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A Study on the Mechanical Properties of Concrete Containing Fly Ash as Partial Cement Replacement-A Critical Review

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Abstract: Concrete has a considerable environmental impact. The demand for concrete is growing on a regular basis day and cement is used to fulfil the need for creation of infrastructure facilities. Portland cement is a high-energy material that requires a lot of heat to manufacture. In addition, the manufacture of this material includes the burning of limestone, and each tone of Portland cement emits almost one tone of CO2 into the atmosphere and can affect the environment. The conservation of cement is the most significant step in reducing both energy utilization and greenhouse gas emission. In order to reduce the amount of Ordinary Portland Cement (OPC) and CO2 emission, the past few decades geopolymers concrete has researched as a sustainable construction material, which they can reduce CO2 emission for its use by industry. Fly ash is considered as a geopolymer material in this study. Many studies have been conducted by researchers over the last few decades on the use of new materials in concrete to reduce the impact of cement and increase the compressive strength and workability of concrete. In this study, a critical review of the mechanical properties of concrete containing fly ash as a partial replacement for cement is carried out in order to provide recommendations. The methodology and results of the previous studies are summarized, and some advantages and disadvantages of their works have been highlighted.

Keywords: Fly Ash, Compressive Strength, Workability, Shrinkage

1. Introduction

Concrete consists of four essential components that are water, sand, gravel and Portland cement. Concrete also is a critical component used in a variety of residential and commercial structures. When it comes into contact with water and is placed, it solidifies and hardens as a result of a chemical reaction known as hydration. Cement, usually powdered, acts as a binding agent in combination with water and aggregates. It joins together on construction materials. It is a material widely used in the building

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process. The substance transforms from a moldable liquid to a firm, rigid solid. In summary, Concrete is a composite material composed of fine, gross aggregates bonds with a time-hardy fluid cement.

Concrete is a part of everyday life in today's world. There are different types of pore space found within it, and the properties of the material are determined by the different types of pore space found within it. The mixing method traps air voids in the capillary pores, which are spaces filled by water during the mixing process. Compressive strength of concrete is proportional to the total porosity of the cement paste and the volume and type of aggregates used.

Concrete production is a significant contributor to the climate crisis, as it releases large quantities of carbon dioxide into the atmosphere during the manufacturing process. The world is faced with a problem due to environmental degradation. Industry expects to significantly reduce carbon emissions (CO2) into the environment. The reduction in Portland cement use by the use of sustainable products such as fly ash is one of the measures to minimize CO2. Fly ash is one of the source materials for geopolymer binders, is widely available worldwide but is still limited in use until now.

The global demand for concrete is increasing. As a result, demand for cement has increased as it acts in ordinary Portland cement concrete. Cement produces heat and carbon dioxide produced by cement influence the environment and increases the greenhouse effect. Besides the generation of CO2, the cement process annually generates millions of tons of cement waste which contribute to the health risks of breathing and pollution. In this study, the main purpose is to review the available technical literature on the effect of fly ash as a partial replacement of cement in compressive strength of concrete, workability and drying shrinkage

2. Literature Review

Compressive strength means the ability to withstand loads of a material or structural element that reduce the structural or material size. The top and bottom of a test sample are supplied with a pressure, causing it to fracture or deform. Fracturing occurs during the compressive strength testing of materials for example concrete and rock. Concrete compressive strengths are frequently tested to assess whether the actual concrete blend meets the design requirements. Compressive concrete strength depends on a number of factors like water cement ratio, concrete resistance, concrete quality, quality control during concrete production, etc. The load applied at the failure point in the cross section of the face on which load was applied is a compression strength formula for any material.

