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"Assessment of Composite Concrete using Fly Ash & Lime Sludge"

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Abstract—

Cement, aggregates, water, and additional ingredients if needed make up concrete, a compound building material. There are numerous inventions that use concrete's various qualities. Cement is the primary ingredient that gives concrete its strength. Portland cement and other cementation materials, like fly ash and slag cement, act as binders for the aggregate. In order to attain different qualities, other chemical admixtures are also applied. Through a chemical process known as hydration, water is then added to this dry composite, allowing it to be shaped before solidifying and hardening into rock-hard strength. After the cement and water react, the other ingredients are bonded together to form a sturdy substance that resembles stone. Lime sludge is another substance that can be used as a cement substitute. Paper, acetylene, sugar, fertilizer, sodium chromate, soda ash, and water softening facilities are among the industries that produce lime sludge. These enterprises produce a total of about 4.5 million tons of sludge per year. Fly ash, on the other hand, is a naturally occurring by product of burning coal. To lessen pollution, it is drawn out by the precipitators in coal-burning power stations' smokestacks. About 112 million tons of fly ash are produced annually by 120 thermal power plants in India that are based on coal. This study has assessed earlier studies that examined the effects of contemporary waste materials, such as fly ash and lime sludge, on the compressive, tensile, and flexural properties of concrete. The performance of such composite concrete with the addition of such waste by products may be determined with the aid of the evaluation above. Additionally, the use of such by products makes the concrete environmentally friendly. The study demonstrates that concrete's strength parameters change dramatically when cement is partially substituted with any waste product, which eventually lowers carbon emissions. It also found that fly ash reduces the cement content for a given grade of concrete in order to achieve characteristic strength. This study examines the effects of contemporary waste materials, such as fly ash and lime sludge, on the compressive, tensile, and flexural properties of concrete of grades M25 and M20. Fly ash and lime sludge are substituted for cement in varying amounts in this study to provide insight into how M25 and M20 grade concrete performs in various scenarios. The findings demonstrate that concrete's strength characteristics change dramatically when lime sludge is used to partially replace cement. They also indicate that lowering the cement percentage for a given grade of concrete to attain characteristic strength also reduces carbon emissions. The approach used in this study complies with the requirements of the IS code.

***Keywords**:* Composite Concrete, Lime Sludge, Fly Ash, Compressive Strength, Tensile Strength, Flexural Strength.

1. Introduction -

Cement production uses a lot of energy and contributes roughly 7% of global carbon dioxide (CO_2) emissions [1][2]. It's common knowledge that CO_2 is a major contributor to the greenhouse effect and causes global warming. In order to produce and use blended cement more frequently rather than Ordinary Portland Cement (OPC), research has therefore expanded on the use of by-product cementing ingredients including FA and granulated slag [3][4]. In relation to cement consumption in India, PPC production has surpassed 70% in recent years [5]. However, rising electricity demand has also led to increased coal usage and, as a result, increased fly ash production.

The world produces millions of tons of fly ash annually, an industrial byproduct that not only pollutes the environment but also takes up a lot of storage space on limited land. Thus, it is practical to use fly ash in place of cement to the greatest extent possible in order to save money, energy, and the environment [1]. One of the most well-liked and extensively utilized pozzolanic materials in the world is fly ash [1]. The loss of plants and animals as well as contamination of the soil, water, and air would result from the untreated disposal of tons of this trash. Because fly ash has a high silica and aluminum reactive form content, its application in concrete has grown significantly [6][7]. Coarse aggregate is typically avoided in mortar mixtures made of cement, fine aggregate, and water. Even if there are benefits to utilizing fly ash in mortar, just like in concrete, there haven't been many studies on the subject up to this point [1]. Fly ash and other Supplementary Cementing Materials (SCM) can partially replace OPC, depending on the resources available [8][9]. Greener concrete production is possible even though natural aggregates can be replaced with different materials in terms of energy and resource use [8] [10]. The capacity of fly ash to increase concrete's durability without sacrificing strength has garnered a lot of interest in certain situations when it comes to its adoption [11]. [12] The recovery of trash from usable products and the use of waste as raw materials in building whenever feasible are the main focuses of current global trends [6]. According to the current study, FA was utilized in several tests without the addition of any admixture, which could have improved its usefulness in cement. 10% CLS, a by-product of the acetylene industry, is used to boost the lime content and the lime-silica ratio in calcium hydroxide, which increases the efficacy of FA.

FLY ASH - Fly ash's economic and environmental advantages have made its usage in civil engineering indispensable (Ravina and Mehta, 1986; Matkovi´c, 1990). The amount of free lime in the ash limits how much cement FA can substitute. The amount of glassy phase present, the specific surface area (SSA), the burning temperature of lignite or coal, the phase composition, and other factors all affect the reactivity of FA in addition to its chemical makeup (Matkovi´c, 1990). According to Tillman et al. (2012), FA is a pozzolanic substance. Materials that have little to no cementing action when left alone but will generate insoluble cementitious compounds when exposed to lime and water are referred to as pozzolanic (Montgomery et al., 1981).

