this case the addition of fly ash to Al6061 matrix is increasing the tensile strength of the composite material.

This may be because of as more glass fibers were added, decrease in inter-fiber distance between hard glass fibers caused an increase in dislocation pile-up. By increasing the wt% of fly in the Al6061 alloy matrix, dispersion of fly ash particles in a soft ductile Al6061 alloy matrix results in improvement in strength . And improvement in UTS may be due to the matrix strengthening that might have occurred following a reduction in composite grain size and the generation of a high dislocation density in the matrix.

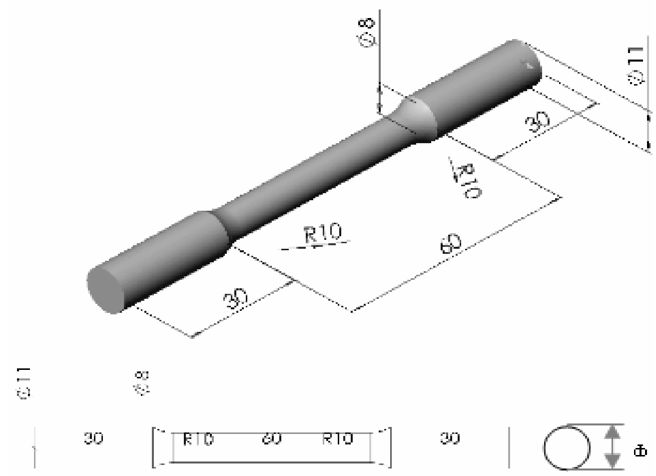

Figure 2.17 : Tensile test specimen. ***(Arun Kumar M. B. and R. P. Swamy, 2011)***

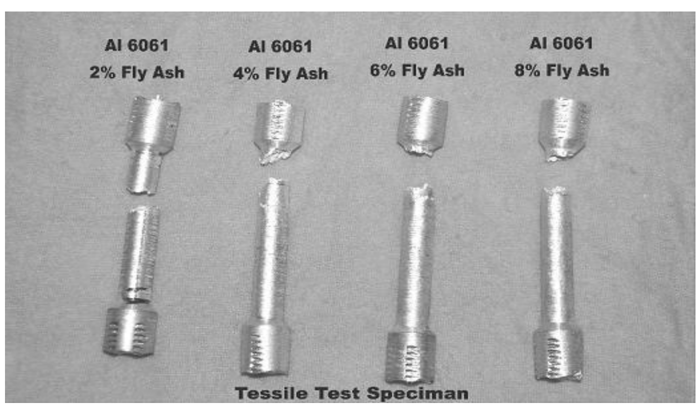

Figure 2.18 : Composite specimen after tensile test. ***(Arun Kumar M. B. and R. P. Swamy, 2011)***

Compression tests are run in much the same manner as the tension test on the specimen having 20mm diameter and 20mm length. Testing is carried out on Universal Testing Machine. The load interval given was 2 tons. For each load interval, respective change in length is measured and same is recorded until breaking takes place. A compressive stress - strain curve is plotted. From this curve, the behavior of the test specimen under compression can be predicted. From the graph, compressive properties of the test specimen, such as Compressive strength, are calculated. Figure:2.20. shows the results obtained from uniaxial compression, as a function of fly ash content of the matrix. Increase in the content of fly ash and e-glass fiber increases the compressive strength of the composites. The increase in compressive strength is due to the increase in the density of the composite material. It is shown that addition of ceramic reinforcement to a soft matrix increases its density and there by its compressive strength. Similar results were demonstrated in various studies made on the compressive strength of composite materials.

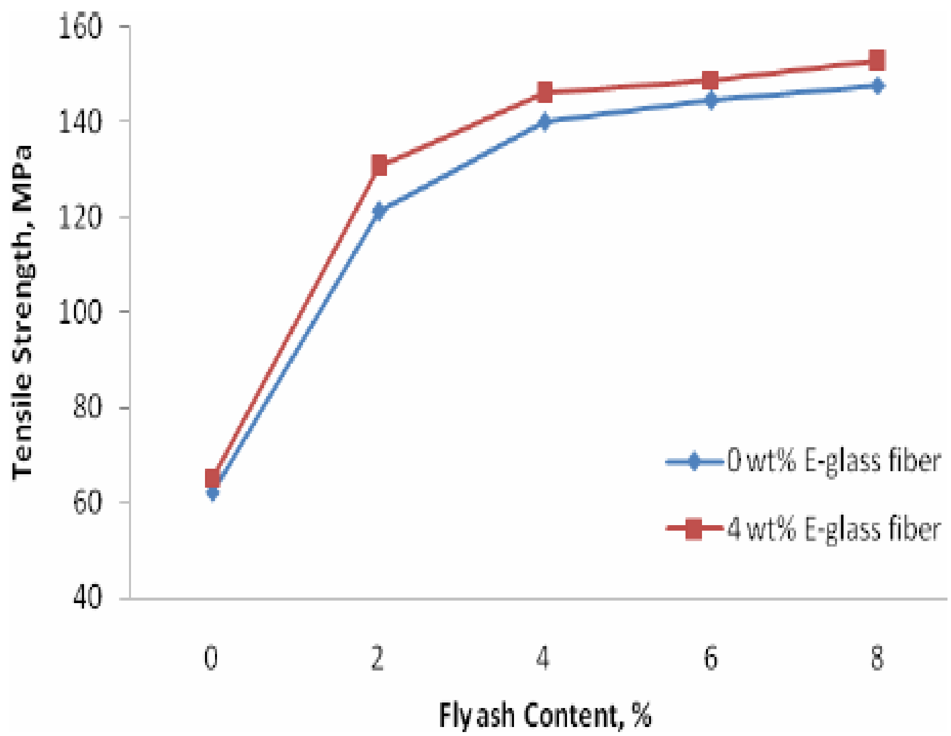

Figure 2.19: Effect of variation of fly ash and e-glass fiber on ultimate tensile strength of composite material. ***(Arun Kumar M. B. and R. P. Swamy, 2011)***

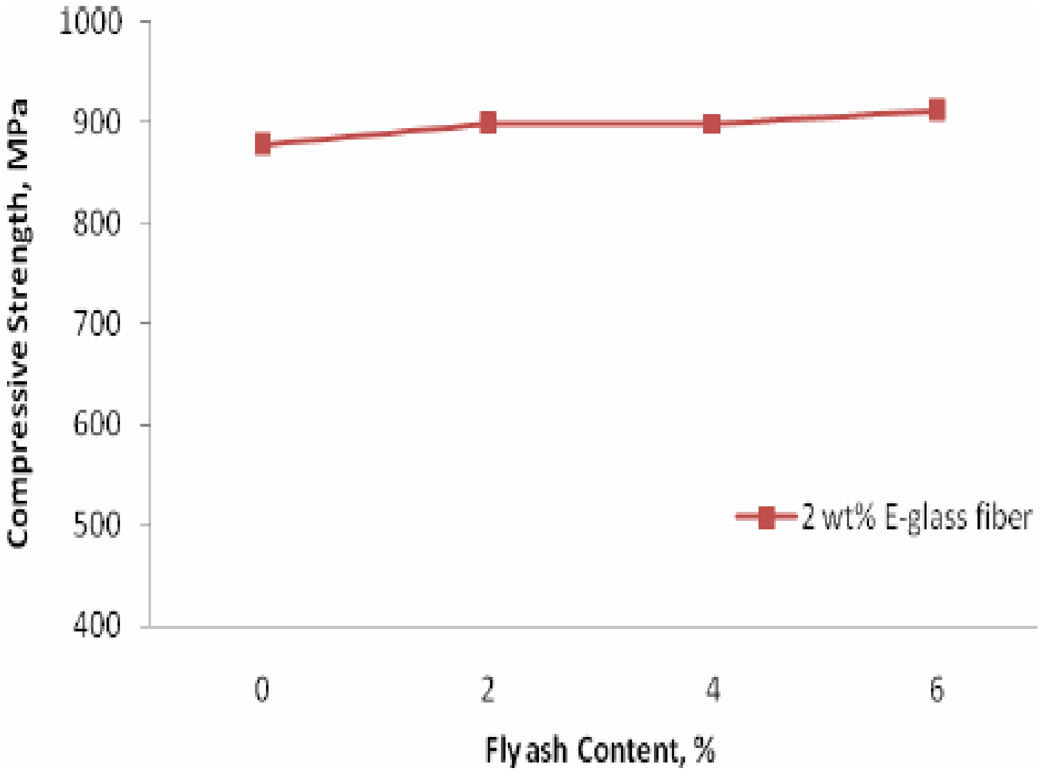

Figure 2.20 : Effect of variation of fly on compressive strength of composite material.
(Arun Kumar M. B. and R. P. Swamy, 2011)

N. Bhanumathidas and N.Kalidas 2003, The earlier apprehensions that fly ash reduces strength is no more valid. Strength development in fly ash-blended concretes is indispensable and depends on the type of fly ash, particle size, reactivity and temperature of curing. When ASTM type Class F fly ashes are used, there is a general trend that rate of initial strength gain is slow. However, ultimate compressive strength surpasses that of control concrete depending on the input and quality of fly ash. Finer the particle size, higher the surface area. As hydration activity occurs on the surface of solid phase through diffusion and dissolution of materials in concentrated paste, surface area plays consider-able role in determining the kinetics of such processes. Mehta's work confirmed a linear relation between percentage of particles of < 10 μm and strength of mortars.

Effect of fly ash in concretes is more pronounced in flexural strength than on compressive strength. Improved bond at the transition zone may be attributed as one of the significant contributions for this phenomenon.

Suresh Chandra Pattanaik, Dr. Akshaya Kumar Sabat 2010,

Studied the effect of partial replacement of cement with fly ash in varying mass of 0%, 10%, 20%, 30% & 40% on target compressive strength of M30 & M40 as shown in table no. 16 & 17. . The test result showed that early gain strength of both control mixes were higher up to 7-

14 days thereafter the strength of mix with 10 and 20% replaced with fly ash were more than that of the control mixes (Figure 2.21 & 2.22). Early strength gain of fly ash replaced concrete decreased. fly ash affects the early strength because it releases the free lime which still reacts during the curing process. The strength of the mix with 30 % replacement was more than control mix after 21 days for M30 (Figure 2.21) and 90 days for M40 (Figure2.22) Mixes. This was because of continued hydration of cementious-pozzolanic materials which increased the long-term strength. The strength of the Mix with 40% replacement with fly ash was all time lower than that of control mix(Figure 2.21 & 2.22). But the rate of gain of strength of all the mixes replaced with fly ash was higher than control mixes. This confirmed the general trend of later strength gain of fly ash replaced
concrete. Figure 2.23 shows that 32% replacement with cement gave the same strength at 28days and 35% replacement with cement gave the same strength at 90 days with the control mixes. Hence for optimal use of fly ash the 28 days target strength of the Mix was achieved with a replacement of 30% of fly ash with the cement. Reduction of water binder helped in achieving the higher strength with a low dosage of superplasticizer.

