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Investigating the impact of fly ash from mechanical soil improvement to concrete property enhancement

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Abstract

Fly ash, a byproduct of coal combustion in power plants, has gained attention in the construction industry due to its unique physical and chemical properties. This material, owing to its high pozzolanic activity, can help improve the mechanical properties of soil and concrete, ultimately optimizing the performance of structures against environmental and mechanical loads. The use of fly ash as a stabilizing agent in soil improvement can lead to reduced permeability, increased cohesion, and enhanced soil resistance to compressive and tensile loads. Additionally, incorporating fly ash into concrete can increase compressive and tensile strength, reduce cracking, and enhance the durability of concrete against harsh environmental conditions, such as freezing and waterlogging. Furthermore, considering the environmental challenges posed by industrial waste production and the need for optimal resource utilization, the application of fly ash can mitigate the negative impacts of industrial waste and reduce construction costs. In the following studies, we will analyze the characteristics of fly ash, its types, and its effects on the mechanical properties of soil and concrete. Various tests, including swelling index, permeability, compressive strength, and other mechanical properties, have been conducted on soil samples containing fly ash. The results of this research indicate that the use of fly ash can lead to improved mechanical performance of soil and increased strength and durability of concrete. Overall, the findings suggest that the use of fly ash can be proposed as a sustainable and economical solution for improving soil and enhancing concrete properties in construction projects.

Keywords: Fly ash, soil, concrete, improvement of mechanical properties of soil and concrete, environmental effects, structures, sustainable and economical solutions
2020 MSC: 03H10, 97M50

1 Introduction

In today's world, rapid population growth and uncontrolled urban development have exerted increasing pressure on existing infrastructure. This situation has significantly heightened the need for creating and maintaining sustainable infrastructure that can withstand environmental and economic challenges [3]. The construction industry, as one of the largest consumers of natural resources and energy, faces multiple challenges, including rising construction costs, environmental constraints, and increasing demand for high-quality and durable structures. These challenges are

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particularly evident in developing countries, which face resource shortages and inadequate infrastructure [17]. The use of by-products and recycled materials in the construction process has gained significant attention as an effective strategy to reduce costs and improve the quality of structures [23]. In this context, fly ash, a byproduct of coal combustion in power plants, has become an attractive option for engineers and designers due to its unique physical and chemical properties. This material can not only be used as an additive in concrete but also serves as a stabilizing agent in soil improvement [10].

Fly ash possesses remarkable pozzolanic properties, allowing it to react with calcium hydroxide present in concrete to produce compounds with desirable properties. These characteristics can lead to improvements in the strength, durability, and stability of concrete. Particularly in harsh environmental conditions, fly ash can help reduce the permeability of concrete, increase adhesion, and enhance its mechanical properties [29]. These advantages enable the production of concrete with better performance and longer lifespan, making it more resistant to environmental factors such as moisture, freezing, and chemical attacks [28]. Additionally, the use of fly ash as an auxiliary material in soil improvement can enhance the cohesion and reduce the permeability of clay and sandy soils [26]. This is especially important in construction projects that require improved mechanical properties of soil, such as the construction of roads, bridges, and other infrastructure, where soil improvement can lead to increased stability and reduced risk of landslides and settlement.

On the other hand, addressing environmental issues and the sustainable management of natural resources is of paramount importance in the present era. Cement production is one of the largest sources of carbon dioxide emissions in the construction industry [15]. The use of fly ash as an auxiliary material can help reduce these environmental impacts. By replacing a portion of cement with fly ash, not only can greenhouse gas emissions be reduced, but natural resource consumption can also be optimized. This research aims to comprehensively examine the impact of fly ash on the mechanical improvement of soil and the enhancement of concrete properties [20]. In this regard, we will first analyze the physical and chemical characteristics of fly ash and its types. Then, we will investigate its effects on the mechanical properties of soil and concrete, including various tests such as swelling index, permeability, compressive strength, and other mechanical properties. These tests will help us gain a better understanding of the performance of fly ash under various conditions and provide optimal strategies for its use [19].

Given the challenges present in the construction industry and the need for innovative and sustainable solutions, it is hoped that this research will contribute effectively to the development and improvement of the quality of construction projects and the reduction of their environmental impacts [12].

2 How fly ash is produced

2.1 Fly ash production process

Fly ash is produced by burning coal in power plant furnaces. In this process, coal is burned at high temperatures (between 1200 and 1500 degrees Celsius) and its fine particles are converted into gases. These gases are converted into solids after cooling and are collected as fly ash [8, 18]. The process of producing fly ash includes the following steps:

Combustion of coal: It is carried out in special furnaces with controlled temperature and pressure. This step requires precise control of temperature and time to prevent the formation of large and inefficient particles. In this step, various coal compounds are converted into various gases, including carbon dioxide, nitrogen oxides, and other polluting gases [18].

