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EFFECT OF LIME SLUDGE ON COMPRESSIVE STRENGTH OF CONCRETE

Partial replacement of cement with lime sludge

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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. 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 lime sludge and a series of possibilities for its use in concrete, this research work demonstrates the possibilities of using lime sludge as partial replacements of cement in concrete.

This research work presents an investigation of different properties of materials used for mix design. Quality tests were conducted to check the suitability of material for mix design. Mix design was done according to IS guidelines and the result of it was 1:1.62:3.40. The objective of the study is to check the compressive strength of concrete by adding lime sludge as partial replacement of cement in various percentages. In this work 20% cement has been replaced by five proportions of lime sludge. The five proportions are (0% Lime sludge), (5% Lime sludge), (10% Lime sludge), (15 % Lime sludge) & (20% Lime sludge).

It has been observed from the 3, 7 & 28 days tests of compressive strength of concrete that compressive strength decreases as the percentage of lime sludge increases in the mix when compared with controlled concrete. The compressive strength, analysis carried out in this work gives a deeper insight into the cementitious properties and pozzolanic behaviour 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.

I. INTRODUCTION

1.1 GENERAL

The disposal of industrial wastes is a problem of increasing importance throughout the world. Sludge from paper mills 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 fibre, creating a tremendous disposal problem.

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 dependent 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.

1.2 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.

1.3 CATEGORISATION OF LIME SLUDGE

The various industrial wastes can be categorised as under.

- **Paper Sludge**

Investigations carried out the utilization of lime sludge from paper industry have indicated that the paper sludge can be utilized up to 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 up to 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 wiz P2O5 and SO3 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 up to 5 percent as mineraliser. Presence of chromium oxide as impurity up to 10 percent restricts its bulk utilization.

1.4 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.

Table 1.1 (a): Particle Size Distribution of Indian Lime sludge
(Source: 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

Table 1.1 (b): Physical Properties of Lime Sludge

(Source: 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 from various industries has been presented in Table 1.2. From the table it is clear that

- All the sludge has essentially lime as a major constituent and its content varies from 35-70% on dry basis. All the sludge other than from carbide industry contains lime as calcium carbonate. The sludge from carbide industry essentially contains calcium hydroxide.
- Lime bearing sludge also contain MgO, Al2O3, Fe2O3 and SiO2 as associated constituents and their contents vary considerably depending upon the occurrence of these constituents in the limestone used in the parent process.
- This sludge also contains specific contaminants associated with the process through which they are generated. Most of the problems regarding the utilization of this 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 SO3, up to 1.5% of P2O5 and up to 2% of fluoride as major contaminants. Paper, Sugar and chromium sludge contain free alkalies up to 2%. The chromium sludge in addition, contains chromium up to 10 percent.

Table 1.2: Chemical Composition of Indian Lime sludge

(Source: J.M Mauskar 2006)

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	-
Cr2O3	-	-	-	-	8-10	-

1.4.1 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 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 has 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 depending on the process type. Solid wastes, sources and qualities are given in Table 1.3.

Table 1.3: Solid waste types and sources from pulp and paper mills

(Source: 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

1.5 PAPER MILL LIME SLUDGE

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 has increased their production capacity more than 100 tpd and has 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 1.1.

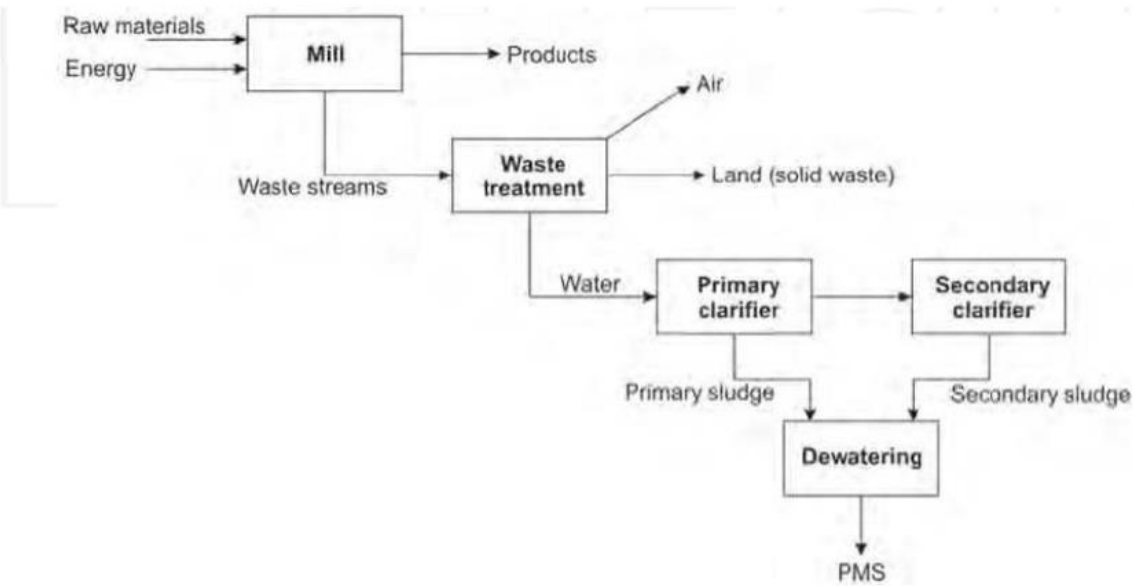

Figure 1.1: Lime sludge formation process

(Source: Progress in Paper Recycling Staff, 1993; Mabee and Roy, 2003)

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:

$$CaO + H_2O + 80\text{-}90°C = Ca(OH)_2$$

$$Na_2CO_3 + Ca(OH)_2 = 2\,NaOH + CaCO_3$$

(White liquor) (Lime Sludge)

The recausticizing reaction occurs at a solid-liquid interface within the solid particle. The green liquor containing dissolved Na_2CO_3 reacts with solid $Ca(OH)_2$, forming solid $CaCO_3$ and NaOH. The solid $CaCO_3$ remains as the interface and NaOH leaves in the dissolved form. Principally $CaCO_3$, 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 of by dumping in low lying areas, open fields thus make them unfertile. Many a times it is spread in a mill yard where it 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.

1.5.1 Characteristics of lime sludge/mud

Lime sludge is a very fine precipitated $CaCO_3$ particles along with unsettled dregs carried over from green liquor clarifier. The average Physico-Chemical properties of lime sludge waste are given in Table 1.4 & Table 1.5.

Table 1.4: Chemical properties of Lime sludge

(Source: 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 Magnesium. Silica enters mainly via raw materials or through purchased lime and goes to chemical recovery loop. During the causticizing operation SiO_2 forms $CaSiO_3$ which is gelatinous in nature. This gelatinous 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.

$$Ca(OH)_2 + SiO_2 + Na_2CO_3 = NaOH + CaCO_3 + CaSiO_3$$

(Green liquor) (Slow setting lime mud)

Table 1.5: Particle Size distribution of Lime Sludge

(Source: CRI-ENG-SP 965 March 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 CO_2 out of $CaCO_3$ to produce CaO is called calcination.

- **Mineralogical Studies**

Mineral analysis of representative lime sludge carried out using X-ray diffraction analysis technique is 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.