FLY ASH

Pulverized fuel ash, or FA, is a mineral addition used in cement and concrete that is a by-product of coal-fired power stations. A typical coal-burning generating station configuration is depicted in Fig. 1. At about 1500 ◦C (2700 ◦F), pulverized coal is blasted into the furnace's burning zone, where its flammable components—primarily carbon, hydrogen, and oxygen—ignite. At this temperature, non-combustible minerals such as feldspar, pyrite, gypsum, quartz, calcite, and clay minerals melt and create tiny liquid droplets. Small, spherical, glassy particles are formed as the droplets carried by the flue gases from the burning zone cool quickly. Solid particles from flue gases are collected by baghouses or mechanical and electrical precipitators. FA refers to the ash particles that, along with the flue gases, "fly" out of the furnace (Thomas, 2013). Numerous factors, such as the type of coal used, the burning conditions, the collection technique, etc., affect the characteristics of FA (McCarthy and Dyer, 2019). In the United States, a comprehensive study on the use of FA in concrete was first published in 1937, although its usage as a pozzolanic element and its reaction potentials were originally identified in early 1914 (McCarthy and Dyer, 2019; Halstead). According to earlier research conducted in the 1980s, using FA in place of concrete can greatly enhance the material's mechanical and durability qualities since it can enhance the paste's microstructure (Montgomery et al., 1981). FA has historically been added to concrete at amounts between 15 and 25 percent by mass of the cementitious material component, depending on the application, FA qualities, specification restrictions, location, and climate (Thomas, 2007). According to reports, concrete has occasionally been effectively laid with up to 80% FA (Marceau et al., 2002). According to ASTM, the FAs used in concrete fall into two categories: class F and class C. The burning of bituminous coal produces the class F FA as a byproduct. Class F FA has a low calcium level but a high iron, silica, and alumina content. It is a glassy material that must be activated by either lime or cement. FA from burning lignite and sub-bituminous coal is categorized as class C. Compared to class F FA, it has higher calcium. Class C FA concrete gains strength significantly faster than class F FA concrete (McCarthy and Dyer, 2019; Marceau et al., 2002). In addition to being economical, the addition of FA to concrete improves workability, strength, and drying shrinkage while also altering the concrete's qualities both while it is fresh and after it has hardened. Additionally, the storage and disposal issue of FA, an industrial by-product, is resolved by using it in concrete (Atis¸, 2003).

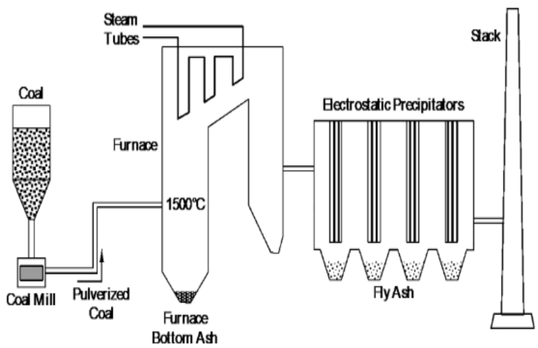

Fig. 1. A schematic diagram of a coal-fired electrical generating station (Thomas, 2013).

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LIME SLUDGE - Globally, the issue of disposing of industrial waste is becoming more and more significant. Because of the widespread use of paper and the need for electrical energy, sludge from paper mills produced by burning coal in thermal power plants is a major environmental issue in the majority of industrialized nations worldwide. Sludge from paper mills is not a substance that can be used in many other industrial processes. Along with other waste cellulosic fiber, the paper mill sludge is simply thrown away due to its non-utility, which leads to a serious disposal issue. The technology used to pulp, wood, and make paper, the kind of effluent treatment that is utilized, the kind and source of coal, and the technique of collecting ash all have an impact on the properties of bio-solids. The composition of solid wastes produced by industrial sources varies; they can be inert inorganic (produced in collieries and mining) or organic (made in industries that make basic consumer goods), and they may even contain dangerous components (produced in the pesticide business). It was anticipated that the Asia-Pacific area would become a significant producer of paper mill sludge as a result of a global shift in the production of paper and paperboard. It was estimated that the amount of paper mill sludge produced worldwide will increase by 48–86% during the following 50 years. The raw materials utilized in various unit processes mostly determine the type of waste produced by parent industries. Numerous substances, some of which are harmful, are included in these wastes produced by industrial sources. The large and small plant categories both produce solid trash. Solid waste from the paper industry is typically produced at different stages of the paper-making process, such as the causticizing phase in the chemical recovery unit as lime sludge, and the raw material handling and preparation phases as sludge from the effluent treatment facilities. Typically, solid trash is disposed of in landfills, however incineration is growing in popularity. The amounts of chemicals of concern must be regularly shown to be below practical regulatory levels before any solid residues are applied to the land. Studying the use and practicality of these industrial wastes as a cementitious/pozzolanic material in the building sector was the aim of this study.

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LIME SLUDGE

CATEGORISATION OF LIME SLUDGE

The different types of industrial waste fall into the following categories –

• Paper Sludge: Research on the use of lime sludge from the paper industry has shown that it can be used up to 74% (dry basis) as a raw material to make Portland cement clinker, which can lead to OPC that satisfies Indian Standard Specifications IS:269-1989 and IS:8112-1989 respectively.

• Carbide sludge: Research and development work has shown that carbide sludge can be utilized as a source of calcareous material in the raw mix used to make cement clinker. Considering the cement raw mix's tolerance limit for chloride concentration, up to 30 percent carbide sludge can be utilized in the raw mix to make clinker, which produces OPC that satisfies all three National Standard Specifications for cement.

• Phospho-chalk: Research and development studies have demonstrated that phospho-chalk can be utilized as a raw mix ingredient in the production of cement clinker. Only < 8% of it can be used due to the presence of contaminants like P2O5 and SO3.