Gas production: Hot gases containing fine fly ash particles are produced. These gases usually contain various compounds such as carbon dioxide, nitrogen oxides and sulfur, which, if not controlled, can lead to environmental pollution. In some power plants, more advanced technologies are used to reduce pollutants and optimize the production process. These technologies include the use of high-efficiency furnaces, exhaust gas cleaning systems and optimization of the fuel-air ratio [18].

Ash collection: Fly ash is collected using collection systems such as electrostatic or bag filters. These systems should be designed to have a high efficiency in collecting fine particles. Also, the quality of the collected fly ash should be regularly monitored to ensure that it meets the required standards [18].

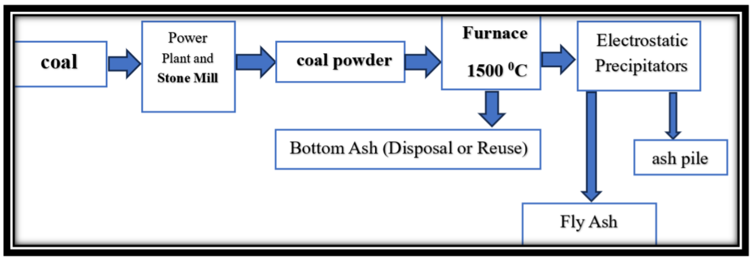

Figure 1: Schematic of Fly Ash Production

2.2 Effect of coal type on fly ash quality

The type of coal used in the production of fly ash has a great influence on its quality and properties. Different coals have different chemical compositions that can affect the properties of fly ash. For example, coals with a high silica content usually produce fly ash with higher pozzolanic activity. This property can help increase the strength and durability of concrete. On the other hand, coals with a high sulfur content may produce fly ash with a higher sulfate content, which can negatively affect the properties of concrete. Also, the type of coal can affect the color, density, and grain size of fly ash [23].

2.3 Quality control of fly ash

Quality control of fly ash is very important at different stages of production. Quality control of fly ash is important not only during the production stages, but also during storage and transportation. Fly ash must be stored in appropriate conditions to prevent moisture absorption and changes in its properties. This is especially important in large and sensitive projects, such as the construction of dams and bridges. For this reason, regular testing and quality control throughout the fly ash supply chain must be carried out to ensure that the final product meets the required standards. Several tests are performed to determine the physical and chemical properties of fly ash, including measurements of particle size, specific surface area, and chemical content [14, 13]. These tests can include the following:

Grain size test: The particle size of the fly ash is determined using standard sieves. This test helps us determine the appropriate particle size for use in concrete and soil improvement [14, 13].

Specific surface area test: The specific surface area of the fly ash is measured using the (BET) method. High specific surface area can help enhance chemical reactions and improve mechanical properties [14, 13].

Chemical composition test: Using spectroscopic devices, the chemical composition of fly ash is determined. This test helps determine the pozzolanic activity of fly ash and its effect on concrete properties [14, 13].

3 Characteristics and properties of fly ash

3.1 Physical properties of fly ash

Fly ash has certain physical properties that make it a suitable material for use in concrete and soil improvement. These properties include:

Fine particle size: The particle size of fly ash is usually less than 45 microns. This fine particle size increases the contact surface with other materials and thus accelerates chemical reactions. This property is especially important for high-strength concretes and in harsh environmental conditions, such as areas with heavy rainfall or frost. Also, fine-grained fly ash can act as a filler in concrete and fill the voids between larger grains, which leads to reduced air bubbles and improved concrete uniformity [6, 26].

High specific surface area: The high specific surface area of fly ash increases its chemical reactions with other materials. This property helps to improve the mechanical properties of concrete and soil. Increasing the specific surface area can lead to increased adhesion and reduced permeability of concrete [6, 26].

Adhesion: Fly ash can help improve the mechanical properties of soil due to its adhesive properties. This adhesive property is especially useful in clay soils that usually have problems such as swelling and high permeability [6, 26].