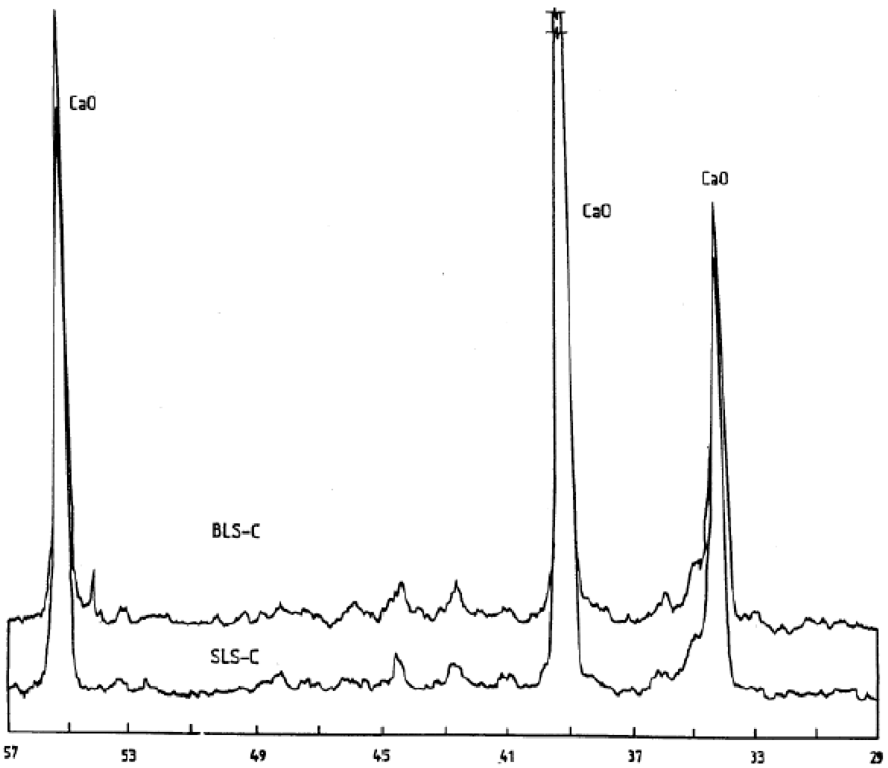

Figure 1.2: XRD of calcined Lime mud
(Source: CRI-ENG-SP 965March 2000)

1.5.2 Theory of Calcination

Manufacture of lime involves thermal decomposition of calcium carbonate under certain conditions of temperature and pressure. The dissociation of CaCO3, the main chemical compound in lime sludge takes places as per reaction:

$CaCO_3 = CaO + CO_2 - 42.52$ Kcal

The reaction indicates that for one-gram molecule of CaCO3, it is necessary to spend 42.53 Kcal heat. Accordingly, for obtaining one kg of lime (CaO) from CaCO3, 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:

- When heating a cube of calcium carbonate from room temperature to calcining temperature, it first expands prior to dissociation.
- Surface calcination, starts, the pore volume increase, the sample volume remains constant.
- When calcination is complete, the sample has the maximum pore volume and simple volume is still largely unchanged.
- With further temperature increase and longer calcination limes, crystals grow and sintering begins, both pore volume and sample volume decrease. The dissociation temperature of CaCO3 can vary from 800-1000°C.

1.5.3 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 is generated annually from these industries. All the lime sludge other than carbide sludge contains 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 contains 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 SO3, up to 1.5 percent P2O5 and up to 2 percent fluoride as major contaminants. Similarly, paper, sugar and chromium sludge contain free alkalies up to 2 percent. The chromium sludge and carbide sludge in addition also contain chromium up to 10 percent and chloride up to 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 up to 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 fibre 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.

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 digestible, 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 continued 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 up to the stage of pilot plant trials, the level of waste utilization in India continues to be very low, only approximately 15 percent.

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:

- 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.
- Transportation waste in dry form in open wagons results in huge transit losses.
- Plant engineering of commercial size plants for manufacturing new materials based on industrial wastes.
- Limitation in distance over which the wastes can be economically transported.
- Variation in the quality of wastes is one of the major problems related to its bulk utilization.
- 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.

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

- Industrial waste-based products should be exempted from excise duty.

1.9 OBJECTIVE OF THE RESEARCH WORK

The objective 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. It has been proposed to partially replace cement with lime mud/sludge and find its effect on the compressive strength of concrete. Five percentage levels of replacement i.e. 0%, 5%, 10%, 15% and 20 % are considered for partially replacing cement with lime sludge. M-20 concrete grade is initially designed without replacement and subsequently cement is partially replaced with lime sludge in the following proportions:

Table 1.6 Content of lime sludge used in this study

S.No	% Cement	% Lime sludge
1.	100	0
2.	95	5
3.	90	10
4.	85	15
5.	80	20

II. LITERATURE REVIEW

2.1 GENERAL

Lime mud/sludge is used as substitute to clinker. The Lime sludge 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 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 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 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.

2.2 LIME SLUDGE

2.2.1 Compressive 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 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 in view, the aim of investigation is the behaviour of concrete while adding of waste with different proportions of hypo sludge in concrete by using tests like compression 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
(Source: 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 proportions are shown in Table 2.2.

Table 2.2: Concrete design mix proportions
(Source: 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. The compressive strength vs. % replacements of cement results are graphically shown in Figure 2.1 and 2.2.

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

- Compressive strength reduces when cement replaced hypo sludge. As hypo sludge percentage increases compressive strength.
- 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
(Source: Pitroda et al, 2013)

Concrete Grade	Concrete Type	Average Compressive Ultimate 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

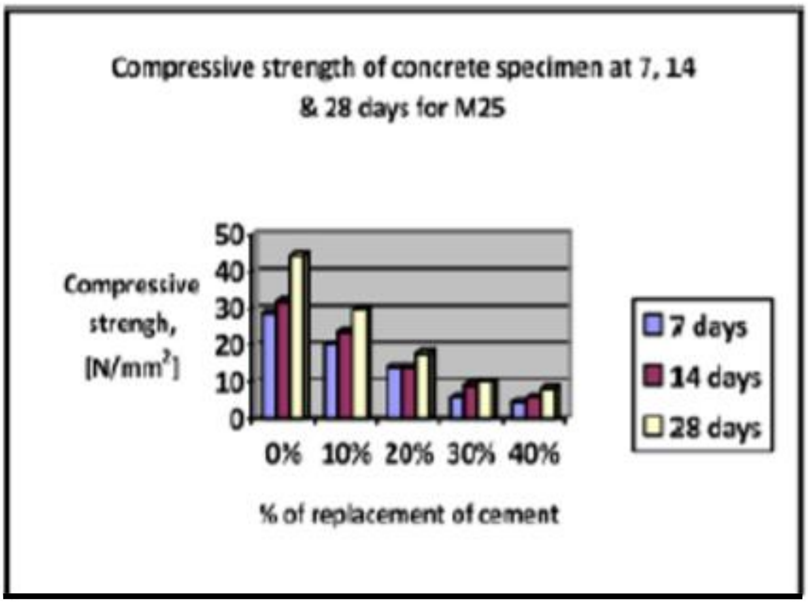

Figure 2.1: Compressive Strength of Cubes at 7, 14 & 28 Days for M25
(Source: Pitroda et al, 2013)

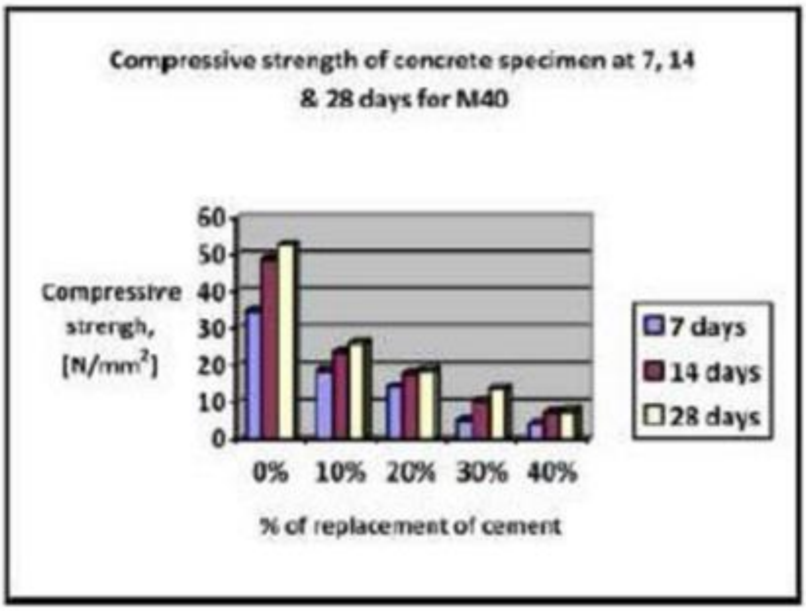

Figure 2.2: Compressive Strength of Cubes at 7, 14 & 28 Days for M40
(Source: Pitroda et al, 2013)

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 2.4.

