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Development of Alkali Activated Calcined Kaolin Based Self – Compacting Geopolymer Concrete Using Waste Powder Materials

A Thesis

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By

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

(فَتَعَالَى اللَّهُ الْمَلِكُ الْحَقُّ وَلَا تَعْجَلْ بِالْقُرْآنِ مِنْ قَبْلِ أَنْ يُقْضَى إِلَيْكَ وَحْيُهُ وَقُلْ رَبِّ زِدْنِي عِلْمًا)

صدق الله العلي العظيم

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Examining Committee Certificate

<u>Certificate</u>

I certify that this thesis, titled "**Development Of Alkali Activated Calcined Kaolin Based Self – Compacting Geopolymer Concrete Using Waste Powder Materials**", has been prepared by "**Ahmed Khudair Mohsen**" under my supervision at the Department of Civil Engineering, the University of Babylon, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

Signature

Supervisors name: **Asst. Prof. Dr. Haider Mohammed Owaid**

Date: / / 2023

Dedication

To the soul of my dear father, may God have mercy on him

To whom fate did not allow me to live with him, my late brother Ali

To my dear mother and dear wife, may God protect them

To those who made an effort to help me and were the best support

(My brothers, sister and children)

to my friends and colleagues

To all of them: I dedicate this work.

Ahmed Khudair Mohsen

<u>Acknowledgment</u>

<u>ABSTRACT</u>

This study focuses on reducing (CO_2) emissions in the ambiance and energy consumption.It covers the development geopolymer self-compacting concrete through via use of calcined pozzolan materials such as calcined kaolin clay (CKC), ground granulated blast furnace slag GGBS and marble dust powder (MDP) as an alternative.Controlling environmental contamination is currently the main focus of study. Industrialization, urbanization, and population increase are the main causes of environmental pollution. Modern thinking holds that new binders are essential for improved environmental and durability performance. The term geopolymer is developed to encourage the use of synthesized natural siliceous materials or industrial by-products in cement manufacturing in order to decrease it. These inert components are activated using alkaline activators like (OH) and (Si_2) to give cement its binding properties. The raw materials utilized in geopolymer include inert substances such as fly ash(FA), GGBS, CKC, etc. Innovative Self-compacting geopolymer concrete (SCGPC) vibration is not necessary for the placement or compacting of concrete. It can be current under its weight and fully compact and fill formwork even when there is a lot of reinforcement present.

To produce SCGPC mixtures, sixteen types of concrete mixes are designed and cast a water-to-binder ratio (w/b = 0.36) and (CKC) content of 486 kg/m^3. In this study, three types of concrete mixes were developed, developed, which are binary and ternary systems in three stages. A reference mixture was created in the first stage using 100% CKC, while the other mixes were created using the binary mix (MDP + CKC, GGBS+ CKC), was substituted by 30, 40, 50, 60, and 70% of GGBS and MDP of 5, 10, 15, 20, and 25%, in the second stage. The ternary blends systems

(CKC+ MDP+GGBS), the replacement ratios for MDP were 5, 10, 15, 20, and 25% with 50% of GGBS in the third stage, as partial replacement of binder (by weight).

To assess the fresh properties of SCGPC mixes were tested by (flow of slump test (Dmm, and T500s) test, V-funnel test, L-box test, and segregation resistance SR test). The performance of SCGPC mixtures in hardened states at various ages is evaluated using the bulk density,compressive strength(FC), splitting tensile strength(SPT), and ultrasonic pulse velocity(UPV) tests. Besides, the durability performance of the binary, and ternary blends SCGPC is investigated in terms of water absorption, porosity, and sorptivity. The findings indicated that the fresh characteristics of SCGPC are improved when GGBS and MDP are used in binary and ternary blends, and that slump flows, flow durations, and SR tests are adequate for SCGPC development. Along with the L-Box height ratio, all SCGPCs are unblocked with values ranging from 0.809 to to 0.957. As a result, all of the fresh concrete combinations met the required characteristics. There is a development in the results of testing the hardening properties of concrete and the durability performance of SCGPC in the system of binary and ternary mixtures. The mixture consisting of 35% of CKC and 15% of MDP with 50% of GGBS gave in ternary blends it is more useful when used as a single material with (CKC) in SCGPC, with better development recorded compared to the reference mix and the binary mixture with CKC in different ratios and ternary mixes with the same substitution levels of clay, At the all days. The concrete mixture containing a replacement ratio of 35% of CKC, of MDP and 50% of GGBS showed the highest FC , SPT and UPV. Due to the concrete models low water absorption, porosity, and absorbency,it also demonstrated the best durability qualities. which contribute to reducing the demand for cement, lowering the rate of CO_2 emissions, and

making SCGPC highly durable, environmentally friendly, and its various uses.

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Nomenclatures/Abbreviations

Symbol	Description
CO_2	Carbon dioxide
GJ	Gegajole
MJ	Megajole
SCMs	Supplementary Cementitious Materials
SCGPC	Self-Compacting Geopolymer Concrete
SCC	Self-Compacting Concrete
CKC	Calcined Kaolin Clay
MDP	Marble Dust Powder
PLC	Portland Limestone Cement
SAI	Strength Activity Index
FA	Fine Aggregate
CA	Coarse Aggregate
SP	Superplasticizer
SF	Slump Flow
PA	Passing Ability
t_v	V-Funnel Flow Time
SR	Segregation Resistance
Fc	Compressive Strength
STS	Splitting Tensile Strength
UPV	Ultrasonic Pulse Velocity

WA	Water Absorption
S	Sorptivity
I	Absorption
LOI	Loss on Ignition
MK	Metakaolin
NS	Sodium silicate
NH	Sodium hydroxide
C-S-H	Calcium-Silicate- Hydrate
MRA	Multiple Regression Analysis
R	Correlation Coefficient
R^2	Determination Coefficient
SPSS	Statistical Package for the Social Sciences
SCGPC	Self-compacting geopolymer concrete
AASA	Activated Alum Sludge Ash
PUNDIT	Portable Ultrasonic Non-Destructive Digital Indicating Tester
POFA	Palm Oil Fuel Ash
HRWR	High-Range Water Reducing
VMA	Viscosity-Modifying Admixture
VEA	Viscosity Enhancement Admixture
wt	Weight of materail
NVC	Normal Vibrated Concrete
W/B	Water / Binder Ratio
ITZ	Interfacial Transition Zone
SF	Silica Fume

GGBS	Ground Granulated Blast Furnace Slag
SAI	Strength activity Index
SCLCC	Self-Compacting Limestone Cement Concrete
CC	Calcined Clay
NP	Natural Pozzolana
KC	Kaolin Clay
SSA	Specific Surface Area

CHAPTER ONE

INTRODUCTION

Chapter One

Introduction

1.1 Background

One of the essential ingredients in making concrete is cement. However, because of the enormous carbon dioxide concentration (CO_2) released through the atmosphere during cement production, the earth suffers severe harm. In order to preserve ecological equilibrium, CO_2 emissions must be controlled as they are a major contributor to global warming. This criterion, which included the synthesis of additional cementitious ingredients and waste byproducts, was the basis for the invention of the geopolymer. According to estimates, the manufacturing of ordinary Portland cement(OPC) raises CO2 emissions by nearly 50% from current levels by the year 2020**(Davidovits 1991).** Therefore, new binders are required to replace the regular portland cement in order to preserve the environment from the effects of cement production.

As a result of the cement industry, greenhouse gases are emitted, and about 7% of gas CO_2 is emitted. It is necessary to create an alternative sustainable technology in order to reduce these negative effects of the cement business. Alkali activated binders with improved durability behavior and greater engineering features can be used to accomplish this.

It was created by **(Davidovits 1991)** to describe a class of mineral binders with a chemical composition, resulting in low-cost and environmentally friendly construction materials. Geopolymer concrete (GPC) is an innovation construction material which shall be produced by chemical action of inorganic molecules. Because it substitutes industrial waste products like fly ash FA, GGBS, CKC, etc. for cement as a binder

material, geopolymer concrete is a new invention. When making geopolymer concrete, GGBS and fly ash are the most often used industrial by-products .

However, the compaction that is done at the time of casting may also affect the strength of any concrete. However, with vast and intricate structures, it can be challenging to guarantee complete compaction. Additionally, competent workers are needed for the installation of fresh concrete to ensure adequate compaction and achieve the maximum strength of the hardened concrete **(Resheidat andAlzyoud 2008).** When used under these circumstances, typical vibrating concrete could put workers at risk and raise questions about the concrete's strength and longevity. Self-compacting concrete (SCC) is one of the innovative concrete that is progressively used for experimental jobs and actual projects, which achieves the strength and durability qualities of the concrete, is one approach of resolving these issues at the construction site**[(Hemant and Khitoliya 2009**)and(**Hariyadi and Tjaronge 2010**)].**

Since self-compacting concrete (SCC) is self-weighted, it can put into any corner of the construction's form work. SCC was created to ensure adequate compaction and to make it simple to put concrete in constructions with obstructed reinforcing and in confined spaces. SCC is currently the most widely used building construction material. Concrete must be sufficiently compacted upon placing in order to achieve the intended strength and durability. Due to a shortage of good workers in the year 1980, it was originally created in Japan, According to **(Ouchi 1999)**. Okamura in1986 originally recognized the necessity for SCC, and the first experiment was developed in 1988. SCC has many benefits over ordinary concrete, provides safer working conditions, uniform and complete consolidation, enhanced

durability, quicker construction times, reduce noise levels from absence of vibration, and increases bond strength, reduces the water-powder ratio and the coarse aggregate content to obtain the SCC(**Resheidat Alzyoud 2008**).

In order to develop self-compacting geopolymer concrete SCGPC, compaction in congested areas is currently being completely eliminated. However, choosing the right mixture of ingredients for self-compacting geopolymer concrete SCGPC, which environmentally freindly and have acceptable strength and durability properties, is also very challenging. Thus, the decision to design SCGPC was made while taking into account the above mentioned points.

1.2 Self-compacting Geopolymer Concrete SCGPC

Geopolymer Concrete has the potential to fail due to a lack of compaction due to the high viscosity design. SCGPC is a modern concrete that does not require vibration for placing and compaction. It can flow under its own weight, fully fill formwork, and accomplish full compaction even when there is substantial reinforcement present. Compared to ordinary concrete, the concrete produced SCGPC is more environmentally friendly and has a smaller carbon footprint.

(**Kumar and Ramesh 2016**)The ratio of water to geopolymer solids must be be carefully chosen because it affects both the workability and compressive strength of SCGPC. Additionally, the fresh characteristics of SCGPC are substantially more impacted by the fine particles than the coarse aggregate. The function of the superplasticizer in the SCGPC is to become adsorbed on the binder grains, allowing a negative charge to be applied to them, causing them to reject one another, leading to deflocculation and dispersion. So, by strengthening the pliable and toughened properties, improving the

microstructure, and resulting in better compressive strength, superior workability and performance are accomplished.

The primary criteria examined on SCGPC included the determination of the ideal sodium hydroxide molarity concentration, superplasticizer SP content, curing temperature (60-70)°C, and curing time. In general, by-products are employed as binder materials because they contain reactive silica (Si) and aluminum (Al) in the composition, such as fly ash (FA), ground granulated blast furnace slag (GGBS), calcined kaolin clay (CKC), rice husk ash (RHA), and silica fume (SF) **(ChennurJithendra and Elavenil 2017)**. The addition of (SP), which also improves the workability qualities, improves the SCGPC filling and passing ability. The choice of constituent materials for SCGPC is mostly determined on the need for strength, cost, and user desire, among other factors.

(Kumar and Ramesh 2016) study SCGPC experimented with the use of GGBS, FA, SF, and other sustainable construction methods. In the world of SCGPC, experiments to improve features including delayed setting time, reduced superplasticizer use, and altered heat curing techniques are among the difficult issues that need to be resolved. Self-compaction and the usage of geopolymer cement are combined with the benefits of both in this kind of concrete. Perivous demonstrate that SCGPC has only seen a small number of tries. This study's goal is to investigate the viability and latency of self-compacting geopolymer concrete SCGPC created from locally accessible resources and trash. In this work, CKC the main pozzolan used in various combinations, is used in self-compacting geopolymer concrete (SCGPC).

The cementitious material calcined kaolin clay (CKC) conforms with **(ASTM C618, 2005).**It has been used for a very long time to make porcelain, a kind of ceramic material. When kaolinite clay is heated to

between 700 and 800 °C, it is thermally activated to produce calcined kaolin (Al2Si2O7), a pozzolanic material **(Liew et al., 2012;and Abo-El-Enein et al., 2014).** Lower calcining temperatures (600-900°C) are necessary for CKC compared to Portland cement (1450°C) **(Scrivener 2014),** the lower calcination temperature results in less energy being consumed, which lowers the cost of production.

Ground granulated blast furnace slag GGBS is a byproduct of making iron in a blast furnace by heating iron ore, limestone, and coke to 1500°C . When these substances melt in the blast furnace, molten slag and liquid iron are both produced. The molten slag floats above the molten iron because it is lighter than it.

Silicates and alumina from the original iron ore's majority are present in the molten slag, along with some oxides from the limestone. The molten slag is cooled using high-pressure water jets as part of the granulating process. As a result, the slag is swiftly quenched, forming granular particles that are typically no larger than 5 mm in diameter. Larger crystals are unable to form due to the quick cooling, leaving behind granular calcium aluminum silicates that make up around 95% of the material. The dried and ground-to-a-very-fine powder GGBS, which is used in regular Portland concrete as a mineral additive or as a component of blended cement, typically replaces 35 to 65% of the binder, is produced from the further processing of granulated slag. Concrete's strength and durability are increased by adding GGBS, which also increases the useful life of concrete structures. The high concentrations of alumina and silica in GGBS, which are required for the geopolymerization reaction to occur, make it a useful source of aluminosilicates **(Kumar and Santhi, 2018).** Using GGBS has some potential advantages for the environment, including producing less carbon

dioxide than regular portland cement and improved workability (For example, simple to mix, move, place, and compact, etc.)

(**Lee & Cheng 2020)** is studied that marble masonry waste is used as the marble dust powder (MDP). Industrial waste products from MDP facilities that have been collected as sludge. It was a by-product of the shaping and sawing of marble. In order to assess whether it might be used in the production of mortar and concrete, it was described from a physical and chemical standpoint. The experimental examination was made due to the effect of marble powder at different levels of cement replacement, looking specifically at the dynamic moduli of elasticity and damage states due to fracture. MDP exists naturally nowadays and can be used with standard construction materials. The marble-based geopolymer concrete was discovered to have good workability and to be resistant to temperature variations. The findings demonstrated the tremendous potential for future engineering development of marble-based geopolymer concrete **.**

In order to activate the binder components, an alkaline activator solution (AAS) is utilized in the production of SCGPC. Na_2SiO_3 (Na_2O = 13.7%, SiO_2 = 29.4%, and H_2O = 55.9% by mass) and sodium hydroxide (NaOH) in the form of pellets with a purity of 97%–98% make up the AAS. The reaction happens more quickly when soluble silicates, like sodium silicate, are included in the alkaline activator than when only alkaline hydroxides are utilized (**Palomo et al., 1999).** As an alkaline activator, sodium silicate solution was added to the sodium hydroxide solution to speed up the interaction between the source material and the solution (**Van Deventer et al., 2000).**

1.3 Advantages of Self-Compacting Geopolymer Concrete (Cong *et al*.2021)

- It can be put more quickly than the ordinary Portland concrete without any mechanical or hand vibrators.

- The concrete can be filled easily either in restricted sections or in hard-to-reach areas.

- By employing this kind of concrete, the homogeneous architectural surface finish is accomplished, to create different architectural shapes and smooth surface finishes by using this type of concrete over conventional concrete.

- It minimizes the gaps between concrete and reinforcement with a better consolidation effect around reinforcement.

- It increases the bond strength between concrete and reinforcement.

- It improves uniformity in concrete and minimizes voids.

- The workable characteristics increase with of concrete this usage

- It may not create any disturbance to the form work, while in case of vibrators are used somewhat of disturbance may create due to mechanical action of instruments.

- Decrease the construction period, labour cost, reduce noise pollution and resulting cost savings.

- SCGPC has improved attributes over conventional concrete, including higher productivity and working conditions.

- The internal segregation can be improved between solid particles and the surrounding liquid.

1.4 Limitations of Self-Compacting Geopolymer Concrete(Bheel & Khahro (2021).

- The mix design of self-compacting geopolymer concrete requires more technical experience person.

- The mixing time of SCGPC may be longer than that of conventional concrete to ensure uniformity and homogeneity in the concrete.

- Super plasticizers are used to get better workability of concrete and it results in total cost.

- plastic shrinkage cracks develop as a result of the low water-to-cement ratio in concrete.

- .Required skilled employee and labour.

1.5 Applications of Self-Compacting Geopolmer Concrete(Patel and Shah (2018)

- It is used for floor repairs in industries.

- It is used in high way and road constructions.

- Precast construction elements like beams and slabs.

- It is used in military fields.

- It is used in constructions like pavement, retaining walls and water tanks etc.

- Composite panels that are fireproof.

- It is used in precast bridge decks

- Retrofitting the structure's structure and doing exterior repairs.

- potential use in decorative and artistic projects.

- It is used in offshore applications.

- casting of waste containment systems, electric power poles, and railroad sleepers, among other things.

1.6 Research Significance

The creation of a non-cement binder using pozzolanic and waste materials CKC, GGBS and MDP is important for the reasons listed below. Due to a variety of benefits, including a decrease in the need for cement, an increase in the durability of concrete, and others.SCGPC-related studies using those components in binary and ternary combinations contained on CKC and MDP are scarce. Despite significant reviews analyzing the effect of combining GGBS and MDP on the results of self-compacting geopolymer concrete SCGPC, the desire to reach the goal of sustainable concrete and binders has made these pozzolanic and waste materials a substitute for cement.Thus, it is significant and meaningful to predict the creation of a new binder using waste and locally accessible pozzolanic material.

In the current study, calcined kaolin clay CKC based geopolymer materials are partially replaced with marble dust powder MDP or ground granulated blast furnace slag GGBS. SCGPC have undergone durability performance testing as well as tests on their initial qualities and hardened properties. Additionally, empirical models that predict the compressive strength of SCGPC have been created. The results obtained when replacing OPC completely, it will not only increase the quality of concrete but will also be beneficial for the environment.

1.7 Scope and Objectives of the Study

Numerous studies have examined the behavior of self-compacting geopolymer concrete employing a range of different source materials, such as FA, GGBS, and silica fume. In the current study, CKC, GGBS, and MDP are blended in binary and ternary combinations for self-compacting geopolymer concrete, and curing temperature is used to create the concrete fresh, hardened properties as well as its durability performance. In chapter

four, the findings of such investigations will be discussed. More specifically, the study sought to accomplish the following goals:

1. To identify and evaluate the physical and chemical properties of CKC, GGBS and MDP.

2. To determine the pozzolanic activity of CKC, GGBS and MDP, by measuring their strength activity index to determine their suitability to replace cement partially.

   3. To develop an optimal mix that produces SCGPC utilizing CKC, GGBS and MDP.

   4. To evaluate the fresh properties of SCGPC mixtures. As fresh state tests, the slump flow (D (mm) and T_{500mm} (s)), V-funnel time, L-box, and segregation resistance are performed.

5. To investigate the hardened properties of SCGPC, including the bulk density, compressive strength, splitting tensile strength, and ultrasonic pulse velocity (UPV) at various ages.

6. To investigate the durability characteristics, including water absorption, porosity, and sorptivity of SCGPC.

7. To predict the compressive strength of SCGPC at different ages using the multiple regression analysis method and to determine the relationship between measured and predicted compressive strengths. Also, figuring out a relationship between compressive strength and ultrasonic pulse velocity (UPV) by SPSS program analysis.

8. The main objective of this study is to produce concrete that is environmentally friendly, as well as to reduce damages from cement production and reduce the risk of carbon dioxide gas.

1.8 Structure of the Thesis

This thesis has a total of five chapters. Each chapter is described as follows:

Chapter One: provides a short overview of the present thesis, the significance, objectives, scope, and structure.

Chapter Two: primarily gives the definition and briefly describes the characteristics of SCGPC. Then, it provides production approaches and focuses on the performance criteria of SCGPC. This chapter also introduces common pozzolanic materials and waste materials (GGBS and MDP). In this regard, the properties of calcined pozzolanic materials CKC, GGBS and MDP, used in this study, are described based on the perious studies of literature and documents. The chapter, highlights also the key properties of fresh, hardened, and durability of concrete employing these ingredients.

Chapter Three: It explains the experimental procedure, including materials utilized, mold preparation, mixing, casting, curing, evaluating the study specimens, and SPSS program analysis.

Chapter Four: presents the results and discussion of the different experiments as mentioned in Chapter three.

Chapter Five: provides a summary of the research findings and gives several recommendations for future study. The thesis ends with a reference list.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO
REVIEW OF LITERATURE

2.1 Background

In the last two decades, concrete has no longer remained a material consisting only of cement, aggregates, and water, but has become an engineered, custom-tailored material with several new constituents to meet the many varied requirements of the construction industry. Exploring current methods and their related advantages and weaknesses can be extremely important for any research or innovation-centred initiative. This helps researchers develop or implement a more efficient and effective solution to reach their expected goals. Research in the field of building or civil engineering has increased dramatically to analyze the factors responsible for reducing harmful emissions from these industries, keeping natural resources from being exhausted, etc. To ensure the development of an eco-friendly solution, the purpose of this research was to create concrete from inorganic materials that would significantly reduce CO_2 emissions. It is important to achieve the objective of effective innovation utilization and identification of different methods implemented to date. The same as **(Jeyaseela and Vishnuram 2015)**

The background and overview are provided in this chapter, the self-compacting concrete (SCC), geopolymer concrete (GP), source materials and geopolymers. The study of literature survey corresponding to the self-compacting geopolymer concrete (SCGPC) has done in this chapter. The same as **(Kumar and Santhi 2018)**

Finally, the influence of fresh, hardened, and durability properties of self-compacting concrete and self-compacting geopolymer concrete that relate to this study is discussed and reviewed in this chapter.

2.2 Self-Compacting Concrete

Self-compacting concrete (SCC) is one of the innovative concrete that is progressively used for experimental jobs and actual projects. It reaches every edge of the formwork and pierces the dense reinforcement, and is solidified by its weight. The performance criteria for the properties of SCC are presented in Table 2.1

Table 2.1: Performance Criteria for SCC (EFNARC, 2005)

Assessment	Testing	Classes		
Filling ability	Slump flow test	*Slump class*	*Slump flow (mm)*	
		SF1	550-650	
		SF2	660-750	
		SF3	760-850	
	T500, V-funnel	*Viscosity class*	*T_{500} time (s)*	*V-funnel time (s)*
		VS1/VF1	≤ 2	≤ 8
		VS2/VF2	>2	9 - 25
Passing ability	L-box test	*Passing class*	*h_2/h_1*	
		PA1	≥ 0.8 with two bars	
		PA2	≥ 0.8 with three bars	
Segregation resistance	Sieve segregation test	*Class*	*Segregation Percentage %*	
		SR1	≤ 20%	
		SR2	≤ 15%	

2.3   Geopolymer Concrete GPC

In the brief overview of the different works of literature associated with SCC concrete was given in the previous section and it was found that the addition of other materials, commonly known as binders such as fly ash (FA), ground granulated blast furnace slag (GGBS), calcined kaolin clay(CKC) etc., showed significant improvements in various properties such as toughness, endurance, fresh SCC properties, etc. **(Davidovits, 1999),** indicated that by combining silicon and aluminum with alkaline liquids in waste or by-product materials derived from geological sources, such as FA and GGBS, binders might be produced. He referred to these as geopolymers or binders.

GPC is one of the groundbreaking inventions and it was created by**(Davidovits,1999),** which results in low-cost and eco-friendly building materials. GPC is a cutting-edge binding substance that can be created by completely substituting cement in manufacturing processes (PC). Since fly ash, ground granulated blast furnace slag (GGBS), calcined kaolin clay (CKC), and other industrial waste products were employed as binder materials rather than cement, geopolymer concrete is a novel concept. Industrial wastes or waste materials were utilized as a binder in the production of eco-friendly concrete **(Davidovits, 1991; Temuujin & van Riessen, 2010),** and they significantly contributed to the strength of geopolymer concrete.

2.4   Self-Compacting Geopolmer Concrete SCGPC

The industrial wastes or waste materials based Geopolymer was introduced to SCC as a way to cut back on cement use while enhancing self-compatibility. Geopolymer Concrete had the potential to fail due to a lack of compaction due to the high viscosity design. SCGPC is an advanced concrete for positioning and compaction that does not require vibration,

considering that fly ash (FA), alkaline solution, and superplasticizer all contribute to the binding process and aid in the development of formation and strength. In SCGPC, the matrix phase aids in the binding of unblended ingredients such as coarse aggregates, fine aggregates, and other materials in order to attain the necessary workability qualities **(Fareed,Muhd and Nasir 2013)**.

Fly ash is used as the source material, together with sodium hydroxide (NaOH) and sodium silicate (Na2SiO$_3$) solutions, super plasticizers (SP), and alkaline materials, to create self-compacting concrete that incorporates geopolymer. Tests are carried out by varying water to geopolymer solids ratios, curing temperature and extra water on SCGPC mixes. Geopolymer source materials are mostly chosen depending on the amount of silica (Si) and aluminum (Al) they contained. Generally, the by-products wastes or pozzolainc materials like fly ash (FA), ground granulated blast furnace slag (GGBS), glass powder (GP), calcined kaolin clay (CKC), (RHA) and (SF) aroi utilized as binders since the composition contains reactive silica and alumina **(ChennurJithendra Reddy & Elavenil,2017)**.

The factors that are primarily researched on SCGPC included the choice of the ideal sodium oxide molarity concentration, SP content, curing temperature, and curing time. In order to accomplish sustainable construction methods, SCGPC tried using pozzolanic materials as GGBS, silica fume, etc. Experiments for improving the properties such as delayed setting time; reducing amount of super plasticiser; altering methods of heat curing are some of challenging terms which has to be rectified in the world of SCGPC.

2.5 Pozzolanic Materials

Pozzolan is defined as siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but will in finely divided form and presence of moisture, chemically react with calcium hydroxide at normal temperature to form compounds possessing cementitious properties **(ASTM C311, 2005)**. Additionally, **(Neville, 2011)** added that pozzolans are materials, either man-made or natural, that include reactive amorphous silica. In the presence of water, silica and calcium hydroxide $(Ca(OH)_2)$ in cement can mix to generate stable calcium silicates with cementitious characteristics.

The American Society for Testing and Materials has specified coal fly ash and raw or calcined natural pozzolan for use as a mineral ingredient in concrete when cementitious or pozzolanic activity is necessary **(ASTM C618, 2005)**. Pozzolans are divided into three classes: class N, class F, and class C. The chemical and physical parameters of the Specification for all types of pozzolans are listed in Table 2.2.

The following are the major justifications for using inert and pozzolanic additions:

1- To improve the stability and the rheology.

3- To extend the consistency retention of fresh concrete.

4- To reduce hydration heat and therefore reduced risk of cracking due to thermal strains.

5- To lower the probability of damages that may be caused by the alkali-silica reaction.

6- To Increase the concrete strength to obtain SCHSC.

Table 2.2: Chemical and Physical Requirements of Pozzolanic Materials

(ASTM C618, 2005)

Chemical and physical requirements	Class of pozzolanic materials		
	N	F	C
$SiO_2 + Al_2O_3 + Fe_2O_3$, min (%)	70.0	70.0	50.0
SO_3, max, (%)	4.0	5.0	5.0
Moisture content, max (%)	3.0	3.0	3.0
Loss on ignition, max (%)	10.0	6.0	6.0
Na_2O, max (%)	1.5	1.5	1.5
Fineness, amount retained when wet-sieved on 45 μm (No. 325) sieve, max (%)	34	34	34
Minimum strength activity index at 7 days compared with OPC, percent of control	75	75	75
Minimum strength activity index at 28 days compared with OPC, percent of control	75	75	75
Water requirement, max, percent of control	115	115	105
Soundness, Autoclave expansion, max (%)	0.8	0.8	0.8
Density, max variation from average, (%)	5	5	5

2.5.1 Pozzolanic Activity

The term 'pozzolanic activity' covers all reactions occurring among the active constituents of pozzolanic materials, lime, and water. The pozzolanic reaction is the chemical reaction that occurs in portland cement upon the addition of pozzolans. The pozzolanic reaction converts a silica-rich precursor with no cementing properties into a calcium silicate with good cementing properties. Cementitious products are also formed as a result of the chemical reactions between alumina and calcium hydroxide, which form calcium aluminate hydrates. In this process, the hydration of the CaO liberates $Ca(OH)_2$, which causes increased pH values up to approximately (12.4). Under these conditions, pozzolanic reactions occur: the Si and Al combine with the available Ca, resulting in cementitious compounds called calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H) **(Yong & Ouhadi, 2007; Chen & Lin, 2009).**

Due to the pozzolanic activity of these materials, they have been used in concrete construction as supplements to cement. Therefore, this approach will be a useful way to reduce cement demand. Utilizing pozzolanic materials as alternative cementitious materials in concrete provides a more sustainable concrete technology through the creation of a balance between development and the environment **(Safiuddin, 2008)**. Additionally, the carbon dioxide emissions linked to cement manufacture may have negative effects on the environment **(Şahmaran et al.,2009)**. The current study focused on a type of pozzolanic material called metakaolin, which is generally available.

The alkaline activators in the study combination of sodium hydroxide (NaOH) solution and sodium silicate (Na_2SiO_3) solution in the ratio 1:2.5

2.5.2 Calcine Kaolin Clay (CKC) or Metakaolin (MK)

Pozzolans can be of natural or industrial origin. (CKC) is distinctive in that it is created especially for cementing applications and is obtained from a naturally existing mineral rather than being a by-product of an industrial process or being fully natural. Contrary to by-product Pozzolans, which can have varying compositions, (CKC) is manufactured under strictly regulated circumstances to enhance its color, eliminate inert impurities, and regulate particle size. Consequently, a lot more purity and pozzolanic reactivity can be attained (**Justice,2005**). (CKC) has a lot of potential as a cementitious material because it can enhance a number of concrete's qualities while consuming less cement. these pozzolanic materials are mostly composed of silica and alumina. The calcined clay pozzolana was widely used in the last couple of decades in several countries in the world (**Lea, 2004**). The raw material input in the manufacture of CKC is kaolin clay. Since clays are found all over the world in the earth's crust, they stand out from other pozzolanic minerals in general because of their accessibility. In igneous rocks like granite, which were created by the solidification of molten components from the earth's interior, clay minerals have been discovered. Approximately equal amounts of the mineral are present in both granite and mica $(K_2O.3Al_2O_3.6SiO_2.2H_2O)$, Quarts (SiO_2), and Feldspar $(K_2O.Al_2O_3.6SiO_2)$, which when exposed to water and air's effects are the least stable. The kaolin clays were produced when feldspar disintegrated over an extended period of time while being exposed to air and water. After all the Potash and Silica in the Feldspar has been dissolved, the remaining material combines with water to form the clay mineral Kaolinite, as illustrated in Equation (2-1) (**Ryan,2013**).

$$K_2O.Al_2O_3.6SiO_2 \longrightarrow Al_2O_3.2SiO_2.2H_2O \qquad (2-1)$$
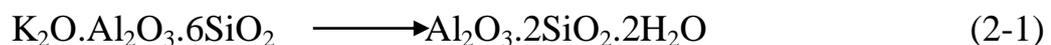
Minerals gain a distinct pozzolanic activity when burned at temperatures between 600°C and 900°C **(Scrivener,2014)**. The nature and number of clay minerals in the raw material, the calcination conditions, and the final product's fineness all play major roles in how pozzolanic qualities emerge in calcined clays.

2.5.2.1 Reactivity and Calcination Process

To remove structural water, clays can be thermally activated by being heated to a specific temperature, the crystal structure is destroyed, and new material with pozzolanic property is formed. This phenomenon is called dihydroxylationPrior research suggested that Kaolinite, following calcination at a certain temperature and under controlled circumstances, forms Calcined Kaolin Clay (CKC) that exhibits pozzolanic properties. MK is an off-White ultrafine powdered form of anhydrous alumino-silicate derived from the calcination of raw kaolin clay **(Ibrahem& Wahab,2008)**.Compared to Portland cement, metakaolin must be produced at lower calcining temperatures (600–900 ^{o}C) (1450 ^{o}C) **(Scrivener,2014)**. Because of the lower calcination temperature, less energy is used during manufacture, which lowers the cost.

Several research have examined the ideal activation temperature of several typical clay materials and analyzed how reactive the calcined clays are when combined with cement. **(Sabir et al., 2001;Bich et al., 2009; Siddique & Klaus, 2009)** conducted that the varying ideal activation temperature was in the range 650-850 °C, according to its minerals cleanliness and impurities, the characterization procedure, etc.

The dehydroxylation of kaolinite, Cement hydration, and Pozzolanic reactivity process are shown in Equations (2-2). (CKC) is a reactive pozzolan that combines with free calcium hydroxide (Ca(OH)$_2$) to produce

new cementitious compounds that replace the weak and soluble calcium hydroxide in the system with cementitious strength and improved durability qualities **(Poon et al., 2006; Aiswarya et al., 2013.**

$$Al_2O_3.2SiO_2.2H_2O \xrightarrow{650-850°C} Al_2O_3.2SiO_2 + 2H_2O$$

Kaolinite   **Metakaolin   Steam**

(2-2)
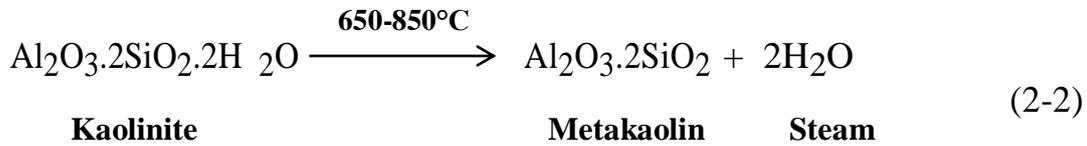
The calcination of kaolin clay in kiln. Less harmful gases that cause environmental pollution are released during the calcination process. However, the extraction and processing of the raw material for CKC may also result in environmental harm such soil erosion, water pollution, and the eradication of natural reserves if sustainable development methods are not adopted **(Asante-Kyei & Addae, 2016).**

2.5.2.2 Physical Properties and Chemical Composition of Calcined Kaolin Clay

Since kaolin is naturally occurring clay, therefore chemical and mineralogical compositions are highly dependent on the parent rock, climatic conditions of kaolin formation, and processes of cleaning impurities **.** The chemical and physical properties of calcined kaolin clay (CKC) and PC, as found in various studies, are presented in Table 2.3. The table demonstrates that CKC contains a lot of silica—50–60% by weight—as well as 40–45% alumina, reduced LOI values, a specific gravity range of 2.01–2.56, and a high specific surface area. Due to its high fineness and silica concentration, it plays a significant role in the creation of pozzolanic materials, which enhance the durability and strength of concrete

Table 2.3: Chemical and Physical Properties of CKC and PC (Wt.%)

Chemical properties of CKC									Reference
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O_3	K_2O	LOI	
52.68	43.11	1.38	0.3	0.2	-	0.62	0.3	1.4	(Özcan & Kaymak, 2018)
51.85	43.78	0.99	0.2	0.18	-	0.01	0.12	0.57	(Mahoutian & Shekarchi, 2015)
Sum(SiO_2+Al_2O_3+$Fe2O_3$) = 93.6			-	-	0.06	0.22	-	1	(Hassan et al., 2012)
Chemical properties of PC									Reference
20.5	5.7	2.6	62.5	2.5	3.7	0.2	0.7	1.6	(Özcan & Kaymak, 2018)
20.3	4.53	3.63	60.25	3.42	2.23	-	-	1.37	(Mahoutian & Shekarchi, 2015)
19.64	5.48	2.38	62.44	2.48	4.32	-	-	2.05	(Hassan et al., 2012)
Physical properties of CKC									Reference
Specific gravity			Mean particle size (μm)		Blaine fineness (cm^2/g)				Reference
2.42			2.6		-				(Özcan & Kaymak, 2018)
2.01			-		2120				(Mahoutian &

				Shekarchi, 2015)
2.56	-	-		(Hassan et al., 2012)
Physical properties of PC				Reference
3.14	15.0	3600		(Özcan & Kaymak, 2018)
3.15	-	3880		(Mahoutian & Shekarchi, 2015)
3.15	-	4100		(Hassan et al., 2012)

2.6 Waste Materials

Each year, the globe produces millions of tons of waste, the majority of which cannot be recycled. Recycling garbage also uses energy and pollutes the environment. Additionally, the ecology is greatly endangered by rubbish disposal and accumulation in the suburbs. Utilizing garbage is a suitable strategy for accomplishing two objectives: getting rid of waste and improving concrete. Waste-contained concrete must be thoroughly assessed in order to establish its potential because the market for green concrete is growing. Worldwide quarrying is thought to yield several million tons of waste materials, including industrial byproducts. Hence, utilization of these wastes has become an important alternative material towards the efficient utilization in concrete for improved harden properties of concrete. The following materials are utilised in the current research as SCGPC source materials.