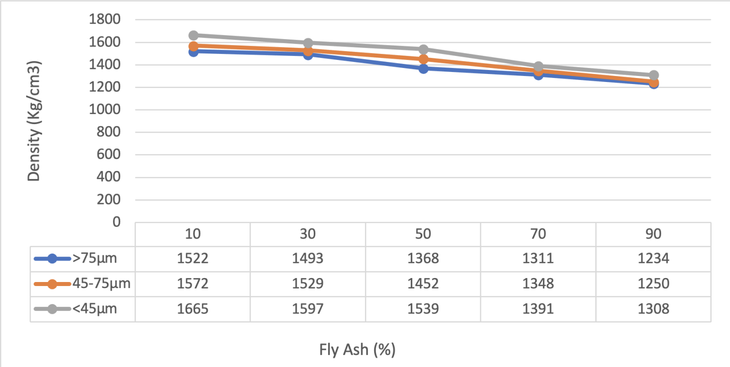

Figure 2: Variation of Soil Density Based on Fly Ash Replacement

3.2 Chemical properties of fly ash

Fly ash usually contains the following compounds:
Silica (SiO2), aluminum (Al2O3), iron oxide (Fe2O3) and calcium (CaO).

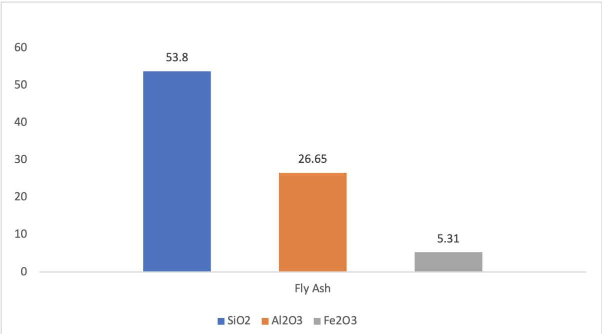

Figure 3: Percentage Ratio of (SiO2, Al2O3, Fe2O3) in Fly Ash Used in the Study

These chemical compounds have a great influence on the mechanical and chemical properties of fly ash. For example, high silica and aluminum content in fly ash increases its pozzolanic activity [3, 8].

Table 1: Results of the Chemical Composition of Fly Ash

Chemical Composition	Ash Minimum Percentage in the Composition of Fly	Maximum Percentage in Fly Ash	Weight Percentage
SiO_2	22.13	70.94	52.38
Al_2O_3	6.98	28.51	21.17
Fe_2O_3	2.32	9.88	8.21
CaO	2.03	16.58	9.49
MgO	0.76	5.06	2.32
K_2O	0.39	1.79	0.62

3.3 Pozzolanic activity

Fly ash has pozzolanic activity due to its high silica and aluminium content. This property causes fly ash to react with calcium hydroxide in concrete to produce compounds with desirable properties that help improve the strength and durability of concrete. These reactions usually occur at normal temperatures and in the presence of moisture and can lead to a decrease in the permeability of concrete and an increase in its adhesion. Also, the use of fly ash can reduce the need for cement and thus reduce the costs and environmental impacts of cement production [22, 8].

4 Types of fly ash and their review

4.1 Class F fly ash

This type of fly ash has high silica and aluminium and is usually used for high-strength concrete. Class F fly ash helps improve the mechanical properties of concrete due to its pozzolanic properties. This type of fly ash is commonly used in construction projects with special requirements, such as bridges and tall buildings. The use of Class F fly ash can reduce the amount of cement used in concrete while increasing the strength and durability of concrete. This feature can help reduce construction costs as well as reduce the environmental impact of cement production [6, 26].

4.2 Class C fly ash

This type of fly ash is high in calcium and is commonly used for soil and concrete improvement. Due to its high calcium content, Class C fly ash can act as an effective stabilizing agent in clay and sandy soils. The use of Class C fly ash can help improve cohesion and reduce soil permeability. This type of fly ash is commonly used in construction projects, including infrastructure projects, such as roads and bridges, which require improved soil properties [23, 8].

4.3 Effect of fly ash type on concrete properties

The type of fly ash has a great influence on the final properties of concrete. For example, the use of class F fly ash can lead to improved compressive and tensile strength of concrete, while class C fly ash can help improve the durability and stability of concrete. Also, the type of fly ash can affect the setting time and workability of concrete [2].

Table 2: Classification of Fly Ash According to Standard (ASTM C-618)

Type of Ash	pH	Chemical Composition	$CaO\%$
Class F	acidic	$SiO_2 + Al_2O_3 + Fe_2O_3 (> 75\%)$	¡12%
Class C	alkaline	$SiO_2 + Al_2O_3 + Fe_2O_3 (> 75\%)$	¿12%

5 Investigation of factors affecting fly ash properties and quality

5.1 Coal type

The type of coal used in the production of fly ash has a great influence on its quality and properties. Different coals have different chemical compositions that can affect the properties of fly ash. For example, coals with a high silica content usually produce fly ash with higher pozzolanic activity. Also, the type of coal can affect the color, density, and grain size of fly ash [20].