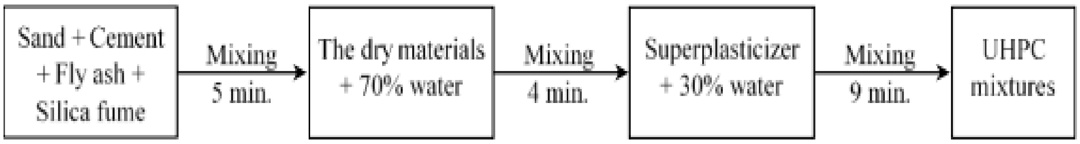
2.1 Critical Review on previous studies on effect of fly ash on compressive strength

The effect of fly ash as partial replacement of cement is investigated by many researchers. For example, Dong [1], the consequences of fly ash in ultra-high-performance concrete for the development of compression strength were examined (UHPC). A total of 20 mixtures have been prepared in order to measure compression strength at different ages, from 3 to 180 days. For the binder of the UHPC mixture, condensed silica fume (SF) and fly ash conforming to ASTM C 618 class F were used. The addition of fly ash can be seen reduced the compressive strength of UHPC at early ages, 3 and 7 days, particularly when the content of fly ash has been increased to 50 and 70%.

Ultra-high-performance concretes (UHPC) have been relatively new in terms of research and application since the late 1990s. These are the result of their outstanding properties, including high fluidity, a compressive strength (over 120 MPa), an elastic module and a high permeability. All UHPC mixtures were prepared in a mixer with a 60-L capacity. To achieve a high-workability UHPC concrete, the following mixing procedure was considered as shown in Figure 1.

After 5 minutes of dry mixing, a total of 20 blends were prepared to cast specimens at various ages, ranging from 3 days to 180 days, to measure compressive strength.

Figure 1: Mixing procedure of UHPC mixture



The effect of nano-CaCO3 (NC) on the durability and compressive strengths of mixed concrete is discussed by Doweidar (2001) [2]. This study examined the enhancement of the strengths and durability of HVS concrete in early years, consisting of 69% blast furnace layer (BFS) and HVS-FA concrete consisting of 69% BFS and fly ash (FA) content combined, as a result of the addition of 1% NC to the mix design. Moreover, possible to observe that the addition of 1% of NC significantly improved the strength of the compressive materials at an early age compared to their control cement without NC, a higher hydrating rate for cement material.

In all pastes of this study, ordinary Portland cement (OPC) was used. The BGC cement has been supplied to the ground granulated blast furnace slag (BFS) and a New South Wales power plant has supplied the Class F fly ash (FA). The average particle size was 15–40 nm of dry nano CaCO3 (NC) powder, 40 m2/g of specific surface areas and 97.8% of the calcite content were given the physical and chemicals characteristics of the particular materials.

Hosan, 2021.[2] revised the work done to replace concrete with fly ash, rice husk ash and its chemically composed effect on the compressive strength of concrete. The compressive strength data of concrete following a fly ash and rice husk ash were added to this figure in percentage increments of 0%, 10%, 20%, 30%, 50% and 0%, 5%, 7%, 10%, 12,5%, 15%, respectively, over a minimum period of seven days and a maximum period of 28 days show that optimum results are obtainable. Concrete has long been a source of contention for architects, engineers, researchers, and constructors.

Concrete is responsible for approximately 5% of global CO2 emissions, and it is the second most widely used material after water in terms of. Cement production accounts for between 8% and 10% of global CO2 emissions. Table 1 shows the Fly ash concrete compressive strength.

Table 1: Fly ash concrete compressive strength

Fly Ash (%)	7 days	14 days	28 days
0	26.7	36.7	40.2
10	27.4	38.25	41.9
20	28.3	39.5	43.23
30	30.25	41.4	45.28
40	27.75	37.74	42.00
50	25.5	37.03	39.15

The ideal replacement percentage for fly ash and rice husk ash for a strong compressive concrete strength was determined to be 30% for fly ash and 7.5 percent for rice husk ash. It can be concluded that when fly ash or rice husk ash was used in the appropriate percentage, the compressive strength of the concrete increased. This demonstrates that fly ash and rice husk ash have the potential to be used in place of cement in the production of concrete. The optimal partial substitution percentage for fly ash and rice husk ash was found to be 30% for fly ash and 7.5% for rice ash for strong compressive concrete strength. In conclusion, the compressive strength of the concrete increased at the right percentage of either fly ash or rice husk ash.

