# Performance Evaluation of Self Compacting Geopolymer Concrete by Incorporating Polyethylene Terephthalate

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# AUTHOR'S DECLARATION

I, Abdul Haseeb hereby state that my BS thesis entitled **"Performance Evaluation of Self Compacting Geopolymer Concrete by Incorporating Polyethylene Terephthalate"** is my own original work and has not been submitted previously by me for award of any degree from Balochistan University of Information Technology, Engineering & Management Sciences, Quetta or elsewhere in the country/world.

At any time, even after my graduation, if the above statement is found incorrect, the university has the right to withdraw my BS degree.

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# DEDICATION

This project is dedicated to my parents and friends who inspired me in doing the right thing and supported me in life, and to my teachers for their untiring encouragement to their students of BUITEMS. I am personally grateful for their guidance and patient advices throughout my career.

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# ABBREVIATIONS

| | |
|---|---|
| ASTM | American Society for Testing Material |
| EFNARC | European Federation of National Associations Representing for Concrete |
| BS/B/EN | British Standard for Concrete |
| OPC | Ordinary Portland Cement |
| CC | Conventional Concrete |
| SCC | Self-Compacting Concrete |
| SCGC | Self-Compacting Geopolymer Concrete |
| GC | Geopolymer Concrete |
| AAC | Alkali Activated Concrete |
| RHA | Rice Husk Ash |
| GGBFS/GGBS | Ground Granulated Blast Furnace Slag |
| FA | Fly Ash |
| PET | Polyethylene terephthalate |
| UTM | Universal Testing Machine |

# ABSTRACT

As the whole world's main focus is to the standard of living, thus urbanization is going on with construction at high speed. Therefore, with the increase in the construction use of the Ordinary Portland Cement (OPC) is also expanding, which causes damage to environment. In high reinforced structures the main problem faced by the labour is compaction of the concrete. Thus, to counter these problems Self Compacting Geopolymer Concrete (SCGC) is gaining much attention. The aim of this research is to analyse the effect of Poly-Ethylene Terephthalate (PET) fibers on SCGC. Ground Granulated Blast Furnace Slag (GGBFS) and class F Fly Ash (FA) were used in three different proportions (40:60, 50:50 and 60:40) as binders along with alkali activators, and analysed the fresh and hardened properties. For fresh properties slump flow and T500 mm test, V-funnel test and L-box test were performed, whereas for hardened properties compressive and flexural strength tests were done accordingly. Results indicated that the hardened properties enhanced with the increase of the slag quantity, while had a negative effect on fresh properties. Then all the three proportions were reinforced with PET fibers in different percentages (0, 0.05%, 0.1%, 0.15%, 0.2%, 0.25%, 0.3%, 0.35%, 0.4%, 0.45%, 0.5%, 1% and 1.5%) by volume of the mix and same properties were analysed. The addition of fibers increased the hardened properties of SCGC but had a negative effect on the fresh properties. Fibers addition till 1% increased the compressive strength by 13% approximately, but at 1.5% addition the strength started to reduce. Same effect was seen for flexural strength, as the 1% addition increased the strength by 42% approximately and after that the strength started to reduce. Hence up to 0.5% addition of PET fibers fresh properties were according to the European Federation of National Associations Representing for Concrete (EFNARC) requirements for Self-Compacting Concrete (SCC). But 1% and 1.5% didn't satisfy the requirements of SCC. This study sought to evaluate the properties of SCGC with PET fibers induction.

# CHAPTER 1 INTRODUCTION

## 1.1 Overview

This chapter contains the background of the research followed by problem statement, aim and objectives of this research, also scope and significance of the study.

## 1.2 Background

The Self-Compacting Concrete (SCC) compacts by own weight, thus can consume every one of the spaces of formwork with next to no requirement for vibration (Olatokunbo M. Ofuyatan, 2020). SCC is sufficiently viscous enough to be taken care of without bleeding or segregation, also unlike Conventional Concrete (CC), SCC isn't vibrated; it flows and compacts under gravity required. SCC contains all the ingredients as of CC, water mineral and chemical admixtures are additionally added (Olatokunbo M. Ofuyatan, 2020).

For strength and durability compaction is required for CC where decreased strength and properties is observed when compaction is not enough which prompts voids. SCC, which streams under its own load because of gravity and any outside vibration for compaction isn't needed. Superplasticizers and viscosity modifying agents are needed to gain high flowability of SCC and for the elimination of segregation (C. Vaidevi, 2020).

Because of the ease of use & accessible material for concrete, cement is the most utilized binding material for structures. Be that as it may, ozone depleting substances ($CO_2$, and so forth) are delivered to the climate when the Ordinary Portland Cement (OPC) is produced, and because of OPC being high energy requiring material also have adverse effects on climate, thus new eco-friendly underlying materials ought to be used rather than conventional cement to adapt to ecological issues (Mehmet Eren Gülsan, 2019).

Geopolymer Concrete (GC) is acquiring attention as to eliminate the OPC as binder & utilize modern byproducts like fly ash, slag, adding to ecological advantages (Sherin Khadeeja Rahman, 2021).

Normally SCC is being used in structures which are highly reinforced, because of its high flowability, filling and passing capacity and the GC's ecological advantages. Thus, Self-Compacting Geopolymer Concrete (SCGC) is a clever thought in the substantial area, which incorporates the properties of both GC and SCC but research is still needed to fully utilize the SCGC in construction (Mehmet Eren Gülsan, 2019).

Reuse of plastic waste is gaining much attention in previous years, to solve issues like dumping it in landfills, burning etc., researchers are trying their best to reuse the plastic in different industries one of them being the construction industry, so that it can be used in concrete for both ecological and economic reasons (Foti, 2019).

Because of the low tensile strength of SCC many types of fibers are being used one of them is steel, as it works on the post-breaking, durability, and malleability of the concrete (Mehmet Eren Gülsan, 2019). One of the disadvantages of using steel fibers is that it effects fresh properties badly, thus many researchers have been using recycled plastic in different forms to increase the strength of SCC, Poly-Ethylene Terephthalate (PET) fibers are also used for enhancing the properties of concrete by different researchers (U.Balamurugan, 2017; Abdulkader Ismail Al-Hadithi A. T., 2019; Vijaya, 2018). Therefore, in this research using PET as reinforcement for SCGC and evaluating the properties accordingly.

## 1.3 Problem Statement

Pakistan is now witnessing fast urbanization as well as industrialization, similar to other emerging nations. As a result, significant infrastructure development is taking place. It is evident that OPC production is one of the main reasons which causes damage to environment because of the high carbon emission (G.Sanjayan, 2008). Also, in high reinforcement structures compaction of concrete is a major issue for labour (Mehmet Eren Gülsan, 2019). To counter these problems SCGC is the answer. However, it is not been fully utilized in construction industry because of its low strength (Tamil Selvi.M, 2014). As the steel fibers shows negative effect on fresh properties as per previous researches (Mehmet Eren Gülsan, 2019), therefore PET fibers were used in this research. Thus, with the objectives in the current study, analyzed SCGC properties by incorporating PET fibers.

## 1.4 Research Aim and Objectives

### 1.4.1 Aim

The aim of this research is to analyze the effect of PET fibers on the properties of self-compacting geopolymer concrete.

### 1.4.2 Objectives

Following are the objectives that needs to be achieved:

i. To evaluate the fresh properties of self-compacting geopolymer concrete by incorporating polyethylene terephthalate fibers.
ii. To evaluate the hardened properties of self-compacting geopolymer concrete by reinforcing with polyethylene terephthalate fibers

### 1.5 Significance of the Research

As it is evident that OPC production is one of the main reasons which causes damage to our environment because of the high carbon emission (G.Sanjayan, 2008). So, this research mainly focuses on to achieve a composite which can be self-compacted, as well as is greener. In Pakistan construction industry will start to grow, as the concrete acquired will not require any vibration which will ease the work of labour and will not have a negative effect on environment.

# CHAPTER 2 LITERATURE REVIEW

## 2.1 Overview

This chapter presents the review of studies, performance and behavior of wastes and chemicals used in concrete composite with zero cement and self-compactness characteristic and those properties which affect performance of the composite.

## 2.2 Self-Compacting Concrete

SCC streams, compacts by its own weight, and can consume every one of the spaces of formwork with next to no requirement for vibration (Olatokunbo M. Ofuyatan, 2020). SCC is sufficiently viscous enough to be taken care of without bleeding or segregation also unlike CC, SCC isn't vibrated; it flows and compacts under gravity required thus SCC contains all the ingredients as of CC, water mineral and chemical admixtures are additionally added (Olatokunbo M. Ofuyatan, 2020).

In 1989 Ozawa et al. introduced the primary model of SCC, then as years passed information and use of SCC expanded (Ozawa, 1989). Moreover, in SCC Superplasticizer/ Viscosity Modifying agent is being used for high flowability.

### 2.2.1 Superplasticizer

Superplasticizers/ water reducers are equipped for diminishing the water necessities by around 30%. They empower the effective use of water in concrete. Sulfonated melamine formaldehyde, sulfonated naphthalene formaldehyde and modified lignosulfonates are the three on which mostly superplasticizers are based on (MakeCivilEasy, 2020).

The water reducers go about as base after connecting themselves with the cement particles which keeps a reaction from occurring. This grants the water to flow because of the low heaps formation in cement particles and keeps the blend hydrated prompting increased workability (Iqbal, 2022)**.** The constituents of Superplasticizer are mentioned in the below Table 1.

Table 2.1: Superplasticizer characteristics

| Description | Explanation |
| --- | --- |
| Main Constituents | Sulfonated melamine formaldehyde, sulfonated naphthalene formaldehyde, modified lignosulfonates, acrylic polymers (MakeCivilEasy, 2020) |
| Cost | Not economic (Iqbal, 2022) |
| Overdose | Mix may segregate (MakeCivilEasy, 2020) |
| Water Reduction | Up to 30% (Iqbal, 2022) |

Some Advantages of Superplasticizers are:

- Without changing water to cement w/c ratio high workable concrete that can have self-compacted and self-leveling property without any bleeding or segregation. (Ultra chemicals; Iqbal, 2022)
- With the assistance of superplasticizer water can be reduced lest of 30-40 percent. (MakeCivilEasy, 2020)
- With Superplasticizer one can produce high performance and high workable concrete which requires less water. (Ultra chemicals; Iqbal, 2022)
- To counter the problems of site like segregation, bleeding, air content variation and slump loss with time superplasticizers are used. (Ultra chemicals)

## 2.3 Geopolymer Concrete

GC doesn't have cement as binding material but different materials (Slag, fly ash) are being used along with alkali activators to bind them together.

For the Environmental reasons investigation to partially/ fully replace the OPC are being made. GC is acquiring a lot of consideration in the current time because of the critical decrease in $CO_2$. From literature it is evident that GC has 5-6 times lower $CO_2$ emission when compared with OPC concrete and also making of geopolymer cement requires less energy, also in addition utilizes the alumino-silicate byproduct to manufacture materials for construction (Mehmet Eren Gülsan, 2019; B. Singh, 2015). Studies on using different materials to replace cement are being made, for example, pumice powder (Reza Bani Ardalan, 2017), nano-silica (Mehmet Eren Gülsan, 2019; J. Bernal, 2018), fly ash (Sherin Khadeeja Rahman, 2021; Mehmet Eren Gülsan, 2019), metakaolin (P. Ghoddousi, 2017), rice husk ash (Yamini J. Patel, 2018), Slag (Olatokunbo M. Ofuyatan, 2020), eggshell powder (Olatokunbo M. Ofuyatan, 2020).

The main constituents of GC are;

- Slag/Ground granulated blast furnace slag
- Fly ash
- Alkali activator
- Aggregate
    - Coarse aggregate
    - Fine aggregate
- Water

### 2.3.1 Ground Granulated Blast Furnace Slag

A cementitious material which is gained as a waste from making iron in blast furnace is GGBFS (CSMA; Yuksel, 2018)**.**

Coke, lime stone and iron ore are all put in the blast furnace which operates at 1500°C. After iron is made and the left-over materials which is called slag floats in the form of molten liquid on top. This is then put in water and after forming of granules is then dried and ground. A typical blast furnace diagram is shown in Fig. 2.1 (CSMA)**.** Table 2.2 and Table 2.3 shows the chemical composition and physical properties of GGBFS respectively.

