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水泥替代劑對混凝土力學性能可持續發展的影響

Effect of Cement Alternatives on the Mechanical Properties of Concrete for the Sustainable Development

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Khan Mohd Atif

中文摘要

不幸的是，水泥和混凝土行業是溫室氣體排放的重要貢獻者。我們把結構維持在很高的位置，但我們也處於為子孫後代製造黑暗的最後階段，我們不會阻止它，因為它有助於經濟增長。氣候變化正處於高峰期；由於全球平均地球溫度升高，海洋水位正在上升，而我們正處於大規模毀滅的末期。為了減少這種溫室氣體排放，我們應該在製造混凝土時尋找一些替代品，這是貢獻者之一。這項研究的重點是可以減少二氧化碳排放的混凝土結構的可持續和經濟發展。

在這項研究中，我們將在一定程度上使用一些 OPC（普通波特蘭水泥）的替代品，如粉煤灰、矽粉和磨碎的高爐礦渣 (GGBS)。研究這些材料在混凝土中替代水泥在環境可持續性方面的可行性。在本研究中，我們將使用粉煤灰、矽粉和 GGBS 以 10% 到 30% 的增加百分比作為水泥的替代品，以觀察混凝土的力學性能。作為水泥的生產，GGBS、粉煤灰和矽粉會產生其生產重量的 95.9%、15.5%、9.3% 和 1.4% 的 CO2。水泥和其他添加劑的碳排放量差異巨大。因此，在不影響安全性和適用性的情況下，可以在一定程度上使用這些材料作為水泥的替代品。

在這項研究中，共澆注了 120 個樣品，其中包括 90 個抗壓強度樣品和 30 個混凝土透水性樣品。實驗結果表明，本研究中觀察到的 GGBS 置換 30% 達到最高強度，而矽粉置換 30% 達到最低強度。

關鍵詞：全球變暖、可持續性、水泥替代品、抗壓強度

Abstract

Unfortunately, the cement and concrete industries are significant contributors to greenhouse gas emissions. We are holding the structures very high, but we are also at the very last stage of creating darkness for future generations, and we are not going to stop this because it helps in growing the economy. Climate change is at its peak; the ocean's water level is rising due to an increase in the global average earth temperature, and we at the very end of mass destruction. To reduce this greenhouse emission, we should look for some alternatives in manufacturing concrete, which is one of the contributors. This research focuses on the sustainable and economic development of concrete structures that can reduce the emission of Co_2. In this research, we will use some alternatives of OPC (ordinary Portland cement) to some extent, like fly ash, silica fumes, and Ground granulated blast furnace slag (GGBS). To examine the feasibility of these materials in the concrete in the replacement of cement in terms of sustainability of the environment. In this study, we will use Fly ash, silica fume, and GGBS in the increasing percentage of 10% to 30% as the replacements of the cement to observe the mechanical properties of the concrete. As production of cement, GGBS, fly ash, and silica fume produces 95.9%, 15.5%, 9.3%, and 1.4% of CO2 of their produced weight. The difference in carbon emissions of cement and other additives is huge. So, it is an opportunity to use these materials as a replacement of cement a certain extent without compromising the safety and serviceability. In this study, a total 120 number of samples have been cast that includes 90 samples for compressive strength and 30 samples for the water permeability of concrete. The experimental results show that 30% replacement of GGBS observed to achieve the highest strength and 30% silica fumes replacement achieved the lowest strength in this study.

Keywords: Global warming, Sustainability, Cement alternatives, compressive strength

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CHAPTER 1: INTRODUCTION

1.1 Background:

Due to global warming, the global average earth temperature has increased drastically in recent years. Unfortunately, cement and concrete have played a vital role in this, equal to 4% of the emissions from the fossil fuel in the year 2016 (Andrew, 2017). So, the construction industry is looking for alternatives to compensate for their pressure towards environmental sustainability in the industry. In the growth of modern infrastructures, the immediate need is concrete, and for this, it requires cement as a primary ingredient. Preparing the concrete requires cement and aggregates, which are available in raw material, and their extraction creates irreversible damage to the environment. According to CEMBUREAU data, global cement production exceeded 3.99 billion tonnes in 2018 (CEMBUREAU, n.d.). The discovery of modern cement is not old; an English scientist Joseph Aspdin called Portland cement because of its properties that resemble Portland's hills discovered it in 1824. After this, the construction industry has grown to a multi-billion-dollar global industry with far-reaching implications for the environment, economy, and society.

1.2 Concrete impact on society

No wonder concrete has played an essential role in modern society because of its easiness to cast in any shape and its strength. But it also places strain on the industry more than ever to work towards sustainable development without damaging the environment for future generations. Cement and concrete sustainability directly impact the environment, the economy, and society.

Unfortunately, in cement and concrete manufacturing, natural resources are consumed in raw material as aggregates; these extractions can damage the environment permanently. The Concrete Society proposed in 2009 that it is possible to reverse the damage to some extent by allowing them to heal or restore to nature (Buss, 2013). These processes also account for the additional costs of quarrying and transporting materials to the plants. Locally-sourced materials or recycled materials such as crushed concrete and bricks are also encouraged to reduce the cost and sustainable development. It will minimize the materials going into the waste streams. Additionally, it will also reduce the dumping cost to landfills.

Sustainable development also incurs an economic impact on society and industry, and it can get minimized by reducing transportation, production, and storage costs. Also, the construction work environment is hazardous, and it poses the risks of skin damage and respiratory irritation. While the automation process can minimize these issues, it also harms society, i.e., unemployment.

On the other hand, it also has additional health issues due to heavy metals in the cement raw materials and dangerous gas emissions during its manufacturing. The cement gets manufacture at a very high temperature, nearly 1500 ^{0}C and it exhausts directly into the environment during the combustion process. It also contains dust, gases, and volatile heavy metals. These concerns are very well taken care of in the developed countries, and they remain a significant concern in developing and under-developed countries. It also encourages the argument for using substitute materials to ordinary cement in concrete for sustainable development.

1.3 Effect of concrete on climate Change

While these above issues are critical, the significant CO_2 emissions are the most influential on a global scale. Almost 7% of carbon footprint emissions are generated from cement production, majorly in China and India, and it presumes to double by 2050 (Barcelo & Kline, 2012).

All the available figures illustrate that developing countries such as India, and China are increasing cement production relative to developed countries, clearly demonstrated here in Figure 2, which shows the rise of cement production from 2001 to 2018. Between the years 2001 and 2018, cement production in Asia and Africa increases steadily, indicating a percentage increase compared to previous data.

It should be clear that these data of CEMBUREAU only specify total cement production, not the Portland cement. But it emphasizes that this is a global threat that has resulted in developing policies, strategies, and agreements aimed at reducing CO_2 emissions and promoting sustainable development over the last few decades. The Paris Agreement (2015/2016 and subsequent governmental and business promises to help cities to combat climate change). For sustainable development, these proposals and initiatives are under consideration by government bodies and industry. The rates of production have varied across the CEMBUREAU countries. The percentage difference in output between 2001 and 2018 data for number of countries is depicted in Figure 2. Although percentage variations exist, the accurate cement output cannot be calculated without accurate data.