Table2.16 : Compressive Strength of M30 Grade Concrete, *(Suresh Chandra Pattanaik, Dr. Akshaya Kumar Sabat 2010),*

Replacement of Cement with Fly ash	Compressive Strength (Mpa)		
	7 Days	28 Days	90 Days
Control	30.64	37.88	38.2
10%	28.33	51.03	52.48
20%	28.14	47.7	51.35
30%	22.96	41.34	43.56
40%	18.45	30.2	28.56

Table 2.17 : Compressive Strength of M40 Grade Concrete, *(Suresh Chandra Pattanaik, Dr. Akshaya Kumar Sabat 2010),*

Replacement of Cement with Fly ash	Compressive Strength (Mpa)		
	7 Days	28 Days	90 Days
Control	38.4	47.53	48.12
10%	30.42	58.16	59.25
20%	32.21	51.91	53.45
30%	28.43	44.64	48.31
40%	25.26	35.1	38.26

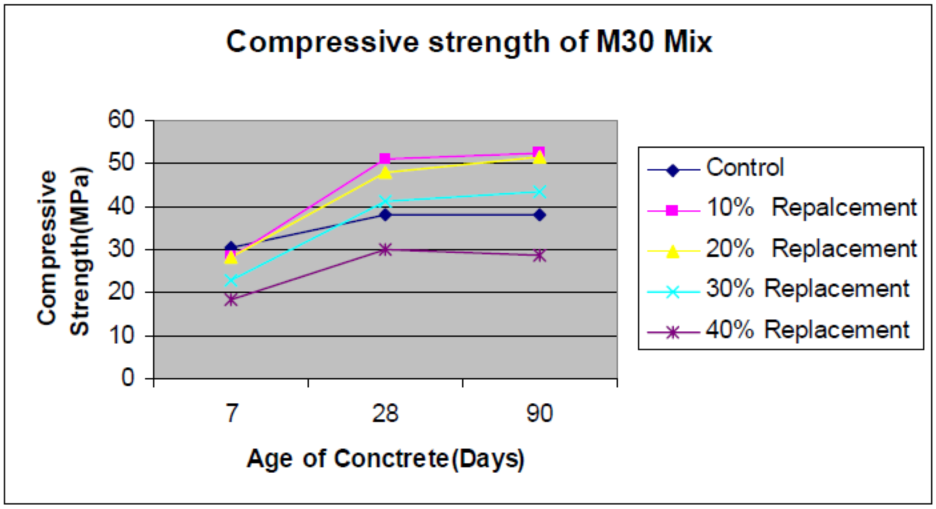

Figure 2.21 : Compressive Strength of M30 Mix with fly ash replacement, (*Suresh Chandra Pattanaik, Dr. Akshaya Kumar Sabat 2010*),

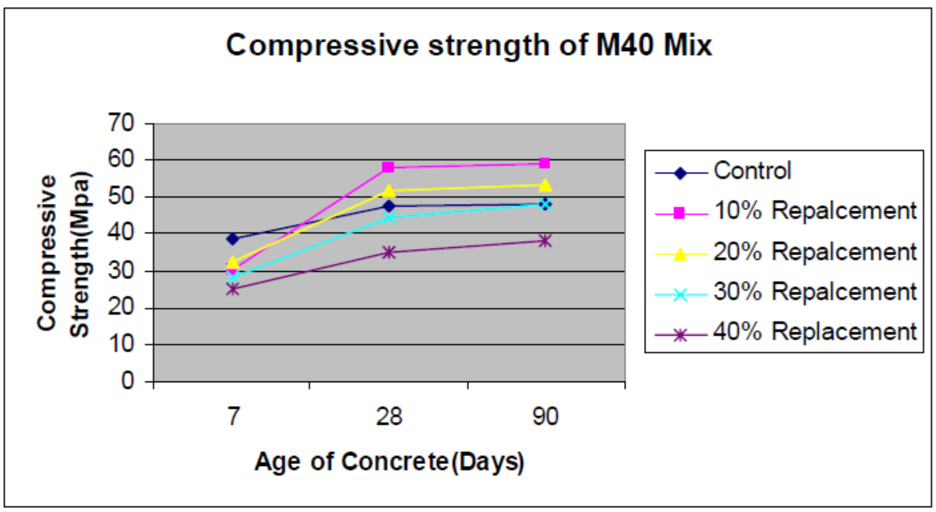

Figure 2.22 : Compressive Strength of M40 Mix with fly ash replacement, (*Suresh Chandra Pattanaik, Dr. Akshaya Kumar Sabat 2010*),

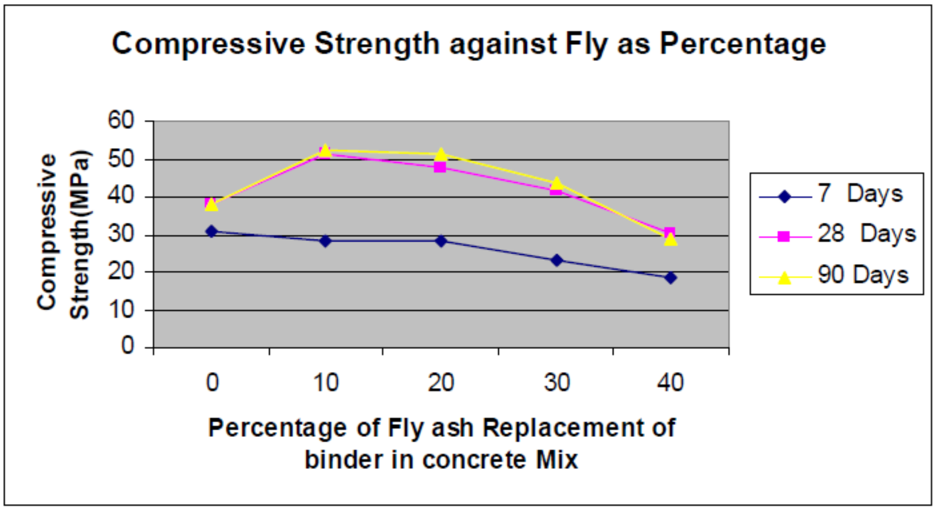

Figure 2.23 : Compressive Strength against age of fly ash replaced concrete, *(Suresh Chandra Pattanaik, Dr. Akshaya Kumar Sabat 2010),*

C.Marthong, T.P.Agrawal 2012, Studied the variation in compressive strength with age by replacement of flyash of cement at various percentage level and grade of cement The variation of cubes strength at different ages of 7, 28, 56 and 90 days with different grades of cement and various percentage of fly ash as partial replacement by weight is shown in Figure:2.24 to 2.26. The plot shows that the strength of concrete decreases with increase of fly ash contents at the early ages for all three grades of cement. The inclusion of fly ash about 40% replacements causes a reduction of 7 days strength about 55, 51 and 50% respectively as compared to that of concrete with pure cement. The 28 days cube strength at 40% replacement also decreases in strength about 42, 38 and 37% respectively as compared to that of concrete with pure cement. Similarly, at 40% replacement the strength reduction for 56 days is about 37, 32 and 30% respectively. At this age, the reduction in strength is lower as compared to that of 7 and 28 days. The rate of strength gained at this age over that of 28 days is about 8, 9 and 10% for pure cement to 17, 21 and 22% for 40% fly ash content. However, the rate of strength gained over that of 28 days being maximum for 20% fly ash replacement. Similarly, the 90 days cube strength reduction for sample containing 40% fly ash is still lower to 33, 26 and 21% respectively for 33, 43 and 53 grades concrete. The reduction in 90 days strength is smaller as compared to 7, 28 and 56 days strength. This shows that strength of fly ash concrete increases with age. Further, it is also observed that at the age of 90 days the rate of strength gain for 33, 43 and 53 grades concrete is increased and being maximum up to 20% fly ash replacement (Figure: 2.27). The rate of strength gain is up to 39, 41 and 41 % respectively over that of 28 days strength with a small difference of 4.62, 2.5 and 1.98 MPa as compared to the pure cement concrete.
This shows that fly ash have an effect of delayed hardening on strength gain of concrete.

For concrete at 90 days the 10, 20, 30 and 40% replacement by fly ash causes a reduction in strength of about 11, 10, 21 and 32% for 33 grades cement while for 43 and 53 grades are 7, 5, 16, 26 and 6, 4, 15, 24% respectively. This indicates that replacement by fly ash for 43 and 53 grades cement is seems to be better in term of ultimate strength reduction and strength gain than that of 33 grade OPC. However, in all grades of cement the replacement upto 20% fly ash has lesser effect on the strength at the later age.

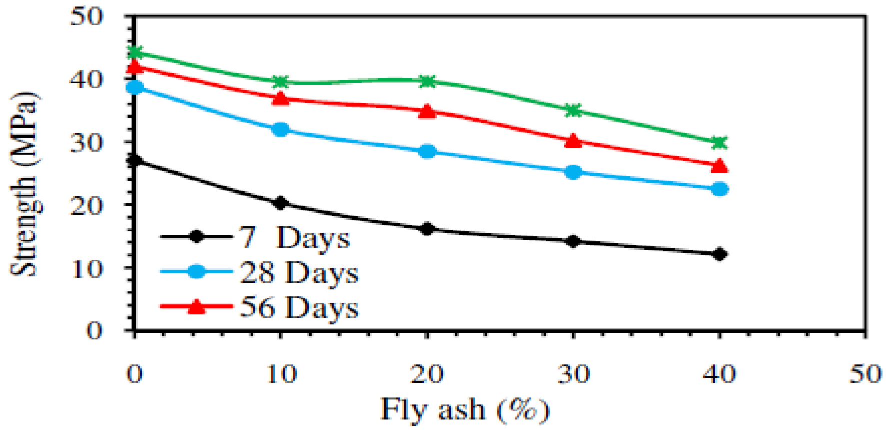

Figure 2.24 : Compressive strength of 33 grade OPC, *(C.Marthong, T.P.Agrawal 2012)*

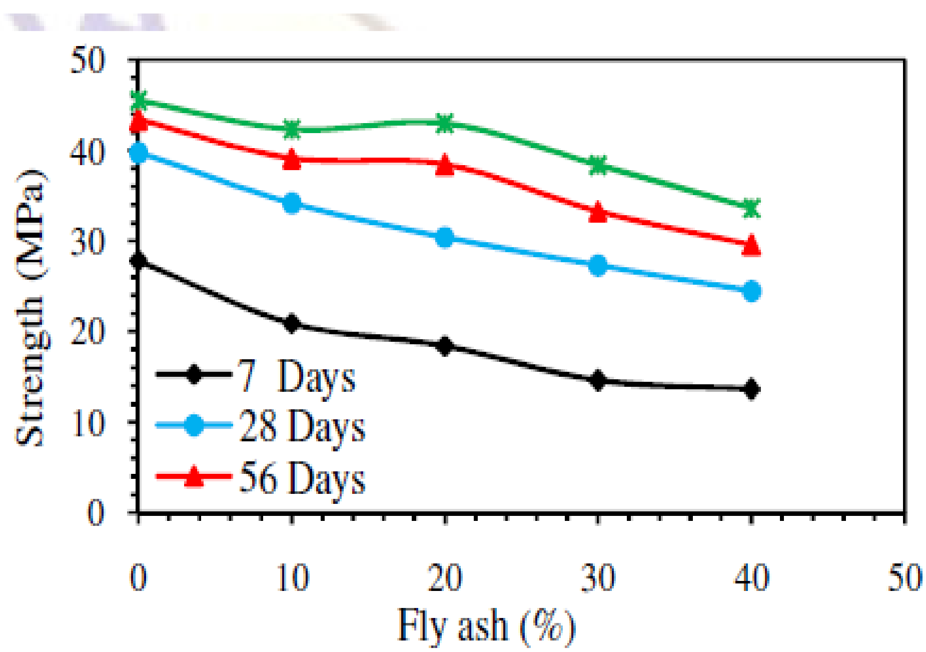

Figure 2.25 : Compressive strength of 43 grade OPC, *(C.Marthong, T.P.Agrawal 2012)*