Table 2.2: Typical Chemical composition

| Description | Percentage |
|---|---|
| Calcium oxide | 40% |
| Silica | 35% |
| Magnesia | 8% |
| Alumina | 13% |

Table 2.3: Typical Physical properties

| Colour | Off-white to brown |
|---|---|
| Specific gravity | 2.9 |
| Bulk density | 1000 - 1100 kg/m$^3$ (loose) 1200 - 1300kg/m$^3$ (vibrated) |
| Fineness | >350 |

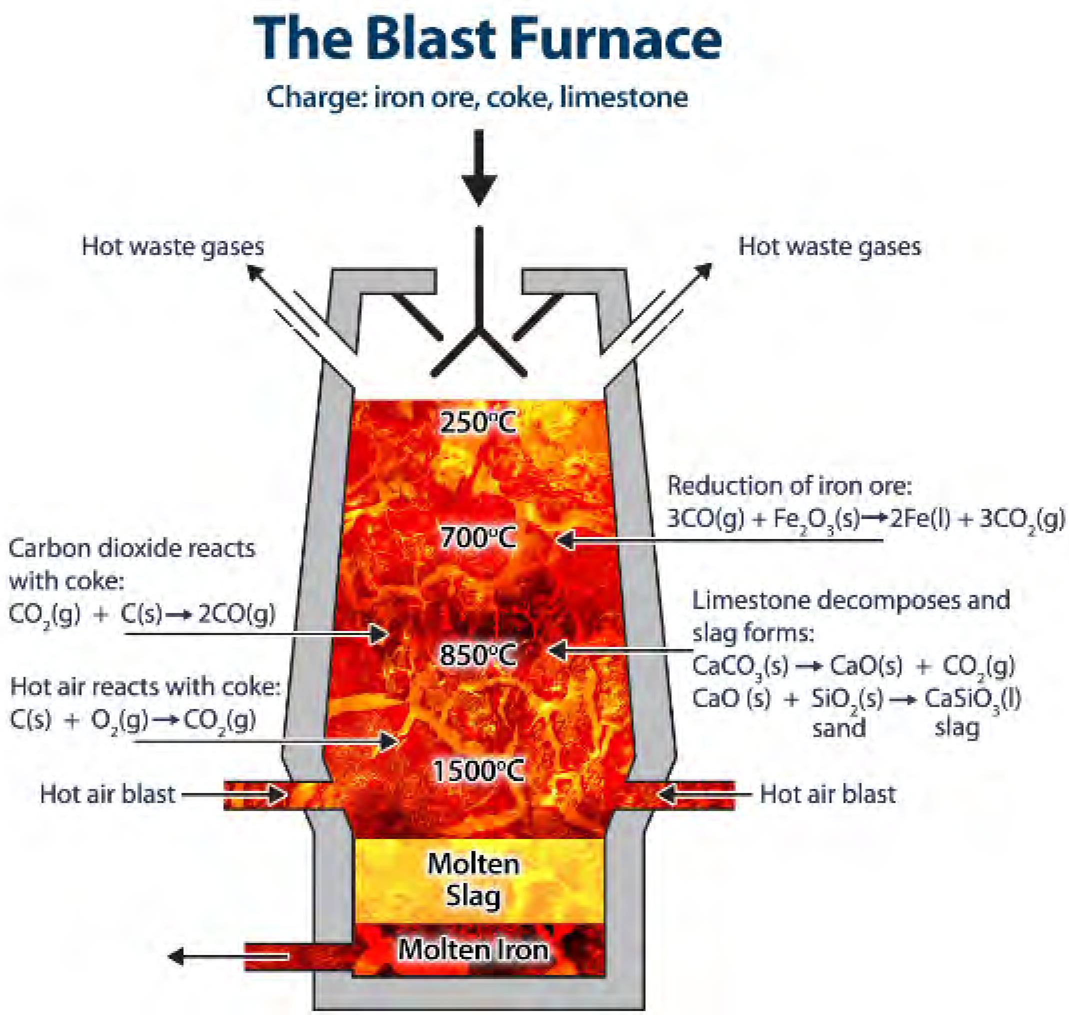


Figure 2.1: Blast Furnace

### 2.3.2 Fly ash

A byproduct of coal ignition is Fly Ash (FA). It is mostly used in pozzolanic concrete, geopolymer concrete, dams, mines landfills etc. because of its pozzolanic characteristic (Corrosionpedia, 2019; Forum)**.** According to American society for testing materials, type C and F are the two types of FA (ASTM-C618)**.**

Type C fly ash contains calcium oxide (CaO) more than 10 percent and is delivered from the ignition of sub bituminous coals or lignite, while type F contains less than 10% CaO and is created by burning of bituminous or an anthracite coal. (Corrosionpedia, 2019; Forum; Theconstructor)

#### 2.3.2.1 Physical Properties of Fly ash

Class F fly ash physical properties are shown in Table 2.4.

Table 2.4: Physical Properties of class F fly ash

| | |
|---|---|
| Size | 1 μm to 100 μm "average is less than 20 μm" (Corrosionpedia, 2019). |
| Specific surface area | 300 $m^2$/kg to 500 $m^2$/kg (Theconstructor). |
| Bulk density | Air between particles "540 kg/$m^3$ to 860 kg/$m^3$" and Packed or vibrated "1120 kg/$m^3$ to 1500 kg/$m^3$" (Theconstructor). |
| Specific gravity | 1.90 and 2.80 (Forum). |
| Color | Grey or tan (Corrosionpedia, 2019) |

#### 2.3.2.2 Chemical composition

The FA composition relies upon the source. As type C fly ash has low silica and alumina content and has more calcium, where type F have high opposite content of all. But FA is for the most part alumino-silicate glass containing silica, alumina, iron, and calcium. Minor parts are magnesium, sulfur, sodium, potassium, and carbon (Corrosionpedia, 2019; Forum; Theconstructor).

### 2.3.3 Alkali Aktivators

Alkali activators play an important role in Cement- free concrete/alkali activated concrete (AAC)/geopolymer concrete. Because of the low energy, durability AAC is being more prominent in the modern era (constructor). The two main ingredients are binder and alkali activators (constructor). Caustic soda and alkaline salts are the two normally used alkaline activators (constructor).

Hydration reaction in AAC is still under research (constructor). Calcium Silicate Hydrate gel (C-S-H) is the room temperature product of hydration. Minor hydration products depends upon the slag and the activator qualities that are being utilized (constructor). The two alkali activators which are used in this research are NaOH & $Na_2Sio_3$.

#### 2.3.3.1 Sodium Hydroxide

Sodium hydroxide (NaOH), corrosive white glass like solid likewise called lye. It promptly absorbs water and then at last dissolves. Sodium hydroxide is the most generally utilized modern base and is in many cases utilized in channel and microwave cleaners. It is profoundly destructive to creature and vegetable tissue. In different processes it neutralizes acids in water. In refining of petroleum, it eliminates sulfuric and natural acids. In soapmaking, it follows up on regular fats or oils, like fat or vegetable oil, to deliver sodium unsaturated fat salt (cleanser) and glycerin (or glycerol); this saponification response is the reason for all soapmaking. In papermaking, sodium hydroxide is utilized for disintegrating wood into mash, cellulose treatment and synthetics production (encyclopedia, 2022)**.**

#### 2.3.3.2 Sodium Silicate

A combination comprising sodium oxide (Na2O) and silica (silicon dioxide, SiO2) that produces a solid with glassy look and can be dissolved in water is known as water glass/ sodium silicate/soluble glass. Water glass is offered for sale as transparent, syrupy liquid, solid lumps, or powders. It serves as an easy supply of sodium for several industrial goods, a fabric softener additive, binder, water treatment flocculant etc.

Since the 19th century, Sodium Silicate has been produced, and "silicate of soda" is still made according to the same fundamental principles. It is typically made by igniting different amounts of soda ash and silica sand at temperatures between 1,000 and 1,400 °C, the whole reaction is shown below:

$$Na_2CO_3 + SiO_2 \rightarrow Na_2O \cdot SiO_2 + CO_2 \qquad \text{Eq. 1}$$

The result is cullet, which may either be crushed into powder and sold as it is or chilled and sold as fused glassy lumps. Lump or ground water glass can be fed one at a time into pressured reactors for hot water dissolution, then it is sold off after being cooled.

NaOH heated solution may be used to dissolve silica sand under pressure, producing sodium silicate liquid as a direct result:

$$2NaOH + SiO_2 \rightarrow Na_2O \cdot SiO_2 + H_2O \qquad \text{Eq. 2}$$

Sodium silicate is being used in bleaching of paper pulp, the de-inking of wastepaper, to filter out unwanted suspended particles from municipal water supplies and wastewater, it may be used as a bonding agent in goods made of cement, such as concrete and abrasive wheels. For glass or porcelain, it works great as an adhesive, used as an egg preserver (encyclopedia, 2022).

### 2.3.4 Aggregates

Aggregate is used in the preparation of concrete, fine and coarse aggregates are the two types based on the particle size (Singh, 1990).

A concrete in which the aggregates are firm, durable, and should not absorb chemicals and free from clay membrane can be referred as a good concrete mix. Almost 60-75 percent of concrete volume is aggregate (i.e. coarse and fine aggregate). When the aggregate are accumulated then the aggregate are further moved for crushing, screening, and grading. To enhance the quality of aggregate the process like jigging and heavy media separation is conducted if necessary. After the refining, the aggregates are stored and handled safely to decrease the effects of segregation, degradation and avoid contamination. Strength, durability and structural performance mostly depends upon the aggregates (Neville, 2010). Fine and coarse aggregate are the two types which are used in concrete.

#### 2.3.4.1 Coarse Aggregate

Coarse aggregates size ranges from 4.75 mm to 7.5 mm (Singh, 1990). In concrete the coarse aggregate contains large amount of crushed stone and gravel. The natural gravel is usually obtained by digging lake, river, pits etc. By crushing large size gravel, boulders, cobbles and quarry rocks, crushed aggregates can be obtained.

#### 2.3.4.2 Fine Aggregate

To fill the voids of the concrete fine aggregate is being used. Fine aggregate particles pass through sieve 4.75 mm gaps and 0.15 mm mesh retains its particles. Sand, crushed stone, ash or cinder and surkhi are mostly used as fine aggregate.

### 3.5 Water

In concrete mix water is the most important ingredient that effect many factors like hardening, compressive strengths, permeability, drying shrinkage, and potential for cracking, therefore the ratio, limits and controlling of water in concrete mix has great impact on strength and durability when cured properly because water is responsible for binging all ingredients of concrete mix together (Singh, 1990).

## 2.4 Self-Compacting Geopolymer Concrete

Research is going on in the whole world to achieve a geopolymer concrete with self-compacted properties called self-compacted geopolymer concrete (SCGC) for the betterment of environment as well as for the ease of work at construction sites using high reinforcement (Mehmet Eren Gülsan, 2019). But there are still many areas that needs to be addressed for SCGC like low tensile strength (Mehmet Eren Gülsan, 2019).

In 2019, Mehmet Eren Gülsan, et al. tried to reinforce the SCGC with steel fibers (SF) and added nano silica (NS) to the mix to achieve high strength/ performance. 50:50 FA GGBFS were used along with NAOH of 12M and Sodium Silicate with 2.5 ratio and alkali to binder ratio used was 0.5. Steel fibers and nano silica were added in different percentages. 0,1 and 2 percent nano silica and 0, 0.5 and 1 percent steel fibers were added and analyzed. Nano silica improved the fresh properties but had negative effect on hardened properties where as the steel fibers effect was the opposite, thus the optimum mix which was achieved had 2 percent nano silica and 1 percent steel fiber content (Mehmet Eren Gülsan, 2019).

In 2018, Yamini J. Patel , et al. tried making of SCGC with GGBFS Rice Husk Ash (RHA). They concluded that that 5% of substitution shows great attributes worked on compressive strength and flowability is as indicated by EFNARC standards, but beyond 5% workability decreases, also reduced hardened properties were observed. FA as 100% binder in SCC had no strength because of ambient curing (Yamini J. Patel, 2018).