According to British cement association, the manufacturing of each tonne of cement emits 930kg of carbon footprint in the environment, accounting for 93 percent of the total manufacturing volume, which is a problem that must be addressed, and the concrete industry as a whole is working on it. The desire to minimize cement usage and thereby environmental effects while also satisfying market needs for a robust and powerful substance has culminated in detailed studies into the use of pozzolana. This material can be used to make durable concrete. The Romans had considerable popularity with natural pozzolana and artificial pozzolana in different forms. Pozzolanic cement was used to build the vast Roman aqueducts.

Recent advancements in concrete manufacturing, most notably IS 10262:2019, have culminated in a comprehensive selection of products (cement and admixtures). Engineers already have a variety of solutions for meeting the industry's overall needs, like sustainability. However, the concrete must continue to follow stringent technological serviceability criteria on its architecture and longevity properties while staying commercially viable. Terminology for cement additives such as GGBS (ground granulated blast furnace slag), silica fumes, and fly ash varies by area. Although others might refer to them as admixtures, this word usually applies to superplasticizers, retarding liquids, and related substances added throughout mixing to achieve a particular task. These additives are commonly used, and therefore, in this study, it refers to GGBS, fly ash, and silica fumes combined with OPC to form hybrid concrete.

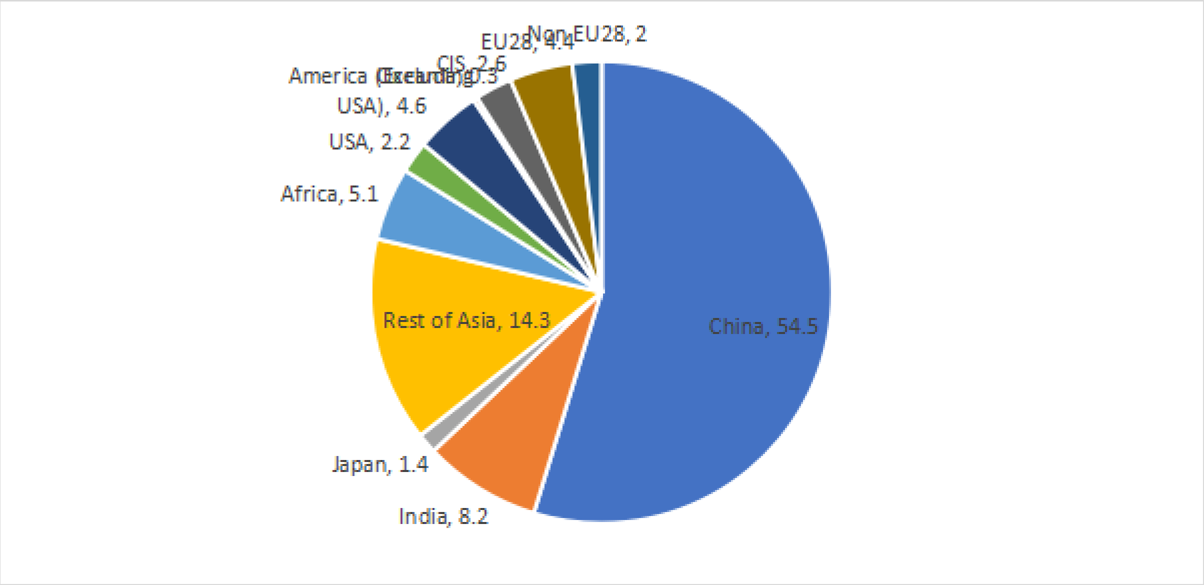

Figure 1 Global cement production, 2018

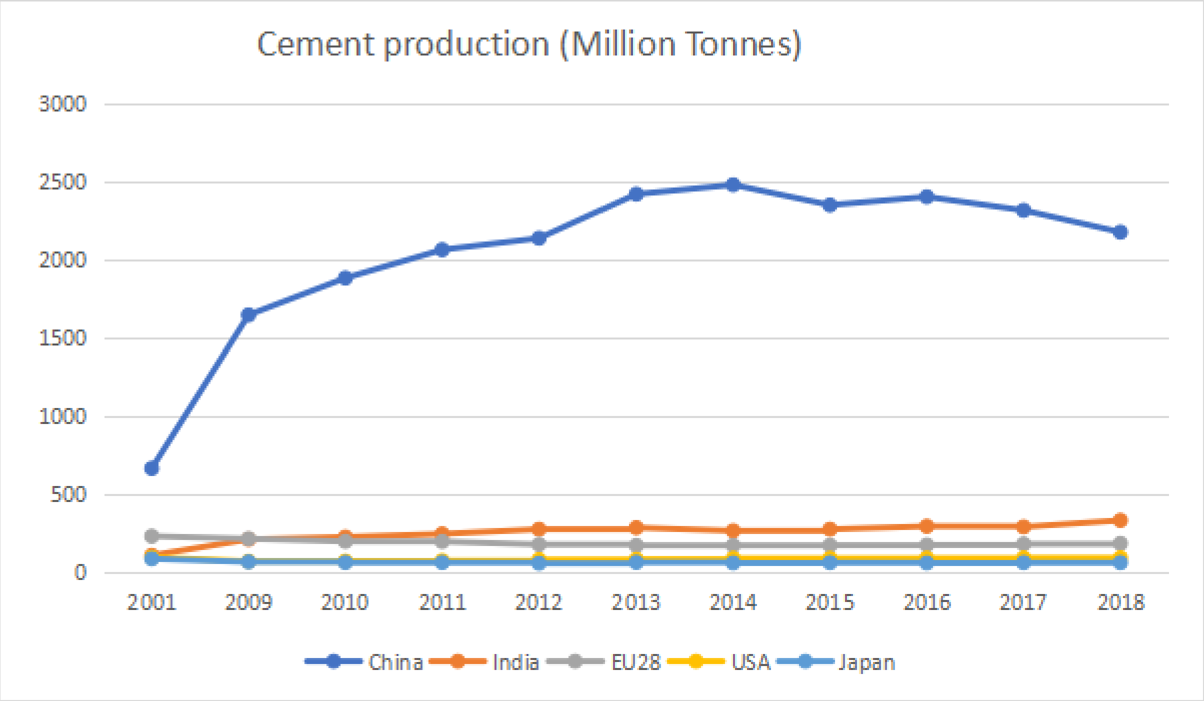

Figure 2: Evolution of cement production from 2001 to 2018

1.4 Environmental Impact of cement and additives

Table 1: Global production of cement

Year	Production (Mt)
2010	3280
2011	3630
2012	3820
2013	4070
2014	4190
2015	4100
2016	4140
2017	4050
2018	4050
2019	4100

