CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

# Properties and Life Cycle Assessment of Conventional Concrete Having Silica Fume, Steel Fibers and Recycled PET Bottle Particles

by

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***This thesis is dedicated to:***

*My Parents and Teachers*

*And everyone who supported me in this journey, Who have been always a symbol of Affection, Happiness, and Bliss.*

# CERTIFICATE OF APPROVAL

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All praises are for almighty ALLAH who bestowed me with the potential to contribute a drop of water to the existing ocean of knowledge. All praises be for Holy prophet Hazrat Muhammad (P.B.U.H) who is forever a model of guidance for humanity as a whole.

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# *Abstract*

After the historical assessment, numerous defects have been found in concrete, including micro-cracks, surface erosion, blisters, spalling, crazing, scaling, and mortar peel-off. Among all these defects, early-age micro-cracks are the major defect that conclusively lowers the durability and serviceability of concrete. The rate of cracking in concrete can be reduced by enhancing its tensile, compressive, and flexural strengths. These improved mechanical properties will help to reduce the flaws in concrete. The use of fibers either natural or artificial in concrete increases its mechanical properties. The use of waste polyethylene terephthalate (PET) particles as a replacement for sand, the use of steel fiber along with silica fume and polycarboxylate has gained considerable attention due to its low density, more ductility, lightweight and less harmful for the environment when compared with conventional concrete. The overall aim of this research is to provide sustainable, economical and eco-friendly solution to reduce cracks that on later stages appear in form of large cracks. Many types of fibers (e.g. jute fibers and artificial fibers) have already been investigated by many researchers but PET bottle particles and steel fibers together in concrete mix need to be explored.

So, the need of hour is to explore the behavior of newly formed concrete to enhance the concretes mechanical dynamic and other properties by the use of waste PET bottle particles and steel fibers to control the flaws in concrete by keeping the environment unharmful. Batches of concrete mixes are prepared with varying content of PET bottle particles (i.e. 5% , 10% , 15%) and fixed content of steel fiber (i.e. 2 %) and silica fume(2 %) by partial replacement of cement and Polycarboxylate superplasticizer is added by 1 % of the volume of concrete with the mix design ratio of 1:1.3:2.3 and w/c of 0.49 is used for casting the specimens (i.e. S1, S2, and S3. The same mix design is used for the preparation of plain concrete (PC) as reference concrete. Life cycle assessment (LCA) and microscopic study is also performed to analyze the behavior of PET particles and steel fibers in concrete.

The result indicates that there is an increase in the compressive strength, flexural strength and splitting tensile of concrete when compared with plain concrete (PC). The increase in dynamic properties is also observed in case of S1, S2, and S3 when compared with plain concrete (PC). Empirical relation is developed between linear shrinkage and PET particles ratio in new formed concrete using experimental data of linear shrinkage and PET particles content ratio in concrete. The relation between L/S and fibers content ratio and each of the compressive strength, splitting tensile strength, splitting pre-crack energy, and flexural pre-crack energy are found because of their observed mutual coherence in experimental outcomes. Life cycle assessment (LCA) showed the $CO_2$ reduction in concrete and S3 showed 58% reduction in $CO_2$ emission. A reasonable relation between experimental and empirical values is observed. S1 showed the best results among all other specimens. By the use of this newly formed concrete, it will help to reduce the rate of cracking and $CO_2$ emission and thus improves the performance. The durability of the new specimens needs to be explored as the construction industry is lacking to form the environment-friendly and cost-friendly concrete.

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# Abbreviations and Symbols

| | |
|---|---|
| **A** | Aggregate |
| **C** | Cement |
| **CS** | Compressive strength |
| **CTI** | Compressive toughness index |
| **CCE** | Compressive energy absorption from peak load to final load |
| **CPE** | Compressive energy-absorption upto maximum load |
| **CTE** | Compressive total energy absorption |
| **FS** | Flexural strength |
| **FCE** | Flexural energy absorption from peak load to final load |
| **FPE** | Flexural energy absorption up to a peak load |
| **FTE** | Flexural total energy absorption |
| **FTI** | Flexural toughness index |
| **Hz** | Hertz |
| **kg** | kilogram |
| **KN** | kilonewton |
| **L/S** | Linear shrinkage |
| **ML** | Mass loss |
| $m^3$ | Cubic meter |
| **mm** | millimetre |
| **MPa** | Mega Pascal |
| $P_{max}$ | Maximum load |
| **PC** | Plain concrete |
| **S** | Sand |
| **STS** | Splitting tensile strength |

| | |
|---|---|
| **s** | Second |
| **SF** | Steel Fiber |
| **SEM** | Scanning electron microscope |
| **SPE** | Split energy absorption up to a peak load |
| **STE** | Split total energy absorption |
| **STI** | Split toughness index |
| **SFC** | Steel fiber concrete |
| **SFRP** | Steel fiber reinforced concrete |
| **TE** | Total energy absorbed |
| **TTI** | Total Toughness Index |
| **W/A** | Water absorption |
| **w/c** | water cement ratio |
| $\xi$ | Damping Ratio |
| $\Delta$ | Delta |
| $\delta$ | Stress |

# Chapter 1

# Introduction

## 1.1 Background

Plain concrete (PC) is brittle in nature. Due to its brittle behavior, shrinkage crack appears (Panzera et al. 2013). Flaws in concrete like early age crack appearance, loss of density, spalling, loss of concrete cover, segregation and efflorescence occurs which causes the low performance of the concrete (Ahmad et al. 2021). The major and most important flaw in concrete is early age micro cracks, which reduces the durability and serviceability of the concrete stated by Fu et al. (2016), Khan and Ali (2016), Mazzoli et al. (2015), Wright et al. (2014), Qiao et al. (2010), Darwin et al. (2004). Preventing from the early age micro cracks reduces the other flaws in concrete as well. There are certain factors which results in early age micro cracks i.e. early water loss in fresh state, sudden rise of temperature, chemical reaction or any other factor results in change in volume of the concrete (Sivakumar and Santhanam 2006 and Mazzoli et al. 2015).

The early age micro cracks allow the structure to get destroyed by disastrous events. These cracks can be controlled by improving the concretes mechanical properties. This can be done by improving the compressive strength, flexural strength and tensile strength of the concrete as stated by Khan and Ali (2016) and Qiao et al. (2010). The major causes of crack appearance are the design of structure, material properties and construction practices. It was observed that more cementitious concrete produce more cracks. To achieve more compressive strength by increasing more cement content results in early age crack appearance stated by Saadeghvaziri and Hadidi (2005). The water-cement ratio is well recognized to influence concrete strength However, even for a given w/c, concrete strength can vary greatly depending on the constituent materials utilized.

The low cement content is concrete results less resistance to micro cracks appearance (Qiao et al. 2010). Steel fiber and PET particles along with pozzolanic material and admixture can be utilized to mitigate crack shrinkage and other flaws, and also to reduce the $CO_2$ content emission from mixture which pollutes the environment. It was observed that by adding PET particles up to 5 % by sand replacement, compressive strength is increased, however, by adding more up to 10 % and 15 %, compressive strength was reduced as the PET particle content is increased, but STS was declined by increasing PET particles content. The addition of fiber reinforcement to high-strength concrete can improve its compressive strength by resisting crack propagation and increasing resistance to various stresses, such as fatigue, shrinkage, impact, and thermal stresses. The mechanical properties of fiber-reinforced concrete depend on factors such as the characteristics of the concrete matrix, fiber efficiency, and fiber content. However, increasing the compressive strength of concrete can also make it more brittle, reducing its ability to withstand strain. Therefore, the use of natural or artificial fiber reinforcement in construction can help improve the strength and endurance of concrete. The use of PET bottle waste in concrete production can be seen as an environmentally friendly approach due to the negative impact of PET waste on the environment and the increasing demand for natural resources in construction. However, some previous studies have shown that incorporating PET bottle particles in concrete can lead to reduced mechanical properties. To address this, researchers have found that using optimal amounts of PET particles in combination with fibers, plasticizers, and superplasticizers can improve the mechanical properties and impact resistance of concrete. This approach can lead to concrete with better mechanical properties and impact resistance compared to conventional concrete, without a significant reduction in these properties.

The mechanical properties of fiber-reinforced concrete depend on factors such as the characteristics of the concrete matrix, fiber efficiency, and fiber content. However, increasing the compressive strength of concrete can also make it more brittle, reducing its ability to withstand strain. Therefore, the use of natural or artificial fiber reinforcement can help improve the strength and endurance of concrete. The use of PET bottle waste in concrete production can be seen as an environmentally friendly approach due to the negative impact of PET waste on the environment and the increasing demand for natural resources in construction

## 1.2 Research Motivation and Problem Statement

Concrete is widely used material for construction purposes and its demand is increasing day by day. But concrete has certain disadvantages like rigid, fractures, chipping, and peeling, etc. The steel fibers have the ability to overcome these flaws. At the same time, environmental pollution is also a big challenge now a days due to the excess use of plastic. As the plastic waste disposal requires land for dumping and oxygen ($O_2$) for burning process which pollutes the environment. So, the combine use of plastic waste and steel fibers might solve both the issues ( i.e. concrete weakness and environmental pollution). The steel fibers improves the characteristics of concrete while the environment pollution due to the PET particles also need to be solved. The newly formed concrete's effects on environment also need to be studied. It is likely that the use of waste PET bottle particles and steel fibers are also good to consider to get the overall benifit in terms of a better composite material. So, the problem statement would be addressed as:

*Concrete owns certain flaws like weak in tension, brittleness, progression of cracks, drying shrinkage cracks, and spalling, which can be countered by many things. The use of steel fibers can be used, but these are expensive as well. There is a need to use an alternate solution. In parallel, the use of plastic is increasing and its waste is a problem for the environment as it emits $CO_2$ and requires land for dumping. At the same time, the use of steel fibers and PET bottle particles in the concrete reduces the strength, so the strength can be retained by the use of admixtures. The new concrete must be environment friendly as compared to conventional concrete to save the environment. The effect of concrete in the emission of $CO_2$ must be explored,Thus, the behavior, so that concrete can be environment friendly. Thus, the behavior and LCA (cradle to the gate using $CO_2$ emission) of concrete with the combined use of silica fume, steel fibers, PET bottle particles, and polycarboxylate still needs to be explored.*

### 1.2.1 Research Questions

Followings are research questions which are explored in this study:

- What is combined effect of PET particles, steel fibers and admixtures on the mechanical, dynamic, and w/a properties of conventional concrete?
- Can SF get proper bond with concrete having PET particles and admixture? Are PET particles get properly mixed in concrete (are there voids) ?
- How much $CO_2$ emission can be reduced with combined use of SF's, PET particles and admixtures when compared to conventional concrete?
- How LS and STE are correlated ?
- How much thickness of rigid pavement can be reduced with the optimized mix having SF's, PET particles and admixtures ?

## 1.3 Overall Goal of the Research Program and Specific Aim of this MS Thesis

To investigate the impact of utilizing waste PET particles and steel fiber along with admixtures that are locally available and their behavior in concrete is the goal of this researchs program. The primary objective of this research program is to develop a sustainable concrete through LCA that is suitable for a range of construction and civil engineering applications. The program also seeks to establish an avenue for the effective utilization of PET waste material.

*The research program's specific goal is to determine the mechanical characteristics, dynamic characteristics, loss in mass, linear shrinkage, and absorption of water properties of concrete having steel fibers and recycled PET bottle particles.* *The research program's specific goal is to determine the mechanical characteristics, dynamic characteristics, loss in mass, linear shrinkage, and absorption of water properties of concrete having steel fibers and recycled PET bottle particles.*

## 1.4 Scope of Work and Study Limitations

Fibers of constant length but variation in PET particles content ratios and admixtures were incorporated in the preparation of plain cocnrete.The average of the two readings are taken to explore the mechanical characteristics, dynamic characteristics, loss in mass, linear shrinkage, and absorption of water characteristics of several types of concrete mixes. The mechanical qualities were examined initially, and failure was indicated when the earliest fracture emerged on the specimen after the load applied. Furthermore, LCA is performed by considering cradle to gate to study the newly formed concrete's characteristics on environment, scanning electron microscopy (SEM) was used to study the fiber-matrix connection and build an empirical relationship.

The characteristics in mechanical, dynamic characteristics, loss in mass, shrinkage in linear, and absorption of water characteristics of washed waste PET particles and steel fibers containing concrete are the only focus of this research. The LCA is performed by considering cradle to gate. The work is confined to experimental examination and durability aspect is not considered due to the shortage of time as it requires constant monitoring over a longer period of time.

### 1.4.1 Rationale behind Variable Selection

Waste PET bottle particles are selected on their local availability and the problem associated with it for dumping and burning which results in polluting the environment. The Steel fibers are selected to improve the mechanical properties with the PET bottle particles by adding some admixture to gain the required strength by utilizing the problems associated with dumping or burning of plastic waste. LCA is performed by considering cradle to gate to study the newly formed concrete's effect on environment. So, by using waste PET bottle particles and steel fibers along with some admixtures have the ability of improving the mechanical characteristics of concrete like strength in compression, splitting strength in tensile and flexural strength. The Steel fibers are selected to improve the mechanical properties with the PET bottle particles by adding some admixture to gain the required strength by utilizing the problems associated with dumping or burning of plastic waste. LCA is performed by considering cradle to gate to study the newly formed concrete's effect on environment.

## 1.5 Novelty of Work, Research Significance and Practical Implementation

As far as the best expertise of the author, there is no such research on the combine use of steel fibers and washed waste PET bottle particles in conventional concrete to study the dynamic and mechanical properties and to produce a sustainable concrete that can be used in different civil engineering applications according to their best usage. So, this study is currently aimed to analyze the mechanical characteristics, dynamic characteristics, linear shrinkage, absorption of water properties, loss in mass, LCA (cradle to gate) and micro study of concrete having waste PET bottle particles and steel fibers.

These materials will help to enhance the conventional concretes characteristics when compared it with plain concrete, and this will help the construction industry to grow further without harming the environment as the plastic waste disposal issue can also be solved. The easy availability of the steel fiber and waste PET bottle particles along with admixtures have the ability to increase the mechanical properties of concrete, makes it a very good feasible option to be used in the construction applications.

This study will help the construction industry to propose a best solution for waste disposal which is polluting the environment. By using these materials, emission of $CO_2$ from the cementous content can also be reduced, as silica fume is partially replaced with the cementous content and the new concrete mix have more characteristics with low cementous content, which can be conventional for the use in construction applications i.e. rigid pavement without damaging the environment. The work is confined to experimental examination with no durability check as the durability check requires constant observation of the casted samples and need to be studied time to time for a longer period.