Joel, (2020) [3] examined on the Ferronickel slag is a by-product of melting nickel ore and bituminous coal, both of these materials are used as raw materials in the high-temperature production of ferronickel, which is a hard metal. This study investigated the fluidity of a ferronickel slag and fly ash concrete mortar, micro-hydration heat, compressive strength, drying reduction and carbonation characteristics. The compressive strength of ferronickel-slag powder mixes ranged from 38.0 to 39.6 MPa.

The compressive strength of ferronickel slag powder mixes ranged from approximately 38,0 to 39,6 MPa in this study. This study concludes. Figure 2 shows the compression force of the mortar, which includes ferronickel slag powder and fly ash.

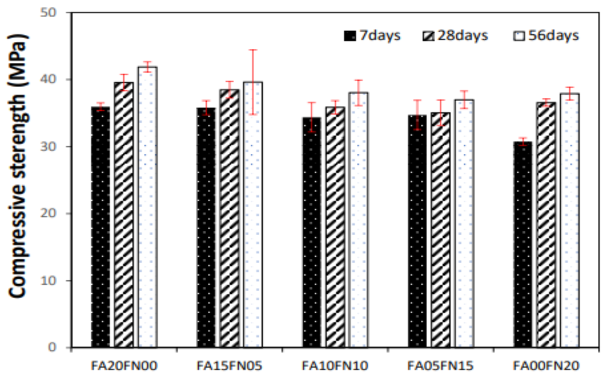


Figure 2: Mortar compressive strength including ferronickel slag powder and fly ash

The compressive strength of the fly ash (FA) FA15 ferronickel-slag powder (FN)FN05 and FA20FN00 mixes containing more than 15% fly ash was relatively high after 7 days, reaching around 35.8 MPa. The compressive strength of the FA20FN00 mix was about 39.6 MPa after 28 days, which was more than that of the other samples, and the ferronickel slag powder compressive strength of the FA05FN15 was 35.0 MPa, less than that of the other ferronickel mixtures.

Choi, (2021) examined the effects of replacing high calcium fly ash is combined with glass containment powder and calcareous powder. The mix design and compressive strength of the geopolymer paste have been determined. The results indicated that geopolymer fine powder settings were increased when glass powder was replaced and calcareous powder was replaced. The compressive forces were generally higher than the controls.

It is well documented that concrete calcareous powder has mainly shown filling, nucleation, dilution and chemical effects and have influenced particle size, dosage, dissolution rate, powder polymorphism of calcareous powder, cement minerals and additional cement powder (Wang et al., 2018). LS can fill the void of the aggregated and improve the compressive strength if it is used to replace the concrete paste or finely assembled. By incorporating LS into the cement paste, the compressive strength of the concrete is significantly increased, while the water cement ratio remains constant.

Geopolymer paste was made of high calcium fly ash (FA) which is the material came from the Coal Electricity Power Plant in the northern province of Lampang. Both were grounded glass (CP) container and ground limestone powder (LP). These powders are more than 95% 325-mesh. Chemical composition of fly ash (FA), grounded container glass and limestone powder

Based on this review, in concrete, the compressive strength decreases as the amount of fly ash in the mix increases. The compressive strength of concrete at 28 days was found to decrease by 4.57 %, 12.20 %, and 20.55 % when 10%, 20%, and 30% of cement was replaced with fly ash, respectively. Concrete's compressive strength decreased more quickly at 7 days than at 28 days when cement was replaced with fly ash. This occurs because in the early stages of fly ash concrete secondary humidification due to pozzolanic action is slower.