2.6.1 Ground Granulated Blast Furnace SlagGGBS

Grinded granulated blast furnace slag is a by-product of the production of iron in a blast furnace (GGBS). It is suitable for use in ready-mix concrete, the creation of significant amounts of site-batched concrete, and the fabrication of precast items since it is inexpensively available in large quantities and needs storage facilities. Blast furnaces are fed with carefully formulated mixtures of iron ore, coke, and limestone at a temperature of around 1600 oC. When iron ore is reduced, iron is produced, and this iron sinks to the bottom of the furnace. Because molten slag is so light, it floats on top of molten iron.

GGBS is utilized in regular Portland concrete, either as a waste product or as a component of blended cement, typically in the range of replacement by 35 to 65% of the binder. The usage of GGBS in the concrete improves the strength and durability properties further lengthens the useful life of concrete constructions. On the other hand, using GGBS may have some positive effects on the environment because it creates less carbon dioxide than regular portland cement and has better workability (i.e., easy to mixing, transporting, placing and compacting etc.). The cementitious properties of GGBS are influenced by a number of factors, including the chemical composition of the GGBS slag, the alkali concentration of the reacting system, the amount of glass in the GGBS, the fineness of the GGBS and Portland cement, and the temperature during the early stages of hydration.

To create these materials, the issues of waste management and environmental contamination have also surfaced **(Singh et al. 2008).** The first country to produce GGBS, which was also utilized for general purpose concrete in North America, was Germany. GGBS has frequently been

employed in cement compositions as a metallic or mixed-cement component (**Demirboga 2003**).

2.6.1.1 Slag Chemical and Physical Characteristics

Slag has a more chemically comparable makeup to OPC. It is used as a pozzalan and contains silica dioxide (SiO2) (30–40%) and a significant amount of calcium oxide (CaO), 40%. Due to the different feeding of raw materials, it differs greatly (**Lang 2002**). When combined with cement, slag has superb cementitious characteristics.

According to earlier research, the physical characteristics and chemical composition of slag are shown in **Table (2.4)**. According to this Table, GGBS, also known as slag, is lighter than OPC. The specific gravity of slag ranges from (2.7 to 2.90), and its fineness depends on the grinding process, but it is typically between 2900 and 5000 cm2/g. Its loss of ignition (LOI) is just over 1%, but chemical composition analyses show that it contains over 40% calcium oxide and over 40% silica. However, slag's bulk density ranged from 1200 to 1300 kg/m^3.

Table 2.4 Physical and chemical properties of GGBS Hanson Cement Purfleet Regen GGBS

Physical properties			
Specific gravity	Fineness		
	Blaine (m^2/Kg)	Median particale size	color
2.9	456	----	white

Chemical composition (%)													
SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	CaO	MgO	SO$_3$	Na$_2$O	K$_2$O	LOI	Tio$_2$	cl-	C	Insoluble Residue	Moisture
34.40	13.26	0.43	38.94	8.82	0.29	0.38	0.59	1.17	0.94	0.01	0.09	0.41	0.11

2.6.2 Marble Dust Powder (MDP)

Marbles are natural stones that are generated when limestone and dolomite are recrystallized at high temperatures and pressures (**Cheng&Ding,2017**). Marble plants produce two forms of trash, marble waste slurry, and marble waste powder, as a result of their cutting and polishing procedures. Because the ornamental stone industry has yet to create an efficient valorization procedure for these waste kinds, they are either held in warehouses for future use in other applications or disposed of in landfills, posing environmental risks (**Tekin 2016; Thakur&Pappu 2019**). (**Colangelo & Roviello2018**). Marble dust powder (MDP) which is an inert material obtained as an industrial by-product during sawing, shaping, and polishing of marble has also successfully been used as an addition in concrete. Numerous million tons of MDP are thought to be produced globally during quarrying.

The performance increase of concrete demonstrates the technical significance of incorporating discarded marble dust in the manufacturing of concrete. The economic benefit typically results from replacing expensive and/or rare ingredients with inexpensive ones. Environmentally speaking, recycling leftover marble dusts reduces landfill trash and conserves more natural resources (**Temuujin & van Riessen,2010**) . Hence utilization of marble powder has become an important alternative material towards the efficient utilization in concrete for improved some properties of fresh and hardened self-compacting concrete (SCC)[(**Alyamaç& Ince,2009)and(Güneyisi & Özbay,2009)]** .The mechanical characteristics characteristics of marble-based geopolymer were investigated with varying marble/BFS weight ratios and SiO2/Na2O mole ratios after mixing blast furnace slag (BFS) and alkali solution. The compressive strength of

marble-based geopolymer can reach 44 MPa after 120 minutes of setting time, according to the results of the experiments (**Cheng&Ding,2017**).

2.6.2.1 The Chemical and Physical Characteristics of Marble Dust Powder

The physical & chemical properties of MDP are given in table (2.5) shown below and table (2.6) respectively. According to the previous studies (**Aliabod, 2014 and Rodrigues, 2015**), the results of calcium oxide (CaO) content in MDP ranging from 33 to 85 percent in compliance with the criteria for natural cement, which range from 31 to 57 percent. But because they contain substances like silicon dioxide (SiO2), aluminum dioxide (Al2O3), iron oxide (Fe2O3), and magnesium oxide (MgO), they do not mix well with cement.

Table (2.5) Physical Properties of MDP

Physical properties	MDP
Specific Gravity	2.63
Colour	white
Form	Powder
Odour	Odourless
Moisture Content (%)	0.60
sieve	0.90mm
hardness	3 on Mohr's scale
Water absorption	0.97%

Table (2.6) Chemical constituents of MDP

Chemical compound	According to (Ali A Aliabdo) MDP (%)	According to (Rodrigues) MDP (%)
Calcium oxide (CaO)	83.22	63.61
Silica dioxide (SiO$_2$)	1.12	18.65
Magnesium oxide (MgO)	0.52	1.54
Iron oxide (Fe$_2$O$_3$)	0.05	4.83
Aluminum dioxide (Al$_2$O$_3$)	0.73	4.83
Sodium oxide (Na$_2$O)	1.12	-
Potassium oxide (k$_2$O)	0.09	-
Sulfur trioxide (SO$_3$)	0.56	3.22
Lost on ignition in %	2.5	

2.7 Fresh Properties of Self-Compacting Geopolmer Concrete

The filling capacity, passage capacity, and segregation resistance are the three main fresh features of self-compacting geopolmer concrete (SCGPC). These requirements must be addressed, irrespective of the complexity of the mixture design or other aspects such as cost. The filling ability and stability of SCGPC in the fresh state can be defined by four key characteristics. Each characteristic can be addressed by one or more test methods are presented in Table 2.7. A change in one feature typically has an impact on both or both of the others. Poor filling and segregation, for instance, can result in insufficient passing ability, or blocking. Segregation danger could develop with increased filling capacity. SCGPC strikes a balance between segregation resistance and filling capabilities.

Table 2.7: Tests Method for Assessment Properties of Fresh SCGPC

Characteristic	Preferred test method
Flowability	Slump-flow test
Viscosity (assessed by the rate of flow)	T_{500} Slump-flow test or V-funnel test
Passing ability	L-box test
Segregation	Segregation resistance (sieve) test

The capacity of the new concrete to flow into and fill the voids within the formwork under its weight is referred to as "filling ability" **(Bartos, 2000; EFNARC, 2005).** It relates to the SCC's formability, self-leveling ability, and finishing capacity. To accomplish self-consolidation capacity, SCC must possess the filling ability. When using the right casting procedure, this feature is essential for placing concrete **(ACI 237R, 2007).** The amount of aggregate, Filling capacity is significantly influenced by the W/B ratio, the quantity of binder, and the HRWR dosage of concrete **(Okamuraand Ozawa,1995).**

By utilizing a superplasticizer and lowering the amount of coarse aggregate in the concrete, it is possible to produce high flowing ability by reducing the friction between the solid particles (coarse aggregates, sand, and powder) **(Khayat, 1999; Sonebi and Bartos,2002). Kumar and Saini (2015),** By reducing intermolecular friction, adding more water may enhance flow, but it also reduces viscosity, and excess water can have negative effects on durability and strength. , which reduces both yield stress and viscosity, the use of superplasticizer reduces interparticle friction while at the same time maintaining the deformation capacity and viscosity of CKC by dispersing the CKC particles. In addition, it reduces the degradation of solid properties compared to added water.

Passing ability is defined as the ability of fresh concrete to flow through tight openings, such as spaces between steel reinforcing bars, without segregation or blocking **(Bartos, 2000; EFNARC, 2005)**. Due to SCC's excellent passing capacity, It might be set up and consolidated using sturdy reinforcement bars in severely reinforced structures without any aggregate blockage **(ACI 237R, 2007).**

The concrete passing ability is influenced by the same elements that determine filling capacity. How well a pass is received is also influenced by the quantity and spacing of the reinforcing bars. A good passing ability can be reached by increasing the filling capacity of fresh concrete and lowering the segregation of coarse particles. As depicted in Figure 2.1, some aggregates may bridge or arch at tiny gaps that block the rest of the concrete.
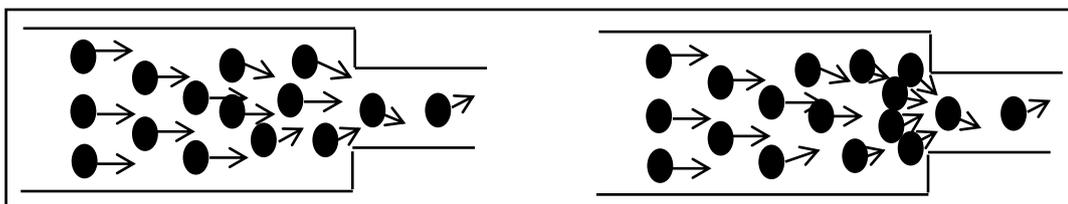
Figure 2.1: Schematic of Blocking **(Billberg et al., 2004)**

Fresh concrete has the ability to resist segregation, also known as stability, by remaining uniform during and after placement without experiencing any stability loss as a result of bleeding, mortar separation, or coarse aggregate settlement **(EFNARC 2005).** If SCC lacks sufficient segregation resistance, the distribution of aggregates, in particular, becomes non-uniform. Concrete's characteristics and toughness may be impacted by this. In SCC, a good segregation resistance can be achieved by using the right mixture composition. Standard geopolymer concrete needs vibration to guarantee optimum compatibility. The vibration of concrete contributes to the noise pollution. Self-compacting concrete is a porous material that

can penetrate blocked reinforcement while filling a formwork from all sides and condensing beneath its surface (**EFNARC,2005; Boukendakdji and Kadri,2012; Kadhum and Owaid,2020; Khoman and Owaid,2022**). **Owaid,2022**). This is due to the high filling and passing capacity, as well as the excellent segregation resistance and lack of external vibration requirements.

Self-compacting geopolymer concrete (SCGPC) is a relatively new concept that combines the benefits of both SCC and GPC and might be considered the most innovative development in concrete technology. SCGPC is a new type of concrete that don't require vibration to set and can be made without using any Portland cement at all.

Improved fresh properties were reported for SCGPC mix with water to geopolymer solids ratio 0.33, curing temperature 70 ^{0}C, curing duration of 48 hours and 12% extra water (**Muhd Nuruddin et al., 2011**). They studied the effect of NaOH molarity and superplasticizer (SP) dosage on the SCGPC. The fresh properties of SCGPC were assessed by increasing molarity from 8M to 12M and the fresh properties were satisfies the **EFNARC 2005** guidelines.

Sashidhar et al. (2016) investigated the fresh characteristics of SCGPC mixtures with 100% manufactured sand and 50% class F fly ash and 50% ground GGBS (MS). The study showed that the decrease in slump flow value caused by the increase in NaOH molarity from 8M to 12M decreased slump flow value was decreased from 690 mm to 670 mm and the same trend was followed in L-box and due to increase in the quantity of NaOH increased the viscosity and reduced the fluidity of concrete which in turn increased the T50cm value. The study also showed that the decrease in filling ability caused the increase in V-funnel time.

Samuel et al., (2011) examined the impact of superplasticizer dosage and curing temperature of low calcium fly ash based self-compacting geopolymer concrete (SCGPC). Sodium hydroxide and sodium silicate were used as an alkaline activator; the concentration of the solution was kept at 12M in the ratio 1:2.5. The authors found that all the other mixes showed good filling ability and passing ability and the workability results were within the EFNARC limits of SCC.

Ushaa,et al., (2015), examined the impact of the workability characteristics of SCGPC that contained various mineral admixtures. In comparison to fly ash, GGBS and silica fume were substituted by 10%, 20%, 30% and 5%, 10%, and 15%, respectively. The water to geopolymer solids ratio by mass for all mixes was maintained at 0.33 and total powder content was fixed at 450 kg/m^3, the water content of 12% and superplasticizer dosage of 6% by mass of binder was used to all the mixes. All the samples were oven-dried at a temperature of 600 ^{0}C for 48hrs followed by ambient curing for 28days. The test results indicated that all the SCGPC In their fresh state, mixtures performed satisfactorily, although the GGBS series outperformed the silica fume series in terms of workability.

Ashraf and Henigal, et al (2017) investigated the engineering charactristes of fly ash based SCGPC. The fresh properties study concluding that sodium hydroxide between 8M to 14M expanded the viscosity and cohesiveness of SCGPC mixes and hence as the molarity increased, the workability decreased. And alkaline solution increased to fly ash ratio from 0.3, 0.4 to 0.5 leading to enhance the flowability and passing ability of the fresh concrete.

 (Kumar and Ramesh 2017), reported the use of metakaolin and ground Granulated Blast furnace slag (GGBS) to produce geopolymer concrete. As the metakaolin content increased with GGBS, the results showed that the

workability of geopolymer concrete reduced. The workability is unaffected by the increase in GGBS.

Ahmad andKontoleon, et al (2022),investigated the effect of GGBS on the workability of concrete is reduced by replacing OPC with GGBS due to the larger surface area and rough surface texture of GGBS particles. Therefore, plasticizer was recommended particularly for the higher dose of GGBS.

2.8 Hardened Properties of Self-Compacting Geopolmer Concrete

Some of the important mechanical properties of SCGPC include compressive strength, tensile strength, and ultrasonic pulse velocity (UPV). Below is a quick discussion of them. Concrete most significant mechanical characteristic is its compressive strength. Typically, for a specific combination using the same circumstances for mixing, curing, and testing of cement and aggregates **(ACI 363R,2010)** . The compressive strength of SCGPC is much higher than that of ordenary concrete. Another discovery is that, because to the higher gel/space ratio at a lower W/B ratio, the kinetics of strength enhancement in SCGPC is substantially faster than in conventional concrete. **(Persson, 2001)**.

Although concrete is not usually designed to withstand direct tension stress, tensile strength knowledge is of value in estimating the load under which cracking can occur. The absence of cracking is of great significance in maintaining the continuity of a concrete structure and in many cases in avoiding problems with durability **(Neville, 2011).** Flexural and tensile strength and compressive strength are connected. An increase in compressive strength causes a rise in flexural and tensile strength, albeit at a slower pace than compressive strength. compressive strength the

interfacial transition zone(ITZ) properties frequently have a significant role in flexural and tensile strength **(Koehler,2007; Mehta and Monteiro,2014)**. In comparison with traditional vibrated concrete, SCGPC typically has increased flexural and tensile strength, probably as a result of the improved ITZ and the better microstructure of bulk cement matrix **(Klug and Holschemacher,2003; Zhu et al.,2004)**.

Memon et al. (2013) SCGPC was studied by varying the NaOH molar content and analyzing its toughened characteristics. Results showed that SCGPC performed best at 12 M concentrations of NaOH, with characteristics degrading above 12 M.

Nuruddin and Memon (2015), examined on comparing the mechanical properties of fly ash-based SCGC to traditional concrete. Fly ash-based SCGPC was made with compressive strength of over 50 MPa and splitting tensile strength was obtained about 8.11% of its compressive strength. The flexural strength of SCGPC was lower than those predicted by ACI 318 and ACI 363 equations and was identified to be slightly lower than the range of 10-20% assigned for ordenary cement concretes.

Kumar and Ramesh (2016) examined the effect of Metakaolin (MK) and GGBS based Geopolymer Concrete (GP) on mechanical properties. Here metakaolin was increased every 10% wt. GGBS. NaOH and Na2SiO3 were used as activator solution in the ratio of 1:2.5 for 8 Molar concentrations. According to the test results, workability declined as MK concentration increased.

Sashidhar et al.(2016) studied hardened properties of SCGPC mixes made made of class F fly ash and ground GGBS in a 50:50 ratio with 100% synthetic sand (MS). Results revealed a significant increase in compressive

strength by the addition of GGBS into SCGPC mix under ambient curing temperature.

Patel and NirajShah (2018), aimed to developed a sustainable SCGPC using blended form of ground granulated blast furnace slag (GGBS) and rice husk ash (RHA). In this study, the GGBS was replaced with different percentages (0, 5, 15 and 25%) of RHA. The mechanical properties of SCGPC were studied at different temperatures i.e., ambient temperature, 60°C and 70°C. Based on test results, it is concluded that the optimum replacement of RHA was 5% at ambient temperature and 15% at 70 °C oven temperature.

Further research on SCGPC was reported on Blending of source GGBS, SF, and low calcium fly ash are examples of appropriate ingredients. **Ushaa , et al., (2015)**, replaced mineral admixtures GGBS and SF in percentages 10, 20 and 30 and SF in 5, 10 and 15 respectively to Class F fly ash SCGPC. Results proved, up to 40% replacement of GGBS with fly ash increases strength and flow properties whereas silica fume showed increase in strength up to 10% of replacement with fly ash under heat cured.

Anuradha et al., (2014), aimed to investigate the optimization of molarity on SCGPC. By using silica fume and GGBS as areplacement of fly ash, the strength characteristics of concrete were investigated. In place of fly ash, 30% silica fume and 10% GGBS were substituted to observe the maximum strength values (compressive strength, split tensile strength, and flexural strength). By using heat curing rather than ambient curing, the concrete develops early strength.

Samuel et al. (2011), examined how temperature and variations in superplasticizer (SP) affected how SCGPC behaved in terms of

compressive strength (SCGPC). They concluded that the compressive strength of concrete showed good results with the increase in SP dosage. From the results, it was also observed that the maximum compressive strength (51.52 MPa) was achieved at SP dosage of 6% with an oven temperature of 70°C, respectively.

Kumar and Sarath (2016) studied the impact of MK and GGBS based Geopolymer Concrete (GP) on mechanical properties. Here metakaolin was increased every 10% wt. GGBS. Alkalis activator were used as activator solution in the ratio of1:2.5 for 8 Molarty concentrations. From the results, it was concluded that the compressive strength, split tensile strength and flexural strength gives an increase trend with the decrease in MK content. Maximum compressive strength, split and flexural strengths were achieved for 30%MK and 70%GGBS mix which was around 38.50, 4.53 and 1.15 at end of 28days respectively.

Mahesh and Ajitha (2021),geopolymer concrete has a higher compressive strength when metakaolin and marble dust are replaced by 10% + 10%. The highest strength given is 41.28 kN/m^2. Concrete split tensile strength Concrete has higher cylinder strength when metakaolin and marble dust were replaced by 10% + 10%. 4.73 kN/m^2 is the maximum strength.

Jawahar et al. (2016), studied fly ash and GGBS-based geopolymer concrete and come to the conclusion that adding more GGBS improved the GPC's mechanical qualities when used outdoors. The oven curing can be removed from fly ash-based systems by including GGBS.

2.9   Geopolmer   concrete's   self-compacting   durability characteristics

Some of the most important SCGPC durability characteristics include sorptivity, porosity, and absorption. The term "porosity" describes the percentage of the entire volume of concrete that the interfacial transition zone, bulk cement paste, and aggregate pores all occupy. It is one of the key elements that affects how strong concrete is **(Neville, 2011).** Porosity also influences electrical resistivity, which impacts concrete's ability to resist corrosion **(Claisse et al., 2001).** There are two types of concrete's porosity, total porosity and capillary or suction porosity. **(Nokken & Hooton, 2002)**. Capillary and air porosity make up a large portion of the total porosity. Contrarily, the network of open pores that makes up concrete's capillary porosity is what makes it most notable. The transport capabilities and thus the durability of concrete are significantly impacted by capillary porosity **(Hearn et al., 1994)**. Due to the compacted pore structure, the total and capillary porosities are anticipated to be lower in SCC's high performances (7 to 15%) than in regular concrete **(Safiuddin, 2008).** In comparison to regular concrete, SCC has a more sophisticated pore system. Low W/B ratio is the main cause of this. The presence of HRWR causes cement particles to deflocculate and disperse, increasing packing and hydration levels, while the combined pozzolanic and micro-filling processes of SCC result in a more refined pore structure. **(Attiogbe et al., 2002).**

A liquid penetrates a porous solid substance, such a concrete component, during the absorption process and tends to fill the open holes (**ASTM C125, 2004**). Strong capillary action causes the absorption to be more significant in the top layer of concrete rather than its inside. The rate of liquid absorption by a dry concrete surface is one sign of concrete's resilience. The most frequent liquid in contact with the concrete is water. So, the absorptivity of concrete is commonly determined by measuring

water absorption. A concrete specimen's increase in mass as a result of water seeping into its open pores can be used to calculate it. Water penetration plays a significant part in many mechanisms of deterioration and transports numerous harmful substances from the environment. Concrete's water resistance is directly correlated with water absorption. penetrationLike other engineering characteristics, porosity has a direct impact on how much water absorbs into concrete **(Hearn et al. 1994).** The porosity controls the microstructure and, as a result, the concrete's ability to absorb water based on the relative numbers of pores of various sorts and sizes **(Hearn et al., 1997).**

Water absorption is also decreased with a decrease in porosity. High-quality concrete, such as self-compacting concrete or concrete with high performance, often absorbs less than 5% of its weight in water **(Kosmatka et al.,2002)**. Additionally, it was said that SCC's excellent performance offers water absorption of between 3 and 6%. **(Safiuddin, 2008).**

 A porous substance's propensity to absorb and transfer water through capillarity is characterized by the material quality known as sorptivity (S). The term "sorptivity" is frequently used to describe soils and porous building materials like brick, stone, and concrete. The total water absorption rises as the square root of the amount of time (t) (per area of the inflow surface) **(Hall and Hoff, 2021).** Sorptivity must be kept to a minimum to prevent the entry of harmful substances that can seriously harm a structure. In cold areas, concrete structures typically experience a mix of freeze-thaw damage and steel reinforcing corrosion from chloride infiltration from deicing salts. Given these climatic circumstances, Whole buildings are prone to early decay, which might result in extra expenses. In addition, a lot of the construction-related building materials are porous. Many technical issues, such corrosion of reinforcing steel and damage from

freeze-thaw cycling or wetting and drying cycles, are now caused by the intrusion of moisture and the transport qualities of these materials (**Shanker and Rao,2017**).

(**Frieh et al., 2014**) investigated the impact of a high replacement metakaolin concentration in the mix—up to 70% replacement by cement—on concrete's ability to absorb water. They discovered that up to 20% MK, increased MK decreased water absorption; after that, it increased MK up to 70%.

 Kannan and Ganesan, 2014, It can be seen that as the MK concentration was raised to 20%, the sorptivity gradually decreased. Water absorption significantly decreased and was lower than that of SCC that had not been blended with MK (up to 30% OPC replacement). In comparison to unblended SCC, SCC specimens blended with 30% demonstrated a sorptivity reduction of 18.82% at 28 days, per the sorptivity data.

 Barkat et al., 2019, examined the impact on self-compacting limestone cement concrete of varying local CKC weight proportions (5, 10, 15, 20, 25) (SCLCC). According to the findings, the concrete containing MK had a little bit less porosity than the control PLC. For lower MK content, the reduction in porosity was around 2% (6% and 19% for 20MK and 25MK, respectively). Except for 10MK, which displayed increased capillary absorption at 90 days of curing, a low capillary absorption for mixes with MK was seen compared to control PLC, Using high calcium bottom ash geopolymer mortars,

Chotetanorm et al. (2013), investigated the pore size and resistance to sulphate sorptivity. The substance employed was ground lignite bottom ashes (BAs), with median particle sizes of 16, 25, and 32 m. The high-calcium bottom ash geopolymer mortars had reasonably high strengths of

40.0-54.5 MPa. As the number of big pores increased, the sorptivity dropped, indicating remarkable resistance to sulphate attack.

Lavanya and Jegan(2015) investigated the durability of geopolymer concrete made with high calcium fly ash and alkaline activators. Water absorption and sorptivity measurements were also used to evaluate durability. The grades M20, M40, and M60 were selected for the inquiry. The ratio of sodium silicate to sodium hydroxide in the solution was 2.50, and the sodium hydroxide molarity was set at 12M. Over the course of 14, 28, and 45 days, samples of ambient cured concrete were examined for surface degradation, density, and strength. M20 fared substantially better than the other geopolymer concrete, losing less density and compressive strength over time.

Farhana et al. (2015) investigated the relationship between the porosity and water absorption of samples of geopolymer paste that were baked at 60°C for 24 hours before being exposed to the elements for 7, 14, and 90 days. According to this study, water absorption for pastes grew for 7 days before the sample's structure started to get denser, resulting in pore size reduction for 90 days, at which point water absorption decreased. On a mass scale,

Jeyaseela and Vishnuram (2015) published research on the durability tests of SCGPC created by substituting the fly ash by OPC up to 20%. The OPC replacement levels used in the sorptivity tests were 0, 5, 10, 15, and 20%. For SCGPC comprised of 5% OPC specimens, a lower sorptivity index was observed.

2.10 Multiple Regression Analysis (MRA)

Multiple regression is an extension of simple linear regression. MRA goal is to concurrently find two or more independent factors that can

account for fluctuations in the dependent variables. The latter was chosen because of its ability to identify relationships among several variables **(Hashim et al., 2017)**. The variable we want to predict is called the dependent variable. The variables we are using to predict the value of the dependent variable are called the independent variables. For statistical analyses for the prediction of the compressive strength, multivariable linear regression analysis (MRA) was employed by using SPSS software. The ability of the developed model to explain the relationship between the independent and dependent parameters must be evaluated by calculating the coefficient of determination (R^2) **(Jafer et al., 2016)**. **(Shubbar et al.,2018)** used a multi-regression (MR) model to examine the effects of curing time and content on the compressive strength in binary and ternary blending systems and to determine the relationship between measured and predicted compressive strengths for ordinary portland cement (OPC), (GGBS), and high calcium fly ash (HCFA). The results revealed that the proposed model explained 89.3 percent of the variance in compressive strength and that there was a high level of agreement between predicted and experimental compressive strength, with an R^2 value of 0.8701. **(Byakodi and Patil,2017)** used multivariable linear regression analysis (MRA) to predict the pre-production compressive strength of admixture concrete. Compressive strength was regarded as a dependent variable, whereas cement, rice husk ash, CKC, and temperature were regarded as independent variables. The results showed that statistical validation of experimental data was performed and both the determination coefficient (R2) and the correlation coefficient (R) values were found.

2.11 Relationship between Ultrasonic Pulse Velocity and Compressive Strength

(**Tharmaratram and Tan, 1990**) established a concrete compressive strength and UPV in a concrete (Vc) relationship (fc′) by general Equation (2-1) based on their experimental results. (**Demirboğa et al., 2004**) UPV and compressive strength for mineral additive concrete exhibit an exponential connection and demonstrated because of the general equation applies to all types of mineral admixtures as below:

$$\text{fc}' = \text{a } e^{bVc} \qquad\qquad\qquad (2\text{-}1)$$

Where

fc′: compressive strength

UPV: Ultrasonic Pulse Velocity

a , b: Empirical constants

(**Owaid et al., 2017**) discovered positive exponential relationship between UPV and compressive strength, with a determined coefficient of correlation (R^2) of 0.889 between 3 and 90 days of curing when binary mixtures (varying amounts of activated alum sludge ash (AASA), silica fume (SF), ground granulated blast furnace slag (GGBS), and palm oil fuel ash (POFA)) and ternary mixtures (AASA + SF, AASA + GGBS, and AASA + POFA) were blended as partial weight substitutes for cement.

2.12 Summary

Considering the rising demand and the use of cement in the construction of concrete, the employing of pozzolanic and waste materials is increasing day by day. This can easily be understood from the numerous research interests regarding the application of these materials and

comprehensive analysis of literature on self-compacting concrete (SCC), geopolymer concrete (GPC) and self-compacting geopolymer concrete (SCGPC) have been cited in this chapter. The research given above leads to the following conclusion that geopolymer works well as a concrete binder because it strong, long-lasting, affordable, and environmentally benign. In order to observe the characteristics of geopolymer concrete, a try has been done. So production, development and application of SCGPC containing non-cement binder from pozzolanic and waste materials (MK, GGBS and MDP is significant for the reasons listed below. Due to a variety of advantages, including a decrease in cement consumption, an increase in the durability of concrete. Although there are extensive literature reviews examining the effect of including GGBS and FA on self-compacting geopolymer concrete (SCGPC) results, SCGPC-related studies with those components in binary and ternary combinations contained on MK and MDP are limited .The current work is going to full gaps being left by the previous studies as there is avital desire to reach the objective of sustainable concrete and sustainable being material to emply pozzolanic and waste materials as an alternative to cement.Thus,the novelty have is to crate a binder by using waste and localy accessible pozzolanic materials

CHAPTER THREE

MATERIALS
&
EXPERIMENTAL
WORK

Chapter Three
Materials and Experimental Work

3.1 Introduction

The modeling and experimental research were the main components of is study. The University of Babylon/Civil Engineering Department/ construction materials laboratory served as the site of the experimental investigation. This chapter contains a detailed description of the materials used in this study as well as the experimental strategy. The methods for producing self-compacting geopolymer concrete (SCGPC). The mixing, casting, curing, and testing of specimens were described. In order to provide a variety of perspectives on the testing procedures, the chapter also includes descriptions of the testing instruments employed in this research and their application methodologies.

The majority experimental nature techniques used in this study were carried out in accordance with the Iraqi specification (IQS), British European (BS (EN), American Society for Testing and Materials (ASTM) standards and (EFNARC 2005). The aim of this experiment is to produce SCGPC using marble dust powder (MDP), (GGBS) and (CKC) that can be obtained locally as an alternative to cement. In this chapter, a practical study is conducted and plans for laboratory tests are provided.

3.2 Experimental Program

The experimental for different SCGPC mixes included material selection and testing, mortar testing, SCGPC mixture design, fresh concrete preparation and testing, and hardened concrete preparation and testing. The flowchart shown in Figure 3.1 depicts the complete experimental research. This study experimental examination was divided into two stages.

In the first stage, the appropriateness of the materials was determined by their selection, processing, and physical and chemical testing. To

determine their viability as partial substitutes for cement, mortars comprising calcined pozzolanic materials CKC, GGBS, and MDP were also evaluated. This stage also describes mixing,casting,curing and testing self-compacting geopolymer concrete in laboratory. When the concrete mixtures were still in the fresh state, the following laboratory tests were carried out slump flow (D (mm),T500), L-box test, V-funnel test, and sieve segregation resistance tests.

In the second stage, after curing in the required ages, laboratory tests were carried out to determine the characteristics of hardened bulk density, compressive strength, splitting tensile strength, and ultrasonic pulse velocity (UPV) and durability performance represented by water absorption, porosity, and sorptivity of the binary and ternary of different SCGPC containing ground granulated blast-furnace slag (GGBS) and marble dust powder (MDP) as a partial replacement material of CKC.

Experimental Program

↓

Materials

↓

| Selection of materials | Preparation of materials | physical and chemical testing |

| CKC | GGBS | MDP | NS, NH |

| Fine agg. | Coarse agg. | Water | superplasticizer |

↓

Mix Design

| M1(Control) | Binary blends | ternary blends |

100% CKC

M2 (5%MDP)	M7 (30%GGBS)	M12 (5%MDP+50%GGBS)
M3 (10%MDP)	M8 (40%GGBS)	M13 (10%MDP+50%GGBS)
M4 (15%MDP)	M9 (50%GGBSS)	M14 (15%MDP+50%GGBS)
M5 (20%MDP)	M10 (60%GGBS)	M15 (20%MDP+50%GGBS)
M6 (25%MDP)	M11 (70%GGBS)	M16 (25%MDP+50%GGBS)

Hardened tests

| density | STS |
| Compressive strength | UPV |

Durability tests

| Water Absorption |
| Porosity |
| Sorptivity |

Fresh tests

slump flow diameter	V-funnel
	L-Box
T500	SR

Figure 3.1: The Overall Experimented Investigation

3.3 Materials

As stated earlier, calcined kaolin clay (CKC), ground granulated blast-furnace slag (GGBS) and marble dust powder(MDP) were selected as calcined pozzolanic material and waste materials, the development of SCGPC, which is the aim of this research. As a result, a brief explanation of the materials source, collecting, and production of SCGPC is provided below.

3.3.1 Calcined Kaolin Clay (CKC)

Calcined kaolin clay (CKC) is a form of mineral admixture also referred to as Metakaolin (MK), one of the more recently created supplemental cementing ingredients. It is made by ultrafine natural kaoline clay at a particular temperature range (650-950) in order to release the chemically bonded water and dissolve the crystalline structure. A substance that is reactive with lime is created as a result of this method. Due to the quasi-amorphous character of the collapsed structure, the calcined clay reacts differently with lime. There is, thus, a preferred calcination temperature for each clay; at temperatures higher than the preferred level, re-crystallization starts, whilst at lower temperatures, the clay lattice structure remains unaltered **(Ibrahem& Wahab, 2008).**

Iraqi Kaolin clay from the Dewekhla district of the Al Ramadi desert, to the west of Baghdad, Iraq, was the source of CKC. To create the (CKC), the kaolin clay was pulverized and heated in a furnace to 800 ℃± 20 ℃ for two hours at a heating rate of 5 ℃ /min. It was then gradually cooled to room temperature for 24 hours, **(Kadhum & Owaid,2020),** then produced reactive material with a finer consistency in Baghdad using the air blast process. calcined kaolin clay that was produced and kaolin clay (KC)and (CKC) are shown in Figure 3.2.

Figure 3.2: Obtained Pozolanic Material (a) KC (b) CKC Powder

3.3.1.1 Chemical Characteristics of CKC

Other significant factors affecting the activation of a binder include its chemical characteristics and oxide composition. Below, a thorough presentation and discussion of the results of the loss of ignition (LOI) test and the oxide composition are provided. Focusing on chemical compositions similar to those found in cement, the calcined kaolin clay's chemical properties were investigated.Table (3.1) presents the chemical compositions of the kaolin clay (KC) and calcined kaolin clay(CKC)

which was greater than the minimum (70%) as specified in (**ASTM C618, 2005**), criteria for class "N" pozzolans, a high-quality pozzolan classification. The existence of anatase or rutile was indicated by the amount of TiO_2, while the presence of micaceous or K-feldspar mineral was suggested by the lower amount of K_2O. The impurities in aluminosilicate phases may be responsible for the occurrence of P_2O_5 and MgO. It was evident that SiO_2 and Al_2O_3 content rose during calcination. Thus, calcining the kaolin at 800 ^{o}C for two hours produced greater SiO_2 and Al_2O_3 than the kaolin in its natural state as seen in Table 3.1.

Table 3.1: Chemical Composition, LOI of KC and CKC(**Khoman and Owaid 2022**)

Oxide composition (%)	K C content%	CKC content%
(SiO_2)	49.3	54.7
(Al_2O_3)	33.8	37.4
(Fe_2O_3)	1.43	1.72
(CaO)	0.71	0.84
(MgO)	0.57	0.42
(Na_2O)	0.26	0.37
(K_2O)	0.41	0.54
(SO_3)	0.19	0.13
(P_2O_5)	0.31	0.29
(TiO_2)	0.52	0.68
(LOI)	11.73	2.91

* Chemical tests were conducted in The National Center for Construction Laboratories and Research (NCCLR) in Babylon.

Table 3.1 also showed that raw kaolin had slightly lower levels of sodium oxide (Na_2O) and potassium oxide (K_2O), and that the amount of these two oxides rose after the raw kaolin was calcined. Other researchers noted similar patterns as well (**Shafiq et al., 2015; Tchakouté et al., 2016; Kadhum and Owaid,2020**). Loss on ignition is the weight that was lost after the material reached 1000 °C (LOI). Normally, any moisture is dried out at this temperature, and any CO_2 that is present in the substance is expelled. The LOI of the CKC was 2.91%. It fell short of the recommended value of 10%. These outcomes, thus, fell short of (**ASTM C618, 2005**) for class "N".

3.3.1.2 Physical Properties of CKC

Physical characteristics, such as specific gravity, particle size dispersion, and fineness. Table 3.2 provides a summary of the specific physical characteristics of CKC. It underwent calcination, which caused it to become harder and change its color to an off-white. CKC had specific gravities of 2.59.