## 1.6 Brief Methodology

In this experimental research, mechanical properties, water absorption, linear shrinkage, loss in mass and dynamic properties of plain concrete (PC) and steel fibers (SF) along PET particles reinforced concrete (concrete containing PET bottle particles and steel fibers) are determined. The mix design ratio is 1:1.3:2.3: (cement: sand: aggregate) with w/c 0.49. Steel fiber of long 40mm with diameter of 0.8mm is used 2 % by the concrete's volume, the PET particles are 5 %,10 % and 15 % partially replaced with sand and 2 % pozzolanic material (silica fume) is partially replaced by cement and admixture (polycarboxylate) is added 1 % by the volume of concrete. The workability of PC and concrete mixes containing waste PET bottle particles and steel fibers are assessed in their fresh state using the standard slump cone test. Specimens are then cast and left in water for 28 days. Various mechanical and dynamic tests are performed on the cylinders and beam-lets of both PC and concrete mixes containing PET bottle particles and steel fibers. Mechanical testing involves compressive testing, split tensile testing, water absorption testing, linear shrinkage testing, loss in mass testing, and flexural testing. Dynamic testing includes the calculation of resonance frequencies, damping ratio, dynamic modulus of elasticity, dynamic modulus of rigidity, and Poisson's ratio of both PC and concrete mixes containing PET bottle particles and steel fibers. Additionally, LCA( cradle to gate $CO_2$) and SEM testing is performed on the concrete mixes containing PET bottle particles and steel fibers. A servo-hydraulic testing machine is used for mechanical testing, while a resonance frequency apparatus is used for the calculation of dynamic properties.

## 1.7 Thesis Outline

There are six chapters in this thesis, which are listed below:

CHAPTER 1: Introduction
This chapter sets the scene for the research, explaining the background, motivation, problem statement, scope, methodology, research aims and thesis outline.

CHAPTER 2: Literature Review
This chapter reviews the relevant research on concrete and its characteristics, the properties of concrete with different additives (such as waste PET bottle particles and steel fibers), and the life cycle assessment of concrete.

CHAPTER 3: Testing Methodology
This chapter explains the methodology used for testing the properties of the different mixes of concrete, including the raw materials used, mixing and casting techniques,

samples details, and testing methodologies.

CHAPTER 4: Analysis and Results
This chapter explains the results of the tests performed on the different mixes of concrete, including their mechanical and dynamic properties, and analyzes the behavior of the specimens during testing.

CHAPTER 5: Discussion
This chapter discusses the findings from the results and provides background information on empirical equations between fiber content and linear shrinkage, the formation of fibers and concrete bond, and their physical implementation.

CHAPTER 6: Conclusions and Recommendations
This chapter summarizes the key findings and conclusions of research and provides recommendations for future research.

# Chapter 2

# Literature Review

## 2.1 Background

Fibers can be used in the concrete mix to enhance its characteristics and to get maximum benefit from the fibers. Number of researchers have used different types of fibers and even used more than one together to get the improved quality of concrete. The main component is cement in concrete, and concretes strength and binding characteristics is enhanced. The cements use in concrete is economical and harmful for environment, so admixtures or pozzolanic materials having similar properties to that of cement when replaced with cement is the best sustainable solution. These are cost friendly and environment friendly materials, and they are easily available also. The main flaw in conventional concrete is the propagation of cracks, spalling and . It further propagates and reduces the durability and strength of the conventional concrete which is called as flaw of concrete. This cracks propagation can be cured by increasing the concretes properties like dynamic, mechanical and other parametersl. The cements use in concrete is economical and harmful for environment, so admixtures or pozzolanic materials having similar properties to that of cement when replaced with cement is the best sustainable solution. In this chapter flaws in concrete and remedial measures, concretes characteristics after adding ingredients, properties of concrete having admixture, properties of concrete having waste PET particles, properties of concrete having steel fibers and life cycle assessment are discussed. Fiber composites prepared from numerous fibrous materials provide a viable solution.

## 2.2 Flaws in Concrete and Remedy

Because of several reasons, the flaws in concrete which affects the concrete performance and its durability. These flaws are investigated by different researchers. Emission of large amount of carbon dioxide ($CO_2$) from cement used in concrete is very harmful for the environment [12]. Cracking is a common issue in concrete and can be caused by factors such as shrinkage, external factors, and stress under tensile forces[13]. Cracks can also make concrete vulnerable to harmful compounds and environmental damage. Crack healing in concrete can help mitigate the development and propagation of cracks[14]. Additionally, spalling is a flaw in concrete that can be caused by reactive agents infiltrating the pores of the material. Both cracking and spalling can impact the physical appearance and load-bearing capacity of structures[15]. Figure 2.1a and 2.1b illustrate the mechanisms of cracking and spalling in concrete.

Figure 2.1: Spalling and Shrinkage Cracks at Initial Stage . a) Spalling in Concrete, b) Shrinkage Cracking at Initial Stage

During the early stages of concrete, there is a tendency for shrinkage and settlement, which can result in plastic shrinkage in the concrete [16]. This phenomenon is particularly harmful in concrete structures with larger surface areas [17]. Plastic shrinkage has been a long-standing issue in concrete, arising from the evaporation of water and settlement of solid particles from the concrete's surface. However, this issue can be minimized by incorporating fibers, admixtures, and superplasticizers [18], thus limiting the occurrence of plastic shrinkage. Plastic shrinkage has been a long-standing issue in concrete, arising from the evaporation of water and settlement of solid particles from the concrete's surface.

## 2.3 Characteristics of Concrete After Adding Ingredients

Cement sand and aggregate are the main ingredients of concrete. We can add anything in concrete and it would also be called as ingredient. To enhance the concretes properties many researchers have found some new techniques. The ad dition of artificial and natural fibers has potential to use in concrete. The use of fibers either natural or artificial have great impact on concretes characteristics. The utilization of waste fibers in concrete can provide an effective solution for their management. Incorporating coconut fibers in concrete has shown to improve its flexural strength by approximately 12% while also promoting good bonding. It was noticed that the optimal fiber content was 3% by weight of cement [19]. Similarly, by adding banana fiber from 0.5 % to 2 % by volume of concrete, more fiber content reduces the workability, but it increases the compressive and tensile properties of concrete [20].

Adding pine needle from 0.5-2 % by concretes volume improves the compressive and flexural strength [21]. the workability of plastic concrete can be improved and strength and durability also enhances of hardened concrete [22]. Adding PET bottle particles by 5 % as replacement of sand gives more compressive strength when compared to PC [23]. Adding steel fibers hooked shaped up to 2 percent by the concretes volume, increases the concretes properties like strength in compression, flexural strength and splitting tensile strength [24]. So, its easy to play with concretes characteristics now-a-days according to the requirement.

### 2.3.1 Properties of Concrete having Admixture

The sand, stone, water, and Portland cement are the main ingredients of conventional concrete. Admixtures are useful in construction applications and they can be used according to the required purpose. Concrete having material other than cement sand aggregate and water is admixture. Concrete technology has undergone significant advancements, driven by two main factors: the need for faster construction and improved durability of concrete [25]. The construction and manufacture of high performance read-mix and precast concrete can also be done by the use of admixtures [26]. The use of admixtures in concrete has been a significant development in recent decades, providing benefits such as high strength, long durability, low shrinkage, and safe placement, especially in the elements with congested reinforcement [27]. Admixtures are not limited to use in prestressed concrete, but can be used in other types of concrete as well. They can improve both early and final strength, as well as enhance the slump retention and workability of concrete [28]. The use of mineral admixtures or pozzolanic materials can reduce pore sizes and porosity, thereby increasing strength, but it may also increase water demand [29]. Powdered silica fume, as shown in Fig 2.2, is an example of a pozzolanic material. To address the issue of increased water demand, Polycarboxylate superplasticizers reduces the requirement of water usage in concrete mixes by keeping slump value at low dosage.

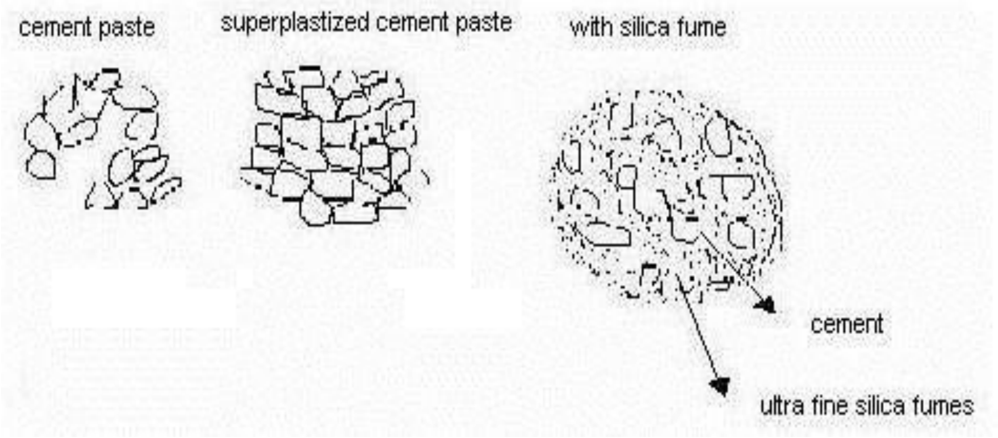


Figure 2.2: Packing of Cement Paste Containing Superplasticizer and Silica Fume [31]

The addition of silica fume and fly ash so called pozzolanic materials in concrete can enhance its ability to react with calcium hydroxide (Ca$(OH)_2$), forms new bonds leading to increased strength [31]. Admixtures are useful in construction applications and they can be used according to the required purpose i.e. reduction of water, enhancement of strength and other paramerters like toughness etc. This new bond forming ability while using pozzolanic material enhances the characteristics of concrete like compressive strength, flexural strength, split tensile strength, and dynamic properties of conventional concrete as well. The use of admixtures in concrete has been a significant development in recent decades, providing benefits such as high strength, long durability. Admixtures are useful in construction applications and they can be used according to the required purpose i.e. reduction of water, enhancement of strength and other paramerters like toughness etc. The chemical and mechanical properties of silica fume and cement is given in Table 2.1.

Table 2.1: Chemical and Mechanical Properties of Portland Cement and Silica Fume [32]

| **Property** | **Cement %age** | **Silica Fume** |
|---|---|---|
| CaO | 64.64 | 0.3 |
| Al2O2 | 5.6 | 1.32 |
| SiO2 | 21.28 | 96.4 |
| Fe203 | 3.36 | 0.87 |
| MgO | 2.06 | 0.97 |
| SO3 | 2.14 | 0.1 |
| Specific gravity | 3.15 | 2.55 |
| Bulk density (kg/m3) | 1400 | 400-650 |
| Color | Grey | White |

The chemical and mechanical properties of silica fume and cement is given in Table

2.1, and the properties of portland cement and silica fume are compared to study their characteristics.

### 2.3.2 Properties of Concrete Having Waste PET Particles

As plastic consumption has skyrocketed, the challenges associated with plastic waste disposal have emerged as a pressing issue [33]. To address this problem, it is important to find alternative ways to use waste plastic bottles effectively. Incorporating waste PET bottle particles in concrete is one such method that not only helps manage plastic waste but also supports the development of economic and sustainable materials in the future [34]. The use of PET particles shows promise as a technique for creating sustainable materials for the construction industry [35]. By utilizing these types of materials, the concretes characteristics can be improved.

The concrete's dynamic as well as mechanical properties strongly depend on the ingredients that used in the concrete mix. The amount of PET bottle particles and their shape also play important role in mechanical and dynamic properties. The rise in plastic consumption has created challenges in the disposal of plastic waste. One potential solution is to utilize waste PET bottles in concrete, which not only promotes effective waste management but also provides a sustainable and economic alternative for the construction industry. Rahmani et al. (2019) [36] conducted a study on the mechanical characteristics of concretes specimens that contains PET particles, with varying amounts (5 percent, 10 percent, and 15 percent) as partially replacement of sand. The results showed an initial increase in compressive strength with increasing PET particle content up to 10%, but a decrease in compressive strength beyond 15%. Other researchers (Ismail and Al-Hashemi, 2015 [37] [38]; Al-Manseer and Dalal, 2015 [39] [40]; Marzouk et al., 2018; Islam et al., 2020; Frigione, 2018 [41][42] reported mixed results on the effect of PET particle addition on the splitting tensile strength (STS) of concrete. The shape and size of the PET particles also play a significant role in the properties of the resulting concrete. Cordoba et al. (2016) used different volumetric percentages of PET particles of various sizes in the concrete mixture and found that the specimens containing 5% PET particles with 5 mm size exhibited the highest modulus of elasticity. In contrast, specimens that contains 5 percent of PET particles with 3 mm size showed the lowest modulus of elasticity. Brittleness is a common characteristic of concrete, and it tends to increase with the increase in strength. Moreover, ordinary concrete is vulnerable to low tensile strength, low consistency at crack initiation, and propagation. Researchers have suggested that the use of PET particles in concrete can affect the STS characteristic. However, by the addition of different types of fibers into concrete has been considered an effective method for improving STS [43] . The shape and size of the PET particles also play a significant role in the properties of the resulting concrete. The use of natural or artificial fibers is an optimal solution for addressing this issue and have alot of benifits accoridng to the nature of the fiber used in conventional concrete.

### 2.3.3 Properties of Concrete Having Steel Fiber

Many researchers have studied the effect of steel fibers on the properties of concrete with different lengths, shapes and proportions. The end results of Nataraja et al. [46] research showed that by applying 0.5% that by applying 0.5 % by volume of SFs, initial crack's impact resistance and the ultimate impact strength of the plain concrete reached 1.5 times and 1.8 times, respectively. The research by Song et al. [47] showed that by adding 1 % by volume of hooked SFs, the impact resistance of the initial crack and the ultimate impact strength of high strength concrete reached 3.9 and 2.4 times, respectively. The use of these types of fiber increases the concrete strength for abrasion, impact, and fatigue stresses, moreover, it increases the tension bearing and bearing of load after cracking, and it also affected the mechanical characteristics of concrete, too. The effect of steel fibers shape, length and percentage used in the concrete mix have greater impact on concretes mechanical and dynamic properties. Mohammad [48], presented the effects of (0.5 percent, 0.75 percent, 1 percent, and 1.5 percent) by volume of SFs on the compressive strength, STS, stress-strain behavior, modulus of elasticity of the HSC, and the SFs high strength concretes strength in compression, STS, behavior, modulus of elasticity of the HSC, and the SFs high strength concrete (HSC). The results showed that at greater SFs ratios, the HSC performed better than the HSC. Kaksal et al. [49] investigated the compressive strength of hooked fiber reinforced concrete at 0.5The effect of steel fibers shape, length and percentage used in the concrete mix have greater impact on concretes mechanical and dynamic properties. Mohammad [48], presented the effects of

(0.5 percent, 0.75 percent, 1 percent, and 1.5 percent) by volume of SFs on the compressive strength, STS, stress-strain behavior, modulus of elasticity of the HSC, and the SFs high strength concretes strength in compression, STS, behavior, modulus of elasticity of the HSC, and the SFs high strength concrete (HSC). The results showed that at greater SFs ratios, the HSC performed better than the HSC. Kaksal et al. [49] investigated the compressive strength of hooked fiber reinforced concrete at 0.5% and 1% ratios, as well as silica fume concentrations in cement. It suggested that specimens combining silica fume and SFs had better compressive strength than specimens containing simply silica fume. The addition of SFs to high-strength concrete enhanced compressive strength marginally. Figure 2.4 shows Pull-out behavior of straight steel fibers embedded in concrete.