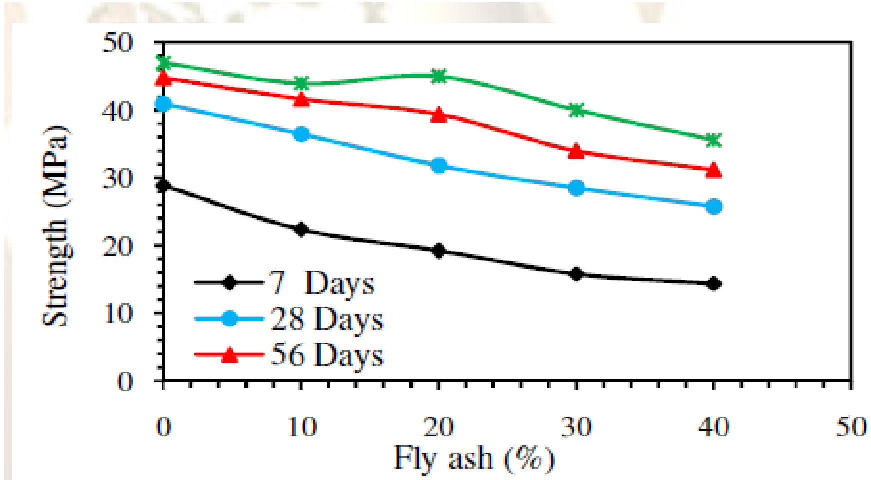

Figure 2.26 : Compressive strength of 53 grade OPC, *(C.Marthong, T.P.Agrawal 2012)*

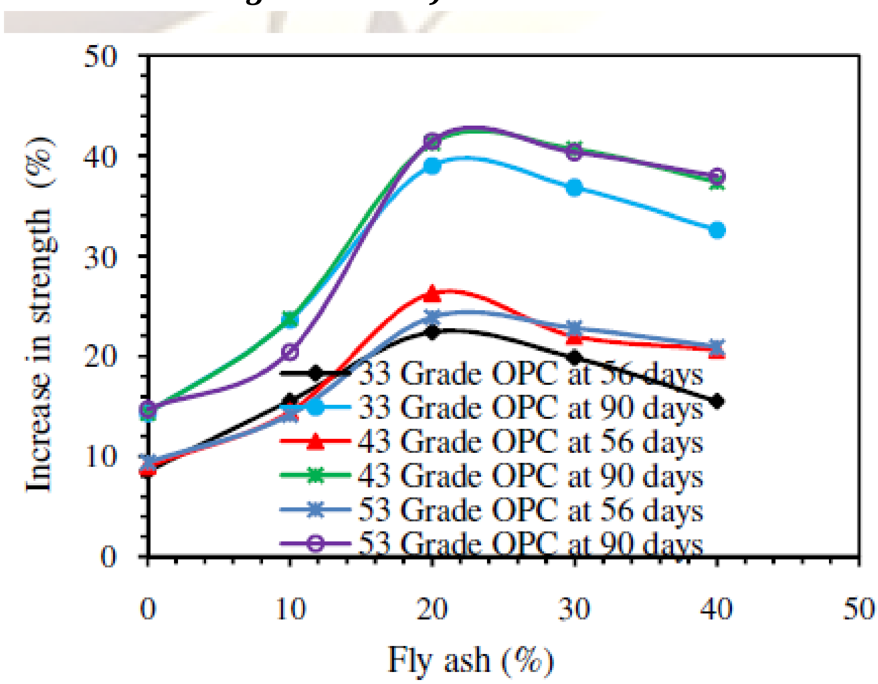

Figure 2.27 : Percentage increase in 56 and 90 days strength over 28 days, *(C.Marthong, T.P.Agrawal 2012)*

By Shiw S. Singh, Tarun R. Naik, Robert B. Wendorf, and Mohammad M. Hossain1999, Observed The influence of inclusion of Class C fly ash on strength and durability properties of high-performance concrete (HPC) was investigated. Concrete mixtures with and without fly ash were proportioned to attain 28-day compressive strength of 6000 psi. fly ash mixtures were proportioned to have cement replacement of approximately 35, 45, and 55% by weight. One pound of cement was replaced with 1.2 lbs of fly ash (a replacement ratio of 1 to 1.2).

Each concrete mixture was tested for compressive strength, splitting tensile strength, flexural strength, abrasion resistance, and chloride permeability. In general, the concrete mixtures up to 55% cement showed adequate performance with respect to all of these parameters for high-strength applications. However, the 35% fly ash mixture (i.e., flyash to cement plus fly ash ratio of 0.40) was found to be especially appropriate for manufacture of HPC.

Compressive Strength

The compressive strength data were recorded as a function of age and cement replacement with fly ash. At 1-day age, fly ash mixtures showed lower compressive strength compared to the no-fly ash mixture. However, beyond 1-day age, the 35% fly ash mixture showed the best results at all test ages. At 28 days, it showed a compressive strength in excess of 8000 psi. The other two fly ash mixtures (45 and 55% cement replacement) attained compressive strengths greater than 6000 psi. at 28 days. In generally, compressive strength of the concrete mixtures increased to a considerable amount when curing was extend to 91 days.

Tensile Strength

In general, addition of the fly ash caused reduction in tensile strength of the fly ash concrete mixture up to 28 days. However, all the fly ash mixtures at 91 days outperformed the reference concrete. This was attributed to improved structure of the fly ash mixtures due to significant pozzolanic reactions of the fly ash beyond 28 days.

Flexural Strength

All the mixture at 28 days attained high values of flexural strength . The no-fly ash mixture showed the highest value of flexural strength of all the mixtures tested at this age. At 91 days, the no-fly ash as well as the 35% fly ash mixture showed similar results.

2.2.2 Durability

N. Bhanumathidas and N.Kalidas 2003, studied the effect of fly ash on durability characteristics that is chloride permeability and electrical resistivity and observed the result shown in the table 2.18 that there is a fall in permeability for fly ash blended concrete in comparison to that of control. The data clearly delink durability from strength, which is a performance of increase in fineness of fly ash and its quantity. This data also highlight the resistivity of the concrete to electric charge manifested in coulombs, which means that lesser the coulombs more the resistivity. Electric charge is the basic activity, in the presence of moisture and oxygen, to initiate corrosion of the reinforcement.

Table 2.18 : Fall in permeability with fly ash blended concretes

(M20 grade, cementitious content = 300 kg/m3), *(N. Bhanumathidas and N.Kalidas 2003)*,

OPC, percent	Fly ash percent	Strength N/mm²			Chloride permeability, coulombs		
		28d	90d	180d	28d	90d	180d
100	-	43.3	47.2	51.4	3852	2451	2251
65	35(C)	28.8	41.1	44.2	2361	503	303
65	35(F)	35.1	53.7	58.4	2529	313	166
55	45(C)	24.9	35.3	41.9	2378	333	195
55	45(F)	28.7	51.0	54.3	2358	230	92

C. Marthong, T.P. Agrawal 2012,

Studied the durability aspect of concrete. Salt concentration of sea water varies from 0.58 to 4.0 g/l with an average of 2 g/l [Buenfeld and Newman, 1984]. In this study, the enhanced sulphate salt concentration as high as eight times that of average salt concentration of sea water was considered. Figure2.28 shows the variation in compressive strength with fly ash content for 28 days exposed in sulphate solution and tap-water. The figure demonstrates that, for each grades of cement the strength of ordinary cube and that replaced by fly ash immersed in sulphate solution have less compressive strength than the corresponding referral cubes immersed in tap-water. The strength was found less as fly ash contents is increase in both cases. Though, the strength exposed to sulphate solution decreases at each proportion of replacement as compared to cube strength exposed in tap-water, the decrease in strength is found to be more for ordinary cube than that of cubes containing fly ash. This loss of strength for ordinary cube may be due to the presence of sulphate salts in OPC which leads to the formation of complex expansive salts i.e. ettringite [Mehta, 1986]. This might have been accompanied by leaching of salts from inside pores. The formation of ettringite results in increased in volume and cause disruption of concrete. The decrease in cube strength exposed in sulphate solution over that exposed in tap-water are about 8% for ordinary cubes and that of 40% fly ash content are about 5% for all grades of OPC. Thus, it shows that addition of fly ash as partial replacement of cement improves the durability when exposed to sulphate environment. Cement paste containing fly ash favored the formation of expansive salts. Addition of fly ash to cement converts the leachable calcium hydroxide into insoluble non-leachable cementitious products. The increase in sulphate resistance may be due to the contained reaction of fly ash with hydroxides in concrete to form additional calcium silicate hydrate (C-S-H), which fills in capillary pores in the cement paste, reducing permeability and the ingress of sulphate solution. Comparing all the three grades of OPC, the strength loss seem to be betters for 53 grade OPC (Figure.2.29) as compared to the other two grades.

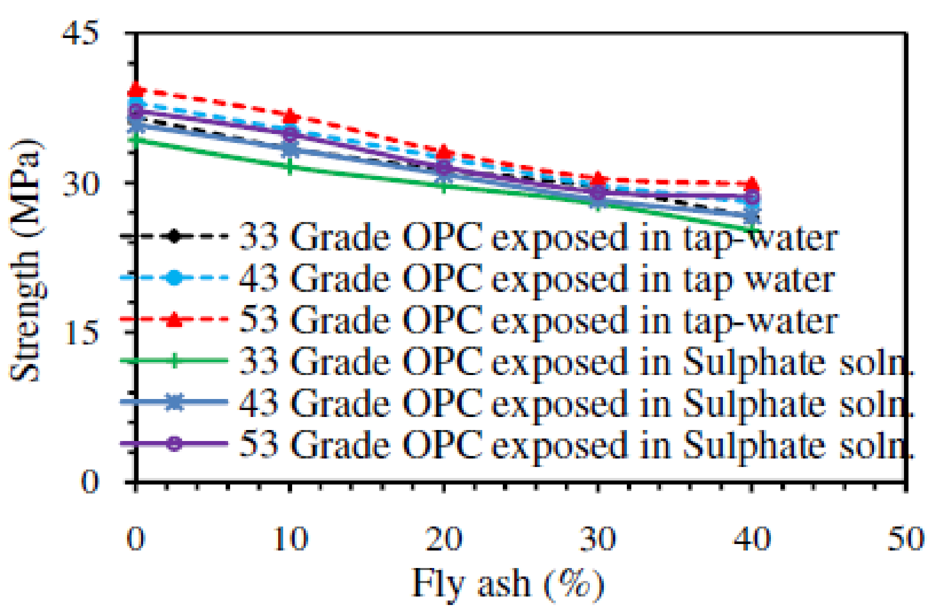

Figure 2.28 : Compressive strength under different Environment, *(C. Marthong, T.P. Agrawal 2012),*