• Sugar Sludge: According to preliminary research, sugar sludge can be utilized as a source of calcareous material in the raw mix used to make cement clinker. To determine the impact of contaminants in sugar sludge on the performance of the cement (OPC) made from it, a thorough investigation is required.

• Chrome Sludge: Research has shown that up to 5% of chrome sludge can be utilized as a mineralizer. The mass use of chromium oxide is limited by its presence as an impurity up to 10 percent.

Characteristics of lime sludge

Very fine precipitated $CaCO_3$ particles and leftover residue from the green liquor clarifier make up lime sludge. The following table lists the typical physico-chemical characteristics of lime sludge waste:

Table 1: Chemical properties of Lime sludge (Source: CRI-ENG-SP 965March 2000)

S NO	CONSTITUENTS	PERCENTAGE
1	Moisture Content	40 – 60
2	SiO2	2 – 8
3	Al2O3	0.8 – 1.2
4	Fe2O3	0.8 – 1.2
5	CaO	48 – 53
6	MgO	0.2 – 3.0
7	LOI	37 – 42
8	SO3	0.1 – 0.3
9	Na2O	0.8 – 2.0

2. OBJECTIVES OF THE STUDY

This study takes into account the following goals:

- To investigate environmental sustainability.
- To research the utilization of lime sludge and fly ash as environmentally friendly materials.
- To research strategies for lowering air pollution.
- To use additives to create cost-effective concrete.
- To recycle the waste materials in order to get the desired strength.

3. EXPERIMENTAL INVESTIGATION

Preparation of sample

For our work, we considered following batching of mixes:

MIX	CEMENTIOUS MATERIALS		
	CEMENT PPC (43 GRADE)	Activated Fly Ash	Lime Sludge
M1	100%	--	-
M2	90%	5%	5%
M3	90%	10%	-
M4	88%	10%	2%
M5	85%	10%	5%
M6	80%	20%	
M7	78%	20%	2%
M8	75%	20%	5%

Mix Proportions

Table: Mix Proportions for M25 Grade Concrete

Cement	Water	FA	CA
440	**197**	**581**	**1088**
1	**0.45**	**1.32**	**1.875**

Table: Mix Proportions for M20 Grade Concrete

Cement	Water	FA	CA
394	**197**	**608**	**1092**
1	**0.5**	**1.54**	**2.77**

Properties of Cement, Fly Ash & Lime Sludge

. S.No.	Chemical Composition %	Lime Sludge	Fly Ash	Cement
1	SiO2	3.185	56.86	20.87
2	Al2O3	0.19	23.51	4.35
3	Fe2O3	0.14	4.39	3.93
4	CaO	67.02	0.83	60.2
5	MgO	0.38	0.6	2.74
6	Na2O	1.06	0.39	0.08
7	K2O	0.8	1.4	0.23
8	Loss of Ignition	3.84	10.68	2.19
9	SO3	2.25	-	2.71
PHYSICAL PROPERTIES				
1	Density (g/cm3)	1.03	2.26	3.14

2	Particle Size (μm)	67.6	32.5	14.73
3	Specific Gravity	2.16	2.2	3.15
4	pH Value	7.8	8.5	13

Tests on specimens

Concrete specimen testing is crucial for maintaining and verifying the material's quality. To investigate the impact of partially substituting fly ash and lime sludge for cement on workability and strength, all of the cast specimens underwent testing. As a result, the experimental study was separated into three primary sections. They are as follows:

1. Study on workability

- Slump test

2. Study on strength

- Compressive strength test
- Splitting tensile strength test
- Flexural strength test
- Durability Tests

4. Results & Discussions –

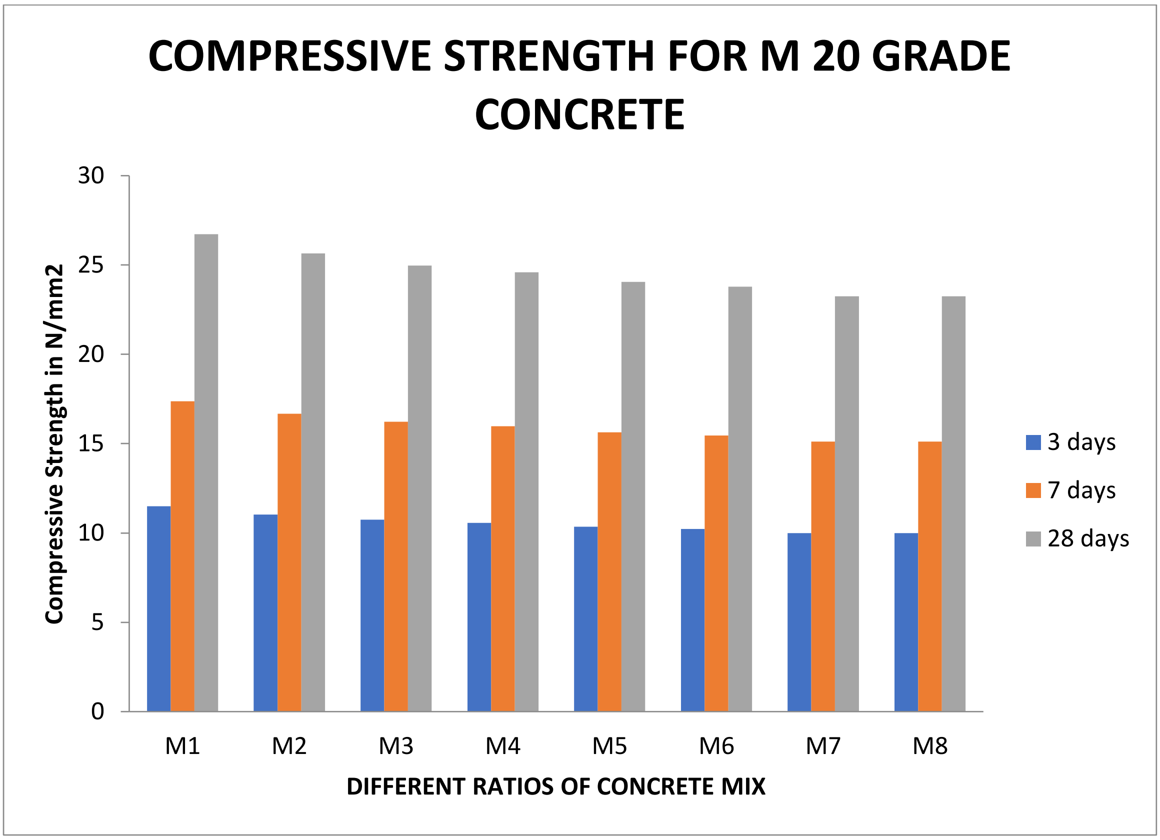
Tests Performed on Cement with the addition of Fly ash & Lime Sludge