5.2 Burning temperature and time

The burning temperature and burning time also affect the particle size and chemical properties of fly ash. Higher temperatures usually result in the production of fly ash with a finer grain size and better pozzolanic properties. In addition, the burning time can also affect the pozzolanic activity of fly ash. These changes can be used as a strategy to improve the quality of fly ash in the production of high-strength concrete. For this reason, careful monitoring and control of temperature and burning time in the fly ash production process is of great importance [21, 9].

5.3 Effect of environmental conditions

Environmental conditions such as humidity and temperature can also affect the quality of fly ash. For example, high humidity can lead to the accumulation of moisture in fly ash and reduce its properties. Also, high temperatures can lead to the evaporation of water in fly ash, which can negatively affect its properties. In addition, the storage conditions of fly ash are also very important. Fly ash should be stored in dry and cool places to prevent moisture absorption and change its properties. Otherwise, the pozzolanic properties of fly ash may decrease and have a negative effect on the quality of concrete [29, 20].

6 Types of soil and their characteristics

6.1 Clay soils

Clay soils have fine grains and high cohesion. This type of soil has good resistance to water and rain due to its high cohesion. However, clay soils can suffer from problems such as landslides and erosion due to their specific structure in certain conditions, such as heavy rainfall. Also, clay soils usually have a high water retention capacity, which can help improve plant growth. However, these types of soils are usually sensitive to changes in temperature and humidity and may swell and shrink [7].

6.2 Sandy soils

Sandy soils have coarse grains and high permeability. This type of soil quickly passes water and is usually not suitable for underground facilities. Since sandy soils quickly pass water, they may lose moisture quickly in dry conditions. This feature can lead to a decrease in the capacity to hold water and nutrients. Sandy soils usually have lower cohesion and are susceptible to erosion and water washout [7].

6.3 Loamy soils

Loamy soils are a combination of clay and sand soils and have the desirable properties of both soil types. This type of soil is usually suitable for agriculture and construction and has a high water and nutrient holding capacity [7].

6.4 Effect of soil type on mechanical properties

Soil type has a great influence on its mechanical properties. For example, clay soils usually have higher cohesion and compressive strength than sandy soils. Also, loamy soils usually have better properties compared to other soil types due to the appropriate composition of the grains [7].

7 Classification of soil types

7.1 Fine grained

Fine grains less than 0.075 mm (clay) are usually highly cohesive and sensitive to moisture changes. This type of grained soil can help increase the capacity to hold water and nutrients. These characteristics make fine-grained soils generally useful in agriculture and horticulture, but they can suffer from problems such as waterlogging and swelling during heavy rainfall [27].

7.2 Medium grained

Medium grains between 0.075 and 2 mm (loamy) are usually desirable for agriculture and construction. This type of grained soil can help improve soil aeration and permeability [27].

7.3 Coarse grained

Coarse grains greater than 2 mm (sandy) are usually highly permeable and allow water to pass through quickly. This type of granulation can lead to a reduction in water and nutrient retention capacity [27].

7.4 Effect of Granulation on Mechanical Properties

The granulation of soils directly affects their mechanical properties. Proper granulation can help improve the strength and stability of the soil. For example, soils with proper granulation usually have higher compressive and tensile strengths [21, 9].

8 How to produce concrete and its ingredients

8.1 Selection of raw materials

The selection of cement, aggregate and water of appropriate quality is of great importance. Each of these materials has a direct impact on the final properties of concrete. For example, the type of cement can affect the setting time and strength of concrete [17].

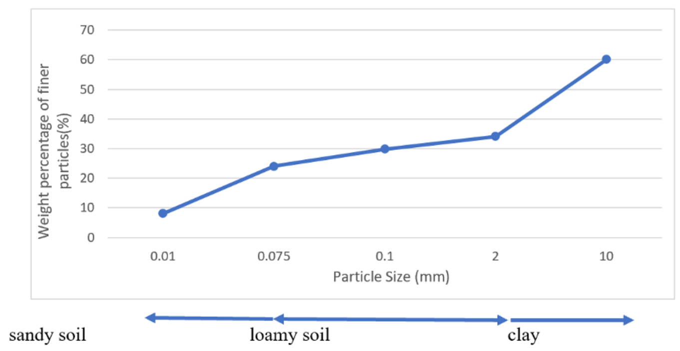

Figure 4: Particle Size Distribution of Different Soils

8.2 Mixing

The mixing of raw materials in specific proportions is carried out using a mixer. This step is very important because it has a great impact on the final properties of concrete. Proper mixing can help improve the uniformity and workability of concrete [17].