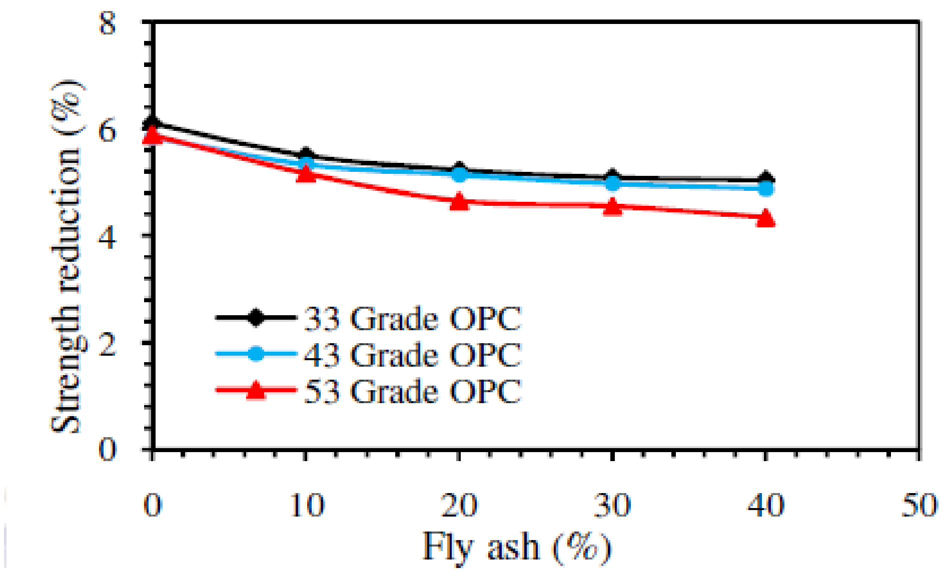

Figure 2.29 : Reduction in strength exposed in sulphate Solution, *(C. Marthong, T.P. Agrawal 2012),*

Shiw S. Singh, Tarun R. Naik, Robert B. Wendorf, and Mohammad M. Hossain1999,

In this study fly ash mixtures were proportioned to have cement replacement of approximately 35, 45, and 55% by weight. One pound of cement was replaced with 1.2 lbs of fly ash (a replace-ment ratio of 1 to 1.2). Each concrete mixture was tested for abrasion resistance, and chloride permeability.

Abrasion Resistance

The abrasion tests were performed at ages of 28, and 91 days. The results indicated that the concrete mixtures up to 35% cement replacement by fly ash had abrasion resistance similar to that for concrete without fly ash. Beyond 35% cement replacement, abrasion resistance decreased slightly up to 55% cement replacement.

Chloride Permeability

The chloride permeability of all the mixtures at 28-day age showed "moderate" chloride permeability in accordance with ASTM C 1202. When duration of curing was increased to 91 days, the chloride permeability values for the mixtures up to 45% cement replacement were rated "low" as per ASTM C 1202. At 91-day age, the 35% fly ash mixture exhibited the highest resistance to chloride ion permeability. At this age, the 45% fly ash mixture attained lower chloride ion permeability value compared to the reference mixture without fly ash.

CHAPTER-3
EXPERIMENTAL PROGRAMME AND METHODOLGY

3.1 GENERAL

The present chapter deals with the presentation of results obtained from various tests conducted on material used for the concrete. In order to achieve the objectives of present study, an experimental programme was planned to investigate the effect of fly ash and lime sludge on compressive strength, split tensile strength and abrasion resistance of concrete.

3.2 MATERIALS

The properties of material used for making concrete mix are determined in laboratory as per relevant codes of practice. Different materials used in present study were cement, coarse aggregates, fine aggregates, silica fume, fly ash in addition to lime sludge from Paper Mill. The aim of studying of various properties of material is used to check the appearance with codal requirements and to enable an engineer to design a concrete mix for a particular strength. The description of various materials which were used in this study is given below:

3.2.1 Ordinary Portland Cement

Although all materials that go into concrete mix are essential, cement is very often the most important because it is usually the delicate link in the chain. The function of cement is first of all to bind the sand and stone together and second to fill up the voids in between sand and stone particles to form a compact mass. It constitutes only about 20 percent of the total volume of concrete mix; it is the active portion of binding medium and is the only scientifically controlled ingredient of concrete. Any variation in its quantity affects the compressive strength of the concrete mix. Portland cement referred as (Ordinary Portland Cement) is the most important type of cement and is a fine powder produced by grinding Portland cement clinker. The OPC is classified into three grades, namely 33 Grade, 43 Grade, 53 Grade depending upon the strength of 28 days. It has been possible to upgrade the qualities of cement by using high quality limestone, modern equipments, maintaining better particle size distribution, finer grinding and better packing. Generally use of high grade cement offers many advantages for making stronger concrete. Although they are little costlier than low grade cement, they offer 10-20% saving in cement consumption and also they offer many hidden benefits. One of the most important benefits is the faster rate of development of strength.

Ordinary Portland Cement (OPC) of 43 Grade (Birla Vikram Primium make) from a single lot was used throughout the course of the investigation. It was fresh and without any lumps. The physical properties of the cement as determined from various tests conforming to Indian Standard IS: 8112:1989 are listed in Table 3.1. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture. The various tests conducted on cement are initial and final setting time, specific gravity, fineness and compressive strength. The results of above said tests are given below in Table 3.1.

Table 3.1 : Properties of OPC 43 Grade

Sr. No.	Characteristics	Values Obtained Experimentally	Values Specified By IS 8112:1989
1.	Specific Gravity	3.15	-
2.	Standard Consistency, percent	29	-
3.	Initial Setting Time, minutes	147	30 (minimum)
4.	Final Setting Time, minutes	305	600 (maximum)
5.	Compressive Strength (N/mm^2)		
	3 days	24.8	23 (minimum)
	7 days	37.5	33 (minimum)
	28 days	47.6	43 (minimum)

It can be observed from tables that all the results satisfy the standard criteria.

3.2.2 Aggregates

Aggregates constitute the bulk of a concrete mixture and give dimensional stability to concrete. To increase the density of resulting mix, the aggregates are frequently used in two or more sizes. The most important function of the fine aggregate is to assist in producing workability and uniformity in mixture. The fine aggregate assist the cement paste to hold the coarse aggregate particles in suspension. This action promotes plasticity in the mixture and prevents the possible segregation of paste and coarse aggregate, particularly when it is necessary to transport the concrete some distance from the mixing plant to placement. The aggregates provide about 75% of the body of the concrete and hence its influence is extremely important. They should therefore meet certain requirements if the concrete is to be workable, strong, durable and economical. The aggregates must be proper shape, clean, hard, strong and well graded.

a) Coarse Aggregates: The aggregate which is retained over IS Sieve 4.75 mm is termed as coarse aggregate. The coarse aggregates may be of following types:-

(i) Crushed graves or stone obtained by crushing of gravel or hard stone.

(ii) Uncrushed gravel or stone resulting from the natural disintegration of rocks.

(iii) Partially crushed gravel obtained as product of blending of above two types.

The normal maximum size is gradually 10-20 mm; however particle sizes up to 40 mm or more have been used in Self Compacting Concrete. Gap graded aggregates are frequently better than those continuously graded, which might expensive grader internal friction and give reduced flow. Regarding the characteristics of different types of aggregate, crushed aggregates tend to improve the strength because of interlocking of angular particles, while rounded aggregates improved the flow because of lower internal friction.

Locally available coarse aggregate having the maximum size of 20 mm was used in this work. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. The aggregates were tested as per IS: 383-1970. Specific gravity and other properties of coarse aggregates are given in Table 3.2. The sieve analysis of coarse aggregate was done. Table 3.3 & 3.4 show the result of sieve analysis. Proportioning of coarse aggregates was done and fineness modulus was obtained.

Table 3.2 : Properties of Coarse Aggregates

Characteristics	**Value**
Colour	Grey
Shape	Angular
Nominal Size	20 mm
Specific Gravity	2.68 (20mm), 2.74 (10mm)

Table 3.3 : Sieve Analysis of Coarse Aggregate (20 mm)

Weight of sample taken = 3000gm					
Sr. No	**IS-Sieve (mm)**	**Wt. Retained (gm)**	**%age retained**	**%age Passing**	**Cumulative % retained**
1	80	0.0	0.00	100.00	0.00
2	40	0.0	0.00	100.00	0.00
3	20	20.0	0.67	99.33	0.67
4	10	2920.0	97.33	2.67	98.00
5	4.75	40.0	1.33	98.67	99.33
6	Pan	20.0	0.67	99.33	
	Total	3000.00		SUM	198 + 500 = 698
				FM =	*6.98*

Table 3.4 : Sieve Analysis of Coarse Aggregate (10 mm)

Weight of sample taken = 3000gm

Sr. No	IS-Sieve (mm)	Wt. Retained (gm)	%age retained	%age Passing	Cumulative % retained
1	12.5	290	9.67	90.33	9.67
2	10	580	19.33	80.67	29
3	4.75	1800	60	40	89
4	2.36	270	9	91	98
5	Pan	60	2	98	
	Total	3000.00		SUM	225.67+400= 625.67
				FM=	6.26

b) Fine Aggregates: The aggregates most of which pass through 4.75 mm IS sieve are termed as fine aggregates. The fine aggregate may be of following types:

i) Natural sand, i.e. fine aggregate resulting from natural disintegration of rocks.

ii) Crushed stone sand, i.e. fine aggregate produced by crushing hard stone.

iii) Crushed gravel sand, i.e. fine aggregate produced by crushing natural gravel.

According to size, the fine aggregate may be described as coarse, medium and fine sands. Depending upon the particle size distribution IS: 383-1970 has divided the fine aggregate into four grading zones (Grade I to IV). The grading zones become progressively finer from grading zone I to IV.

In this experimental program**,** fine aggregate was locally procured and conformed to Indian Standard Specifications IS: 383-1970. The sand was sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and conforming to grading zone II. It was coarse sand light brown in colour. Sieve analysis and physical properties of fine aggregate are tested as per IS: 383-1970 and results are shown in Table 3.5 and Table 3.6

Table 3.6 : Physical Properties of fine aggregates

Characteristics	**Value**
Specific gravity	2.56
Bulk density(kg/m^3)	1.3
Fineness modulus	2.43
Water absorption, %	0.89

Table 3.5 : Sieve Analysis of Fine Aggregate

Weight of sample taken =1000 gm.

Sr. No.	IS-Sieve (mm)	Wt. Retained (gm)	%age retained	%age Passing	Cumulative % retained
1	4.75	3	0.30	99.70	0.30
2	2.36	21	2.10	97.90	2.40
3	1.18	156	15.60	84.40	18.00
4	600 μ	240	24.00	76.00	42.00
5	300 μ	375	37.50	62.50	79.50
6	150 μ	184	18.40	81.60	97.90
7	Pan	21	2.10		
	Total	1000.00		SUM	240.10
				FM =	*2.40*

3.2.3 Water

Generally, water that is suitable for drinking is satisfactory for use in concrete. Water from lakes and streams that contain marine life also usually is suitable. When water is obtained from sources mentioned above, no sampling is necessary. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent tap water is used for casting. The potable water is generally considered satisfactory for mixing and curing of concrete. Accordingly potable water was used for making concrete available in Material Testing laboratory. This was free from any detrimental contaminants and was good potable quality.