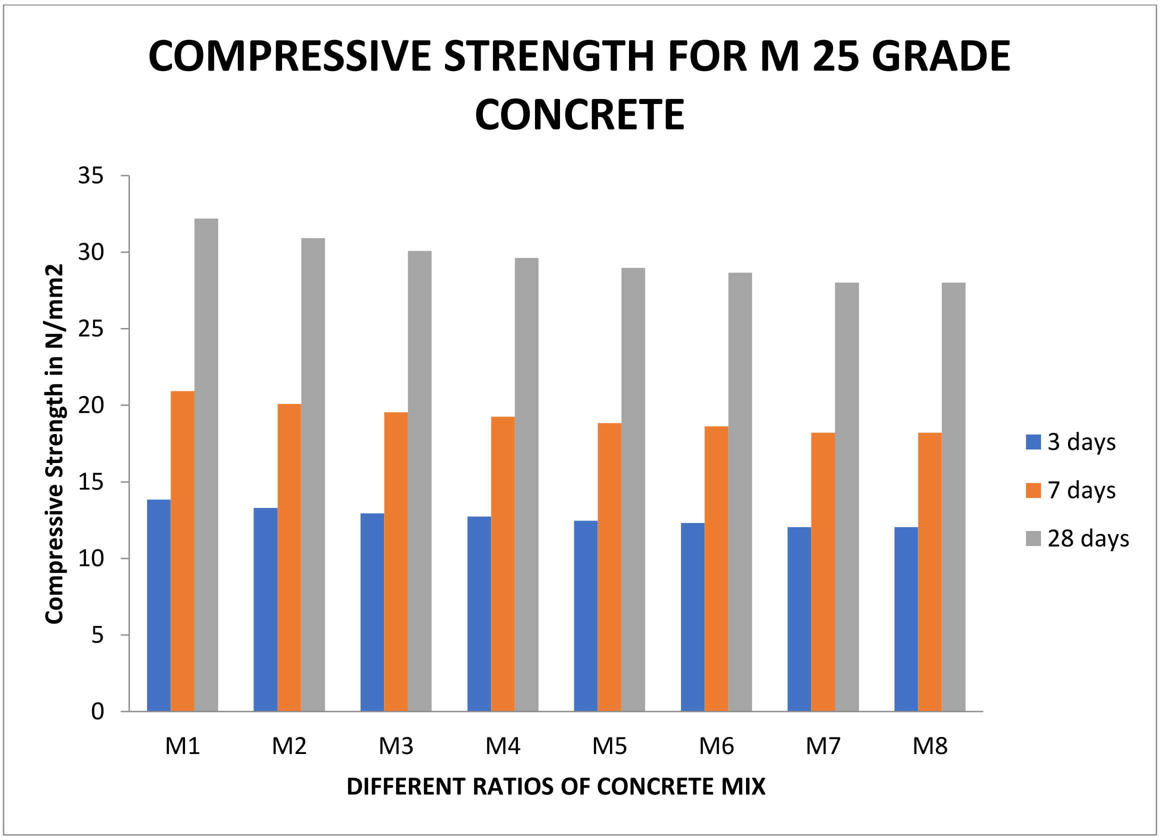
MIX TYPE	NORMAL CONSISTENCY IN %	INITIAL SETTING TIME IN MIN	FINAL SETTING TIME IN MIN	Compressive Strength at 28 Days
M1	40	33	560	46.6
M2	30	42	575	45.2
M3	35	30	475	45.6
M4	37	35	510	44.75
M5	33	38	540	44.7
M6	34	25	450	44.5
M7	32	28	480	43.2
M8	32	32	500	43.2