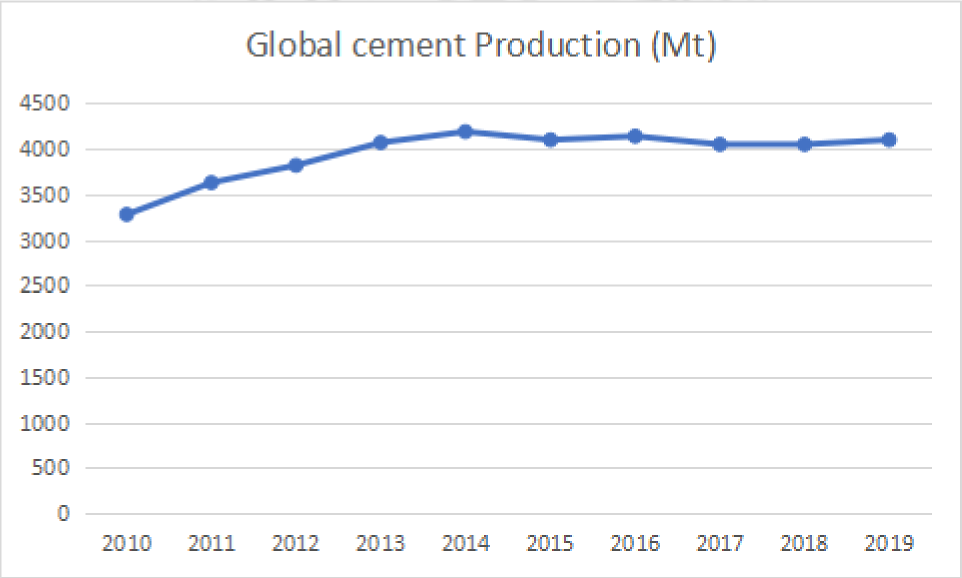

Figure 3: Graphical representation of cement production

Table 2: CO_2 Emissions (Kg/Tonne)

Components	CO_2 Emissions Kg per metric tonnes
Portland Cement	959
GGBS	155
Class F Fly Ash	93
Silica fume	14

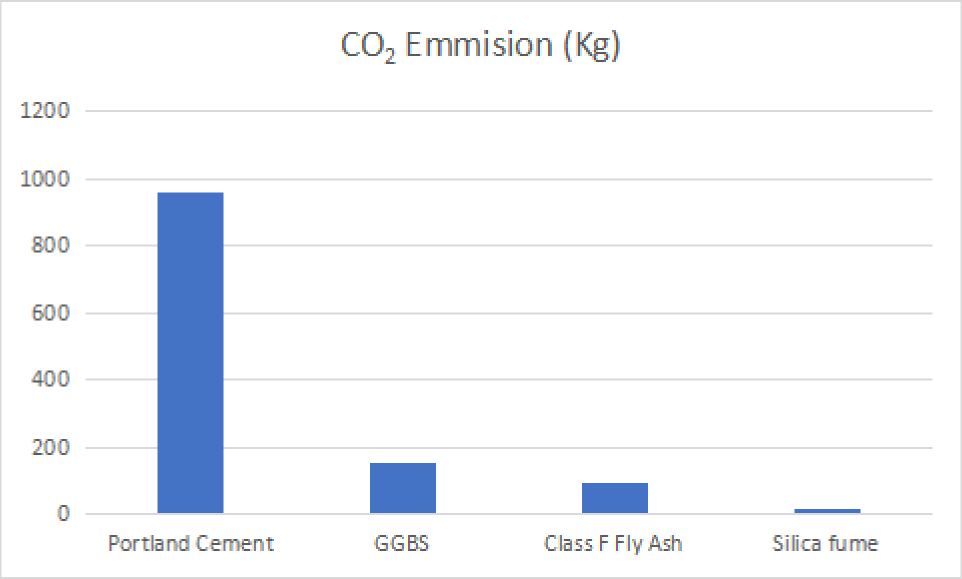

Figure 4: CO2 Emissions (Kg)

Table 3: Global Fly ash production and Consumption

Sl.No.	Country	Annual Fly Ash Production, (Mt)	Ash Utilization (%)
1	India	112	38
2	China	100	45
3	USA	75	65
4	Germany	40	85
5	UK	15	50
6	Australia	10	85
7	Canada	6	75
8	France	3	85
9	Denmark	2	100
10	Italy	2	100
11	Netherlands	2	100

The use of silica fume, pound for pound, provides the most positive Sustainability impact of all the Supplementary Cementitious Materials (SCM), only three of which (Silica Fume, Fly Ash and Slag) are also known as Recovered Mineral Components (RMC) (*US EPA*, n.d.).

The table 1 shows the global production of cement from the year 2010 to 2019 and it increases from 3280 million tonnes to 4100 million tonnes (*Global Cement Production, 2010-2019 – Charts – Data & Statistics*, n.d.). In addition, Table 2 shows the emissions of CO_2 for the Portland cement is 959 kg/ tonne Which is almost equal to the production of cement clinkers. Whereas the GGBS, Fly ash, and silica fume produces far lesser CO_2 when comparing with the cement(Yusuf & Mahar, 2014). Globally the industry is not able to utilize the total produced pozzolana such as fly ashes are only utilized to 38% and 45% by India and China. This utilization globally can decrease the global carbon emissions.

1.5 Aims & Objectives

The objective of this study is to observe the feasibility (mechanical properties) of these additives (GGBS, Fly ash, Silica fume) in the place of cement as they do not affect environment as cement do.

1.6 Scope of the Study

This research analysis can be used in construction that requires similar strength and other properties. This research also has much future scope in terms of replacement. These mixtures can also be mix together then replace with cement to find the optimum amount that is more sustainable in terms of cost and carbon emission.

1.7 Outline of the thesis

This thesis is divided into five chapters; the first chapter is about introducing the topic, including its background, effect on society, and environment.

In chapter 2, literature review of previous studies related to the topic to get a broader idea of their findings by using different materials to replace cement to reduce the carbon footprint in which cement is a significant contributor.

Chapter 3 is all about the materials used in the study and their factual theories and chemical composition. Additionally, it also includes the test method involved in this study.

Chapter 4 includes the result and discussion of the experimental findings in the form of graphs and tables.

Chapter 5 includes the conclusion and the future scope of the study.

Chapter 2: LITERATURE REVIEW

2.1 Introduction

There has been much research about the substitution of cement with other materials to make it economical or sustainable. As the global infrastructure is rising and concrete is the main ingredient involved in this, it also concerns the industry about its effect on the environment. Many industries are trying to reduce the carbon footprint as per united nations guidelines on sustainability. Blended concrete is in use in different parts of the world for various purposes.

2.2 Hydration of cement:

2.2.1 Ordinary Portland cement

Due to the critical nature and complexity of cement hydration and substitution reaction, it is vital to examine this mechanism independently to grasp the fundamental concepts.

Hydration occurs as a result of the addition of water to cementitious products. This is a sequence of never ending chemical reactions after addition of water in concrete (Taylor et al., 2006). When mineral compounds, especially silicates and aluminates, combine with water, hydrates are produced (S.S, n.d.). (Celik et al., 2015) suggested two hydration routes. In the early phases of anhydrous molecules, solvent hydration occurs, resulting in the oxidation of their ionic components. Due to the fact that this ionic mobility is limited to a topo chemical or solid condition, hydration occurs at the anhydrous cement's surface, assisting remaining cement to hydrate.

Four chemicals, collectively referred to as Bogue's compound, are involved in the hydration of cement: C_3A (tricalcium aluminate), C_4AF (tetra calcium alumino ferrite), C_3S (tricalcium silicate), and C_2S (tricalcium silicate) (Dicalcium silicate). However, C_3S and C_2S are critical because they provide the concrete with early and progressive strength.