3.2.4 Silica fume

Physical and chemical composition of silica fume used in the experiments is given in the table 3.7 & 3.8. Silica fume is Pale Gray in colour as shown in Figure: 3.1

Table 3.7 : Physical Properties of Silica Fume

Characteristics	Value
Specific gravity	2.30
Bulk density(kg/m^3)	300
Colour	Gray
Specific Surface Area (m^2/kg)	20000

Figure 3.1 : Silica fume

Table 3.8 : Chemical Composition of Silica Fume

Constituents	Percent
SiO_2	92.00
$Al_2 O_3$	0.50
MgO	1.20
Fe_2O_3	1.00
CaO	0.60
Na_2O	0.70
K_2O	0.90
C	1.0
S	0.5

3.2.5 Fly ash of class C grade was arranged from Panipat Thermal Power Plant and a single lot was used throughout the course of the investigation. It was dry without lumps and Gray in colour as shown in Figure 3.2 . The physical properties of the fly ash as determined from various tests in the laboratory are listed in Table 3.9. Chemical composition was got derived from Sophisticated Analytical Instruments Laboratories Thapar Technology Campus, Bhadson Road, Patiala. are given below in Table 3.10

Table 3.9 : Physical Properties of Fly ash

Characteristics	Value
Specific gravity	2.20
Bulk density(kg/m^3)	400
Colour	Gray

Figure 3.2 : Fly ash

Table 3.10: Chemical Composition of fly ash

S.No.	Constituents	Percentage
1	Al_2O_3	23.08
2	CaO	0.90
3	Fe_2O_3	3.11
4	K_2O	1.36
5	MgO	0.42
6	Na_2O	0.23
7	S	1.15
8	SiO_2	58.54
9	Loss on Ignition	9.92

3.2.6 Lime sludge

In this work, the Lime Sludge is taken from the Ballar Pur Paper Mill Industries Yamuna Nagar Haryana . It is White in colour and look like as slaked lime as shown in figure 3.3. The Physical and Chemical analysis of lime sludge is shown in Table 3.11

3.3 TEST METHODS

The procedure of methods used for testing cement, coarse aggregates, fine aggregate and concrete are given below:

3.3.1 Specific Gravity

Specific gravity is ratio of the weight of a given volume of a substance to the weight of an equal volume of some reference substance, or equivalently the ratio of the masses of equal volumes of two substances.

Figure 3.3 : Lime sludge

Table 3.11 : Properties of Lime sludge

S. No.	Constituents	Percentage
1	Colour	Pale white
2	Specific gravity	2.65
3	Al_2O_3	0.03
4	CaO	42.00
5	Fe_2O_3	0.07
6	K_2O	0.05
7	MgO	0.52
8	Na_2O	1.29
9	S	0.39
10	SiO_2	0.63
11	Loss on Ignition	55.12

3.3.2 Sieve Analysis for Coarse and Fine Aggregates as per IS: 2386 (Part I) – 1963

The sieve analysis is used for the determination of particle size distribution of fine and coarse aggregates by sieving or screening.

3.3.3 Compressive Strength of Concrete

Cube specimens of size 150 mm x 150 mm x 150 mm were taken out from the curing tank at the ages of 7 & 28 days, Surface water was wiped off and tested as shown in figure 3.4**.** The position of cube when tested was at right angle to that as cast. The tests were performed on Universal Testing Machine (UTM). The load as applied gradually without shock till the failure of the specimen occurs and thus the compressive strength was found.

Figure 3.4: Compression testing of cube

The quantities of cement, coarse aggregate 10mm & 20 mm, fine aggregate, silica fume, fly ash , lime sludge and water for each batch i.e. for different percentage of Lime sludge replacement was weighed separately. The cement ,lime sludge, silica fume and fly ash were mixed dry to a uniform colour separately. Fine aggregate was mixed to this mixture in dry form. The coarse aggregates were mixed to get uniform distribution throughout the batch. Water added to the mix. Firstly, 50 to 70% of water was added to the mix and then mixed thoroughly for 3 to 4 minutes in mixer. Then the concrete was filled into the cube moulds and then get vibrated to ensure proper compaction. The surface of the concrete was finished level with the top of the mould using trowel. The finished specimens were left to harden in air for 24 hours. The specimens were removed from the moulds after 24 hours of casting and were placed in the water tank, filled with potable water in the laboratory.

3.3.4 Split Tensile Strength of Concrete

The split tensile strength of concrete is determined by casting cylinders of size 150 mm X 300 mm. The cylinders were tested by placing them uniformly. Specimens were taken out from curing tank at the age of 7 & 28 days of moist curing and tested after surface water dipped down from specimens. This test was performed on Universal Testing Machine (UTM) as shown in figure.

Figure 3.5 : Split Tensile strength test

The magnitude of tensile stress (T) acting uniformly to the line of action of applied loading is given by formula

$$T = 0.637P/DL$$

Where,
T = Split Tensile Strength in N/mm^2
P = Applied load,
D = Diameter of Concrete cylinder sample in mm.
L = Length of Concrete cylinder sample in mm.

The quantities of cement, coarse aggregate 10mm & 20 mm, fine aggregate, silica fume, fly ash , lime sludge and water for each batch i.e. for different percentage of lime sludge replacement was weighed separately. The cement , lime sludge, silica fume and fly ash were mixed dry to a uniform colour separately. Fine aggregate was mixed to this mixture in dry form. The coarse aggregates were mixed to get uniform distribution throughout the batch. Water added to the mix. Firstly, 50 to 70% of water was added to the mix and then mixed thoroughly for 3 to 4 minutes in mixer. Then the concrete was filled into the cylindrical moulds and then get vibrated to ensure proper compaction. The surface of the concrete was finished level with the top of the mould using trowel. The finished specimens were left to harden in air for 24 hours. The specimens were removed from the moulds after 24 hours of casting and were placed in the water tank, filled with potable water in the laboratory.

3.3.5 Abrasion Resistance Test

Tests performed for checking the abrasion resistance of concrete, produced using fly ash and Lime sludge as partial replacement for cement, Concrete specimens of size 70 mm x 70 mm x 25 mm were casted and cured at normal temperature for 7 & 28 days abrasion resistance test as shown in figure 3.6. Samples were taken out from curing tank and oven dried for 24 hours at 100° ± 5°. Before testing at the ages of 7 & 28 days. In this work abrasion test was performed as per IS 1237. and loss of mass was recorded for each replacement level in each grade of concrete.

Figure 3.6 : Concrete specimens for Abrasion test

3.4 MIX DESIGN (M20) ,(M25) & (M30) GRADE OF CONCRETE

A) Test data for materials:

(i) Specific gravity of cement 3.15
(ii) Specific gravity of coarse aggregates (20mm) 2.68
(iii) Specific gravity of coarse aggregates (10mm) 2.74
(iii) Specific gravity of fine aggregates 2.56
(iv) Zone of fine aggregates II
(v) Water absorption of coarse aggregates 0.40%
(vi) Water absorption of fine aggregates 0.89%

The mix proportions obtained for Design Mix and various other mixes cast are tabulated in Table 3.12 & 3.13

Table 3.12 : Design Mix Proportion of Concrete in (kg/m^3)

		Water (W)	Cement (C)	Fine Aggregate (F.A)	Coarse Aggregate (CA-I) (10mm)	Coarse Aggregate (CA-II)(20mm)
M-20	By Weight (kg)	186	372	676.10	407.35	756.51
	Ratio	0.5	1	1.817	1.095	2.033
M-25	By Weight (kg)	186	395.74	658.72	407.15	756.14
	Ratio	0.47	1	1.665	1.029	1.91
M-30	By Weight (kg)	186	422.73	639.20	405.38	752.84
	Ratio	0.44	1	1.512	0.958	1.78

Table 3.13: Proportions of Concrete Mixtures

Mix Type			Design Mix Proportion Ratio by weight (kg/m^3)					
	W	C	F.A	C.A (10mm)	C.A (20mm)	SILICA FUME	FLY ASH	LIME SLUDGE
A1-M20	0.5	1	1.817	1.095	2.033	-	-	-
C1-M20	0.5	0.7	1.817	1.095	2.033	0.05	0.25	-
C2-M20	0.5	0.7	1.817	1.095	2.033	0.05	0.20	0.5
C3-M20	0.5	0.7	1.817	1.095	2.033	0.05	0.15	0.10
C4-M20	0.5	0.7	1.817	1.095	2.033	0.05	0.10	0.15
A2-M25	0.47	0.7	1.665	1.029	1.91	-	-	-
C5-M25	0.47	0.7	1.665	1.029	1.91	0.05	0.25	-
C6-M25	0.47	0.7	1.665	1.029	1.91	0.05	0.20	0.5
C7-M25	0.47	0.7	1.665	1.029	1.91	0.05	0.15	0.10
C8-M25	0.47	0.7	1.665	1.029	1.91	0.05	0.10	0.15
A3-M30	0.44	0.7	1.512	0.958	1.78	-	-	-
C9-M30	0.44	0.7	1.512	0.958	1.78	0.05	0.25	-
C10-M30	0.44	0.7	1.512	0.958	1.78	0.05	0.20	0.5
C11-M30	0.44	0.7	1.512	0.958	1.78	0.05	0.15	0.10
C12-M30	0.44	0.7	1.512	0.958	1.78	0.05	0.10	0.15

CHAPTER-4
RESULTS AND DISCUSSION

4.1 GENERAL

This chapter deals with the presentation of results obtained from various tests conducted on concrete specimens cast with four replacement levels of Lime sludge and fly ash. The main objective of the research program was to understand the compressive strength, split tensile strength and abrasion resistance aspects of concrete obtained using lime sludge and fly ash as partial replacement for cement. In order to achieve the objectives of present study, an experimental program was planned to investigate the combined effect of Lime sludge and fly ash on compressive strength, split tensile strength and abrasion resistance of concrete. The experimental program consisted of casting, curing and testing of controlled concrete and concrete mix with varying proportions of Lime sludge and fly ash along with a 5% fixed proportion of silica fume, at the ages of 7 & 28 days.

The experimental program included the following:

- Testing the properties of materials used for making concrete.
- Design mix (M20), (M25) &(M30)
- Casting and curing of cubes of 150X150X150mm for compressive strength, cylinders of 150X300mm for split tensile strength and concrete blocks of 70X70X25mm for abrasion resistance test.
- Tests to determine the compressive strength, split tensile strength and abrasion resistance of concrete.

4.2 COMPRESSIVE STRENGTH

4.2.1 General

In most structural applications, concrete is employed primarily to resist compressive stresses. When a plain concrete member is subjected to compression, the failure of the member takes place in its vertical plane along the diagonal. The vertical crack occurs due to lateral tensile strains. A flow in the concrete, which is in the form of micro crack along the vertical axis of the member will take place on the application of axial compression load and propagate further due to the lateral tensile strains.

4.2.2 Test Procedure and Results

Test specimens of size 150 X 150 X 150 mm were prepared for testing the compressive strength of concrete. In the concrete mixes 30% of cement was replaced with 5% of Silica fume as fixed proportion for all mixes and 25% of fly ash, further 25% of fly ash was replaced with varying percentages (5%, 10% and 15%) of Lime sludge keeping the silica fume content fixed at 5%. Six cubes were casted for subsequent testing at 7 & 28 days. The mix type with

% replacement of cement, fly ash, and Lime sludge with fixed 5% proportion of silica fume, are given in Table 4.1. In this study, to make concrete, cement, fly ash, lime sludge, silica fume and fine aggregate were first mixed dry to uniform colour and then coarse aggregate was added and mixed. Water was then added and the whole mass mixed. The interior surface of the moulds and the base plate were oiled before concrete was placed. After 24 hours the specimens were removed from the moulds and placed in clean fresh water at room temperature for curing. The specimens so cast were tested after 7 & 28 days of curing measured from the time water is added to the dry mix. For testing in compression, no cushioning material was placed between the specimen and the plates of the machine. The load was applied axially without shock till the specimen was crushed. Average results of three specimens of the compressive strength test on concrete of all five mix including the controlled mix at the age of 7 & 28 days are given in the Table 4.2.