## 2.5 Polyethylene terephthalate

Polyethylene terephthalate (PET) is synthetic polyester fiber, that is used in making soda or water bottles. PET is made from polymerization of terephthalic acid and ethylene glycol with chemical accelerators (Britannica, 2022).

The primary use for PET is the production of packaging materials for food items including fruit and beverage containers. In addition to being converted into polyester fibres, PET may also be recycled back to its basic components. These polyester fibres are used to create artificial carpets, artificial garments, and other textile goods. Because PET fibres don't wrinkle, they are frequently combined with natural fibres. Additionally, it is employed in the production of microwaveable trays, the packaging of microwaveable meals, and the packaging of cosmetic and medicinal items (Britannica, 2022).

PET transparent and healthy, with good purity, also its goods are tasty and adhere to international guidelines for food contact. PET bottles and other products are robust and nearly indestructible, they may be used for storage and transit with ease. PET goods retain the integrity of items with a long shelf life since they have a low permeability to oxygen, carbon dioxide, and water, also PET items are lighter in weight as compared to other packaging with no leakage. PET polymer may be recycled and moulded into a variety of forms. PET materials hold up well to a variety of acids, bases, and other chemicals.

### 2.5.1 Background of PET Being used in Construction

Presently one of the central issues of current period is plastic waste whether it is as bottles, bags etc. As plastic waste (PW) is most risky ecological contamination because of its non-biodegradable property, they are appropriately unloaded off to squander landfills (Waseem Khairi Mosleh Frhaan, 2021). However, this work isn't to the point of disposing off PET, but reusing it in construction industry (Waseem Khairi Mosleh Frhaan, 2021; Sadaqat Ullah Khana, 2020).

Plastic waste is being used by other industries along with construction industry. The most widely recognized illustration is soda/water bottles. PET is being used in a few enterprises, like development, car, bundling, building electrical and gadgets. PET bottles were introduced in 1930s and from 1950 to 2017 has expanded vastly by 1.7 million tons to 335 million tons (Ismail ZZ, 2007; Roland Geyer, 2017; Waseem Khairi Mosleh Frhaan, 2021).

Many researches have been done on using of PET bottles in the form of fibers or strips in the SCC with different length, width and aspect ratio.

In 2020, Sadaqat Ullah et al. attempted to reinforce SCC with PET fibers. Beams were examined containing fibers and also PET fibers were added as shear and flexural reinforcement. 13% increment was there in flexural mode of failure. It was concluded that the significance of PET is in shear zone (Sadaqat Ullah Khana, 2020).

In 2019, Matar et al. researched on flow of SSC by using filaments of polypropylene and aggregate that were being recycled from concrete. It was concluded that the filaments and aggregates when jointly used can reduce segregation and produce stable concrete, where as fresh properties reduced by using filaments (Pierre Matar, 2019). Also, Faraj et al. (2020, 2021) researched on the rheology of SCC. SCC contained silica fume, FA and particles of reused plastic. Two mixes were used, first contained 80% OPC, 20% FA and the ther one contained 70% OPC, 20% FA and 10% silica fume, the outcomes revealed that silica fume increased the fresh properties (Rabar H.Faraj, 2020; Rabar H. Faraj, 2021).

In 2019 Farhad Aslani et al., analyzed the SCC by adding polypropylene, and steel fibers with aggregates that are being recycled from concrete. Fresh properties were reduced while hardened properties increased by using both fibers. 0.1% for plastic fibers and 0.75% for steel fibers were the percentages that had the best results (Farhad Aslani, 2019).

In 2017, U.Balamurugan and V.Goutham, attempted to effectively utilize PET fibers in SCC. 0.5, 1 and 1.5 were the three percentages of fibers by total volume of the mix It was seen on adding 1% of the fibers, that the fresh properties were according to the EFNARC requirements and strength was maximum. For split tensile strength 1.5% addition of PET fibers mix was gave the optimum result (U.Balamurugan, Effective Utilization of PET Bottles in Self Compacting Concrete, 2017).

In 2016, Abdulkader Ismail Al-Hadithi etal., tried to enhance some properties of SCC by adding PET fibers. SCC was made by substituting cement with fly ash 35% by weight and PET fibers were added 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2 percent by volume of the total mix. The results showed that more than 1.5% addition of the fibers will reduce the compressive strength, while still 1.5% addition of the fibers is not up to the whole requirement of EFNARC as per fresh properties (Abdulkader Ismail Al-Hadithi N. N., 2016).

It is evident from the literature that cement emits high carbon because of which our environment is getting damaged and in high reinforcement structures compaction is difficult, thus to counter these two problems SCGC is gaining attention but because of its low strength it is not fully utilized in the construction industry. It is apparent from the literature that strength was enhanced by using PET fibers in SCC. Therefore, incorporating PET fibers in SCGC to evaluate the fresh and hardened properties.

# CHAPTER 3 MATERIALS AND METHODS

## 3.1 Overview

In this chapter, the materials and the methods that were used to carry out the research are discussed.

## 3.2 Research Design

The current study is research in which three proportions of self-compacting geopolymer concrete with different percentages of GGBFS and class F FA (40:60, 50:50 and 60:40) as binder were analysed. Moreover, reinforcing the same proportions with PET fibers. Tests were done in laboratory to evaluate the fresh and hardened properties.

## 3.3 Materials

The materials used for this research are NaOH, $Na_2SiO_3$, GGBFS, FA, coarse and fine aggregates, superplasticizer, cold drink bottles, water.

### 3.3.1 Ground granulated blast furnace Slag

Grade 80 GGBFS as per ASTM C-989 and BS 6699 was used as a binder along with fly ash, it was also included in three proportions 40% (Sherin Khadeeja Rahman, 2021), 50% (Mehmet Eren Gülsan, 2019), 60% (Md Adil Ahmed, 2021). Color was off white/brown as shown in Fig. 3.1. GGBFS was obtained from Nukshi Slag Azad Kashmir.


Figure 3.1: Ground granulated blast furnace slag

### 3.3.2 Fly ash

F class FA was used as per standard ASTM C618 and EN 450 as a binder along with GGBFS because of its good pozzolanic characteristics. Fly ash was used in three different quantities 40% (Md Adil Ahmed, 2021), 50% (Mehmet Eren Gülsan, 2019), 60% (Sherin Khadeeja Rahman, 2021) and the results were analyzed. The ash was very fine and had a dark grey color as shown in Fig. 3.2. Fly ash was obtained from Mangi Dam site near Ziarat.

Figure 3.2: Fly ash

### 3.3.3 Alkali activators

12 molarity (M) Sodium Hydro oxide along with Sodium Silicate ($Na_2SiO_3$) as alkali activators were used as shown in Fig. 3.3 and Fig. 3.4, with 2.5 as silicate to hydro oxide ratio, and 0.5 was taken as alkali to binder ratio (Mehmet Eren Gülsan, 2019).

Figure 3.3: Sodium Hydroxide

Figure 3.4: Sodium Silicate

### 3.3.4 Coarse aggregate

Size 10-20mm coarse aggregate was used as per ASTM- C33/C33M and EN 12620 as shown in Fig. 3.5. Coarse aggregate used was locally available.

Figure 3.5: Coarse aggregate

### 3.3.5 Fine aggregate

Sand, which was passed through sieve #4 as per ASTM- C33/C33M and EN 12620 was used as fine aggregate, shown in Fig. 3.6. Fine aggregate used was locally available.

Figure 3.6: Sieve Analysis of fine aggregate

### 3.3.6 Water

Ratio of water to binder is very important in concrete mix design which is known as water to binder ratio (w/b). As per standards ASTM C1602 and EN 1008 portable water was used with water to binder ratio of 0.44.

### 3.3.7 Viscosity modifying agent/ Super plasticizer

Naphthalene based Superplasticizer/ viscosity modifying agent Ultra Super Plast 470 product of Ultra Chemicals, LLC. USA was acquired from supplier of Quetta which was added for high flowability as per standard EN 934-2: 2000. The color was dark brown as shown in Fig. 3.7.

Figure 3.7: Superplasticizer

### 3.3.8 PET fibers

PET fibers were cut form soft drink/ water bottles of 2-4mm width and 25-35 mm length (U.Balamurugan, 2017; Abdulkader Ismail Al-Hadithi N. N., 2016), and were added in different proportions 0.05%, 0.1%, 0.15%, 0.2%, 0.25%, 0.3%, 0.35%, 0.4%, 0.45%, 0.5%, 1%, 1.5% in the three mixed proportions of FA and GGBFS ratio of 50:50 (Mehmet Eren Gülsan, 2019), 40:60 (Md Adil Ahmed, 2021) and 60:40 (Sherin Khadeeja Rahman, 2021) respectively. Fig. 3.10 shows the PET fibers used, Fig. 3.8 and Fig. 3.9 shows that how the fibers were cut.

Figure 3.8: Cutting of PET Fibers

Figure 3.9: PET fibers cutter

Figure 3.10: PET fibers

### 3.4 Apparatus

The tools and equipment used are

- Electronic balance
- Slump cone
- Universal Testing Machine (UTM)
- Shovel
- Mixing pan
- Graduated cylinder
- Molds for cylinder and beam
- Measuring tape
- Curing tank
- Sieves
- Protective gear (Rubber shoes, gloves, googles etc.)
- L-Box
- V-funnel

### 3.5 Preparation of Specimen

Samples were prepared by following method:

### 3.5.1 Mix proportion

Total of 234 Samples (3 cylinders and 3 beams for each mix) were prepared for this project as per table 3.1 for hardened properties test, fresh properties tests were also done accordingly. Firstly, SCGC samples were prepared with FA and GGBFS different ratios and then all proportioned mixtures were reinforced with PET fibers.

Table 3.1: Sample preparation for self-compacting geopolymer concrete

| Mix (M) | Fly ash (in place of binder) | Slag (in place of binder) | PET (by volume of total mix) |
|---|---|---|---|
| SCGC (M1) | 50% | 50% | 0 |
| SCGC (M2) | 60% | 40% | 0 |
| SCGC (M3) | 40% | 60% | 0 |
| SCGC (M4) | 50% | 50% | 0.05% |
| SCGC (M5) | | | 0.1% |
| SCGC (M6) | | | 0.15% |
| SCGC (M7) | | | 0.2% |
| SCGC (M8) | | | 0.25% |
| SCGC (M9) | | | 0.3% |
| SCGC (M10) | | | 0.35% |
| SCGC (M11) | | | 0.4% |
| SCGC (M12) | | | 0.45% |
| SCGC (M13) | | | 0.5% |
| SCGC (M14) | | | 1% |
| SCGC (M15) | | | 1.5% |
| SCGC (M16) | 60% | 40% | 0.05% |
| SCGC (M17) | | | 0.1% |
| SCGC (M18) | | | 0.15% |
| SCGC (M19) | | | 0.2% |
| SCGC (M20) | | | 0.25% |
| SCGC (M21) | | | 0.3% |
| SCGC (M22) | | | 0.35% |
| SCGC (M23) | | | 0.4% |
| SCGC (M24) | | | 0.45% |
| SCGC (M25) | | | 0.5% |
| SCGC (M26) | | | 1% |
| SCGC (M27) | | | 1.5% |
| SCGC (M28) | 40% | 60% | 0.05% |
| SCGC (M29) | | | 0.1% |
| SCGC (M30) | | | 0.15% |
| SCGC (M31) | | | 0.2% |

| Mix | Fly ash (in place of binder) | Slag (in place of binder) | PET (by volume of total mix) |
|---|---|---|---|
| SCGC (M32) | | | 0.25% |
| SCGC (M33) | | | 0.3% |
| SCGC (M34) | | | 0.35% |
| SCGC (M35) | 40% | 60% | 0.4% |
| SCGC (M36) | | | 0.45% |
| SCGC (M37) | | | 0.5% |
| SCGC (M38) | | | 1% |
| SCGC (M39) | | | 1.5% |

### 3.5.2 Batching

Measurement of materials for making concrete is known as batching. Used volume batching to know the quantity of all ingredients as shown in table 3.2.