8.3 Pouring into molds

The mixed concrete is poured into the desired molds. This step requires care and attention to prevent air bubbles and other defects. Also, proper vibration and compaction must be ensured to improve the adhesion and uniformity of the concrete [17].

8.4 Curing

The concrete is kept for a certain period of time to improve its strength and properties. This step involves keeping the concrete in suitable humidity and temperature conditions. Proper curing can help reduce cracking and increase the durability of the concrete[17].

8.5 Effect of material ratio on concrete properties

The ratio of the ingredients of concrete has a great influence on its final properties. For example, increasing the water to cement ratio can lead to a decrease in the strength of the concrete. Also, the appropriate ratio of aggregates to cement also affects the workability and durability of the concrete. These ratios should be adjusted according to the type of project and environmental conditions [17].

9 How to stabilize soil with fly ash

9.1 Soil Stabilization Process

The use of fly ash as a stabilizing agent can help improve the mechanical properties of soil. It helps improve soil performance by increasing cohesion and reducing permeability. Soil stabilization with fly ash can be particularly effective in civil engineering projects that require improving soil properties [10, 27].

9.2 Soil Stabilization Steps

Mixing the soil with fly ash: The appropriate ratio of fly ash to soil is determined and mixed. This step requires care to ensure uniformity of the mixture [10, 20].

Compaction: The mixture is thoroughly compacted to improve mechanical properties. This step can involve the use of mechanical compaction devices [10, 20].

Mechanical Properties Testing: After stabilization, the mechanical properties of the soil are examined. These tests can include measuring the compressive strength, permeability, and cohesion of the soil [10, 20].

9.3 Benefits of soil stabilization with fly ash

Reduction of permeability: Fly ash can reduce soil permeability and prevent waterlogging. This feature is especially useful in areas with high rainfall [10, 20].

Increase in strength: Adding fly ash to soil can increase its compressive and tensile strength. This increase in strength can help improve the stability of civil structures [10, 20].

Reduce costs: Using fly ash as an additive can reduce construction costs. This cost reduction can be due to the reduction in the need for raw materials and improved efficiency [10, 20].

10 Investigating the effect of fly ash on improving subsoil using different tests

10.1 Swelling index test

The purpose of this test is to measure the changes in soil volume due to changes in moisture content and to determine the swelling of clay soils in the presence of fly ash [10].

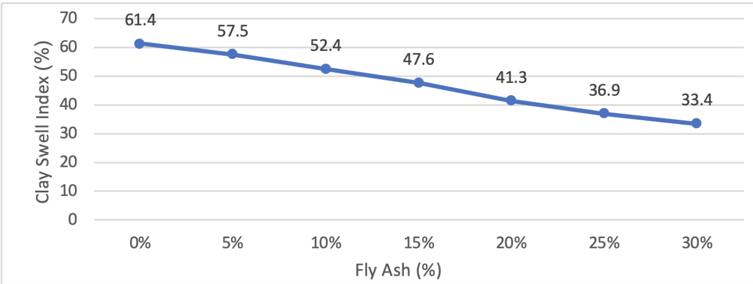

Figure 5: Diagram of Changes in the Swelling Index of Clay Soil Relative to Different Percentages of Fly Ash

⋆ Formula for measuring the swelling index:

swelling index= $\frac{V_f - V_i}{V_i} \times 100$

V_f: Final volume (volume of the sample after moisture absorption)

V_i: Initial volume (volume of the sample before moisture absorption)

The swelling index test shows that adding fly ash to clay soils can help reduce swelling. This test is done by measuring the changes in soil volume due to changes in moisture content. The results of this test can help us prevent problems caused by soil swelling.

10.2 Permeability test

The purpose of this test is to measure the speed of water passing through soil samples and the effect of fly ash on soil permeability [20]. Permeability coefficient formula:

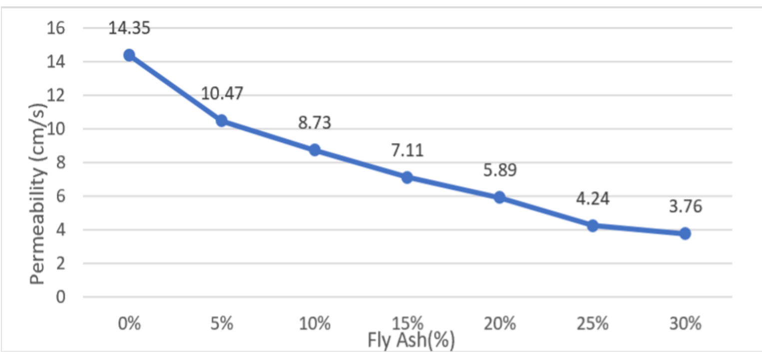

Figure 6: Diagram of Changes in the Permeability of Clay Soil Based on Different Percentages of Fly Ash

$$K = \frac{L \times Q}{h \times t \times A}$$

K: Permeability coefficient (cm/s)