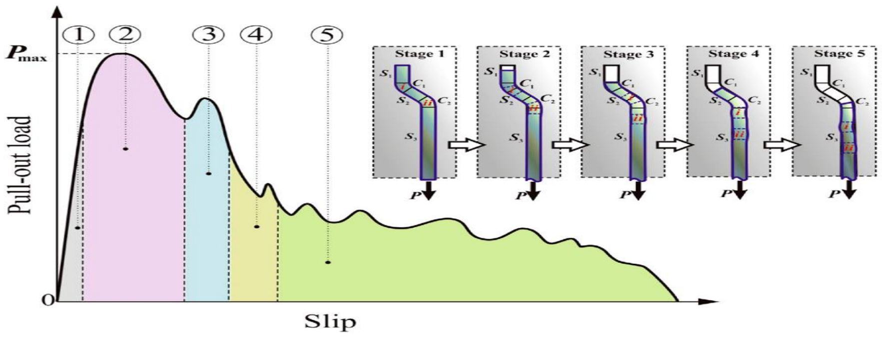


FIGURE 2.3: Pull-out Behavior of Straight Steel Fibers Embedded in Concrete [50]

Five stages were identified for hooked-end steel fibers, as presented in Figure 2.4. The first stage, elastic debonding and partial, consists of the elastic and partial debonding components of the interface property until it fully de-bonds. The curve of the hooked-end fiber is linear and nonlinear until it is completely de-bonded. The C1 and C2 of curved ducts align with the initial arc segments of the hooks, as presented in Figure 2.3. This segment makes up for the pull-out slip's lowest point. After the fiber is completely de-bonded, the curved segments 1 and 2 start entering the straight ducts S2 and S3, and the fiber segments in the straight ducts S1 and S2 enter the curved ducts in the second stage, which is also known as the first plastic deformation stage. This results in the fiber segments being exposed to bending and plastic deformation, increasing the pull-out load significantly. The full pull-out load is often reached when the slippage is between 0.5 and 1.5 mm. At this point, the hybrid fiber effect primarily manifests in two ways: resisting matrix cracking and increasing matrix power [50]. So, the strength of the new concrete is upgraded due to the addition of steel fibers. The steel fibers have ability to bridge the the craks, and it helps to prevents the cracks propagation.

Table 2.2: Ingredients Used in Concrete Mix and their Advantages

| **Material** | **Effect on Concretes Properties** | **References** |
|---|---|---|
| Steel Fiber | When adding 0.5% SFs by volume, the 1.5 and 1.8 times of ordinary concretes resistance in impact of the first crack and the ultimate strength in impact increased, correspondingly. Meanwhile, 1% hooked SFs by volume improved the resistance in impact of the first crack and the ultimate concretes strength in impact by 3.9 times and 2.4 times, correspondingly. | [45] [46] |
| Steel fiber+ Silica fume | When SFs were added at 0.5 percent and 1 percent ratios, together with the content of 0-15 percent for silica fume for cement replacement, the specimens showed higher compressive strength compared to the specimens with only silica fume. | [48] |
| Washed PET bottle particles | The 5 percent PET particles containing specimens with a size of 5 mm showed the highest modulus of elasticity, while the specimens with 5% PET particles with a size of 3 mm had the minimum modulus of elasticity. | [41] |

| | | |
|---|---|---|
| Polycarboxylate | Polycarboxylate is commonly used in concrete mixtures because of its ability to significantly reduce water and its effectiveness in retaining slump at low dosage. | [30] |

Table 2.2 shows the ingredients used in concrete mix and their advantages for the improved mechanical properties of conventional concrete.
However, it is important to note that an increase in the strength in compression of concrete can make it extra brittle, which is a consideration when choosing the properties of the concrete for a particular use [50]. The steel fibers provides bridging effect which improves the mechanical characteristics of the concrete.

## 2.4 Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is a method used to assess the environmental performance and impacts of products, processes, and systems, which can help identify options for mitigating the effects. LCA is a useful tool for addressing waste management issues [52,53]. Additionally, LCA is being increasingly used to evaluate the stability and composition of materials, such as concrete [54], and many studies have demonstrated the positive environmental effects of using waste in concrete [55]. Various software packages, such as LCV-system, KCL-EKO, TEAM and TEAM Plus, and PEMS can be used for LCA [56]. There are two primary types of LCA: theoretical/unit process data and environmental input-output (EIO) data. Unit process data is collected from direct surveys of companies or plants that produce the product of interest, while EIO data is based on national economic input-output data [57].While software offers greater precision, it consumes a significant amount of time, and unacceptably large computation times are required for day-to-day consultants purposes [58]. The LCA has various forms, which are known as LCA variants. The most commonly used LCA variants are described below [59]: Cradle to grave, which is a complete life cycle assessment that incorporates the all stages of a product's life cycle. The Cradle to gate, which focuses at most on the extraction of raw material, making, packaging, and transportation processes that occur within the factory. The disposal, consumer, distribution phases is not considered. Cradle to cradle, which is the assessment of cradle-to-grave, where the products recycling process is the end-of-life stage, so the product will not be discarded even after the end of its useful life, it can be recycled be used again.

The base values for the calculation of $CO_2$ used by different researchers are given in table 2.3.

TABLE 2.3: Emission Factors of Raw Materials along their Citation in $CO_2$-kg/kg for Current Study

| **Sr. No** | **Cement** | **Sand** | **Aggregate** | **Water** | **Steel Fibers** | **PET Particles** | **Silica Fume** | **Admixture** | **Cite** |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 0.885 | 0.0023 | $0.00279^3$ | - | - | - | - | - | [60] |
| **2** | 0.827 | 0.0025 | $0.00253^3$ | $0.000331^4$ | - | - | $0.00122^7$ | - | [61] |
| **3** | 0.920 | 0.0024 | 0.0071 | - | - | $-3.38^6$ | - | - | [62] |
| **4** | 0.931 | 0.0026 | 0.0075 | 0.000196 | - | - | - | - | [63] |
| **5** | 0.994 | 0.0026 | 0.0075 | 0.000196 | $1.6^5$ | - | - | - | [64] |
| **6** | 0.951 | $0.0010^1$ | $0.00611^2$ | - | - | - | - | $0.944^8$ | [65] |

$*^1$= 0.0010 is for quartz sand, where as 0.0023-0.0026 is for crush sand.

$*^2$= 0.611 is for limestone.

$*^3$= 0.0023-0.00279 is for recycled aggregates, whereas 0.0071-0.0078 is for normal aggregates.

$*^4$= 0.000331 is for river water, while 0.000196 is for tap water.

$*^5$=1.65 is for steel wires

$*^6$= -3.38 is for PET, the negative sign indicates that using PET bottle waste can reduce $CO_2$ emissions in the energy-saving recycling process

$*^7$=0.00122 is for silica fume

$*^8$= 0.944 is for polycarboxylate

There is a little difference for similar materials, whereas the difference is large for varied materials e.g. for normal limestone, and recycled aggregates, the values are 0.0071-0.075, 0.0061, and 0.00253-0.00279, respectively. This is can be seen clearly from the above table.

## 2.5 Summary

Improving the mechanical characteristics of concrete can help control the cracking phenomenon in rigid pavements and enhance their performance. One approach is to reduce the linear shrinkage values. The presence of fibers in concrete can lead to improved characteristics and positively impact the performance of the structure that is shown by previous studies .This chapter presents flaws in concrete and remedial measures, concretes characteristics after adding ingredients, properties of concrete having admixtures, properties of concrete having waste PET particles, properties of concrete having steel fibers and life cycle assessment is are discussed.

# Chapter 3

# Experimental Program

## 3.1 Background

Fibers either natural or unnatural have great impact on concrete. These fibers when used along with some pozzolanic material have unexpected change in the mechanical properties of concrete, as these are easily available, environment friendly, extremely low cost and mitigate the waste disposal issue. Pozzolanic material have also great impact on concrete in terms of chemical and mechanical properties. Admixtures also plays a vital role for controlling the concretes properties according to the required purpose. The fibers and particles chosen for this research is steel fibers and washed waste PET bottle particles along with binding material (silica fume powdered) and admixture (Polycarboxylate). The particles that has been used in this research is waste PET bottle particles replaced with sand, PET bottle particles enhance the compressive strength and saves the environment and easily available. The fiber chosen for this research is steel fiber, as they increase the flexural strength along with compressive strength and their easy availability. Pozzolanic material is silica fume partially replaced with cement to get the good strength and better mechanical properties. While using pozzolanic material, it increases the water demand, so polycarboxylate (admixture) is used to balance the required quantities and to enhance the concretes characteristics. It is quite important to know the characteristics of this new concrete when compared with plain concrete (PC). This work is purely limited, and durability is considered as it requires constant observtion of the casted samples time to time for a longer period.

Therefore, the mechanical properties, dynamic properties, water absorption prop- erties and microstructural analysis of concrete having waste PET bottle particles along with steel fiber are considered. This chapter includes raw materials, treatment of fiber, the procedure of preparation and casting of Plain concrete specimens, and, concrete specimens having PET bottle particles and steel fiber are discussed along with the methodology for testing these specimens and using the material properties for the design of rigid pavements using the mechanistic-empirical design approach.

## 3.2 Raw Materials

The material used for the concrete which need to be compare with our new fiber reinforced concrete is cement, sand, aggregate and water. While PET bottle particles, steel fiber, silica fume and polycarboxylate is used for preparing our new concrete. The mix design and casting details are discussed in detail in this section.

### 3.2.1 Properties of PET Bottle Particles

Polyethylene Terephthalate (PET) is a polymer which is used widely in the production of fibers as polyester, bottle resin, and polyester for engineering worldwide. PET is commonly used in the food packaging industry, but due to its slow decomposition in nature, researchers have sought to look the ways of recycling and reusing of PET waste materials. These wastes need to be recycled to save the environment from the emission of harmful gasses. The environment saving is the big challenge for the construction industry, as the construction practices pollutes the environment, which need to be solved as soon as possible. Figure 3.1 shows the washed PET bottle particles. Polyethylene Terephthalate (PET) is a polymer which is used widely in the production of fibers as polyester, bottle resin, and polyester for engineering worldwide. PET bottle particles have the potential to be used in concrete to enhance its characteristics. It can be seen clearly from the figure 3.1 that the individual PET particles are irregular in shape. The maximum size of PET particles is 7 mm. whereas, the maximum size of sand is 4.75 mm. The sand is partially

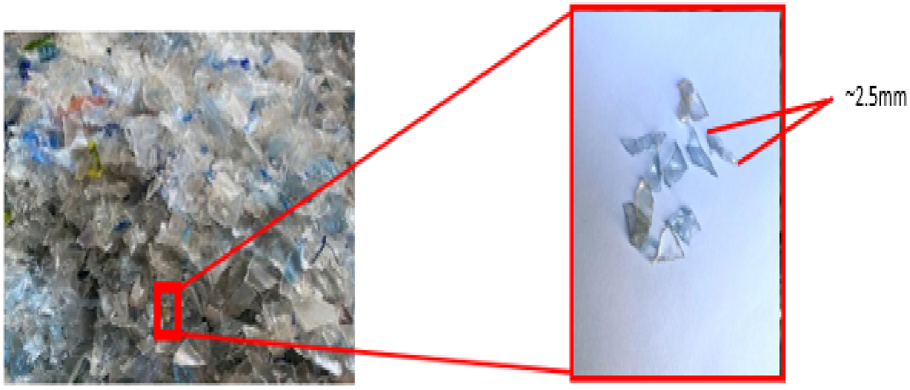


Figure 3.1: Single Washed PET Bottle Particles

Table 3.1: PET Particles Specification

| **Percentage-remaining on sieve** | **Sieve Size** |
|---|---|
| 7.00 mm | 1 |
| 4.75 mm | 12.5 |
| 2.36 mm | 66.5 |
| 1.18 mm | 2.5 |
| 600 um | 1.5 |
| 300 um | 1 |
| 150 um | 2.14 |
| Unit weight (ASTM S29) (kg/$m^3$) | 464.265 |
| Specific gravity (g/$cm^3$) | 1.11 |

replaced with PET bottle particles [55], in which the maximum size of PET particles is 7 mm and is partially replaced with sand containing 4.75 mm particles. PET particles were collected from the industry where these were prepared by washing and grinding trash PET bottles in a shredding machine. The particles of PET had a unit weight of

464 kg/$m^3$, and a specific gravity of 1.11 g/$cm^3$ [66]. Table 3.1 shows the PET particles specification, sieve size and percentage remaining on the sieve for the preparation of concrete containing steel fibers and waste PET bottle particles. PET is considered as the polymer of semi-crystalline having tensile and flexural elastic modulus of 2.9 GPa and 2.4 GPa, correspondingly. It has a maximum tensile strength of around 60 MPa and excellent chemical resistance. PET has a melting point of 260 degrees Celsius.

### 3.2.2 Properties of Steel Fiber

The concrete matrix containing steel fibers is typically within the range of 0.25 percent to 2 percent by volume of concrete. It has been observed that beyond this range, both the strength and workability of the concrete decrease. A fiber dosage of 0.5% to 1% generally performs well, but this depends on the type and size of fibers used. Fibers come in various shapes, including hooked, crimped, straight, and deformed, with lengths ranging from 19 mm up-to 60 mm. Microfibers, with lengths less than 19 mm, are also available but are not typically used in general concreting.

Table 3.2: Steel Fiber Characteristics

| **Material** | **Length** | **Diamete** | **Tensile Strength** | **MOE** | **Specific Gravity** |
|---|---|---|---|---|---|
| | **(mm)** | **(mm)** | **(MPa)** | **(GPa)** | |
| Steel Fiber | 40mm | 0.8 | 1,225 | 210 | 7.850 |

Table 3.2 shows some important properties of steel fibers, length diameter, tensile strength, modulus of elasticity and specific gravity. The steel fiber content increases the weight density of concrete, and the slump value will also decrease at a higher percentage of steel fibers (SF) and lower water-cement ratio. The workability of concrete improves as the

percentage of SF increases. The addition of SF significantly increases the compressive characteristic, split tensile characteristic, and the strengths in flexural of the concrete mix.