C_3S reacts early with water to form C-S-H gel for early strength development.

$$2Ca_3SiO_5 + 6H20 \rightarrow 3CaO\ 2SiO_2\ 3H_2O + 3Ca\ (OH)_2$$

C2S also produces the same C-S-H gel, but its hydration rate is slower than C3S, and it produces lesser heat of hydration, Ca(OH)2, and is responsible for progressive and ultimate strength to concrete.

$$Ca_2SiO_2 + 4H_2O \rightarrow 3CaO\ 2SiO_2\ 3H_2O + 3Ca\ (OH)_2$$

The other Bogue compounds C_3A and C_4AF contain aluminate, which reacts faster than silicate. These two compound hydrates early in less than 24 hours of the addition of water.

C_3A is more reactive than C_3S and C_2S, and it hydrates rapidly, termed as the flash setting of concrete, releases a large amount of heat of hydration, and reduces the workability of the concrete.

To avoid the flash set of concrete, gypsum is added to the cement clinkers during cement manufacture. It forms a protective layer around the particles of C3A and loses its water. However, when water is added for concrete production, it absorbs most of the water and helps to prevent the water from reacting with C3A, and it appears to be set but is termed as a false set.

2.2.2 Steps involved in the hydration of cement

Ca, Si, Al, Fe, Mg, O_2

↓

CaO, SiO_2, Fe_2O_3, Al_2O_3, MgO

↓

Bogue's compound

(C_3A, C_4AF, C_3S, C_2S)

↓

Hydration

↓

C-S-H and $Ca(OH)_2$

2.3 Properties of concrete:

2.3.1 Fresh properties:

Inclusion of fly ash improves the workability of concrete (Yao et al., 2015), whereas (Kearsly & Wainwright, 2003) finds high carbon fly ash reduces the workability and (Wang & Iowa State University, 2004) observed high volume of fly ash reduces the water demand and improves workability. Silica fume decreases the workability of concrete (Srivastava et al., 2012) and (V et al., 2019) observe the above study true that inclusion of silica fume reduces the workability of concrete. As (S.S, n.d.) address fresh (plastic) concrete, they highlight the value of workability. Workability of concrete refers to the ease with which it can be placed, compacted, and finish. Compaction is essential to remove air voids; inadequate compaction can reduce strength (S.S, n.d.). Slag increases the workability because of its texture (Tattersall, 1976). Due to GGBS's lower specific gravity than Portland cement on a weight-for-weight basis, there is an increase in powder volume for a given replacement.

A GGBS concrete needs less water than ordinary concrete to obtain the same cohesiveness, flow, and compaction characteristics. This decrease in water content is required to maintain workability and it is proportional to the amount of GGBS and cement content in concrete (Sivasundaram & Malhotra, 1992). (Tattersall & Baker, 1989) anticipates a 5 percent reduction in water, and While (Collins & Sanjayan, 1999) confirms above observation and demonstrates that the GGBS's texture, especially its glassy surface, affects water demand. According to Day, only a small amount of water is needed. (Bijen, 1996) asserted that GGBS concrete possessed comparable workability, pumpability, and compact ability to control mix concrete. Though GGBS slows setting time, opinions on silica fume have varied. According to (Khedr & Abou-Zeid, 1994) and (Alshamsi, 1997) silica fume retards setting period, with the increase in substitution level. (Brooks & Megat Johari, 2001) compared the metakaolin and silica fume results and discovered that each slowed the setting time. There was enough proof that as the concentration of metakaolin was increased, both the initial and final setting times were extended.

2.3.2 Development of strength:

(Saha, 2018) Compared to the control specimens, the fly ash displayed lower compressive strength in the early stages. Strength increased rapidly over a prolonged period due to the pozzolanic reaction, while control samples ceased strength development after a certain period of curing. (Zabihi-Samani et al., 2018) When commissioning the concrete after 28 days, it is preferable to use 20% coal fly ash (CFA) additive composites. The unconfined compressive strength (UCS) determined that recycled concrete aggregate and 15 percent of fly ash (FA) was the optimal blend for strength at both room and 40 degrees Celsius temperature. (Kearsly & Wainwright, 2003) observes 30% is the upper limit for the replacement in ordinary Portland cement with fly ash and high carbon fly ash reduces strength of the concrete by increasing the water-cementitious ratio. Replacing the cement with high fineness and low carbon is preferable as it exhibit high degree of pozzolana, so increases significant later age compressive strength (Davis et al., 1937). (Mazloom et al., 2004) finds on increasing the amount of silica fumes it increases the compressive at 28 days of curing. (Srivastava et al., 2012) that silica fume improves the mechanical properties and durability of concrete. Apart from its pozzolanic activity, silica fume's primary physical influence in concrete is that of a filler, which, due to its fineness, will fit into small spaces.

(Arivalagan, 2014) Since the grain size of GGBS is smaller compared to ordinary Portland cement, its early strength is poor, but it gradually gains strength over time and increased strength is a result of GGBS's filler impact. (D. E. Wimpenny, 1989) stated that the compressive strength development is slower in GGBS based concrete when compared with ordinary concrete. It is observed that GGBS-based concretes have achieved an increase in strength for 20% replacement of cement at the age of 28 days, and Increasing strength is due to filler effect of GGBS (Arivalagan, 2014). The strength of concrete is dependent on fineness, and mixed proportion of the materials (Masatane Kokubu and Shigeyoshi Nagataki, 1989), and (Sivasundaram & Malhotra, 1992), other variables such as exposure conditions (Jean-Chuan Chern and Yin-Wen Chan, 1989), water/cementitious ratio, and method of curing also affect the strength of concrete (Austin et al., 1992).

According to (Jean-Chuan Chern and Yin-Wen Chan, 1989), changing the GGBS amount affects intensity growth and fineness, and exposure temperature. Indeed, higher GGBS levels correlate with a slower rate of intensity increase, (Hogan & Meusel, 1981). He has observed a more significant rise in sensitivity at later ages than PC alone after 28 days. (Ganesh Babu & Sree Rama Kumar, 2000) studied the effectiveness of GGBS in binary concretes at concentrations varying from 10% to 80% (using comparable measuring methods to those used by fly ash and silica fume). We collected and compared data from previous studies using fly ash and silica fume binaries and GGBS to create a picture of the cement manufactured at the time. The study confirmed the compressive strength of GGBS concretes depend both on percentage replacement level and on the age (Ganesh Babu & Sree Rama Kumar, 2000).

(Takashi Miura and Ichiro Iwaki, 2000) the study investigated the impact of the curing procedure on GGBS concrete strength with solids varying from 50% to 80% and three unique fine grades. Heat curing in GGBS improved early-age strength without reducing later-age strength, although overall strength growth followed previous trends. GGBS, on the other hand, has a greater specific surface area, hence this was not the case in GGBS. (Takashi Miura and Ichiro Iwaki, 2000). Rapid hydration led to a brittle microstructure of the hydrated concrete paste in finer GGBS because of hot curing outcomes, which minimized reactions in subsequent ages. A related study tested BRECEM concretes for GGBS concentrations of 40%, 50%, and 60% using both water and air curing techniques (Quillin, 2001). (Barnett et al., 2006) observed that the GGBS reactions, which contributes in the development of strength, are more dependent on temperature than the types of cement. The observation that increased early-age temperatures stimulate the formation strength in GGBS concrete also supported by (Roy & Idron, 1982) results.