Table 2.4: Design Mix Proportion
(Source: 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.

150mm×150mm×150mm concrete cubes were casted 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 casted. During casting the cubes were mechanically vibrated by using a table vibrator. After 24 hour 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. The obtained results are given in Tables 2.5, 2.6 and Figures 2.3, 2.4.

Table 2.5: Compressive Strength of Cubes at 14 Days
(Source: 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

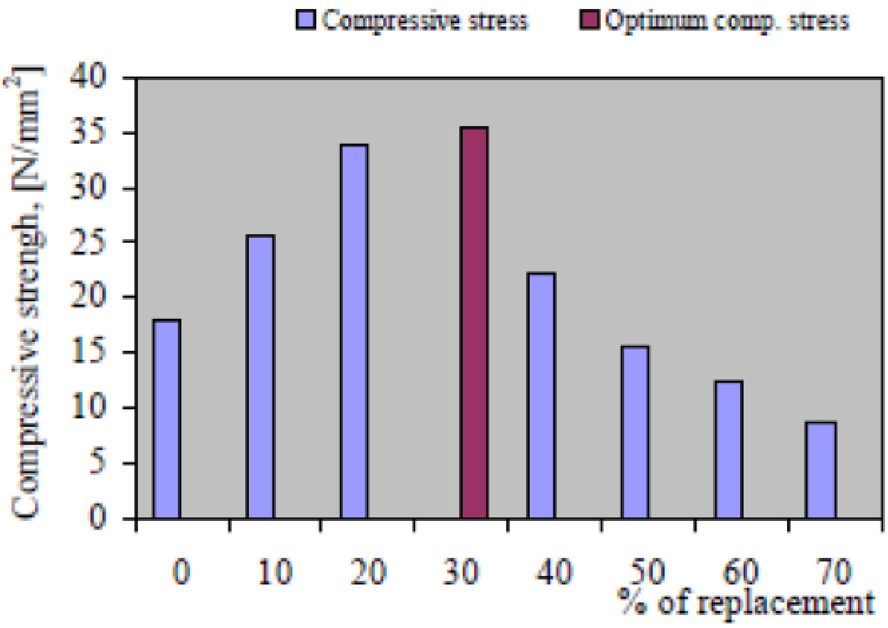

Figure 2.3: Compressive strength of concrete specimen at 14 days
(Source: Srinivasan et al, 2010)

Table 2.6: Compressive Strength of Cubes at 28 Days
(Source: 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

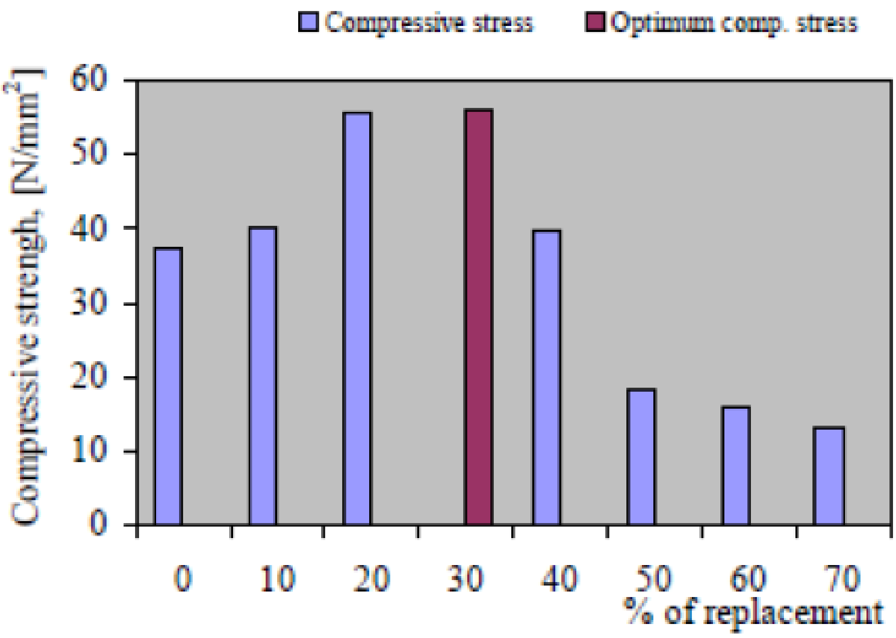

Figure 2.4: Compressive strength of concrete specimen at 28 days
(Source: Srinivasan et al, 2010)

Based on limited experimental investigation concerning the compressive 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.
- From this level, replacement of cement with this waste of hyposludge material provides maximum compressive strength at 30% replacement.
- 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.

Designed M20 grade mixes, the design mix proportions for which are tabulated in Table 2.7 and 2.8.

Table 2.7: Design mix proportions
(Source: 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 2.8: Concrete design mix proportions
(Source: Solanki & Pitroda, 2013)

Sr.No.	Concrete Design Mix proportion for M-20 Grade of Concr				
	W/C ratio	Cement	F.A	C.A	Hypo sluge
1	0.48	1.0	1.89	3.12	
2	0.48	0.9	1.89	3.12	
3	0.48	0.8	1.89	3.12	
4	0.48	0.7	1.89	3.12	
5	0.48	0.6	1.89	3.12	
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

Moisés Frías & Iñigo Vegas, (2009) Figure 2.5 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 micrometres or the average diameter of the distribution of particle sizes.

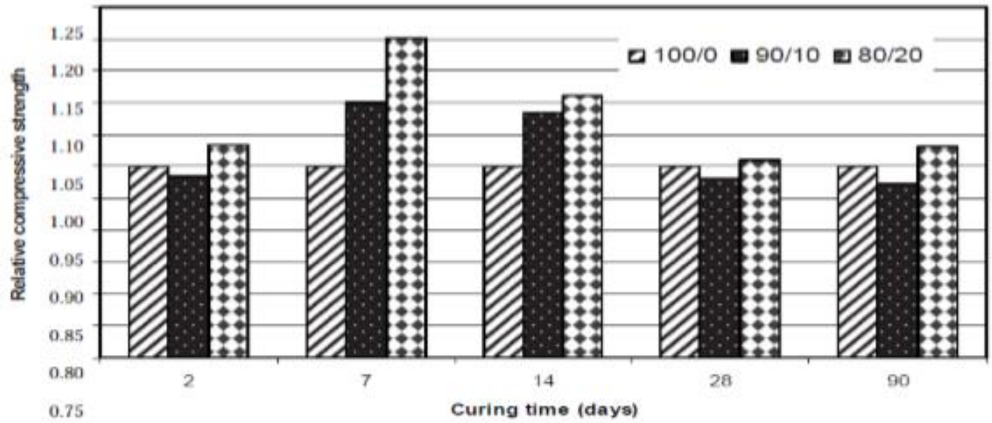

Figure 2.5: Relative compressive strength of blended cements with paper sludge calcined at 700deg.C
(Source: Moisés Frías & Iñigo Vegas, 2009)

Figure 2.6 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.