### 3.2.3 Properties of Silica Fume

Silica fume in cement creates new bonds which gives ultimate strength. The specific chemical and physical properties are shown in Table 3.3 according to ASTM-S1240 [64] while the figure of powdered form silica fume is also given. As by the appearance, it looks like cloudy white color as shown in figure 3.2.

Figure 3.2: Powdered form Silica Fume

The chemical properties of silica fume ensures its strong bond forming ability. when added in concrete, it starts reacting with cement. The chemical bonding is seen between the cement and silica fume. The new bonds are formed, the strength of concrete is enhanced. The excess dosage of such type of materials results in crack formation due to the dehydration. The superplasticizer can be used along with silica fume which has the property of reduction in water requirement , so the newly formed concrete will not have the less water content which results in propagation of cracks. So the optimum values of silica fume with superplasticizer is the good option to gain the high strength with low cost and the best mechanical characteristics concrete can be formed.

TABLE 3.3: Chemical Properties

| Content | Percentage |
|---|---|
| $SiO_2$ | 98 % |
| $SO_3$ | 0.15 % |
| Cl | 0.90 % |
| $Na_2O$ | 0.33 % |
| $K_2O$ | 0.17 % |
| Available alkali | 0.40 % |

Table 3.3 shows some important physical and chemical properties of silica fume according to ASTM-S1240.

### 3.2.4 Properties of Polycarboxylate

As the construction practices are increasing due to the increase in the population rapidly. There is a need of advancement in the construction material as well according to our requirement. Polycarboxylate while using in the concrete have great positive effect. It influences many fresh and hardened properties. Some important properties of polycarboxylate is given in table 3.4

TABLE 3.4: Properties of Polycarboxylate

| Parameters | Polycarboxylate |
|---|---|
| Appearance | Looks dark, slightly yellowish |
| pH , 25 C | 6.2 |
| Viscosity cP | 896 |

| | |
|---|---|
| Mass average molecular weigh | 50,000 |

Table 3.3 shows some characteristics of polycarboxylate i.e. appearance, pH at 25C, mass average molecular weight and viscosity.

## 3.3 Mix Design, Casting Procedure, Fresh Properties and Specimens

The ratio which was designed for the preparation of mixes is 1:1.3:2.3; is used for the production of PC and concrete having steel fiber and PET bottle particles, with w/c ratio of 0.49. The maximum size of PET bottle particles is 7mm. whereas, the maximum size of sand is 4.75 mm. The sand is partially replaced with PET bottle particles [55]. As no bleeding is noted while doing the slump check and molds filling (this indicates that no strength is loss). The concrete containing fibers of steel and waste PET bottle particles, steel fiber is added 2 %. The steel fiber is added by the volumetric percentage of concrete, and PET bottle particles are partially replaced with sand by 5 %,10 % and 15 %. The steel fiber used in concrete are same in length 40 mm for with 0.8 diameter, and the PET particles used is the maximum size of 7mm and their characteristics are shown in table. Silica fume is used and replaced with cement by 2 %. Polycarboxylate is added by 1 % of the concrete mix. The target strength is 30 MPa. Table 3.5 shows the preparation of specimens of PC and concrete having steel fiber and PET bottle particles and the mix ratio used.PC refers to plain cement concrete, S1, S2, and S3 refer to concrete having steel fiber and PET bottle particles with different contents.

To prepare the both PC and mixtures having fibers of steel and waste PET bottle particles, a concrete mixer is used. To produce PC, the raw ingredients (cement, sand, aggregate, and water) when put in the mixer rotator and give rotation for approximately three minutes. Then, slump is checked to determine the concretes workability before putting it into the molds.The concrete containing waste PET bottle particles and steel fibers, one by third of the different ingredients is put in the The concrete containing waste PET bottle particles and steel fibers, one by third of the different ingredients is put in the mixer rotator into layers, then the method is repeated unless required quantity for a particular number of molds and specimens is reached. To ensure proper mixing of the materials and calculated fiber proportions in their dry state, the rotation of mixer is for around three minutes. Then, the addition of one by third of the water is put into the mixer, which is then rotated for another three minutes for the preparation of specimens. The remained water is then added to the mixer, and rotated again for another three mins. The new formed concrete is shown.

The figure given below shows that the presence of PET particles and steel fiber's can be observed. The main purpose of showing this figure is to observe the workability of concrete by its appearance. The workability of concrete having waste washed PET bottle particles, if the content of waste washed PET bottle is increased by keeping the same water-to-cement ratio, the workability is quite low. This is due to the addition of low density waste washed PET bottle particles that creates voids in concrete as well.

The concrete containing five percent waste washed PET bottle particles have bertter slump, so it means its workability is better as compared to the concrete having fifteen percent PET botltle content. So the workability of concrete having ten percent PET particles content would be intermediate, as 5% and 15% showed the high and lowest workability. So, the workability of concrete having 10% waste washed PET particles content would be intermediate.

Figure 3.3: Concrete mix containing 15% waste PET bottle particles and steel fibers

The workability test is performed before filling the concrete into the mold and observed it as workable at that time. The workability test for concrete with PET bottle waste particles and steel fibers is the similar as done for PC. The filling procedure is standard and done in three separate layers and tempering rod having 16 mm diameter is used for each of the layers with 25 blows. To remove any air voids, the method of lifting the mold up and then dropping it from the 165-230 mm height and the same method is adopted for these mixtures. All the specimens of PC and concrete containing waste PET bottle particles and steel fibers are prepared using the same procedure. The best method for enhancing the slump of concrete containing waste PET bottle particles and steel fibers is recommended. The specimens are then cured for twenty-eight days. Table 3.5 provides the casting details and mix proportions of the mixtures.

TABLE 3.5: Mix Proportions

| **Sample** | **Cement** | **Sand** | **Coarse Aggregate** | **Water** | **Steel Fiber** | **PET bottle Particles** | **Silica Fume** | **Polycarboxylate** |
|---|---|---|---|---|---|---|---|---|
| | | | | | $*^1$ | $*^2$ | $*^3$ | $*^4$ |
| | **(Kg)** | **(Kg)** | **(Kg)** | **(Kg)** | (%) | (%) | (%) | (%) |
| PC | 13.33 | 17.32 | 30.65 | 6.39 | 0 | 0 | 0 | 0 |
| S1 | 13.06 | 16.454 | 30.65 | 6.39 | 2 | 5 | 2 | 1 |
| S2 | 13.06 | 15.588 | 30.65 | 6.39 | 2 | 10 | 2 | 1 |
| S3 | 13.06 | 14.722 | 30.65 | 6.39 | 2 | 15 | 2 | 1 |

$*^1$ = added 2% by volume of concrete

$*^2$ = partially replaced with sand

$*^3$ = partially replaced with cement

$*^4$ = added 2% by volume of concrete

The slump of fresh concrete reduced gradually with the increment of steel fiber and PET particles concentration. The maximum slump observed was 110mm for PC. Contrary to this, the values of slump for S1, S2, and S3 was 90mm, 65mm and 45mm. A significant deviation in the value of slump of PC is due to the interlocking effect of the fibers and PET bottle particles that reduces the slump of the concrete. Contrarily, using silica fume powder and polycarboxylate liquid increases the value of the slump of concrete, reduces the viscosity of the mixtures and increases the workability of concrete. The highest value of slump is 88mm and the lowest value of slump is 45mm. The slump values of S1, S2 and S3 decreased by 12 %, 35 % and 55 %. The minimum slump observed is 45mm for S3 that is due to the more PET bottle particles content. Compaction factor test on the PC, S1, S2 and S3 were performed. It was seen that the compaction factor value for PC was 0.90, for S1 the compaction factor value was 0.88, for S2 the compaction factor value was 0.82, and for S3 the compaction factor value was 0.80. The observed fresh densities of PC, S1, S2 and S3 are 2304 kg/$m^3$, 2288 kg/$m^3$, 2254kg/$m^3$, 2222 kg/$m^3$ correspondingly.

Hence, S1, S2, and S3 have reduced gradually due to the more PET bottle particles content. Among all the batches, S3 shows the lowest density as the maximum amount of PET particles included in this batch as compared to other batches. While the given figure shows the slump of concrete which contains the waste washed PET bottle particles which has the content of 15% and also contains the steel fiber which is two percent by volume of the concrete.So, from the below figure it can be seen that the slump of concrete having 15% PET bottle particles shows the slump of 45mm. This indicates that this newly formed concrete is lower in density if we compare it with plain concrete. So, the presence of low density waste washed PET bottle particles have the impact on concrete which lowers the slump value due to its low density property. For the flexural strength and linear shrinkage tests, beamlets sized at 100 mm x 100 mm x 450 mm were used. Two readings were taken for each property, following ASTM S39, and an average was calculated for both PC and concrete with steel fibers and waste PET bottle particles. A total of 36 specimens, including 24 cylinders and 12 beamlets, were marked to distinguish them based on fiber proportion. The workability of both PC and concrete with steel fibers and waste PET bottle particles in their fresh state was determined according to ASTM S143/S143M15a. ASTM C642-13 was used to determine the density of the specimens.

Figure 3.4: Slump of concrete having 15% waste washed PET bottle particles and steel fibers

However, due to the lack of the standard, the standard was followed for both workability and density. The slump values of the concrete with steel fibers and waste PET bottle particles were reduced compared to those of plain concrete due to the retention and confinement effect of the fibers. Among all the batches, S3 shows the lowest density as the maximum amount of PET particles included in this batch as compared to other batches. While the given figure shows the slump of concrete which contains the waste washed PET bottle particles which has the content of 15% and also contains the steel fiber which is two percent by volume of the concrete. The presence of fibers in concrete having waste PET bottle particles and steel fibers (SFs) caused a decrease in densities due to their addition when compared with plain concrete (PC).

## 3.4 Testing Methodology

Mechanical behavior, dynamic behavior, absorption of water, loss in mass, and shrinkage in linear properties of both PC, and concrete containing PET bottle particles, silica fume and steel fibers were measured in accordance with standard procedures. ASTM standards specify that an average of two readings can be used to minimize human errors. To minimize human errors, an average of two readings was taken for each test. ASTM standards specify that an average of two readings can be used to minimize human errors.

### 3.4.1 Determination of Mechanical Properties

The compressive characteristic, S.T.S, and flexural behavior of both the PC and concrete with PET bottle particles and steel fibers are determined using a Universal Testing Machine (U.T.M) in accordance with ASTM standards. ASTM S39/S39M-17 is used to measure the compressive behavior, pre-crack (C.P.E) and cracking post energy (C.C.E), strain at the peak stress (), total energy absorption in compression (C.T.E), and the toughness index in compression (C.T.I).

Cylinder capping is done for the distribution of uniform load over the cylinder, with the help of plaster of Paris. The splitting tensile strength, the behavior in split-tensile, pre-crack and post-crack energies in split tensile behavior, and the toughness index in splitting tensile properties are determined as per ASTM C496/C496M-11. The flexural properties of both PC and concrete with PET bottle particles and steel fibers are determined following ASTM S293/S293M-16. To avoid human error, the sum of three readings and then divided by three is used, as permitted by the standard of ASTM.

### 3.4.2 Determination of Dynamic Properties

The dynamic behavior of the specimens, including the cylinders and beamlets of both PC and concrete containing PET bottle particles and steel fibers, were evaluated according to the ASTM standard S215-14. The damping ratio was used to determine the frequencies, and the relative MOE, dynamic modulus of rigidity, and dynamic Poisson ratio were calculated based on the ASTM C666/C666M-1 standard.

### 3.4.3 Water Absorption, Linear Shrinkage and Mass Loss Tests

The absorption of water is measured in accordance with ASTM-C642. By drying the specimens in an oven, the test is carried out, then immersing the dried specimen in room temperature water and boiling it for around 5 hours. The same approach is used to calculate the rate of absorption of water of all concrete mix specimens. As there is no record exists to calculate the linear shrinkage of a concrete specimen. By measuring the difference in length of specimens, ASTM standard S157/S157M- 08 is used to derive the concrete including PET bottle particles and steel fibers (OPSS LS-435 standard). With the exception that the dimensions of the beam let specimen are approximately 100 mm x 100 mm x 450 mm, reference bar of gauge length used. The specimen in a heating oven of each concrete mix type is placed, and the temperature is enhanced from 20$^o$C to 100$^o$C at an average rate of 3$^o$C/min.

### 3.4.4 SEM Analysis of Damaged Surfaces of Concrete Having PET Paritcles and Steel Fibers

Micro structural examination of shattered specimens is performed. The micro-level study of concrete specimens including PET bottle particles and steel fibers aids for impact of bonding determination between the fibers and matrix. The primary goal of SEM investigation is to determine the collapse mechanism of the fiber-matrix bond.

### 3.4.5 Life Cycle Assessment (LCA)

Life cycle assessment is a method of quantifying the environmental performance and impacts of goods, processes, and systems, as well as assisting in the identification of effect mitigation strategies. This is a useful tool for discovering relevant waste management solutions [58,59].In addition, the LCA approach is widely utilized to analyses the stability of materials such as concrete and its composition. The life cycle is performed theoratically by multiplying the required quantites for the preparation of concrete mixtures, and the reference base values for different ingredients. Many studies have been conducted to investigate the environmental benefits of utilizing trash in concrete. A generalized study has been undertaken on the LCA that explored the recycled polypropylene fiber in concrete pavements has also been studied in an- other study of self-compacting LCA incorporating waste PET particles. Although software provides more accurate results, but it is time-consuming, while theoretical assessments are more reliable when time is limited [58]. The life cycle is performed theoratically by multiplying the required quantites for the preparation of concrete mixtures, and the reference base values for different ingredients. The life cycle assessment is purely limited to $CO_2$ emission.Superplasticizer has a considerable influence on the variety in $CO_2$ emissions from mixtures.

PET particles indicates that employing PET bottle trash in the energy-saving recycling process can minimize $CO_2$ emissions. It has the potential to cut $CO_2$ emissions by 3.38 kg $CO_2$ per kilogram of PET bottle trash. $CO_2$ emission through the crushing machine is 0.00071 per kg of PET, which has a very tiny influence and may be omitted in the calculations. Table 3.6 shows the emission factors of raw materials.