2.3.3 Permeability of concrete:

(Saha, 2018) The use of fly ash as a binder decreased the concrete's porosity. As a consequence, the fly ash concrete has a lower water sorptivity and permeability to chloride. (Zabihi-Samani et al., 2018) on increasing the amount of fly ash porosity decreases and least porosity observed at 30% fly ash replacement.

CHAPTER 3: MATERIALS AND TEST METHOD

3.1 Experiment outline:

The selection of cement and additive for the preparation of concrete is based upon Indian standards code and experimental observations. A concrete cylinder of 100% ordinary Portland cement was cast. After that, different combinations of OPC with fly ash, silica fumes, and GGBS was cast with the different percentages of OPC replacement ranging between 10% to 30%. The previous studies of these substitutes have already been discussed in the last chapter 2 of literature review.

3.2 Materials:

In this study, all the materials were purchased from local building materials shop. Cement is ordinary Portland cement according to (*IS 456 (2000): Plain and Reinforced Concrete – Code of Practice,* n.d., p. 456), class F fly ash, ground granulated blast furnace slag, and silica fumes according to IS code were primary binders in the concrete. The chemical composition of these materials was provided by the source. To get workable concrete naphthalene super plasticizer was used. The crushed angular aggregate of nominal size of 20mm was used in the concrete.

3.2.1 Ordinary Portland cement:

Cement is one of the most used materials on planet earth, and among all the cement variants, the regular ordinary Portland cement is most common. It is a mixture of calcareous and argillaceous compounds that constitutes lime, silica, alumina, oxides of iron, magnesium, sulfur, and alkali. It reacts with water to form hardened materials after some preliminary time for placing and finishing. The modern cement was first patented by English researcher joseph aspdin in 1824 and called it Portland cement because its properties and appearance resemble with cliffs of Portland, England. The manufacturing of ordinary Portland cement involves quarrying, grinding, mixing, preheating, calcination, combustion, cooling, and addition of gypsum. The calcination and combustion occur in the temperature range of 1200-1500 ^{O}C. In the calcination, the calcareous compound becomes reactive and breakdown into two compounds, lime, and carbon dioxide. In the combustion zone, argillaceous compounds get reactive. Calcareous and argillaceous compounds fuse at a very high temperature to form cement clinkers in the form of Bogue’s compound, mainly responsible for the strength of cement.

Figure 5: Ordinary Portland cement

The different oxides in the cement are CaO, SiO_2, Al_2O_3, Fe_2O_3, MgO, SO_3, and alkali oxides like K_2O, Na_2O less. All oxides have their specific purposes at the different stages of cement. Cao is responsible for strength and soundness in the cement, SiO_2 accountable for strength and setting time of the cement, Al_2O_3 has quick setting property. It acts as a flux in cement manufacturing to reduce the clinkering temperature. After burning and fusing these oxides, they form different compounds termed Bogue's compound, which is mainly responsible for all the activities in cement.

Table 4: Bogue’s compound in ordinary Portland cement

Name of compound	Chemical Composition	Abbreviation
Tricalcium Silicate	$3CaO.SiO_2$	C3S
Dicalcium Silicate	$2CaO.SiO_2$	C2S
Tricalcium aluminate	$3CaO.Al_2O_3$	C3A
Tetra calcium aluminium ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C4AF

Table 5: Chemical composition of ordinary Portland cement

Chemical composition of OPC (%)	
Lime (CaO)	65
Silica (SiO_2)	21
Alumina (Al_2O_3)	5
Iron oxide (Fe_2O_3)	3.2
magnesia (MgO)	2.1
Sulphur trioxide (SO_3)	2.5
Potash and soda (Na_2O_3 +K_2O)	1.2

3.2.2 Fresh coarse aggregates:

The aggregate governs the properties of concrete in which it is used. However, aggregates mainly govern two properties of concrete that are strength and workability. The strength and workability of aggregates depend on several factors such as shape, size, texture, absorption capacity, flakiness index, grading, etc. Coarse aggregate is classified into four weight classes: heavyweight, medium weight, lightweight, and ultra-lightweight. However, we mostly used lightweight concrete particles and coarse aggregate. Certain mixtures are designed exclusively for professional purposes, such as nuclear radiation protection given by heavyweight concrete and thermal insulation provided by lightweight concrete.

The coarse aggregates used in this study are of a maximum nominal size of 20mm, observed from sieve analysis of the aggregate with the reference of table 7 IS 383:2016.

Figure 6: Coarse aggregate

3.2.3 Fine aggregates:

These aggregates fall in the category of fine aggregates when it is of a size less than 4.75 mm. These aggregates act as a filler in concrete. These aggregates also increase strength in concrete and protect it from shrinkage. Finer the particle size greater the strength. As the sand-to-gravel ratio increases up to 8%, the mortar achieves bulk and strength. When the sand-to-gravel ratio exceeds 8%, the compressive resistance after seven days starts to deteriorate (Schaefer et al. 2009). Compressive strength was improved from 14 to 19 Mpa by optimizing 10% to 20% of the fine sand to a coarse mix. A marginal reduction in permeability is associated with a rise in the number of fine particles.

In this study we used the fine aggregate of zone 2, observed from the gradation analysis with the reference of table 9 IS 383:2016.

Figure 7: Fine aggregate

3.2.4 Fly ash:

Fly ash is the ash produced in coal-based power plants. It consists of fine particles of specific surfaces as 300 to 500 m2/kg. The term “fly ash” refers to the waste material collected from the emissions emitted from coal-fired furnaces, most often thermal power plants. In other words, the mineral dust left behind following coal combustion is referred to as fly ash. With the assistance of a powerful Electro Static Precipitator, vegetation gathers these fly ashes (ESP).

Figure 8: Fly ash

Fly ashes are nanoparticles mainly composed of alumina, silica, and iron. Since fly ash particles usually are spherical, they mix and flow more easily, enabling them to create a good link. The fly ash produced contains both amorphous and crystalline minerals. Its content differs according to the kind of coal burned, but it is non-plastic silt. For this analysis, fly ash from a thermal energy plant must be obtained. ASTM C618 defines two categories of fly ash for concrete use: Class F, which is usually derived from anthracite or bituminous coal combustion, and Class C, which is typically derived from lignite sub-bituminous coal combustion.

Additionally, ASTM C618 defines the chemical and mechanical characteristics of these two fly ash forms. Class F fly ash is pozzolanic, which means it cements slowly or not at all. Class C fly ash possesses both self-cementing and pozzolanic properties. Consequently, we would use designation F fly ash in our inquiry to observe the concrete's binding properties. Up to 85% of fly ash is composed of silica and alumina, while 15% is composed of other constituents.

Table 6: chemical composition of fly ash

Chemical composition of class F fly ash (%)	
Lime (CaO)	9.2
Silica (SiO2)	54.8
Alumina (Al_2O_3)	25
Iron oxide (Fe_2O_3)	7.5
magnesia (MgO)	2.5
Sulphur trioxide (SO_3)	1

3.2.5 GGBS (Ground granulated blast furnace slag):

Blast furnace slag is a by-product in the manufacturing of pig iron. If the cooling process is rapid while pig iron is manufactured, glassy pallets are produced as a by-product. On grinding this product, pozzolana is known as granulated blast furnace slag (GGBS).