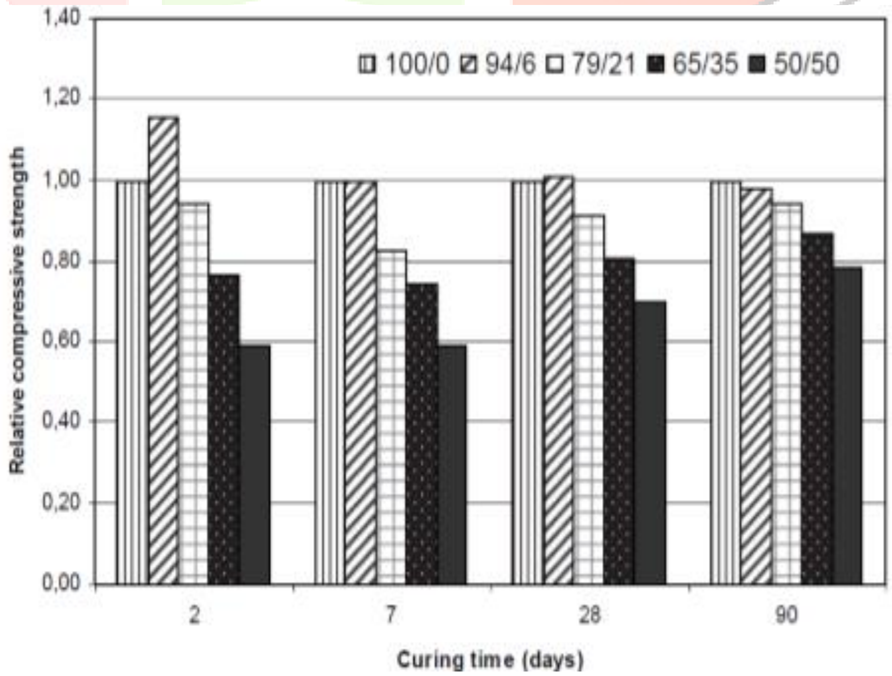

Figure 2.6: Relative compressive strength in relation to ternary cement mixtures with paper sludge calcined at 700ºC
(Source: Moisés Frías & Iñigo Vegas, 2009)

Sumit A Balwaik, S P Raut (2011) used paper-mill pulp in concrete formulations & 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 for compressive strength test. These tests were carried out to evaluate the mechanical properties for up to 28 days. As a result, the compressive strength increased up to 10% addition of waste paper pulp and further increased in waste paper pulp reduces the strengths gradually. The compressive strength test results are given in Table 2.9.

Table 2.9: Compressive strength test results
(Source: Sumit A Balwaik, S P Raut, 2011)

Mix	Waste Paper Pulp in %	Cube compressive strength (N/mm²)		28-days strength (N/mm²)	
		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 strength 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 2.7.

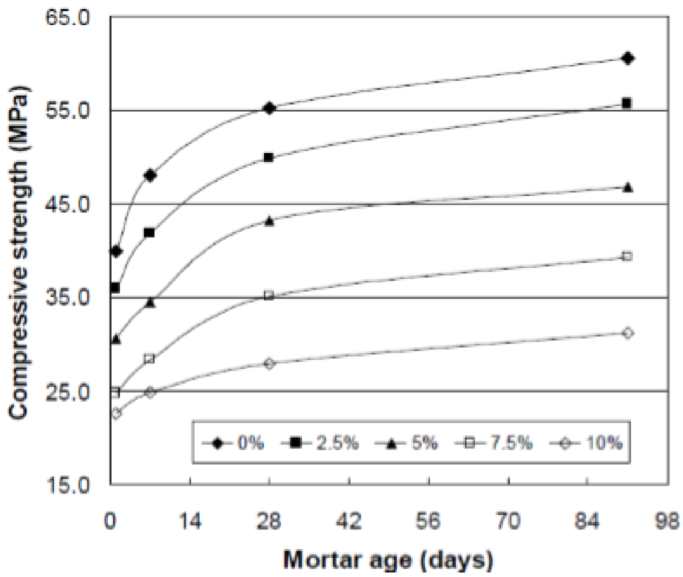

Figure 2.7: Compressive strength development with curing time
(Source: Shiqin Yan, and Kwesi Sagoe–Crentsil, 2012)

2.2.2 Durability properties

According to Zala & Umrigar (2013), durable concrete is one that performs satisfactorily under the exposed environmental conditions during its service life span. Concrete requires too 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 2.10: Acceptance limits for durability indexes
(Source: 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 2.11: Average % water absorption at 90 days for M25 and M40
(Source: 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

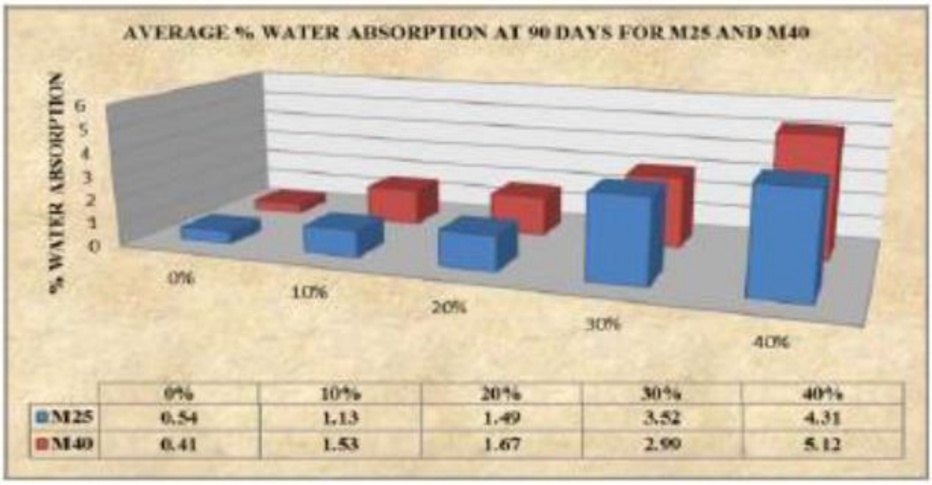

Figure 2.8: % Replacement of cement versus % water absorption
(Source: Zala & Umrigar, 2013)

Table 2.12: Sorptivity at 90 days for M25 & M40
(Source: 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

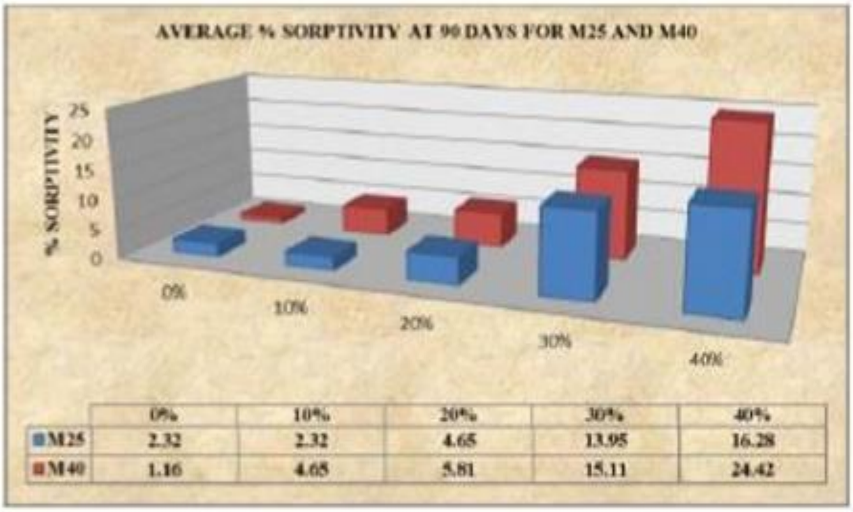

Figure 2.9: % Replacement of cement versus sorptivity
(Source: Zala & Umrigar, 2013)

Tables 2.11 and 2.12 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 2.8 and 2.9. 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. After that 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 freeze 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 (Figure2.10). 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).

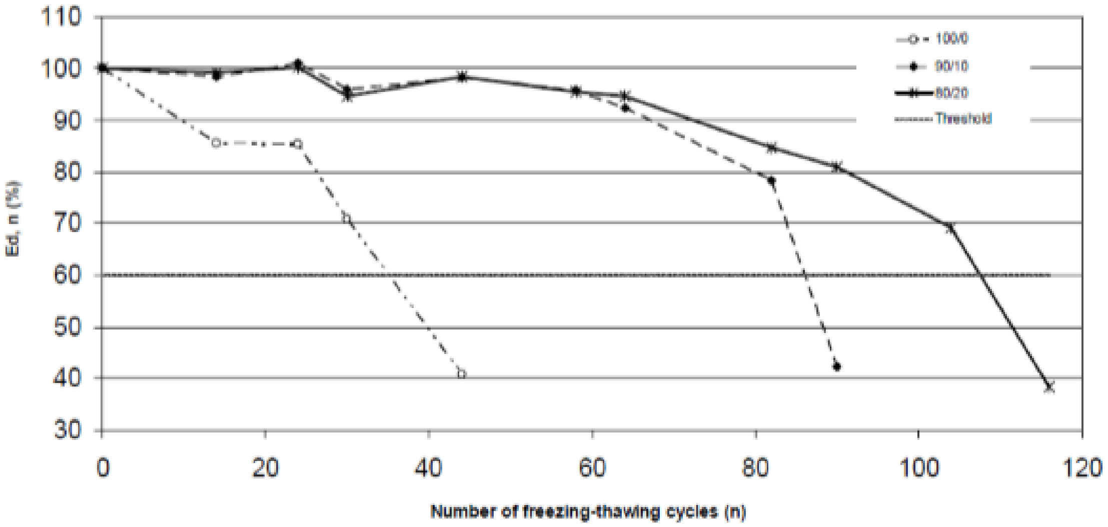

Figure 2.10: Evolution of the dynamic modulus of binary cement mixtures with paper sludge activated at 700ºC subjected to freezing/thawing cycles