Table 3.6: Emissions Factors of Raw Materials

| **Parameters** | **Cement** | **Sand** | **Coarse Aggregate** | **Water** | **Steel Fibers** | **PET** | **Silica Fume** | **Superplasticizer** |
|---|---|---|---|---|---|---|---|---|
| **Emissions factors;GWP (kg $CO_2$/kg)** | 0.994 | 0.00122 | -3.38 | 0.0075 | 0.0026 | 1.6 | 0.000196 | 0.944 |
| | [64] | [61] | [62] | [63],[64] | [63],[64] | [64] | [63],[64] | [65] |

The values that has been used in current work is given in table 3.6.

## 3.5 Summary

The ratio which was designed for the PC preparation and concrete having particles of PET bottle particles and fibers of steel is 1:1.3:2.3 having w/c ratio of 0.49 is cast-off for both PC and concrete having PET bottle particles and steel fibers. There are 36 specimens produced in all, 24 cylinders and 12 beamlets for testing of both PC and concrete havingl fibers of steel and particles of PET bottle. The casting was done in university lab.The proportion of steel fiber in concrete is 2 % by volume having length of 40mm and diameter of 0.8mm, silica fume powder 2 % partially replaced with cement, 5 %,10 % and 15 % PET bottle particles partially replaced with sand and 1 % polycarboxylate liquid is added by the volume of concrete. There are 36 specimens produced in all, 24 cylinders and 12 beamlets for testing of both PC and concrete havingl fibers of steel and particles of PET bottle.

# Chapter 4

# Results & Discussions

## 4.1 Background

The designed ratio which was used for the preparation of specimens of both PC and concrete having partices of PET bottle and fibers of steel is 1:1.3:2.3. The water to cement ratio of 0.49 is preferred for all type of specimens. For the preparation of concrete having PET particles and steel fibers, 2 % cement is partially replaced with silica fume, steel fiber is added 2 % by volume with aspect ratio of 50 and PET particles are added by 5 %,10 % and 15 % partially replaced with sand. The chapter explains the detailed results after analysis and testing of all specimens of PC and concrete having PET particles and steel fibers.

## 4.2 Mechanical Properties

### 4.2.1 Properties Under Compressive Loading

Figure 4.1 shows the fracture pattern of specimens of the PC and concrete having particles of PET and fibers of steel under loading compression. The conventional PC (i.e. C: S: A: W only) and the mixtures containing admixtures, steel fibers and PET particles i.e. S1, S2, and S3 are compared. The admixtures were added to compromise in the target strenth i.e. 30 MPa. Similarly figure 4.2 shows the stress and strain curve of PC and concrete having PET particles and steel fibers. This situation is in three different stages; the cracks at initial, the cracks at peak, and the cracks at ultimate load. The target strength is 30 MPa with a mix design of C:S:A:W= 1:1.3:2.3:0.49. As the average of two readings are taken, so first sample of PC showed the 31.424 MPa , while the second sample showed the strength of 29.90, so the average of two readings gave us the 30.66 Mpa. The 30 MPa strength can be achieved while using C:S: A: W=1:1.58:2.27:0.46 with no binding material admixture [67].

The early appearance of crack at the surface of the particular PC specimens and that of concrete containing particles of PET and fibers of steel (i.e. S1, S2, and S3) is observed at 112 %, 94 %, and 79 % of their particular peak loads. The width of cracks in concrete having PET particles and steel fibers. The more crack width was observed in PC when compared with the concrete having PET particles and steel fibers i.e. S1, S2, and S3. The cracking process can be seen clearly in figure 4.1. Although, PC was broken into two pieces after the peak load, while the specimens containing PET particles and steel fibers were held together. The cracks propagation was visually observed. The values of C.S, C.P.E, C.C.E, C.T.E, and C.T.I of PC and concrete having PET particles and steel fibers i.e. S1, S2, and S3 are given in Table 4.1.

The strain values against the peak stress for PC, S1, S2 and S3 are 0.0046, 0.0044, 0.0047 and 0.0048. The S1 showed the minimum strain due to the maximum compressive strength as compared to PC, S2, and S3. This ensures that S3 have high property of elongation that allows the matrix to with stand together and resistance against the forces. Strain values are reduced in other specimens of concrete having steel fiber and PET bottle particles could be due to sliding effect of PET particles in matrix of concrete. The C.P.E of PC and concrete having PET particles and steel fibers i.e. S1, S2, and S3 are 0.070 MPa, 0.075 MPa, 0.067 MPa, and 0.058 MPa, correspondingly.

The steel fibers and PET bottle particles along with silica fume and polycarboxylate have played an important role in retaining the target strength. The combination of all the ingredients i.e. steel fiber, silica fume, polycarboxylate, and PET bottle particles have the potential to be used in civil engineering application. This will help the construction industry to solve the waste managment issue as the dumping of PET bottle particles requires landfill and also emits $CO_2$ which pollutes the environment.

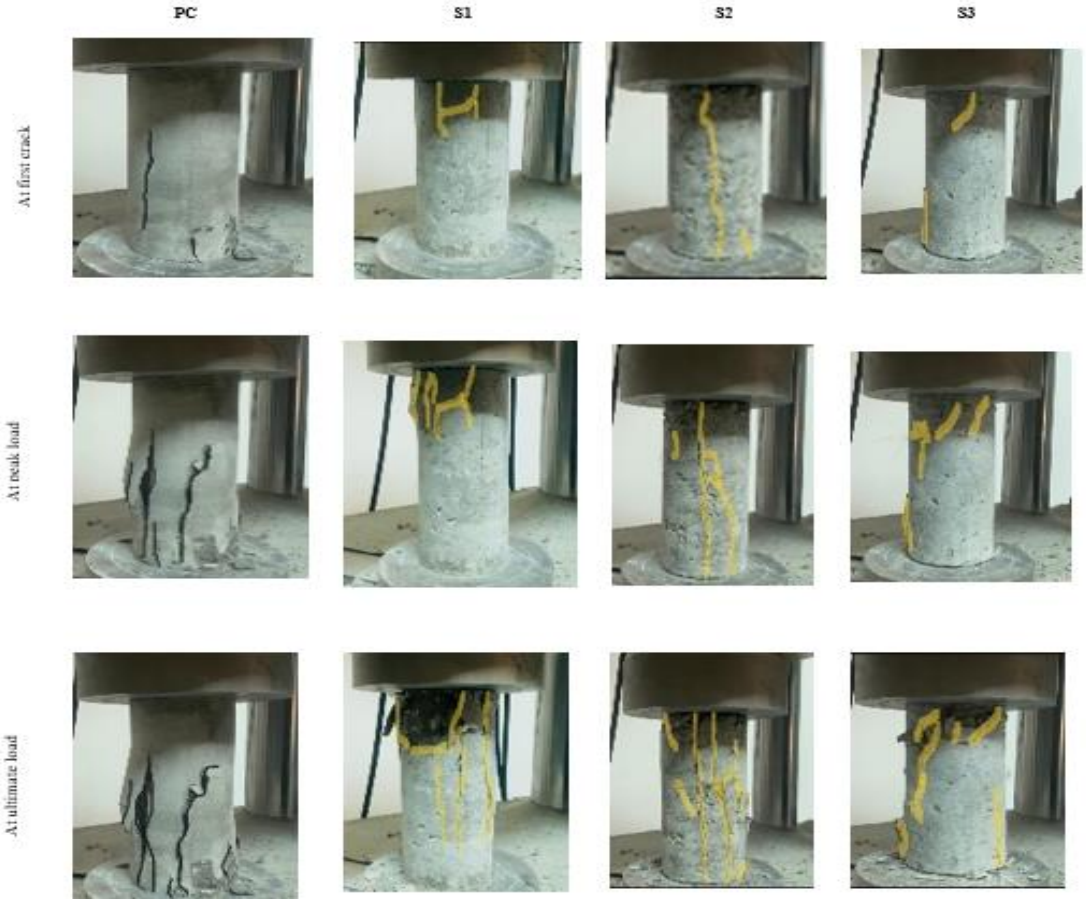


FIGURE 4.1: Cracking Pattern of PC and Mixtures

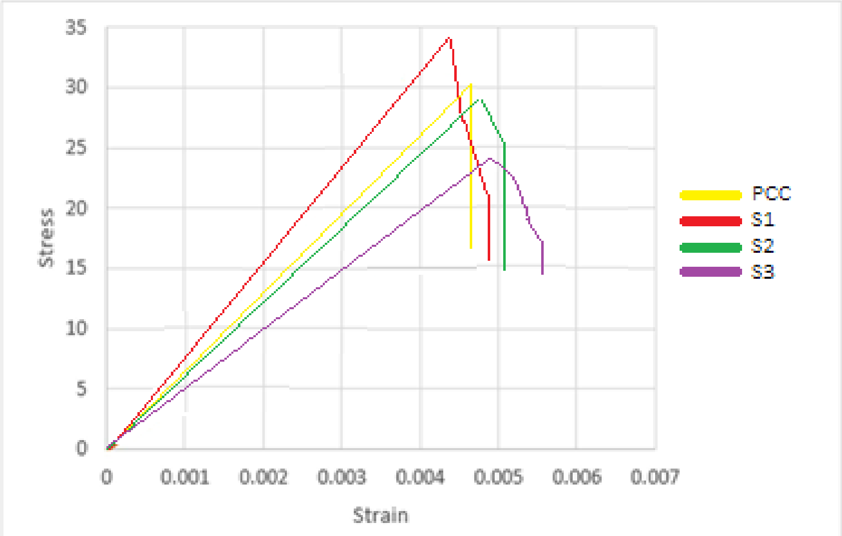


FIGURE 4.2: Compression Stress Strain Curve

Table 4.1: Compressive Strength Properties of PC and Concrete having PET Bottle Particles and Steel Fiber

| **Specimen** | **C.S (MPa)** | **Strain(-)** | **C.P.E (MJ/$m^3$)** | **C.C.E (MJ/$m^3$)** | **C.T.E (MJ/$m^3$)** | **CTI(-)** |
|---|---|---|---|---|---|---|
| **PC** | 30.6 | 0.0046 | 0.070 | 0.0013 | 0.071 | 0.98 |
| **S1** | 34.4 | 0.0044 | 0.075 | 0.011 | 0.086 | 0.872 |
| **S2** | 28.84 | 0.0047 | 0.067 | 0.010 | 0.077 | 0.870 |
| **S3** | 24.22 | 0.0048 | 0.058 | 0.014 | 0.072 | 0.80 |

When CPE values are compared with PC, there is reduction in values of concrete containing particles of PET and fibers of steel i.e. S1, S2, and S3, decrease in CPE value of S2 and S3 are observed when compared with PC, while there is increase in C.P.E of S1. The obtained values against C.C.E of PC and concrete having PET particles and steel fibers i.e. S1, S2, and S3 are 0.0013 MPa, 0.011 MPa, 0.010 MPa and 0.014 MPa correspondingly. The values of C.C.E is increased for the specimens having PET particles and steel fibers i.e. S1, S2, and S3 when compared with PC. The increment in the values of C.C.E in case of S1 and S2 are due to the increased energy absorption at post crack stage which resulted from the presence of steel fibers and less PET particles content as compared to S3. A reduction in the value of S3 when compared with S1 and S2 is due the more PET particles content. Same phenomenon can be observed when S2 is compared with S1. This is due to the increasing content of PET particles, which lowers the density and increases the air voids. Post cracks energy follows the same trend, less density results less post cracks energy and vice versa. So S1, S2, and S3's post crack energy depends upon the amount of PET particles which results the air voids enlargement and reduction in energy absorption in post crack stage values of these specimens.

The observed values for C.T.E of PC and concrete having PET particles and steel fibers i.e. S1, S2, and S3 are 0.071 MPa, 0.086 MPa, 0.077 MPa and 0.072 MPa. These shows an increase in values of S1, S2, S3 against C.T.E of PC. The increment in the values of C.T.E and C.C.E could be due to the addition of steel fibers in concrete mix and PET particles ratio that have improved the energy absorption at post crack stage of concrete. The value of C.T.I for PC and concrete having PET particles and steel fibers i.e. S1, S2, and S3 are 0.98, 0.872, 0.870 and 0.80 correspondingly. C.T.I values of PC and concrete having PET particles and steel fibers i.e. S1, S2, and S3 are observed. The addition of steel fibers and PET particles. The decrease in the value of S3 when compared with S1 and S2 is due to more ratio of PET particles. S1 and S2 have more C.T.I than PC and S3. S1 contains high C.T.I than other specimens. It can be noted that the addition of admixtures (silica fume and polycarboxylate) to the samples containing steel fibers and PET particles have played an important role in retaining the targeted strength. Without admixtures, strength could have been more compromised.

### 4.2.2 Properties Under Split Tensile Loading

Figure 4.4 depicts load-time curve of split loading at tensile. Figure 4.5 depicts the cracking behavior of PC and concrete specimens with PET particles and steel fibers, namely S1, S2, and S3 of split tensile loading. The pattern of loading for the crack at initial, the crack at loading at peak, and the pattern of cracking at loading at ultimate are all presented. Specimens of PC and concrete with PET particles and steel fibers, S1, S2, and S3, revealed cracks at peak load values of 100%, 97%, 93%, and 91%, correspondingly (see the upper four images of Figure 4.5). The fracture widths in concrete with PET particles and steel fibers, i.e. S1, S2, and S3, are substantially less than those in PC. The fracture lengths measured in concrete with PET particles and steel fibers, namely S1, S2, and S3, are around 66 mm, 61 mm, and 57 mm. The specimen of plain concrete (PC) breaks down into two parts without any time gap at its initial fracture. S1, S2, and S3 concrete specimens with PET particles and steel fibers, contrary to this, continue to make bonding so called bridging behavior. The breadth of fractures in concrete containing PET particles and steel fibers, i.e. S1, S2, and S3, is less at peak load value (look middle four images of Figure 4.5) that splits into two at its first crack. The fracture width in concrete with PET particles and steel fibers, i.e. S1, S2, and S3, is increased to 69 mm, 72 mm, and 76mm at this stage. S1, S2, and S3 concrete specimens with PET particles and steel fibers have provided values at load at ultimate that contradict the behavior of PC, moreover size of cracks found at ultimate loading are 73 mm, 78 mm, and 83 mm, correspondingly (see the bottom four photos in figure 4.4).Previous investigations on the fibrous concrete indicated that the width of the crack and phenomena of cracking in concrete containing PET particles and steel fibers, i.e. S1, S2, and S3, were smaller than plain concrete (PC). These describes the action of fibers, which reduces the brittleness of concrete by narrowing the fracture width.