Q: Volume of water passing through (cm^3)

L: Length of sample (cm)

A: Cross-sectional area of sample (cm^2)

t: Time (s)

h: Water height difference (cm)

The results of the permeability test show that fly ash can reduce soil permeability. This test was performed by measuring the speed of water passing through soil samples. Reducing permeability can help improve the stability of structures against flooding.

10.3 Dampness test

The purpose of this test is to measure the soil's dampness and the effect of fly ash on it [4].

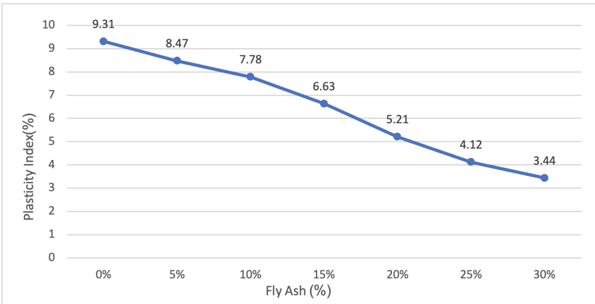

Figure 7: Diagram of Changes in the Permeability of Clay Soil Based on Different Percentages of Fly Ash

Formula representing the dough index is $IP = LL - LP$, where IP is the plasticity Index, LL is the upper Atterberg Limit, and LP is the lower Atterberg Limit. The addition of fly ash to clayey soils reduces the plasticity. This test was conducted by measuring the moisture content and the behavior of the soil under loading. Reducing the plasticity can help improve the performance of the soil in civil engineering projects.

10.4 Compaction Characteristics Test

The purpose of this test is to measure the density and moisture content of the soil and the effect of fly ash on it [30]. The initial density of our clay (KN/m3) is 19. The density formula is $\rho = \frac{m}{V}$, where m is the sample mass (g), and V is the sample volume (cm^3).

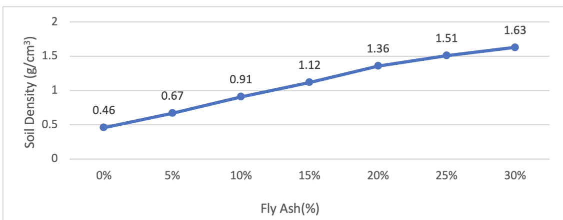

Figure 8: Variations in the Density of Clay Soil with Different Percentages of Fly Ash

Compaction tests show that fly ash can help improve the compaction of clay. This test was performed by measuring the density and moisture content of the soil. Improving compaction can help increase the resistance of the soil to loading.

10.5 Compressive Strength Test

The purpose of this test is to measure the force required to break the soil samples and the effect of fly ash on it [24].

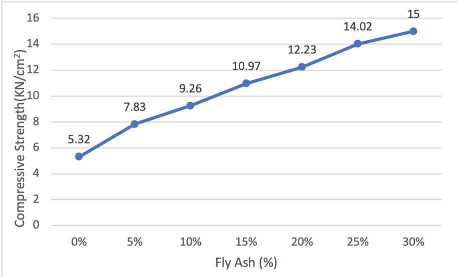

Figure 9: Changes in the Compressive Strength of Clay with Different Percentages of Fly Ash

The compressive strength formula is $C^\sigma = \frac{F}{A}$, where C^σ is the compressive strength (kN/cm^2), F is the applied force (kN), and A is the cross-sectional area of the sample (cm^2). Adding fly ash to the soil can increase its compressive strength. This test was performed by measuring the force required to break the soil samples. Increasing the compressive strength can help improve the stability of structures.

10.6 California Bearing Ratio (CBR) Test

The purpose of this test is to measure the resistance of the soil to external force loading and the effect of fly ash on it [30].

