International Journal of Engineering Research and Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 21, Issue 6 (June 2025), PP 125-133

Experimental Analysis of Compressive and Tensile Strength in Concrete by Partial Replacement of Cement with Fly Ash

Md. Tanbhir Rahman, Yousuf Abdulla Zihan, Tasnia Siraj Oishby, Ms. Sayka Banu
Department of Civil Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh

ABSTRACT
In recent years, the use of supplementary cementing materials has become an integral part of high strength and high-performance mix design for concrete and mortar which can be economic and sustainable. These materials can be either derived naturally, or can also be by-products of industrial waste. Would fly ash serve this necessity, is the question of the interest. The aim of the study is to find the maximum and optimum proportion of Fly ash that can be efficiently used as partial replacement of Ordinary Portland Cement and Fine aggregate to make comparison between different percentages of Fly ash. In the present experimental investigation, the fly ash has been used to study the effect on compressive strength and permeability in concrete. Along with this, in this thesis paper we will be checking the condition of concrete cylinder for Thermal conductivity, sound insulation and Flexure Test. By comparing it to the ideal condition (100% concrete). We are checking partial mixture for fly ash of 20% & 25% for optimum

---

Date of Submission: 15-06-2025 Date of acceptance: 30-06-2025

I. INTRODUCTION

Waste materials, when left unattended in the environment, pose significant threats, necessitating robust waste management strategies to mitigate potential environmental degradation. Hence, there is a growing emphasis on the importance of waste material reuse to minimize ecological impacts. These materials offer opportunities for repurposing, either by creating novel products or integrating them as valuable admixtures in various industrial processes.

One such waste material of considerable significance is fly ash, a finely divided mineral residue generated from the combustion of ground or powdered coal in thermal power plants. Despite its origins as a byproduct, fly ash boasts beneficial properties as a mineral admixture in concrete formulations. Its inclusion exerts profound effects on numerous properties of cement, both in its fresh and hardened states.

By incorporating fly ash into cement, notable enhancements can be observed, including reduced permeability and enhanced density of calcium silicate hydrate (C-S-H), a critical component influencing concrete performance. Extensive research supports the notion that partial substitution of cement with fly ash, typically below the 40% threshold, yields favorable outcomes across various aspects of concrete behavior, encompassing both fresh and hardened states.

In the contemporary construction landscape, characterized by the pursuit of innovative and visually striking structures, concrete emerges as a pivotal material. To meet the evolving demands of modern architecture and engineering, continuous advancements in concrete technology are imperative. These advancements aim to develop concrete formulations endowed with distinct characteristics and tailored to specific project requirements.

This ongoing experimental investigation delves into the intricate interplay between fly ash incorporation and concrete performance. The research endeavors to comprehensively assess the impact of fly ash on crucial parameters such as compressive strength and permeability. Moreover, it extends its scope to evaluate additional properties of concrete cylinders, including thermal conductivity, sound insulation capabilities, and flexural behavior. Through meticulous analysis and comparison against the benchmark of 100% concrete compositions, this study seeks to illuminate the potential benefits and challenges associated with leveraging fly ash in contemporary construction practices.

In the present experimental study, the fly ash percentages that are used to work with are 20% and 25%. It is noteworthy that the exclusion of lower percentages of fly ash in this study is deliberate. Given the extensive research already conducted on such lower proportions, the focus shifts to investigating the potential benefits and limitations associated with higher concentrations of fly ash. Which is why, any fewer percentage of fly ash has not been taken to experiment in this specific study.

II. Objectives of this Study

The main objective of the research are:
1.To make concrete more available at cheaper cost by reducing the cement percentage used in it and incorporating other partial replacements.
2.To utilize waste materials in a more effective way.
3.To compare between conventional and partially replaced concrete.
4.To cast the concrete specimens like cubes or cylinders and study the mechanical properties of concrete.

III. Scope of the Research

The conventional concrete has several drawbacks such as very low tensile strength, lack of durability. etc. These drawbacks may be overcome by introducing admixtures of various sorts. The scope of the project is to study the strength and behavior of concrete by the way of including admixtures in the concrete at the different level of replacement of cement.