Table 3.2: Physical Properties of CKC

Property	CKC
Specific gravity	2.59
Fineness (Blaine Method), m^2/kg	1640
Median particle size (μm)	14.3
Color	Off-White

The high specific surface area of the pozzolanic materials prepared for this study was a good presumption that they possess the right quality to potentially be an effective pozzolan. The particle size distribution of CKC had a mean diameter (d_{50}) about 14.3 μm.

3.3.2 Ground Granulated Blast-Furnace Slag (GGBS)

The granular substance created when molten iron blast furnace slag is quickly chilled (quenched) by immersion in water is known as ground granulated blast-furnace slag. It is a granular substance that forms relatively few crystals and has a highly cementitious composition. It has a Portland cement-like hydration and is pulverized to cement fineness. Properties of GGBS are shown in Table 3.3. Figure 3.3 shows the GGBS used in this study. obtained from Hanson cement company -Purfleet Regen.

Table 3.3: Physical and Chemical Properties of GGBS

Physical properties													
Specific gravity	Fineness												
	Blaine (m²/Kg)		Median particale size			color							
2.9	456		----			white							
Oxide composition (%)													
SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	CaO	MgO	SO$_3$	Na$_2$O	K$_2$O	LOI	Tio$_2$	cl-	C	7d activity index	28d activity
34.40	13.26	0.43	38.94	8.82	0.29	0.38	0.59	1.17	0.94	0.01	0.09	65%	90%

Figure 3.3 GGBS used in this study

3.3.3 Marble Dust Powder (MDP).

The marble dust power (MDP) used in this study is a leftover from marble masonry. Sludge from companies in Iraq's Al-Hilla city, in the Middle Euphrates region, was collected as MDP industrial waste. It was acquired as a by-product of shaping and sawing marble. To assess the likelihood of employing it in the manufacturing of mortar and concrete, it was described from a physical and chemical point of view. The picture perspective of the MDP as it left the factory is shown in Figure 3.4.

Figure 3.4 MDP used in this study

3.3.3.1 Chemical Properties of Marble Dust powder (MDP).

Table 3.4 lists the chemical components of marble dust powder (MDP), with calcium oxide (CaO) as the main component and tiny amounts of silicon dioxide (SiO_2), aluminum dioxide (Al_2O_3), iron oxide (Fe_2O_3), and magnesium oxide (MgO), which indicate the carbonate nature of the powder.

the weight lost as a result of heating the material to 1000°C is known as the loss on ignition (LOI). At this temperature, the material usually dries out and exhales any moisture or CO_2.Table 3.4, **Haider M. Owaid and Hayder M. Al-Khafaji, (2018),** displays the MDP LOI test data. For MK, the LOI is higher, but it falls short of the required 10% of the value **ASTM C618 (2001).** Despite the LOI for marble dust powdere is 2.83 percent. It is lower than the recommended level of 10%of **ASTM C618 (2003).**

Table 3.4: Chemical compositions of marble dust powder

Chemical composition (%)	MDP
Silicon dioxide (SiO_2)	1.47
Aluminum trioxide (Al_2O_3)	0.84
Iron oxide (Fe_2O_3)	0.34
Calcium oxide (CaO)	82.1
Magnesium oxide (MgO)	0.40
Sodium oxide (Na_2O)	1.17
Potassium oxide (K_2O)	0.08
Sulfur trioxide (SO_3)	0.68
Phosphorus pentoxide(P_2O_5)	0.28
Loss on ignition (LOI)	2.83

3.3.3.2 Physical Preperties Of Marble Dust powder(MDP).

One of the most important factors that must be taken into account when determining the relative density and weight of a substance is the specific gravity of 2.68. As a result, CKC and MDP have lower specific gravity

than cement.Table 3.5 Physical properties of MDP, **Haider M. Owaid and Hayder M. Al-Khafaji, (2018).**

The specific surface area (SSA) of CKC is higher than those of MDP and cement due to certain transformations. The high SSA of the CKC was determined to be 1640 m^2/kg, whereas those of MDP were 569 m^2/kg It is obvious that all the pozzolanic materials possess greater SSA than the OPC. It is safe to assume that the pozzolanic materials created for this study have the necessary qualities to possibly function as an efficient pozzolan due to their high specific surface area. The diameter (d50) of CKC and MDP particles, which range in size from 0.1 to 90 μm, is 14.3 μm and 24.8 μm, respectively.

Table 3.5: Physical Properties of MDP

Property	MDP
Specific gravity	2.68
Fineness (SSA), m^2/kg	569
Median particle size (μm) (d_{50})	24.8
Color	Light grey

3.3.4 Fine Aggregate

Three important factors must be taken into consideration when producing self-compacting concrete, This includes particle size, grading, and the quantity of fine aggregate. The Al-Akhaidher region's natural sand was used as the fine aggregate in this investigation. The grading of fine aggregate is provided in Table 3.6 and shown in Figure 3.5, while the physical properties of fine aggregate are provided in Table 3.7. Through the the results, it was found that the used fine aggregate is located within the third gradient zone, conforms to the Iraqi standards **(IQS 45,1984)**, and has has a fineness modulus of (2.34).

Table 3.6: Grading of fine aggregate used through out the work.

Sieve size (mm)	Cumulative Passing by weight (%)	Limits of the Iraqi specification IQS 45 (zone 3)
10	100	100
4.75	100	90-100
2.36	87	85-100
1.18	78	75-100
0.60	64	60-79
0.30	30	12-40
0.15	7	0-10

*Sieve Analysis and sulfate content were Conducted by the Constructional Materials Laboratory at the University of Babylon.

Table 3.7: Physical Characteristics of the Fine Aggregate Used in This Work

Property	Test Results	IQS 45, the Iraqi specification, has limitations
Specific gravity	2.65	--
Absorption (%)	0.94	--
Fineness Modulus	2.34	--
Sulfate content (%)	0.309	≤ 0.50 %
Material finer than 0.075 mm (passing from sieve (75μm)) %	1.81	≤ 5.0 %

*Physical Tests were Conducted by the Constructional Materials Laboratory in the University of   Babylon.
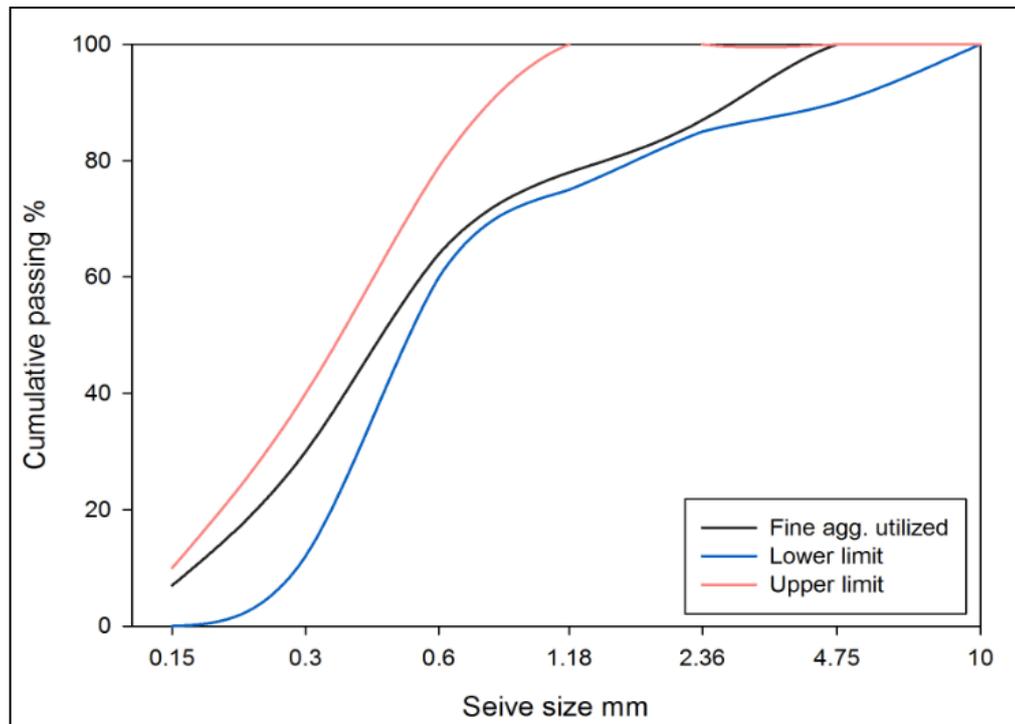
Figure 3.5: Grading of Fine Aggregate

3.3.5 Coarse Aggregate

In this study, the washed gravel from the Al-Nabai'i area with a maximum size of 10 mm was used, as Table 3.8 and Figure 3-6 show the gradation of coarse aggregate. Through the results of the examination, it was found that the coarse aggregate conforms to the Iraqi standard specifications (**IQS 45,1984**). The values (absorption, sulfate content, and specific gravity) of the coarse aggregate are provided in Table 3.9.

Table 3.8: Grading of Coarse Aggregate

Sieve Size (mm)	Cumulative Passing by Weight (%)	Limits of the Iraqi Specification IQS 45
14	100	100
10	100	85 – 100
5	20	0 – 25
2.36	0	0 – 5

Table 3.9: Physical Properties and Sulfate Content of

Coarse Aggregate*

Properties	Test Results	Limits of Iraqi Specification IQS 45
Specific Gravity	2.58	-
Sulfate Content SO_3, (%)	0.03	< 0.1%
Absorption, (%)	0.5	_

*Physical tests were conducted in the construction materials laboratory at the University of Babylon.
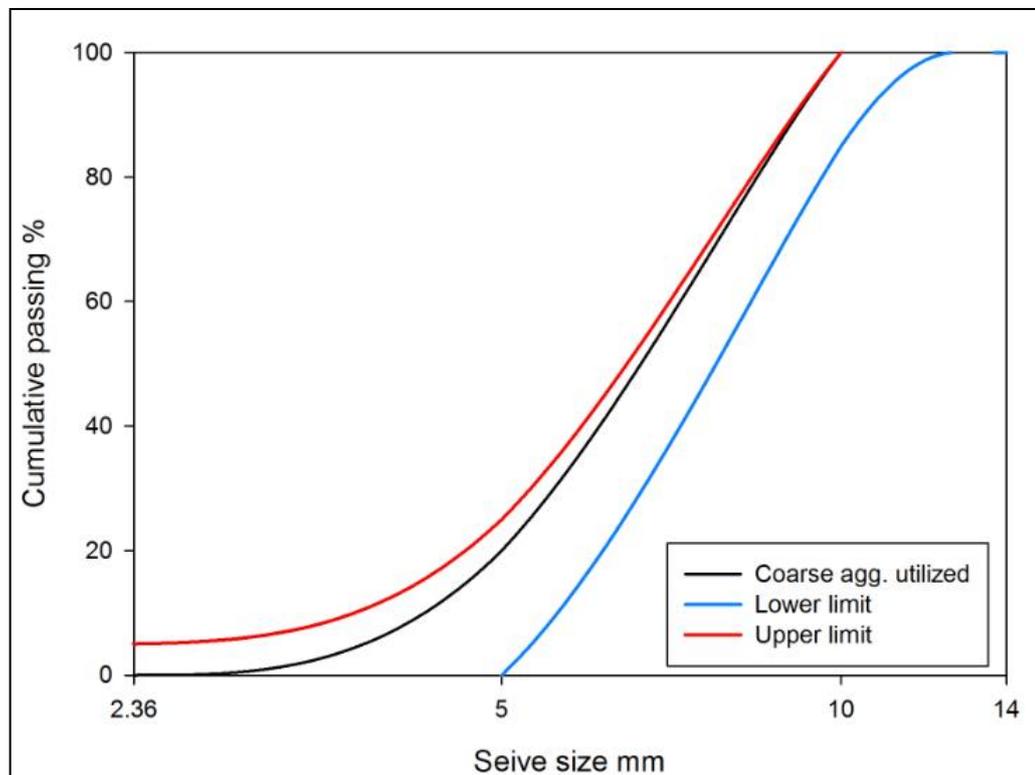
Figure 3.6: Grading of coarse aggregate

3.3.6 Water

The mixing water used for all the mixes was normal tap water from the domestic water supply. So it was clear of residual and organic materials that could have impacted the concrete properties.

3.3.7 High Range Water Reducing Admixture HRWRA

For the production of SCGPC ,high range water reducing admixture (HRWRA)is need to improve the flowing ability.Using SP Glenium 54,It is made by the BASF company and is type F (**ASTM C494, 2017**) compliant. **Table 3.10**.

Table 3.10: Typical Properties of High Range Water Reducing Admixture [*]

Form	Viscous liquid
Commercial name	Glenium 54
Appearance	Whitish to straw-colored Viscous liquid
pH	5-8
Relative density	1.07 gm/cm^3 at 20 ^{o}C
Chloride content	Nil
Storage	Should be stored in original containers and at above 5 ^{o}C
Transport	Not classified as dangerous
Alkali content (as NaO$_2$) equivalent)	0.26%

*According to manufacturer

3.3.8 Alkaline Activators

In this study, the combination of sodium hydroxide (NaOH) solution and sodium silicate (Na$_2$SiO$_3$) solution used for alkaline activator solution (AAS).

Both of these substances are on the market for commercial purposes. Solutions based on sodium were chosen because they were cheaper than

solutions based on potassium. Sodium silicate helps to dissolve the binder components more easily. Both the alkalis had industrial grades and were purchased from local suppliers. Sodium hydroxide pellets are 99% purity with a specific gravity of 2.13. It is shown in Figure 3.7. Sodium silicate (NS) {SpecificationNa$_2$O% content (13.1-13.7) SiO$_2$% content (32-33) density (51) specific gravity (1.534-1.551) viscosity (600-1200)} it shows in Figure (3.8).

Figure 3.7 Sodium hydroxide NaOH used in this study

Figure 3.8 Sodium silicate NaSiO$_2$ used in this study

3.3.8.1 Preparation of Alkaline Solution

The mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions is the alkaline solution used in this research program. In order to produce a solution at the appropriate concentration, sodium hydroxide must be incorporated into water in the form of pellets. The mass of NaOH solids present in a solution was vary depending on the concentration of the solution and it mainly expressed in terms of molarity, M. For example, NaOH solution with a concentration of 8M, 10M and 12M consist of 8x40 = 320 grams, 10x40 = 400 grams and 12x40 = 480 grams of NaOH solids (pellet form) per litre of the solution, where, 40 is the molecular weight of NaOH. This solution is processed 24 hours before it is mixed with a silicate sodium solution.

In this study, the molarity was fixed to 12 M on SCGPC. At room temperature, the alkaline solution is prepared by combining the solution of sodium hydroxide and sodium silicate. When the mixture is mixed together, the polymerization process starts reacting with one another and releases large quantities of heat so it is advised to leave for 20 min and then use. A ratio of sodium silicate solution to sodium hydroxide by weight is fixed as 2.5 for the entire study (**Kumar and Ramesh 2016**)

3.4 Concrete Mixture Proportion

To provide a distinguishable observation of the effectiveness of the replacement levels of CKC, GGBS and MDP, a total of 16 SCGPC mixtures were designed and cast at a water to binder ratio (w/b) of 0.36 and a total binder content of 486 kg/m^3. The superplasticizer dosage was 2% by mass of cementitious material to fulfill performance requirements of SCC as according to (**EFNARC, 2005**).

All the mixes were designed based on the typical range of SCGPC mix composition proposed by (**EFNARC, 2005**) standards, was set up with with similar of grade of SCGPC. This develops two blend systems as

shown in Table 3.11: In two steps, binary and ternary. The control mix was created in the first stage using CKC as the binder. In the second stage, the binary blend systems, the replacement ratios for CKC were 5%, 10%, 15%, 20% and 25% of MDP, and 30%,40%,50%,60% and 70% of GGBS respectively, as partial replacement of binder by weight. In the third phase replacement ratios for the ternary systems CKC were replaced 5%, 10%,15%,20% and25% of MDP and 50% of GGBS in these mixes.

Table 3.11: Notation of the Mixes

Mix Notation	Details
M1	Reference mix of SCGPC was made with only Calcined Kaolin Clay CKC (100%CKC)
M2	The binary blend of SCGPC was made with (95%CKC+5%MDP)
M3	The binary blend of SCGPC was made with (90%CKC+10%MDP)
M4	The binary blend of SCGPC was made with (85%CKC+15%MDP)
M5	The binary blend of SCGPC was made with (80%CKC+20%MDP)
M6	The binary blend of SCGPC was made with (75%CKC+25%MDP)
M7	The binary blend of SCGPC was made with (70%CKC+30%GGBS)
M8	The binary blend of SCGPC was made with (60%CKC+40%GGBS)
M9	The binary blend of SCGPC was made with (50%CKC+50%GGBS)
M10	The binary blend of SCGPC was made with (40%CKC+60%GGBS)
M11	The binary blend of SCGPC was made with (30%CKC+70%GGBS)
M12	The ternary blend of SCGPC was made with (45%CKC+5%MDP+50%GGBS)
M13	The ternary blend of SCGPC was made with (40%CKC+10%MDP +50%GGBS).
M14	The ternary blend of SCGPC was made with(35%CKC+15%MDP+50%GGBS).
M15	The ternary blend of SCGPC was made with (30%CKC+20%MDP+50%GGBS)
M16	The ternary blend of SCGPC was made with (25%CKC+25%MDP+50%GGBS)

Table 3.12and Table 3.13 shows the weight quantities of the materials used in this study (binary and ternary).

Table 3.12: Mix Proportions of Binary Blends SCGPC

Mix	*W/B*	Quantities of ingredients (kg/m3)								
		CKC	MDP	GGBS	FA	CA	NaOH	Mol.	NS	SP %
M1	0.36	486	--	--	850	862	74	12	185	2
M2	0.36	461.7	24.3	--	850	862	74	12	185	2
M3	0.36	437.4	48.6	--	850	862	74	12	185	2
M4	0.36	413.1	72.9	--	850	862	74	12	185	2
M5	0.36	388.8	97.2	--	850	862	74	12	185	2
M6	0.36	364.5	121.5	--	850	862	74	12	185	2
M7	0.36	340.2	--	145.8	850	862	74	12	185	2
M8	0.36	291.6	--	194.4	850	862	74	12	185	2
M9	0.36	243	--	243	850	862	74	12	185	2
M10	0.36	194.4	--	291.6	850	862	74	12	185	2
M11	0.36	145.8	--	340.2	850	862	74	12	185	2

Table 3.13: Mix Proportions of Ternary Blends SCGPC

Mix	*W/B*	Quantities of ingredients (kg/m3)								
		CKC	MDP	GGBS	FA	CA	NaOH	Mol	NS	S.P %
M12	0.36	218.7	24.3	243	850	862	74	12	185	2
M13	0.36	194.4	48.6	243	850	862	74	12	185	2
M14	0.36	170.1	72.9	243	850	862	74	12	185	2
M15	0.36	145.8	97.2	243	850	862	74	12	185	2

| M16 | 0.36 | 121.5 | 121.5 | 243 | 850 | 862 | 74 | 12 | 185 | 2 |

3.5 Mixing Procedure and Casting of Specimens

To create a consistent mixture of concrete, mixing is necessary to achieve the regured homogeneity and performance a mechanical process. In SCGPC as opposed to ordenary concrete combinations, the mixing process and duration are more crucial. Due of its higher plastic viscosity at a low W/B ratio, SCGPC requires more mixing time than ordenary concrete **(Chopin et al., 2004)**. Also, due to reduced frictional forces and the need to fully activate the super plasticizer, experience has shown that the time required to achieve complete mixing of SCGPC may be greater than for ordenary concrete. However, with SCGPC, it is especially crucial that the mixer is in good mechanical condition, able to provide complete and uniform mixing of the solid components, and capable of producing enough shear action to disseminate and activate the super plasticizer **(EFNARC,2005)**.

To prevent moisture loss from the freshly mixed concrete during the mixing process, the mixer should be covered. Throughout the course of the investigation, concrete was mixed in a laboratory at a temperature of 25°C using a horizontal drum laboratory mixer. Before mixing, GGBS, MDP were mixed with calcined kaolin clay(CKC) in dry form for 5 min using an electric mixer in all mixes. Sodium hydroxide and sodium silicate in an alkaline solution were added at a 2.5 ratio to start the mixing process **(Kumar&Ramesh,2016)**. The mixing water was added, one-third of it, while the mixer was running. After adding the remaining water, the mixer ran for another 30 seconds. Before stopping to rest, the mixer mixed for a further three minutes. For an additional 3 minutes, the lid of the mixer was left closed while the concrete rested. After that, the concrete (SCGPC) received 2% of the super plasticizer dose by mass of the binder, and was

again mixed for three minutes **(ASTM C192, 2003)**. Then the mixture was was produced, tested for fresh properties, and cast.

The mixing process is important for obtaining the requisite workability and homogeneity of SCGPC mixes. The mixtures were cast as specimens using, 100 mm × 100 mm × 100 mm standard cube molds, and 100 mm × 200 mm cylinders. To prevent adhesion with the mixture once the mixture had dried, the interior surfaces of these molds were cleaned and oiled. In order to fill the molds completely without compacting them, the mixes were then poured into them. Following casting, the specimens were wrapped in nylon sheets to maintain a humid environment and placed in the casting room at a temperature of 25 °C for 24 hours before demoulding, as shown in Figure 3.9. After that molds were removed, cubes were put in oven at (60-70) °C for 24 hours, then put in laboratory to be tested later at room temperature for the required ages.

Figure 3.9: Mixer, and Cast Samples for (a) Mortars (b) SCGPCs

3.5.1 SCGPCs Specimens

The mixtures in this study were cast as specimens to examine SCGPC property using the molds as followed:

1. (100×100×100) mm cubes to obtain specimens for bulk density, compressive strength, ultrasonic pulse velocity (UPV), water absorption, porosity, and sorptivity.

2.(100×200) mm cylinders to obtain specimens for the splitting tensile strength test.

3.5.2 Curing of Specimens:

All SCGPC specimens must be cured before testing, so the specimens should be placed in an oven after demoulding and kept there for 24 hours at a temperature of (60-70)°C, then placed in the laboratory at 25°C until the required testing ages, as shown in Figure 3.10.

Figure 3.10: Curing of the SCGPC specimens

3.6 Fresh Tests on Self-Compacting Geopolymer Concrete

The ability to fill, pass through, and resist segregation are three attributes that self-compacting geopolymer concrete must demonstrate in new experiments that are crucial to its evaluation. To measure all three traits simultaneously, there is no one test available. Slump flow (D (mm), T500, V-funnel, L-box, and segregation resistance tests were used in this

experiment to determine the fresh properties of SCGPC. Below are descriptions of the experimental techniques used for the tests stated.

3.6.1 Slump Flow Tests

The slump-flow test to assess the flowability and flow rate of SCGPC in the absence of obstructions. The result is an indication of the self-compacting geopolymer concrete's filling ability. The test equipment and technique as defined in **(EFNARC, 2005)**. Figure (3.11) shows the equipment and the   slump flow of the fresh mix. The largest diameter of the flow spread of the SCGPC and the diameter of the flow spread at right angles to it are measured, and the mean is the slump-flow, expressed to the nearest (10) mm as shown in Equation (3-1).

$$SF = (D1 + D2)/2 \qquad\qquad (3\text{-}1)$$

Where :

SF = Slump Flow, mm

D1 = diameter mm

D2= diameters perpendicular, mm
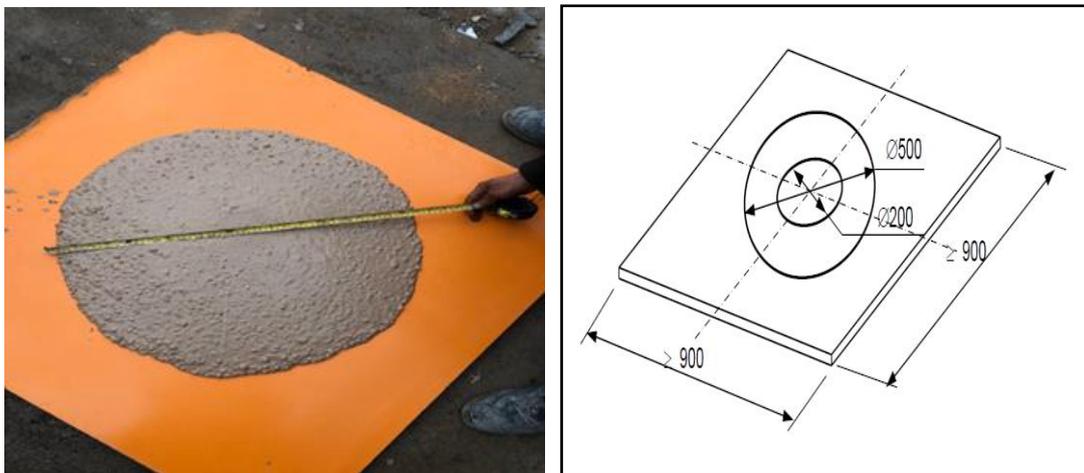
Figure 3.11: Slump Flow of SCGPC

3.6.2 V-Funnel Test

The test used to assess the filling ability and viscosity of SCGPC is the V-funnel test. Whereas the test procedure and the apparatus used are described in **(EFNARC, 2005; De Schutter, 2005)**. The apparatus of the V-funnel test used in this study is shown in Figure 3.12. The test was conducted by placing the V funnel vertically on a flat, stable surface, with the top opening positioned horizontally. Using a wet sponge or towel, we moisturize the inside of the funnel and remove excess water by opening it. Noting that the inside of the funnel remains wet. Then, we the gate closed and place the container under the funnel to retain the concrete to be passed. Then the funnel was filled with SCGPC without applying any pressure or rodding. A straight edge was used to scrape off any extra concrete from the funnel's top. The gate was opened and the timer set to the nearest 0.1 seconds after waiting for (10 + 2) seconds to pass after the funnel had finished full, was measured from the opening of the gate to when it was possible to see vertically through the funnel into the container below for the first time. t_v is the V-funnel flow time.
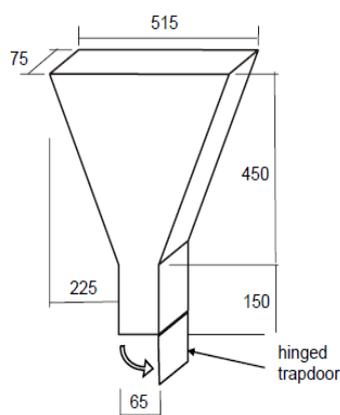
Figure 3.12: V-Funnel Test

3.6.3 L-Box Test

The L-Box test is used to determine the SCGPC passing ability to flow without segregation or obstruction when there are supporting barriers. There are two version, the two-bar test and the three-bar test. According to **(EFNARC,2005; De Schutter, 2005)**, the three-bar test was used to predict more congested reinforcement. The L-box test in this study is shown in Figure 3.13. Before the starting of the test, the testing apparatus was clean and only slightly damp. First, the L-box was placed centrally in a stable and level position. Then, the vertical part of the L box was filled with fresh SCGPC and allows the concrete to sit in the vertical section for 1 minute. During this time, The stability of the concrete will be demonstrated (segregation). The sliding gate was then raised, allowing the concrete to pour forth into the horizontal part. Using a rule with a graduation of (0-300) mm, and measured the depth of the concrete right behind the gate as H1 mm and the depth of the concrete at the end of the horizontal portion as H2 mm when the concrete stopped moving. Using Equation (3-2) stated in dimensionless to the closest integer, the passing ability (PA) was determined (0.01).

$$PA = H2/H1 \qquad\qquad\qquad (3\text{-}2)$$

Where:

PA= blockage ratio

H_1= Concrete depth directly behind the gate, mm.

H_2= Concrete depth at the end of the horizontal section, mm.
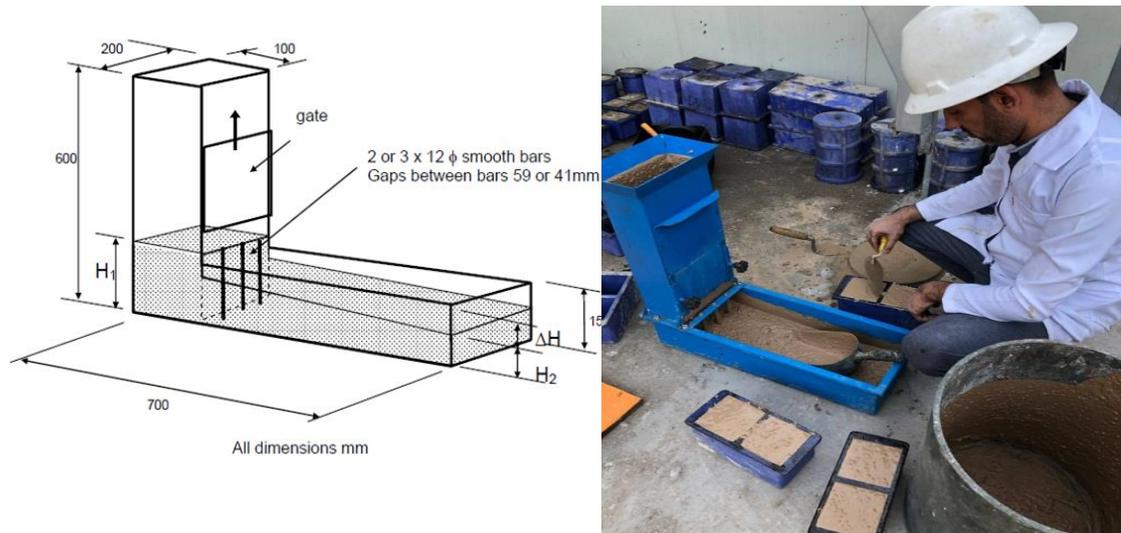
Figure 3.13: L – Box Test

3.6.4 Test for Sieve Segregation Resistance

Segregation resistance refers to a fresh mix's capacity to retain the original, suitably uniform dispersion of its component elements. The SCGPC's resistance to segregation is evaluated using this test. The test apparatus and procedure specified in **(EFNARC, 2005)**. The test is shown in Figure 3.14, about (10± 0,5) liters of concrete were placed into a container and allowed to stand in a level position without disturbance for (15 ± 0,5) min. The sieve receiver was placed on the weighing machine and its weight (Wp g) was recorded. A sample of (4.80.2) kg of concrete was poured into a 5 mm sieve with a diameter of 300 mm from a height of (500± 50) mm, and the actual weight of the concrete (WC g) was noted on the sieve. The concrete was placed in the sieve for (120±5) seconds to allow any laitance or mortar to pass through it while standing on the sieve receiver. The weight of the receiver was recorded with concrete that had passed into it (Wps g). The (SR) was calculated from the following Equation (3-3) to the nearest 1%.

$$SR(\%) = (\frac{Wps - Wp}{Wc}) \times 100 \qquad\qquad (3\text{-}3)$$
   Where:

SR: Segregation resistance.

Wps: weight of the receiver and concrete, g.

Wp: weight of the receiver, g.

Wc: actual mass of concrete, g.

Figure 3.14: Sieve Segregation Resistance Test

3.7 HardenedTests on SCGPC

The hardened specimens of various SCGPC in this study were tested regarding bulk density, compressive strength, splitting tensile strength and ultrasonic pulse velocity. The details of these tests are provided below.

3.7.1 Bulk Density Test

The density of concrete has a significant impact on its mechanical qualities. Because there are fewer holes and porosities in denser concrete, it typically has superior strength, durability, and resistance to permeability. Any structure's self-weight is entirely reliant on the bulk density (or unit weight) of its component parts. As a result, it is a significant criterion for mortar or concrete. The bulk density, measured in kilograms per cubic

meter, is the weight of a unit volume of hardened concrete. At the ages of 7 and 28 days, the bulk density of hardened SCGPC was calculated using Equation (3-4) and in accordance with (**BS 1881: Part 114, 1983).** The average results of three cube specimens with dimensions of (100×100×100) (100×100×100) mm as shown in Figure 3.15, were reported for each mixture and age.

$$\text{Density} = \frac{m}{v}$$ (3-4)

Where

m: The weight of the specimen in the air (in kg).

V: The volume of the specimen calculated from its dimensions(m^3)

Figure 3.15: Weights of Cubes for Bulk Density Test

3.7.2 Compressive Strength

One of the most significant mechanical properties of concrete, is compressive strength,it has been measured consistently and can give a general idea of the caliber of concrete. The compressive strength test was performed as described in (**BS1881: Part 116, 1983**). For each mixture and and age, the average results of compressive strength of three cube specimens with dimensions (100×100×100) mm were calculated at 3, 7, 28,56, and 90-days age. The test involves recording the maximum applied load at failure, by using a compression machine with a load capacity of 1900 kN, by increasing the load continuously at a nominal rate of 0.2

N/(mm^{2}s) to 0.4 N/(mm^{2}s) until no greater load can be sustained (see Figure 3.16). The compressive strength was calculated by dividing the maximum load by the cross-sectional area of the specimen .

Figure 3.16: Compressive Strength Test

3.7.3 Splitting Tensile Strength

Tensile strength is an important characteristic of concrete. This test is carried out on (100×200) mm cylinder. Since it is challenging to perform direct tensile testing on concrete specimens, the tensile splitting strength test was used to measure the tensile strength of the concrete. The splitting tensile strength was calculated using the method described in **(ASTM C496, 2004)**. Three-cylinder specimens with dimensions of (100 mm × 200mm) were used to splitting tensile strength for each SCGPC mix,the specimen tested at 7, 28, and 90 days of curing. The specimen was positioned between the upper and lower bearing blocks of the testing machine and two thin bearing strips of plywood (3.2 mm thick). Utilizing a testing device with a 1900 kN load capacity, the test entails applying a

steady rate of between 0.7 and 1.4 MPa/min until the highest applied load at failure is recorded (see Figure 3.17). The following Equation (3-5) is used to determine the specimen's splitting tensile strength (T):

$$T = \frac{2P}{\pi dl}$$ (3-5)

Where:

T: Splitting tensile strength, (MPa).

p: Maximum applied load indicated by the testing machine, (N).

d: Cylinder diameter, (mm).

l: Cylinder length, (mm).

Figure 3.17: Splitting Tensile Strength Test

3.7.4 Ultrasonic Pulse Velocity Test

The ultrasonic pulse velocity test (UPV) method is a non-destructive method, as the technique uses compressional waves, resulting in no damage to the concrete element being tested. The pulses are introduced into the cube specimens by a piezoelectric transducer, and a similar transducer acts as a receiver to monitor the surface vibration caused by the arrival of the pulse, as shown in Figure (3.18). The nominal frequency of the transducers used for testing concrete cubes was 50 kHz, and the transmission time was

measured in microseconds, with an accuracy of 0.1 μs. A test of the ultrasonic pulse velocity was performed in accordance with **(ASTM C597, 2002)**, using (100×100×100) mm cubes.

The UPV test was carried out using a portable ultrasonic non-destructive digital indicating tester (PUNDIT). The transducers were zeroed by putting water-soluble coupling gel between them before utilizing the PUNDIT. To ensure a strong coupling between the transducer faces, the end surfaces of the samples were polished and lubricated. The specimen ends were securely linked to the transducers throughout testing, and the transit duration was recorded. The (UPV) was computed using the route length and transit time (T) measurements, with three specimens for each mixture and age, as well as the results (L). The following formula (3-6) was used to get the pulse velocity:

$$V = \frac{L}{T} \tag{3-6}$$

Where:

V= pulse velocity ,(m/s) .

L= distance between transducers,(m) .

T= effective transmit time, (s).

Figure 3.18: Ultrasonic Pulse Velocity Test

3.8 Tests for Durability Performance of SCGPC

One of the most important criteria for using a material in practice is its performance in terms of durability. Three tests for toughness, including ones for water absorption, porosity and sorptivity were measured in this study. The current test methodologies for the aforementioned SCGPC tests are further discussed below.

3.8.1 Water Absorption

In order to the voids in hardened concrete and ascertain the increase in resistance towards water penetration in concrete, The concrete sample' water absorption test was performed according to **(ASTM C642, 2013)**. At the ages of 28 and 90 days, a mixture of SCGPC and three (100×100×100) mm cube specimens were evaluated (after initial curing for 28 days)**(Siddique& Kadri,2011)**, and the average values were recorded. Cube specimens were dried in an oven for no less than 24 hours at 110 ± 5 ^{O}C to a constant weight (A) until two values agreed closely or the difference between any two successive values was less than 0.5% of the lowest value obtained, as shown in Figure 3.19.

Then, the specimens were immersed in tap water for not less than 48 hours and until two successive measurements of the weight of the surface-dried samples at intervals of 24 hours indicated constant mass or until the increase in mass was less than 0.5% of the heavier weight, which defines the saturation stage. After the desired immersion period had passed, the specimens were taken out and surfaces were wiped with a wet cloth quickly, then the saturated surface dried (SSD) specimen was weighed (B) immediately. As a result of this test, the total volume of penetrable pores was determined. Using the results of three specimens, the following

equation (3-7) was used to compute the percentage of (WA), which was then averaged.

Water Absorption (%) $= \frac{(B - A)}{A} \times 100$ (3-7)

Where:

A = weight of oven-dried sample in air, g.

B = weight of surface -dry sample in the air after immersion, g.