To study the failure process in concrete with PET particles and steel fibers, i.e. S1, S2, and S3 specimens after purposely breaking the specimens following loading. The greatest load value is used to calculate the splitting tensile strength (S.S) of specimens. The absorbed energy of split at tensile before the fracture is defined as the area under the curve up to the value of the first crack (SPE). While the splitting-tensile post-crack absorbed energy is defined as the area following the first fracture value (S.C.E). This is vital to observe that the value for PC specimens is the same in both S.P.E and S.C.E scenarios since

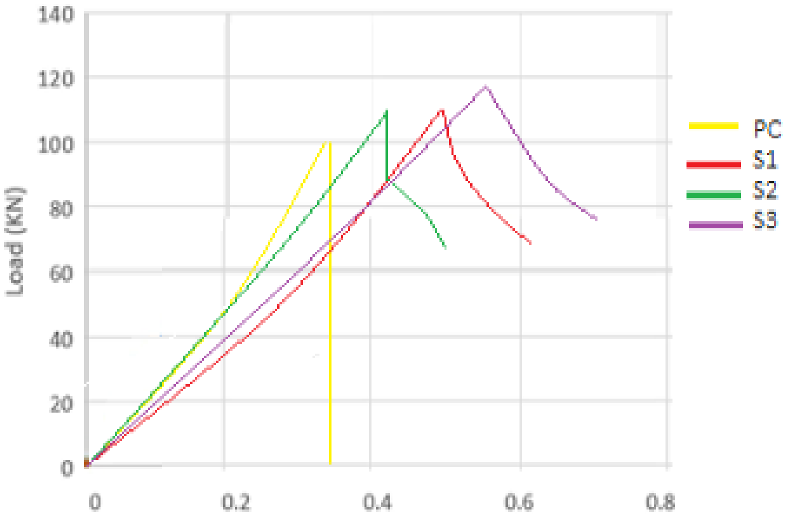


FIGURE 4.3: Load Deflection Curve under the Split- Tensile Loading

As energy absorbed at total for the split at tensile, the total area under the curve is calculated (S.T.E). The splitting-tensile toughness index is the percentage difference between splitting-tensile total absorbed energy and splitting-tensile pre-crack absorbed energy (STI).

Table 4.2 shows the load deflection curve data obtained against S.S, S.P.E, S.C.E, S.T.E, and S.T.I of plain concrete and that of concrete having PET particles and steel fibers i.e. S1, S2, and S3. The value for S.S of the specimens of PC and concrete having PET particles and steel fibers i.e. S1, S2, and S3 are 3.08 MPa, 3.39 MPa, 3.55 MPa, and 3.64 MPa correspondingly. An increase of 9%, 13.75%, 15 % observed in S.S of concrete having PET particles and steel fibers i.e. S1, S2, and S3 when compared with PC. The values of PC and concrete having PET particles and steel fibers i.e. S1, S2, and S3 obtained against SPE are 13.5 Nm, 24.75 Nm, 24.15 Nm, and 27.73 correspondingly.

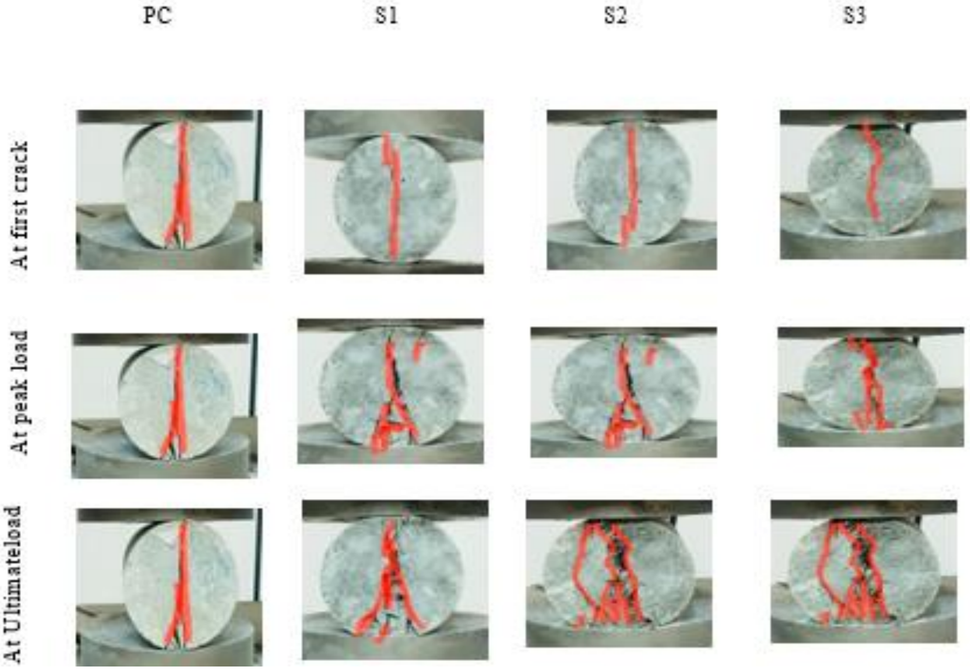


Figure 4.4: Cracking Pattern of PC and Mixtures

When the SPE of the PC is compared, the values for concrete having PET particles and steel fibers i.e. S1, S2, and S3 are increased by 45 %, 44 %, and 105 % correspondingly. The increased S.P.E values of concrete having PET particles and steel fibers i.e. S1, S2, and S3 could be due to the more content of lesser dense PET particles and steel fibers was used in a same manner as that for the process of PC.

The most decreased values of SPE of S3 are because of decreased bonding capacity of concrete matrix. While in case of S1, presence of steel fiber and PET particles negotiates the cracks generation at early stage due to the resistance towards the forces at shear. S3 shows a reasonably high value of SPE for this proposal i.e. 27.73. The SCE values for PC and concrete with PET particles and steel fibers, namely S1, S2, and S3, are 0 Nm, 9.9 Nm, 8.1 Nm, and 13.26 Nm. When compared to PC, the SCE of concrete specimens containing PET particles and steel fibers, i.e. S1, S2, and S3, has a higher value. The S1 and S3 have the highest SCE values.

Table 4.2: Split Tensile Strength Properties of PC and Concrete Having PET Bottle Particles and Steel Fibers

| Specimen | S.S (MPa) | S.P.E (Nm) | SC.E (Nm) | S.T.E (Nm) | S.T.I (-) |
|---|---|---|---|---|---|
| **PC** | 3.08 | 13.5 | - | 13.5 | 1 |
| **S1** | 3.39 | 24.75 | 9.9 | 34.65 | 0.71 |
| **S2** | 3.55 | 24.15 | 8.1 | 32.25 | 0.75 |
| **S3** | 3.64 | 27.73 | 13.26 | 40.56 | 0.68 |

Due to the steel fibers and PET particles bridging effect, these SCE values demonstrated the post fracture energy absorption behavior of concrete with PET particles and steel fibers, i.e. S1, S2, and S3, than that of PC. The S1, S2, and S3 values observed against STE of PC and concrete including PET particles and steel fibers are 13.5 N.m, 34.65 Nm, 32.25 Nm, and 40.56 Nm, correspondingly. In comparison to the STE value of PC, S1, S2, and S3 show increases of 156 %, 138 %, and 200 %, correspondingly. S1, S2, and S3 STI values for PC and concrete with PET particles and steel fibers are 1, 0.71, 0.75, and 0.68, correspondingly. In comparison to PC, STI of concrete with PET particles and steel fibers decreases by 29%, 25%, and 32 %, correspondingly.

### 4.2.3 Properties Under Flexural Loading

The figure 4.5 shows the bridging effect caused by steel fibers and PET particles while the region beneath the load-deflection curve is depicted in Figure 4.6. The Figure 4.7 depicts the cracking pattern of PC and concrete specimens with PET particles and steel fibers (S1, S2, and S3) under flexural stress, which may be notice at the generation of crack at first, load at peak, and the point of ultimate load. The photographs that is shown at first, the five photographs shows the cracking phenomena of PC and concrete with PET particles and steel fibers at the first fracture. The specimens of PC and concrete containing PET particles and steel fibers exhibit their first fracture at peak load values of 100%, 98%, 96%, and 93%, correspondingly. The breadth and length of early cracks in concrete containing PET particles and steel fibers are less than those in PC. The PC specimen was shattered at its first crack into two pieces, but beam-lets of concrete containing PET particles and steel fibers did not shatter into fragments due to the combined bridging action of the steel fibers and PET particles together as shown in figure 4.5.

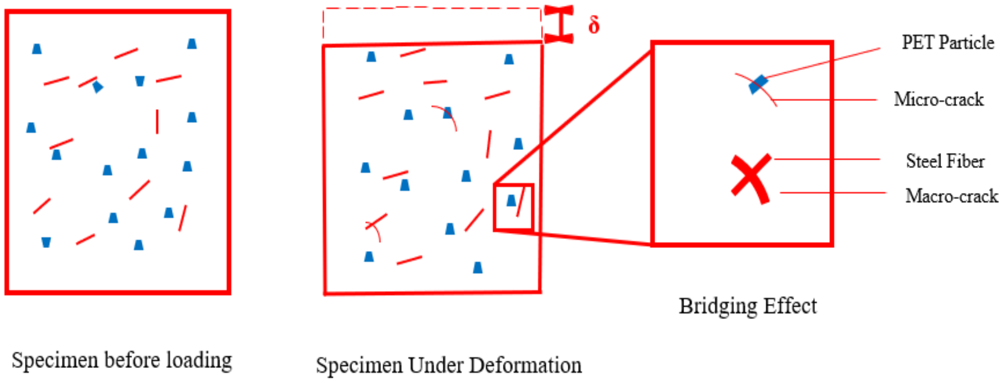


Figure 4.5: Bridging Effect Caused by Steel Fibers and PET particles

Figure 4.5 shows the appearance of cracks and the bridging effect caused by the steel fibers and PET particles. The waste PET particles when observed have the ability to brige cracks [55]. As the size of PET particles are small, so it can be seen from the figure that the steel fibers bridge the macro-cracks, while PET particles bridge the micro-craks. At peak load, concrete specimens containing PET particles and steel fibers have fewer fractures and are narrower than PC samples. At maximal load levels, cracks in concrete specimens containing PET particles and steel fibers grows less when compared it to the PC sample as given in the middle four photos in fig 4.7). The samples conatining 5%, 10% and 15% PET particles showed more bridging effect as we increase PET particles percentage. The cause of pull-out behavior and specimen fracture in flexural tests is similar to that discussed under the topic of split against tension property of PC and that of concrete containing PET particles and steel fibers. The load-deflection curve is used for finding the modulus of rupture (MoR) by taking the maximum load versus deflection value. The flexural energy is defined as the total area under the load-deflection curve (FTE). The toughness index at flexural (FTI) values are thus calculated by dividing the total absorbed energy at flexural by the pre-crack absorbed energy at flexural. The cause of pull-out behavior and specimen fracture in flexural tests is similar to that discussed under the category of split at tension property of PC and that of concrete with steel fiber and PET bottle particles.

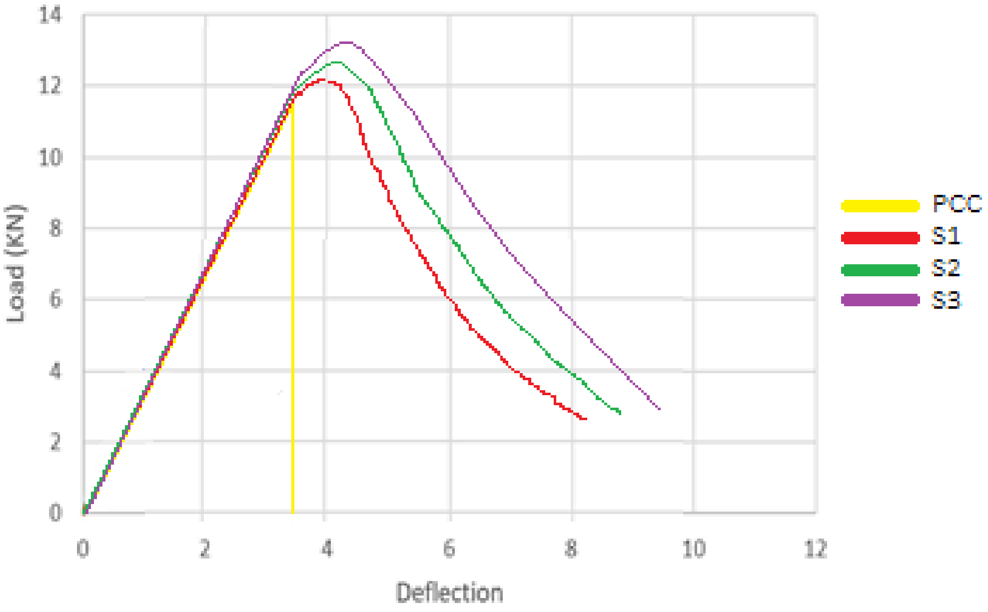


FIGURE 4.6: Flexural Behavior of PC and Mixtures

The maximum load versus deflection value derived from the load-deflection curve is used to determine the M.O.R. Flexural observed energy before crack incidence (FPE) is defined as the area under the load-deflection curve prior to the onset of the first fracture.

The graph and the figure shows that initial crack value of load and the peak load crack value are the same for PC specimens, since it fractured and distributed it into the two pieces at initially.

The values of MoR, F.P.E, F.C.E, F.T.E, and F.T.I derived from the load-deflection curve under flexural loading are shown in Table 4.3. MoR values for S1, S2, and S3 are 14.1 MPa, 14.64 MPa, 15.52 MPa and 15.84 respectively, and increased by 3%, 9%, and 12%, correspondingly, compared to PC. The improved MoR values in those specimens are attributed to the enhancement of post energy absorption at fracture and fiber bridging-effect due to the suitable steel fiber and PET particle loading in them. The decrease in MoR is related to poorer capacity of bridging, which may attributable to the existence of voids in those specimens is due to abundance of steel fibers and PET particles. The deflection peak load in PC and concrete with PET particles and steel fibers are 3.4mm, 3.9mm, 4.3 mm, and 4.6 mm, correspondingly. The greater magnitude of deflection is seen in specimens of S2 and S3. The rationale behind this might be the high fiber ratio of pull-out in those specimens. The F.P.E derived from load- deflection curve for PC and concrete incorporating PET particles and steel fibers are 19.97 Nm, 23.79vNm, 27.62 Nm, 30.36 Nm correspondingly.