Table 4.1: Mix Types

S. No.	Mix Type	% Ingradients			
		Cement	Silica Fume	Fly ash	Lime Sludge
1	A1-M20	100	-	-	-
2	C1-M20	70	5	25	-
3	C2-M20	70	5	20	5
4	C3-M20	70	5	15	10
5	C4-M20	70	5	10	15
6	A2-M25	100	-	-	-
7	C5-M25	70	5	25	-
8	C6-M25	70	5	20	5
9	C7-M25	70	5	15	10
10	C8-M25	70	5	10	15
11	A3-M30	100	-	-	-
12	C9-M30	70	5	25	-
13	C10-M30	70	5	20	5
14	C11-M30	70	5	15	10
15	C12-M30	70	5	10	15

Table 4.2: Compressive strength of concrete mixes of specimen size (150×150×150)

Mix Type	Compressive Strength in N/mm²	
	7 days	**28 days**
A1-M20	18.00	28.14
C1-M20	14.39	24.28
C2-M20	14.31	22.88
C3-M20	11.30	19.66
C4-M20	9.00	17.40
A2-M25	21.29	35.04
C5-M25	16.74	28.86
C6-M25	15.98	25.74
C7-M25	14.80	23.43
C8-M25	12.48	20.4
A3-M30	26.80	39.18
C9-M30	18.00	32.00
C10-M30	16.79	30.80
C11-M30	16.07	26.71
C12-M30	14.79	24.69

The average test results of three cubes for compressive strength of concrete of all mixes at the age of 7 & 28 days are shown graphically in Figure 4.1. The variation of 7 & 28 days compressive strength of M-20, M-25 & M-30 Grade of concrete for all mixes under examination are shown in figures 4.2 to 4.4. From the graphs it is observed that

- The compressive strength decreases as compared to control mix as the percentage of lime sludge is increased in the Mix.
- After replacing 30% of cement with (25% fly ash +5% Silica fume) there is a decrease of 20% strength in 7 days for M-20, 21.37% strength in 7 days for M-25 & 32.83% strength in 7 days for M-30 concrete, whereas, the reduction at 28 days is comparatively less and is of the range of 13.71% reduction in strength at 28 days for M-20, 17.63% reduction for M-25 & 18.32% reduction in strength for M-30 as compared to the control mix. This indicates that early strength gain is lesser as compared with later strength gain for all the mixes containing silica fume and fly ash.
- Replacement of fly ash with lime sludge keeping silica fume constant shows further reduction in 7 & 28 days strength as the percentage of lime sludge increases. On replacing fly ash with 5% lime sludge in the mix, there is a decrease of 20.5% strength in 7 days for M-20, 25% reduction for M-25 & 37.35% reduction in strength for M-30 grade concrete. A similar trend is observed for strength reduction at 28 days. There is a 18.69% reduction in strength in 28 days for M-20, 26.54% reduction for M-25 & 31.24% reduction in strength for M-30 concrete as compared to the control mix.

- On replacing fly ash with 10% lime sludge in the mix, there is a decrease of 37.22% strength in 7 days for M-20, 30.48% for M-25 & 40.03% for M-30, whereas, there is a decrease of 30.13% strength in 28 days for M-20, 33.13% for M-25 & 34.38% strength in 28 days for M-30 as compared to the control mix.
- On replacing fly ash with 15% lime sludge in the mix, there is a decrease of 50% strength in 7 days for M-20, 41.38% for M-25 & 44.81% strength in 7 days for M-30 concrete, whereas, there is a 38.16% strength reduction in 28 days for M-20, 41.78% for M-25 & 36.98 % reduction in strength for M-30 concrete as compared to the control mix. Thus, the strength reduces further if the lime sludge replacement level is increased.
- From figures 4.2 & 4.3 it can be seen that up to a replacement level of 5% of fly ash with Lime sludge the reduction in strength is lesser as compared with higher replacements. Also it can be seen that early strength gain is lesser in M-20 grade of concrete with higher replacement level of fly ash with Lime sludge that is beyond 5%, as compared with later strength gain.
- From figure 4.2 & 4.3 it can be seen that up to a replacement level of 10% of cement with optimal 5% fly ash and 5% lime sludge desired strength can be achieved after 28 days.

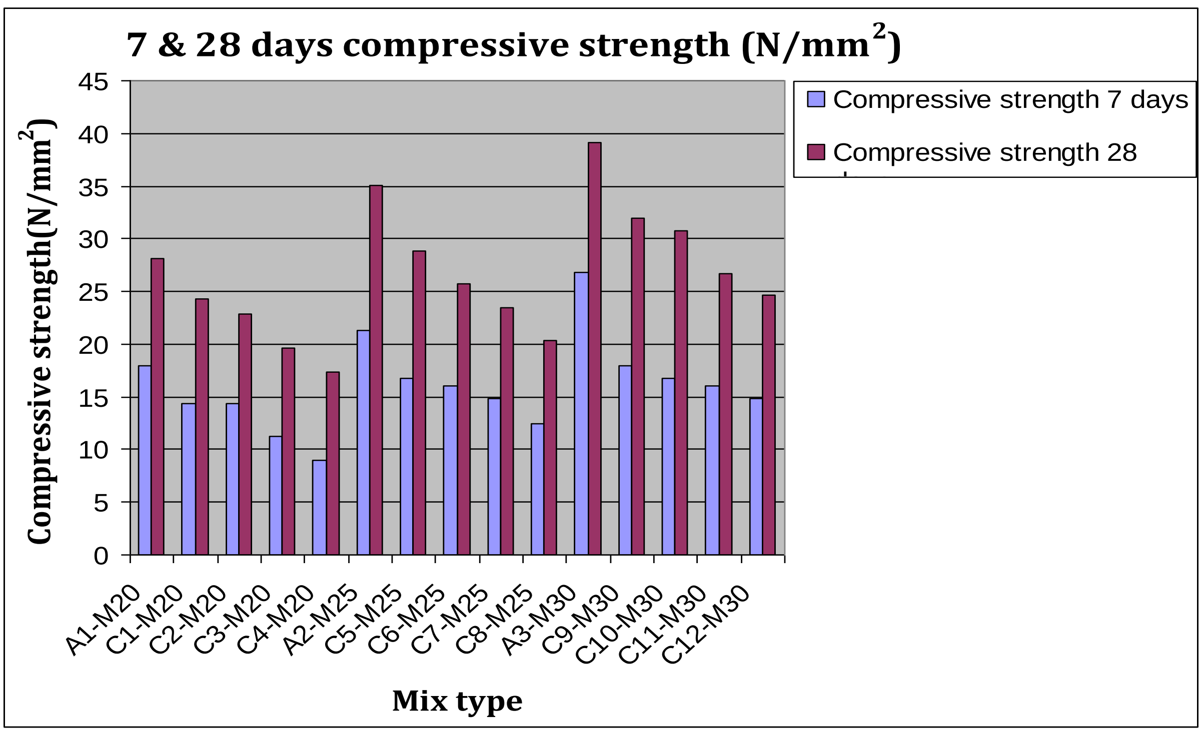

Figure 4.1 : Compressive strength of Concrete Mixes (N/mm^2) at 7 & 28 days.