The use of fly ash in Portland cement concrete (PCC) has many benefits and improves concrete performance in both the fresh and hardened state. Fly ash use in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete. Fly ash use is also cost effective. When fly ash is added to concrete, the amount of Portland cement may be reduced. Fly ash concrete mixes typically result in lower strengths at early ages. However, fly ash use in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete in long term. Fly ash use is also cost effective. When fly ash is added to concrete, the amount of Portland cement may be reduced. Benefits to Fresh Concrete

Fly ash can increase the water retention, plasticity and long-term strength of concrete, also save cement and lime and reduce material costs. Adding percentage of fly ash in cement can not only reduce cost but also improve the workability of cement. As the particles of fly ash are almost ten times smaller than that of cement, adding fly ash to replace part of cement can play a vital role in filling and compaction of voids. In addition, fly ash has a certain activity, which can produce secondary reactions with hydration products of cement and improve the strength of mortar. As a result, it is generally realized that the use of fine fly ash improves the compressive and tensile properties of concrete.

Higher fly ash contents will yield higher water reductions. The decreased water demand has little or no effect on drying shrinkage/cracking. Some fly ash is known to reduce drying shrinkage in certain situations. Replacing cement with the same amount of fly ash can reduce the heat of hydration of concrete. This reduction in the heat of hydration does not sacrifice long-term strength gain or durability. The reduced heat of hydration lessens heat rise problems in mass concrete placements. Concrete durability enhances by fly ash and affords several benefits such as improved resistance to corrosion.

A comprehensive analysis of compressive strength at various curing ages provides insights into the impact of fly ash on the long-term strength characteristics of concrete. Fly ash may contribute to the development of strength over time, leading to enhanced durability. Again, the flexural performance of original cement and fly ash-based concrete has been investigated by conducting tests on RC beams and slabs as well as cylindrical specimens. The flexural performance of fly ash based concrete structural elements is found to have increased strength of concrete. Fly ash also tends to mitigate the brittle behavior of concrete, making it more ductile. This is especially crucial for applications like beams and slabs where flexural performance is essential.

Besides the tests regarding strength, fly ash also shows significantly improved results of sound insulation and thermal conductivity in concrete. Different tests have been carried out with a sound insulation layer consisting groups of fiber admixtures along with fly ash which convey the results of varying transmission loss curves of the tested specimens. The sound insulation property is also controlled by the stiffness of the materials, and the stiffness grows continuously with the increase in the layer's thickness. In case of thermal conductivity, Preliminary findings indicate a reduction in thermal conductivity with the incorporation of fly ash. The pozzolanic reactions of fly ash could potentially contribute to a more thermally insulating concrete matrix. Studies also explore the influence of porosity on thermal conductivity. Fly ash, through its pozzolanic reactions, may contribute to a denser concrete matrix, reducing overall porosity and enhancing thermal insulation.

Some fly ash is known to reduce drying shrinkage in certain situations. Replacing cement with the same amount of fly ash can reduce the heat of hydration of concrete. This reduction in the heat of hydration does not sacrifice long-term strength gain or durability. The reduced heat of hydration lessens heat rise problems in mass concrete placements. Concrete durability enhances by fly ash and affords several benefits such as improved resistance to corrosion.

The quality of fly ash can affect the quality and strength of cement concrete. Poor quality fly ash can increase the permeability of the concrete and cause damage to the building. However, the advantages of using fly ash far outweigh the disadvantages. The most important benefit is reduced permeability to water and aggressive chemicals. Properly cured concrete made with fly ash creates a denser product because the size of the pores is reduced. This increases strength and reduces permeability.

The climate change is attributed to not only the global warming, but also to the paradoxical global dimming due to the pollution in the atmosphere. Global dimming is associated with the reduction of the amount of sunlight reaching the earth due to pollution particles in the air blocking the sunlight. With the effort to reduce the air pollution that has been taken into implementation, the effect of global dimming may be reduced; however, it will increase the effect of global warming.