This is due to the fact that as the fly ash content increases, so does the consistency of the cement. This occurs because the fineness of the fly ash molecules determines the consistency of the cement, and the fly ash molecules are finer than the cement molecules. Other than that, increasing the amount of fly ash in concrete also causes a delay in the setting time of the concrete. As a result, the compressive strength of ordinary concrete with no fly ash was found to be 67% of its proper compressive strength in the 7 days, and 60% of its characteristic compressive strength for concrete containing 30% fly ash in the 7 days.

3. Effect of Fly Ash on Workability of Concrete

Concrete workability is one of the most significant physical parameters of the concrete, and it has an impact on its durability and strength. When the concrete has been thoroughly mixed and compacted homogeneously, that is, without segregation or bleeding, it is considered workable and ready for use. 3 main factors affect the workability of concrete, which include water cement ratio, the combination of size, shape and admixture.

3.1 Previous study on effect of fly ash on workability

Topark, (2019) [5] studies to determine the effect of workability on a geopolymer paste containing fly ash. Additionally, it investigated the impact of synthesizing parameters such as alkali content, silica content, and water to geopolymer binder ratio on the workability of geopolymer mortar and reached a level of understanding that will be beneficial to researchers and manufacturers. During the research work, typical low calcium class F ash was used from a thermal power plant near Kolkata.

This study found that time and operability as well as a microstructure were primarily dependent on alkaline content, silica content and water-to-bind ratio. For the dissolution of fly ash during the geopolymerization process, strong alkaline solutions are needed. During dissolution, polycondensation and stages of geopolymerisation, the water plays an important role.

Doweidar, (2001) [6] studied the mechanical properties of fly ash silica-fume (FA-SPC). The silica fume content is 15% by concrete mass, 0% by addition, 10% and 15% by cement mass fly ash content by addition. The high strength concrete can be formed by silica fume as an additive or by replacing the concrete. As a result, combining fly ash and silica-fume was intriguing alternative. The cemented material, including fly ash and silica fume, enhances mechanical characteristics in concrete. In order to assess the operability of fresh FA-SPC concrete, ASTM Standard C143 and ACI Committee 544.2R were followed. The slump values of FA-SPC and FA-SCFRC are presented in Table 2.

Table 2: Slump of FA-SPC specimens (Doweidar et al., 2001)

FA (%)	PC (With W/C ratio: 0.50) (mm)
00	76.2
0	25.4
5	23
10	17
15	0

Khan, (2019) [7] The comparisons between ordinary Portland concrete (OPCC) and geopolymer concrete (GPC) have been researched in depth. According to the findings of this study, GPC has improved mechanical properties while also having a lower carbon footprint, making it a potential building material in the near future. The demand for cement, which is a critical component of concrete, is increasing around the world. It has a significant carbon footprint, accounting for approximately 8% of global CO2 emissions. There is tremendous potential for geopolymer concrete to be used in place of ordinary Portland concrete.

Chowdhury, (2020) [8] studied the effect of fly ash (FA) on workability, compression strength and bending strength of palm oil clinker as a partial cement substitute. A total of five mixtures, consisting of 0%, 10%, 20%, 30%, and 40% FA, used as substitutions for cement. This paper concludes that the lightweight concrete mix of the plain palm oil clinker shows the lowest slump value. Fly ash includes the mixture of improved workability starting from 10 per cent replacements and later. With 40 percent fly ash, the most successful combination of these is generated with the highest depression.

Figure 3 shows the effect on concrete workability of the fly ash (FA) as a partial cement replacement. The lowest slump value is demonstrated by the plain palm oil clincher lightweight concrete mix. Fly ash includes the mixture of shapes with improved workability starting with 10 percent change and further with 40 percent fly ash, the most workable mix of all is produced with the highest depression value.