Table 3.2: Mix proportion of SCGC

| Mix | Binder $Kg/m^3$ | Slag $Kg/m^3$ | Fly ash $Kg/m^3$ | Alkali activators ratio to binder | $Na_2SiO_3/NaOH$ | Coarse Aggregate $(Kg/m^3)$ | Fine Aggregate $(Kg/m^3)$ | Water - $(kg/m^3)$ | Superplasticizer (Liters in 100kg of binder) | PET fibers (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| M1 | 450 | 225 | 225 | 0.5 | 2.5 | 742.88 | 865.61 | 200 | 2 | 0 |
| M2 | 450 | 180 | 270 | 0.5 | 2.5 | 742.88 | 865.61 | 200 | 2 | 0 |
| M3 | 450 | 270 | 180 | 0.5 | 2.5 | 742.88 | 865.61 | 200 | 2 | 0 |
| M4 - M15 | 450 | 225 | 225 | 0.5 | 2.5 | 742.88 | 865.61 | 200 | 2 | 0.05,0.1,0.15,0.2,0.25,0.3,0.35,0.4, 0.45,0.5,1, 1.5 |
| M16-M27 | 450 | 180 | 270 | 0.5 | 2.5 | 742.88 | 865.61 | 200 | 2 | 0.05,0.1,0.15,0.2,0.25,0.3,0.35,0.4, 0.45,0.51, 1.5 |

| Mix | Binder Kg/m³ | Slag Kg/m³ | Fly ash Kg/m³ | Alkali activators ratio to binder | $Na_2SiO_3/NaOH$ | Coarse Aggregate (Kg/m³) | Fine Aggregate (Kg/m³) | Water (kg/m³) | Superplasticizer (Liters in 100kg of binder) | PET fibers (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| M28-M39 | 450 | 270 | 180 | 0.5 | 2.5 | 742.88 | 865.61 | 200 | 2 | 0.05,0.1,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.51,1.5 |

### 3.5.3 Mixing

To achieve desired strength mixing is the most important step. Proper mixing ensures the homogeneity and consistency. In this study, mixing was done by hand as per mixing procedure explained by (Mehmet Eren Gülsan, 2019) as shown in Fig.3.11, and constituents for SCGC are shown in Fig. 3.12.

Figure 3.11: Mixing of SCGC

Figure 3.12: Constituents of SCGC

### 3.5.4 Casting

Mixture was put into the cylinder and beam molds after all the constituents were mixed together. Total 234 samples were prepared in which 117 were cylinders of 6in diameter and 12in height, and 117 were beams of 18”x 6”x 6”. Three samples were casted for every mix proportion and the average value was taken as shown in Fig. 3.13. Moreover, Table 3.3 shows the details of test specimens.

Figure 3.13: Casting of SCGC samples

Table 3.3: Details of Test Specimen

| Test Details | Shape and Dimension of the Specimens |
|---|---|
| Compressive Strength | Cylinder: 6” diameter, 12” height |
| Flexural Strength | Beam: 6 x 6 x 18 inches |

### 3.5.5 Curing Regime

As the procedure was done under ambient conditions thus a rest period was required before curing the samples. As per literature a rest period of 4 days gives the best result (S Oyebisi, 2019). Thus left the samples for 4 days before curing as shown in Fig. 3.14.

Figure 3.14: Samples at Rest period

### 3.5.6 Curing

After the rest period was completed curing of all the samples was done. In this research, 28 days curing was done of all the cylinders and beams for achieving maximum strength as shown in Fig. 3.15.

Figure 3.15: Curing Tank

### 3.5.7 Drying

Samples were left to dry at ambient conditions for 1 week after curing shown in Fig. 3.16, because from literature it is evident that drying is needed after curing (Mehmet Eren Gülsan, 2019; Sherin Khadeeja Rahman, 2021).

Figure 3.16: Dry samples

### 3.6 Tests

Following are the tests which were performed for this project:

#### 3.6.1 Fresh Properties

There is a rundown of fresh properties that are critical to comprehend to choose the appropriateness of SCGC. For better quality control, workability, flowability, capacity to pass and fill the voids fresh properties tests are significant. Following tests were performed for fresh properties:

##### 3.6.1.1 Slump Flow and T500 mm Test

Standard that was used to perform this test is B. 12350-8 EN, Testing self-compacting concrete: slump flow test, Br. Stand. Int. (2010). Firstly, slump cone was filled with concrete, after that it is lifted upward vertically and the concrete left the concrete to flow. After that the diameter of the circle was noted as shown in Fig. 3.18. Simultaneously with the help of stop watch noted the time to reach the 500mm circle.

Slump testing and the time of T500 flow as 650–800mm and 2–5 s, respectively is set by European Federation of National Associations Representing for Concrete (EFNARC) (EFNARC, 2002). Fig. 3.17 shows the apparatus used for this test which was performed at BUITEMS concrete lab.

Figure 3.17: Slump flow apparatus

Figure 3.18: Slump flow Test

#### 3.6.1.2 V-funnel Test

To check the segregation V-funnel test was performed. Apparatus is shown in fig. 24 and fig. 25. Ozawa et al. firstly used this test to check segregation (Ozawa, 1989). Standard that was used to perform the V-funnel test is B. 12350-9 EN, Testing self-compacting concrete: V-Funnel Test, Br. Stand. Int. (2010). Concrete was poured in the apparatus. After filling, opened the gate within 10 sec and recorded the time with stop watch in which the apparatus is emptied. 6–12 sec standard is set for SCC by EFNARC (EFNARC, 2002). Fig. 3.19 shows the test apparatus and the test was performed at BUITEMS concrete lab.

Figure 3.19: V-Funnel Apparatus

#### 3.6.1.3 L-Box Test

Passing ability was check with the help of L-box test. Standard that was used to perform the L-box test is B. 12350–10 EN, Testing self-compacting concrete: L-box test, Br. Stand. Int. (2010). The apparatus is shown in fig. 26 and fig. 27. Three #4 reinforcements bars were fitted in front of Horizontal portion (HP) and both the sections were separated by a movable gate. Filled the Vertical Portion (VP), after that opened the gate and concrete started flowing into the HP. After that the Height of concrete in both portions were noted, At last blocking ratio was calculated by dividing horizontal portion concrete height with vertical portion. 0.8–1 blocking ratio standard is set by EFNARC standard specifications for SCC (EFNARC, 2002). Fig. 3.20 shows the apparatus that was used and the test was performed at BUITEMS concrete lab.

Figure 3.20: L-box apparatus

### 3.6.2 Hardened Properties

Mechanical properties are the most important in determining the concrete durability and stability. Thus, compressive and flexural strength tests were performed for checking the sustainability of the composite.

#### 3.6.2.1 Compressive Strength

Compressive strength was determined by casting cylinders (6” diameter and 12” height) and testing them on UTM as per ASTM standard C39/C39M-12a as shown in Fig. 3.21.

Figure 3.21: Compressive Strength Test

### 3.6.2.2 Flexural Strength

PET fibers were used to counter to crack initiation. Flexural strength was determined by casting beams (6”x6”x18”) and testing them on UTM as per ASTM standard C293M as shown in Fig. 3.22.

Figure 3.22: Flexural strength test center point loading

# CHAPTER 4 RESULTS AND DISCUSSION

## 4.1 Overview

This chapter deals with result obtained from the experiments carried out in the laboratory, taken into account the aims and objectives of the research. The data collected were analyzed using Microsoft excel.

## 4.2 Slump Flow and T500 mm Test

Slump flow and T500mm test were performed to check the flowability of the mixes. Results showed no major change in the results of the three main mixes M1, M2 and M3. Whereas, observed small reduction in the slump flow with the increase of slag quantity, which is due to the angular shape of GGBFS as compared to the spherical shape of class F FA (Partha Sarathi Deb, 2014). Moreover, as the quantity of the PET fibers in the mix increased the diameter of the slump reduced with each increment, also T500 mm time increased. Results indicated that till 0.5% of PET fibers addition the mixes were according to the European Federation of National Associations Representing for Concrete (EFNARC) requirements (U.Balamurugan, 2017; Abdulkader Ismail Al-Hadithi A. T., 2019). Whereas, at 1 and 1.5 percent addition the slump flow values were not satisfactory as per EFNARC, while T500 mm for all the mixes satisfies the EFNARC requirements "i.e., 2 to 5 seconds" (U.Balamurugan, 2017; Abdulkader Ismail Al-Hadithi A. T., 2019) . Table 4.1, Fig. 4.1 and Fig. 4.3 shows the slump flow and T500 mm results, whereas Fig. 4.2 and Fig. 4.4 shows the trend lines of slump flow and T500mm test which gives an assumption of the fiber quantities that are not added in this research.

Table 4.1: Slump Flow and T500 mm Test Results

| **Mix (M)** | **Slump (mm)** | **Slump Average (mm)** | **T500mm (sec)** | **According to the EFNARC(Y/N)** | **Remarks** |
|---|---|---|---|---|---|
| M1 | 690-700 | 695 | 2 | Y | Ok as per EFNARC |
| M2 | 700-715 | 707 | 2 | Y | Ok as per EFNARC |
| M3 | 675-677 | 676 | 2 | Y | Ok as per EFNARC |
| M4 | 693-696 | 694 | 2 | Y | Ok as per EFNARC |
| M5 | 685-703 | 694 | 2 | Y | Ok as per EFNARC |
| M6 | 690-693 | 691 | 2 | Y | Ok as per EFNARC |
| M7 | 684-695 | 689 | 2 | Y | Ok as per EFNARC |
| M8 | 685-694 | 689 | 2.5 | Y | Ok as per EFNARC |
| M9 | 677-685 | 681 | 2.5 | Y | Ok as per EFNARC |

| Mix (M) | Slump (mm) | Slump Average (mm) | T500mm (sec) | According to the EFNARC(Y/N) | Remarks |
|---|---|---|---|---|---|
| M10 | 675-685 | 680 | 2.5 | Y | Ok as per EFNARC |
| M11 | 676-680 | 678 | 2.67 | Y | Ok as per EFNARC |
| M12 | 671-682 | 676 | 3 | Y | Ok as per EFNARC |
| M13 | 670-680 | 675 | 3 | Y | Ok as per EFNARC |
| M14 | 600-600 | 600 | 4 | N | Slump flow is not according to the EFNARC requirements but time taken to reach 50cm circle is ok |
| M15 | 550-570 | 560 | 5 | N | Slump flow is not according to the EFNARC requirements but time taken to reach 50cm circle is ok |
| M16 | 695-720 | 707 | 2 | Y | Ok as per EFNARC |
| M17 | 696-715 | 705 | 2 | Y | Ok as per EFNARC |
| M18 | 694-715 | 704 | 2 | Y | Ok as per EFNARC |
| M19 | 690-710 | 700 | 2 | Y | Ok as per EFNARC |
| M20 | 691-708 | 699 | 2 | Y | Ok as per EFNARC |
| M21 | 687-700 | 693 | 2 | Y | Ok as per EFNARC |
| M22 | 688-697 | 692 | 2 | Y | Ok as per EFNARC |
| M23 | 683-697 | 690 | 2 | Y | Ok as per EFNARC |
| M24 | 686-695 | 690 | 2 | Y | Ok as per EFNARC |
| M25 | 683-692 | 687 | 2 | Y | Ok as per EFNARC |
| M26 | 610-613 | 611 | 3 | N | Slump flow is not according to the EFNARC requirements but time taken to reach 50cm circle is ok |
| M27 | 572-572 | 572 | 5 | N | Slump flow is not according to the EFNARC requirements but time taken to reach 50cm circle is ok |
| M28 | 676-676 | 676 | 2 | Y | Ok as per EFNARC |
| M29 | 672-678 | 675 | 2 | Y | Ok as per EFNARC |
| M30 | 670-672 | 671 | 2 | Y | Ok as per EFNARC |
| M31 | 660-673 | 666 | 2 | Y | Ok as per EFNARC |

| Mix (M) | Slump (mm) | Slump Average (mm) | T500mm (sec) | According to the EFNARC(Y/N) | Remarks |
|---|---|---|---|---|---|
| M32 | 662-667 | 664 | 2 | Y | Ok as per EFNARC |
| M33 | 660-663 | 661 | 2 | Y | Ok as per EFNARC |
| M34 | 661-661 | 661 | 2.5 | Y | Ok as per EFNARC |
| M35 | 659-660 | 659 | 2.5 | Y | Ok as per EFNARC |
| M36 | 657-659 | 658 | 3 | Y | Ok as per EFNARC |
| M37 | 656-656 | 656 | 3 | Y | Ok as per EFNARC |
| M38 | 590-593 | 591 | 4 | N | Slump flow is not according to the EFNARC requirements but time taken to reach 50cm circle is ok |
| M39 | 540-547 | 543 | 5 | N | Slump flow is not according to the EFNARC requirements but time taken to reach 50cm circle is ok |