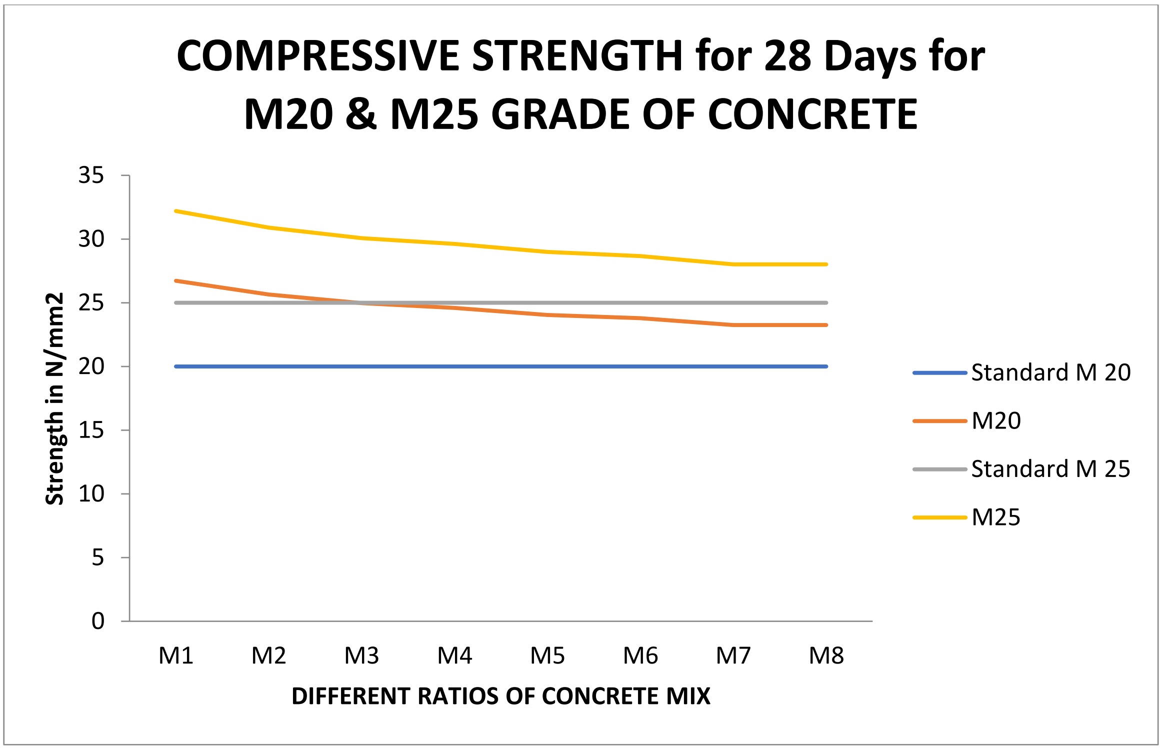
Workability Test

MIX PROPORTIONS	VALUE OF SLUMP IN mm.	
	M25	M20
M1	110	95
M2	100	90
M3	110	95
M4	100	85
M5	115	90
M6	125	110
M7	120	100
M8	120	105