Figure 3.19: Oven-Dried and Weights of cubes for Water Absorption Test

3.8.2 Porosity

The total porosity of the different SCGPC mixes was evaluated in this study. Three cubes (100 × 100 × 100) mm were prepared for porosity testing . According to this technique, concrete porosity was measured **(ASTM C642, 2013).** At 28 and 90 days age, samples were analyzed (after (after initial curing for 28 days). At least 24 hours were spent drying cube specimens in an oven set to 110 ± 5 C to a constant weight (A) until two values agreed closely or the difference between any two successive values was less than 0.5% of the lowest value obtained. Then, the specimens were immersed in tap water for not less than 48 hours and until two successive

measurements of the mass of the surface-dried samples at intervals of 24 hours indicated constant weight or until the increase in weight was less than 0.5% of the heavier weight. After the samples were removed from the immersion chamber, the surfaces were cleaned using a moist towel. The saturated surface dry (SSD) weight was calculated following immersion (C). Finally, the specimens were immersed and weighted in water to determine their apparent weight (D), as shown in Figure 3.20. The Porosity Porosity of the concrete was determined in accordance with Equation (3–8) based on the outcomes of three samples, and averaged.

$$\text{Porosity(\%)} = \frac{C - A}{C - D} \times 100 \qquad (3\text{-}8)$$

Where:

A = weight of oven-dried sample in air,g.

C = weight of surface-dry sample in the air after immersion, g.

D= Apparent mass of sample in water after immersion, g

Figure 3.20: Oven-Dried and porosity Test

3.8.3 Sorptivity

This test is performed to determine the susceptibiley of an unsaturated concrete to penetration of water.It measures the rate of

absorption of water in to unsaturated concrete through capillary suction. Concrete is more resistant to absorbing water when the sorptivity rating is lower. The measurements of sorptivity (capillary water absorption) were assessed using **(ASTM C1585, 2004).** For each mixture and age, a set of three ($100 \times 100 \times 100$) mm cubes were selected for testing to evaluate sorptivity coefficients at ages 28, 90 days (after the initial 28-day cure). The samples were taken out of the water, and after that they were put in an the oven about to 50 ± 2 °C and relative humidty 80% for 3 days until they reached constant weight, and then allowed to cool to the ambient temperature in a sealed container before starting the absorption procedure. Only one surface of the concrete specimen was allowed to be in contact with water, with the depth of water (1 to 3) mm above the base of the specimen. In order to guarantee the unidirectional passage of water through the concrete specimen, the opposite surface was exposed to air, while the other four surfaces were sealed with epoxy resin. Prior to the specimens being discovered in the water, their initial weights were measured to the nearest 0.01g. Then, the specimens were rested on a dedicated test-specific tray. to allow free access of water to the surface, and in order to prevent moisture loss, they were placed under a plastic sheet and maintained in the conditioning room, as seen in Figure 3.21. Immediately after the immersion immersion of the cube surface into the water, the water absorption was measured (specimens were removed from the tray and the weights were recorded) at intervals of 1, 5, 10, 30, 60, 120, 180, 240, 300, and 360 min, for initial absorption properties. After that, the measurements were measured once daily for up to 3 days, then three times, each time at least 24 24 hours apart, from days 4 to 7; the last measures, for secondary absorption properties, are done at least 24 hours after the measurement on day 7. Because of the longer time frame, water can enter the specimen's center by capillary action. During the test, water was re-filled into the tray

to maintain a water depth of 3 mm. The calculated absorption value at each time is plotted against the square root of time. The sorptivity was determined by the slop of the best line that fits these data. The sorptivity was computed by using the following Equation 3-9 based on the outcomes of three samples, and averaged.

$$S = \frac{I}{\sqrt{t}}$$

(3-9)

where:

S = Sorptivity cofficient in (mm/min$^{0.5}$), I=m_t /ad   .

I= absorption(mm)

m_t = the change in specimen mass in grams, at the time t .

a= the exposed area of the specimen, in mm^2.

d= density of water (used 0.001 g/mm^3) or 1gm/cm^3

t = time elapsed in (min)
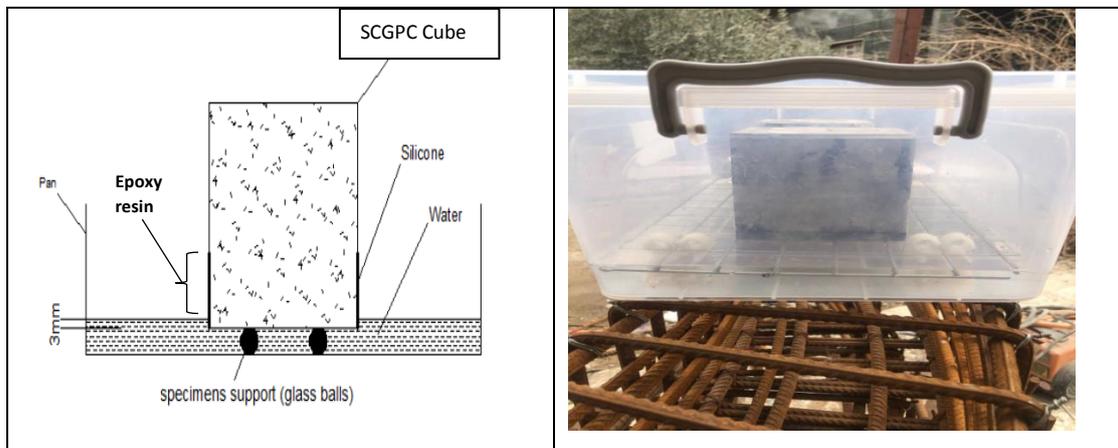
Figure 3.21: Sorptivity Test

3.9 Statistical Evaluation of Experimental Test Results of Compressive Strength of Self-Compacting Geopolymer Concrete

There have been several research on compressive strength modeling, prediction, and variations with the SCGPC's ultrasonic pulse velocity test (UPV), which uses low carbon binders. As a result, this study was the first

to use SCGPC with (CKC), (GGBS), and (MDP) as a partial substitute for cement in ternary and binary mixtures.

3.9.1 Multiple Regression Analysis (MRA)

Given below is the general(MRA) equation used in this study, where the dependent variable compressive strength is a linear function of multiple independent variables **(Khoman and Owaid 2022).** Using the subsequent multiple linear regression Equation (3–10), the best fit to the study data is determined.:

$$Y = a + b_1X_1 + b_2 X_2 + \ldots\ldots\ldots + b_i X_i \hspace{3cm} (3\text{-}10)$$

Where:

     Y: dependent variable
     a: constant
     $b_1,\ldots, b_i$: coefficients

$X_1,..,X_n$: Independent variables (CKC, GGBS and MDP) but (FA, CA, SP, NaoH, NS and W/B) are constant for all SCGPC mixture.

CHAPTER FOUR

RESULTS & DISCUSSION

Chapter Four
Results and Discussion

4.1 Introduction:

This chapter presents and discusses the findings of the tests mentioned in Chapter 3. The goals of this study were looked into and supported by a number of experiments in this regard. Additionally, the findings of recent experiments on the flow (D (mm), and T 500 (s), L-box test, V-funnel, and sieve segregation resistance tests of self-compacting geopolymer concrete (SCGPCs) were given and discussed.

Finally, results of hardened properties including ultrasonic pulse velocity UPV, compressive strength, splitting tensile strength, and bulk density, and durability properties water absorption, porosity, and sorptivity of SCGPC are presented and discussed in this chapter.

4.2 Pozzolanic Activity of Materials

By using the strength activity index (SAI), it is possible to determine a material's pozzolanic activity before using it as a pozzolan with cement (SAI). During the hydration of Portland cement, it can react with portlandite $Ca(OH)_2$. A pozzolanic activity index test was performed on mortar samples made using calcined kaolin clay CKC, ground granulated blast-furnace slag GGBS and marble dust powder MDP after they had been produced. (**ASTM C311, 2005**).

The results of SAI of mortar cubes at 7 and 28 days are presented in Table 4.1 and Figure 4.1.Three cubes(50x50x50)mm were taken out of the curing curing tank at each testing age. According to the results showed, it was observed that the SAI of CKC was 96% and 102% at the ages of 7 and 28

days, compared to the control mix, which was over 75%. (CKC) used in research possess certain pozzolanic properties due to their capacity to react with portlandite, resulting in cementitious compounds called calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H).Therefore, the results of the pozzolanic material used in this study satisfied the requirements of **(ASTM C618, 2005)** class **N**.

The SAI values of MDP were 68% and 83%, while those of GGBS were 65% and 90% at the ages of 7 and 28 days, respectively, compared to control mix. Therefore, all the results of pozzolanic materials CKC, GGBS and MDP used in this study satisfies the classifications requirements of pozzolans based on **(ASTM C618 ,2005)** specification.

Table 4.1 Strength activity index of materials(CKC , MDP and GGBS)

No. Mix	Strength activity at 7 days (%)	Strength activity at 28 days (%)
OPC- Control	100	100
Calcined Kaolin Clay(CKC)	96	102
Marble Dust Powder	68	83
Ground Granulated Blast Furnace Slag (GGBS)	65	90
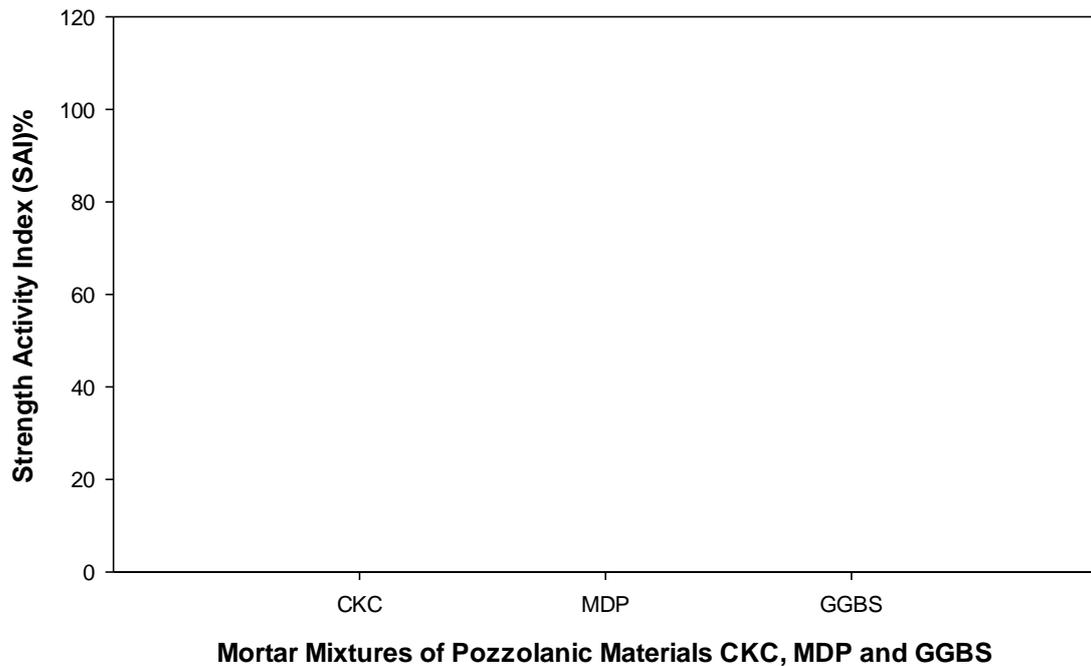
Figure 4.1: Strength Activity Index of Mortars with CKC,MDP and GGBS at 7 and 28 Days

4.3 Freshly Mixed Self-Compacting Geopolymer Concretes Properties

According to the **(EFNARC,2005)**, Only a mix that meets the criteria for all three properties—filling ability (flowability and viscosity), passing ability, and segregation resistance properties—can be designated as (SCGPC). The test findings for distinct SCGPC fresh properties were given and discussed.

Table 4.2 and Figures(4.2 to 4.15) provide these findings about the SCGPC fresh features. In this experimental program, slump flow (D (mm) and T 500 mm (s)), the L-box test, the V-funnel time, and segregation resistance were used to fresh properties of SCGPC. The slump flow diameters of all SCGPC were in the range of 580-735 mm, the slump flow

times (T_{500}) were in the range of 3.2-6.8 s, and the V-funnel flow times (s) were in the range of 8.2-13.2 s. The L-box height ratio was in the range of 0.809 to 0.957, and the segregation percentage values were in the range of 6.1%-11.2%, which was measured by the sieve segregation resistance test. These results were conforming to acceptable criteria for SCC reported by (**EFNARC, 2005**).

Table 4.2: The Results of Fresh Properties Tested of SCGPC

Mix Proportion	Slump Flow-D (mm)	T_{500mm} (Sec)	V-Funnel Time (Sec)	L-Box height ratio (H2/H1)	Segregation Resistance (%)
M1	580	6.8	13.2	0.809	6.1
M2	590	6.5	12.8	0.816	6.1
M3	595	6.4	12.6	0.826	6.3
M4	610	6.1	12.4	0.841	6.6
M5	625	5.7	11.7	0.868	6.9
M6	630	5.2	11.2	0.878	7.3
M7	605	6.3	12.9	0.817	6.7
M8	615	5.9	12.6	0.821	6.8
M9	640	5.4	12.2	0.827	7.2
M10	655	4.8	11.8	0.858	7.9
M11	670	4.2	11.2	0.887	8.7
M12	680	3.9	10.3	0.898	9.4
M13	695	3.8	9.8	0.913	9.7
M14	710	3.5	9.2	0.927	10.2
M15	720	3.3	8.5	0.948	10.8
M16	735	3.2	8.2	0.957	11.2

4.3.1 Filling Ability of Self-Compacting Geopolymer Concrete Mixes

The filling ability (flowability and viscosity) of self-compacting geopolymer concrete SCGPC is to flow into all spaces within the formwork under its weight. The slump flow values for binary and ternary blends incorporating CKC, GGBS, and MDP are presented in Table 4.2. The results of the slump flow varied from 580 mm to 735mm. Thus, all the mixes were assumed to have good consistency and workability from the filling point of view.

The lower slump values were obtained by (M1, M2, and M3) for binary blend systems, respectively, of SCGPC. As seen in Table 4.2, most concrete mixes could be conformed to SF1 class in terms of slump flow according to **(EFNARC, 2005)**. Except for the binary mixtures containing (M11) and ternary mixes which were located within the SF2 class.

In the binary mixtures (M2, M3, M4, M5, and M6), increased The value of slump flow diameter (mm), decreased the T500 mm and V-funnel flow time (tv) (1.72, 2.52, 4.91, 7.20 and 7.93)%, (4.41, 5.88, 11.4, 16.17 and 23.52)%, and (3.03, 4. 54, 6.06, 11.36 and 15.15)%,respectively when compared to the control mixture as shown in Figures 4.2- 4.3 and 4.4. The lowest T_{500} and V-funnel flow times of 3.2 s and 8.2 s, respectively, while control mix, 100% CKC had the highest T_{500mm} and V-funnel flow times of 6.8 s and 13.2 s. Including CKC generally makes the concrete more viscous.
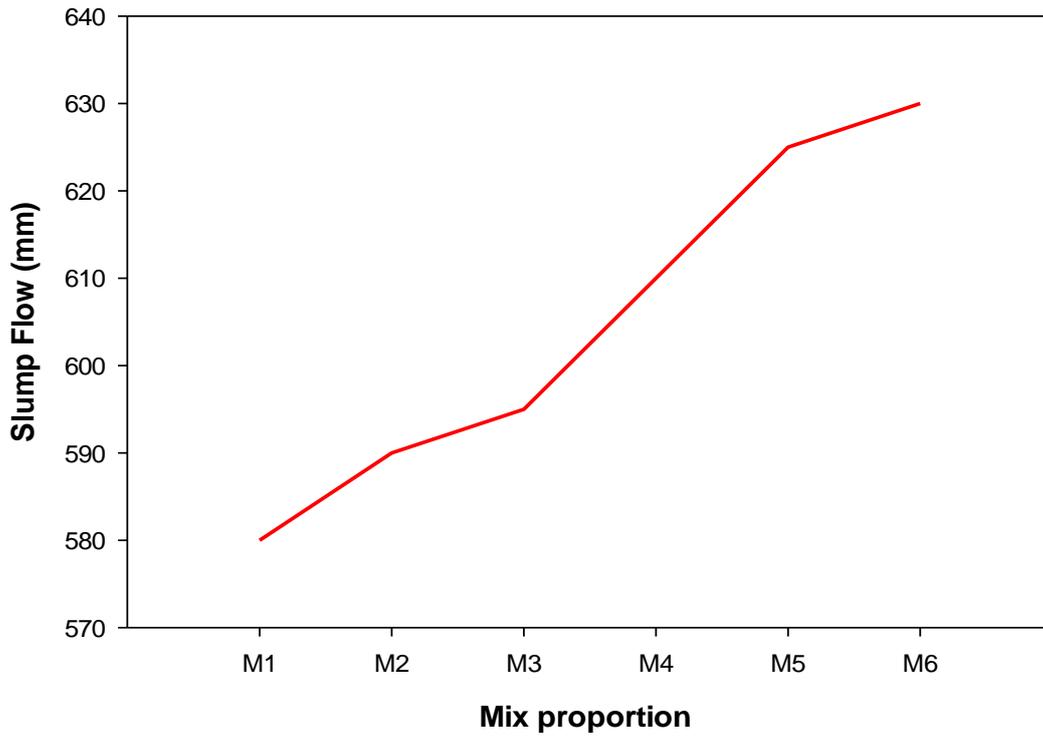
Figure 4.2: Effect of MDPcontent on the Slump flow.
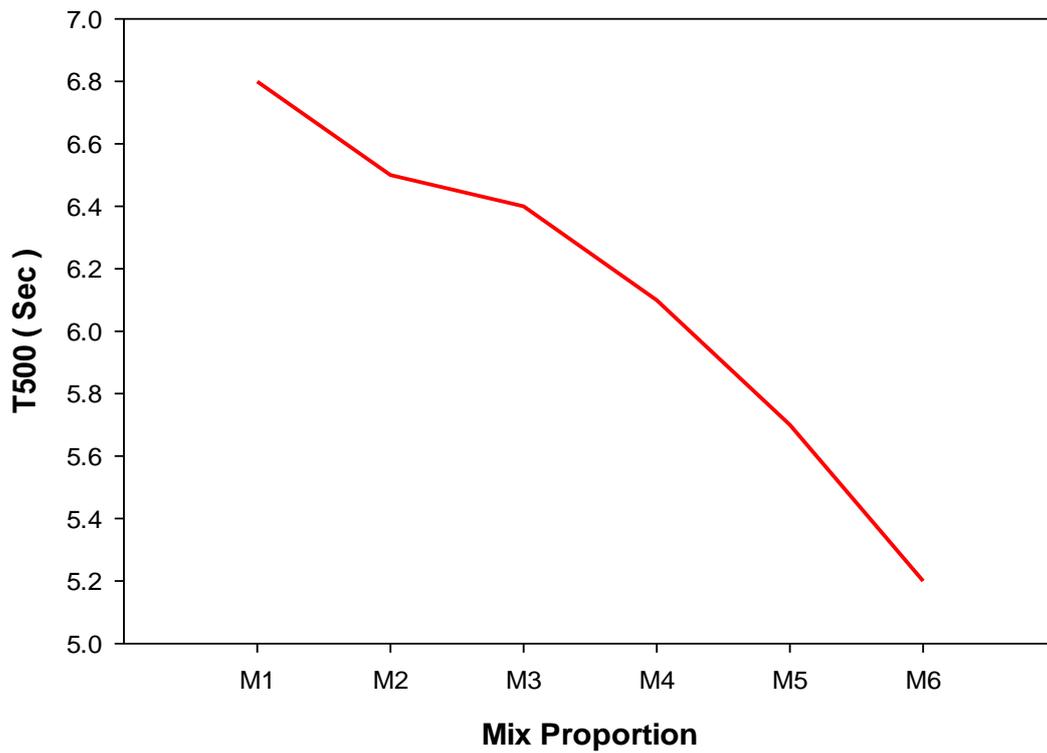
Figure 4.3: Effect of MDP content on the T_{500mm} Slump flow
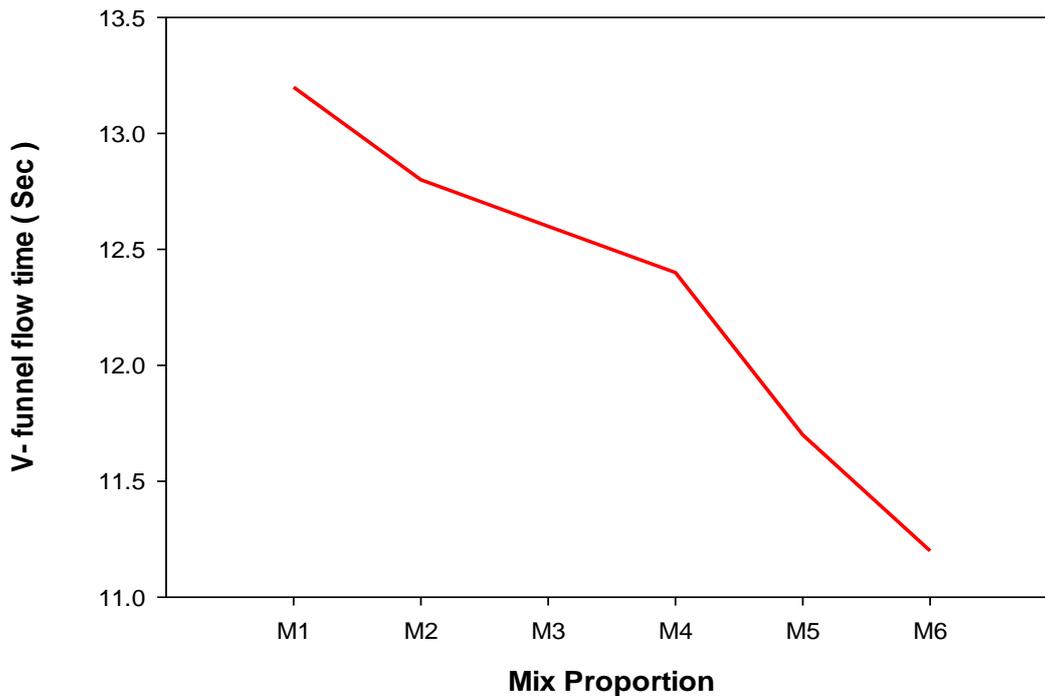
Figure 4.4: Effect of MDP content on the V-Funnel Flow Time

The calcined kaolin clay particles' size and form, which are long, hexagonal plates that create obstructions in the fresh mixture and enhance friction between the particles, may be to blame for the results. However, the irregular or plate-like shape of the MK particles is assumed to reduce the ability of the mixture to expand, leading to reduce slump-flow diameters Also, The pozzolanic materials used GGBS and MDP have a low water absorption capacity, leaving more water to contribute to the flowability significantly, meaning that the requirements for water are less. Similar trends were also stated by other researchers **(Li et al., 2015; Kumar and Saini, 2015; Kannan, 2018; Faez et al., 2020).**

In the binary and ternary blends mixes (M7, M8, M9,M10,M11)and(M12,M13,M14,M15,M16)that shown in figures (4.5-4.10), it could be seen that the value of slump flow increased, and the T_{500mm} and V-funnel flow time decreased, by about (4.31, 6.03,

10.34,12.93,15.51,17.24,19.82,22.41,24.13 and 26.72)%, (7.35, 13.23, 20.58,29.41, 38.23, 42.64, 44.11, 48.52, 51.47 and 52.94) % and (2.27,4.54,7.57,10.60,15.15,21.96,25.75,30.30,35.60and37.87)% according according to comparisons with the reference blend. In the case of binary mixtures, the similar tendency was seen, however the impact on ternary blends was more apparent. The two causes mentioned above worked together to produce this, as can be seen. Other researchers reported parallel trends. **(Nazari and Riahi, 2011d; Kumari et al., 2016; Kadhum and Owaid,2020).**
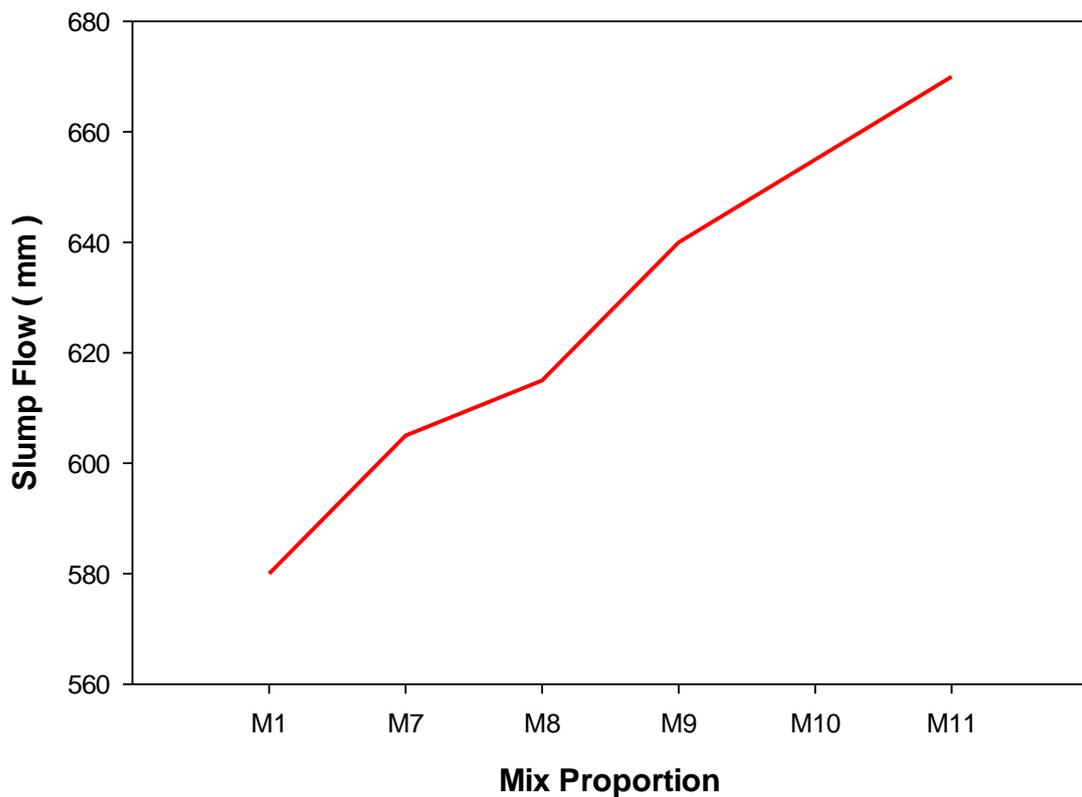
Figure 4.5: Slump Flow Diameter Changes for Binary of SCGPC
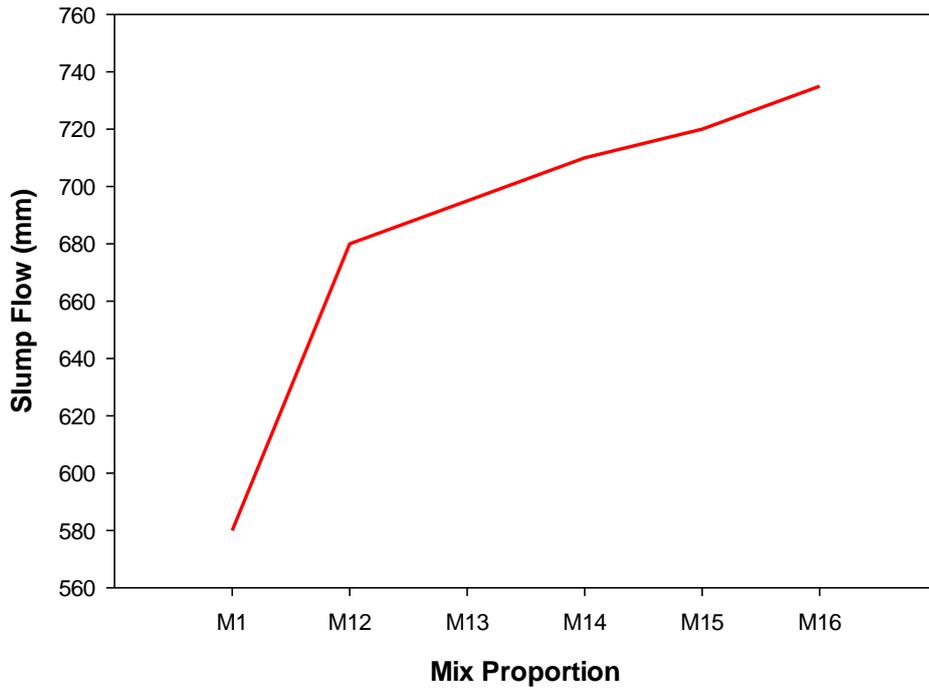
Figure 4.6: Slump Flow Diameter Changes for Ternary of SCGPC
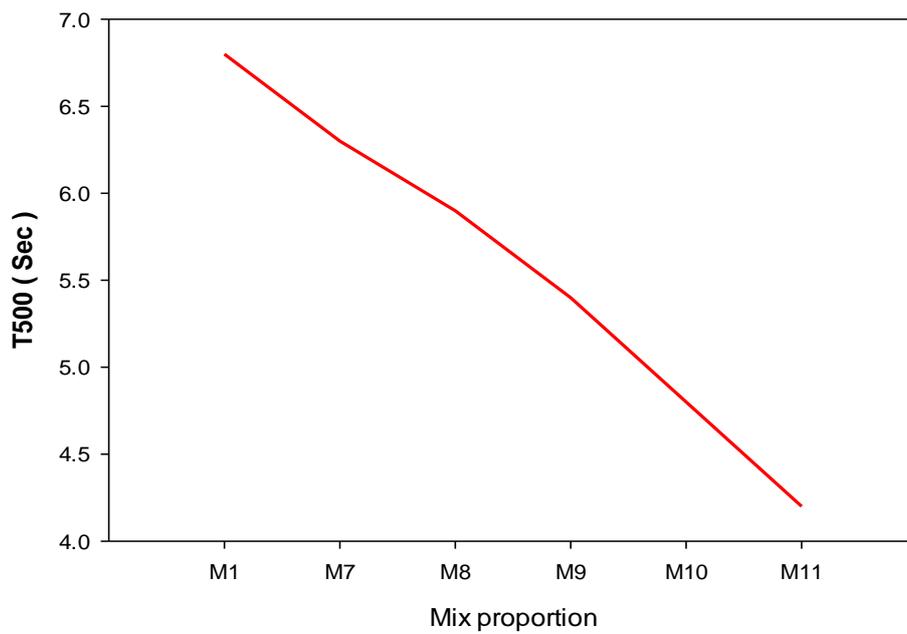
Figure: 4.7: T_{500mm} Results for Binary Mixes of SCGPC.
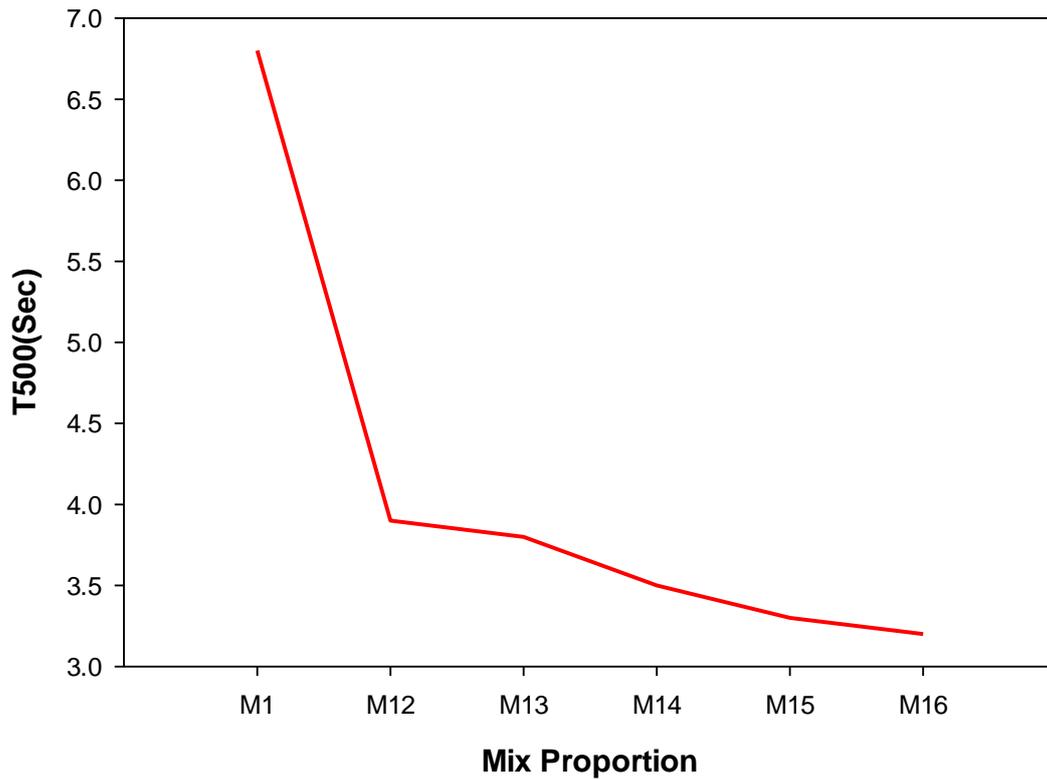
Figure: 4.8: T_{500mm} Results for Ternary Mixes of SCGPC.
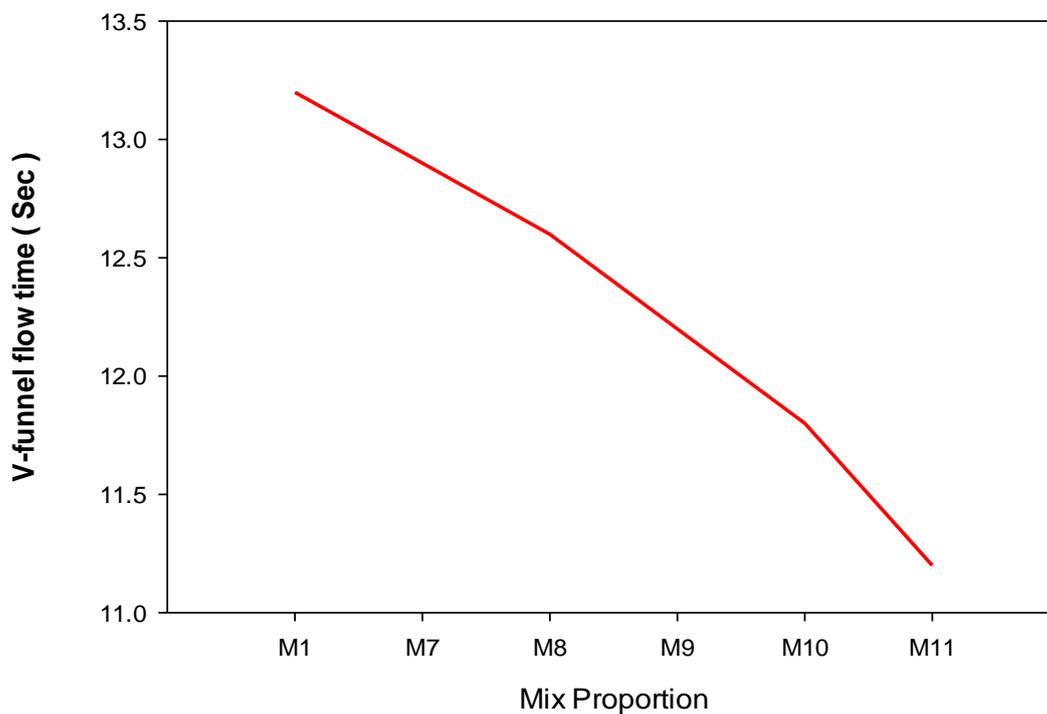
Figure 4.9: V-Funnel Flow Time Results for Binary Mixes of SCGPC.
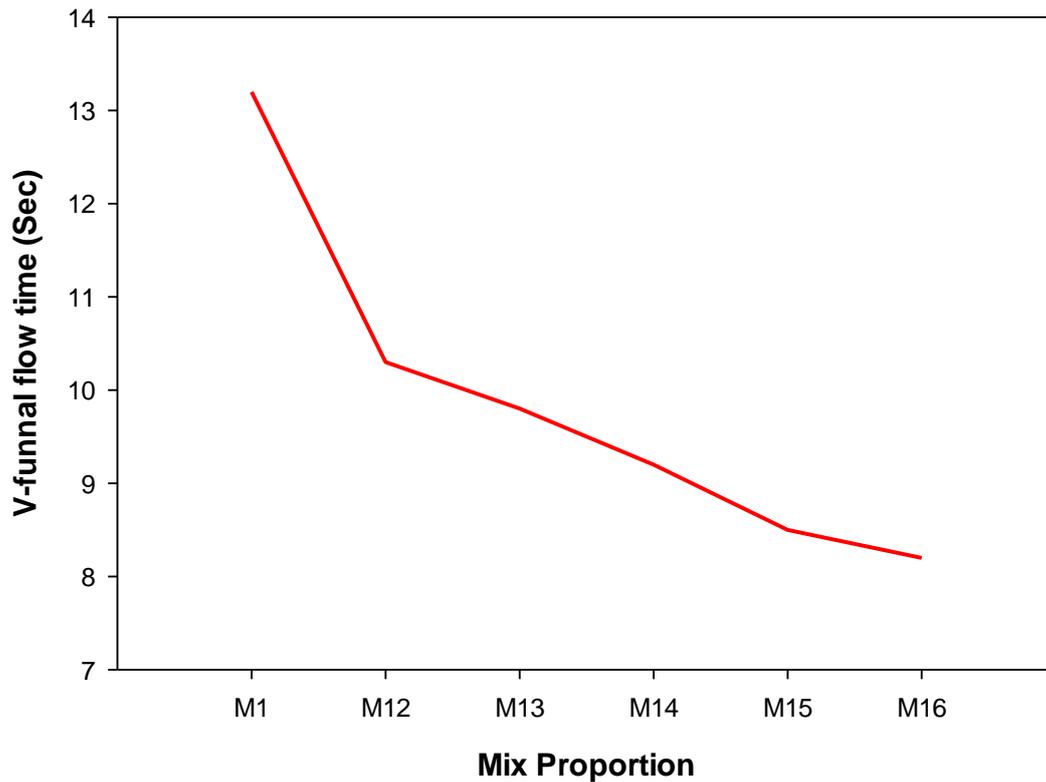
Figure 4.10: V-Funnel Flow Time Results for Ternary Mixes of SCGPC.