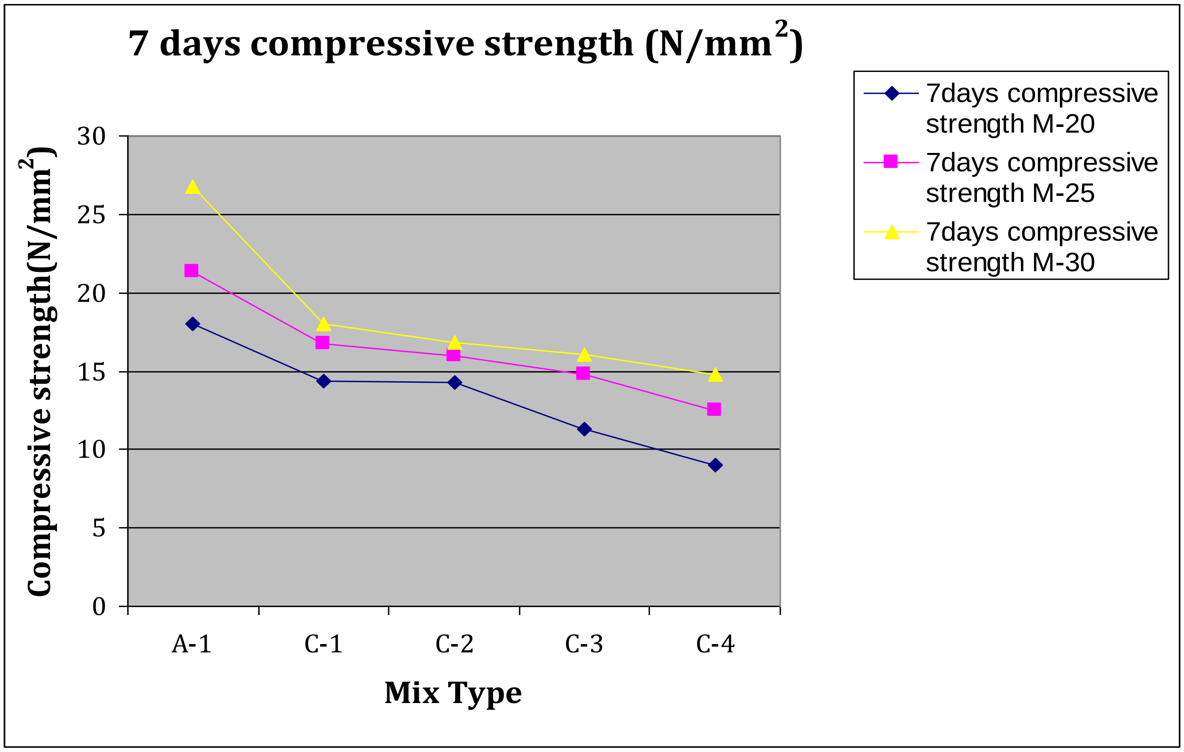

Figure 4.2: Compressive strength of concrete mixes (N/mm²) at 7days

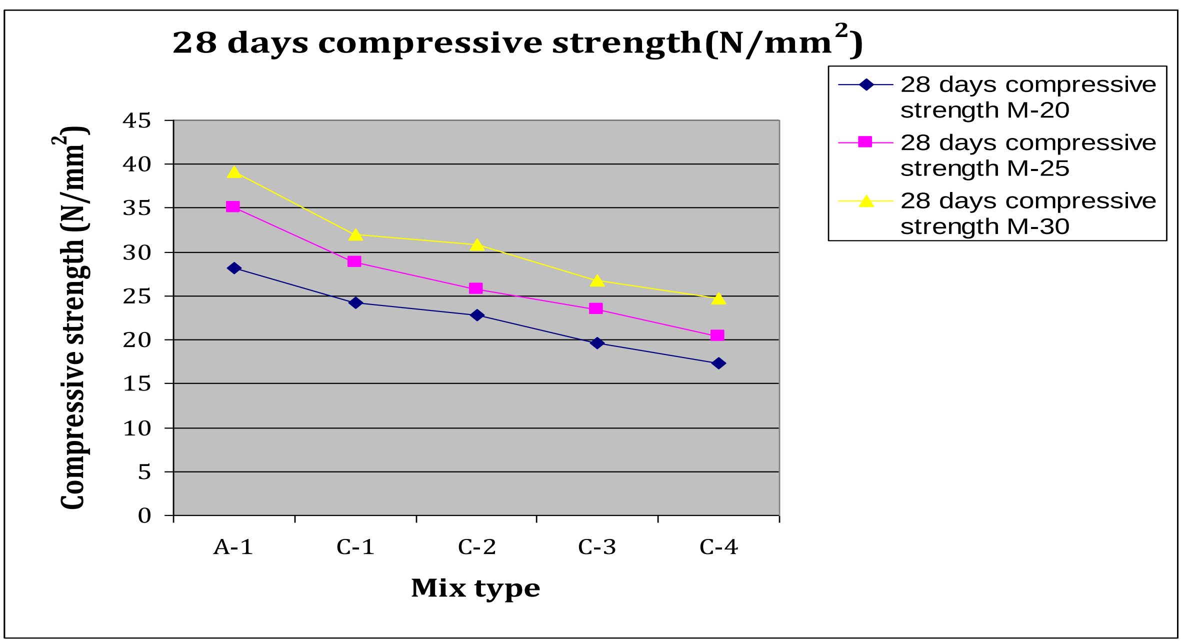

Figure 4.3: Compressive strength of concrete mixes (N/mm²) at 28 days

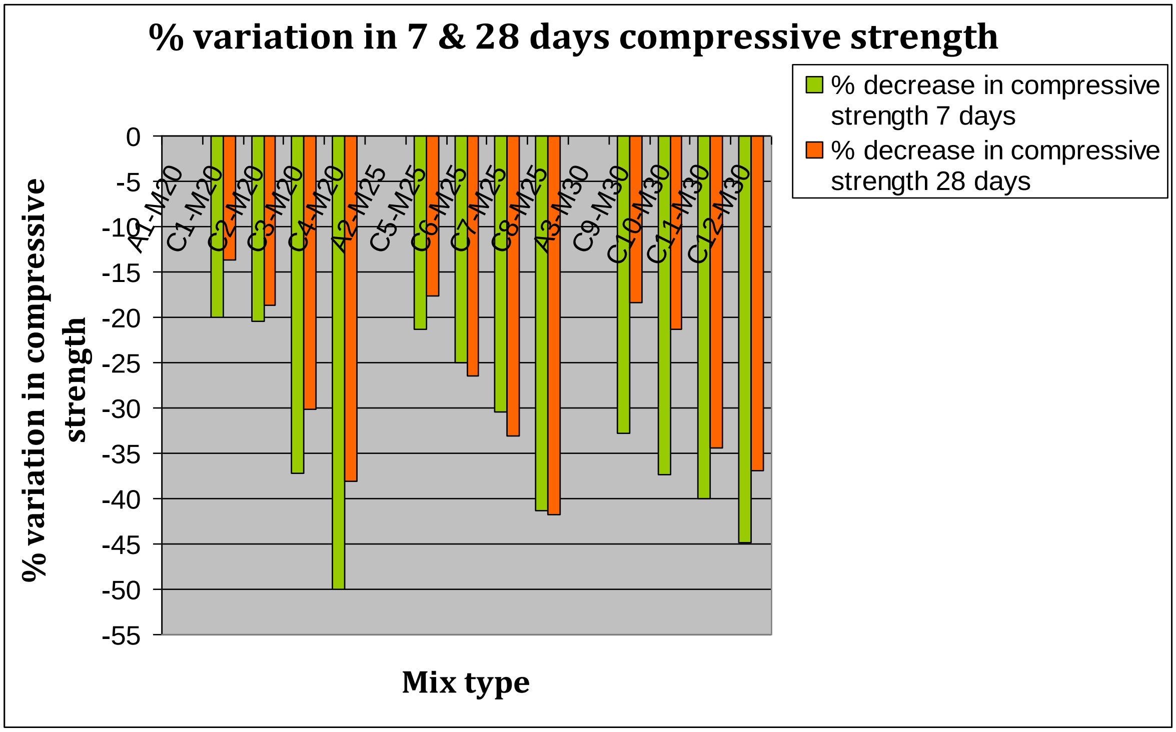

Figure 4.4 : % Variation in Compressive Strength

4.3 SPLIT TENSILE STRENGTH

Split tensile strength tests were carried out on the cylinders of size 150 X 300mm at the age of 7 & 28 days. The average test results of three cylinders are given in Table 4.3. The average results of the split tensile strength on three cylinders of concrete mix are also shown graphically in Figure 4.5. The variation in strength gains at 7 & 28 days for M20, M25 & M30 Grade of concrete are also shown graphically in figures 4.6 & 4.7. From the figures it is observed that

- The split tensile strength results for concretes with partial replacement of cement by silica fume (5%), fly ash and lime sludge, in varying proportions, in general, are observed to be less as compared to control mix. However, as we increase the percentage of lime sludge in the mix an increase in the split tensile strength is observed up to 10% replacement level and then it is again observed to decrease.
- After replacing 30% of cement with (25% fly ash +5% Silica fume) there is a decrease of 63% in split tensile strength in 7 days for M-20 grade concrete, 41.48% for M-25 & 41.13% for M-30, respectively. Further, a decrease of 30.10% in split tensile strength in 28 days for M-20 grade concrete, 28.76% for M-25 & 24% for M-30, respectively is observed as compared to the control mix.
- A 5% replacement of fly ash with lime sludge further decreases the 7 & 28 days split tensile strength of all grades of concrete. After replacing 5% of fly ash with lime sludge in the mix, there is a decrease of 69% strength in 7 days for M-20 grade

concrete, 68.88% for M-25 & 66.66% for M-30, respectively, and there is a decrease of 38.26% strength in 28 days for M-20, 32.87% for M-25 & 39.20% for M-30 respectively, as compared to the control mix.

- On replacing fly ash with 10% Lime sludge in the mix, there is a decrease of 40.47 % strength in 7 days for M-20 grade concrete, 21.48% reduction for M-25, and a 16.31% reduction in split tensile strength for M30 grade of concrete, however, there is a decrease of 12.24 % strength in 28 days for M-20, 16.43% reduction for M-25, and 23.6% reduction for M30 grade concrete when compared to the control mix.
- Replacing fly ash with 15% Lime sludge in the mix, there is a decrease of 52.38% strength in 7 days for M-20, 33.33% for M-25 & 13.47% decrease in strength in 7 days for M-30 grade of concrete, whereas, there is a 19.38% decrease in strength in 28 days for M20, 22.37% for M25 and 30% decrease in strength in 28 days for M-30 grade of concrete, respectively when compared to the control mix.
- It is observed that a partial replacement of fly ash with 10% lime sludge gives the maximum tensile strength for all mixes, although it is less than the controlled concrete, indicating better flexural behavior.
- From all replacement level it is observed that 10% replacement of fly ash with Lime sludge is best optimal replacement level.

Table 4.3: Split tensile strength of concrete mixes

Mix Type	Split Tensile Strength in N/mm^2	
	7 days	28 days
A1-M20	1.26	1.96
C1-M20	0.46	1.37
C2-M20	0.39	1.21
C3-M20	0.75	1.72
C4-M20	0.6	1.58
A2-M25	1.35	2.19
C5-M25	0.79	1.56
C6-M25	0.42	1.47
C7-M25	1.06	1.83
C8-M25	0.9	1.7
A3-M30	1.41	2.5
C9-M30	0.83	1.9
C10-M30	0.47	1.52
C11-M30	1.18	1.91
C12-M30	1.02	1.75