From this point of view, the global warming phenomenon should be considered more seriously and any action to reduce the effect should be given more attention and effort. The production of one ton of cement liberates about one ton of CO_2 to the atmosphere, as the result of de-carbonation of limestone in the kiln during manufacturing of cement and the combustion of fossil fuels. The use of fly ash in concrete mix design helps to decrease the rate of CO_2 in atmosphere which might be produced by cement

Classification of Fly-Ash

Two types of fly ash are commonly used in omens Class C and Class F. C calcium fly ashes with carbon content loss then 21%, whereas, Class Fry - fly ashes with carbon contents less than 37% but sometimes we high w 100%.gr, Class ashes are produced from burning sub-bituminous of lignite coals and Class F anthracite coals. Performance properties between Class C and F ashes vary depending on the chemical and physical properties of the ash and how the ash interacts with cement in the concrete Many Class C ashes when exposed to water will react and become hard just like cement, but not Class F ashes. Most, if not all, Class F ashes will only react with the byproducts formed when cement reacts with water. Class F fly ashes might be used in this experiment.

Currently, more than 50% of the concrete placed in the U.S. contains fly ash. Dosage rates vary depending on the type of fly ash and its reactivity level. Typically, Class F fly ash is used at dosages of 15% to 25% by mass of cementitious material and Class C fly ash at 15% to 40%. However, fly ash has not been used in interior, steel-troweled slabs because of the inherent problems or challenges associated with fly ash variability and delayed concrete hardening.

Properties

Chemical Properties

It is spherical in shape and solid in state, ranges in size from 0.5µm-300µ. The major constituents of fly ash are silica (SiO_2), Al min (Al_2O_3), F i Oxid (F $_2O_3$) and Cl i m Oxide (CaO). The other minor constituents of fly ash are MgO N $_2$O, K_2O, SO_3, MnO, TiO_2, nd n n C on. Th variation in the principal constituents is about Silica (25-60%), Alumina (10-30%) and Ferric Oxide (5-25%). When the sum of these three principal constituents is 70% or more if calcium oxide is less than 10% -Technically the fly ash is considered As siliceous fly Ash or class F fly ash. Such type of fly ash is produced by burning of anthracite or bituminous coal having pozzolanic properties. If some of these constituents is more than 50% and reactive calcium oxide is not less than 10% , fly ash will be considered as calcareous fly ash also called Class C fly Ash. This type of fly Ash is produced by burning of ignite or sub-bituminous coal and possess both pozzolanic and hydraulic properties [9][10].

Physical Properties

Fly ash particles are generally glassy Solid or hollow and spherical in shape. The hollow spherical particles called as cenospheres. The fineness of individual fly ash particle range from 1 micron to 1 mm size. The fineness of fly Ash particles has a significant influence on its performance in cement concrete[11].The fineness of particles is measured by specific surface area of fly ash by Blaine's specific area technic .Greater the surface area more the fineness of fly ash. The specific gravity of fly ash varies over a wide range of 1.9 to 2.55[12][13]. 1.3

Pozzolanic Properties

Fly Ash is a pozzolanic material which is defined as siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value, chemically react with Calcium Hydroxide (lime) in presence of water at ordinary temperature and form soluble compound comprises cementitious property similar to cement. The pozzolana term came from Roman. About 2,000 years ago, Roman used volcanic ash along with lime and sand to produce mortars, which possesses superior strength characteristics & resistances to corrosive water. The best variety of this volcanic ash was obtained from the locality of pozzoli and thus the volcanic ash had acquired the name of Pozzolana. In section I introduction part is explained.

A Comparative Analysis of Compressive Strength: Ordinary Cement vs. Fly Ash in Concrete

1)Early Strength: Preliminary results may indicate changes in early-age strength, with fly ash mixes potentially exhibiting slower initial strength gain due to pozzolanic reactions.

2)Long-Term Strength: A comprehensive analysis of compressive strength at various curing ages will provide insights into the impact of fly ash on the long-term strength characteristics of concrete. Fly ash may contribute to the development of strength over time, leading to enhanced durability.

3)Microstructural Analysis: Microscopic examinations, such as scanning electron microscopy (SEM) and X-ray diffraction (XRD), can be employed to investigate the influence of fly ash on the concrete's microstructure and hydration products.