Figure 4.11 illustrates the relationship between the slump flow time (T_{500} (s)) and V-funnel flow times. According to **(EFNARC, 2005),** SCC is classified as VS1/VF1 when $T_{500 \, mm}$ and V-funnel flow time are ≤ 2 s and $\leq$ 8 s, respectively, while SCC is categorized as VS2/VF2 when T_{500mm} exceeds 2 s and V-funnel flow time ranges from 9 to 25 s. Therefore, most the mixtures might be grouped into the VS2/VF2 class, which may be necessary for enhancing segregation resistance as flow duration increases. With the exception of mix, which fell between the VS2 and VF1 classes according to EFNARC (M15 and M16).
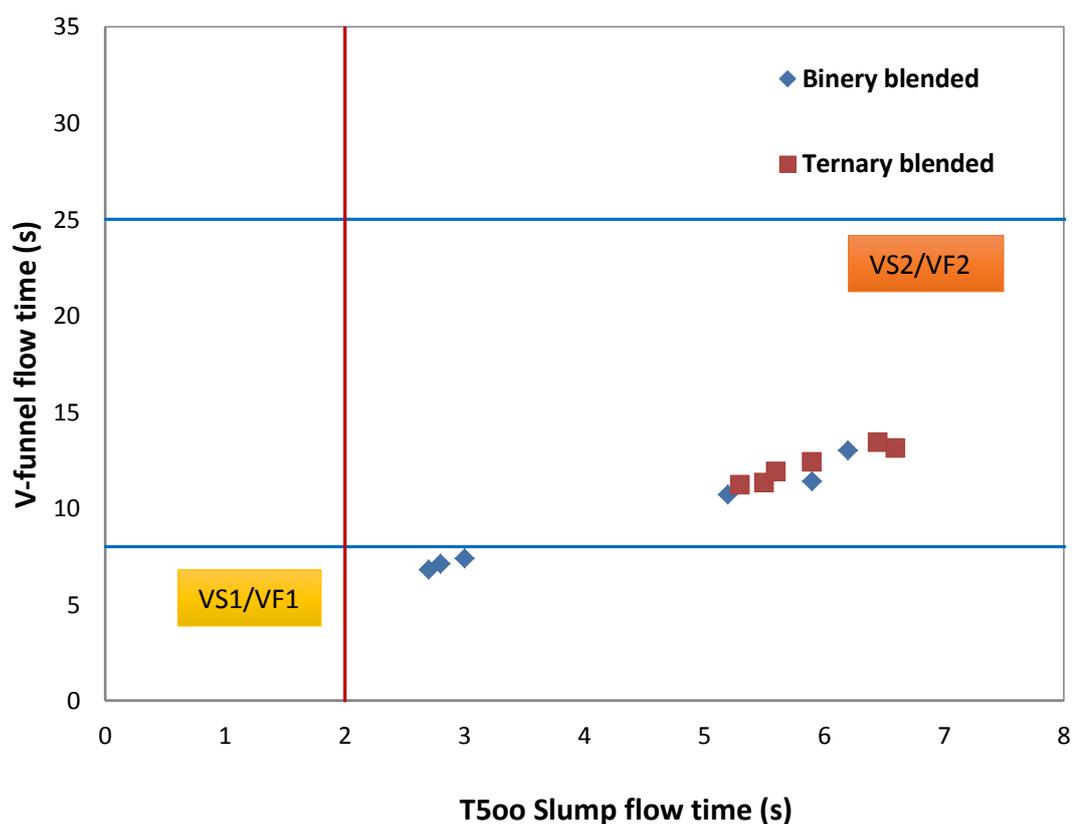
Figure 4.11: Variation of Viscosity Classes with T_{500} Slump Flow and V-Funnel Flow Times of SCGPC

4.3.2 Passing Ability of SCGPC Mixes

The results of the L-box test are tabulated in Table 4.2. Test results explained that the L-box height ratios ranged from 0.809 to 0.957 for binary and ternary blends of SCGPC mixtures containing CKC, GGBS, and MDP as replacements for CKC. As it is observed, all SCGPC mixes made with binary and ternary blends of CKC, GGBS, and MDP were classified as PA2 (H2/H1 ≥ 0.80 for three bars) in terms of the passing ability. The mixtures in this class would have a good passing ability where it was greater than 0.8, which is considered the minimum critical value according to (**EFNARC, 2005**). It should be noted that (**Felekoğlu et al.,2007; Kasemchaisiri and Tangtermsirikul,2008**) concluded that a blocking

ratio higher than 0.6 had been accepted for SCC to achieve good filling ability. At the time of the execution of the test, no blocking or segregation phenomena were observed in the mixtures.

Figure (4.12) shows that the binary mixtures in comparison to the control mixture, the passing ability of (M2, M3, M4, M5, and M6) was higher by roughly 0.86, 2.10, 3.9, 7.29, and 8.52%, respectively. However, it was shown that the binary and ternary mixes had a stronger impact on this result (M7,M8,M9,M10,M11,M12,M13,M14, M15 and M16) that had bigger passing ability by about (0.98, 1.48, 2.22, 6.05, 9.64, 11.08, 12.85, 14.58,17.18, and 18.29) % respectively, compared to the control mixture (100%CKC) as shown in Figure 4.13 and 4.14 .

With CKC partially replaced, the L-box blocking ratio increased, because due to the fineness effect of GGBS and MDP. which increase the ability to pass in the same way that it increase the filling ability but for the previously stated reasons, the synergetic impact led to an increase in this effect in binary and ternary mixes. Other researchers noted comparable patterns. **(Madandoust& Mousavi, 2012; Kannan,2018; Kadhum and Owaid,2020; Faez et al.,2020; Joshaghani et al.,2020)**.
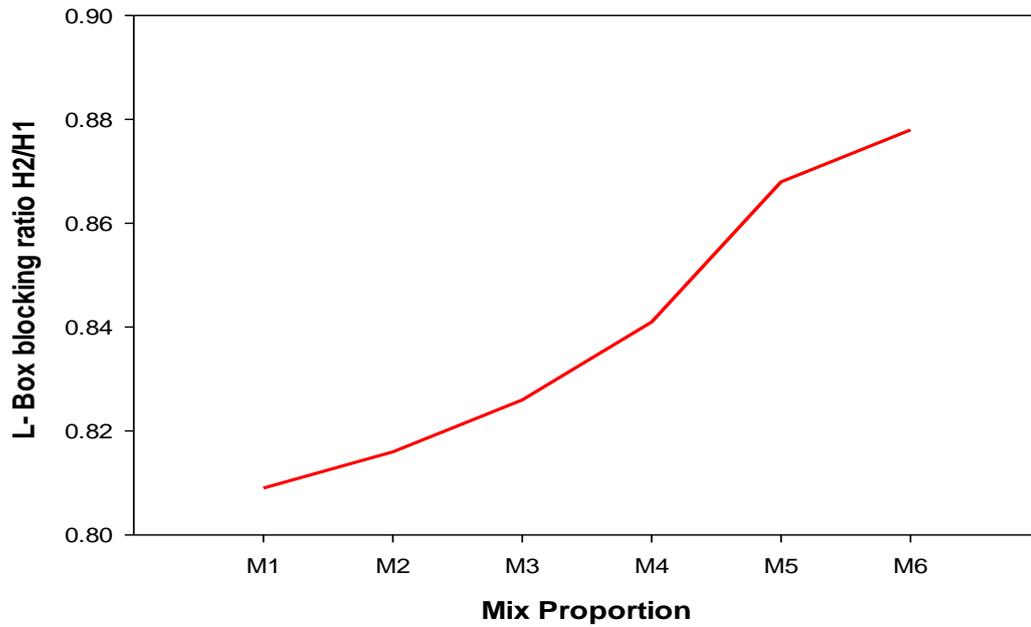
Figure 4.12: L-box Height Ratio Results for Binary Mixes of SCGPCs.
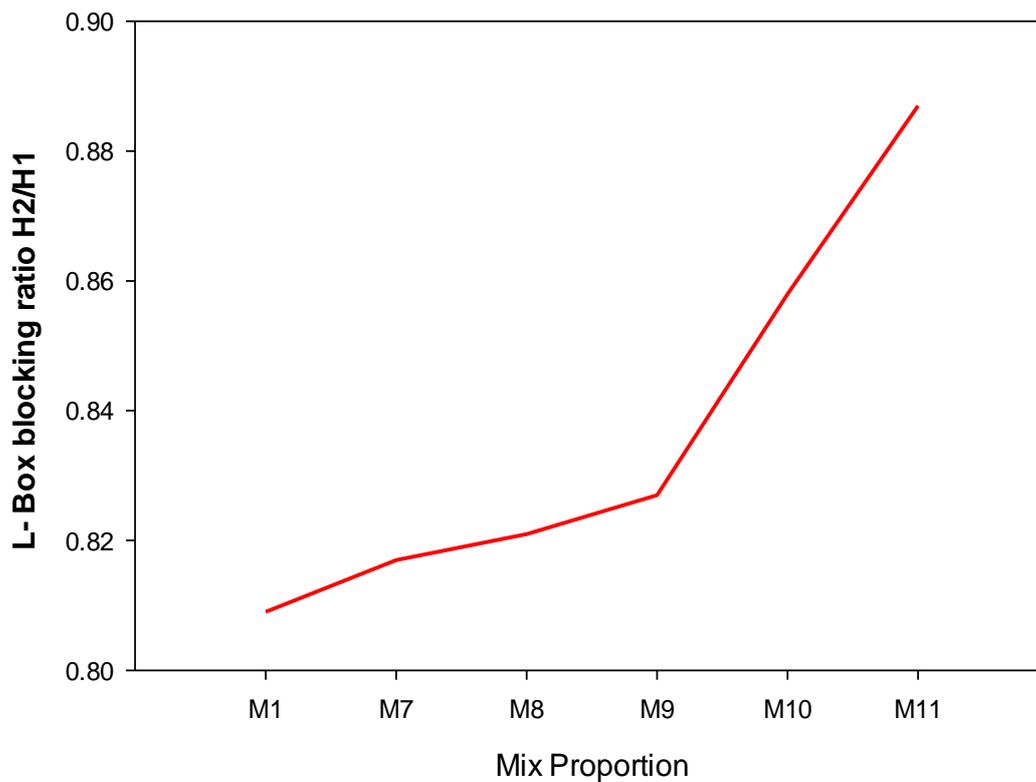
Figure 4.13: L-box Height Ratio Results for Binary Mixes of SCGPC.
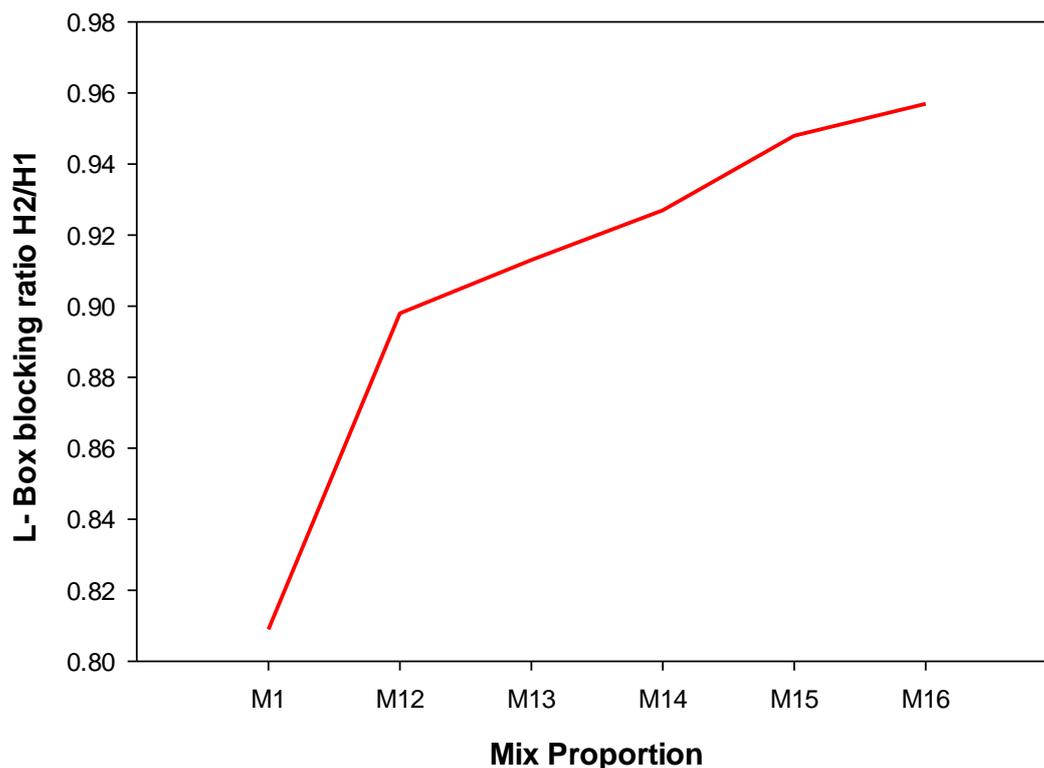
Figure 4.14: L-box Height Ratio Results for Ternary Mixes of SCGPC

4.3.3 Segregation Resistance of SCGPC Mixes

The SCGPC capacity to maintain homogeneity while being transported and placed. The Sieve segregation resistance test can be used to assess the segregation resistance of SCGPC blends. During the slump flow test, it can also be visually examined. Table 4.2 presents the findings of the sieve segregation resistance test values for binary and ternary blends of SCGPC mixes.Through the results obtained and shown in Figure 4.15, it was found that the segregation rate was good for all mixtures, as it was between (6.1–11.2%), which were considered determinants of **(EFNARC, 2005)**, which determined the segregation rate $\leq 15\%$ (SR2 class).

From Table 4.2, it could be seen that the binary mixtures (M2, M3, M4, M5, and M6) had more segregation resistance in comparison to the

reference mixture. The increase of segregation percentage was about (0, 3.27, 8.19, 13.11, and 19.67) % for the binary mixes above, respectively. The binary and ternary mixtures(M7, M8, M9, M10, M11,M12, M13,M14, M13,M14, M15 and M16) had higher segregation resistance than reference, reference, where the segregation percentage increased further in this mixes by about (9.83, 11.47, 18.03, 29.50, 42.62, 54.09, 59.01, 67.21,77.04 and 83.60%), respectively, as compared with reference mixtures. From Figure 4.15, the binary and ternary mixes showed an increase in segregation resistance.

These test findings demonstrated reduction in aggregate content. This has to do with the CKC ability to absorb water during mixing since doing so has the effect of raising the CKC surface area, which raises the plastic viscosity of freshly-poured concrete. The mixture must have a moderate to high viscosity in SCGPC in order to maintain homogeneity and prevent segregation. In support of the finding that there was no segregation in these mixes, the greater plastic viscosity lowers the rate at which coarse aggregate settles and so increases the resilience of fresh concrete to segregation. Other researchers reported parallel trends. **(Madandoust and Mousavi, 2012; Panesar and Shindman,2012; Joshaghani et al.,2020; Kadhum and Owaid,2020)** .
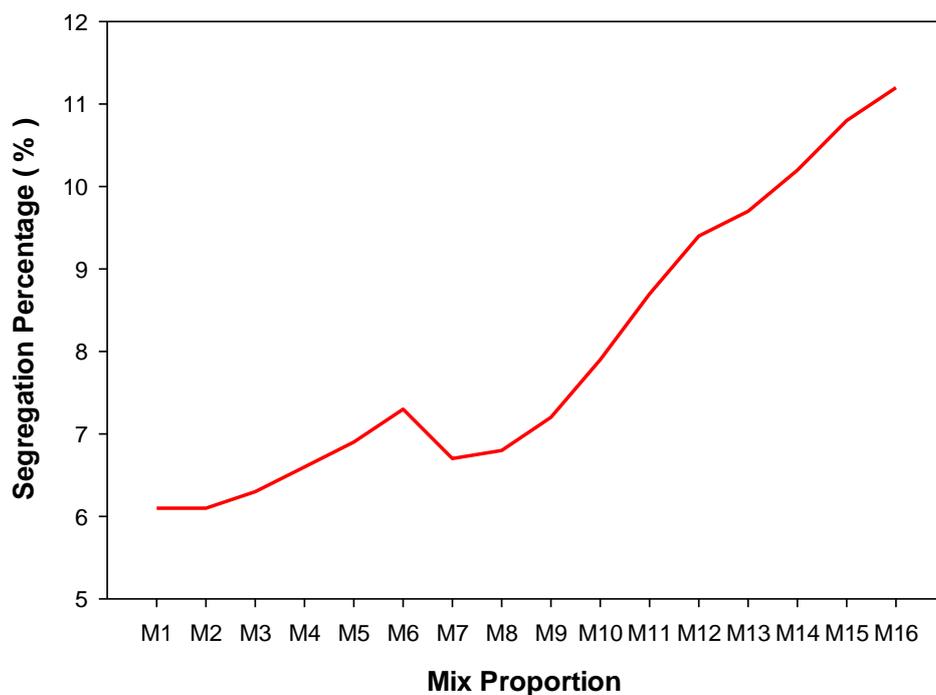
Figure 4.15: Segregation resistance results for binary, ternary Mixes
SCGPC

4.4 Properties of Hardened SCGPC Mixes

The property that is most needed for structural application is the hardened property or mechanical strength of mortar or concrete. Concrete's strength is influenced to some extent by the aggregate own strength as well as by the cohesion of the mix ingredients, their adhesion to the aggregate particles, and other factors. In this investigation, the main toughened characteristics of SCGPCs were bulk density, compressive strength, splitting tensile strength, and ultrasonic pulse velocity (UPV). Below, there is a detailed description and discussion of the tests' findings for binary and ternary SCGPC blends.

4.4.1 Bulk Density

The bulk density of any structure depends entirely on the unit weight of the constituent materials. Thus, it is a considerable parameter for mortar or concrete. Therefore, the weight of concrete per unit volume was used to calculate the bulk density of concrete. The bulk density of SCGPCs was calculated as the average value of the three specimens, and the results obtained are plotted graphically as shown in Figure 4.16. The results of bulk density tests of SCGPCs at 7 and 28 days are tabulated in table 4.3. The bulk density of blended SCGPC was higher than that of the control mix. As shown in Figure 4.16, the bulk density of all the types of SCGPC increased with curing age. From the results, it was found that the addition of CKC, GGBS, and MDP tends to increase density in binary and ternary mixes.

Table 4.3: The Results of Bulk Density Tested of SCGPC

Mixes	Bulk density (kg/m^3)	
	7days	28days
M1	2348	2372
M2	2356	2387
M3	2371	2398
M4	2384	2408
M5	2391	2417
M6	2396	2422
M7	2403	2431
M8	2417	2446
M9	2432	2462
M10	2439	2471
M11	2453	2479
M12	2433	2458
M13	2442	2469
M14	2448	2476
M15	2459	2483
M16	2468	2496

This outcome could be explained by the pozzolanic material CKC specific gravity being smaller than that of (MDP and GGBS) CKC, MDP, and GGBS all have specific gravities of 2.59, 2.68, and 2.9, respectively. This trend was also in line with findings from earlier research on pozzolanic components CKC, MDP, and GGBS in concrete mixtures. **(Frieh et al., 2014).**

The percentages of increase in bulk density of SCGPC (M2, M3, M4, M5, M6and M7, M8, M9,M10,M11,M12, M13,M14, M15, M16) were 0.34, 0.97, 1.53, 1.83, 2.04, 2.34,2.93,3.57,3.87,4.47,3.62,4.00,4.25,4.72 and 5.11%at7daysand(0.63,1.09,1.51,1.89,2.10,2.48,3.11,3.79,4.17,4.51,3.62, 4.08,4.38, 4.67 and 5.22) % at 28 days, in comparison to the control mixture, respectively.The bulk density increased further in binary and ternary mixes.
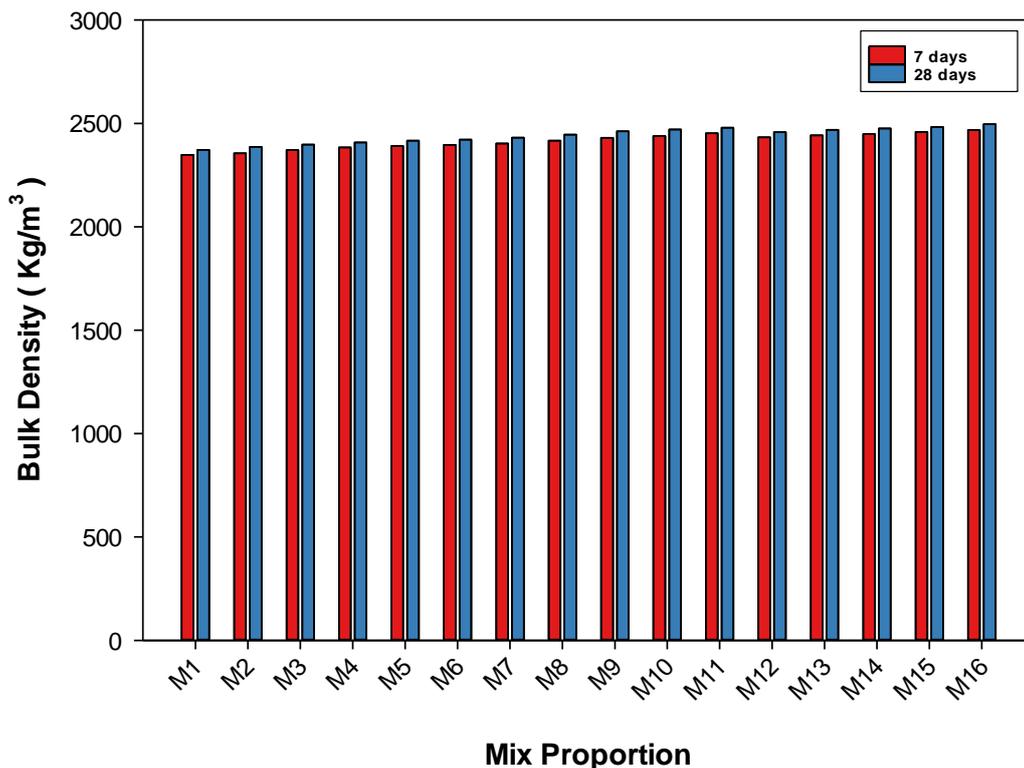
Figure 4.16: Binary and ternary blended SCGPC mixtures bulk densities

4.4.2 Compressive Strength

The most crucial design factor for any kind of concrete construction is compression strength. This important factor directs the design process and can affect a project and a building cost. For various ages, the strength growth of SCGPC was examined in this regard. Figures 4.17 to 4.19 demonstrate the development of the compressive strength of SCGPC made up of binary and ternary mixtures with varying amounts of CKC, GGBS, and MDP after curing for 3, 7, 28, 56, and 90 days.

4.4.2.1 Binary Mixtures of CKC and MDP

Table 4.4 and Figure 4.17 present the average compressive strength results for binary mixtures of SCGPC at all ages, containing 5%, 10%,15%,20% and 25% of (MDP). The compressive strength of the control SCGPC mix(100%CKC) ranged between 30.5–53.3 MPa, while the compressive strength of binary blends of SCGPC mixes including MDP in all percentages varied between 26.8 and 59.3 MPa, mainly depending on the replacement percentages and conditions of curing (show Table 4.4).

Table 4.4 Compressive Strength Results in Binary Blended Mixes of CKC and MDP

Ages (days)	Compressive strength MPa					
	M1	M2	M3	M4	M5	M6
3	30.5	31.8	33.2	35.4	28.7	26.8
7	37.7	38.2	41.9	43.6	35.4	33.2
28	47.6	49.2	50.8	52.3	43.1	41.2
56	50.4	52.8	54.6	57.6	46.2	43.6
90	53.3	55.9	57.1	59.3	49.4	47.1

As shown in Figure 4.17, the results of compressive strength showed that inclusdes of MDP (M2, M3 and M4) in binary blended increase the compressive strength of SCGPC mixtures in comparison with that of control mix (100CKC) in all ages. At 3 days, the rise was roughly 4.26%, 8.85%, and 16.06%; at 7 days, 1.32%, 11.14%, and 15,64%; at 28 days, 3.36%, 6.72%, and 9.87%; at 56 days, 4.76%, 8.33%, and 14.28%; and at 90 days, approximately 4.87%, 7.12%, and 11.25%, respectively. The interfacial transition zone was stregthered by the finer marble waste .It is quite natural to expect such adevelopment in stregth.
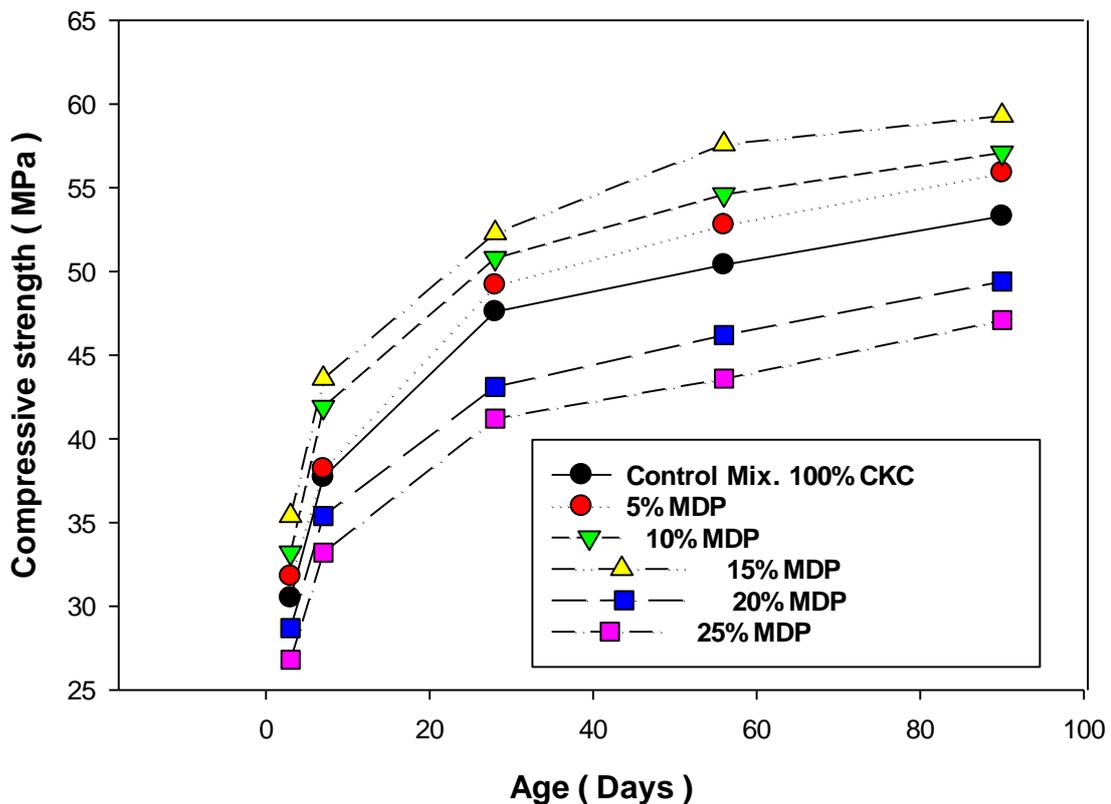
Figure 4.17: Development of Control and Binary Blended SCGPC with CKC and MDP Compressive Strength at Different Ages

In comparison to the control mix(100%CKC) mixture, the addition of M5 and M6 to the binary blended decreased compressive by 5.90% and 12.13% at 3 days, 6.10% and 11.93% at 7 days, 9.45% and 13.44% at 28

days, 8.33% and 13.49% at 56 days, and 7.31% and 11.63% at 90 days.The reason this might be due to reduction in the quantum of the available cementiy materials. Similar trends were also stated by other researchers **(Tekin, 2016; Cheng , et al, 2017)**

It could be seen from Figure 4.17 that M2,M3,M4 exhibited the highest compressive strength at all ages (early and long term). The fact that MDP particles most likely operated as very fine agents that filled pores in the concrete, reducing porosity and improving the mix's structure, can be used to explain why there was an improvement in compressive strength after the MDP was added.

4.4.2.2 Binary Mixtures of CKC and GGBS

Table 4.5 and Figure 4.18 illustrate the effects of binary blends incroprating with GGBS of SCGPC mix M7, M8,M9,M10 and M11 with on the compressive strength in comparison to the control mix(100%CKC) at various ages. It could be seen from the results, the performance of all binary blend mixtures was observed to outperform the performance control mixture of compressive strength at all ages. It could be concluded that 50%GGBS(M9) was more effective in improving the compressive strength in comparison with the binary system with the replacement ratio of CKC.

The binary blends SCGPC (M7, M8, M9, M10 and M11) mixes revealed in the increased compressive strength by (16.39, 22.95, 31.80, 27.21and 10.81)%, (14.58, 19.62, 29.44, 17.24 and 9.28)%, (15.12, 20.37, 20.37, 24.78, 15.96 and 10.50)%, (16.07, 18.45, 22.22, 14.08 and 7.73)% and (13.32, 16.03, 20.45, 12.19 and 8.25)% at 3, 7, 28, 56, and 90 days of age, respectively, compared with control mix as shown in Figure 4.18. It could be seen that the compressive strength of binary blends SCGPC mix

containing 50%CKC and 50% GGBS exhibited the highest compressive strength at all ages.

Table 4.5: The Compressive Strength Results in Binary Blended Mixes of CKC and GGBS

Age (days)	Compressive strength, MPa					
	M1	**M7**	**M8**	**M9**	**M10**	**M11**
3	30.5	35.5	37.5	40.2	38.8	33.8
7	37.7	43.2	45.1	48.8	44.2	41.2
28	47.6	54.8	57.3	59.4	55.2	52.6
56	50.4	58.5	59.7	61.6	57.5	54.3
90	53.3	60.4	61.8	64.2	59.8	57.7
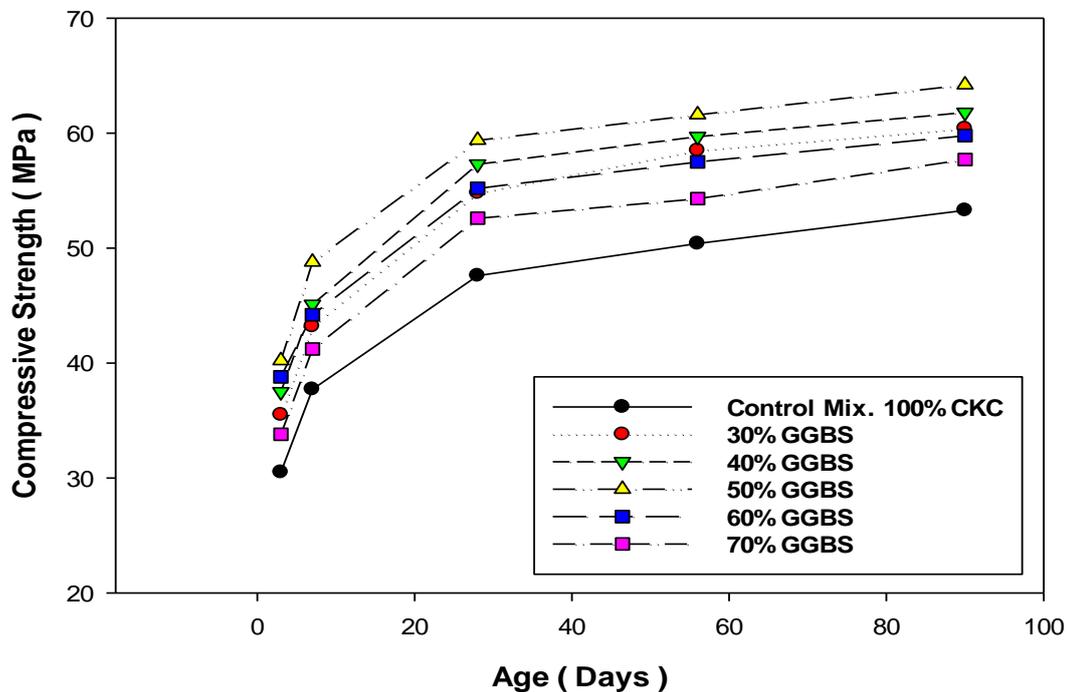
Figure 4.18: Binary Blended Compressive Strength Development of Control SCGPC Mixtures Incorporating CKC and GGBS at Various Ages

This could be because the alkaline interaction between GGBS particles and calcium CKC has increased, and also due to formation of dense microstructure. Besides this, the exothermic reaction of CaO in GGBS

accelerates formation of C-S-H gel which thus increases the compressive strength of SCGPC mix.Similar trends were also stated by other researchers **(Kumar and Ramesh, 2016; Sireesha and Madhavi, 2018**) . The results in table 4.5 show that replacing 50% of GGBS give the best results.

4.4.2.3 Ternary Mixtures of CKC,GGBS and MDP

Table 4.6and Figure 4.19 illustrate the effects of ternary blends of SCGPC mixes(M12,M13,M14,M15 and M16) on the compressive strength in comparison to the control mixture at various ages. It could be seen from the results that the performance of mixes containing (5, 10,15,20 and 25%) MDP with blends of 50%GGBS was found to perform better than control combinations did. (100%CKC).

Table 4.6: The Compressive Strength Results in Ternary Blended

Mixes of CKC, MDP and GGBS

Ages (day)	Compressive strength, MPa					
	M1	**M12**	**M13**	**M14**	**M15**	**M16**
3	30.5	42.2	43.8	46.1	35.8	32.2
7	37.7	49.4	51.3	53.8	42.3	39.5
28	47.6	62.1	64.7	66.4	53.1	50.8
56	50.4	64.2	65.6	67.6	55.0	52.4
90	53.3	66.3	67.7	69.2	56.4	53.8

As shown in Figure 4.19, SCGPC (M12, M13, and M14) mixes had higher compressive strengths of (38.36,43.60 and 51.14)%, (31.03, 36.07 and 42.70)%, (30.46, 35.92 and 39.49)%, (27.38, 30.15 and 34.12)% and (24.39, 27.01 and 29.83)% at the ages 3,7, 28, 56 and 90 days, respectively, respectively, compared with SCGPC control mix(M1). The compressive strength of the (M14) SCGPC mix exhibited the highest compressive strength at all ages.
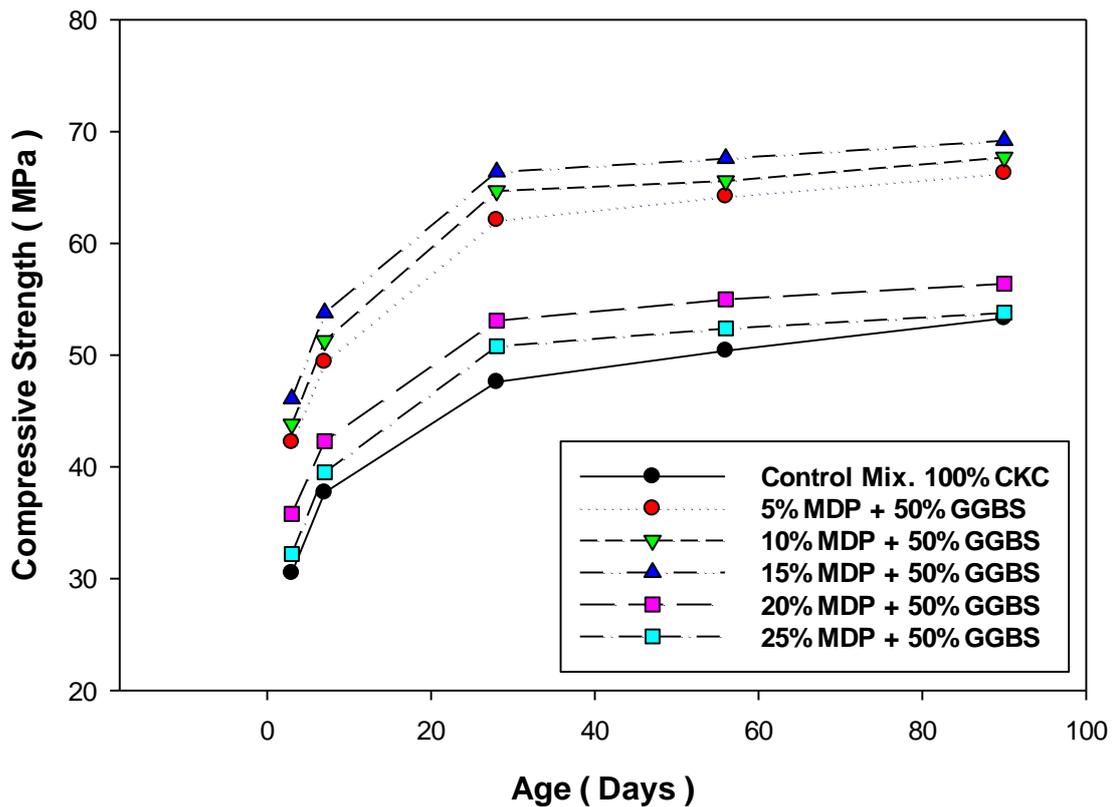
Figure 4.19: Compressive Strength Development of Control and Ternary

Blended SCGPCs Mixtures Incorporating CKC, MDP, and GGBS at

Various Ages

This outcome can be attributable to the double-blind MDP and GGBS on the properries of the concrete mix as mentioned in the previous explanation and the use of MDP and GGBS is more effective than the single use of CKC to improve the microstructure of concrete. The use of MDP and GGBS has an effect on improveing compressive strength at an early age and long term strength.No systematic investigation on the effect of incorporating of GGBS and MDP as the replacement material for CKC onThe properties of the developed SCGPC. The present study aims to fill in this blank with the help of laboratory testing.