Figure 9: Ground granulated blast furnace slag

Table 7: Chemical composition of GGBS

Chemical composition of GGBS (%)	
Lime (CaO)	41.5
Silica (SiO_2)	37
Alumina (Al_2O_3)	14
Iron oxide (Fe_2O_3)	1.4
magnesia (MgO)	0.7
Sulphur trioxide (SO_3)	0.06
Potash and soda (Na_2O +K_2O)	2.3

3.2.6 Silica fumes:

It is a by-product during the manufacture of silicon metal using furnaces heated with coal, coke, and wood. It comprises at least 85% ultrafine, glassy silicon dioxide particles.

Figure 10: Silica fume

Table 8: chemical composition of silica fume

Chemical composition of silica fume (%)	
Lime (CaO)	2
Silica (SiO_2)	92
Alumina (Al_2O_3)	1.7
Iron oxide (Fe_2O_3)	2.4
magnesia (MgO)	0.2
Sulphur trioxide (SO_3)	0.8
Potash and soda (Na_2O +K_2O)	0.9

3.3 Mix design and proportions:

The method of deciding the correct amounts of cement, fine aggregate, fly ash, admixture, water, and coarse aggregates for concrete to obtain the required strength in structures is called concrete mix design. Consequently, the concrete mix's geometry can be expressed as Concrete Mix = Cement: Sand: aggregate: admixtures if required. This concrete mix design was conducted as per IS 10262:2019.

1. Find target mean strength of concrete.
2. Selection of w/c ratio as per target strength.
3. Selection of water content, including the effect of workability and superplasticizer.
4. Selection of cementitious ratio.
5. Calculation of volume of cementitious material, water, and admixture.
6. Calculation of total aggregate volume by subtracting above calculated volume from required volume of concrete.
7. Calculation of coarse aggregate and fine aggregates by estimating the maximum nominal size of aggregates and shape of aggregates.
8. Convert the above calculated volume of coarse and fine aggregate into mass.
9. Adjustment in water content if the aggregate has any absorption and moisture.

3.4 Compressive strength:

Many tests can be performed on concrete, but the most significant include information about all of the material's characteristics. This test is also known as the compressive strength test. This single test allows one to determine the significant properties of concrete. The compressive strength of concrete is governed by several variables, including the cement fineness, the water-cement ratio (w/c), the cement strength, the consistency of the concrete materials, and quality control during the production phase. Compressive strength determines using either a cube or a cylinder. Concrete prepared as per the standards of the specimen. This concrete is poured into the mold and ideally tempered with 25 blows in three distinct equivalent layers from the top with constant height and force. The molds are discarded after 24 hours, and the test specimen is put in room temperature water to heal. The top surfaces of these specimens should be flat and smooth. To achieve this, apply a coating on the whole surface of a sample with cement paste.

After 3, 7, and 28 days of curing on concrete cylinders, the strength of these cylinders was determined using the universal testing machine. Constant loading of 140kg/cm2 per minute before the specimen fails. The compressive strength of concrete is determined by the standardized distribution of the load at failure around the specimen's surface region.

3.5 Preparation of samples:

3.5.1Mixing of ingredients:

- Weigh batching of all cement ingredients
- Mixing of batched ingredient
- Addition of water as per the water-cement ratio
- Mix ingredients in the concrete mixer for 2 to 3 minutes until no lumps and ingredients are properly mixed.
- Take out the concrete to fill the cement molds.

Figure 11: Concrete mixer

3.5.2 Sampling:

- Clean the cylindrical molds
- Greasing the inside surface of the cylinder
- Fill the mold with concrete in three layers
- Compact the layers with 25 blows from constant height and load using a tamping rod of weight
- Level the top surface of the cylinder using a trowel.

Figure 12: Concrete molds

3.5.2 Curing:

It is a process to provide enough water to concrete samples required for hydration and achieve its desired properties. Curing improves concrete's short-term strength, eliminates surface shrinkage cracks, and reduces long-term shrinkage cracks. Since fly ash's pozzolanic reaction is slower than cement's hydration reaction, the setting time becomes longer.

3.6 Procedure for determining compressive strength:

- Remove the sample from curing
- Apply plaster of Paris to remove unevenness
- Take the longitudinal and transverse direction
- Clean the base and top of the UTM
- Put the sample in proper centrical alignment in UTM
- The top and bottom of UTM should touch the sample
- Apply gradual loading till the specimen fails

Figure 13: Universal testing machine

3.7 Water permeability:

In the water permeability test of the concrete cylinders fine aggregate was removed and it tested after the curing age of 28 days. This test was performed for the constant head permeability test. In this method water was allowed to pass through the sample and the time was recorded.

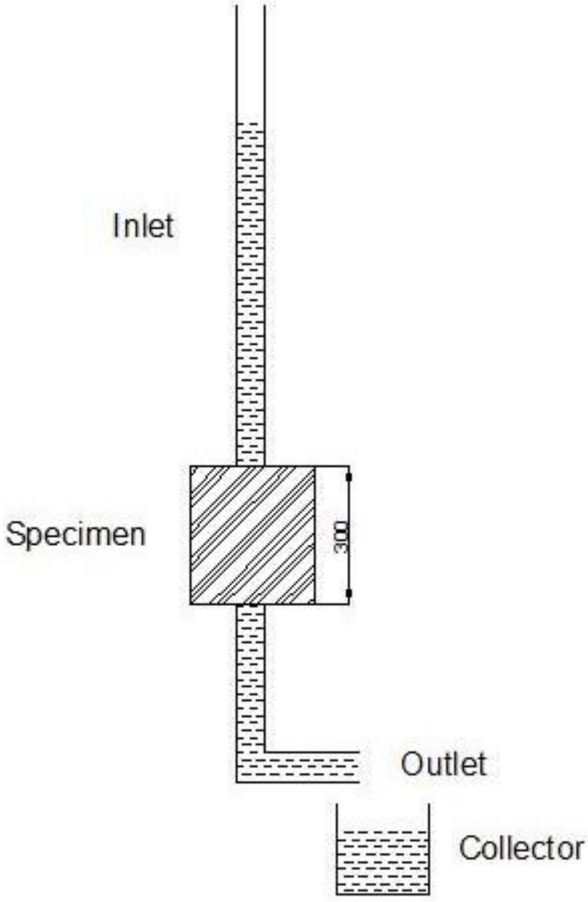

Figure 14: Experimental setup of Permeability

k=QL/ATH

k= Coefficient of permeability in cm/seconds

Q=Volume of discharge in cm^3

L= Length of the specimen in cm

A= Area of cross-section of the specimen from which water pass in cm^2

T= Time of discharge in cm

H= Head difference in cm

In this case, constant head permeability test was performed so, the head will remain constant.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction:

This chapter incorporates the results of the compressive strength and permeability of concrete. In this, it correlates the results in graphical and tabular form. In this study a total number of 120 specimens were casted for 40 samples that includes 30 samples of compressive strength of control mix concrete and substituted concrete. 10 samples to observe the permeability of concrete.