Comparative Analysis of Cylinder Flexural Test: Ordinary Cement vs. Fly Ash in Concrete

1)Improved Strength: The flexural performance of original cement and fly ash based concrete has been investigated by conducting tests on RC beams and slabs as well as cylindrical specimens. The flexural performance of fly ash based concrete structural elements is found to have increased strength of concrete.

2)Cracking Moments: Tests have shown that the significant cracking moments of cylinders containing up to 40% fly ash have been observed particularly in higher grade of concrete.

3)Reduction in Brittle Behavior: Fly ash tends to mitigate the brittle behavior of concrete, making it more ductile. This is especially crucial for applications like beams and slabs where flexural performance is essential.

Advantages of Fly Ash in Concrete

The most important benefit is reduced permeability to see and aggressive chemicals. Property crushed concrete made with fly ash creates a denser product because the size of the pores reduced. This increases strength and reduces permeability,

Strength in concrete depends on many factors, the most important of which is the ratio of water to cement. Good quality fly ash generally improves workability or at least produces the same workability with less water. The reduction in water leads to improved strength. Because some fly ash contains larger or less reactive particles than Portland cement, significant hydration can continue for six months or longer, leading to much higher ultimate strength than concrete without fly ash. There have been several cases in which the early strength of concrete was low, particularly where a significant portion-30 percent or more of the Portland cement was replaced with fly ash. This need not be a serious problem today, since set time is also controlled by many other factors that can be altered to compensate for added fly ash, if necessary. The observed slow set and low early strength obtained with fly ash has caused a reduction in the amount of this mineral admixture used in concrete. Although some fly ash materials will reduce early strength and slow the setting time it does not have to be the case today. Some fly ash actually accelerates set. The addition of accelerators, plasticizers or a small amount of additional CSF, as well as the proper beneficiated fly ash, can mitigate this problem. Properly proportioned concrete containing fly ash should create a lower cost. Because of the reduced permeability and reduced calcium oxide in properly selected fly ash, it should be less susceptible to the alkali-aggregate reaction. A superplasticizer combined with fly ash can be used to make high-performance and high-strength concrete. Concrete containing fly ash generally performs better than plain concrete in drying shrinkage tests.

Disadvantages of Fly Ash in Concrete

The quality of fly ash is important-but a can vary. Poor-quality fly ash can have a negative effect on concrete. The principal advantage of fly ash is lowered permeability, but fly ash of poor quality can actually increase permeability. Some fly ash, such as that produced in a power plant, is compatible with concrete. Other types of fly ash must be beneficiated, and some types cannot be improved sufficiently for use in concrete.

Compressive Strength Test of cylinder:

Concrete test cylinders, also known as cylindrical concrete specimens, are paramount in evaluating the compressive strength of concrete, thereby ensuring the structural integrity of the construction. They serve a dual purpose – measuring the compressive strength and acting as a part of quality control procedures to validate the quality of the concrete utilized. The strength of concrete is ascertained by subjecting cylindrical specimens to a compression-testing machine, dividing the failure load by the cylinder's cross-sectional area to calculate the strength.

We shall explore further the significance of assessing concrete strength and the functioning of the structure of these test cylinders.

Factors Affecting Test Results

Various factors can influence determine the accuracy of test results, including:

1) Human error, such as insufficient casting, handling, and curing of concrete cylinders,
2) Environmental conditions, such as improper temperature and relative humidity control
3) Inadequate storage conditions. All of these factors can lead to inaccurate test results.