4.4.3 Splitting Tensile Strength

Depending on the overall amount of compressive strength of concrete or mortar, the ratio of tensile to compressive strength will vary. The compressive strength of concrete and the splitting tensile strength (STS) are inversely correlated. However, the ratio of the two strengths is influenced by the concrete's overall level of strength. **(Neville, 2011).** This means that while the compressive strength rises, the STS likewise rises, although at a slower rate. Due to the ease with which cracks can spread under tensile pressures, the tensile strength of concrete is often substantially lower than the compressive strength. But given that cracking in concrete typically results from tensile strains that occur under load or from environmental changes, it is a crucial feature. Microcracking, namely at the interfacial region between the aggregate particles and the cement paste, known as the interfacial transition zone(ITZ), controls the failure of concrete under tension. The STS findings of SCGPC and control mix for the binary and ternary blended systems are shown in Figures 4.20 to 4.22.

4.4.3.1 Binary Mixtures of Calcined Kaolin Clay and MDP

Splitting tensile strength results for binary blends SCGPC of CKC and MDP are listed in Table 4.7. This test was conducted to determine the splitting tensile strength of SCGPC at ages (7, 28, and 90) days.

Table 4.7: The Splitting Tensile Strength Results in Mixes of CKC and MDP Binary Blended

Ages (day)	Splitting tensile strength, MPa					
	M1	M2	M3	M4	M5	M6
7	3.12	3.19	3.37	3.53	2.87	2.64
28	3.71	3.83	3.96	4.16	3.41	3.27
90	4.06	4.27	4.34	4.53	3.76	3.62

Figure 4.20 illustrates that the increasing of splitting tensile strength an increase in CKC replacment (5, 10, and 15% MDP) in the binary blend of SCGPC mixture as opposed to control-Mix. The increase were approximately 2.24%, 8.01%, and 13.14% at 7 days; 3.23%, 6.73%, and 12.12% at 28 days and 5.17%, 6.89%, and 11.57% at 90 days, respectively, compared to the control mixture. Also, it was clear that the influence of CKC on specimensplitting tensile strength was more noticeable at a later age than at an earlier one.This behavior is caused by CKC slow pozzolanic reaction with $Ca(OH)_2$ in the presence of water at an early age. The decrease in splitting tensile strength with increasing CKC replacement ratios with (MDP)(20%and25%) at 7,28 and 90 days is most likely due to a significantly lower level of $Ca(OH)_2$ generation in these mixes due to the high volume of MDP, resulting in less C-S-H gel being produced to bind the materials together, and less improvement in the density of the interfacial transition zone, which tends to be an important factor influencing tensile strength. Similar trends were also stated by other researchers **(Ramezanianpour and Jovein, 2012; Frieh et al., 2014).**
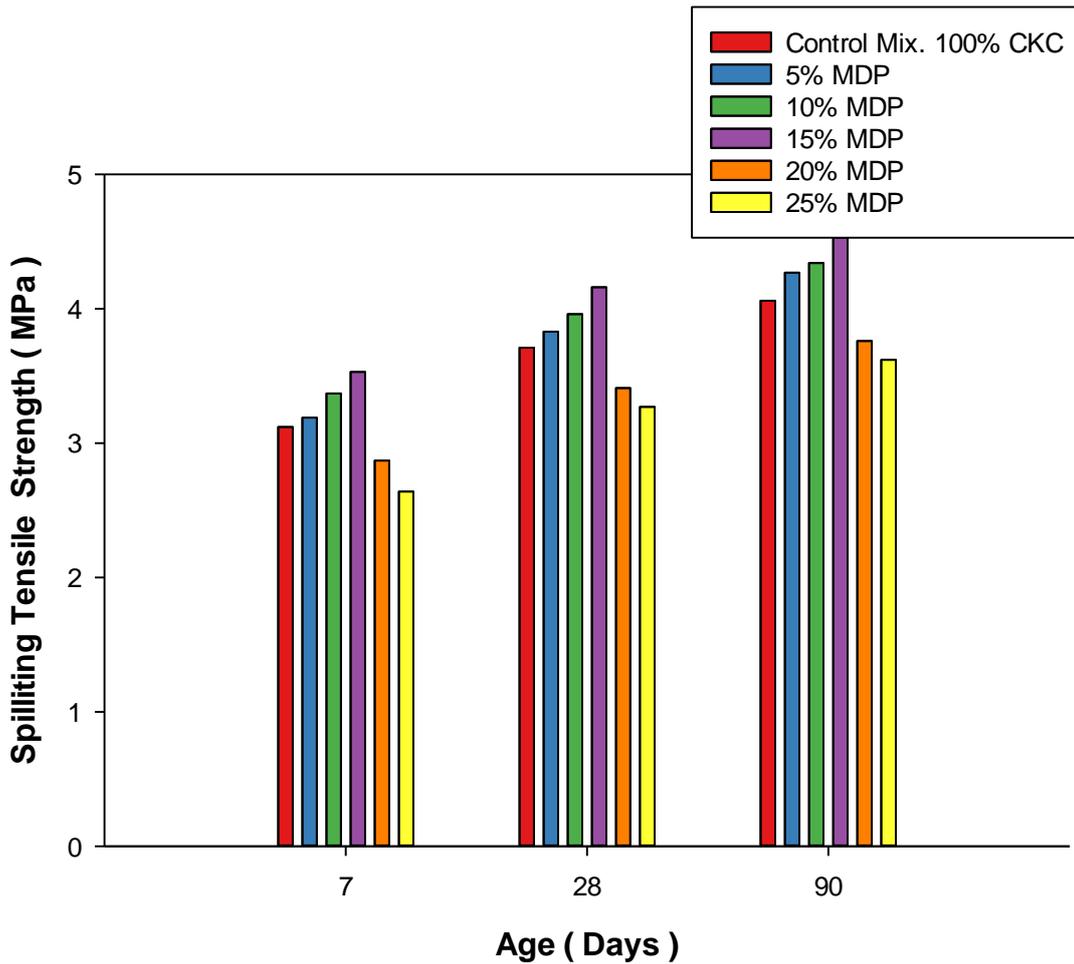
Figure 4.20:Splitting Tensile Strength Results of Control and Binary Blended SCGPC Mixes Containing CKCand MDP at Various Ages

4.4.3.2 Binary Mixtures of CKC and GGBS

The results of splitting tensile strength for binary blends of SCGPC mixtures of calcined kaolin clay(CKC) and GGBS at various ages are shown in Figure 4.21 and are tabulated in Table 4.8. It can be observed from the results that the STS (M7,M8 , M9,M10,M11) in binary blend systems was higher than the STS of control mix in 7, 28, and 90-day ages. The binary blend system of (50%GGBS)with(50%CKC) was better value of splitting tensile strength at all ages .

Table 4.8: The Splitting Tensile Strength Results in Binary Blended Mixes of CKC and GGBS

Ages (day)	Splitting tensile strength, MPa					
	M1	**M7**	**M8**	**M9**	**M10**	**M11**
7	3.12	3.49	3.64	3.92	3.53	3.31
28	3.71	4.26	4.47	4.65	4.34	4.13
90	4.06	4.59	4.71	4.87	4.53	4.36

The significant improvements in the splitting tensile strength of (M7, M8, M9, M10, and M11) were (11.85, 16.66, 25.64, 13.14, and 6.08) % at the ages of 7 days, (14.82, 20.48, 25.33, 16.98, and 11.32) % at the ages of 28 days, and (13.05, 16.00, 19.95, 11.57, and 7.38)% at the ages of 90 days, respectively, compared with the SCGPC control mix. This may be the same reason indicated for the compressive strength. Overall, the effect of CKC and GGBS on the splitting tensile strength was similar to that on the compressive strength. interaction between GGBS particles and calcium CKC improving the microstructure and reaction of Cao in GGBS accelerates formation of C-S-H gel which thus increase the splitting strength of SCGPC. Similar trends were also stated by other researchers **(Kumar and Ramesh, 2016; Sireesha and Madhavi, 2018).**
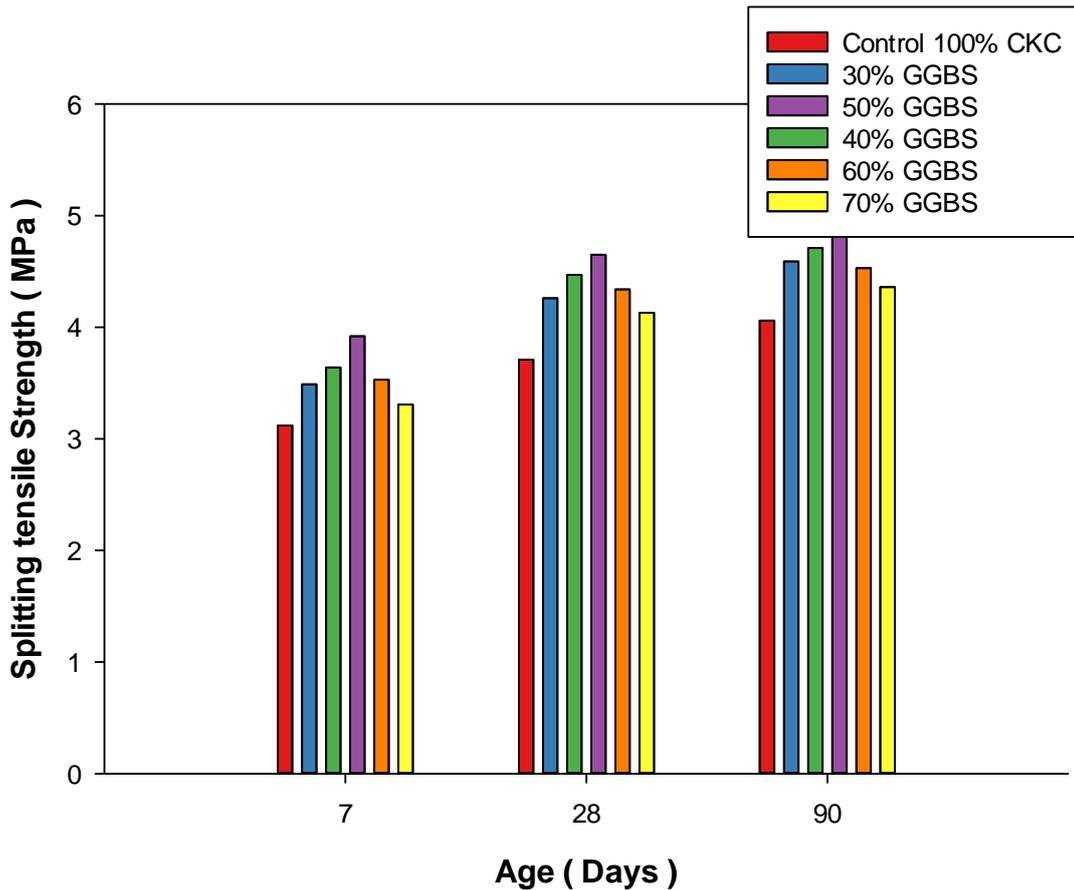
Figure 4.21 Splitting Tensile Strength Results of Control and Binary Blended   SCGPC Mixes Containing CKC and GGBS at Various Ages

4.4.3.3 Ternary Mixtures of CKC,MDP andGGBS

The results of splitting tensile strength for ternary blends of SCGPC mixtures of CKC, MDP and GGBS at various ages are shown in Figure 4.22 and are tabulated in Table 4.9. It can be observed from the results that the STS of mixes containing (45, 40,35,30 and 25%) CKC with blends of(5,10,15,20 and 25% MDP) and (50% GGBS) were found to be superior to the STS of control mixture, ternary blends mixes at the identical CKC replacement levels at ages of 7, 28, and 90 days.

Table 4.9: The Splitting Tensile Strength Results in Ternary Blended Mixes of CKC, MDP, and GGBS

Ages (day)	Splitting tensile strength, MPa					
	M1	**M12**	**M13**	**M14**	**M15**	**M16**
7	3.12	3.97	4.16	4.33	3.45	3.23
28	3.71	4.76	4.93	5.17	4.11	3.93
90	4.06	4.97	5.04	5.21	4.26	4.13

Figure 4.22 shows that the splitting tensile strength of SCGPC (M12,M13,M14,M15,and M16) improved by (27.24, 33.33,28.78,10.57 and 3.52)%, (28.30, 32.88, 39.35, 10.78 and 5.92)% and (22.41, 24.13,28.32,4. 92 and 1.72%) respectively, was assessed at ages 7, 28, and 90 days in comparison to the control-mix. The mix (M14) the maximum splitting tensile strength at all ages.

This is for the same reason indicated in compressive strength. As explained previously, the use of MDP and GGBS particles is more effective due to their higher activity and filler effect than single-use. These characteristics ofMDP and GGBS particles strengthen the aggregate paste transition zone and hence increase the splitting tensile strength of concrete by improving the aggregate paste, the use of MDP and GGBS improve the microstructure of concrete and improveing splitting tensile at an early age and long-term . Similar trends were also stated by other researchers **(Orakzai, 2021; Khoman and Owaid,2022).**
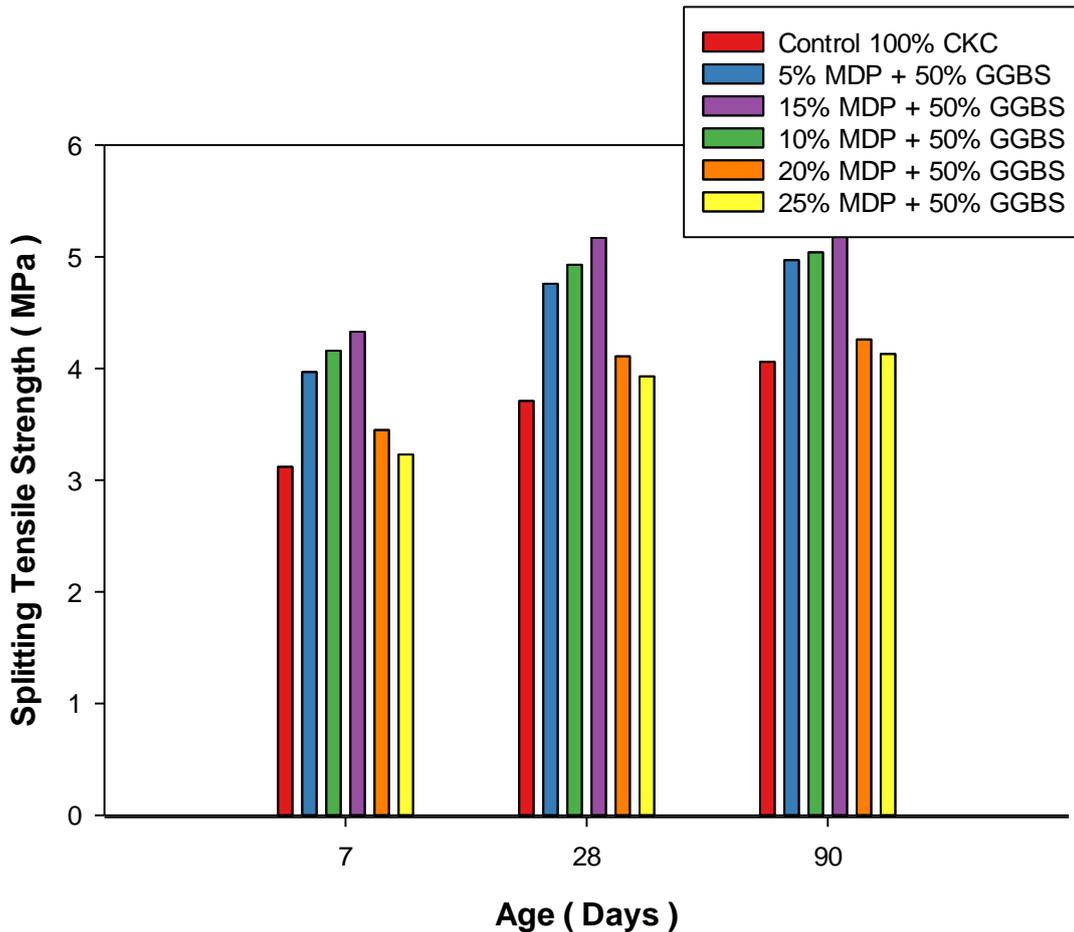
Figure 4.22: Splitting Tensile Strength Results of Control and Ternary Blended SCGPC Mixtures Incorporating CKC, MDP, and GGBS at Various Ages

4.4.4 Ultrasonic Pulse Velocity

Generally, the ultrasonic pulse velocity (UPV) propagating through a solid material depends on its density and elastic properties. Therefore, when the density, consistency, and homogeneity of the concrete are good, a comparatively higher velocity is attained. As a result, pulse velocity is a highly desired approach for investigating structural concrete. Pulse velocity is a highly desirable method for studying structural concrete as a result. It is highly evidenced that concrete with a higher UPV is probably associated with higher compressive strength, but not necessarily in the same

proportion. In this study, self-compacting geopolymer concrete (SCGPCs) constructed using CKC, MDP, and GGBS had its UPV tested over the course of 3, 7, 28, 56, and 90 days. Table 4.10 classifies the quality of concrete based on the pulse velocity that is possible according to (**IS 13311: Part 1, 1992**).

Table 4.10: Ultrasonic Pulse Velocity Ratings for Concrete Quality Grading (**IS 13311: Part 1, 1992**)

Pulse velocity (m/s)	Quality Grade of Concrete
> 4500	Excellent
3500-4500	Good
3000 – 3500	Medium
< 3000	Doubtful

4.4.4.1 Binary Effect of Calcined Kaolin Clay and MDP on Ultrasonic Pulse Velocity of Self-Compacting Geopolymer Concrete

Table 4.11 lists the results of the UPV experiment of binary blended mixes (MDP of 5%, 10%, 15%, 20%, and 25%) for infants 3 to 90 days of age. As anticipated, the UPV data revealed a general trend that increased with specimen age, comparable to the results for compressive strength. This trend was mostly attributable to the fact that concrete gets denser with age and has fewer places of discontinuity.

Figure 4.23 illustrates the effect of incorporating MDP,GGBS as CKC CKC 100% replacement of cement on the UPV values of SCGPC at all ages. It could be seen that the UPV values of binary blends SCGPC were increaed with an increasing replacement percentage of CKC. the higher UPV at all ages (early and long term) in (M2,M3and M4)approximately(1.52,3.30and5.99)at3days;(3.09,3.64and4.82)at7days; (1.88,3.47and5.11)at28days;(0.63,2.24and3.13)at56days;(0.39,1.90and

2.49) at 90 days,while The reduction occurred at (M5,M6) replacement. The UPV has been cut back of samples with MDP the content (20 and 25%) were approximately 2.18%, 4.66% at 3 days; 2.56%, 4.80%, at 7 days; 2.65%, 4.98% at 28; 6.55%, 7.59% at 56; 3.98%, 5.88 % when compared to the control concrete mixture at 90 days, respectively.

Table 4.11: The Ultrasonic Pulse Velocity Results in Binary Mixes of CKC and MDP

Ages (days)	Ultrasonic pulse velocity (m/s)					
	M1	**M2**	**M3**	**M4**	**M5**	**M6**
3	4120	4183	4256	4367	4030	3928
7	4329	4463	4487	4538	4218	4121
28	4512	4597	4669	4743	4392	4287
56	4726	4756	4832	4874	4416	4367
90	4773	4792	4864	4892	4583	4492

Due to a lower level of $(Ca(OH)_2)$ in these mixes when a volume of CKC replacement by MDP was applied, less calcium silicate hydrate gel was produced, resulting in more discontinuities, less strength improvement, and lower UPV values. Similar trends were also stated by other researchers **(Madandoust and Mousavi,2012; Frieh et al., 2014)**.

The mix of 15% MDP exhibited the highest UPV at all ages (early and long term).

Figure: 4.23 Ultrasonic Pulse Velocity Values for Control and Binary Blended SCGPC Mixtures Incorporating CKC and MDP at Various Ages

Due to the alteration in the gel/space ratio brought on by paste hydration, UPV increased with curing age. Increased paste hydration (which rises with age) correlates to a reduced volume of pores and greater UPV because the pulse velocity through voids is lower than that through solid matter. Additionally, a higher pulse velocity is caused by the concrete's smaller porosity and denser internal structure. Other researchers noted comparable patterns. (**Mohseni et al.,2016; Cao et al.,2019; Ashok et al.,2021**)

4.4.4.2 Binary Effect of Calcined Kaolin Clay and GGBS Mixtures on Ultrasonic Pulse Velocity of SCGPC

The results of a UPV test for binary mixtures are illustrated in Figure 4.24 and Table 4.12. Noteworthy are the outcomes of UPV of binary blend mixes(M7,M8,M9,M10 and M11) were observed mixtuer to be better than the performance of the control mixture in UPV at ages of 3, 7, 28, 56, and 90 days.

The increase in UPV of binary blends SCGPC mixes (M7,M8,M9,M10 and M11) were (3.66, 6.01, 6.40,5.26 and 1.60)%, (1.98, 4.08, 6.07,3.09 and 0.13)%, (3.39, 4.12, 6.00,3.83 and 3.10)%, (0.88, 1.33, 2.75,1.88 and 0.57)% and (0.71, 2.49, 2.93,0.83 and 0.12)% of the ages 3,7, 28, 56 and 90 days, respectively, compared with SCGPC control mix. As we saw from these percentages, all mixes had UPV higher than the control mix at all ages, The mix the binary blends (M9) has UPV highest at all ages.

Table 4.12: The Ultrasonic Pulse Velocity Results in Binary Blended Mixes of CKCand GGBS

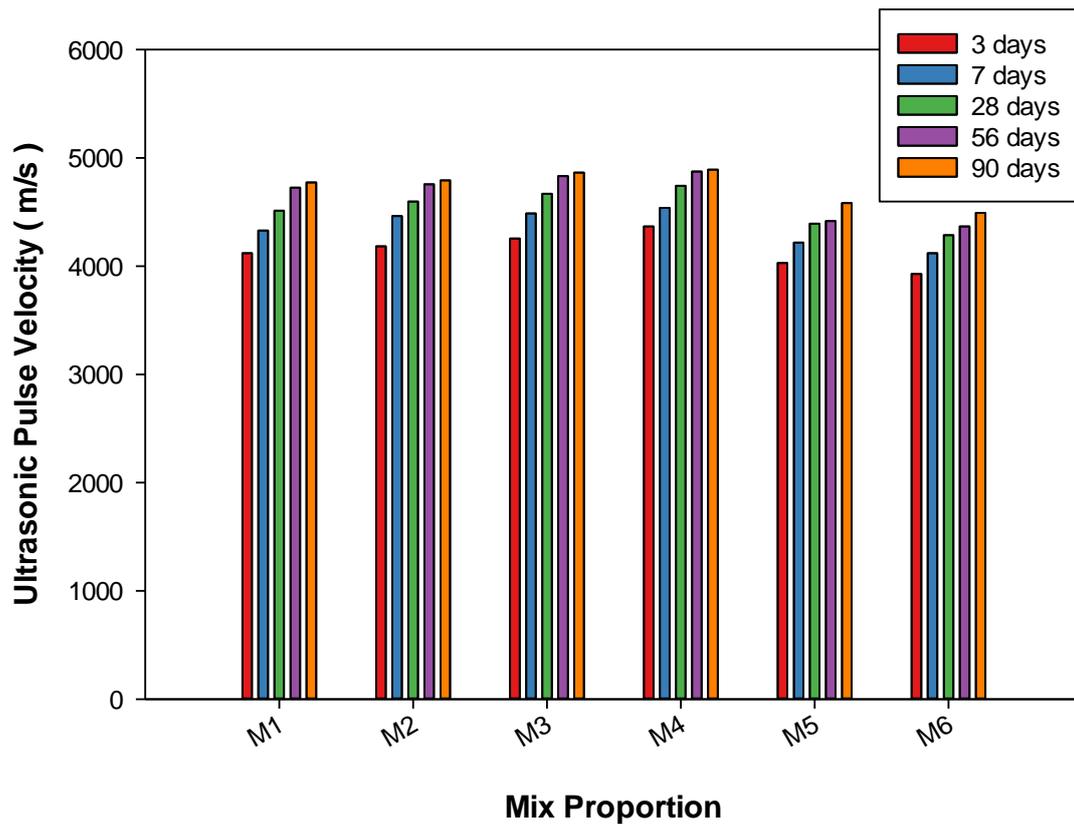| Ages (day)	Ultrasonic pulse velocity (m∕s)					
	M1	**M7**	**M8**	**M9**	**M10**	**M11**
3	4120	4271	4368	4384	4337	4186
7	4329	4415	4506	4592	4463	4335
28	4512	4665	4698	4783	4685	4652
56	4726	4768	4789	4856	4782	4753
90	4773	4807	4892	4913	4813	4779

Figure 4.24: Ultrasonic Pulse Velocity Values for Control and Binary Blended SCGPC Mixtures Incorporating CKC and GGBS at Various Ages

These results mean that the concrete that contains GGBSparticles has an increase in UPVfor the ability of GGBS particles to fill the largest voids in concrete mixture.Also the reason is the increase in the interaction between the molecules GGBS and calcium in CKC,and this interaction accelerates the formation of the gel (C-S-H) which lead to filling the spaces between the particale in the concrete mixture and increase the compacting of the samples,which leads to an increase in pulse velocity. Similar trends were also stated by other researchers **(Shariq and Masood, 2013).** Furthermore, the sensitivity of UPV is dependent on the age and strength of the concrete.

4.4.4.3 Ternary Effect of CKC,MDP and GGBS Mixtures on UPV of SCGPC

The results of a UPV test for ternary mixtures are illustrated in Table 4.13 and Figure 4.25. It could be noted from the results that the UPV values for ternary blends mixes (M12, M13,M14,M15, and M16) were higher than the control mixture at all age

The increase in UPV for ternary blends of SCGPC mixes was (7.11,11.31,11.74,4,02 and 1.24%), (6.79,8.50,9.47,0.87 and 0.55%), (6.71,7.66,8.53,1.55 and 0.64%), (3.53,4.04,4.38,0.44 and 0.25%), and (3.21,3.76,4.11,0.87, and 0.52%) the SCGPC control mix, at ages 3, 7, 28, 56, and 90 days, respectively. These percentages showed that all mixes had a higher UPV than the control mix at all ages. The (M14) SCGPC mix exhibited the highest UPV.

Table 4.13: The Ultrasonic Pulse Velocity Results in Ternary Blended Mixes of CKC, MDP, and GGBS

Ages (day)	Ultrasonic pulse velocity (m∕s)					
	M1	M12	M13	M14	M15	M16
3	4120	4413	4586	4604	4286	4172
7	4329	4623	4697	4739	4367	4353
28	4512	4815	4858	4897	4582	4541
56	4726	4893	4917	4933	4747	4738
90	4787	4941	4967	4984	4829	4812

These findings may be related to the use of MDP and GGBS particles in the mixed blended CKC being more effective than the single use of MDP or GGBS particles, which both contribute to increasing or accelerating pozzolanic reactions, resulting in the consumption of $Ca(OH)_2$

and the formation of an "additional" C–S–H gel and filling the voids between concrete grains. Also, MDP and GGBS make the matrix homogenous and make the structure compact, so this led to improve the microstructure of concrete. Similar trends were also stated by other researchers **(Mohseni et al., 2015;Mohseni et al., 2016)**.
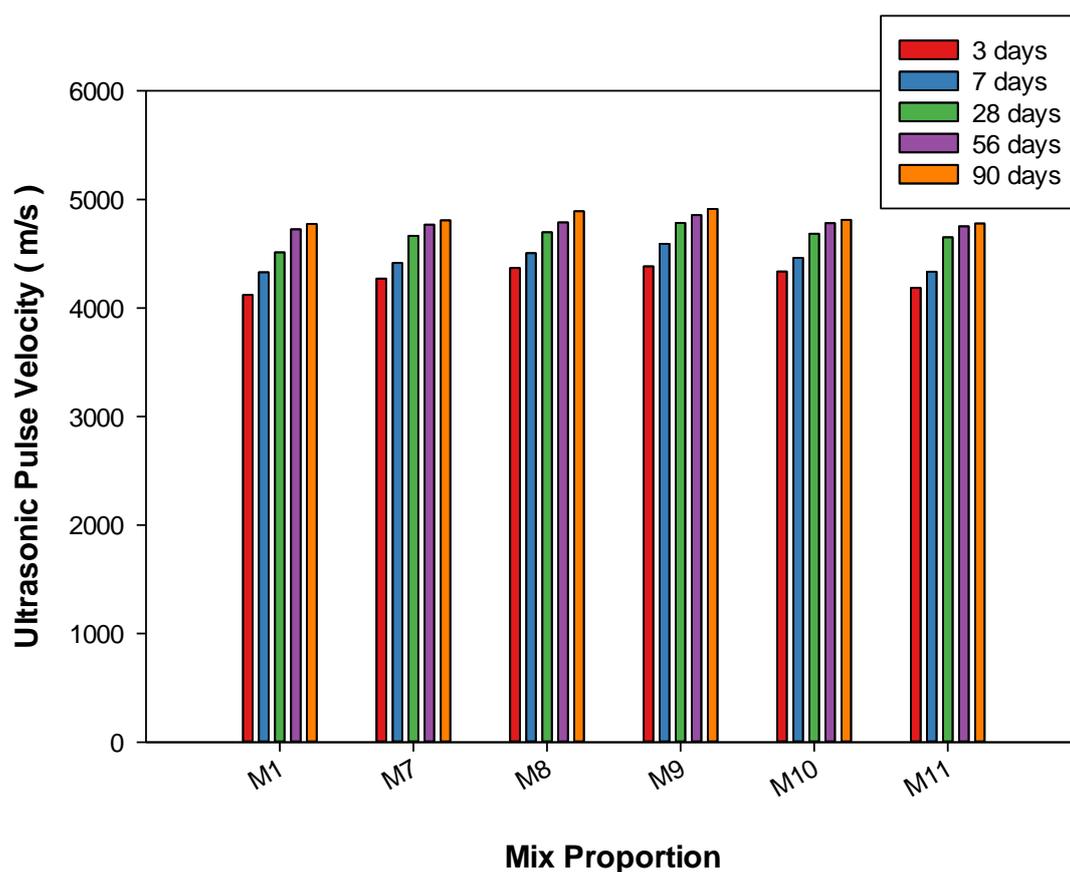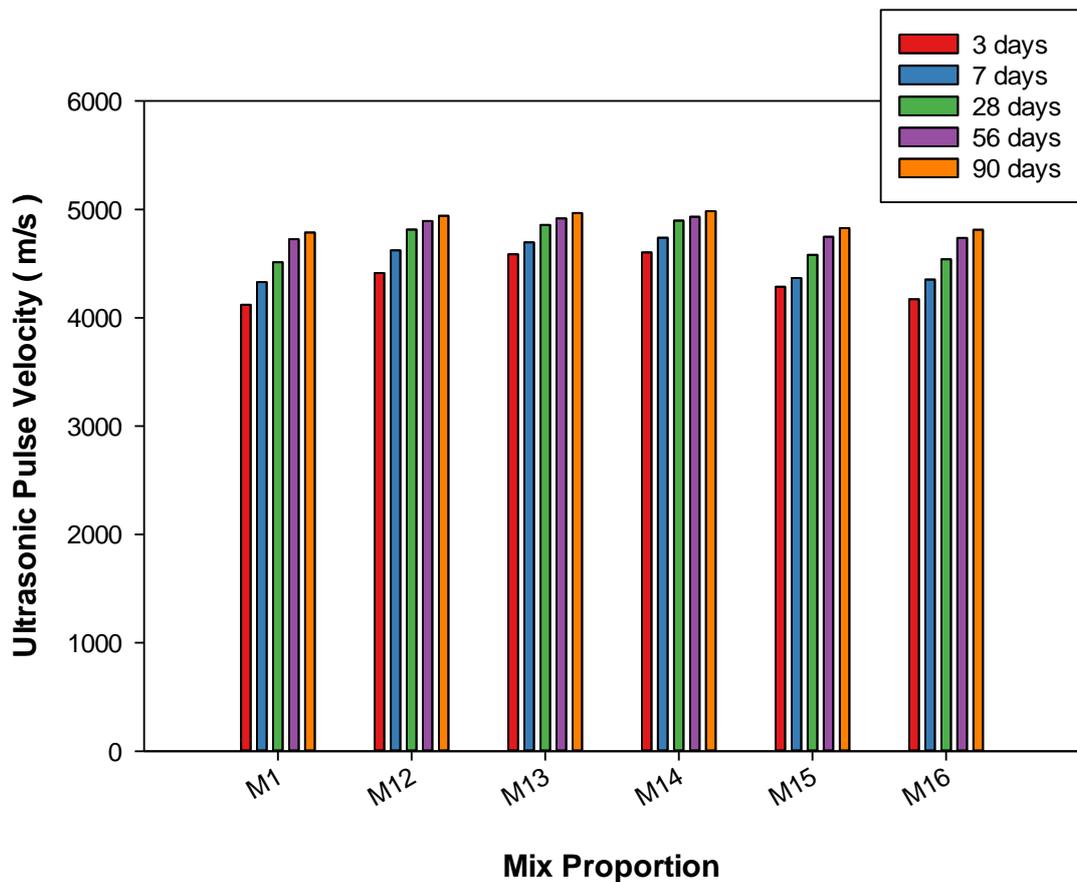
Figure 4.25:Ultrasonic Pulse Velocity Values for Control and Ternary Blended SCCs Mixtures Incorporating CKC, MDP, and GGBS at Various Ages

4.4.4.4 Effect of Calcined Kaolin Clay, MDP and GGBS on Quality of SCGPC Through UPV Values

According to the **(IS 13311: Part 1, 1992)**, the degree of compactness, or UPV, has a significant impact, the presence of voids/pores

in the concrete matrix, mix proportion, placing and curing of concrete, temperature, and moisture content of concrete, etc. The UPV values will be higher if the concrete matrix has sufficient homogeneity, uniformity, and packing density. The measured UPV for all mixes ranged from 3928 to 4984 m/s from 3 to 90 days of age. According to **(IS 13311: Part 1, 1992)**, **1992)**, all SCGPCs were found to have good and excellent quality as shown shown in Table 4.14.

Table 4.14: The Effect of CKC, MDP, and GGBS on Quality of SCGPC.

Mix Proportion	Ultrasonic pulse velocity (m∕s)				
	Time (days)				
	3	7	28	56	90
M1	Good	Good	Excellent	Excellent	Excellent
M2	Good	Good	Excellent	Excellent	Excellent
M3	Good	Good	Excellent	Excellent	Excellent
M4	Good	Excellent	Excellent	Excellent	Excellent
M5	Good	Good	Good	Good	Excellent
M6	Good	Good	Good	Good	Good
M7	Good	Good	Excellent	Excellent	Excellent
M8	Good	Excellent	Excellent	Excellent	Excellent
M9	Good	Excellent	Excellent	Excellent	Excellent
M10	Good	Good	Excellent	Excellent	Excellent
M11	Good	Good	Excellent	Excellent	Excellent
M12	Good	Excellent	Excellent	Excellent	Excellent
M13	Excellent	Excellent	Excellent	Excellent	Excellent
M14	Excellent	Excellent	Excellent	Excellent	Excellent
M15	Good	Good	Excellent	Excellent	Excellent
M16	Good	Good	Excellent	Excellent	Excellent

4.5   Durability Properties of Self-Compacting Geopolymer Concretes

The durability of mortar and concrete is one of the important properties. Durability is largely dependent on transport properties, which are highly influenced by the pore system. The water absorption, porosity, and sorptivity tests for samples were carried out at 28 and 90 days to assess the durability of the concrete mixes. The results have been noted and discussed for each test below.