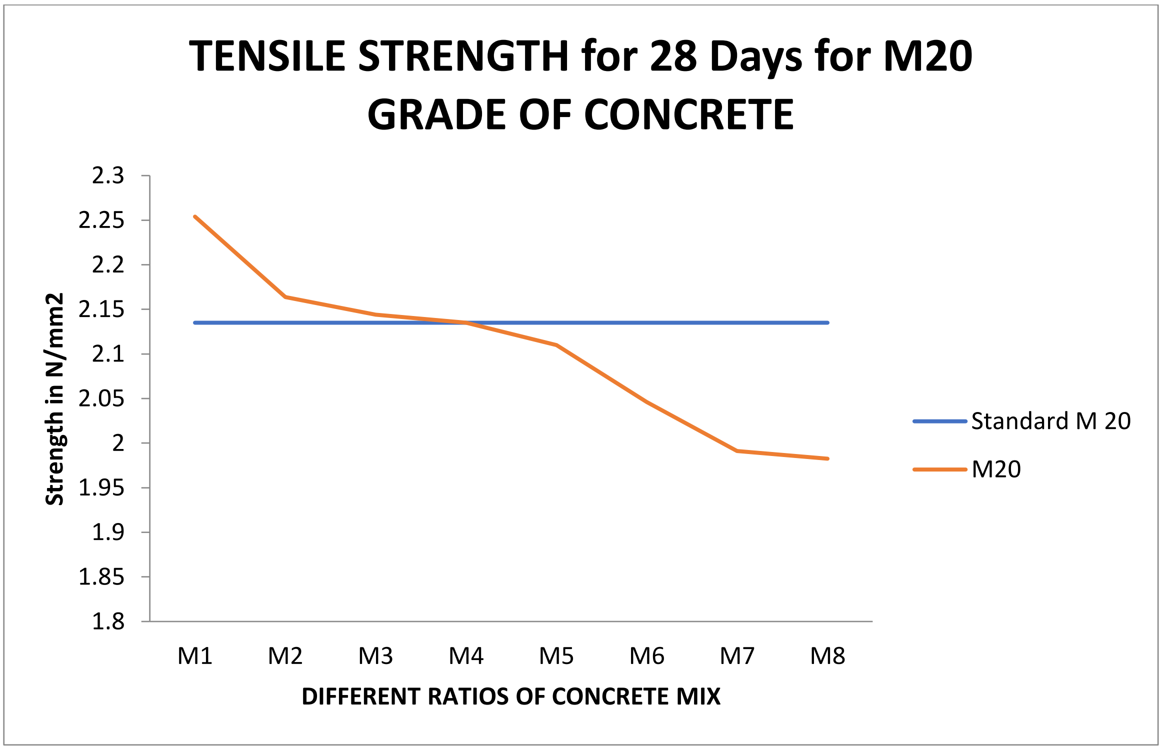
Compressive Strength Test

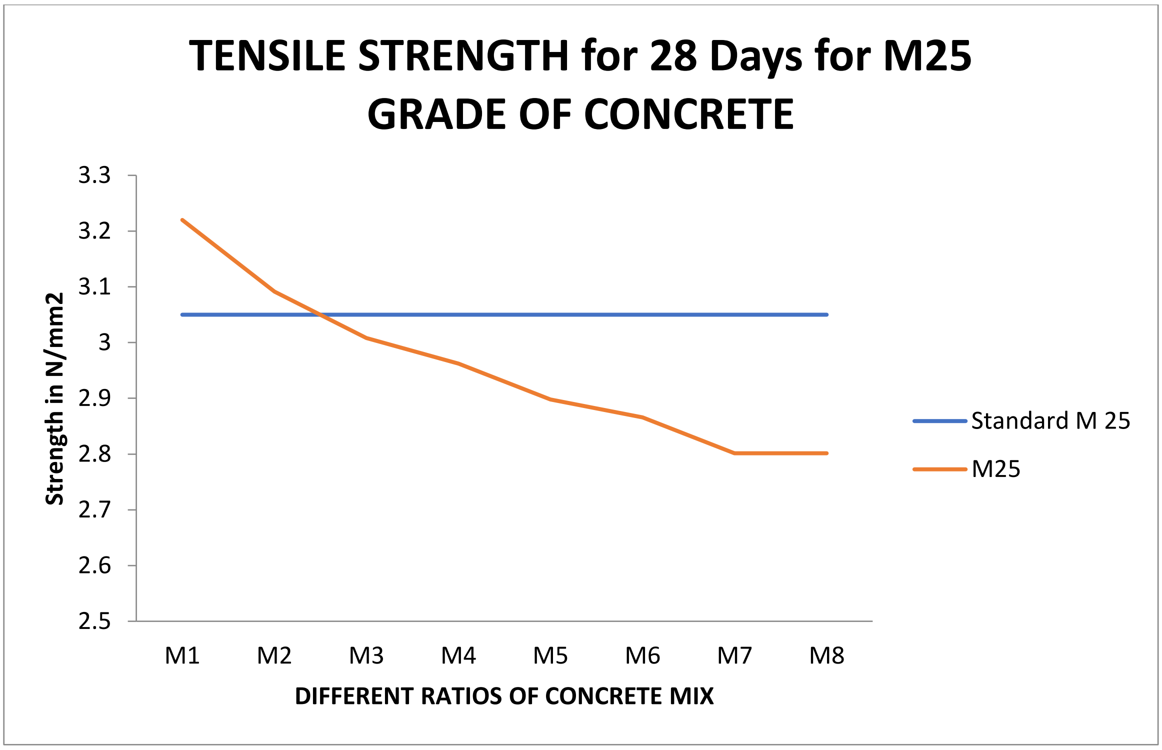




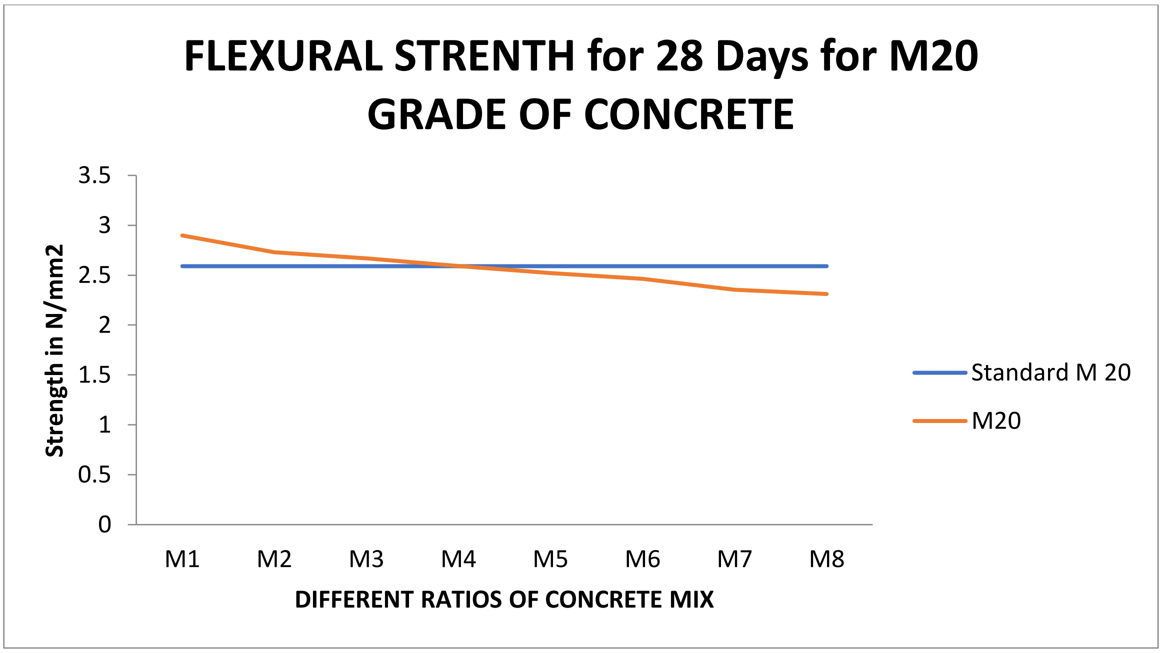


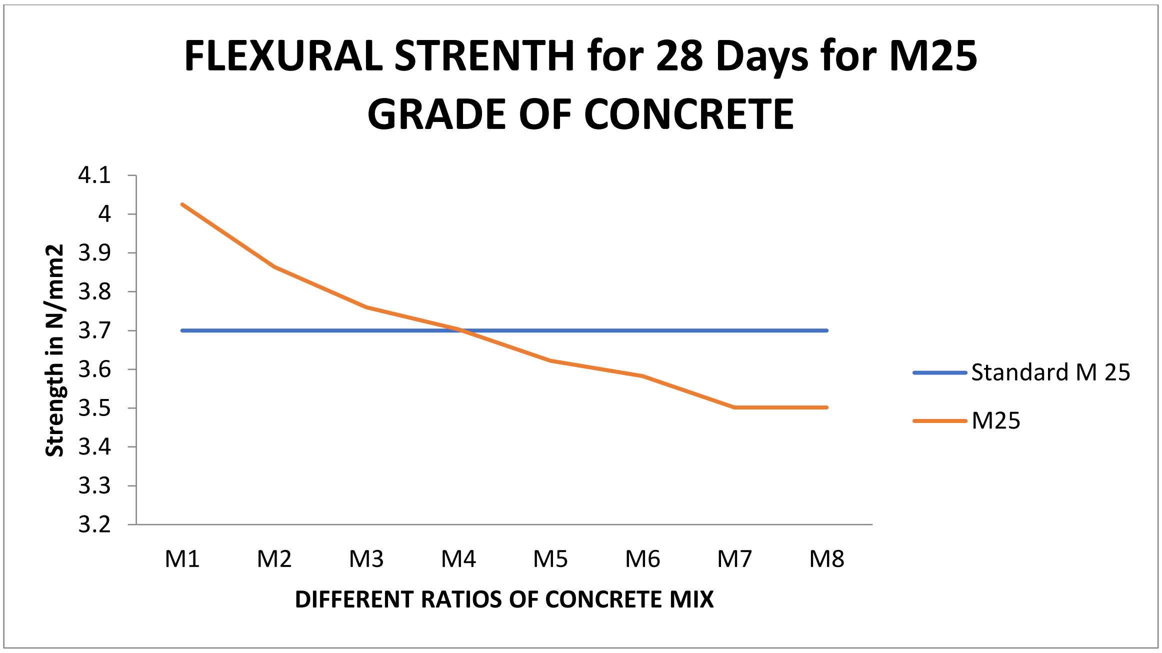
Split Tensile Strength Test





Flexural Strength Test

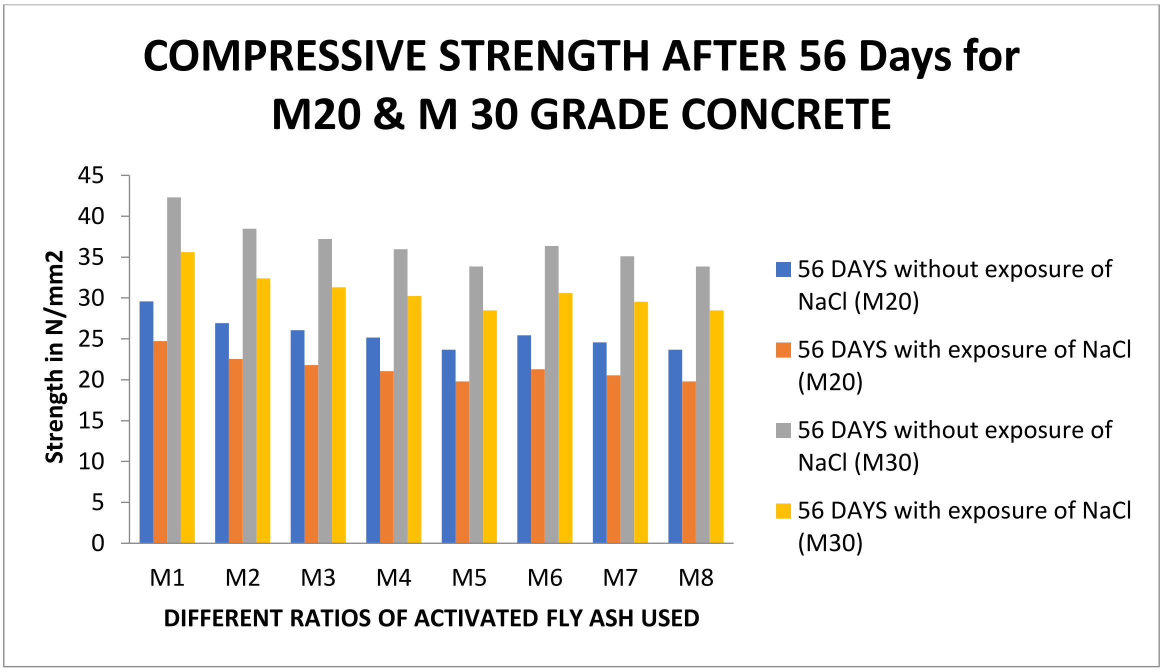




Durability Tests –

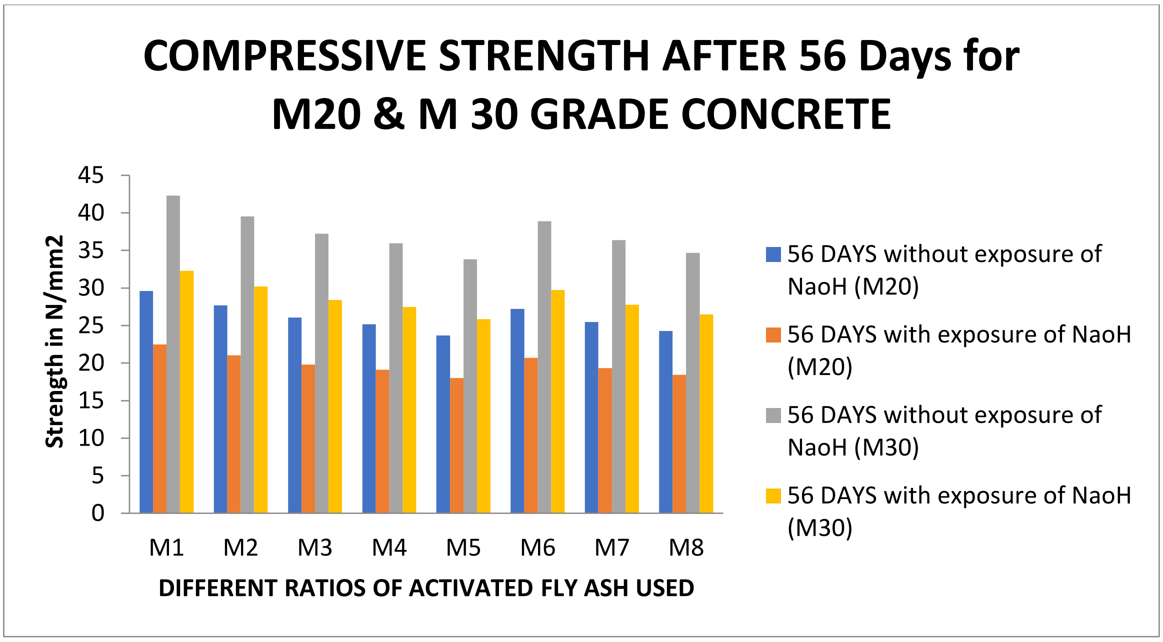
Sea Water Attack Test

The compressive strength of specimens after sea water exposure at 56 days were determined and compared with normal cured specimen at 56 days. Below table shows the percentage strength loss in NaCl solution.



Sodium Hydroxide Test

The compressive strength of specimens after NaoH exposure at 56 days were determined and compared with normal cured specimen at 56 days. Below table shows the percentage strength loss in alkaline solution.



Cost Analysis –

COST COMPARISON OF M25 GRADE CONCRETE FOR 1 m³ CONCRETE									
S No	**Materials**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**
1	**CEMENT**	**3212**	**2891**	**2891**	**2825**	**2730**	**2570**	**2506**	**2409**
2	**FLY ASH**	**-**	**110**	**220**	**220**	**220**	**440**	**440**	**440**
3	**LIME SLUDGE**	**-**	**231**	**0**	**95**	**231**	**0**	**95**	**231**
4	**M SAND**	**700**	**700**	**700**	**700**	**700**	**700**	**700**	**700**