(Source: Moisés Frías & Iñigo Vegas, 2009)

Resistance to sulphates-It is well known that sulphates constitute one of the most aggressive agents against cement based materials and cause different deterioration mechanisms as a consequence of the direct reaction between sulphate 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 (and metakaolinite) can be more susceptible to sulphate attacks, owing to the incorporation of the reactive alumina of the pozzolan (Taylor, 1997; Siddique, 2008). The bibliographic data found on the behaviour of normal Portland cements prepared with calcined paper sludge highlights the lower strength in the face of sulphate 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 2.11, hence providing good prospects of overall potential for waste paper sludge incorporation in production of building and masonry elements. The result indicates 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.

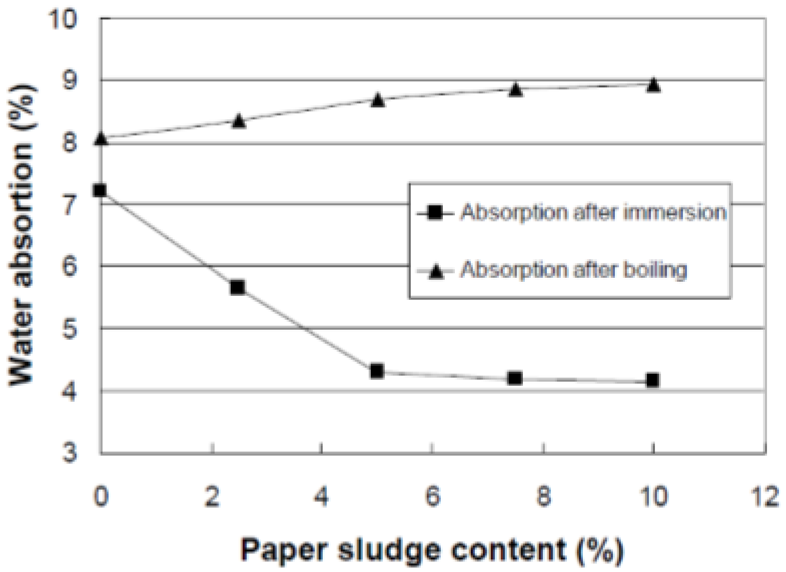

Figure 2.11: Water absorption of mortar specimens after immersion and boiling

(Source: 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 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.

III. MIX DESIGN

3.1 GENERAL

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability and workability as economically as possible, is termed as the concrete mix design. The proportioning of ingredients of concrete is governed by the required performance of concrete in 2 states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance. The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour. The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregates, thus the aim is to produce as lean a mix as possible. From technical point of view the rich mixes may lead to high shrinkage and cracking in the structural concrete and to evolution of high heat of hydration in mass concrete which may cause cracking. The actual cost of concrete is related to the cost of materials required for producing a minimum mean strength called characteristic strength that is specified by the designer of the structure. This depends on the quality control measures, but there is no doubt that the quality control adds to the cost of concrete. The extent of quality control is often an economic compromise, and depends on the size and type of job. The cost of labour depends on the workability of mix, e.g. a concrete mix of inadequate workability may result in a high cost of labour to obtain a degree of compaction with available equipment.

3.2 REQUIREMENTS OF CONCRETE MIX DESIGN

The requirements which form the basis of selection and proportioning of mix ingredients are:

- The minimum compressive strength required from structural consideration.
- The adequate workability necessary for full compaction with the compacting equipment available.
- Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions.
- Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

3.3 TYPES OF MIXES

- **Nominal Mixes**
  In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.
- **Standard mixes**
  The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under or over rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.
  IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm^2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.
- **Designed Mixes**
  In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.

For the concrete with undemanding performance nominal or standard mixes (prescribed in the codes by quantities of dry ingredients per cubic meter and by slump) may be used only for very small jobs, when the 28-day strength of concrete does not exceed 30 N/mm^2. No control testing is necessary reliance being placed on the masses of the ingredients.

3.4 FACTORS AFFECTING THE CHOICE OF MIX PROPORTIONS

The various factors affecting the mix design are:

- **Compressive strength**
  It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix. The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the degree of compaction. According to Abraham's law the strength of fully compacted concrete is inversely proportional to the water-cement ratio.
- **Workability**
  The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement and the method of compaction to be used. For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site.
- **Durability**

The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used.

- **Maximum nominal size of aggregate**
  In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular water-cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate. However, the compressive strength tends to increase with the decrease in size of aggregate.
  IS 456:2000 and IS 1343:1980 recommend that the nominal size of the aggregate should be as large as possible.
- **Grading and type of aggregate**
  The grading of aggregate influences the mix proportions for a specified workability and water-cement ratio. Coarser the grading, leaner will be mix which can be used. Very lean mix is not desirable since it does not contain enough finer material to make the concrete cohesive.
  The type of aggregate influences strongly the aggregate-cement ratio for the desired workability and stipulated water cement ratio. An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions.
- **Quality Control**
  The degree of control can be estimated statistically by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. The lower the difference between the mean and minimum strengths of the mix lower will be the cement-content required. The factor controlling this difference is termed as quality control.

3.5 MIX PROPORTION DESIGNATIONS

The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. For e.g., a concrete mix of proportions 1:2:4 means that cement, fine and coarse aggregate are in the ratio 1:2:4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass

3.6 FACTORS TO BE CONSIDERED FOR MIX DESIGN

- The grade designation giving the characteristic strength requirement of concrete.
- The type of cement influences the rate of development of compressive strength of concrete.
- Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.
- The cement content is to be limited from shrinkage, cracking and creep.
- The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

3.7 PROCEDURE

1. Determine the mean target strength f_t from the specified characteristic compressive strength at 28-day f_{ck} and the level of quality control.
   $$f_t = f_{ck} + 1.65\ S$$
   where, S is the standard deviation obtained from the table of approximate contents given after the design mix.
2. Obtain the water cement ratio for the desired mean target using the empirical relationship between compressive strength and water cement ratio so chosen is checked against the limiting water cement ratio. The water cement ratio so chosen is checked against the limiting water cement ratio for the requirements of durability given in table and adopts the lower of the two values.
3. Estimate the amount of entrapped air for maximum nominal size of the aggregate from the table.
4. Select the water content, for the required workability and maximum size of aggregates (for aggregates in saturated surface dry condition) from table.
5. Determine the percentage of fine aggregate in total aggregate by absolute volume from table for the concrete using crushed coarse aggregate.
6. Adjust the values of water content and percentage of sand as provided in the table for any difference in workability, water cement ratio, grading of fine aggregate and for rounded aggregate the values are given in table.
7. Calculate the cement content from the water-cement ratio and the final water content as arrived after adjustment. Check the cement against the minimum cement content from the requirements of the durability and greater of the two values is adopted.
8. From the quantities of water and cement per unit volume of concrete and the percentage of sand already determined in steps 6 and 7 above, calculate the content of coarse and fine aggregates per unit volume of concrete from the following relations:
   $$V = \left[W + \frac{C}{S_c} + \frac{1}{p}\frac{f_a}{S_{fa}}\right] \times \frac{1}{1000}$$
   $$V = \left[W + \frac{C}{S_c} + \frac{1}{1-p}\frac{C_a}{S_{ca}}\right] \times \frac{1}{1000}$$
   Where, V = absolute volume of concrete = gross volume ($1m^3$) minus the volume of entrapped air
   S_c = specific gravity of cement
   W = Mass of water per cubic metre of concrete, kg
   C = mass of cement per cubic metre of concrete, kg
   p = ratio of fine aggregate to total aggregate by absolute volume

f_a, C_a = total masses of fine and coarse aggregates, per cubic metre of concrete, respectively, kg and
S_{fa}, S_{ca} = specific gravities of saturated surface dry fine and coarse aggregates, respectively.