4.5.1 Water Absorption

Bulk absorption, which is the total amount of water absorbed into an unsaturated sample, and sorptivity, which is the rate at which water is absorbed by capillary suction and can be used as a measure of moisture transport into unsaturated concrete, are the two parameters that can be used to express the water absorption (WA) of concrete. Concrete's pore size distribution and capillary pore interconnectivity both affect how much water is absorbed and how permeable the material is **(Razak et al., 2004)**. The water absorption(WA) test evaluates the absorption value and the voids present in the hardened concrete when it is subjected to aggressive environments. It is associated with the concrete ability to resist water penetration, which plays an important role in various deterioration mechanisms containing many harmful agents from the adjacent.

The typical test outcomes for a substance water absorption of self-compacting geopolymer concrete SCGPCin binary and ternary blends, at 28 and 90 days are listed in Table 4.15 and illustrated in Figures 4.26, 4.27, and 4.28. It could be noted that the water absorption values declined with an increase in the curing period for all blended SCGPC tested mix

This is due to the reduction of pore volume with hydration products. For all concrete mixtures, the lowest amount of water absorption was likewise discovered at long-term ages (90 days). The water absorption of self-compacting geopolymer concreteis generally less than 5% (**Kosmatka et al.,2002**). Also, The absorption for binary and ternary blended mixes. So all SCGPC could be categorized as high quality.

Table 4.15: Results of Water Absorption of Binary and Ternary Mixes for SCGPC at Different Ages

Mix proportion	Water absorption%	
	28 days	**90 days**
M1	3.91	3.48
M2	3.79	3.29
M3	3.63	3.17
M4	3.48	3.09
M5	4.17	3.74
M6	4.32	3.93
M7	3.38	2.97
M8	3.22	2.89
M9	3.08	2.76
M10	3.42	3.04
M11	3.58	3.23
M12	2.92	2.63
M13	2.79	2.48
M14	2.58	2.36
M15	3.63	3.27
M16	3.71	3.39

For binary blended mixes, in comparison to the control mix, the replacement ratio of CKC (5, 10, and 15% MDP) led to decreasing water

absorption as shown in Figure 4.26. The increase in (WA) for (20, 25%MDP). This is due to high replacement ratios of CKC. So, there isnot enough portlandite in the medium for the formation of new C-S-H gels (less C-S-H) and hydrated calcium aluminates of pozzolan origin, which leads to increase porosity and thus increase water absorption. Similar trends were also stated by other researchers (**Siddique and Kadri,2011; Frieh et al., 2014; Kannan and Ganesan,2014; Alsubari et al.,2018).**

Mahesh and Ajitha, (2021). Concrete strength and durability are improving . Generally, the results in this study showed improving the durability in all mixture , the results for the water absorption of SCGPC that contains (5,10 and 15%MDP) at 28 and 90 days are demonstrated in Figure 4.26. The finding explained that the replacement of CKC by (5,10 and 15%MDP) could effectively reduce water absorption. In comparison to the control mix the reduction of (WA) was obtained for the SCGPC were (3.16,7.71 and 12.35%) and (5.77,9.77 and 12.62%) at the ages of 28 and 90 days, respectively. The results showed that adding (5,10 and 15%MDP) had a greater reduction in (WA) than other additions due to the lesser size of particles and effective filling of the voids and gel pores present in the specimen. It was noticeable that the performance of the binary blends mixtures containing 15% MDP was found to operate more effectively than binary mixes compositions including (20 and 25% of MDP) with replacement levels of CKC. Similar trends were also stated by other researchers (**Cheng and Ding,2017;Tekin,2016**)

Figure 4.26: Water Absorption of Binary Mixes for SCGPCs Made With CKC, and MDP at Various Ages.

From Figure 4-27, it was perceived that the decrease in water absorption for binary mixes (30, 40, 50, 60 and 70% GGBS). These test results showed a considerable improvement in the quality of concrete containing GGBS particles compared with control-mix and binary blended with CKC at different percentages due to the addition of GGBS particles improving strength and refinement of pore structure by filling up the minute voids and pores.It was noticeable that the mix of (50%CKC and 50%GGBS) was the best due to lower water absorption at all ages. Similar trends were also stated by other researchers **(Faez et al., 2020 ; Khoman and Owaid, 2022).**
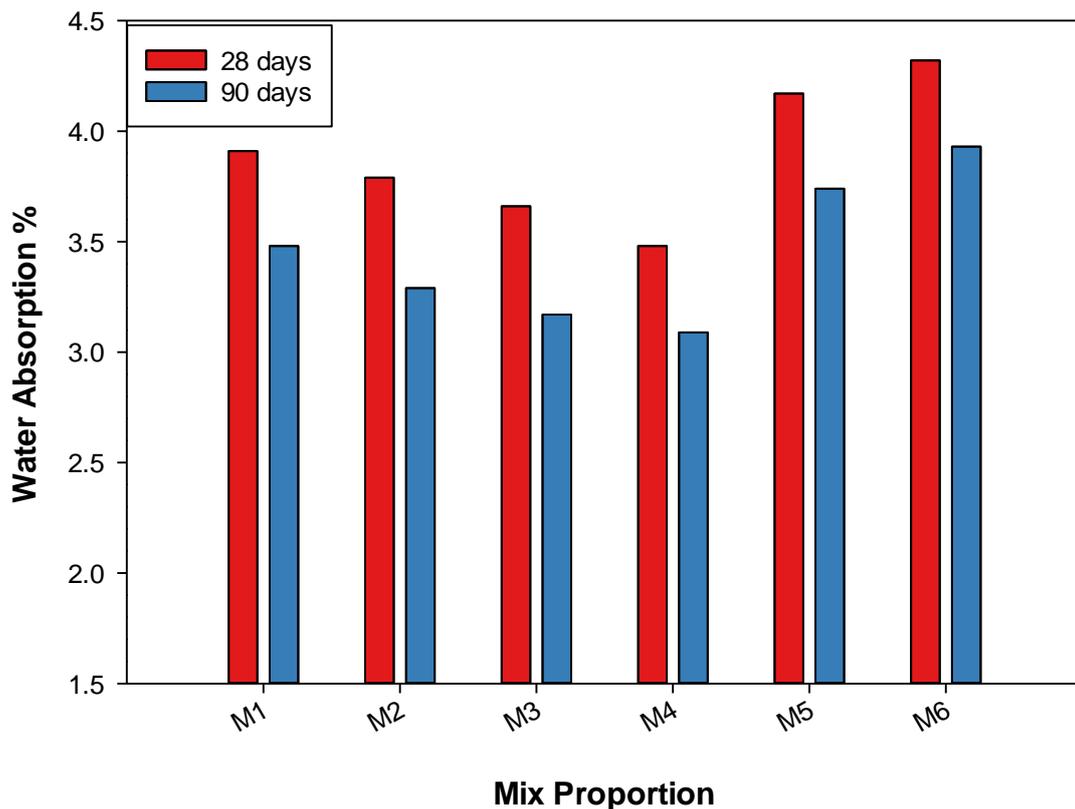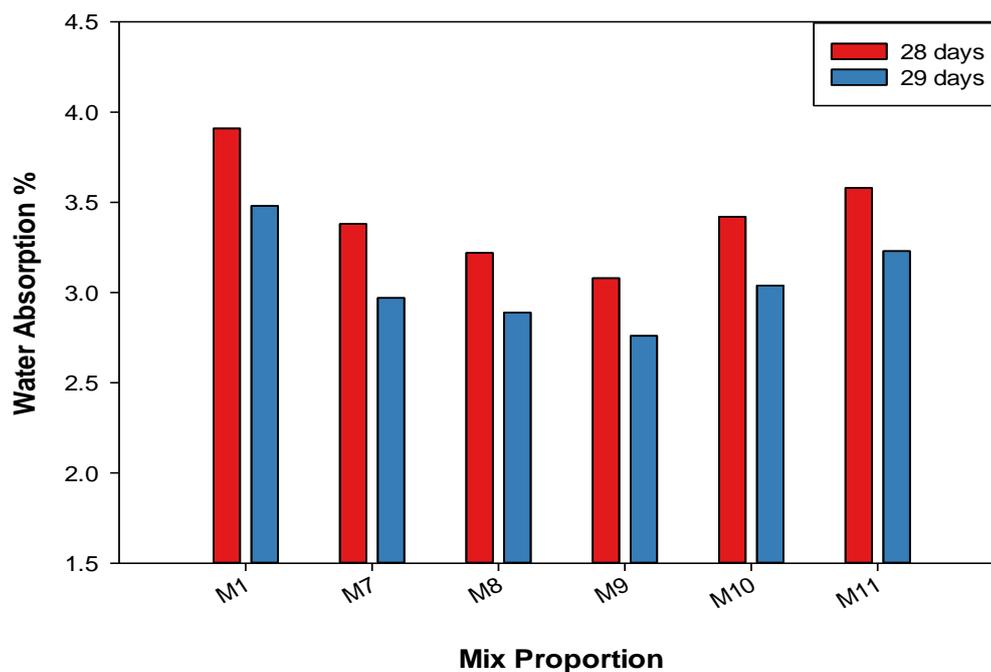
Figure 4.27:Water Absorption of Binary Mixes for SCGPC Made With

CKC and GGBS at Various Ages

From Figure 4-28, it was perceived that the decrease in water absorption for ternary mixes (M12, M13, M14, M15 and M16). The use of MDP and GGBS was more effective than the single use of MDP or GGBS in the mixed blended CKC to improve the microstructure of concrete. The ternary blended system exhibited the lowest water absorption at all ages in comparison to control mixtures, a binary blend with different percentages of CKC and ternary blended with the same replacement levels of CKC.

The study found that the mix (M14) was the best among all other mixtures due to the lower water absorption at all ages. This is due to the effect of MDP and GGBS, which work as very fine fillers that fill the pores and densify the microstructure. Moreover, its high pozzolanic reactivity refines the pore system and reduces the effective capillary pores, which govern the water absorption. The interfacial transition zone in concrete is improved, MDP and GGBS leading to the rapid formation of C–S–H gel.

Similar trends were also stated by other researchers (**Sireesha and Madhavs,2018; Khoman and Owaid,2022**).
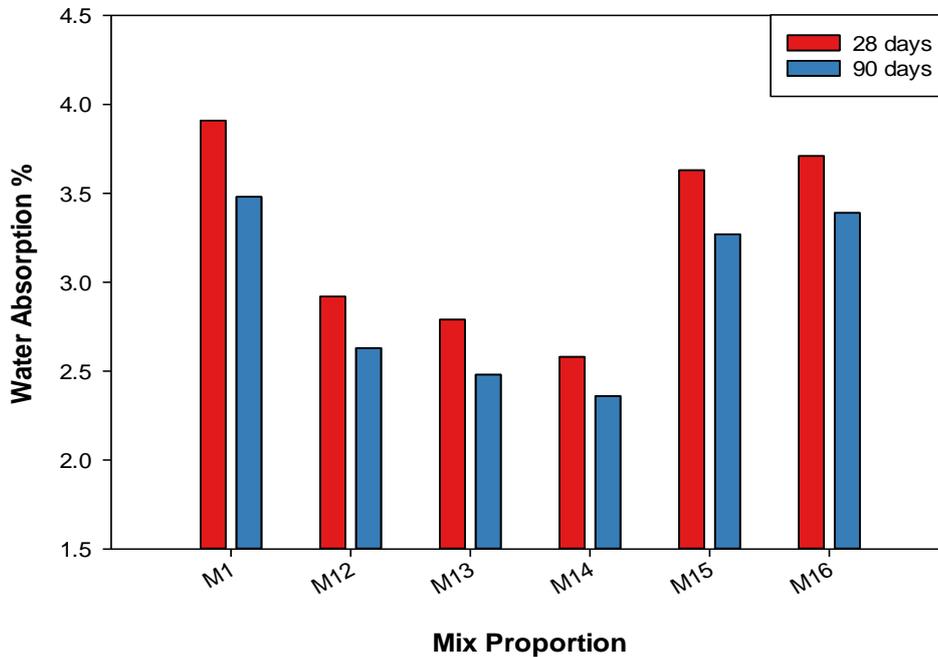
Figure 4.28: Water Absorption of Ternary Mixes for SCGPC Made With CKC, MDP, and GGBS at Various Ages

4.5.2 Porosity

The term porosity describes the percentage of the total volume of concrete that is occupied by the pores in the aggregates, interfacial transition zone, and concrete paste. It is a key element in determining how strong concrete will be (**Neville, 2011**). The porosity of concrete directly influences water absorption, just like it does with other technical parameters(**Hearn et al. 1994**). In binary and ternary blend systems, porosity data for all SCGPC containing CKC, MDP, and GGBS at 28 and 90 days are shown in Table 4.16, Figures 4.29, 4.30 and 4.31. All blended SCGPC mixtures porosity values decreased as the curing time increased. As seen, the values of the porosity test ranged between 6.56% and 11.31%

for all curing ages. The overall test results showed the porosity of the SCGPC was less than 15% at 28 and 90 days of age.

The incorporation of at (20 and 25 % MDP) in binary blends of SCGPC increased the porosity more than the control mix, as shown in Figure 4.29. The increase in porosity for (20 and 25 % MDP) was recorded by about (7.73 and 9.38%) and (7.11 and 10.03%), at 28 and 90 days, respectively. This might be attributed to the fact that the dissolved portlandite is not sufficient to react with amount of CKC and a large MDP, so there is less C-S-H gel and hydrated calcium aluminates of pozzolan origin that lead to more porous system. Similar trends were also stated by other researchers **(Frieh et al., 2014; Barkat et al., 2019)**.

Table 4.16: Results of the Porosity of Binary and Ternary Mixes for SCGPCs at Different Ages

Mix proportion	Porosity%	
	28 days	90 days
M1	10.34	8.57
M2	10.13	8.23
M3	9.86	7.98
M4	9.62	7.74
M5	11.14	9.18
M6	11.31	9.43
M7	9.33	7.66
M8	8.97	7.47
M9	8.68	7.18
M10	9.27	7.74
M11	9.65	8.06
M12	8.32	6.93
M13	7.98	6.71
M14	7.76	6.56
M15	9.94	8.20
M16	10.10	8.38

While the porosity of the SCGPC specimens that contain (5%,10% and 15%MDP) recorded the lowest values in comparison with the porosity of control mixture for the same period, The decline in porosity was (2.03,4.64 and 6.96)% and (3.96,6.88 and 9.68%)% at the ages of 28 and 90 days, respectively, in comparison to the control mix. The binary blend mixture with 15%MDP had the lowest value of porosity. This is due to the interfacial transition zone has improved due to the pozzolanic reaction as well as the filler effect of the MDP. Similar trends were also stated by other researchers **(Cheng and Ding,2017;Tekin,2016) .**
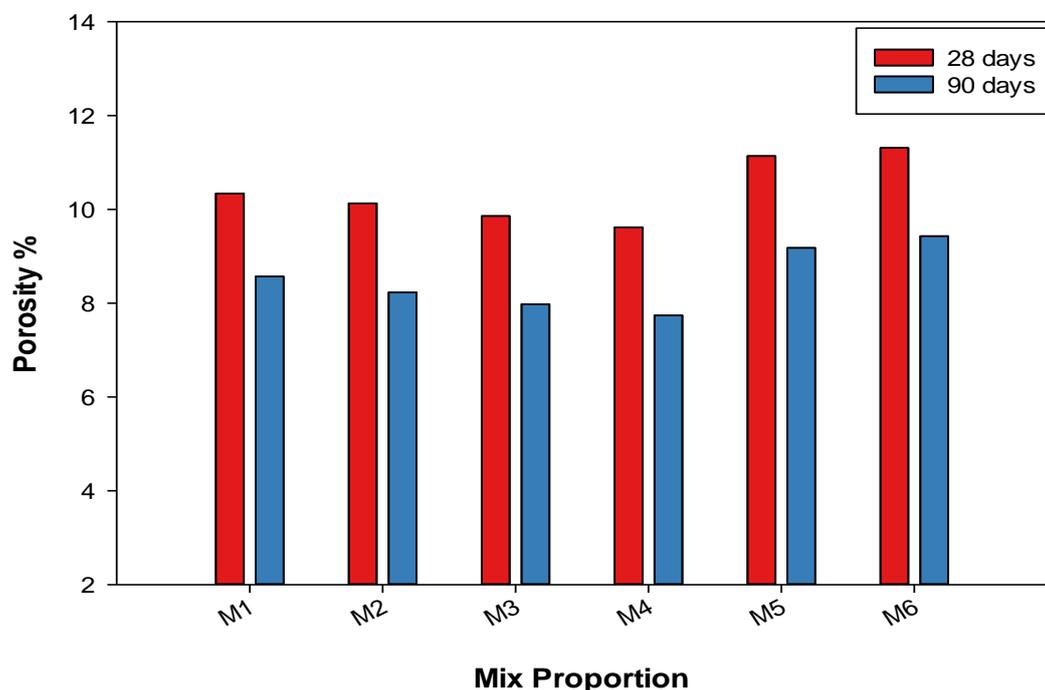

Figure 4.29: Porosity of Binary Mixes for SCGPC Made With CKC, and MDP at Various Ages

As shown in Figure 4.30, the decrease in the porosity results of binary mixes (M7,M8,M9,M10 and M11) were (9.76, 13.24, 16.05, 10.34, and 6.67%) and (10.61, 12.83, 16.21, 9.68, and 5.95%) in comparison to the control mix at ages 28 to 90 days, respectively. These test results showed a

considerable improvement in the quality of concrete containing GGBS compared with control mix and binary blended with CKC at different percentages. These results due to the inclusion of GGBS lead to a much denser microstructure inside concrete matrix also changed the formation of hydration products as well as the filler effect of GGBS that enhance the microstructure of the concrete, hence contributing to the improved durability properties of concrete. The mixture of (M9) gave lower values of porosity. It was noticeable that the performance of the binary mixtures with 50% GGBS was be better than the other results at the same replacement levels of CKC in terms of porosity, as seen in Figure 4.30. Due to the development of C–H–S, GGBS topped off the pores of the free net structure around the sand molecule, diminished the porosity, and expanded the thickness level of ITZ through research results due to their high reactivity. Similar trends were also stated by other researchers(**Sireesha& Madhavs,2018**; **kumar&Ramesh,2016).**
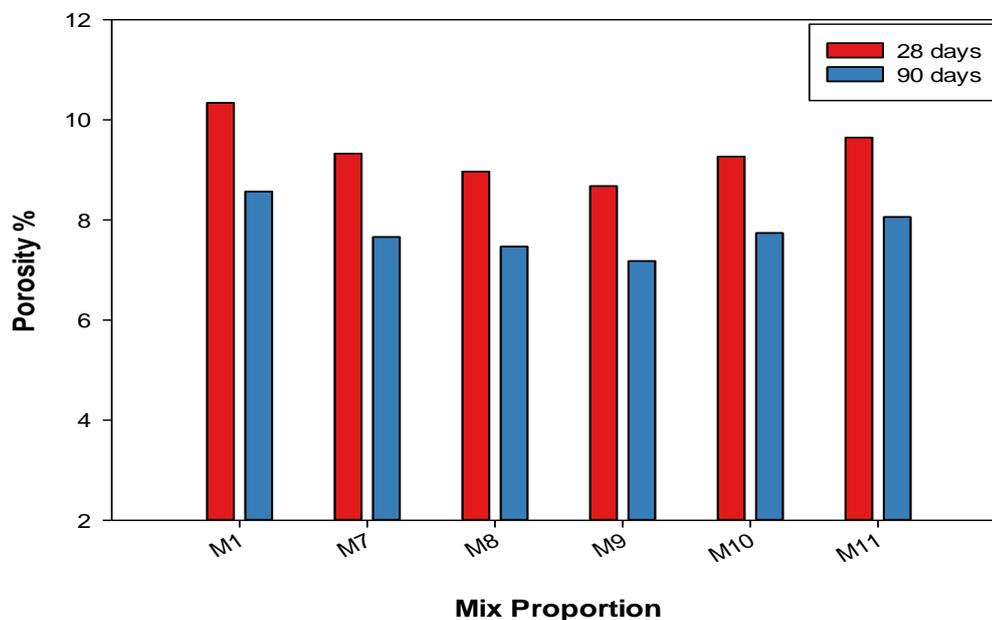
Figure 4.30: Porosity of Binary Mixes for SCGPC Made With CKC and GGBS at Various Ages

From Figure 4.31, the decrease in porosity for ternary mixes (M12,M13,M14,M15 and M16) were (19.53,22.82,24.95,3.86 and 2.37%) and (19.13,21.70,23.45,4.31 and 2.21)% ,in comparison to the control mix at ages 28 to 90 days, respectively.

The use of MDP and GGBS was more effective than the single use of MDP or GGBS particles on the mixes blended CKC to improve the microstructure of concrete. The ternary blended system exhibited the lowest porosity at all ages in comparison to control mixtures, binary blend at different percentages of CKC and ternary blended with the same replacement levels of CKC. The study found that the mix M14 was the best due to the lower porosity at all ages. This is due to the filler effect provided by MDP and GGBS, where MDP and GGBS can act as hogeneous nuclei for concrete pastes, further accelerating concrete hydration because of their high reactivity, as MDP and GGBS-filler densifies the microstructure, thereby, leading to a reduced porosity. Similar trends were also stated by other researchers (**Claisse and Hunt,2001; Al Menhosh and Augusthus-Nelson,2018).**
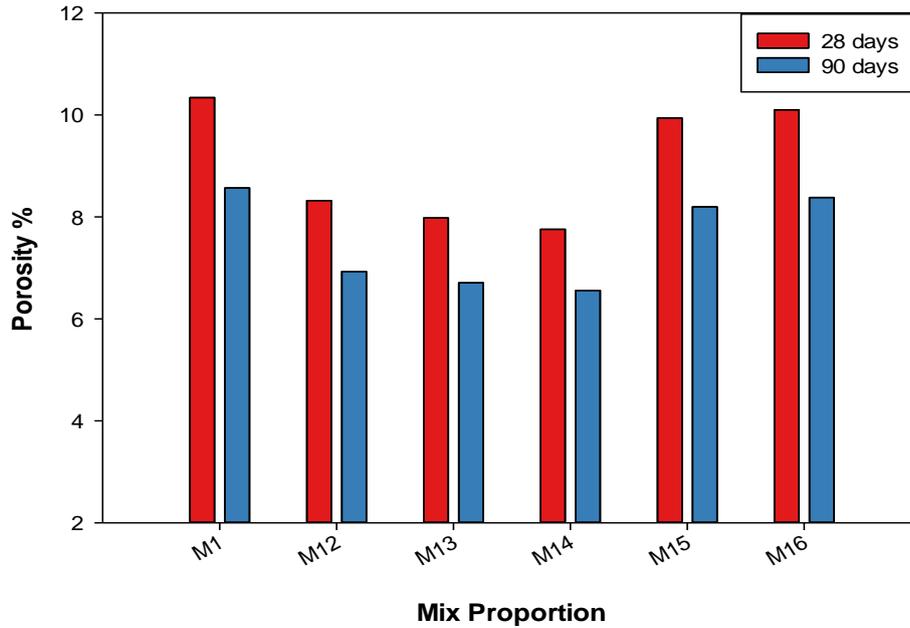
Figure 4.31: Porosity of Ternary Mixes for SCGPC Made With CKC, MDP, and GGBS at Various Ages

4.5.3 Sorptivity

Sorptivity is an index of moisture transport into unsaturated specimens that can be recognized as an important index of concrete durability. In other words, The rate of water absorption by capillary suction is known as sorptivity, and it serves as a measure of the amount of moisture that is transported into unsaturated concrete. The propensity of a porous substance to absorb and transport water by capillary action is a readily quantifiable material attribute. In order to understand how CKC, MDP, and GGBS as partial cement replacements in binary and ternary and mixes affect inner core permeability, the sorptivity test was conducted. The sorptivity value, expressed in the metric of mm/min$^{0.5}$, explains the water mass pickup by concrete from the bottom surface. Concrete has a better resistance to absorbing water the lower its sorptivity rating. The ultimate sorptivity values of the binary and ternary blends for all SCGPC mixes at 28 and 90

days are shown in Table 4.17 and Figures 4.32, 4.33 and 4.34. Sorptivity was shown to gradually decline during the course of the healing time. As was expected for concrete cast using a low water/binder ratio, all mixtures generally exhibited low sorptivity values that were below 0.1 mm/min$^{0.5}$ and had low absorption characteristics that were less than 10%**(Razak et al., 2004)**.

Table 4.17: Values of Sorptivity for Binary and Ternary Mixes for SCGPC SCGPC at Different Ages

Mix proportion	Sorptivity (mm/min$^{0.5}$)	
	28 days	**90 days**
M1	0.082	0.061
M2	0.074	0.056
M3	0.069	0.051
M4	0.062	0.046
M5	0.093	0.074
M6	0.098	0.080
M7	0.057	0.047
M8	0.051	0.041
M9	0.042	0.037
M10	0.059	0.045
M11	0.065	0.052
M12	0.043	0.033
M13	0.039	0.028
M14	0.033	0.021
M15	0.067	0.057
M16	0.071	0.059

Figure 4.32 demonstrates the outcomes of sorptivity for binary mixes of SCGPC. It was indicated that SCGPC mixtures with (20 and 25%) MDP

had the highest sorptivity values. The increase in sorptivity for (20%MDP and 25%MDP) was recorded by about (13.41 and 19.51%) and (21.31 and 31.14%), at 28 and 90 days, respectively. The sorptivity of SCGPC increased with an increase in the replacement percentages of CKC (20 and 25%MDP)at all ages. These results showed that increasing MDP replacement levels adversely affected the inner permeability. This is due to higher replacement ratios of MDP do not help to improve the inner durability of concrete. $Ca(oH)_2$ is not being sufficient to react with a large amount of MDP , As a result, there is less additional C-S-H gel and hydrated calcium aluminates of pozzolan origin produced. This leads to less densification of the mix and the permeability and sorptivity of the concrete is increased. Similar trends were also stated by other researchers **(Siddique& Kadri,2011; Elawady et al.,2014; Frieh et al., 2014; Kannan& Ganesan,2014; Tariq et al.,2020).**

The lowest sorptivity values were found in SCGPC with (5,10 and 15%MDP). The reduction in sorptivity was obtained for the SCGPC including (5,10 and 15%MDP) were (9.75,15.85 and 24.39%) and (8.19,16.39 and 24.59%) at the ages of 28 and 90 days, respectively, in comparison to the control mix. The mix with 15% MDP had the lowest sorptivity value among the other mixtures. Overall, the addition of MDP improves the pore structure of concrete, which can act as fillers, resulting in the consumption of $Ca(OH)_2$ and the formation of an "additional" C–S–H gel to increase the density of concrete, which reduces the porosity and sorptivity significantly. Similar trends were also stated by other researchers **(Khoman and Owaid,2022).**
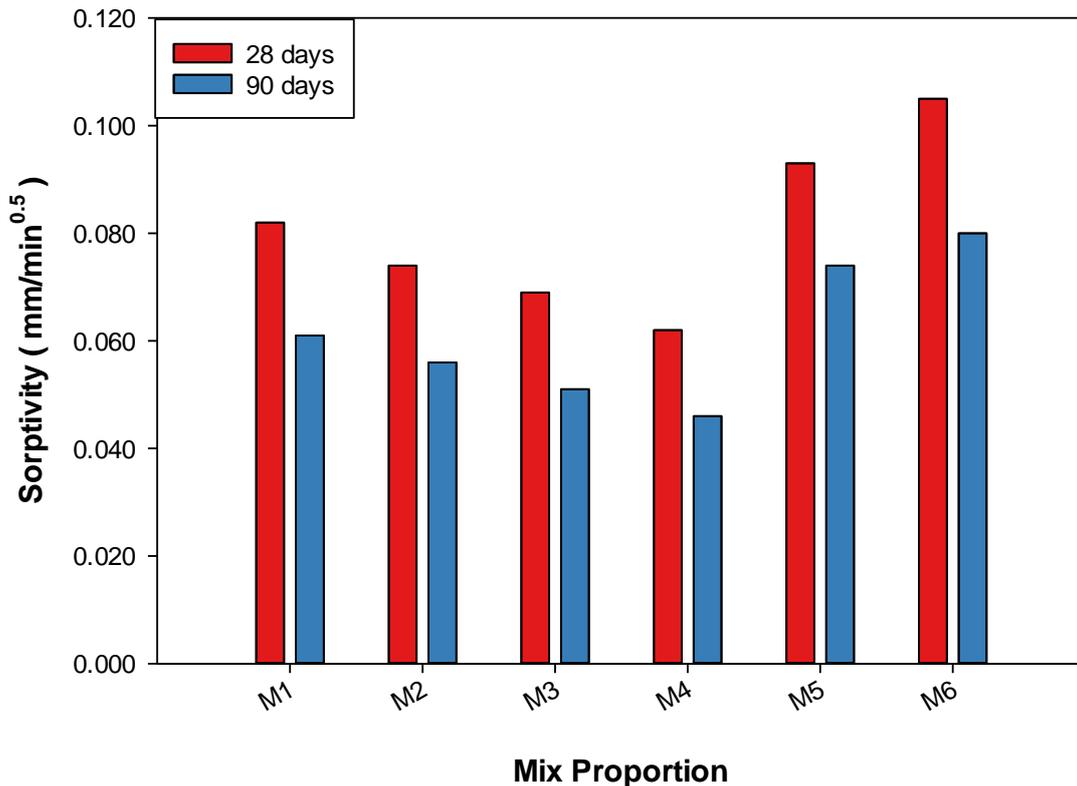
Figure 4.32: Sorptivity Values for Binary Blends of SCGPC Mixes
CKC and MDP at Various Ages

From Figure 4.33, it can be noticed the effect of binary mixtures on sorptivity results, which decreased significantly compared to the binary mixes with CKC at different percentages as well as the control mixture. At age 28 to 90 days, the sorptivity values of (30,40,50,60 and 70%GGBS) were decreased by (30.48, 37.80, 48.78,28.04 and 20.73%) and (22.95, 32.78, 39.34,26.22 and 14.75) %, respectively, in comparison to the control mix.

The use of (50%CKC) with (50%GGBS) in SCGPC gave better resistance against sorptivity than other values at the same replacement of CKC at all ages. Among all binary blends, the mix that has 50% CKC and 50% GGBS revealed the highest resistance to water sorptivity. It was concluded that the presence of GGBS in SCGPCs had a greater impact on

decreasing sorptivity. Whereas sorptivity is representative of concrete permeability, It could be said that adding GGBS to the mixture results in a reduction of sample permeability. This improvement in the durability properties of SCGPC by the addition of GGBS was due to the small size of GGBS, the higher fineness, Furthermore, by allowing the hydration reactions to proceed, Al can be taken up by C-S-H, which can fill the small pores of the concrete, contributing to the low sorptivity value. Similar trends were also stated by other researchers **(Langaroudi& Mohammadi, 2018)**

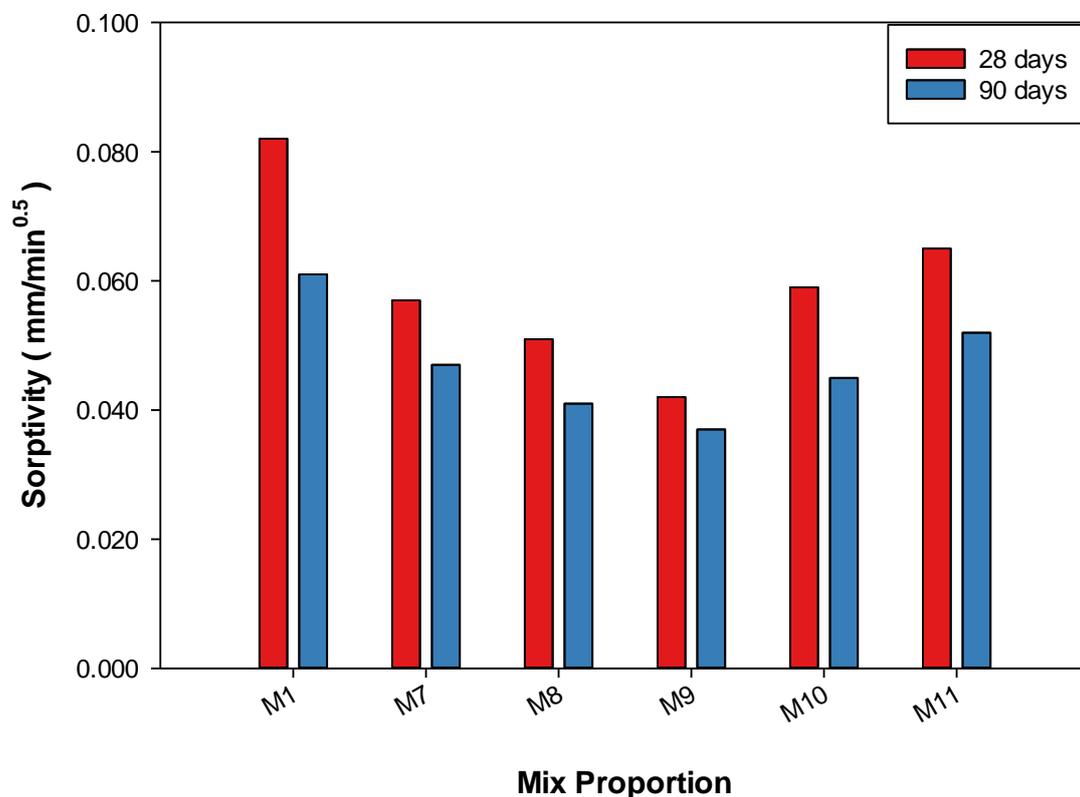**Figure 4.33:** Sorptivity Values for Binary Blends of SCGPC Mixes CKC and GGBS at Various Ages

The sorptivity values for ternary mixes (M12,M13, M14, M15, M16) were decreased by (47.56, 52.43,59.75,18.29 and 13.41) % and (45.90,54.09,65.57,6.55 and 3.27) %, in comparison to the control mix, at ages 28 to 90 days, respectively.

The use of MDP and GGBS was more effective than the single-use in the mixes blended with CKC to improve the microstructure of concrete. The ternary blended system exhibited the lowest sorptivity at all ages (see Figure 4.34) in comparison to other blended systems. The research found that the mix (M14) was the best due to it had the lowest sorptivity at all ages. This is due to decreased total specific pore volumes of concrete, and the most probable pore diameters of the concrete shift to smaller pores and fall in the range of few-harm pores due to use of MDP and GGBS. Where MDP and GGBS can act as fillers, the porosity of concrete is reduced significantly, which enhances the density of concrete, improves the resistance to water permeability of concrete, and reduces sorptivity. MDP and GGBS make the concrete matrix homogenous and make the structure compact. Moreover, the specimens having lower sorptivity showed less permeability and higher compressive strength. These results were confirmed by a previous study **(Khoman and Owaid,2022;Sireesha and Madhavs,2018).** Thus, MDP and GGBS added to SCGPC improve their durability and provide an effective solution for a more sustainable environment.
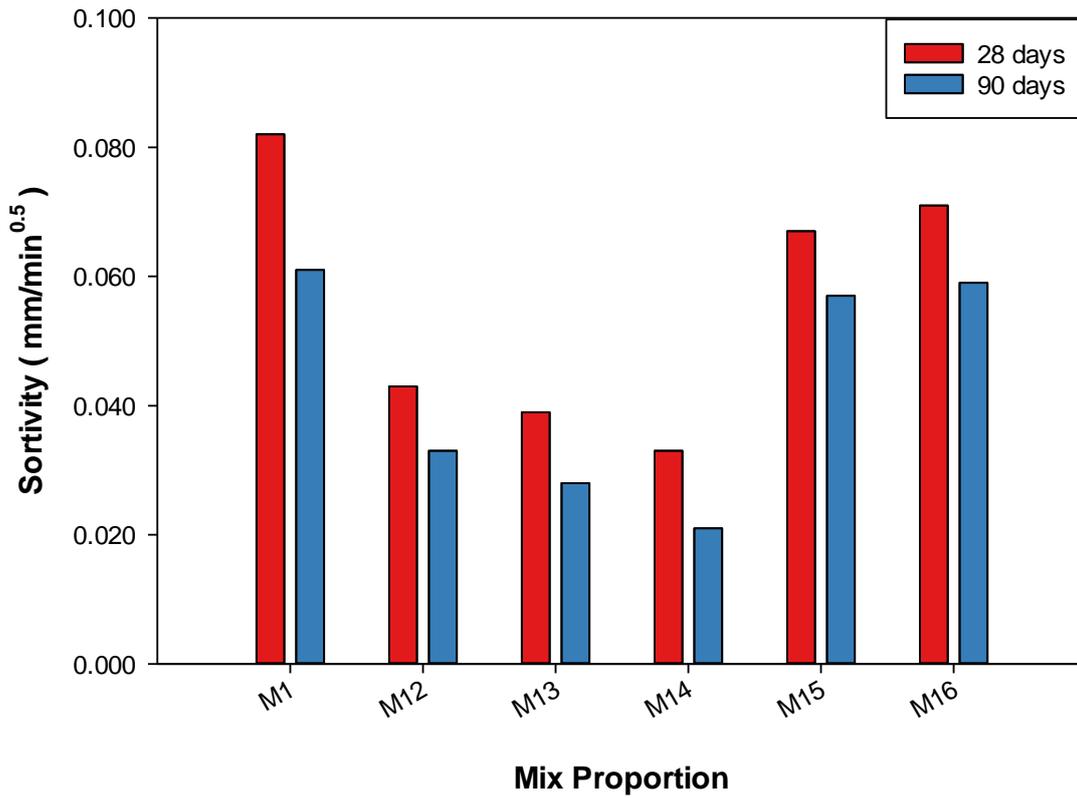
Figure 4.34: Sorptivity Values for Ternary Blends of SCGPC Mixes
CKC,MDP and GGBS at Various Ages

4.6 Statistical Evaluation of Experimental Test Results of Compressive Strength of Self-Compacting geopolumer Concretes

In the construction industry, strength is a primary criterion in selecting concrete for a particular application. Concrete used for construction gains strength over a long period after pouring. Therefore, rapid and reliable prediction for the strength of concrete would be of great significance. There are few studies on modeling and prediction of the compressive strength and the variations in the compressive strength with ultrasonic pulse velocity

test UPV of the SCGPC. Also, multiple linear regression has not been used till now for behavior prediction of SCGPC mixes utilizing low carbon binders calcined kaolin clay CKC, MDP, and GGBS in ternary and binary mixtures, which was undertaken In this research for the first time

4.6.1 Relationship Between Experimental and Predicted Compressive Strength of SCGPC

To investigate the level of agreement between the predicted and measured SCGPC strength. at 3, 7, 28, 56, and 90 days, respectively, the relationship between the experimentally measured compressive strength and the anticipated compressive strength was found. In this study, general Equation (4-1) with a determined coefficient of correlation (R^2) was determined from the relationship between the experimental and predicted values of the compressive strength for SCGPC, having been cured for various periods, as shown in Figure 4.35. The regression determination coefficient for this relationship appeared to lie in an acceptable range ($R^2 = 0.877$), which revealed a very good level of agreement between the predicted and experimental readings.By using SPSS programm

$$Y=0.8291X+8.5895 \tag{4-1}$$

Where

Y= predicted compressive strength in MPa.