5	**COARSE AGGREGATES**	**980**	**980**	**980**	**980**	**980**	**980**	**980**	**980**
TOTAL		**4892**	**4912**	**4791**	**4820**	**4861**	**4690**	**4721**	**4760**
% Cost Increment		**-**	**0.4%**	**-2%**	**-1.4%**	**-0.6%**	**-4.2%**	**-3.4%**	**-2.7%**

5. Conclusion –

- Workability rose as the fly ash ratio increased, and the maximum workability of concrete was reached by replacing up to 20% of the cement with fly ash. Only when fly ash is added does the workability of concrete improve in comparison to conventional concrete when lime sludge is added.
- The cement's setting time drops as fly ash and lime sludge are used to replace more cement; however, the cement's setting time increases when the fly ash and lime sludge ratio remains constant at 5%.
- When comparing the M8 mix to the M1 mix, the compressive strength of the concrete grades M20 and M25 dropped by up to 9%. However, the compressive strength loss with the M2 mix is minimal and can be taken into account.
- For the traditional mix, the cylinder's splitting tensile strength was greater. Compared to M1, there is a 12% reduction in splitting tensile strength. As we raised the cement replacement by 10% of fly ash, the figures were lower than expected. The M2 mix can be taken into consideration and displays standard values. The tensile strength decreases by 8% for M20 grade.
- Conventional mix M1 is shown to have a higher flexural strength. The flexural strength of the M2 mix is higher than the normal value for the M25 mix, and the strength of the remaining mix fraction indicates a significant 15% decline compared to the conventional mix.
- When lime sludge is added to concrete of M20 grade, the value drops by 11%.In terms of strength and workability, the M2 mix performs comparably to the standard mix. Its cost can range up to 0.4% per cubic meter, and it can be justified because it recycles trash, which appears to be environmentally beneficial.

With the addition of 5% lime sludge, the ideal proportion for fly ash is maintained at 5% cement replacement, yielding satisfactory results. It is recommended to use green concrete for environmentally friendly scenarios since its strength values are higher than the standard compressive strength, provided that the required strength is properly achieved at the site using regulated means. No admixtures were used to get the test results shown above. Moreover, the design mix ratio serves as the foundation for the design mix.

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