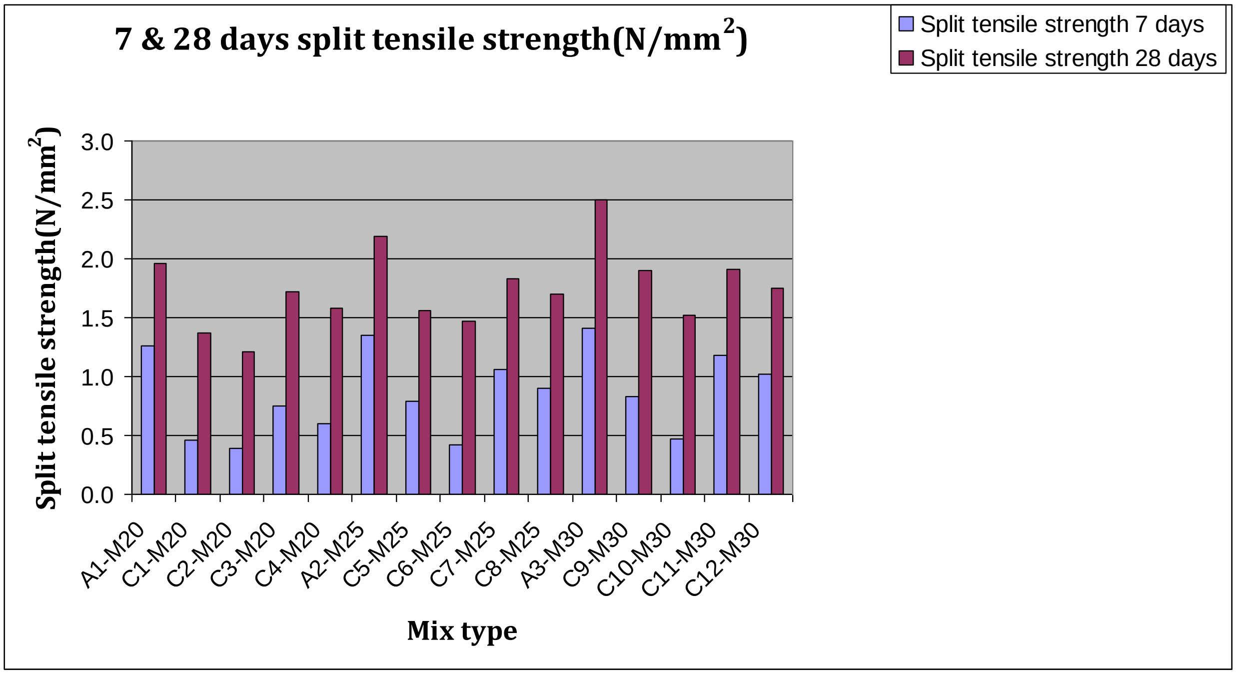

Figure 4.5: Split tensile strength of concrete mixes in (N/mm²) at 7 & 28 days

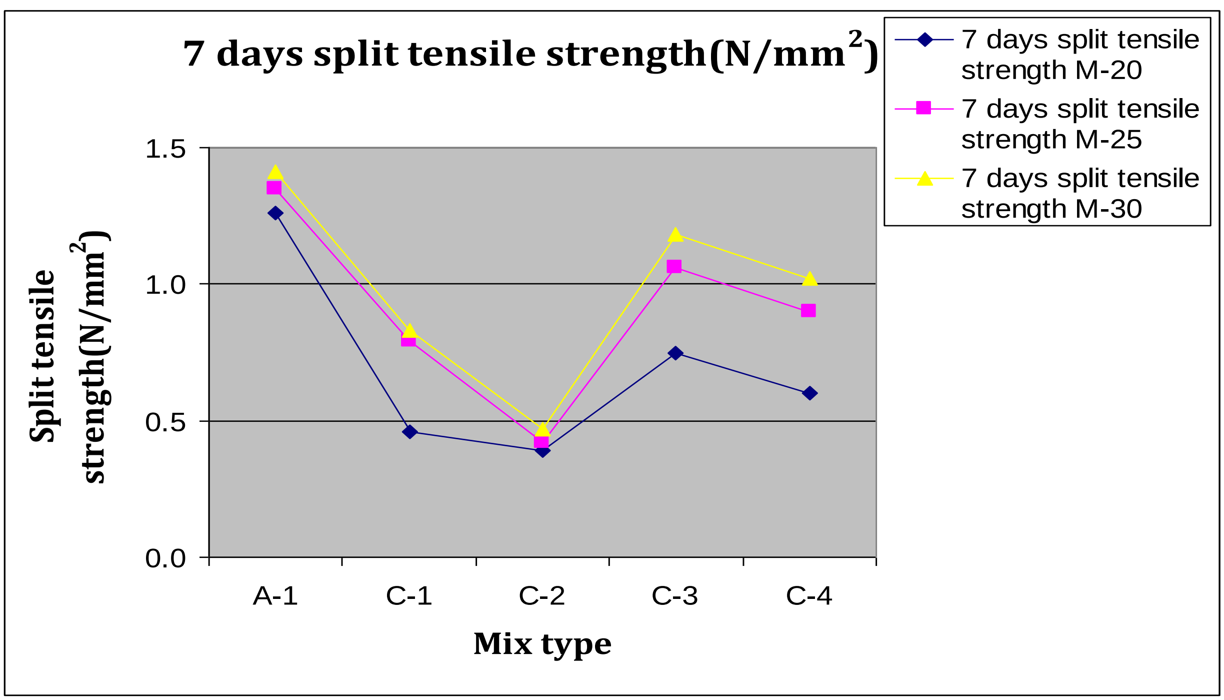

Figure 4.6 : Split tensile strength of concrete mixes (N/mm²) at 7 days

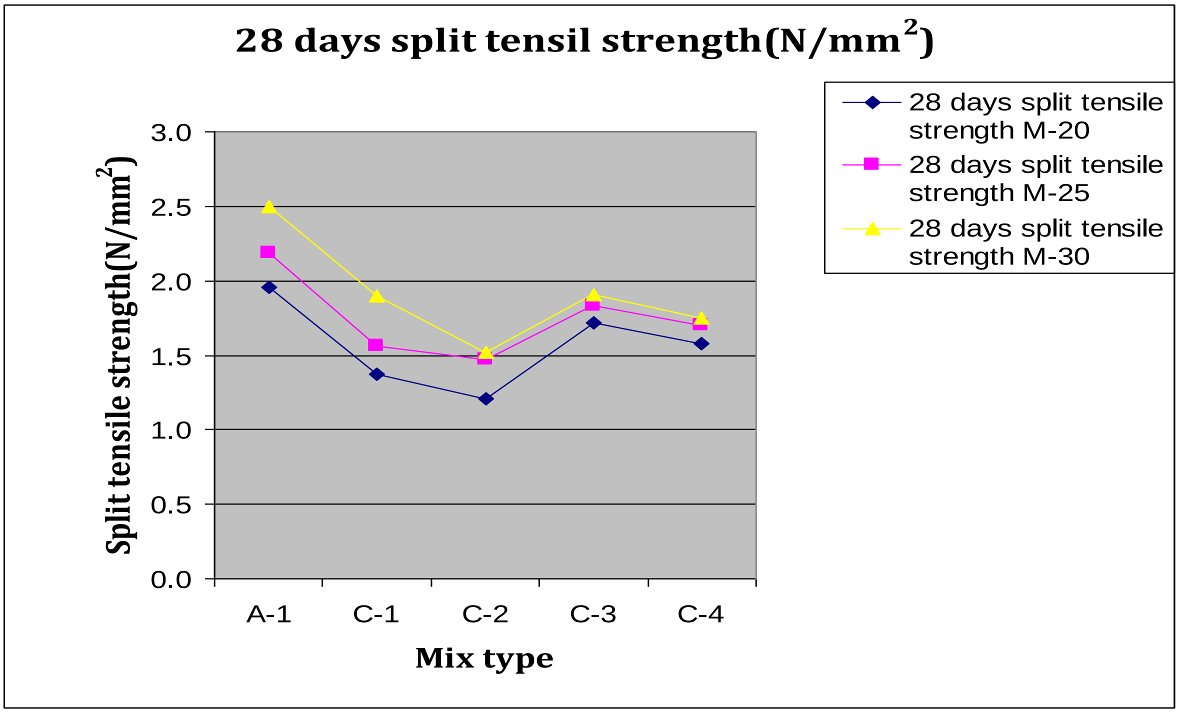

Figure 4.7 : Split tensile strength of concrete mixes (N/mm^2) at 28 days

4.4 ABRASION RESISTANCE OF CONCRETE

4.4.1 General

Abrasion resistance of concrete is one of the method to determine the durability of concrete, This test was conducted as per IS Code 1237-1980.

4.4.2 Test Procedure and Results

Test specimens of size 70 X 70 X 25 mm were cast for testing abrasion resistance of concrete. In this study, to make concrete, cement, fly ash, lime sludge, silica fume and fine aggregate were first measured and then mixed dry to uniform colour and then measured coarse aggregate was added and mixed. Water was then added and the whole mass mixed. The interior surface of the moulds was oiled before concrete was placed. After 24 hours the specimens were removed from the moulds and placed in clean fresh water at room temperature. The specimens so cast were tested after 7 & 28 days of curing measured from the time water is added to the dry mix. For testing abrasion resistance, the specimens were dried at 110°± 5°C for 24 hours and then weighed.

The grinding path of the disc of the abrasion testing machine as shown in figure:4.8 shall be evenly strewn with 20 g. of aluminium oxide abrasive powder The specimen shall then be fixed in the holding device with the surface to be ground facing the disc, and loaded at the centre with 300 N (30 kgf).

The grinding disc shall then be put in motion at a speed of 30 rev/min and the abrasive powder is continuously fed back on to the grinding path so that it remains uniformly distributed in a track corresponding to the width of the test piece. After every 22 revolutions, the disc shall be stopped, the abraded tile powder and the remainder of the abrasive powder shall be removed from the disc, and fresh abrasive powder in quantities of 20 g applied each time. After every 22 revolutions the specimen shall be turned about the vertical axis through an angle of 90' in the clockwise direction and it should be repeated 9 times thereby giving total number of revolutions of 220. The disc, the abrasive powder and the specimen shall be kept dry throughout the duration of the test. After the abrasion is over, the specimens were reweighed. The Average results of three specimens of the loss In weight due to abrasion of concrete with varying proportions of fly ash and Lime sludge replacement at the age of 7 & 28 days are given in the Table 4.4.

From the results shown in table 4.4 it is observed that there is no abrasion in the concrete made with cement replaced by fly ash and lime sludge. Although there may be some loss to the tune of milligrams, but it may not be measureable up to 1 gm and so has not been recorded. Thus, it can be said that there is no appreciable abrasion resistance for mixes containing fly ash and lime sludge as partial replacement of cement.

Table 4.4 : % Loss in weight due to Abrasion of Concrete Mix

S.No.	Mix Type	After 7 Days			After 28 Days		
		Initial weight w1(gm)	Final weight w2(gm)	% loss in weight (w1-w2)/ w1 x100	Initial weight w3(gm)	Final weight w4(gm)	% loss in weight (w3-w4)/w3 x100
1	A1-M20	258.0	258.0	0	258.0	258.0	0
2	C1-M20	259.5	259.5	0	256.5	256.5	0
3	C2-M20	248.0	248.0	0	253.5	253.5	0
4	C3-M20	258.5	258.5	0	257.5	257.5	0
5	C4-M20	256.5	256.5	0	254.0	254.0	0
6	A2-M25	253.0	253.0	0	260.0	260.0	0
7	C5-M25	255.0	255.0	0	259.0	259.0	0
8	C6-M25	253.5	253.5	0	249.5	249.5	0
9	C7-M25	255.0	255.0	0	253.0	253.0	0
10	C8-M25	252.0	252.0	0	258.5	258.5	0
11	A3-M30	260.5	260.5	0	249.5	249.5	0
12	C9-M30	247.5	247.5	0	247.0	247.0	0
13	C10-M30	253.5	253.5	0	250.0	250.0	0
14	C11-M30	240.5	240.5	0	245.5	245.5	0
15	C12-M30	257.5	257.5	0	247.5	247.5	0

Figure 4.8 : Abrasion Resistance Test

CHAPTER-5
CONCLUSIONS

5.1 GENERAL

The strength and durability characteristics of concrete such as Compressive strength, Split Tensile Strength and Abrasion resistance of concrete mixtures have been studied in the present work by replacing 30% of cement in the following five proportion of fly ash, lime sludge keeping silica fume constant in all mixes.

Cement		Silica Fume		Fly ash		Lime Sludge
100%	=	0%	+	0%	+	0%
30%	=	5%	+	25%	+	0%
30%	=	5%	+	20%	+	5%
30%	=	5%	+	15%	+	10%
30%	=	5%	+	10%	+	15%

On the basis of present study, following conclusions can be drawn.

5.2 COMPRESSIVE STRENGTH

- Compressive strength of all grades of concrete decreases when 30% of cement is replaced by a varying proportion of fly ash and lime sludge keeping a fixed proportion of silica fume at 5%, as compared with control mix.
- There is an increase in early strength of M-25 grade of concrete when 30% cement is replaced with 15% fly ash and 10% lime sludge with fixed proportion of silica fume as 5% as compared with control mix of M-25 Grade.
- There is a trend of increase in later age strength in all the concrete mixtures.
- The desired concrete grade strength can also be achieved by partially replacing cement with 20% fly ash and 5% lime sludge, keeping 5% silica fume as a fixed replacement parameter.

5.3 SPLIT TENSILE STRENGTH

- The split tensile strength results for concretes with partial replacement of cement by silica fume (5%), fly ash and lime sludge, in varying proportions, in general, are less as compared to control mix.
- As we increase the percentage of lime sludge in the mix an increase in the split tensile strength is observed up to 10% replacement level and then it is again observed to decrease. Thus, lime sludge can be a better replacement of fly ash when higher flexural strengths are required.
- There is an increase in early strength in all grade of concrete when 10% and 15% of fly ash is replaced with lime sludge as compare with controlled concrete.

5.4 ABRASION RESISTANCE

- All the concrete mixes with mineral admixtures (in proportions as taken for the study) showed adequate abrasion resistance at 28 days.
- During the hydration process, the ettringite and portlandite ($Ca(OH)_2$) phases diminish causing more dense and durable concrete after 28 days.

5.5 SCOPE FOR FUTURE WORK

- In the present study 30 percent replacement of cement has been considered. The other percentages i.e. 20, 40 & 50 percent need investigation.
- In the present study only 15% percent replacement of cement by lime sludge has been considered. The other percentages i.e. 25 and 30 percent need investigation.
- Raw Lime sludge has been used for experimental work obtained from causticizing process in paper mill. This lime sludge needs investigation after calcinations.
- Lime sludge obtained from other industries other than paper mill need investigation on the strength characteristics of concrete.
- Strength properties of concrete with partial replacement of cement with fly ash and lime sludge need investigation for longer period i.e. 90, 180 and 360days.

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