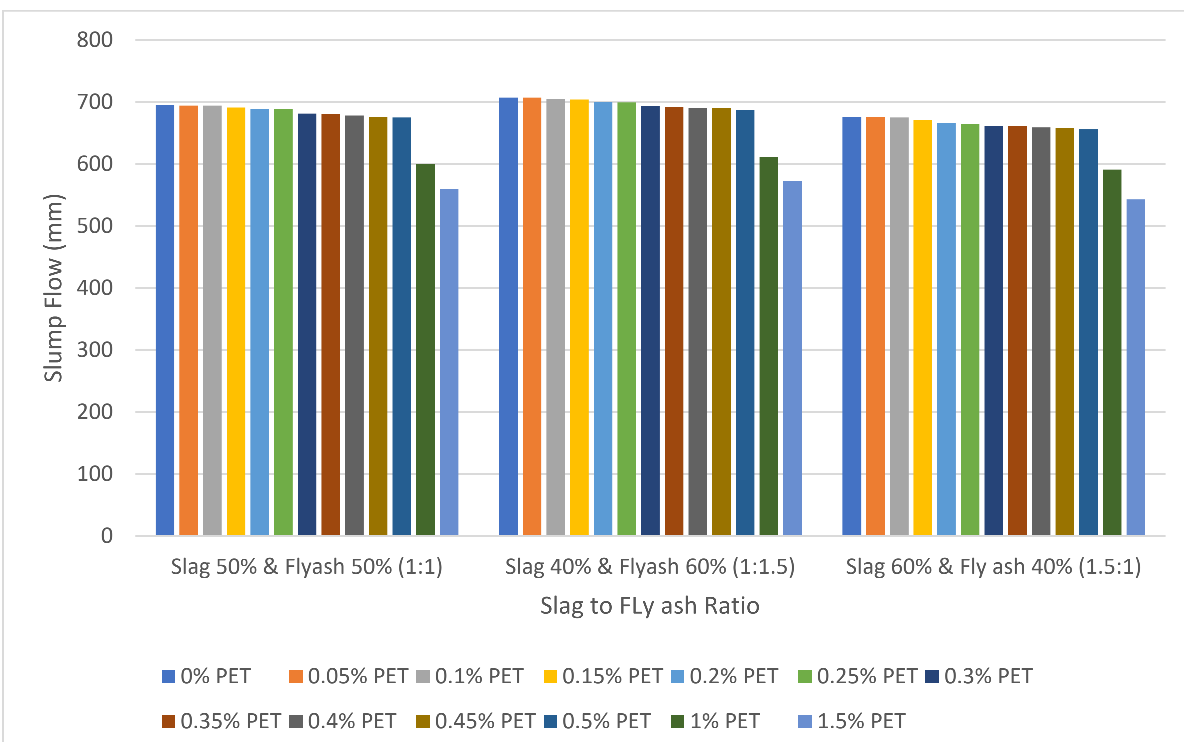


Figure 4.1: Slump Flow test results comparison

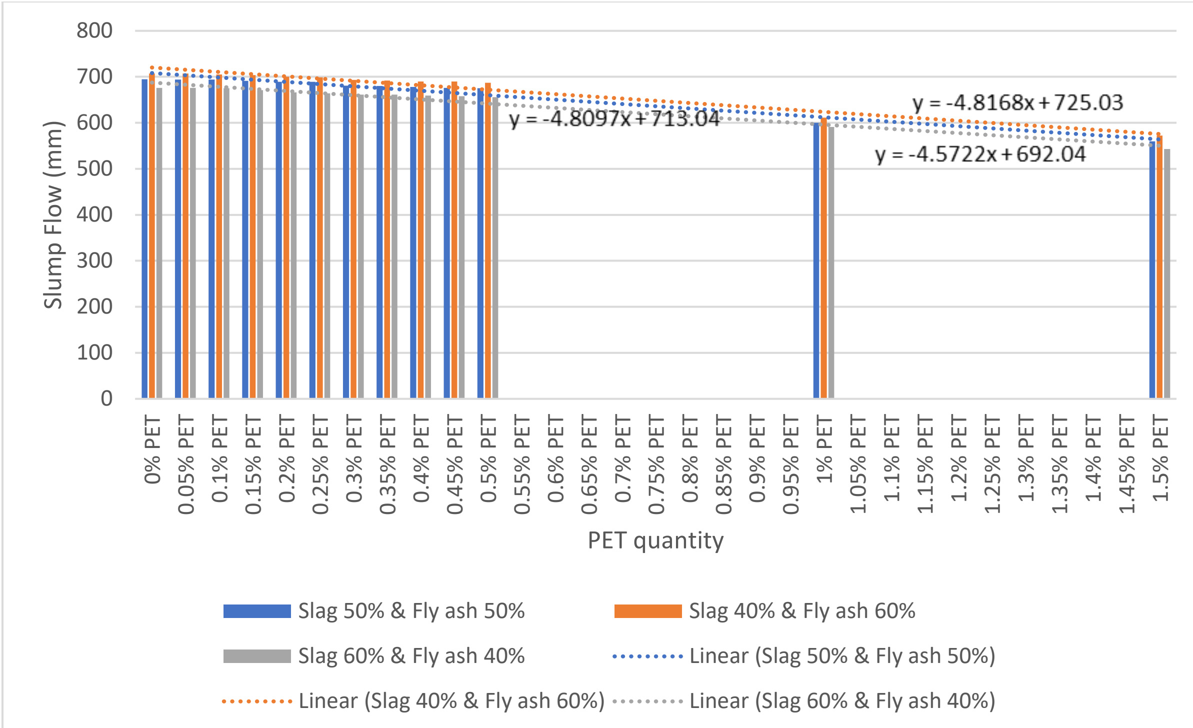


Figure 4.2: Trend line of Slump Flow Test

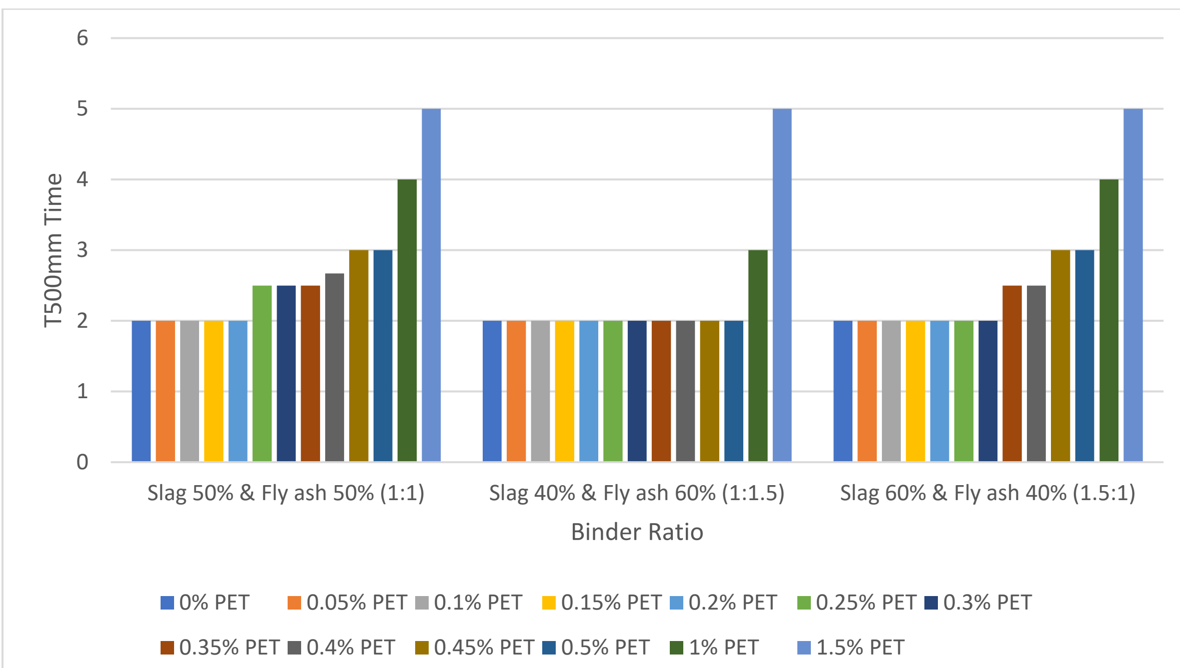


Figure 4.3: T500mm test results comparison

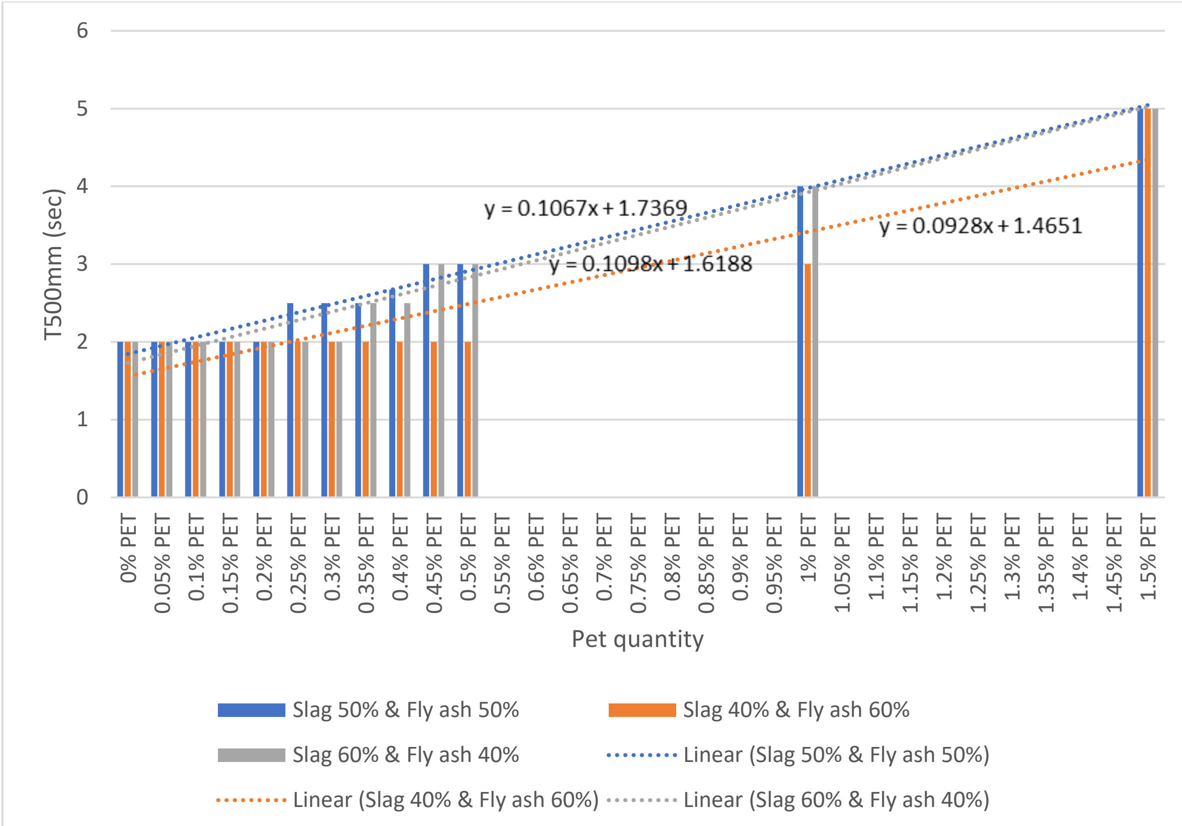


Figure 4.4: Trend line of T500mm Test

### 4.3 V-funnel Test

V-funnel test was performed to check the resistance to segregation of the mixes. Results showed no major change in the results of the three main mixes M1, M2 and M3. Whereas, observed small increase in the discharge time with the increase of slag quantity, which is due to the angular shape of GGBFS as compared to the spherical shape of class F FA (Partha Sarathi Deb, 2014). Moreover, with each increment of PET fibers in the mix the discharge time also increased. Results indicated that till 0.5% of PET fibers addition the mixes were according to the EFNARC requirements (U.Balamurugan, 2017; Abdulkader Ismail Al-Hadithi A. T., 2019). Whereas, at 1 and 1.5 percent addition the time taken for full discharge didn't satisfy EFNARC requirements. Table 4.2 and Fig. 4.5 shows the results of V-funnel test. Trend line is shown in the Fig. 4.6 which gives an approximation of the results for PET fibers percentages that are not included in this research.