Interpreting Test Results

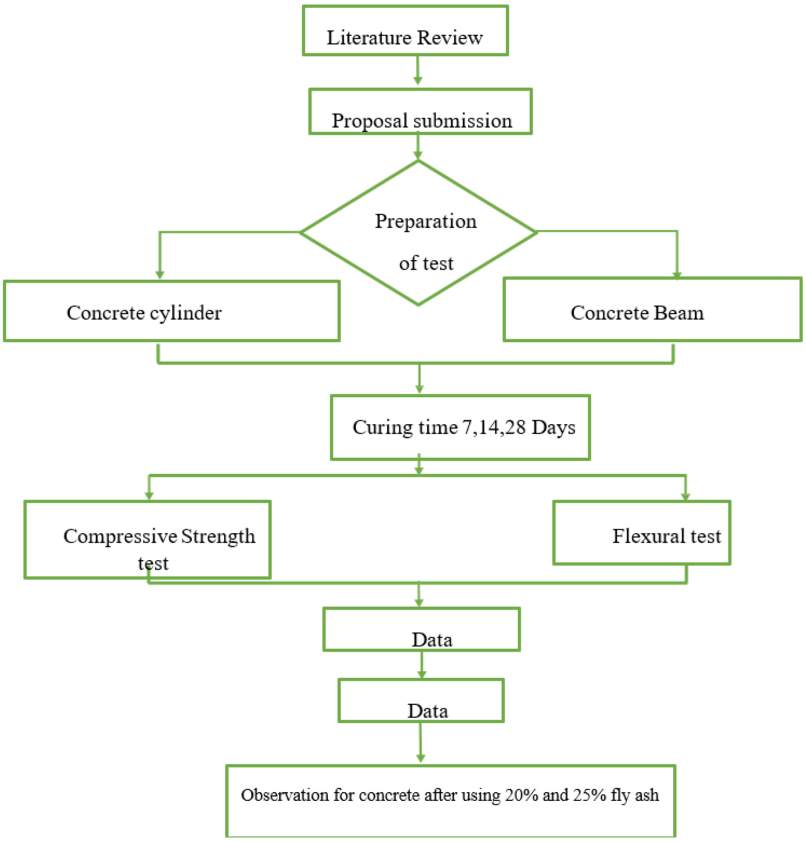
Interpreting test results involves comparing the compressive strength of the concrete cylinder to project specifications and industry standards. Meeting or surpassing the specified strength in the test results indicates that the concrete meets the project requirements.

An irregular shape in the fracture pattern of a concrete cylinder test suggests that the results may not accurately represent the compressive strength of the concrete, indicating potential issues with the test procedure.

Summary

In conclusion, concrete test cylinders play a critical role in ensuring the quality, durability, and safety of concrete structures. By adhering to industry standards, following best practices for sampling, preparation, testing, and management of test cylinders, and regularly maintaining and cleaning the molds, we can ensure accurate results and uphold the structural integrity of our concrete structure

Flow Chart of required test



Compressive Test Result

Compressive strength test was carried out on specimen cylinder (4"X8") of concrete with the replacement of cement by fly at 7th. 14th and 28th days of curing by Universal Testing Machine (UTM). (The compressive

strength of plain concrete was compared with the compressive strength of concrete cylinder having replacement of cement by fly ash (20%,25%). The compressive strength data are given in table-4.1. The desired strength was 20 Mpa. The figure 4.2 to 4.7 shows graphical representation of compression test.
Table 4.1 shows that compared to the compressive strength of plain concrete.

Tensile Test Result

The compressive strength of plain concrete was compared with the compressive strength of concrete cylinder having replacement of cement by fly ash 20%,25%. The figure 4.8 to 4.12 shows graphical representation of tensile test.

Figure 4.1 Concrete cylinder specimen under compressive load (for 0%,20% and 25% replacement of cement by fly ash)

Table 4.1.1. Compressive and tensile strength of cylinder specimen for 7 Days

7 Days (Cylinder)	Percentage of fly ash	Compressive Strength(Mpa)	Percentage of fly ash	Tensile Strength (Mpa)
	0%	12.5	0%	1.58 1.58
	20%	10.98	20%	1.4 1.4
	25%	10.15	25%	1.2 1.2

Table 4.1.2. Compressive strength of cylinder specimen for 14 Days

14 Days (Cylinder)	Percentage of fly ash	Compressive Strength (Mpa)	Percentage of fly ash	Tensile Strength (Mpa)
	0%	19.6	0%	2.46
	20%	17.23	20%	2.2
	25%	15.92	25%	1.95