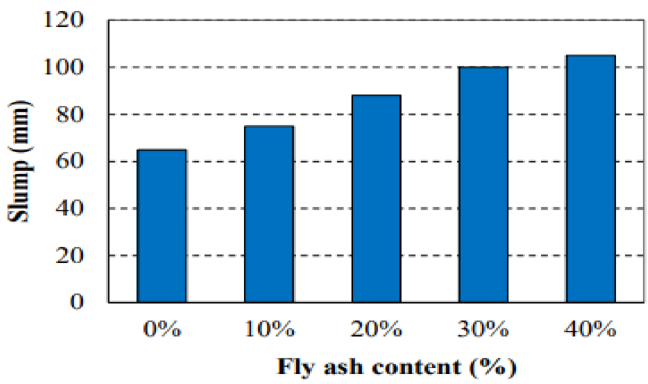


Figure 3: Effect of fly ash on workability of concrete [8]

It was found that TiO2 adding up to 3% could improve concrete's strength, while adding Nano CaCO3 or its combination with TiO2 Nano increased the strength up to 2%, and then the strength decreased by increasing the content of nanoparticles. Cylindrical samples were compressed by a concrete compression machine (VJT6000, UK). On average of the tested specimens, the compressive strength of the samples was determined. The addition of 10% NF gave a similar compressive strength of 11.8 MPa without significant modifications, so that the effect of the additional 5% NF was irrelevant. Accompanying discussions that further explain observations of the results are usually placed immediately below the results paragraph.

Nano ferum and micro ferum still have similarities with increasing particulate dosage as to the trend of decreasing compressive strength. The lowest 5% NF and MF doses showed the highest compressive strength in all Fe3O4 particulate samples at 11.8 MPa and 9.4 MPa respectively. This suggests that the compressive strength can be improved by low NF and MF. The pressure strength decreased slightly by 5.7%, while adding 5% to 15% MF dramatically lowered the pressurizing force by 74.9%. The concentration rose from 5% to 15% NF. The results showed that the additive dosage was increased.

According to the results from this section, the water content in mix is affect the result of workability. The molar concentration of alkali activator is reduced by increasing the water content of the mix, resulting in a reduction in viscosity and a slower rate of Geopolymerisation, which improves workability. Furthermore, higher concentrations of sodium hydroxide (in the range of 10 Molar to 16 Molar) solution reduce the workability of geopolymer concrete, resulting in a higher compressive strength. Based on the results, the workability of a concrete composite containing fly ash and silica fume is reduced when polypropylene fiber is added. Both the slump and the slump flow are gradually decreasing as the fiber volume fraction increases.

4. Literature Review on Effect of Fly Ash on Shrinkage of Concrete

Cracks created by volume restraint caused by excess water loss. The time of shrinking cracking depends on the drying rate but normally is several months to 3 or 4 years after casting. Drying shrinkage takes place if water evaporates from the exposed surface and the differential humidity along the slab's depth results in stress that induces tensile stress. This drying shrinkage makes it possible to detect cracks on the concrete surface. These are normally non-structural cracks and do not influence building safety and stability, but show poor construction quality, poor performance and the sense of instability.

4.1 Critical Review on previous studies on effect of fly ash on shrinkage

In the study of Hanjitsuwan, (2020) [9] order to mitigate autogenous shrinkage, metakaolin was added to the alkalized slag-fly ash (AASF) paste. The mechanism for reducing the shrinkage of metakaolin was explained by the study of its metakaolin impact on the microstructure, its shrinking properties and the mechanical properties of AASF paste. The addition of metakaolin was found to reduce the chemical and autogenous shrinkage of AASF paste significantly. This decrease in shrinkage is accompanied by a decrease in the alkalinity of the AASF paste pore solution, a decrease in internal relative humidity, and an increase in the porosity of the AASF paste.

Meanwhile, MK has no influence on the growth of the paste's elastic modulus. During the MK period the self-destroying in AASF paste has been mitigated due to the reduced chemical shrinkage and increase in porosity. MK has meanwhile not affected the elastic modulus development of the paste.