Table 4.2: V-Funnel Test Results

| Mix (M) | Time for full discharge of V-funnel (sec) | According to the EFNARC(Y/N) |
|---|---|---|
| M1 | 6.25 | Y |
| M2 | 6 | Y |
| M3 | 6.37 | Y |
| M4 | 6.3 | Y |
| M5 | 6.3 | Y |
| M6 | 6.31 | Y |
| M7 | 6.31 | Y |
| M8 | 6.5 | Y |
| M9 | 7 | Y |
| M10 | 8 | Y |
| M11 | 9 | Y |
| M12 | 9.25 | Y |
| M13 | 10 | Y |
| M14 | 14 | N |
| M15 | 17 | N |
| M16 | 6 | Y |
| M17 | 6 | Y |
| M18 | 6.25 | Y |
| M19 | 6.25 | Y |
| M20 | 6.3 | Y |
| M21 | 6.75 | Y |
| M22 | 7 | Y |
| M23 | 7.5 | Y |
| M24 | 8.5 | Y |
| M25 | 9.67 | Y |
| M26 | 14 | N |
| M27 | 16 | N |
| M28 | 6.4 | Y |
| M29 | 6.45 | Y |
| M30 | 6.45 | Y |
| M31 | 6.94 | Y |
| M32 | 7.2 | Y |
| M33 | 7.25 | Y |
| M34 | 9 | Y |
| M35 | 10 | Y |
| M36 | 10.5 | Y |
| M37 | 11.75 | Y |
| M38 | 15 | N |
| M39 | 17 | N |

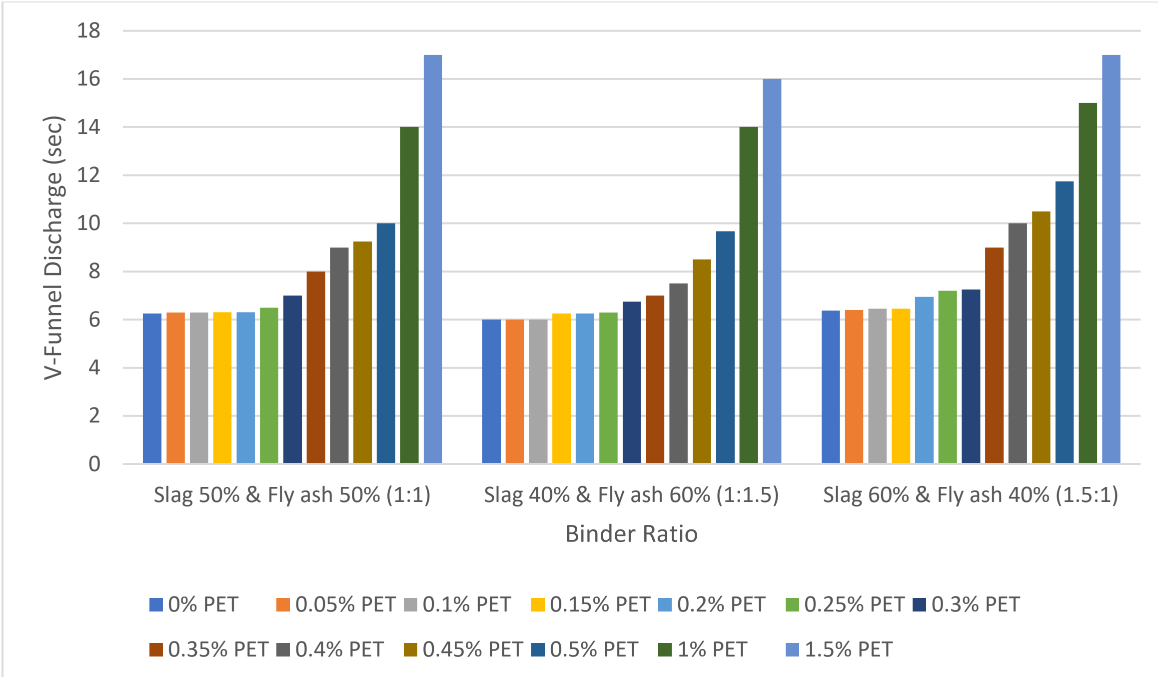


Figure 4.5: V-Funnel Test results comparison

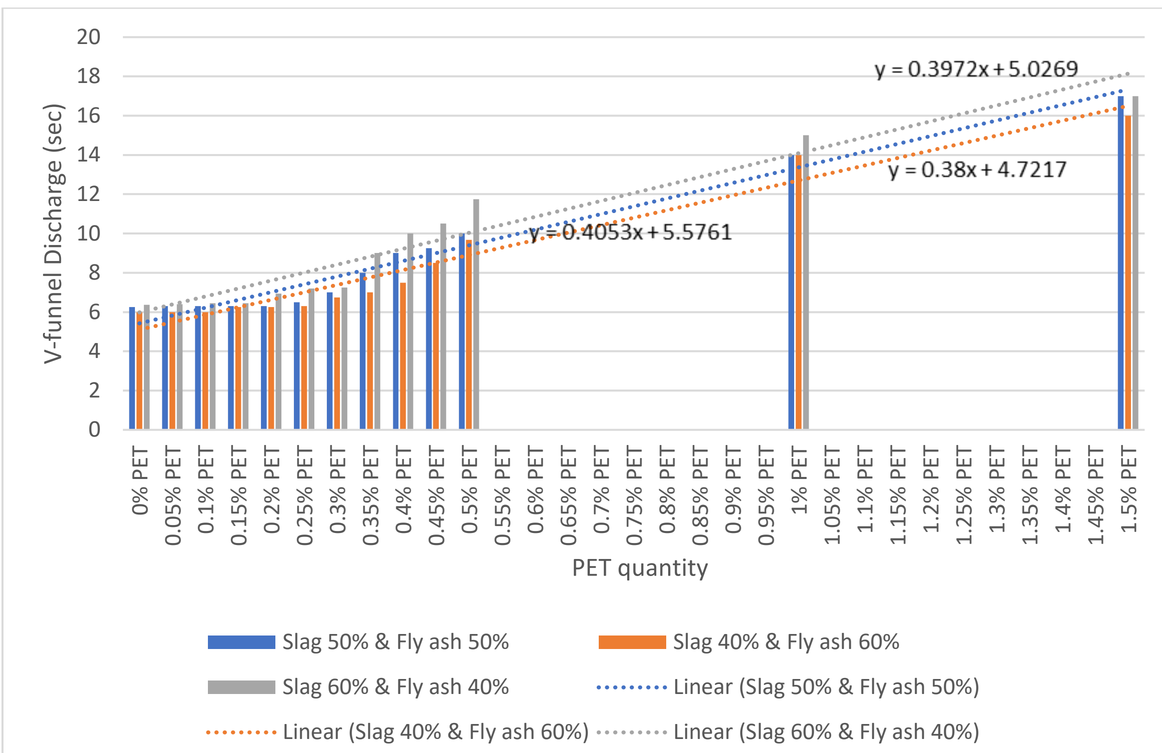


Figure 4.6: Trend line of V-funnel Test

### 4.4 L-Box Test

L-box test was performed to check the passing ability of the mixes. Observed no major change in the results of the three main mixes M1, M2 and M3. Moreover, with each increment of PET fibers in the mix the blocking ratio also decreased (U.Balamurugan, 2017; Abdulkader Ismail Al-Hadithi A. T., 2019). Results indicated that till 0.5% of PET fibers addition the mixes were according to the EFNARC requirements (U.Balamurugan, 2017; Abdulkader Ismail Al-Hadithi A. T., 2019). Whereas, at 1 and 1.5 percent addition the passing ability didn't satisfy EFNARC requirements. Table 4.3 and Fig. 4.7 shows the results of l-box test. Trend line is also shown in the Fig. 4.8 which gives an approximation of the results for fibers quantities that are not included in this research.

Table 4.3: L-box Test Results

| **Mix (M)** | **Vertical Portion concrete depth (H1) (mm)** | **Horizontal portion concrete depth (H2) (mm)** | **Blocking ratio (H2/H1)** | **According to the EFNARC(Y/N)** |
|---|---|---|---|---|
| M1 | 87 | 82 | 0.94 | Y |
| M2 | 87 | 82 | 0.94 | Y |
| M3 | 87 | 82 | 0.94 | Y |
| M4 | 87 | 82 | 0.94 | Y |
| M5 | 89 | 82 | 0.92 | Y |
| M6 | 89 | 82 | 0.92 | Y |
| M7 | 91 | 82 | 0.9 | Y |
| M8 | 91 | 81 | 0.89 | Y |
| M9 | 93 | 80 | 0.86 | Y |
| M10 | 94 | 77 | 0.82 | Y |
| M11 | 95 | 77 | 0.81 | Y |
| M12 | 95.5 | 77 | 0.8 | Y |
| M13 | 95 | 76 | 0.8 | Y |
| M14 | 127 | 52 | 0.4 | N |
| M15 | 127 | 25 | 0.19 | N |
| M16 | 88 | 81 | 0.92 | Y |
| M17 | 89 | 81 | 0.91 | Y |
| M18 | 89 | 80 | 0.89 | Y |
| M19 | 89 | 79 | 0.88 | Y |
| M20 | 93 | 80 | 0.86 | Y |
| M21 | 91 | 77 | 0.84 | Y |
| M22 | 93 | 78 | 0.83 | Y |
| M23 | 94 | 77 | 0.82 | Y |
| M24 | 94 | 77 | 0.82 | Y |

| Mix (M) | Vertical Portion concrete depth (H1) (mm) | Horizontal portion concrete depth (H2) (mm) | Blocking ratio (H2/H1) | According to the EFNARC(Y/N) |
|---|---|---|---|---|
| M25 | 95 | 77 | 0.81 | Y |
| M26 | 135 | 60 | 0.44 | N |
| M27 | 130 | 20 | 0.15 | N |
| M28 | 88 | 80 | 0.9 | Y |
| M29 | 90 | 81 | 0.9 | Y |
| M30 | 90 | 80 | 0.88 | Y |
| M31 | 92 | 81 | 0.88 | Y |
| M32 | 93 | 77 | 0.82 | Y |
| M33 | 93 | 76 | 0.81 | Y |
| M34 | 94 | 76 | 0.8 | Y |
| M35 | 94 | 76 | 0.8 | Y |
| M36 | 92 | 74 | 0.8 | Y |
| M37 | 92 | 73 | 0.79 (Approx 0.8) | Y |
| M38 | 140 | 40 | 0.3 | N |
| M39 | 130 | 30 | 0.23 | N |