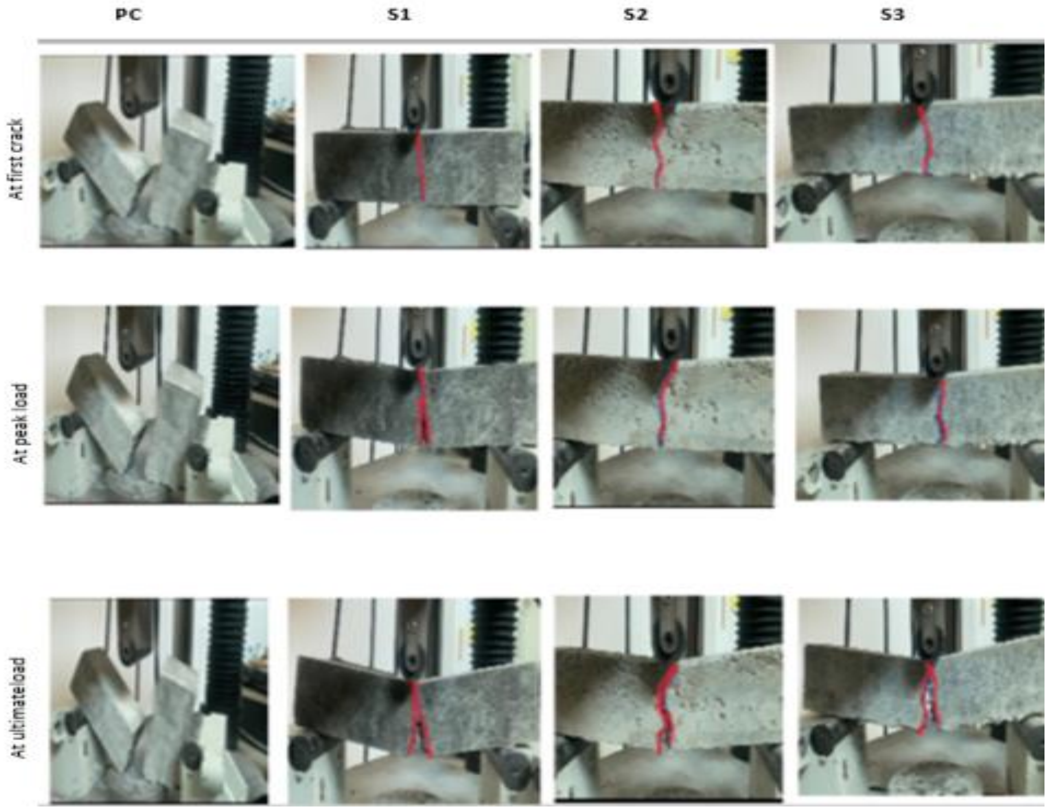


Figure 4.7: Cracking Pattern of PC and Mixtures

Concrete with PET particles and steel fibers had 19%, 38%, and 52% higher FPE values than PC. The explanation for the lowering values might be the high ratio of PET particles due to their less dense characteristic, which disrupts their appropriate distribution in matrix. The values of FCE of concrete incorporating PET particles and steel fibers derived from load-deflection curve are 32.25 Nm, 36.76 Nm, and 40.5 Nm correspondingly. The F.C.E value is not achieved for PC since it splits into duplets at the load at peak and first fracture. FTE values for PC and concrete with PET particles and steel fibers are 19.97 Nm, 56.04 Nm, 64.38 Nm, and 70.86 Nm, correspondingly. The increment in the values of F.T.E is observed in case of S1, S2 and S3 by 180 %, 222 % and 254 %, correspondingly, then the FTE value of PC. The FTI in case of PC and concrete having PET particles and steel fibers are 1, 0.73, 0.75, and 0.74 correspondingly.

TABLE 4.3: Flexural Strength Properties of PC and Concrete Having Steel Fibers and Waste PET Bottle Particles

| **Specimen Parameters** | **MoR (MPa)** | **$\Delta$ (mm)** | **FPE (Nm)** | **FCE (Nm)** | **FTE (Nm)** | **FTI(-)** |
|---|---|---|---|---|---|---|
| **PC** | 14.1 | 3.4 | 19.97 | - | 19.97 | 1 |
| **S1** | 14.64 | 3.9 | 23.79 | 32.25 | 56.04 | 0.73 |
| **S2** | 15.52 | 4.3 | 27.62 | 36.76 | 64.38 | 0.75 |
| **S3** | 15.84 | 4.6 | 30.36 | 40.5 | 70.86 | 0.74 |

For F.T.I of PC an decrease of 27 %, 25 %, and 26 % are observed in FTI of concrete having PET particles and steel fibers. The increased post-crack energy levels and superior post-crack behavior of concrete containing PET particles and steel fibers result in improved flexural toughness indices. S1 is suggested since it has the finest qualities among the other specimens. In specimens of S2 and S3, the presence of PET particles and steel fibers created a bridging effect with somewhat acceptable properties, which is important for holding cracking in rigid pavements. However, the presence of a high concentration of PET particles reduces toughness while creating a bridging mechanism that resists cracking and causes higher energy absorption for concrete specimens including PET particles and steel fibers.

## 4.3 Dynamic Properties

The dynamic characteristics of the PC and concrete containing PET particles and steel fibers are evaluated in order to examine the influence of impact on concrete specimen properties. ASTM standard S215-14 are used to determine the dynamic parameters of all types of specimens. Due to the lack of a particular standard, the dynamic characteristics of concrete containing PET particles and steel fibers are determined using the same standard. For accurate findings, an average of three readings is written. Table 4.4 displays the determined dynamic characteristics of concrete. In the case of cylinders, the damping ratio of concrete including PET particles and steel fibers is 142%, 87.9%, and 38% higher than PC. In the case of cylinders, the damping ratio for the concrete including PET particles and steel fibers is 142%, 87.9%, and 38% higher than that of PC. The damping ratio of concrete incorporating PET particles and steel fibers beam lets is raised by 88.7

Table 4.4: Dynamic Properties of PC and Concrete Having PET Bottle Particles and Steel Fibers

| **Specimen** | **RFI (Hz)** | **RFt (Hz)** | **RFr (Hz)** | **Dynamic ratio (%)** | **Dynamic modulus of elasticity (GPa)** | **Dynamic modulus of rigidity(GPa)** | **Poisson ratio(-)** |
|---|---|---|---|---|---|---|---|
| **Cylinder** | | | | | | | |
| **PC** | 5684 | 3454 | 3410 | 3.83 | 4.1 | 4.56 | 0.49 |
| **S1** | 5278 | 5312 | 3368 | 9.3 | 9.92 | 6.56 | 0.77 |
| **S2** | 3398 | 3410 | 3289 | 7.2 | 4.26 | 4.41 | 0.47 |
| **S3** | 3306 | 3298 | 1288 | 5.29 | 4.18 | 4.22 | 0.47 |
| **Beam** | | | | | | | |
| **PC** | 3376 | 3302 | 3340 | 1.78 | 2.10 | 4.06 | 0.27 |
| **S1** | 3410 | 3536 | 3306 | 3.36 | 5.26 | 3.98 | 0.66 |
| **S2** | 2066 | 3171 | 1247 | 4.28 | 6.08 | 4.17 | 0.75 |
| **S3** | 3845 | 1677 | 3448 | 3.10 | 6.60 | 4.34 | 0.79 |

The cylinder specimens of concrete with PET particles and steel fibers experi- enced a rise in dynamic modulus of elasticity by 141.9%, 3.9%, and 1.9% as compared to that of plain concrete. In the case of concrete with PET particles and steel fibers beams, a rise

of 150.4%, 189.5%, and 214.2% is seen above PC specimens. The cylinder specimens of concrete with PET particles and steel fibers exhibits an enhanced modulus of stiffness values are 6.56 GPa, 4.41 GPa, and 4.22 GPa, whereas the PC value is 4.56 GPa. While the specimens of beam-lets of concrete containing PET particles and steel fibers exhibit higher values of 3.98GPa, 4.17GPa, and 4.34GPa, correspondingly, than PC.
These concluding findings of dynamic properties reveal that the specimens S1, and S2 have performed better in comparison with S3 and PC against dynamic characteristics, that displays their performance against the effects of loading. As a result, S1 and S2 specifications can increase the impact loading in pavement improvement.

## 4.4 Water Absorption, Linear Shrinkage and Mass Loss

Water absorption is defined as the transfer of liquid by the capillarys action and is calculated as the total absorbed water mass divided by the original mass after drying in oven. Water absorption values are shown in Table 4.5.

Table 4.5: W/A and L/S (%) of PC and Concrete Having PET Bottle Particles and Steel Fibers

| **Parameters** | **PCC** | **S1** | **S2** | **S3** |
|---|---|---|---|---|
| **W/A** | 2.45 | 2.72 | 3.06 | 3.88 |
| **L/S** | 0.082 | 0.073 | 0.091 | 0.0112 |

The shrinkage in linear values of PC and concrete having PET particles and steel fibers are 0.082, 0.073, 0.091, and 0.112 respectively. An increased L.S value of 10.9% in S2 and 36.5 % for S3, while 10% decreased for S1 is noticed, correspondingly. The reduced .An increased L.S is high values of strength at tensile . The wetting and drying caused the change, so the decrease values of L.S of S1 tells its good progress towards the prevention of cracks by the reduction in stress at tensile that originates due to the dry and shrinkage process. Hence, the conclusion is that S1 helps the reduction in tensile stresses. The definition of mass is as the specimens variation in mass of specimens as the temperature increases, and it is calculated for the specimen by heating upto 100 degrees Celsius and progressively raising the temperature by 3 degrees Celsius every minute. This slow transition enables the specimens water to escape. The change in loss in mass is indicated in given Table 4.6. It was cleared that specimens drop bulk progressively with rising temperature. For 50C, 75C, and 100C, the loss in mass was higher, ranging from -0.036 to -0.042 to -0.104.

Table 4.6: M/L (%) of PC and Concrete Having PET Bottle Particles and Steel Fibers at high temperature

| **Concrete mix** | **Temperature 50 (C)** | **Temperature 75 (C)** | **Temperature 100 (C)** |
|---|---|---|---|
| **PC** | -0.036 | -0.042 | -0.104 |
| **S1** | -0.044 | -0.052 | -0.130 |
| **S2** | -0.059 | -0.062 | -0.144 |
| **S3** | -0.061 | -0.066 | -0.159 |

However, due to the strong water absorption characteristics of the fiber in these specimens, larger values of loss in mass were reported for concrete containing PET particles and steel fibers. The loss in mass in case of concrete incorporating PET particles and steel fibers was observed gradually at high temperature upto 100 degree Celsius, the mass lost doesnt cause any wider fractures or spalling. Melting of PET particles and the production of micro fissures in concrete regulated the generation of internal pressure in concrete, reducing the spallings and laminations process at high temperatures. Thus, it is obvious from inquiry that PET particles and steel fibers regulate the abrupt loss in mass and concretes spalling by bridging, production of micro-cracks, melting and by lowering internal pressures. The silica fume and polycarboxylate played an important role in retaining the targeted strength as PET bottle particles reduces the some parameters, while using silica fume and polycarboxylate maintains the strength that has been lost.

## 4.5 SEM Analysis of Concrete Samples having PET Bottle Particles and Steel Fiber

SEM investigation of concrete specimens containing PET particles and steel fibers reveals the presence of air spaces in the concrete mix, as illustrated in the image below. High magnification reveals a needle-like Ettringite structure. Under SEM inspection, both PET particles and steel fibers may be detected in a fragmented specimen of concrete containing PET particles and steel fibers. Figure 4.9 depicts circumferential debonding around fibers and particles. The existence of two distinct fibers and particles in a concrete mix results in a large number of air spaces. The implanted PET particles size reveals that size induce increase in the forces of pull-out and enhanced particle size. The given figure of SEM depicts the particles size and fibers length resistance and its bond in the concrete matrix using SEM examination.

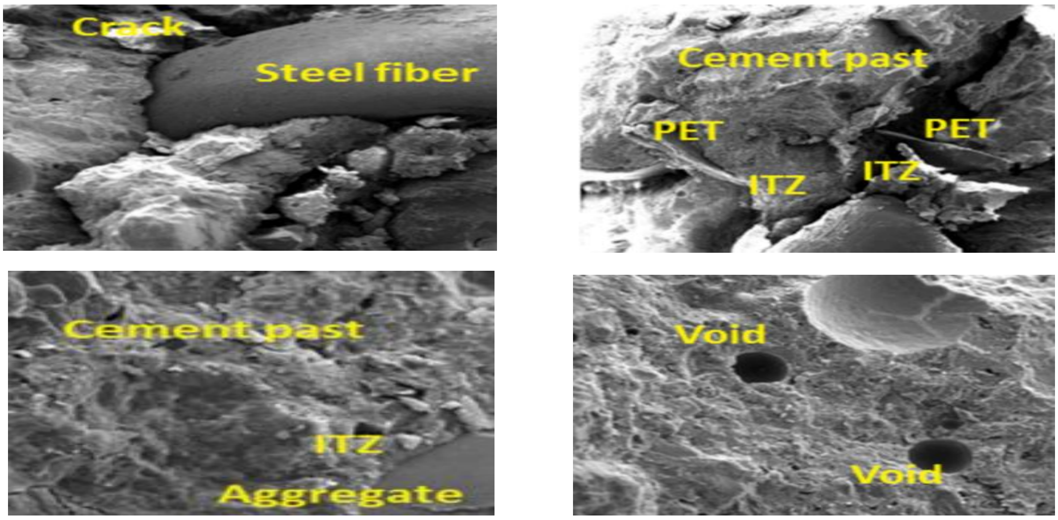


Figure 4.8: SEM of Damaged Surfaces

Fiber's roughened and damaged surfaces demonstrate that the resistance to debonding. The SEM photos clearly shows the particles and fibers remains in the concrete matrix even after the pull-out forces and heavy loading, demonstrating the bridging effect and pull-out resistance, which considerably improves qualities of concrete. The admixtures in concrete mix also played an important role for the reduction in air voids, which lowers the concrete durability and strength.

## 4.6 Life Cycle Assesment (C$O_2$ Emission from Cradle to Gate)

The quantities which have utilized for the manufacture of PC and other concrete mixes i.e. S1, S2 and S3 is listed in table 4.7. The quantity of $CO_2$ emitted that will harm the environment is also computed, as is the amount of $CO_2$ avoided from entering the environment and contaminating

TABLE 4.7: $CO_2$ Emission Evaluation of Concrete Mixes

| **Mixture** | **Cement** | **Sand** | **Aggregate** | **Water** | **Silica Fume** | **Superplasticizer** | **PET particles** | **Steel Fibers** | **Total-amount-(kg-C$O_2$/kg)** |
|---|---|---|---|---|---|---|---|---|---|
| **PC** | 13.25 | 0.045 | 0.23 | 0.0012 | - | - | - | - | 13.52 |
| **S1** | 12.98 | 0.043 | 0.23 | 0012 | 0.0003 | 0.63 | -2.52 | 2.08 | 13.44 |
| **S2** | 12.98 | 0.040 | 0.23 | 0012 | 0.0003 | 0.63 | -5.85 | 2.08 | 10.11 |
| **S3** | 12.98 | 0.038 | 0.23 | 0012 | 0.0003 | 0.63 | -8.75 | 2.08 | 7.2 |

As given in table 4.7, the emission of C$O_2$ for PC is more than the mixtures. The reduction in the amount of C$O_2$ for S1 is 8% while for S2 and S3 shows 28 % and 52.3 %, when compared with PC, reduction in the C$O_2$ emission is observed which is polluting the environment. According to the Habert et al [68] it has to be noted that the carbon dioxide emission factor for the transfer of materials is 0.00017 kg per km.