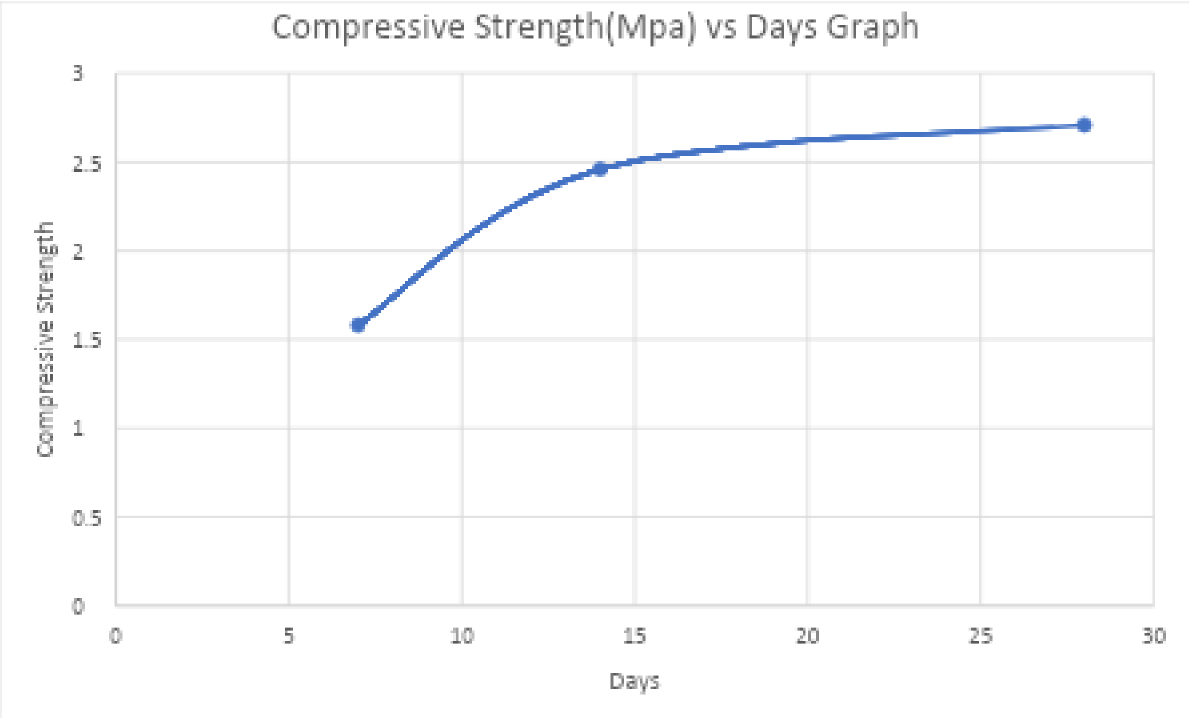


Figure 4.2. Compressive strength of concrete specimen for 0% fly ash graph

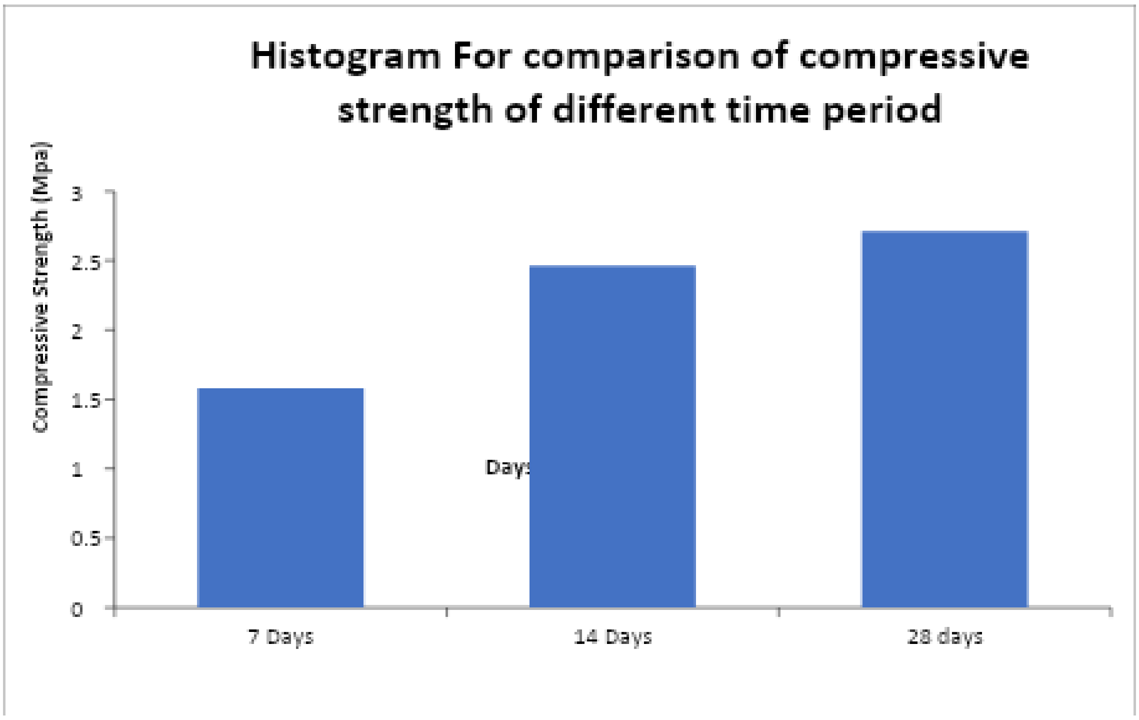


Figure 4.3. Compressive strength of concrete specimen for 0% fly ash histogram

Recommendation for future studies

Fly ash-based concrete stands out for its remarkable durability, making it a favored choice across various construction projects. However, it grapples with a significant drawback: its initial compressive strength tends to be lower, particularly within the crucial 28-day timeframe. Despite this initial setback, the compressive strength of fly ash-based concrete steadily improves over time, typically reaching satisfactory levels after an extended curing period of 90 days.

In order to address this inherent limitation and elevate the performance of fly ash-based concrete, integrating glass fiber-based concrete emerges as a highly innovative solution. Glass fiber-based concrete possesses outstanding initial compressive strength, effectively compensating for the shortcomings observed in fly ash-based concrete during its early developmental stages.