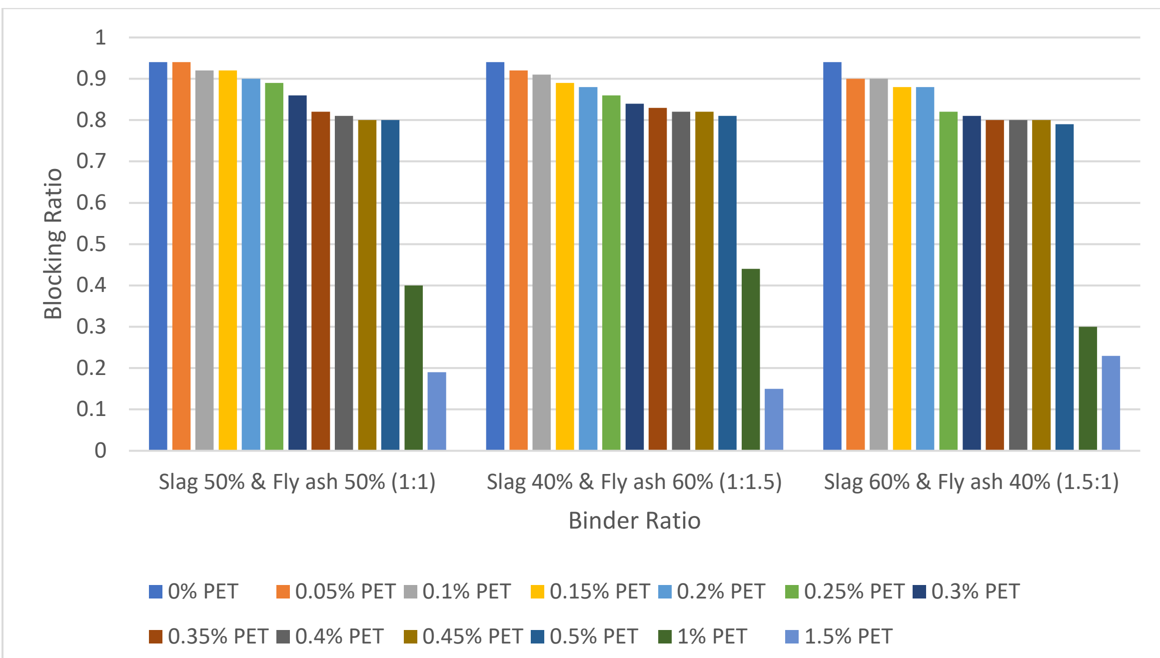


Figure 4.7: L-box Test results comparison

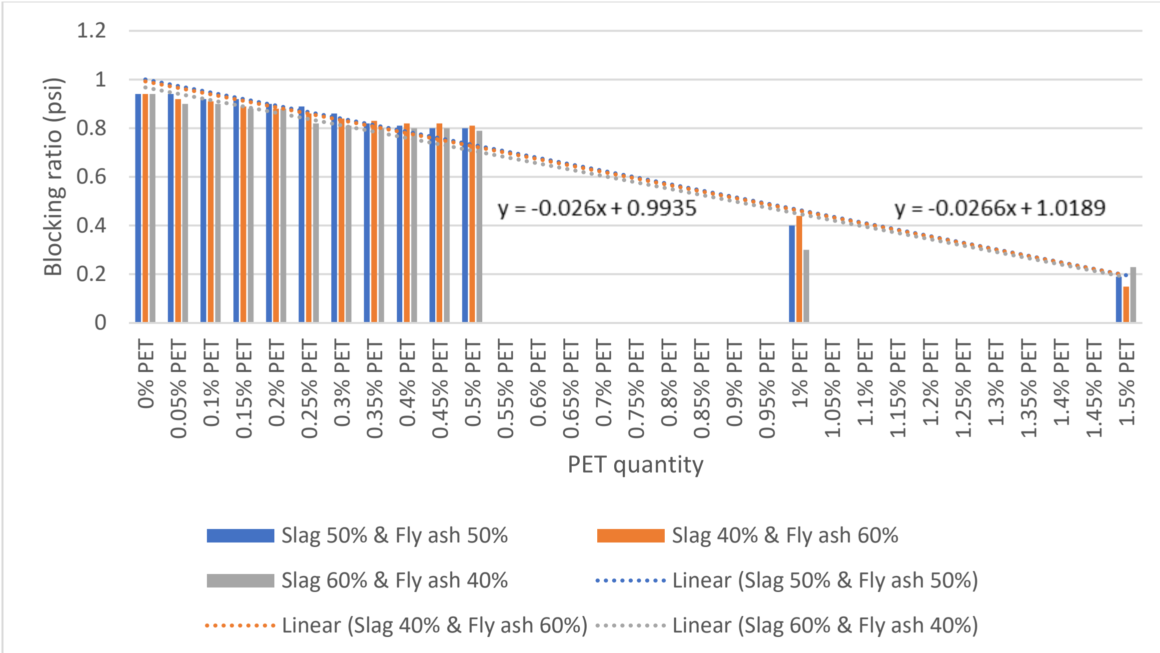


Figure 4.8: Trend line of L-box test

### 4.5 Compressive Strength Test

Determined compressive strength by casting cylinders (6” diameter and 12” height) and testing them on UTM. Table 4.4 and Fig. 4.9 shows the compressive strength of mix proportions.

The results indicated that the compressive strength increased with the increase of the slag quantity in the binder (Partha Sarathi Deb, 2014). Moreover, in samples having 0% PET, observed 12% increase when the slag quantity increased from 40% to 50%, also achieved 23% more strength when the slag quantity increased from 50% to 60%. Thus, from the results it was obvious that at ambient conditions the strength increased with the increment of Slag quantity (Partha Sarathi Deb, 2014).

Samples when reinforced with PET the results were approximately same till 0.15% PET quantity. Whereas, with each increment of PET percentage the strength also increased till 1% reinforcement (U.Balamurugan, 2017; Abdulkader Ismail Al-Hadithi A. T., 2019), approximately 13% more than the normal samples. At 1.5% inclusion of PET the strength started to diminish. Moreover, trend line is also shown in the Fig. 4.10 gives approximate results for PET quantities that are not included in this research.

Table 4.4: Compressive strength of SCGC samples

| Specimen | Compressive Strength (Psi) | | | | |
|---|---|---|---|---|---|
| | S1 | S2 | S3 | MEAN | Standard Deviation of the Samples |
| M1 | 440 | 455 | 431 | 442 | 12.12 |
| M2 | 389 | 395 | 410 | 389 | 10.82 |
| M3 | 564 | 581 | 580 | 575 | 9.54 |
| M4 | 450 | 438 | 432 | 440 | 9.17 |
| M5 | 455 | 459 | 421 | 445 | 20.88 |
| M6 | 430 | 480 | 440 | 450 | 26.46 |
| M7 | 497 | 478 | 510 | 495 | 16.09 |
| M8 | 486 | 499 | 515 | 500 | 14.53 |
| M9 | 492 | 500 | 514 | 502 | 11.14 |
| M10 | 530 | 501 | 499 | 510 | 17.35 |
| M11 | 529 | 511 | 505 | 515 | 12.49 |
| M12 | 515 | 504 | 535 | 518 | 15.72 |
| M13 | 514 | 536 | 510 | 520 | 14.00 |
| M14 | 527 | 533 | 560 | 540 | 17.58 |
| M15 | 462 | 468 | 480 | 470 | 9.17 |
| M16 | 387 | 400 | 395 | 394 | 6.56 |
| M17 | 398 | 385 | 402 | 395 | 8.89 |
| M18 | 389 | 395 | 410 | 398 | 10.82 |
| M19 | 409 | 416 | 420 | 415 | 5.57 |
| M20 | 420 | 419 | 427 | 422 | 4.36 |
| M21 | 410 | 426 | 430 | 422 | 10.58 |
| M22 | 440 | 420 | 409 | 423 | 15.72 |
| M23 | 440 | 425 | 437 | 434 | 7.94 |
| M24 | 450 | 418 | 440 | 436 | 16.37 |
| M25 | 424 | 439 | 460 | 441 | 18.08 |
| M26 | 460 | 455 | 465 | 460 | 5.00 |
| M27 | 416 | 399 | 400 | 405 | 9.54 |
| M28 | 579 | 570 | 585 | 578 | 7.55 |
| M29 | 576 | 580 | 584 | 580 | 4.00 |
| M30 | 595 | 610 | 595 | 600 | 8.66 |
| M31 | 612 | 601 | 611 | 608 | 6.08 |
| M32 | 598 | 607 | 625 | 610 | 13.75 |
| M33 | 606 | 610 | 629 | 615 | 12.29 |
| M34 | 624 | 615 | 627 | 622 | 6.24 |
| M35 | 634 | 631 | 637 | 634 | 3.00 |
| M36 | 634 | 630 | 650 | 638 | 10.58 |
| M37 | 648 | 647 | 655 | 650 | 4.36 |
| M38 | 702 | 695 | 700 | 699 | 3.61 |
| M39 | 572 | 611 | 620 | 601 | 25.51 |

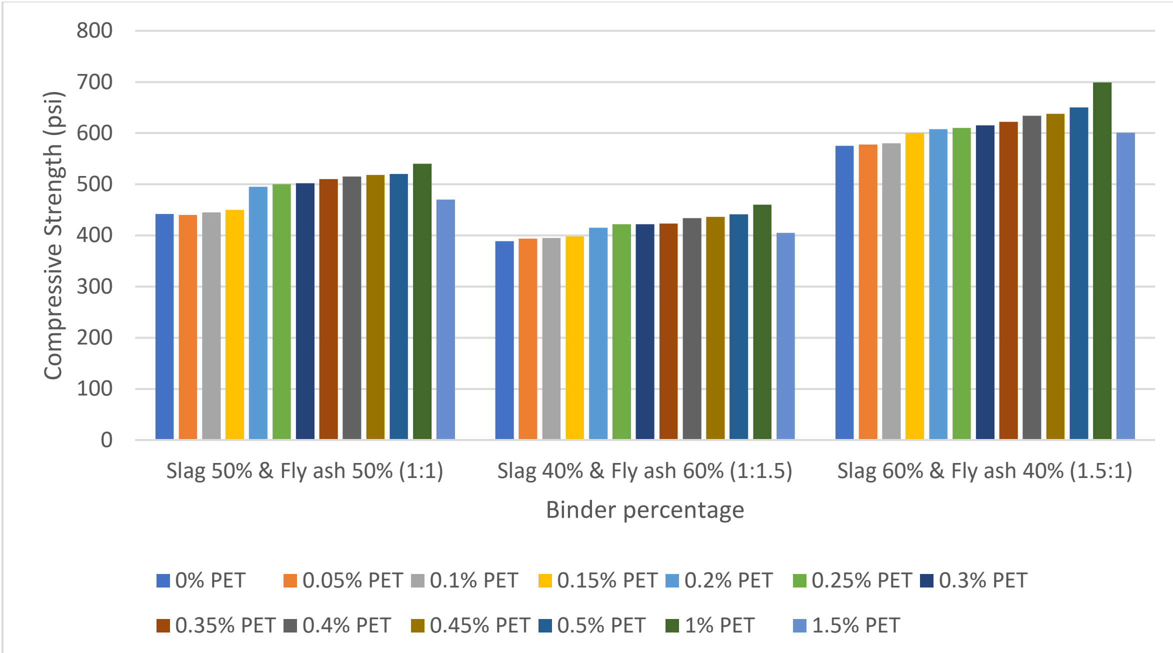


Figure 4.9: Comparison of compressive strength of SCGC Samples

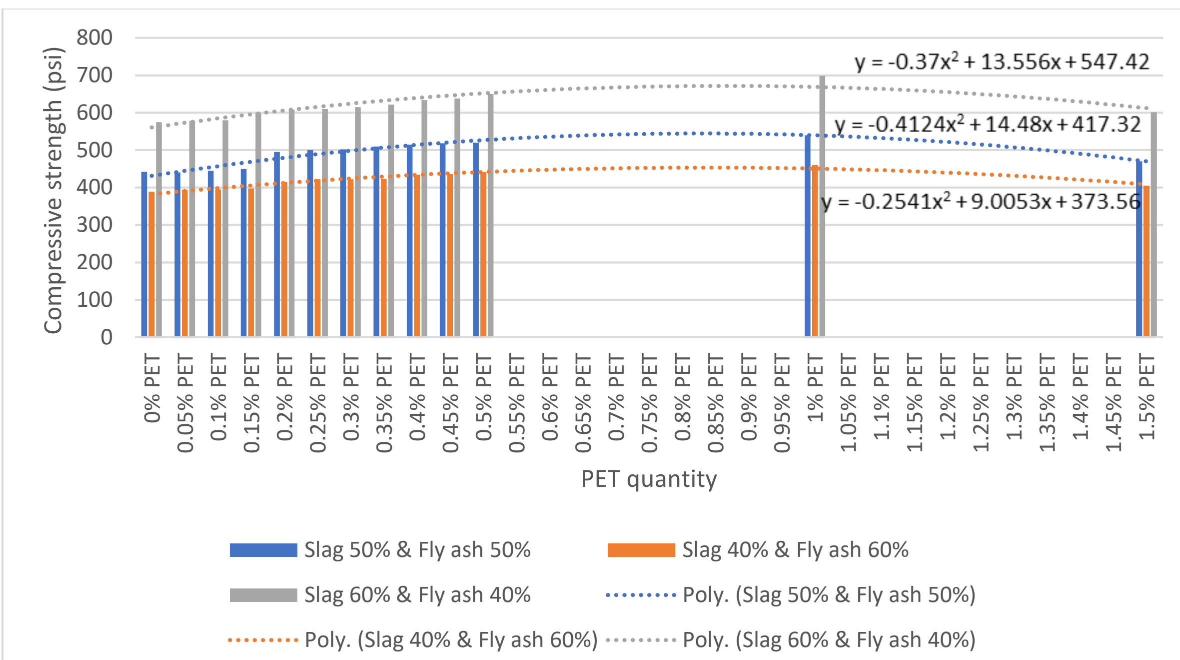


Figure 4.10: Trend line of compressive strength of SCGC samples

### 4.6 Flexural Strength Test

Determined flexural strength of the samples by casting beams (6”x6”x18”) and testing them on UTM. Table 4.5 and Fig. 4.11 shows the flexural strength of all proportions.