9. Determine the concrete mix proportions for the first trial mix.
10. Prepare the concrete using the calculated proportions and cast three cubes of 150 mm size and test them wet after 28-days moist curing and check for the strength.
11. Prepare trial mixes with suitable adjustments till the final mix proportions are arrived at.

3.8 VARIOUS TESTS FOR MIX DESIGN

The description of various tests which were conducted in this study to check the quality of material is given below:

3.8.1 Los Angeles abrasion value test

This experiment was conducted to check the suitability of aggregates in construction works. The apparatus is as per IS: 2386(Part IV)-1963. The principle of Los Angeles abrasion test is to produce abrasive action by use of standard steel balls which when mixed with aggregates and rotated in a drum for specific number of revolutions also causes impact on aggregates. The percentage wear of the aggregates due to rubbing with steel balls is determined and is known as Los Angeles Abrasion Value. Los Angeles test is commonly used to evaluate the hardness of aggregates.
The result shows that the Los Angeles abrasion value comes out to be 3315g by using 8 steel balls.

Figure 3.1 Los Angeles abrasion value test

3.8.2 Soundness of OPC by Le chatelier method

Soundness of cement is determined by Le-Chatelier method as per IS: 4031(Part 3)-1988. The apparatus for conducting the Le-Chatelier test should conform to IS: 5514-1969. It should not be more than 10 mm for OPC.

Figure 3.2 Le Chatelier test

The result shows that the soundness value of cement comes out to be 2mm.

3.8.3 Sieving of coarse aggregates

Sieving of coarse aggregates was done by using various sieves of different size conforming to IS codes. The following are the results of sieve analysis test:

Table 3.1 Sieve analysis of coarse aggregates

IS Sieve size	Percent retained	Cumulative % retained	Percent passing
40 mm	0.00	0.00	100.00
20 mm	0.60	0.60	99.40
10 mm	66.40	67.00	33.00
4.75 mm	22.80	89.80	10.20

Figure 3.3 Sieve Analysis of coarse aggregates

3.8.4 Sieving of fine aggregates

Sieve analysis of fine aggregates was done by using different sieves conforming to IS codes.

The following are the results of fine aggregates test:

Table 3.2 Sieve analysis of fine aggregates

IS Sieve size	Percent retained	Cumulative % retained	Percent passing
10 mm	0.00	0.00	100.00
4.75 mm	5.20	5.20	94.80
2.36 mm	3.00	8.20	91.80
1.18 mm	8.60	16.80	83.20
600 µ	25.80	42.60	57.40
300 µ	32.80	75.40	24.60
150 µ	20.70	96.10	3.90
Pan	0.00	96.10	3.90

Figure 3.4 Sieve analysis of fine aggregates

3.8.5 Consistency of cement test

The basic aim is to find out the water content required to produce a cement paste of standard consistency as specified by the IS: 4031(Part 4)-1988. The principle is that standard consistency of cement is that consistency at which the Vicat plunger penetrates to a point 5-7mm from the bottom of Vicat mould.

Figure 3.5 Consistency of cement test

Weight of cement taken = 400 g
Weight of water taken = 120 g
The amount of water as a percentage of the weight of dry cement is 30%. (Experimental result)

3.8.6 Initial and final setting time of cement

The initial and final setting time is calculated as per IS: 4031(Part 5)-1988. To do so we need Vicat apparatus conforming to IS: 5513-1976.

The time period elapsing between the time, water is added to the cement and the time, the needle fails to pierce the test block by 5.0 ± 0.5mm measured from the bottom of the mould, is the initial setting time.

The period elapsing between the time, water is added to the cement and the time, the needle makes an impression on the surface of the test block, while the attachment fails to do so, is the final setting time.

The results comes out to be
Initial setting time = 35 minutes
Final setting time = 480 minutes

Figure 3.6 Initial & final setting time test

3.8.7 Fineness of cement test

To determine the fineness of cement by dry sieving as per IS: 4031(Part 1)-1996 we need 90µ sieve. The principle of this is that we determine the proportion of cement whose grain size is larger than specified mesh size.

Figure 3.7 Fineness of cement test

The mass of cement taken = 100 g
The mass of residue after sieving for 15 min = 1.3 g
The results show that the cement used is fine as the residue was not exceeding 10% of its original value.

3.8.8 Elongation and Flakiness test

The main objective of this test is to determine the relative amounts of flaky and elongated particles which when present in large quantities may result in more voids in the concrete, thus requiring larger amount of sand, cement and water for a particular workability. These particles tend to be oriented on one plane which affects the durability.

Figure 3.8 Flakiness test

Figure 3.9 Elongation test

The results show that the particles are not flaky or elongated as it was not exceeding 10-15%.

3.8.9 Specific gravity test

This test is done to measure the strength and quality of material. Water absorption shall not be more than 0.6 per unit by weight.

Figure 3.10 Specific gravity test

The results of it are as shown below:

- Specific gravity of cement = 3.05; Water absorption = 0
- Specific gravity of coarse aggregates = 2.68; Water absorption = 1.46
- Specific gravity of fine aggregates = 2.6; Water absorption = 0.5

3.8.10 pH of water sample

This test was done to check the suitability of locally available water & the pH comes out to be 7.53 which is suitable to use.

Figure 3.11 pH of water test

3.9 MIX DESIGN FROM IS GUIDELINES

The following procedure is followed in mix design:

1. Requirements

a) Specified minimum strength = 20 N/mm^2

b) Durability requirements

i) Exposure: Moderate (According to table 3 of IS: 456-2000)

ii) Minimum Cement Content = 300 Kg/cum (According to table 5 of IS: 456-2000)

c) Cement

i) J.K. Cement

ii) Type OPC

iii) Grade 43

d) Workability

i) Compacting factor = 0.7

e) Degree of quality control: Good

2. Test data for materials supplied

a) CEMENT

i) Specific gravity = 3.05

b) COARSE AGGREGATE

i) 20mm Graded

Type Crushed stone aggregate

Specific gravity = 2.68

Water absorption = 1.46

Free (surface) moisture = 0

SIEVE ANALYSIS RESULTS:

IS Sieve size	Percent retained	Cumulative % retained	Percent passing
40 mm	0.00	0.00	100.00
20 mm	0.60	0.60	99.40
10 mm	66.40	67	33
4.75 mm	22.80	89.8	10.2

(Conforming to table 2 of IS: 383-1970)

c) FINE AGGREGATE (Coarse sand)

i) Type Natural (Ghaggar)

Specific gravity = 2.6

Water absorption = 0.5

Free (surface) moisture = 1.4

SIEVE ANALYSIS RESULTS:

IS Sieve size	Percent retained	Cumulative % retained	Percent passing
10 mm	0.00	0.00	100.00
4.75 mm	5.20	5.20	94.80
2.36 mm	3.00	8.20	91.80
1.18 mm	8.60	16.80	83.20
600	25.80	42.60	57.40
300	32.80	75.40	24.60
150	20.70	96.10	3.90
Pan	0.00	96.10	3.90

(Conforming to grading zone 2 of table 4 of IS: 383-1970)

3. Target mean strength (TMS)

a) Statistical constant K = 1.65

b) Standard deviation S = 4.6 (According to IS: 456-2000)

Thus, TMS = 27.59 N/mm^2

4. Selection of w/c ratio

a) As required for TMS = 0.5

b) As required for 'Moderate' Exposure = 0.55(According to table 5 of IS: 456-2000)

Assume w/c ratio of 0.5

5. Determination of water & sand content

For w/c = 0.6

C.F. = 0.8

Max. Aggregate Size of 20 mm

a) Water content = 186 Kg/cum

b) Sand as percentage of total aggregate by absolute volume = 35%

Thus,
Net water content = 180.42 Kg/cum
Net sand percentage = 33%

ADJUSTMENTS (According to IS: 10262-1982)