4.2 Compressive strength development:

Table 9: Mix quantities and compressive strength of Fly ash-based concrete

Fly ash (%)	Cement (kg/m^3)	Fly ash (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	compressive strength (MPa)		
						3 Days	7 Days	28 Days
0	330	0	1320	600	148	10.3	17	29
10	297	33	1320	600	148	10	13	23.2
20	264	66	1320	600	148	8.5	11.7	20.1
30	231	99	1320	600	148	6.3	10.2	18.4

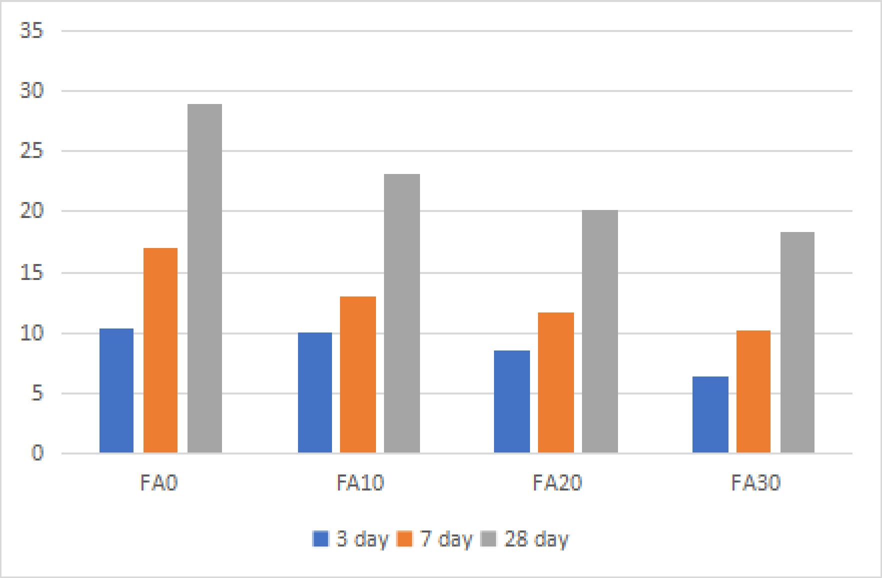

Figure 15: Compressive strength development in fly ash substituted concrete

Figure 12 shows the average compressive strength of the specimens after various curing durations. The control samples, which do not include any substitution, have high early compressive strengths of 10.3 MPa and 17 MPa after 3 and 7 days of curing, respectively. At the curing age of 28 days, compressive strength has increased to 29 MPa. The addition of fly ash, on the other hand, reduces the compressive strength of concrete. The early compressive strength is reduced by a rise in class F fly ash due to a low lime concentration in class F fly ash. It also lowers hydration heat, resulting in low compressive strength at an early age. After three days of curing, the compressive strength of the samples containing 0, 10, 20, and 30% fly ash was 10.3, 10, 8.5, and 6.3 MPa, respectively. The early age compressive strength of concrete steadily declines as the fly ash content increases, which is consistent with the majority of prior studies on fly ash additions. With the increment in the amount of fly ash, the compressive strength decreases steady at all the ages from 3, 7, and 28 days due to the pozzolanic property of class f fly ash which contains less amount lime, and lime is mainly responsible for the early strength in the concrete.

Table 10: Mix quantities and compressive strength of silica fume-based concrete

Silica fume (%)	Cement (kg/m^3)	Silica fume (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	compressive strength (MPa)		
						3 Days	7 Days	28 Days
0	330	0	1320	600	148	10.3	17	29
10	297	33	1320	600	148	13.2	19	28.5
20	264	66	1320	600	148	11.6	16.1	18
30	231	99	1320	600	148	9.4	13.2	15.1

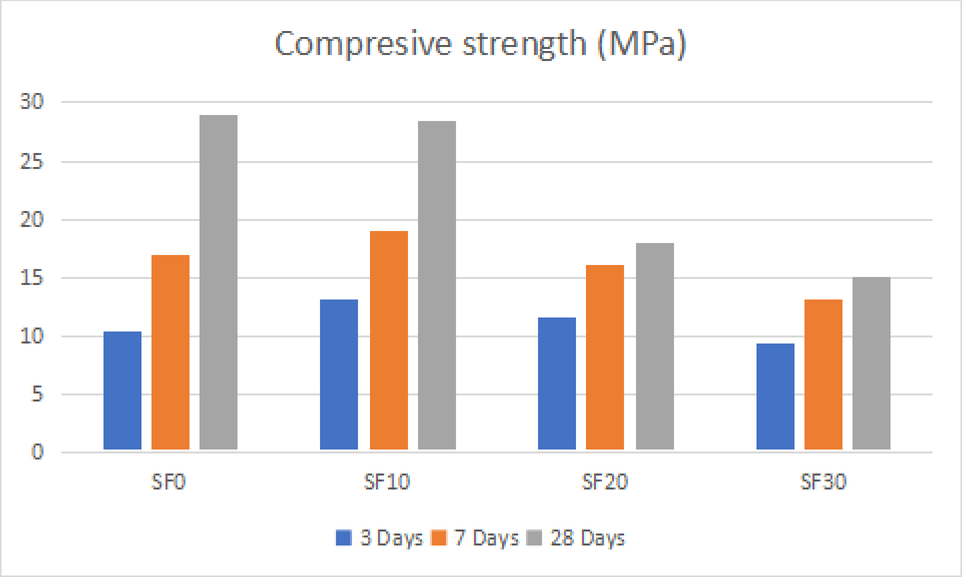

Figure 16: Compressive strength development in silica fume substituted concrete

The development of strength with age can be seen in Figure 13. It can be seen that the compressive strength development of concrete mixtures containing silica fumes increases at the percentage replacement of 10% and have a comparative strength at the curing age of 28 days due to the filler effect of silica fumes as its size is very small when comparing with the size of cement. It is well known that the size of silica fumes is tiny and makes the concrete dense, increasing its compressive strength. So, it increases it increases the strength at 10% replacement level by making the concrete cylinder dense. As the amount of silica fumes increases, compressive strength decreases as silica contains minimal lime and a high amount of silica. So, increase in the amount of silica fume beyond 10% reduces the strength further.

Table 11: Mix quantities and compressive strength of GGBS based concrete

GGBS (%)	Cement (kg/m^3)	GGBS (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	compressive strength (MPa)		
						3 Days	7 Days	28 Days
0	330	0	1320	600	148	10.3	17	29
10	297	33	1320	600	148	12.1	17.3	27.8
20	264	66	1320	600	148	13	17.4	28.9
30	231	99	1320	600	148	9.2	18.1	30.4