X=experimental compressive strength in MPa.

The scatter plot shows Predicted Compressive Strength MPa (y-axis, 20 to 70) versus Experimental Compressive strength MPa (x-axis, 20 to 80), with fitted line equation:

$$y = 0.8291x + 8.5895$$
$$R^2 = 0.877$$
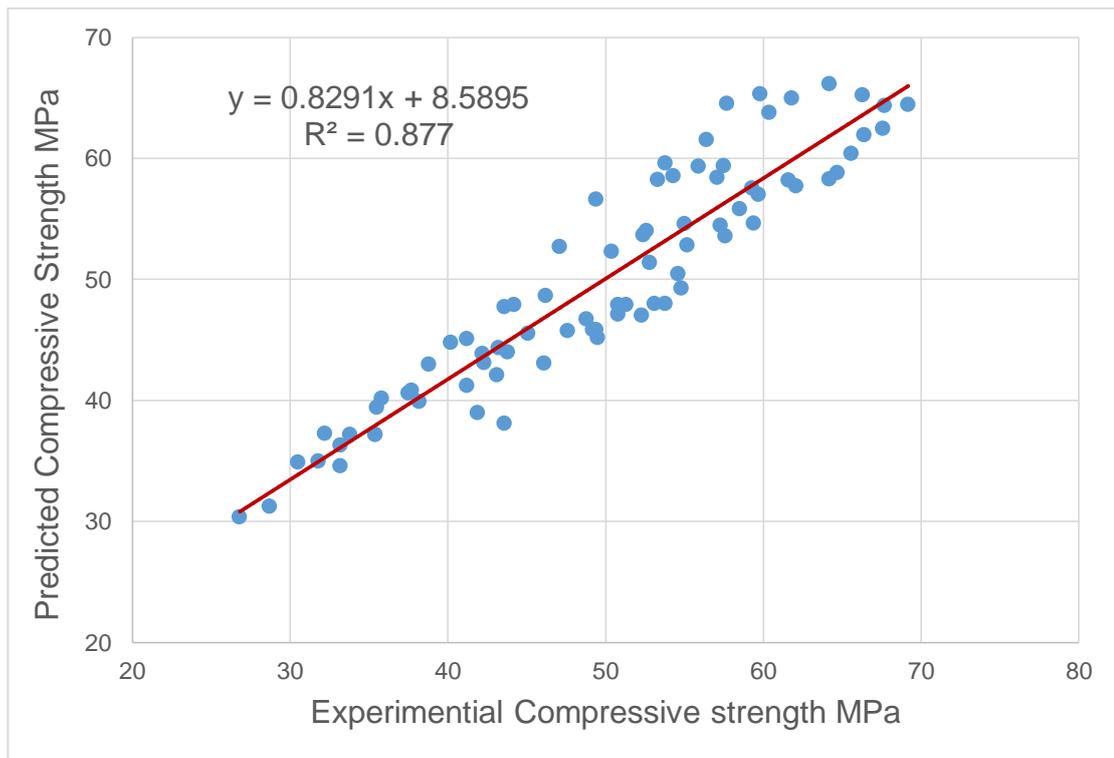
Figure 4.35: Relationship of Experimental and Predicted Compressive Strength for All Results between 3 and 90 Days of Curing

Table 4.18 and Figures 4.36–4.38 present the equations of the relations with the coefficients of determination (R^2) and a graph of a comparison of experimental and anticipated compressive strengths of binaryblends (M2,M3,M4,M5andM6) and (M7,M8,M9,M10andM11), (and ternary blends(M12,M13,M14,M15 and M16) at various ages.

Table 4.18: The Equation of the Relations Between the Experimental and Predicted Compressive Strength and R-Squared Coefficients at Various Mixes and Ages

Type of blended	Mixes	Equations	R^2
Binary blended	CKC +GGBS	Y=0.9539X+4.1745	0.934
Binary blended	CKC+MDP	Y=0.9262X+4.2435	0.913
Ternary blended	CKC+MDP+GGBS	Y=0.8482X+7.352	0.926

Figure 4.36: Relationship Between Experimental and Predicted Compressive Strength of Binary Blends CKC+ GGBS, for Various Ages of Curing Periods

Figure 4.37: Relationship Between Experimental and Predicted Compressive Strength of Binary Blends (CKC + MDP) for Various Ages of Curing Periods

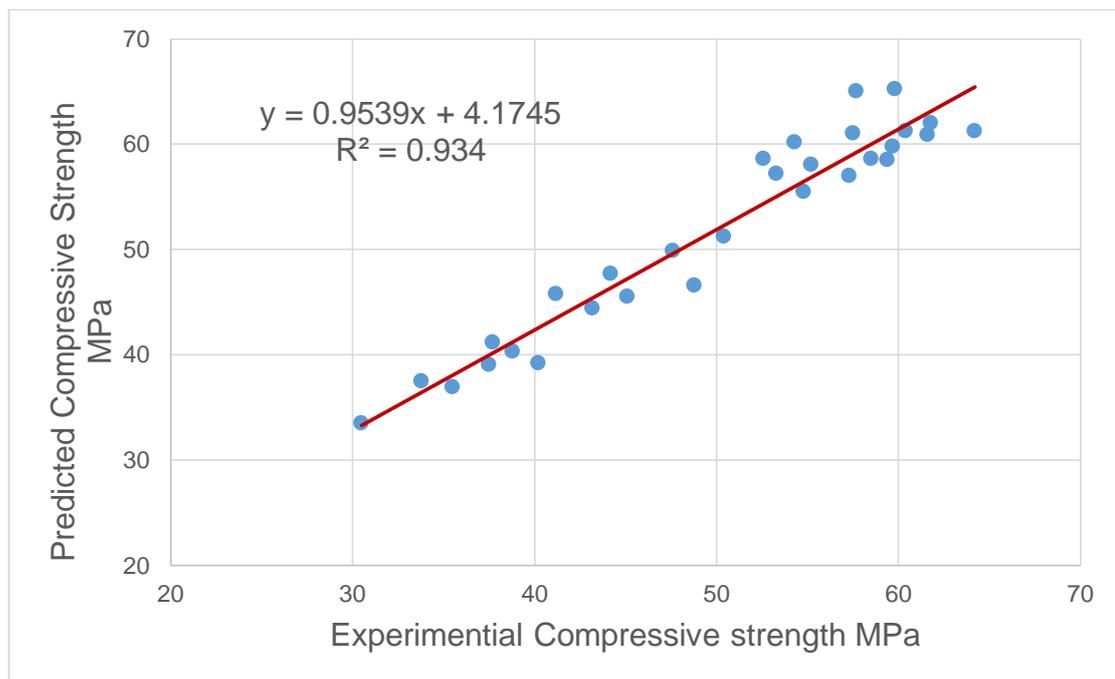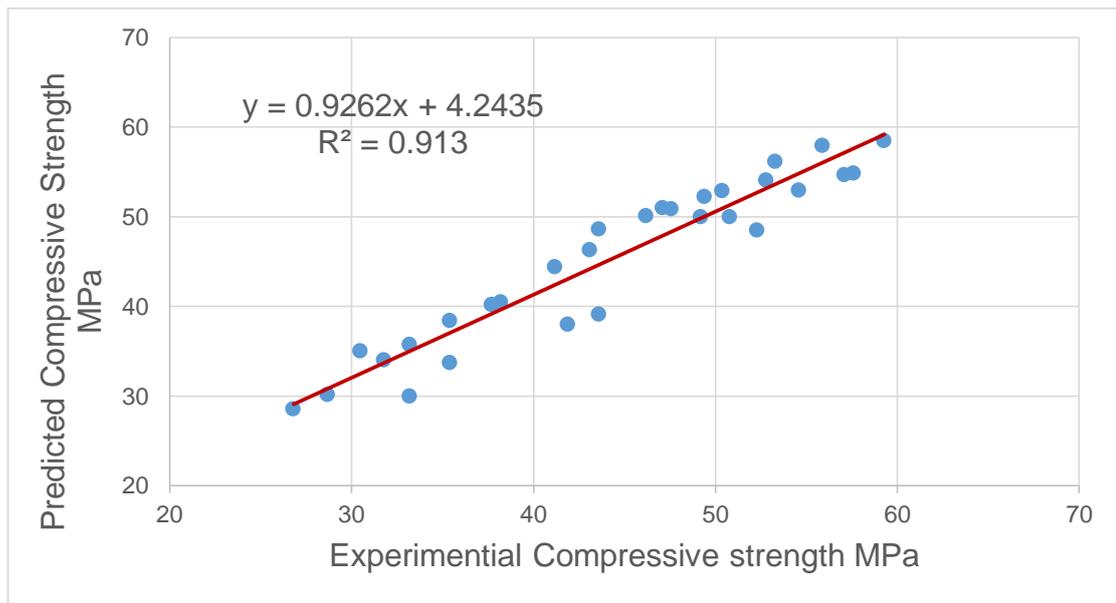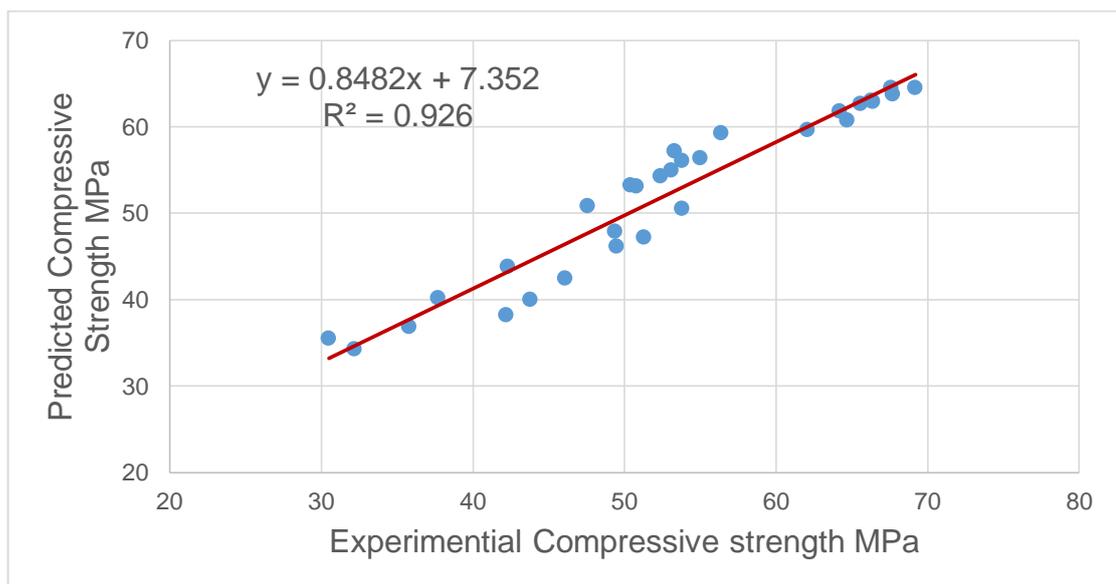**Figure 4.38:** Relationship Between Experimental and Predicted Compressive Strength of Ternary Blends (CKC + MDP + GGBS) for Various Ages of Curing Periods

As shown from Figures 4.36–4.38, the values of the multivariable regression determination coefficient (R^2) for binary blends including CKC at different percentages, binary blends including GGBS and MDP, ternary blends for various ages were (R^2 = 0. 934, 0.913 and 0.926, respectively), which appeared to lie in an acceptable range, indicating an excellent correlation between the experimental and predicted compressive strength. Similar trends were also stated by other researchers (**Atici,2011; Chithra et al.,2016; Byakodi& Patil, 2017; Shubbar et al.,2018**).

4.6.2 Relationship Between Compressive Strength and Ultrasonic Pulse Velocity of Self-Compacting Concretes

A correlation between the results of the ultrasonic pulse velocity (UPV) and compressive strength tests can be determined. This correlation was studied through statistical analysis using exponential regression. The exponential regression was found to be more adequate, as it gives a higher coefficient of determination, meaning that it gives a more precise adjustment (**Presa et al., 2021**).

Figure 4.39 illustrates the correlation between the UPV and the compressive strength (Fc) for all results at various ages. This correlation was discovered for compressive strengths between 26.8 and 69.2 MPa and ultrasonic pulse velocities between 3928 and 4984 m/s. A very strong exponential relationship between UPV and compressive strength was shown by the best fit curve's determination coefficient (R^2), which was 0.895. One may say that the exponential relationship between compressive strength values and UPV accounted for 89.5% of the variation in those values. The UPV value and compressive strength increase together in time, and an increase in the UPV value corresponds to an increase in

compressive strength. The general Equation (4-2) was determined from the statistical analysis of exponential regression of all results for ages 3 to 90 days as follows:

$$Y = 0.9132 \times e^{0.0009X} \tag{4-2}$$

Where

Y= compressive strength in MPa.

X=Ultrasonic pulse velocity in m/s.
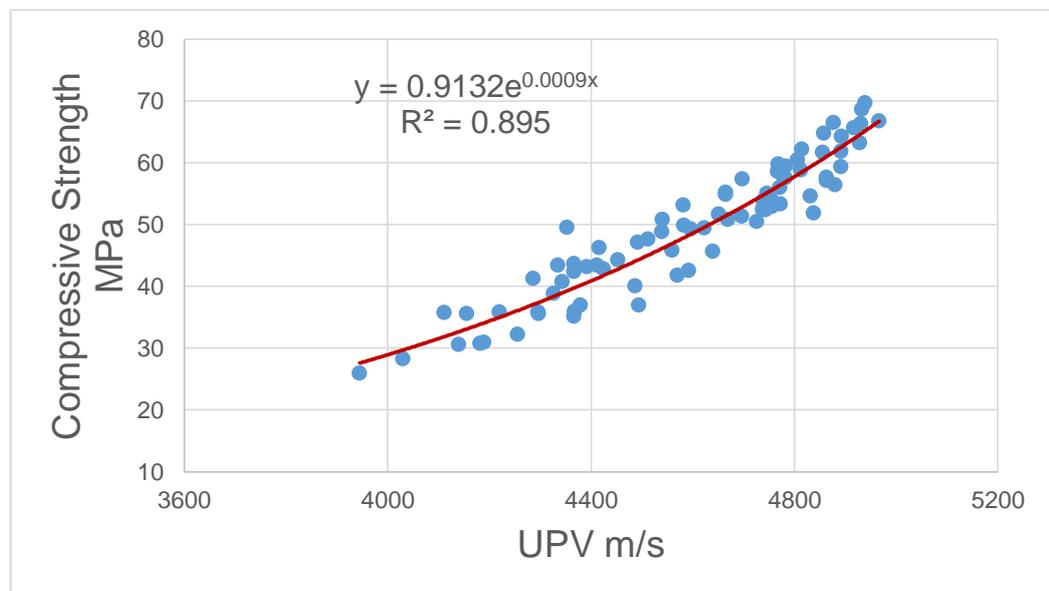
Figure 4.39: Relationship Between Compressive Strength and UPV for All Results at Various Ages

Table 4.19 and Figures 4.40–4.42 present the equation with the coefficients of determination (R^2) of the statistical analysis of exponential regression results and a graph of the correlation obtained between the ultrasonic pulse velocity (UPV) and the compressive strength (Fc) of binary blends with CKC, binary blends with GGBS and MDP and ternary blended at various ages, respectively.

Table 4.19: The Equations and R-Squared Coefficients of Correlation Between Ultrasonic Pulse Velocity (UPV) and Compressive Strength of Various Mixes and Ages

Type of blended	Mixes	Equations	R2
Binary blended	CKC +GGBS	$Y=0.7909{\times}e^{0.0009X}$	0.933
Binary blended	CKC+MDP	$Y=1.0697{\times}e^{0.008X}$	0.925
Ternary blended	CKC+MDP+GGBS	$Y=0.8765{\times}e^{0.0009X}$	0.927

Figure 4-40 illustrates the correlation obtained between the ultrasonic pulse velocity (UPV) and the compressive strength (Fc) of binary blended mixes with (30, 40,50,60 and70%) GGBS. The link between compressive strength, which ranged from 33.8 to 64.3 MPa, and ultrasonic pulse velocity, which ranged from 4186 to 4913 m/s, was discovered. The best fit curve determination coefficient (R^2) was 0.933, which indicates a strong link. This relationship was obtained for ages 3 to 90 days. Similar trends were also stated by other researchers **(Kannan,2015; Owaid et al.,2017)**.
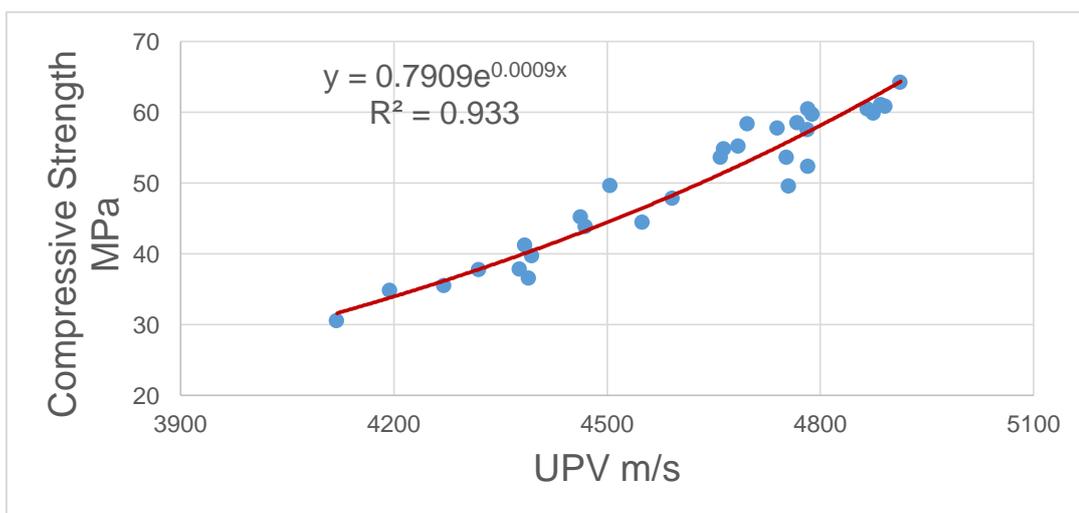
Figure 4.40: Relationship Between Compressive Strength and UPV for Binary Blends with (CKC + GGBS) at Various Ages

The relationship between the ultrasonic pulse velocity (UPV) and the compressive strength (Fc) of binary blended mixes at various ages with(5%,10%,15%,20 and 25%MDP) was plotted in Figures 4.41. It was discovered for compressive strengths between 26.8 and 59.3 MPa and ultrasonic pulse velocities between 3928 and 4892 m/s. With an outstanding association, the best fit curve determination coefficient (R^2) was 0.925. Ages 3 to 90 days were covered by this relationship. Other researchers reported parallel trends**(Nik and Omran, 2013**).

The chart shows: y = 1.0697e^{0.0008x}, R² = 0.925

Figure 4.41: Relationship Between Compressive Strength and UPV for Binary Blends with (CKC + MDP), at Various Ages

Figure 4.42 illustrates the correlation obtained between the ultrasonic pulse velocity (UPV) and the compressive strength (Fc) of (45, 40, 35, 30 and 25%) CKC, (MDP of 5%, 10%, 15%, 20%, and 25%) and (50% ternary blended mixes at various ages. This correlation was discovered for compressive strengths between 32.2 and 69.2 MPa and ultrasonic pulse velocities between 4172 and 4984 m/s. With a good association, the best fit curve's determination coefficient (R^2) was 0.927. Ages 3 to 90 days were

covered by this relationship. Other researchers reported parallel trends**(Owaid et al ., 2017).**

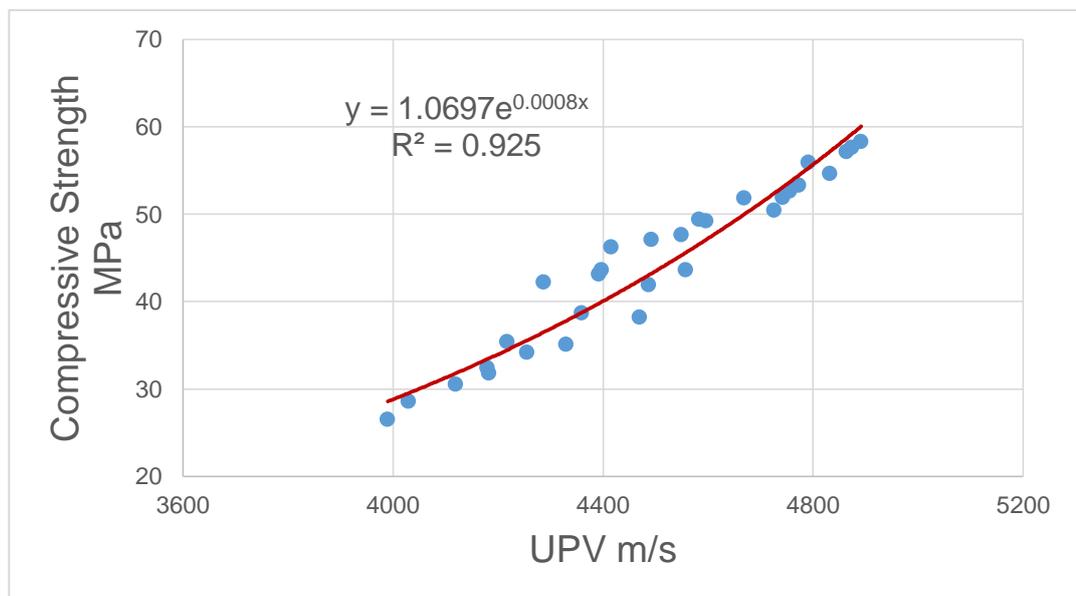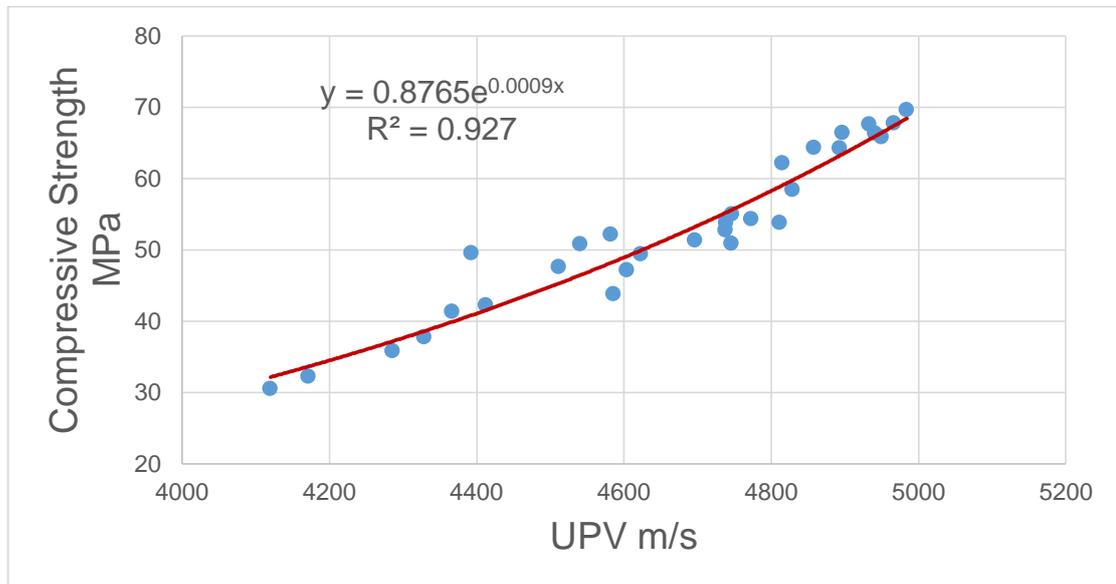**Figure 4.42:** Relationship Between Compressive Strength and UPV for Ternary Blends with (CKC+MDP+GGBS) at Various Ages

CHAPTER FIVE

CONCLUSIONS – SUGGESTION FOR FUTURE STUDIES

Chapter Five

Conclusions –Suggestion for future studies

5.1 Conclusion

This study achieved a remarkable development in the use of environmentally friendly materials CKC, GGBS and MDP to produce concrete that possesses self-compacting property.

Through the practical application that was used of the materials and the laboratory results obtained, the essential conclusions of the current work will be presented and clarified

5.1.1 Fresh Properties

1.   (GGBS) show the highest pozzolanic activity among other materials.

2. Self-compacting geopolymer concrete (SCGPC) could be successfully produced with binary and ternary binder combinations.

3. In a binary and ternary blends of mixtures the slump flow increases further while T_{500} and V funnel decreases more compared to reference mixtures.

4. The use of the ternary mixture (MDP, GGBS, CKC) with different replacement ratios achieves the requirements of the laboratory test (L-Box) without clogging.

5.1.2 Hardened Properties

1. The replacement of CKC by MDP and GGBS increases the bulk density. CKC,MDP and GGBS could be used in concrete as lighter materials than cement.

2. Compressive strength generally increases with the increase in CKC replacement in binary and ternary blended but decrease with 20%MDP and 25%MDP (early and long term) in comparison with the control mixture at all ages.

3. It could be concluded that the mix (35%CKC+15%MDP+50%GGBS) exhibit the highest compressive strength at all ages.

4. Splitting tensile strength (STS) of SCGPC mixes follow a similar pattern to that of compressive strength, the increase is at a lower rate compared to that obtained in compressive strength,but decreases in binary blended (20%and25%MDP),the results of the laboratory test (STS) for the materials that are used with mixing ratios (CKC of 35%) and (GGBS of 50%) and (MDP of 15%) are highly resistant to splitting tensile and are better than other mixtures.

5. By conducting the laboratory examination (UPV), the results are similar to the results of the laboratory examination (FC), but it is less while the use of binary mixtures with the following mixing ratios (MDP of 20%) and (MDP of 25%) and for all other mixtures.

5.1.3 Durability Properties

1. The water absorption (WA), porosity and sorptivity values declined with an decrease in the curing period for all blended SCGPC mixes.

2. The replacement ratios of CKC by (20and 25%MDP) lead to increase in water absorption, porosity and sorptivity.

3. The replacement of cement by 15%MDP and 50% GGBS could effectively reduce water absorption, porosity and sorptivity.

4. The ternary blended system exhibits the lowest water absorption, porosity   and   sorptivity   at   all   ages.   The   mix (35%CKC15%MDP50%GGBS) is the best due to the lower absorption rates, porosity and absorption at all ages.

5. The water absorption (WA) and porosity of SCGPCs is found to be less than 5% and 15% at all curing ages, respectively, so all SCGPCs could be categorized as "high quality".

6. All mixtures have a low sorptivity value that is below 0.1 mm/min$^{0.5}$.

5.1.4 Statistical model

1. The statistical model developed provides an excellent prediction for the compressive strength.

2. The relationship between the experimental and predicted values of the compressive strength for SCGPC cured for various periods reveals an excellent level of agreement between the predicted and experimental readings.

3. The correlation between the compressive strength (Fc) and UPV at various ages indicats an excellent exponential relationship between them.

4. the best mix(35%CKC+15%MDP+50%GGBS)at the all tests and all ages.

Finally, based on the main findings from this study, the utilization of calcined kaolin clay (CKC) and (MDP and GGBS) as cement replacement could provide a low-carbon binder for producing and developing SCGPCs for different construction and structures, thereby reduce the cement demand, which would contribute to reducing the emission of greenhouse gases from the globe,

5.2 Essential recommendations for future research

Most of the laboratory tests related to the current work are not taken, so the researchers should look into the effects of other tests that are not conducted.

- The development of SCGPC was studied using calcined kaolin clay material. Thus, a similar investigation can be done using other materials, such as fly ash, silca fume, and so on.

- Can be used and changed the percentage of material such as(SP ,NaoH,NS and W/B) for producing SCGPC by using calcined kaolin clay.

- Studying the effects of elevated curing conditions and steam curing conditions and the performance of SCGPCs containing CKC, MDP, and GGBS in binary and ternary blended binders.

- Studying of the microstructure properties of SCGPC at different ages using SEM, XRD, and BET techniques. However, there is a need to investigate these at all ages.

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الخلاصة

السيطرة على التلوث البيئي هو التركيز الرئيسي للدراسة في الوقت الحالي. التصنيع والتحضر وزيادة السكان هي الأسباب الرئيسية لتلوث البيئة. تزايد الاختلال البيئي الناجم عن نقصان الموارد المستمر وانبعاثات غاز ثاني أكسيد الكربون المرتفعة من إنتاج الخرسانة القائمة على السمنت البورتلاندي (PC). تحظى تقنيات السمنت البديلة باهتمام متزايد منذ أن زادت صناعة السمنت من المخاوف البيئية. التفكير الحديث من ضروري تحسين الأداء البيئي والمتانة للخرسانه. تم تطوير مصطلح "جيوبوليمر" لتشجيع استخدام المواد الطبيعية المركبة أو المنتجات الثانوية الصناعية في تصنيع السمنت. يتم تنشيط هذه المكونات الخاملة باستخدام المنشطات القلوية مثل (OH) و (Si2) لإعطاء الخليط خصائص الارتباط الخاصة به. تشتمل المواد الخام المستخدمة في الجيوبوليمر مثل fly ash(FA) وخبث الافران المنصهره(GGBS)، (CKC)، ونظرًا للزوجة العالية للخرسانه الجيوبولميريه (GPC) لديها القدرة على الفشل بسبب نقص الضغط. لذلك تم انتاج الخرسانة الجيوبوليمرية ذاتية الضغط (SCGPC) ، وهي حل للمشكلة الاهتزاز المبتكر لوضع أو ضغط الخرسانة. يمكن أن يكون تحت تاثيروزنه لملئ القوالب.

تركز هذه الدراسة على الحد من انبعاثات (CO_2) في الأجواء واستهلاك الطاقة. علاوة على ذلك ، فإنه يعطي الخرسانة المطورة ذاتي الضغط الجيوبوليمر من خلال استخدام مواد البوزولانية مثل طين الكاولين المحروق (CKC) و GGBS ومسحوق الرخام (MDP) كبدائل. لإنتاج الخلطات SCGPG تم تصميم ستة عشر نوعًا مختلفًا من الخلطات الخرسانية وصب نسبة الماء إلى الخليط (w/b = 0.36) ومحتوى (CKC) يبلغ 486 كجم / م3. في هذه الدراسة ، تم تطوير ثلاثة أنواع من الخلطات الخرسانية ، وهي أنظمة ثنائية وثلاثية وعلى ثلاث مراحل. تم إنشاء خلطه مرجعيه في المرحلة الأولى باستخدام 100 ٪ فقط من CKC ، بينما تم إنشاء الخلطات الأخرى باستخدام الخليط الثنائي (MDP + CKC) ، (CKC+ GGBS).

حيث تم استبدال GGBS عند 30 ، 40 ، 50 ، 60 ، 70 ٪ من CKC و MDP عند 5 و 10 و 15 و 20 و 25 ٪ من CKC في المرحلة الثانية ، أنظمة الخلطات الثلاثية (CKC + MDP + GGBS)، كانت نسب الاستبدال لـ MDP 5 ، 10 ، 15 ، 20 ، 25٪ مع 50٪ من GGBS ، على التوالي كاستبدال وزني جزئي .

و لتقييم قابليه الملء وقابليه المرور ومقاومه الانعزال لخلطات الخرسانة ، تم اختبار الخصائص الجديدة لـ SCGPC عن طريق اختبار تدفق اختبار الركود D (mm) و T500 (s) ، واختبار V-funnel، واختبار L-box ، واختبار مقاومه الانعزال تم تقييم أداء الخلطات SCGPC في

الحالات الصلبة في مختلف الأعمار باستخدام اختبارات الكثافة الظاهرية و FC و SPT و UPV. بالإضافة إلى ذلك ، تم فحص مقاومه الانضغاط للخلطات الثنائية والثالثة من حيث امتصاص الماء والمسامية والامتصاصيه. أشارت النتائج إلى أن الخصائص الجديدة لـ SCGPC قد تحسنت عندما تم استخدام GGBS و MDP في الخلطات الثنائية والثالثة ، وأن تدفقات الركود ، وفترات التدفق ، ومقاومه الانعزال كانت كافية لتطوير SCGPC إلى جانب نسبة ارتفاع L-Box ، وكانت النتائج لجميع نماذج SCGPC بقيم تتراوح من 0.809 إلى 0.957. نتيجة لذلك ، استوفت جميع تركيبات الخرسانة الجديدة الخصائص المطلوبة. هناك تطور في نتائج اختبار خصائص تصلب الخرسانة وأداء المتانة SCGPC في نظام الخلطات الثنائية والثلاثية. الخليط المكون من 35٪ من CKC و 15٪ من MDP مع 50٪ من GGBS أعطى في الخلطات الثلاثية فائدة أكبر عند استخدامه كمادة مفردة مع طين الكاولين المحروق (CKC) في الخرسانة الجيوبوليمرية ذاتية الرص ، مع تسجيل تطور أفضل مقارنة مع الخلطه المرجعيه والمزيج الثنائي مع CKC بنسب مختلفة والخلطات الثلاثية مع نفس مستويات الاستبدال من الطين. في عمر 90 يومًا ، أظهر الخليط الخرساني المحتوي على نسبة استبدال 35٪ من CKC و 15٪ من MDP و 50٪ من GGBS أعلى مقاومة مقاومة للانضغاط وقوة شد ، UPV 69.2 ميجا باسكال, 5.21 ميجا باسكال و 4984 م / ث على على التوالي. نظرًا لانخفاض امتصاص الماء والمسامية والامتصاصيه في النماذج الخرسانية ، فقد أظهرت أيضًا أفضل صفات المتانة. كان معامل المحدد (R^2) للنموذج العام ، والذي تم إنشاؤه للتنبؤ بقوة الانضغاط باستخدام عدة متغيرات 87.7٪ ، مما يشير إلى ارتباط قوي جدًا ونماذج أفضل تناسب مع بيانات المختبر. مما يقلل الطلب على السمنت ، وخفض معدل انبعاثات ثاني أكسيد الكربون ، وجعل الخرسانة الجيوبوليمرية ذاتية الرص (SCGPC) متينة للغاية وصديقة للبيئة ولها استخدامات المختلفة.

تطوير الخرسانة الجيوبولمرية ذاتية الرص القلوية الفعالة المعتمدة على الكاؤولين المحروق باستخدام مخلفات الرخام

رســالــــة

مقدمة الى كلية الهندســة / جامعة بابـــــــل

كجزء من متطلبات الحصول على درجة الماجستيــــر في الهندسة / الهندسة المدنية / المواد الإنشائية

من قبل

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