Sr. No.	Change in condition	Adjustment (in %) required in			
		Water content		Sand content	
		Rate	W	Rate	P
1.	Sand conforming to zone 2	0	0	0	0
2.	Decrease in C.F. by 0.1 (as CF required = 0.7)	-3	-3	0	0
3.	Each 0.05 decrease in w/c ratio Required w/c = 0.5 Decrease 0.6-0.5 = 0.1	0	0	-1	-2
4.	For rounded aggregates	NA		NA	
Total Adjustments			-3		-2

6. Determination of cement content
w/c ratio = 0.5
Water content = 180.42 Kg/cum
Thus, Cement content = 360.84 Kg/cum
Adequate for moderate exposure Say 360 Kg/cum
7. Determination of coarse and fine aggregate content
Assume entrapped air as 2 %
Thus,
0.98 cum = [180.42+ (360/3.05) + {1/0.33}*{fa/2.6}]/1000
& 0.98 cum = [180.42+360/3.05 + {1/0.67}*{Ca/2.68}]/1000
Hence,
fa = 584 Kg/cum
Ca = 1223.8 Kg/cum

The final mix proportions of M-20 grade of concrete become:

Water (kg/cum)	Cement (kg/cum)	FA (kg/cum)	CA (kg/cum)	
			20mm	**10mm**
			734.28	489.52
180.42	360	584	1223.8	
0.50	1.00	1.62	3.40	

Note:
1. The above recommended mix design must be verified, by actual cube tests.
2. The mix design is based on the quality and grading of the materials actually supplied.

Figure 3.12 Block's compressive strength testing machine

Figure 3.13 Crushing lime using roll crusher

IV. RESULTS AND DISCUSSIONS

4.1 COMPRESSIVE STRENGTH RESULTS

The compressive strength of various concrete blocks is tested. The five proportions used are (0% Lime sludge), (5% Lime sludge), (10% Lime sludge), (15 % Lime sludge) & (20% Lime sludge).

Figure 4.1: Casting concrete blocks in moulds

Figure 4.2: Casted concrete blocks

Figure 4.3: Compression testing of blocks

Table 4.1: Compression test results for 3 days

STRESS (N/mm^2)					
Lime (%) → Days ↓	**0**	**5**	**10**	**15**	**20**
3	11.067	13.17	14.519	13.274	7.028

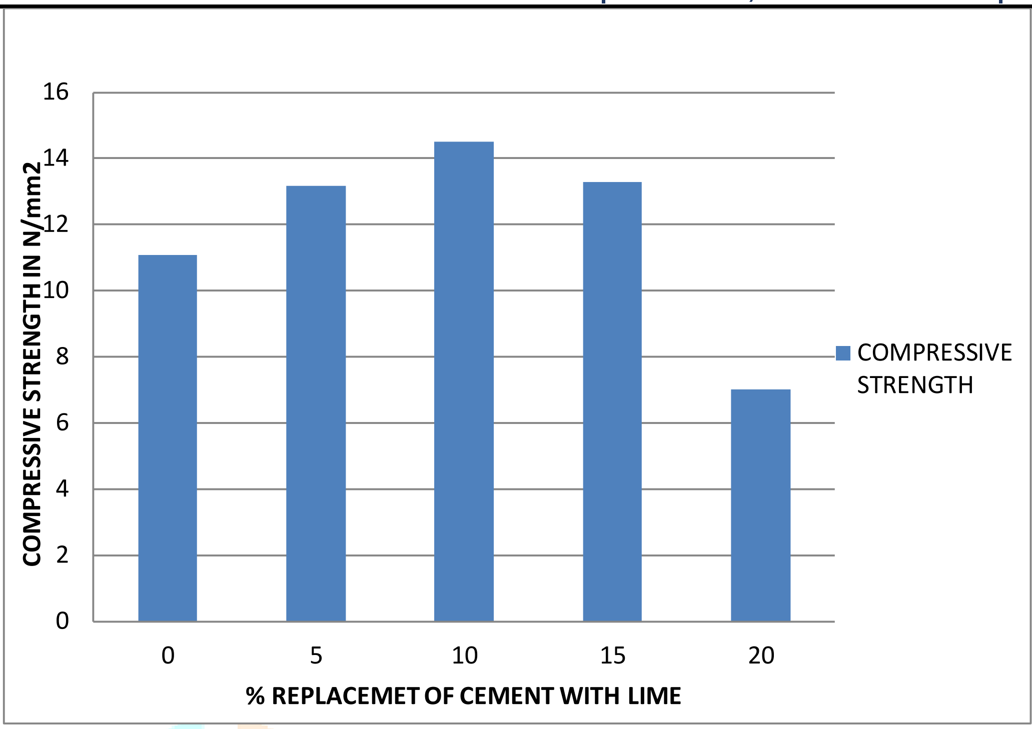

Figure 4.4: Compressive strength of concrete for 3 days

Table 4.2: Compression test results for 14 days

STRESS (N/mm^2)					
Lime (%) → / **Days ↓**	**0**	**5**	**10**	**15**	**20**
14	16.444	20.889	22.608	21.378	15.852

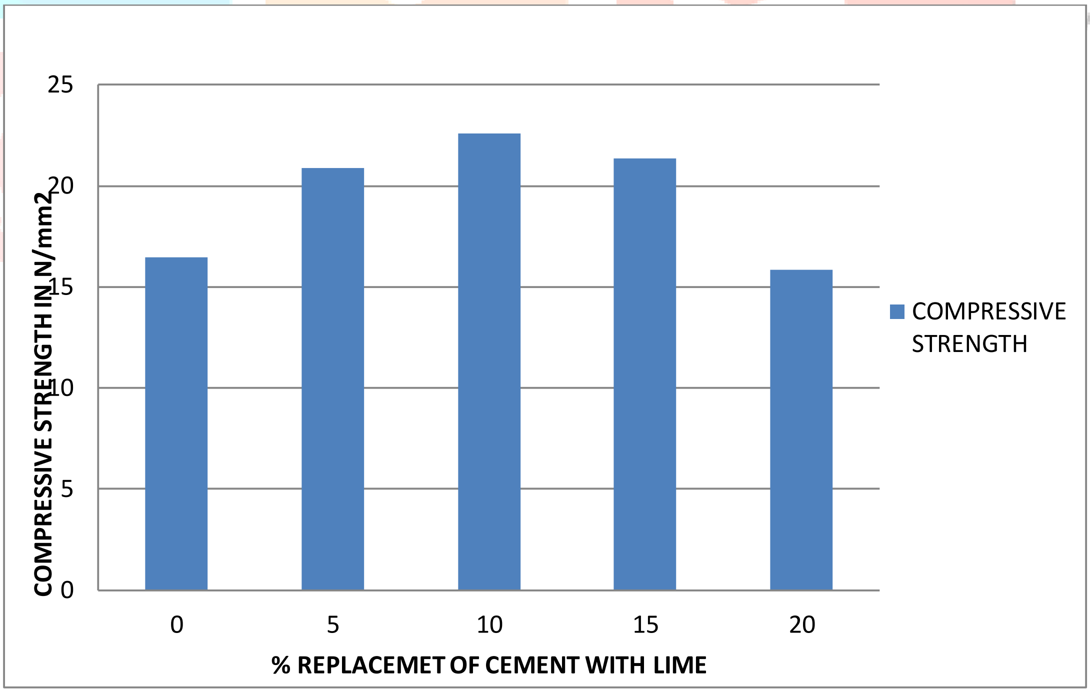

Figure 4.5: Compressive strength of concrete for 14 days

Table 4.3: Compression test results for 28 days

STRESS (N/mm^2)					
Lime (%) → / **Days ↓**	**0**	**5**	**10**	**15**	**20**
28	25.629	26.370	30.518	27.037	22.963