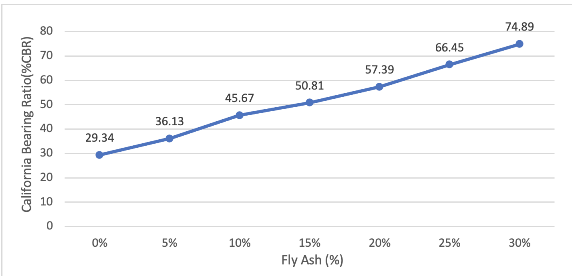

Figure 10: Variations of California Bearing Ratio (CBR) of clay with different percentages of fly ash

The California Bearing Ratio Formula is $CBR = \frac{P}{dradnats^P} \times 100$, where CBR is the California Bearing Ratio, P is the force applied to the specimen (kN), and $dradnats^P$ is the standard force for the same penetration (kN). The results of the CBR test show that fly ash can improve the bearing capacity of the soil. This test is carried out by measuring the resistance of the soil to loading. Increasing the bearing capacity can help improve the performance of the soil in civil engineering projects.

10.7 Atterberg Limit Test

The purpose of this test is to measure the cohesion of the soil and the effect of fly ash on it. To obtain the Atterberg limit, we must first pass the clay through a sieve of size (40) because the Atterberg limit is not defined for soils with larger sizes [15].

The Atterberg limit formula:

$$LL = \frac{(W_2 - W_1)}{(W_2 + W_1)} \times 100$$

where, $LL$is the upper Atterberg Limit, W_1 is the sample weight at upper Atterberg limit (g), W_2 is the sample weight at lower Atterberg limit (g). Fly ash helps to reduce the Atterberg limit of clayey soils. This test is performed by measuring the moisture content and the behavior of the soil against moisture changes. Reducing the Atterberg limit can help improve the performance of the soil in construction projects.

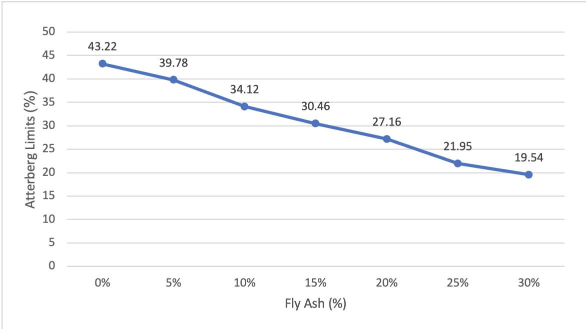

Figure 11: Variations of Atterberg Limits of Clay Soil with Different Percentages of Fly Ash

11 How to improve the properties of concrete with fly ash

11.1 Effect of fly ash on the mechanical properties of concrete

The use of fly ash in concrete can lead to increased compressive strength and durability of concrete. This material improves the properties of concrete by reducing permeability and increasing adhesion. For example, the addition of fly ash can help reduce cracking and increase the service life of concrete [3, 5].

11.2 Effect of fly ash percentage on concrete properties

Compressive strength: The addition of fly ash can increase the compressive strength of concrete. This increase in strength can be due to chemical reactions between fly ash and calcium hydroxide present in concrete [15, 6].

Tensile strength: Fly ash helps improve the tensile strength of concrete. This feature can help reduce cracking and increase the durability of concrete [15, 17].

Durability: The use of fly ash can help increase the durability of concrete against environmental conditions. For example, concrete containing fly ash usually has higher resistance to water and frost [17, 6].

12 Concrete hardness testing with different percentages of fly ash

12.1 Concrete hardness testing methods

Various tests were conducted in this field and showed that the appropriate percentage of fly ash can increase the hardness of concrete. For example:

Compression test: The purpose of this test is to measure the resistance of concrete to compressive loading. This test can help determine the ultimate strength of concrete [1, 22].

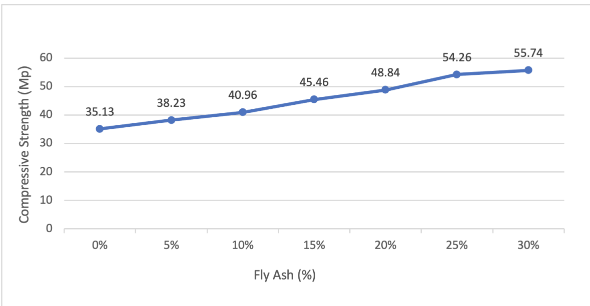

Figure 12: The Ratio of Compressive Strength of Concrete with Varying Percentages of Fly Ash

The formula for compressive strength of concrete is $C^f = \frac{P}{A}$, where cf is the compressive strength of concrete (kN/cm^2), $P$is the applied force (kN), $A$is the cross-sectional area of the specimen (cm^2).