The results indicated that the flexural strength increased with the increase of the slag quantity in the binder (Partha Sarathi Deb, 2014). Moreover, in samples having 0% PET, observed 37% increase when the slag quantity increased from 40% to 50%, also achieved 9% more strength when the slag quantity increased from 50% to 60%. Thus, from the results it was obvious that at ambient conditions the strength increased with the increment of Slag quantity (Partha Sarathi Deb, 2014).

Samples when reinforced with PET the results were approximately same till 0.15% PET quantity. Whereas, with each increment of PET percentage the strength also increased till 1% reinforcement (U.Balamurugan, 2017; Abdulkader Ismail Al-Hadithi A. T., 2019), approximately 42% more than the normal samples. While, at 1.5% inclusion of PET the strength started to diminish. Moreover, trend line is also shown in the Fig. 4.12 which shows that the PET inclusion more than 1% reduces the flexural strength.

Table 4.5: Flexural Strength of SCGC

| **Specimen** | **Flexural strength (Psi)** | | | | |
|---|---|---|---|---|---|
| | **S1** | **S2** | **S3** | **MEAN** | **Standard Deviation of the Samples** |
| M1 | 71 | 95 | 80 | 82 | 12.12 |
| M2 | 47 | 50 | 59 | 52 | 6.24 |
| M3 | 93 | 79 | 98 | 90 | 9.85 |
| M4 | 68 | 79 | 93 | 80 | 12.53 |
| M5 | 78 | 81 | 93 | 84 | 7.94 |
| M6 | 106 | 88 | 97 | 97 | 9.00 |
| M7 | 98 | 101 | 115 | 105 | 9.07 |
| M8 | 95 | 100 | 120 | 105 | 13.23 |
| M9 | 105 | 105 | 120 | 110 | 8.66 |
| M10 | 138 | 118 | 110 | 122 | 14.42 |
| M11 | 145 | 116 | 111 | 124 | 18.36 |
| M12 | 120 | 111 | 141 | 124 | 15.39 |
| M13 | 120 | 125 | 130 | 125 | 5.00 |
| M14 | 116 | 135 | 160 | 137 | 22.07 |
| M15 | 102 | 89 | 94 | 95 | 6.56 |
| M16 | 48 | 59 | 61 | 56 | 7.00 |
| M17 | 60 | 52 | 65 | 59 | 6.56 |
| M18 | 69 | 61 | 74 | 68 | 6.56 |
| M19 | 68 | 66 | 76 | 70 | 5.29 |

| Specimen | Flexural strength (Psi) | | | | |
|---|---|---|---|---|---|
| | S1 | S2 | S3 | MEAN | Standard Deviation of the Samples |
| M20 | 65 | 71 | 80 | 72 | 7.55 |
| M21 | 78 | 77 | 73 | 76 | 2.65 |
| M22 | 80 | 75 | 82 | 79 | 3.61 |
| M23 | 80 | 69 | 85 | 78 | 8.19 |
| M24 | 75 | 77 | 85 | 79 | 5.29 |
| M25 | 77 | 80 | 86 | 81 | 4.58 |
| M26 | 88 | 90 | 101 | 93 | 7.00 |
| M27 | 65 | 66 | 70 | 67 | 2.65 |
| M28 | 100 | 90 | 95 | 95 | 5.00 |
| M29 | 102 | 94 | 98 | 98 | 4.00 |
| M30 | 124 | 101 | 105 | 110 | 12.29 |
| M31 | 120 | 110 | 115 | 115 | 5.00 |
| M32 | 120 | 116 | 121 | 119 | 2.65 |
| M33 | 114 | 123 | 135 | 124 | 10.54 |
| M34 | 137 | 119 | 138 | 128 | 10.69 |
| M35 | 121 | 126 | 140 | 129 | 9.85 |
| M36 | 127 | 129 | 134 | 130 | 3.61 |
| M37 | 125 | 140 | 128 | 131 | 7.94 |
| M38 | 141 | 151 | 170 | 154 | 14.73 |
| M39 | 103 | 118 | 109 | 110 | 7.55 |

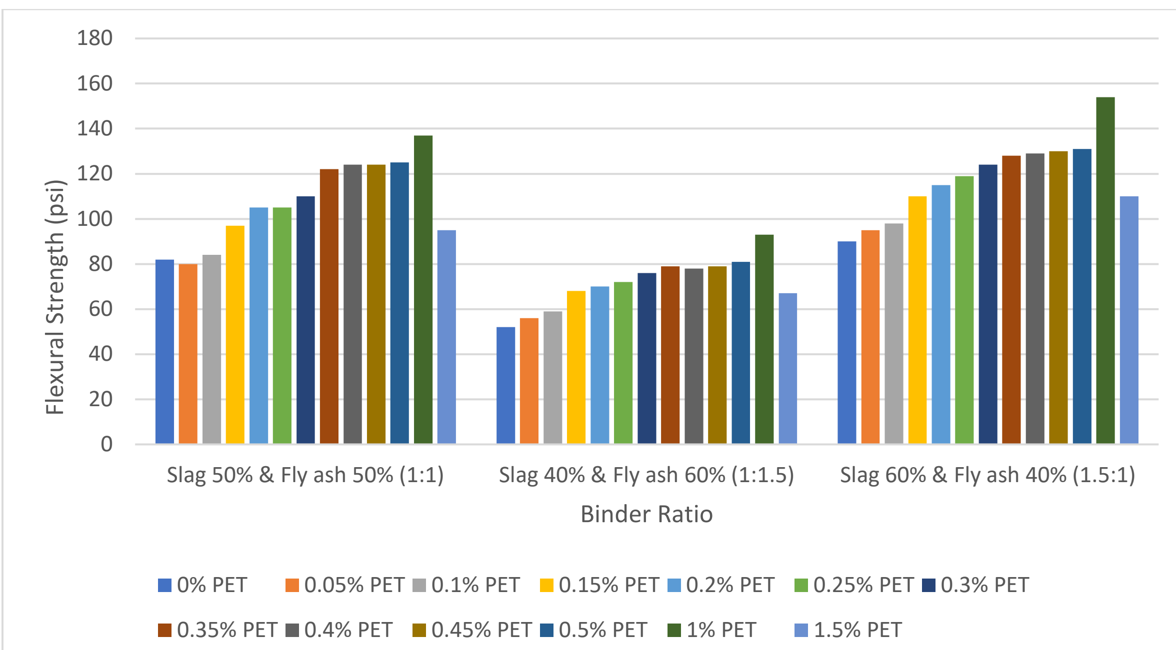


Figure 4.11: Comparison of Flexural Strength Test of SCGC Samples

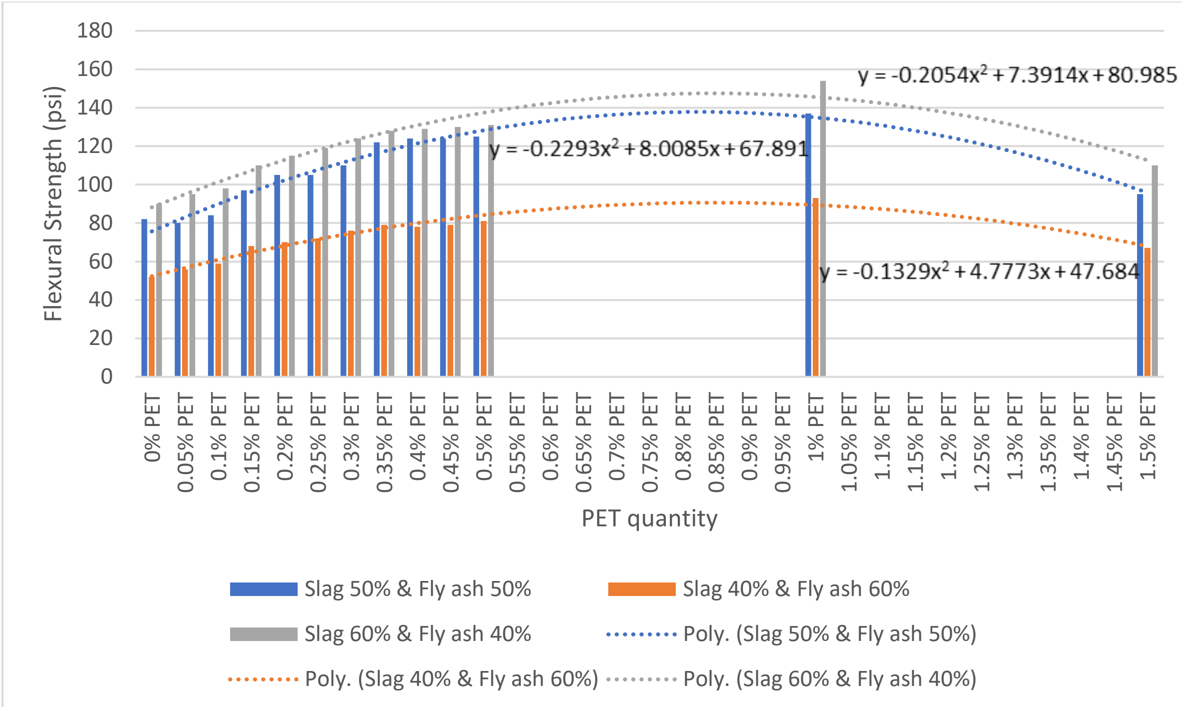


Figure 4.12: Trend line of Flexural Strength Test of SCGC Sample

# CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Overview

The current study was designed to evaluate the properties of SCGC concrete at ambient conditions, which was also reinforced with PET fibers. To achieve this series of laboratory test were carried out. This chapter presents the detailed discussion of the observed findings and the conclusions drawn from the study. Also provided the recommendation for future work.

## 5.2 Conclusions

This study was carried out to know about the fresh and hardened properties of SCGC with PET fibers. From the results obtained through experimental phase, it is apparent that;

- GGBFS in the binder effects fresh properties negatively.
- Addition of PET fibers increase the hardened properties till 1% by total volume of the mixture. Whereas after 1% addition the strength starts to diminish.
- Fresh properties of SCGC reinforced with PET fiber till 0.5% were according to the EFNARC requirements but at 1% and 1.5% addition the fresh properties requirements were not satisfied.
- The key findings of this research were that the PET fibers inclusion in SCGC had a positive effect on hardened properties but also showed negative effect on fresh properties, thus this finding is significant for further research in this area.

## 5.3 Recommendation

This research was conducted to know about the properties of the SCGC concrete at ambient condition. It is advised that further research can be carried out by;

- Oven drying, which could increase the strength.
- Reinforcing the samples with smaller width of PET fibers.
- Using alkali activator that is economical.

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