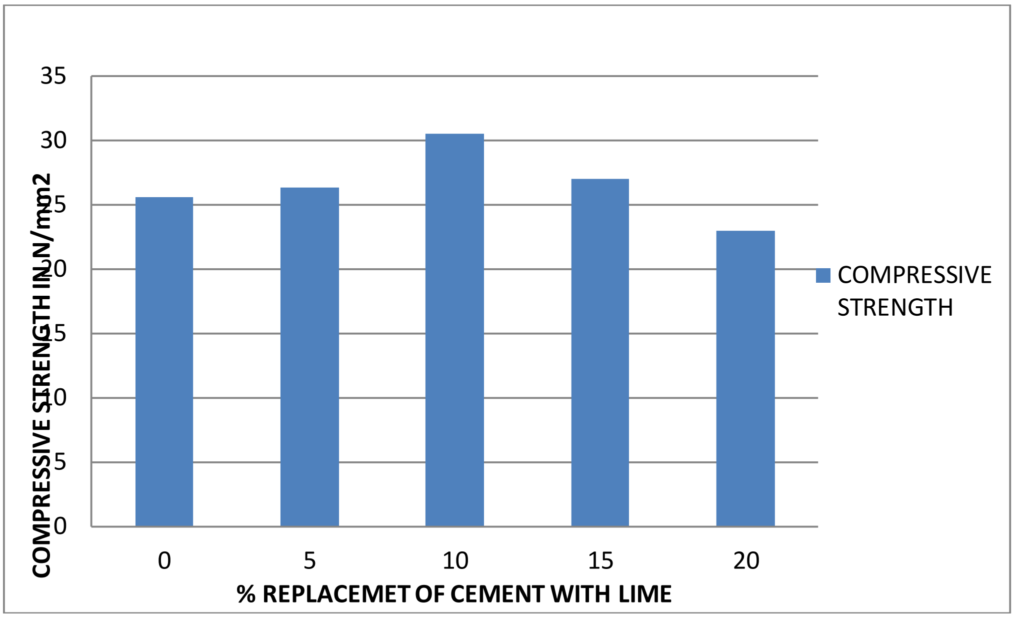

Figure 4.6: Compressive strength of concrete for 28 days

Table 4.4: Compression test results

	STRESS (N/mm^2)				
Lime (%) → / **Days ↓**	**0**	**5**	**10**	**15**	**20**
3	11.067	13.17	14.519	13.274	7.028
14	16.444	20.889	22.608	21.378	15.852
28	25.629	26.370	30.518	27.037	22.963

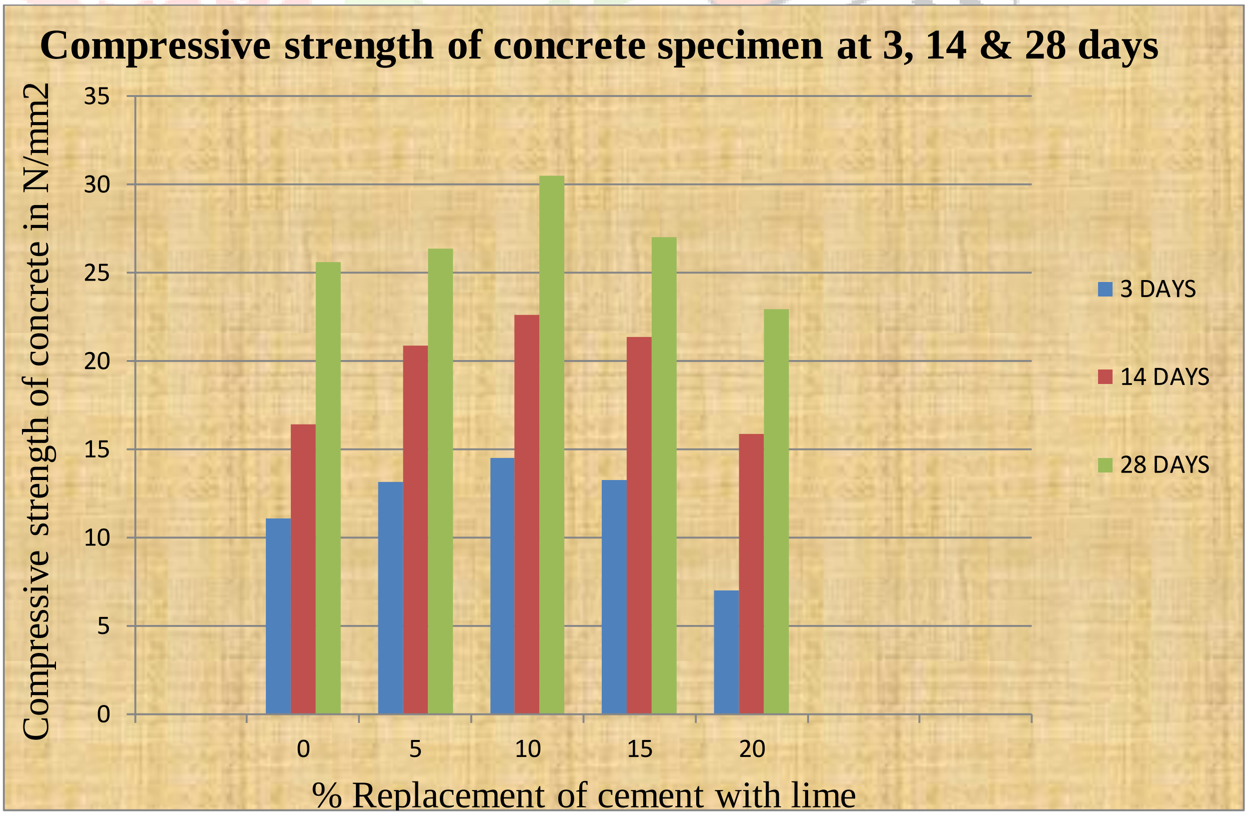

Figure 4.7: Compressive strength of cubes at 3, 14 & 28 days for M20

V. CONCLUSIONS

5.1 COMPRESSIVE STRENGTH

- At 3 days
  - The compressive strength of concrete increases with an increase of lime sludge up to 15%.
  - On adding 5% of lime sludge the percentage increase in compressive strength is 19.00%, compared to conventional concrete.
  - On adding 10% of lime sludge the percentage increase in compressive strength is 31.19%, compared to conventional concrete.
  - On adding 15% of lime sludge the percentage increase in compressive strength is 19.94%, compared to conventional concrete.
  - On adding 20% of lime sludge the percentage decrease in compressive strength is 36.49%, compared to conventional concrete.
- At 14 days
  - The compressive strength of concrete increases with an increase of lime sludge up to 15%.
  - On adding 5% of lime sludge the percentage increase in compressive strength is 27.03%, compared to conventional concrete.
  - On adding 10% of lime sludge the percentage increase in compressive strength is 37.48%, compared to conventional concrete.
  - On adding 15% of lime sludge the percentage increase in compressive strength is 30%, compared to conventional concrete.
  - On adding 20% of lime sludge the percentage decrease in compressive strength is 3.6%, compared to conventional concrete.
- At 28 days
  - The compressive strength of concrete increases with an increase of lime sludge up to 15%.
  - On adding 5% of lime sludge the percentage increase in compressive strength is 2.89%, compared to conventional concrete.
  - On adding 10% of lime sludge the percentage increase in compressive strength is 19.07%, compared to conventional concrete.
  - On adding 15% of lime sludge the percentage increase in compressive strength is 5.93%, compared to conventional concrete.
  - On adding 20% of lime sludge the percentage decrease in compressive strength is 10.40%, compared to conventional concrete.

From all the above results we conclude that

- The compressive strength of concrete increases up to 10% and decreases on adding 15% lime but is still more than conventional concrete.
- The compressive strength of concrete decreases on adding 20% of lime sludge.
- Save the paper industry disposal costs and produces a 'greener' concrete for construction.
- Cement reduction decreases cost of concrete, but at the same time strength also decreases after a certain limit.
- Can be innovative supplementary cementitious construction material but judicious decisions are to be taken by engineers.

5.2 SCOPE FOR FUTURE WORK

- 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 lime sludge need investigation for longer period; i.e., 90, 180 and 360 days.

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