Reference

[1]. https://www.researchgate.net/publication/316889800_Strength_and_Durability_Aspect_Study_of_Glass_Fiber_Reinforced_Concrete_with_Fly_ash
[2]. https://nischinth.com/quantity-calculation-for-ingredients-of-concrete/
[3]. https://www.researchgate.net/figure/Relation-between-the-compressive-strength-and-Fly-Ash-as-a-partial-replacement-of_fig3_255963880
[4]. V. Gayathri The Use of Fly Ash and Lime Sludge as Partial Replacement of Cement in Mortar International Journal of Engineering and Technology Innovation, vol. 4, no. 1, 2014
[5]. A. Oner, S, Akyuzb, R. Yildiza,(2004)"An experimental study on strength development of concrete containing fly ash and optimum usage of fly ash in concrete" Cement and Concrete Research, Vol.35, Issue 6, pp 11651171.
[6]. R. Siddique, "Effect of fine aggregate replacement with class F fly ash on the mechanical properties of concrete," Cement and Concrete Research, vol. 33, pp. 539-547, 2003.
[7]. Aman Jatale, Kartiey Tiwari, Sahil Khandelwal (2013) -"Effects on Compressive Strength When Cement is Partially Replaced by Fly Ash" IOSR Journal of Mechanical and Civil Engineering, e-ISSN 2278-1684, Vol. 5, pp 34-43.
[8]. https://www.sciencedirect.com/book/9781845699550/building-materials-in-civil-engineering?fbclid=IwAR3RH8jhybt0kSdpes0UH4BOQ3RkNQegstixigwiTL2jWcninmKGKQ4h_P0
[9]. Sarker, H. and hossain,C. (2019) . The comparison of parametric properties of ceter mortar made with partial replacement of cement by fly ash and rice husk.
[10]. ACI 211.1-91, Reapproved 2009, Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete, American Concrete Institute, Farmington Hills, MI, 48331-3439 USA.
[11]. Hwang, K., Noguchi, T., and Tomosawa, F. 1998. Effects of fine aggregate replacement, compressive strength and carbonation properties of fly ash and mortar. Special Publication, 178, 401-410.
[12]. http://www.researchgate.net/publication/283713379_Fly_Ash_as Sustainable Material_for_Green _Concrete - A State of Art Fly Ash as Sustainable Material for Green Concrete - A State of Art, May 2015 Dhananjay K Parbat, Vikrant Vairagade.
[13]. Chavan,p. (2014) Lhtps://ww.researchgate.net/journal/22489622.of_ Engineering Research and_International _Journal_Applications]
[14]. V. Gayathi The Use of Fly Ash and Lime Sludge as Partial Replacement of Cement in Mortar International Journal of Engineering and Technology Innovation, vol. 4, no. 1, 2014, pp. 30-37.
[15]. Sarker, H. and hossain,C. (2019) . The comparison of parametric properties of cement. mortar made with partial replacement of cement by fly ash and rice husk.
[16]. ACT 211.1-91, Mix design of concrete, American Concrete Institute.
[17]. ASTM C 192/C 192M-02 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory, American Society for Testing and Materials.
[18]. Boobala Krishna k.V, N.Vignnesh, S.KulandhiAntony(2017) "Experimental investigation on partial replacement of cement by wood ash and fine aggregate by wood powder" South Asian Journal of Engineering and Technology Vol3,No7(2017)46-52.