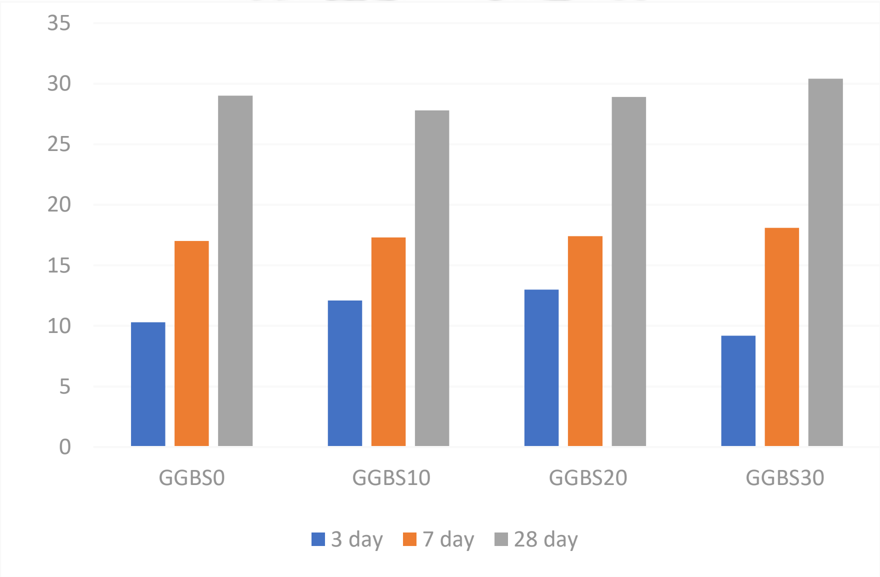

Figure 17: Compressive strength development in GGBS substituted concrete

The average compressive strength of the specimens at different replacement levels and curing periods can be seen In figure 14. The control sample with 100% cement content has a compressive strength of 10.3, 17, 29 MPa at curing periods of 3, 7, and 28 days. However, the compressive strength with the addition of GGBS increases to some extent because of the lime content present in the GGBS. After the curing of 3 days, the compressive strength of the concrete increases at the replacement level of 10% and 20%, i.e., 12.1 and 13 MPa, but it decreased when the replacement level was 30%, i.e., 9.2MPa. It is noticeable that there is an increase in the early age compressive strength except when the replacement level was 30%. The increase in compressive strength of GGBS substituted concrete is mainly due to the filler effect of GGBS.

4.3 Permeability of concrete cylinders

To determine the permeability of concrete cylinders constant head method was used. In this method concrete cylinder was placed in the plastic pipe and water was to allowed to pass through for a fixed time interval and one retaining pot below the setup to accumulate the water passing through cylinders. We perform the permeability tests for the samples having highest strength.

Calculation of coefficient of permeability

Q=1140 cm^3

L= 30 cm

$A=\pi r^2 = (22/7) * 7.5^2 = 176\ cm^2$

T= 60 sec

H= 120 cm

$k = QL/ATH = (1140*30)/(176*60*120) = 0.027\ cm/sec$

Table 12: Different Quantities and permeability of concrete cylinders

Time(T) sec	Discharge (Q) cm^3	Length (L) cm	Head difference (H) cm	Area of cross-section (A)cm^2	Coefficient of permeability (k) cm/sec
60	1140	30	120	176	0.027
60	971	30	120	176	0.023
60	887	30	120	176	0.021
60	1267	30	120	176	0.030

Table 13: Results of water permeability

Mixes	Water permeability (cm/s)	
	k	% Of OPC
OPC (100%)	0.027	100
10% FA	0.023	85.19
10% SF	0.021	77.78
30% GGBS	0.03	111.11

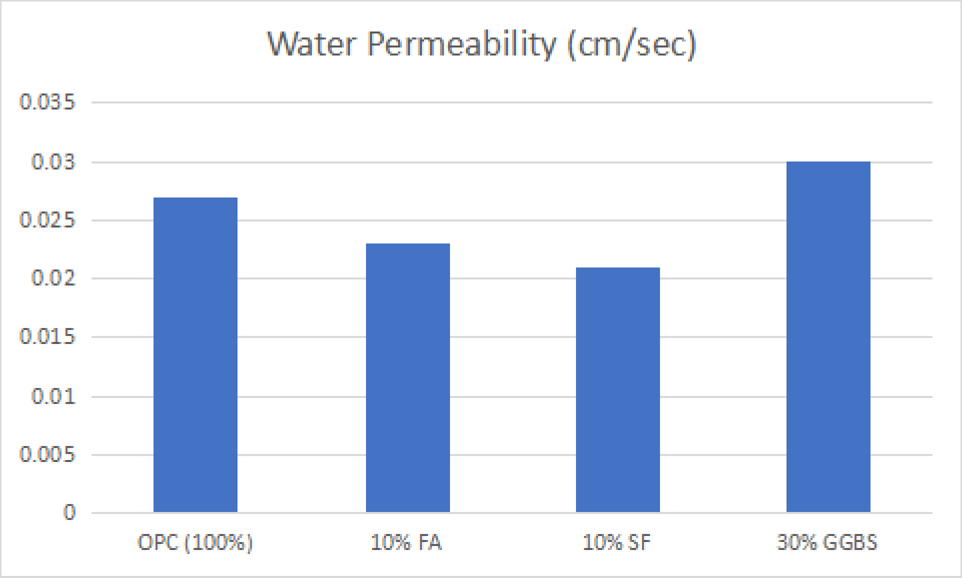

Figure 18: Effect on water permeability in different substitutions

Figure 15 shows the permeability coefficient of the control mix concrete and additive concrete with different percentages of fly ash, silica fume, and GGBS. Concrete should be less permeable to provide compressive strength and, this figure shows that the water permeability coefficient improved to some extent in every addition and 30% GGBS addition shows the highest permeability whereas 10% silica fume addition shows the lowest permeability compare to 100% OPC control mix.

CHAPTER 5: CONCLUSION AND FUTURE SCOPES

Environmental impact of cement is very unfortunate. So, in this study we replaced cement with the additives produces less CO_2 in the environment, shown in table 2, for the sustainable development and better quality of life for the future generations.

As the table 3 shows global cement producing countries are also producing fly ash but the utilizations are not up to the mark. As India and China are utilizing only 38% and 45% of the total fly ash produced. The increase in utilization of fly ash will definitely reduce the carbon emission as shown in table 2. And the observations show the comparable results on mechanical properties of these additives concretes with the control mix concrete at later of curing age. The essential understandings of concrete and its effect are discussed in chapter 1.

As additives contain higher argillaceous compounds than cement, it hinders the early compressive strength of concrete. However, with time they start reacting with calcium hydroxide to form a C-S-H gel, its strength increases.

- With the addition of fly ash compressive strength decreases due to the pozzolanic effect of fly ash. In this study for the replacement level of the

10% to 30% and curing age of 28 days the optimum percentage of replacement was observed at 10% fly ash replacement.

- The addition of silica fumes decreases the compressive strength but, 10% silica fume was found to be the optimum percentage as strength increases at early age. The 28 days compressive strength of 10% replacement was comparable with control mix concrete but, after that it keeps on decreasing.
- However, the addition of GGBS as a substitute has a comparable strength at the curing age of 28 days with the control mix concrete. it also increases the compressive strength at the early age (7 days) of 10% and 20% replacement but it decreases at 30% GGBS level.
- The maximum coefficient of permeability was found at the 30% GGBS replacement level and the minimum value was found to be at the replacement level of 10% silica fumes.
- Permeable concrete with good strength is very useful in today’s world as the infrastructures are increasing and open soil are decreasing in the cities for storm water penetration which results in flooding and it is also affecting the ground water levels.

The conclusion of this study is that we can utilize the production of these additives (GGBS, Fly ash and silica fume) up to certain compressive strength level (20 MPa-25 MPa) and it will be sustainable for our environment.

FUTURE SCOPE OF THE RESEARCH:

In this study, we focused on replacing cement with three different materials, ranging from 10% to 30% as every material have a different effect in the property of concrete samples. These materials can expand with an extensive range of additives. All the discussed combinations are binary combinations with the replacement of cement with one substitute in different degrees.

There is a solid use of ternary combinations in cement replacements by replacing cement with two substitutes, e.g., Cement + fly ash + silica fumes in the different range to find the optimum replacement percentage to compare with the control concrete mix.

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