Mermerdas, (2020) [10] examined high calcium fly ash drying shrinkage, strength, and microstructure with extensive additives like FGD-gypsum (FGD) and dolomite (DLM). As an alkaline activator for all combinations the 10 Molar sodium hydroxide was used, together with the sodium silicate solutions. Different steps have been taken to prepare the AAHF paste. First, the study focused on the impacts of high calcium fly ash alkaline paste (FGD and DLM) and liquid/command ratios (L/B) on drying shrinkage. The drying shrinkage, time limitation, compressive strength and high calcium fly ash alkaline paste microstructure, including FGD and DLM, have been studies.

A drying shrinkage of AAHF pastes can also increase, although the FGD and DLM levels are replaced, with a high L/B ratio. Due to its great improvement in drying shrinkage as well as the long-term strength of the AAHF mixed pastes compared to that of the AAHF pastes with FGD, DLM pastes with AAHF are recommended as a complement.

Li, (2021) [11] studied on the determination of the shrinkage resistance and the free shrining of the lightweight-weight geopolymer mortars (LWGM) based on fly ash impact of different NaOH molarities, ratio of sodium silicate to sodium hydroxide, quantities of binder, age.

Conclude, the higher amount of the binder and NaOH molarity led to the reduced drying reduction and a greater autogenous decrease of LWGMs. The increase in binder quantity improves the geopolymerization of the structure. The reduction of drying shrinkage is due to the high strength of geopolymers. With higher NaOH molarity, the $Na2O/SiO2$ mole oxide ratio of lightweight geopolymer mortars (LWGM) increases and results in stronger shape and reduced drying shrinkage.

Fine fly ash influence on high-performance concrete (HPC). In this study, fine fly-ash modified concrete shrinkage and water permeability. The water permeability should be less important in the durability of consideration. If more permeable concrete leads to structural distortion, it reduces the structural age. This research examines concrete mixtures in which fine fly ash replaces cement with different proportions of 0% to 50%.

When fly ash replacement is initiated, shrinkage at all ages is reduced. The most significant observation from the all-ages test is that the percent replacement of Fine Fly-ash (FGFA) with cement has the lowest shrinkage value, while the compressive strength has the highest shrinkage value.

In this section some recent articles have been reviewed to find the effect of drying shrinkage when some amounts of cement are replaced by fly ash. Drying shrinkage is the contraction of concrete caused by the loss of moisture as the concrete dries and hardens.

According to the results from previous works, the rate of drying of cement mortar with Nano-particles increased more than normal cement mortar, and the mortar with Nano-particles fell faster at an early drying rate. Compared to normal cement mortar. The improvement of Nano-particle mechanisms on the wearing resistance and drying shrinking of concrete is most likely due to its surface effect, pozzolanic response and micropillar fill.

It also demonstrates that concrete with a cement replacement of up to 30% for fly ash has a shrinkage value, although those with higher fly ash replacement value show a shrinkage. The replacement of fly ash can reduce the shrinkage effect extensively. The shrinkage value of concrete increases with its age.

5. Conclusions

Based on the review of currents research works, it is identified that fly ash can be as partial cement replacement by 20% replacement to the concrete. For instance, the addition of high calcium fly ash limestone powder can help to increase the compressive strength. From the literature, 10% of fly ash as partial cement replacement can slightly improve and increase workability compared to use 100% of cement. It also can be concluded that by adding of nano-Fe_3O_4 as an admixture (from 1% to 5% of the cement mass) the workability of concrete can be increased.

Also, according on the results from different research works discussed in this study, the replacement of fine fly-ash (FGFA) in specimens has been concluded to decrease the drying shrinkage. Results indicated that while concrete with a shrinkage of up to 30% FGFA substitute for cement shows less or no shrinkage at initial ages and thereby shows no significant gain in compressive strength compared to those with a greater percentage of FGFA substitute.

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