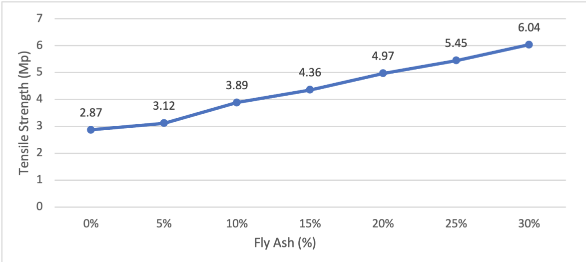

Figure 13: The Ratio of Concrete Tensile Strength to Changes in Fly Ash Percentage

Tensile test: The purpose of this test is to measure the resistance of concrete to tensile loading. This test can help determine the ability of concrete to withstand tensile forces [1, 22].

The formula for tensile strength of concrete is $t^f = \frac{P}{A}$, where $t^f$is the tensile strength of concrete (kN/cm^2), P is the applied force (kN), and A is the sample cross-sectional area (cm^2).

Fatigue test: The purpose of this test is to investigate the behavior of concrete under cyclic loading. This test can help determine the durability of concrete under cyclic loading conditions [1, 22].

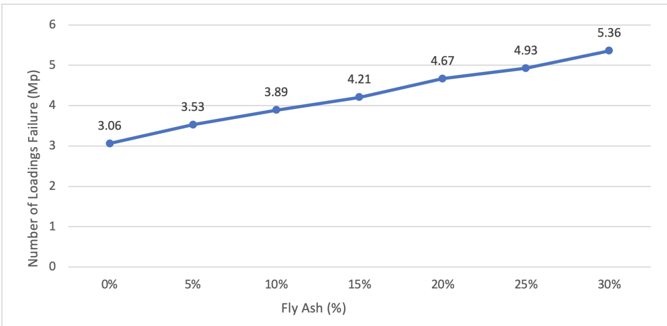

Figure 14: Ratio of Load Cycles to Failure vs. Change in Percentage of Fly Ash

The formula for number of loads to failure is $f^N = \frac{P}{A}$, where $f^N$is the number of cycles to failure, P is the applied force (kN), and A is the sample cross-sectional area (cm^2).

12.2 Test results

The test results show that adding 15 to 25% fly ash to concrete can help improve its hardness and strength. These results can help us determine the optimal ratio of fly ash for different projects.

13 Comparison of fly ash and cement in concrete

13.1 Advantages of using fly ash

Fly ash as a substitute for cement can reduce costs while improving the properties of concrete. The comparison of the properties of fly ash and cement is as follows:

Compressive strength: In some cases, concrete containing fly ash can have higher compressive strength than concrete containing pure cement. This increase in strength can be due to the pozzolanic activity of fly ash [1, 25].

Durability: Concrete containing fly ash is generally more durable against environmental conditions. This feature can help reduce maintenance and repair costs [1, 25].

Cost: Using fly ash as a cement substitute can reduce the cost of concrete production. This cost reduction can be due to the reduction in raw material requirements and improved efficiency [1, 25].

13.2 Effect of fly ash type on concrete properties

The type of fly ash has a great influence on the final properties of concrete. For example, the use of class F fly ash can lead to improved compressive and tensile strength of concrete, while class C fly ash can help improve the durability and stability of concrete. The type of fly ash can also affect the setting time and workability of concrete [2, 28].

14 Useful ratio of fly ash to cement in concrete

14.1 Optimal ratio of use

The optimal ratio of fly ash to cement in concrete is usually between 15 and 30 percent, depending on the type of concrete and environmental conditions. This ratio can be adjusted based on the results of various tests and the needs of the project. For example, in projects that require high strength, the fly ash ratio may be reduced [28].

14.2 Effect of usage ratio on concrete properties

Lowest ratio: Using 15 percent fly ash can help improve the mechanical properties of concrete. This ratio is usually suitable for projects with normal needs [16].

Highest ratio: Using more than 30 percent fly ash may lead to a decrease in the mechanical properties of concrete. This decrease may be due to an imbalance in the chemical composition of the concrete [16].

15 Conclusion

Using fly ash as an additive in soil improvement and improving the properties of concrete can be considered as an effective and economical solution in the construction industry. The results of the experiments show that fly ash can help improve the mechanical properties of soil and concrete and be considered as a sustainable option in modern construction. Given the environmental and economic benefits of using fly ash, it is hoped that this material will be used more widely in the construction industry in the future.

This study comprehensively examines the effect of fly ash on soil improvement and improving concrete properties and hopes that it can help develop the use of this material in the construction industry. Given the increasing needs for sustainable and economical infrastructure, the use of secondary materials such as fly ash can be an effective and sustainable solution to the challenges in the construction industry.

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