[19]. Amrutha anju sambath manaurath, Devika balachandran, Dona Maria Sebastian, "Partial replacement of cement with wood ash", IJSTE vol2 issue 11 may 2016.
[20]. Bye, G. C. (1999). Portland cement: Composition, production and properties. Thomas Telford
[21]. A. Oner, S. Akyuzb, R. Yildiza, (2004)"An experimental study on strength development of concrete containing fly ash and optimum usage of fly ash inconcrete" Cement and Concrete Research, Vol.35, Issue 6, pp 11651171.
[22]. A. Oner, S. Akyuzb, R. Yildiza, (2004)"An experimental study on strength development of concrete containing fly ash and optimum usage of fly ash inconcrete" Cement and Concrete Research, Vol.35, Issue 6, pp 11651171.
[23]. Volume: 06 Issue: 03 | Mar 2019 www.irjet.net p-ISSN: 2395-0072 © 2019, IRJET | Impact Factor value: 7.211 / ISO 9001:2008 Certified Journal | Page 4806 Experimental Study of Partially Replacement of Cement by Prosopis Juliflora Concrete P. Saralal S.
[24]. P.Mehta, High-performance, high-volume fly ash concrete for sustainable Technology, Beijing, May 20-21, 2004.Development, International Workshop on Sustainable Development and Concrete
[25]. Alvin Harison, Vikas Srivastava and Arpan Herbent (2014) - "Effect of Fly-ash on Compressive Strength of Portland Pozzolona Cement Concrete" Journal of Academia and Industrial Research, Vol. 2, ISSN:2278-5213.
[26]. Aman Jatale, Kartiey Tiwari, Sahil Khandelwal (2013) - "Effects on Compressive Strength When Cement is Partially Replaced by Fly Ash" IOSR Journal of Mechanical and Civil Engineering, e-ISSN 2278-1684, Vol. 5, pp 34-43.
[27]. A. Raheem,B. S. Olasunkanmi,C. S. Folorunso. Saw Dust Ash as Partial Replacement for Cement in Concrete https://hreak.srce.hr/otme
[28]. Swamy R.N and Sami.A.R.Ali, Early Strength of Fly ash Concrete for Structural Applications. ACI Journal, October 1983, Vol.80, PP 414-423.
[29]. ACI 211.1-91, Reapproved 2009, Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete, American Concrete Institute, Farmington Hills, MI, 48331-3439 USA.
[30]. Hwang, K., Noguchi, T., and Tomosawa, F. 1998. Effects of fine aggregate replacement, compressive strength and carbonation properties of fly ash and mortar. Special Publication,178, 401-410.
[31]. A. Oner, S. Akyuzb, R. Yildiza,(2004)"An experimental study on strength development of concrete containing fly ash and optimum usage of fly ash inconcrete" Cement and Concrete Research, Vol.35, Issue 6, pp 11651171.
[32]. Shetty MS (2003) Concrete Technology, S.Chand and Company Ltd, New Delhi.
[33]. R. Siddique, "Effect of fine aggregate replacement with class F fly ash on the mechanical properties of concrete," Cement and Concrete Research, vol. 33, pp. 539-547, 2003.
[34]. https://certifiedmtp.com/blog?p=concrete-test-cylinder-methods-maximizing-accuracy