## 4.7 Summary

The mix ratio which was designed is 1:1.3:2.3 and a w/c ratio of 0.49 for the specimens casting, the mechanical characteristics, dynamic characteristics, absorption of water, loss in mass, and shrinkage in linear parameters of PC and concrete including PET particles and steel fibers are determined. When compared to PC, the concrete with PET particles and steel fibers had a higher MoR and improved post-crack energy absorption behavior. The inclusion of PET particles and steel fibers in concrete having PET particles and steel fibers results in higher value of absorption of water. When compared to PC, there is a decrease in LS of S1. By improving both the mechanical and dynamic qualities of concrete, S1 outperformed all other concrete specimens. This concrete mix also decreased the LS of concrete specimens, ensuring their crack-controlling ability.

# Chapter 5

# Discussion

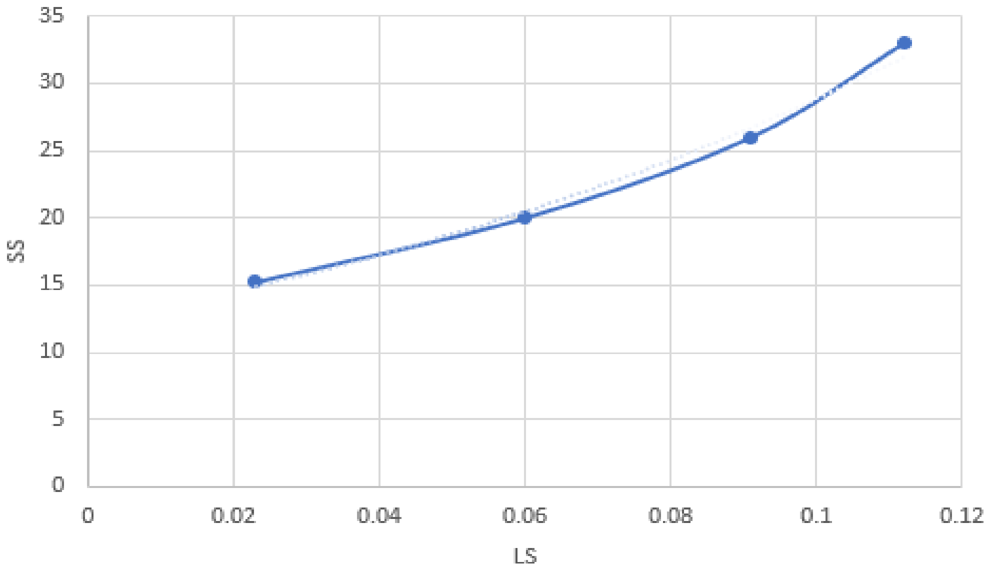
## 5.1 Background

The testing findings provided quantifiable information on the influence of the PET particle/steel fiber ratio on the characteristics of concrete containing PET particles and steel fibers. The graphs of stress and strain, deflection at load, and deformation at load depict the influence of particles and fibers on the mechanical characteristics and dynamic characteristics of concrete containing PET particles and steel fibers. This information is then used to build an empirical relationship between the mechanical and dynamic properties of concrete containing PET particles and steel fibers. Furthermore, discussion on employment of this freshly produced concrete in practical world approach is presented in this chapter.

## 5.2 Empirical Relation Between Linear Shrinkage and Splitting Tensile Absorb Energy

The mechanical characteristics, dynamic characteristics, absorption of water, loss in mass, and shrinkage in linear qualities of a structure may be used to evaluate its performance. Concrete characteristics are influenced by a variety of factors, including material attributes and content. These causes cause cracking and faulting, impairing structural performance.

Most commonly cracking in concrete pavements is due to shrinkage in linear. The characteristic of split at tensile in concrete and the quantity of absorbed energy by specimens are also connected to cracks in concrete. Before cracking, the empirical relationship is established in between shrinkage in linear and split strength energy absorption at tensile. It can be used as a production indicator, particularly although artificial fibers and particles are used in concrete.



$$y = 12.242e^{8.578x} \ldots\ldots\ldots\ldots 5.1$$

Figure 5.1: Empirical Relation Between Linear Shrinkage and Splitting Tensile Energy Absorption Before Cracking

Figure 5.1 depicts the empirical relationship between shrinkage in linear and energy absorption of split at tensile before cracking. The cracking in concrete pavements is due to shrinkage in linear. The characteristic of split at tensile in concrete and the quantity of absorbed energy by specimens are also connected to cracks in concrete. Before cracking, the empirical relationship is established in between shrinkage in linear and split strength energy absorption at tensile. It can be used as a production indicator, particularly although artificial fibers and particles are used in conventional concrete. The empirical relationship is established in between shrinkage in linear and split strength energy absorption at tensile.

Table 5.1: Values of Linear Shrinkage from Empirical Equations and Experimental Data With Their Percentage Difference

| **Specimen** | **Linear Shrinkage and Splitting Tensile Energy Ab-sorption** | **Linear Shrinkage** | **Linear Shrinkage** | **Linear Shrinkage** |
|---|---|---|---|---|
| - | **J** | **Experimental Results (%)** | **Empirical Results(%)** | **Difference%** |
| **PC** | 15.22 | 0.082 | 0.058 | 24 |
| **S1** | 24.26 | 0.073 | 0.072 | 1 |
| **S2** | 22.16 | 0.091 | 0.088 | 3 |
| **S3** | 38.90 | 0.112 | 0.108 | 4 |

## 5.3 Design of Rigid Pavement

The two key parameters are M.o.E and M.o.R which influences the depth of the rigid pavement in rigid pavement design. AASHTO and ACPA Street Pave software both use these two parameters. Thus, the thickness of concrete pavement may be lowered by raising the M.o.E and M.o.R values while holding all other factors constant [69]. According to Delatte [70], ASSHTO suggests determining M.o.E using specimen compressive strength. Because M.o.E no significantly influences thickness of concretes pavement. As a result, the compressive strength of concrete specimens may be used to compute it. Table 5.2 compares the computed thickness values for concrete with PET particles and steel fiber specimens to PC.

For each concrete mix, the M.o.R and M.o.E values would be different. The width of concretes pavement is estimated manually by ASSHTO equation for pavement, that is expressed as; Except for Ec i.e. concretes elastic modulus (psi) and Sc = strength of concrete at flexural (psi), that are changeable and derived by experiment, the values of other parameters will be constant.

$$\log_{10} W_{18} = Z_R S_o + 7.35 \log_{10}(D+1) - 0.06 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.5-1.5}\right]}{1+\frac{1.624\times 10^{7}}{(D+1)^{8.46}}} + (4.22 - 0.32\rho_t)\left[\frac{S'_c C_d \left[D^{0.75} - 1.132\right]}{215.63 j \left[D^{0.75} - \frac{18.42}{\left(\frac{E_c}{k}\right)^{0.25}}\right]}\right]$$

Constant

Table 5.2: Pavement Thickness Design of Rigid Pavement by Using ASSHTO Equation

| Specimen | Modulus of rupture-(MoR) | Compressive Strength | Elastic Modulus(E) | Thickness from ASSHTO equation (h1) | Thickness from ASSHTO equation (h1) |
|---|---|---|---|---|---|
| **-** | **(MPa)** | **(MPa)** | **(Mpa)** | **(inch)** | **(mm)** |
| **PC** | 7.8 | 30.68 | 18650.4 | 11.13 | 282.702 |
| **S1** | 8.6 | 34.4 | 15203 | 7.59 | 192.786 |
| **S2** | 8.9 | 28.84 | 14884.6 | 8.5 | 215.9 |
| **S3** | 9.2 | 24.22 | 11494.8 | 9.74 | 247.396 |

W18 =equivalent standard axle loads for Traffic load (5.1 106 ESALs), ZR = deviation at standard normal for intended reliability (value corresponds to 95% reliability (R) are -1.645, S.O = Overall standard deviation i.e. 0.30 PSI=index of serviceability 2.5 with initial serviceability 4.2, Cd= coefficient of drainage, J=-3.2 coefficient of load transfer, and k=72 is subgrade reaction modulus (psi/in). When comparing S1 to PC, the low thickness value of stiff pavement is achieved. While S2 and S3 have lower thickness values with superior mechanical and dynamic qualities when compared to PC, they are somewhat greater than S1. The presence of PET particles in these specimens may be the cause of the higher MoR readings. The modulus of rupture (MoR) is an essential factor in lowering concrete thickness. The thickness of the S1 specimens was lowered, resulting in a reduction in material requirements and an overall cost reduction for the project. The need of hour for the under-developing counties is to discover the materials that sustainably improve the working of a structure and low demand of natural resources that cannot be recycle and requires low budget.

## 5.4 Practical Implementation

Concrete in diverse application and also endures numerous sorts of loadings which includes the dynamic loading as well as mechanical loading. These loadings have an impact on the performance of the concrete and parameters such as tensile strength, compressive strength, and so on. In applications of rigid pavement, the crack appearance results in failure, which is primarily driven by shrinkage in linear, absorption of water, and strength at tensile, is typically hold out against by the concrete's characteristics of flexural and tensile[71]. Cracking in concrete could be controlled when the produced stresses are lesser than the strength at tensile of the concrete [72]. The settlement of differential may also addressed by increasing the strength at flexural of the . So in-results, to minimize concrete damage, both mechanical and dynamic loadings must be properly considered.

The behavior of PC and concrete containing PET particles and steel fibers is examined in this study as the PET particle concentration varies. In compared to PC and S3 specimens, S1 and S2 specimens performed better in terms of pavement application by improving mechanical characteristics of concrete. It is also crucial to note that S3 specimens fared better than PC specimens. S1 and S2 can minimize cracking due to improved strength at flexural and strength at tensile qualities of the concrete. These can also be seen in the relationship between ratio of damping values and dissipation of energy values derived from the data obtained from the experiment. Because the resonance created during a seismic event can induce structural collapse (bridges, for example) [73].

FIGURE 5.2: WFRC Pavement [73]

The increased damping ratio values in the case of concrete containing PET particles and steel fibers demonstrate their influence on an system of oscillation due to the greater absorption of energy of the specimens when compared with PC. The enhanced properties of concrete including PET particles and steel fibers demonstrated crack reduction capabilities; practical adoption of the researched material which will result in higher pavement in functionally, durably, and efficiently. Farooqi and Ali [74] built the rigid pavement by the fibers reinforced concrete, ensuring its practicality and performance. Figure 5.2 depicts the installation and construction of FRC. The construction rigid pavement having fiber reinforced has demonstrated the efficacy of fibers for rigid pavement applications. Due to the excess availability, simple tackling, efficient qualities, particles and fibers are the mostly researched and used material in the concrete now-a-days. The only disadvantage of their actual execution is their lack of easy availability for the use in commercial application. The enhanced properties of concrete including PET particles and steel fibers demonstrated crack reduction capabilities; practical adoption of the researched material which will result in higher pavement in functionally, durably, and efficiently. If processed fibers are distributed to the construction sector with sufficient knowledge, utilization of various resources that are natural may be reduced while total costs are reduced and structural performance and life are increased, particularly for the construction of hard pavements.

## 5.5 Summary

Concrete's characteristics relationship and cracks has been investigated. In the above chapter explored the effect of particles and fibers on the characteristics of concrete, as well as their quantities. The studies reported here demonstrated that concrete containing PET particles and steel fibers may prevent cracking in stiff pavements better than plain concrete. Concrete fibers result in substantial post-crack energy absorption. According to the final suggestions, S1 and S2 can effectively limits the cracking rate in stiff pavements.

# Chapter 6

# Conclusion and Recommendations

## 6.1 Conclusion

To evaluate the feasibility of using PET bottle particles and steel fibers containing admixtures in concrete, various experimental procedures were conducted. In the current study PET bottle particles are used as partial replacement of sand in three different proportions i.e. 5%, 10%, and 15%. The mix design used is 1:1.3:2.3 with a water cement ratio of 0.49. The dynamic, mechanical, water absorption, linear shrinkage, and mass loss tests are performed along with the microstructural analysis and following conclusions are drawn:

- S1 shows the maximum compressive strength when compared with S2, S3 and PC. Increase in the content of PET particles decreases the compressive strength due to the low density of PET particles. On the other hand, silica fume restricts the compromise in compressive strength due to its bonding property in cement matrix.
- The splitting tensile strength of S1, S2 and S3 are increased as compared to the reference specimens due to the bridging effect of steel fibers .An increase of 9%, 13.75%, 15 % observed in S.S of concrete having PET particles and steel fibers i.e. S1, S2, and S3 when compared with PC. S3 showed the more split tensile energy when compared with S1, S2 and PC. This increase is due to the bridging effect of steel fibers and high content of PET particles i.e. 15%, that increase the splitting

tensile value of the concrete.

- The Flexural strength of concrete increases with the increase in the content of PET particles. The modulus of rupture of S1, S2 and S3 increased up to 3%, 9%, and 12%, correspondingly than that of PC. The overall flexural energy absorption capacity also increases with the increase in the content of PET particles. This means that the even after peak load the specimen absorbs energy due to the PET particles.
- The dynamic testing reveals that the damping ratio of S1 concrete is more as compared to the S2, S3 and PC. The increase in the dampness is due to the decrease in the density of concrete. S2 shows more damping ratio as compared to S3.
- The water absorption values increases when we add more PET particles, this is due to the improper compaction due to the presence of steel fibers and PET particles, and more PET particles creates voids, which results in increase in water absorption values.
- The Linear shrinkage of concrete having PET particles and steel fibers increases with the increase in the content of PET particles. An increased LS value of 10.9% in S2 and 36.5% for S3, while 10% decreased for S1 is noticed, respectively, this happens due to the tensile load bearing capacity of the PET particles and steel fibers. Moreover, the water absorption capacity of the concrete having PET particles and steel fibers increases due to the water absorbing capacity of the fibers and particles.
- A correlation has been established between the split tensile pre-crack energy absorption, linear shrinkage, and properties of PET and steel fibers reinforced concrete and those of PC. This correlation aids in determining the shrinkage rate through the utilization of split tensile pre-crack energy absorption of the specimens.
- The SEM imaging reveals that some of the particles and fibers were pulled out while others were broken. The particles and fibers act as anchors between the concrete matrix. More- over, a higher densification was observed due to the silica fume. The SEM also confirms the formation of new bonds which lead towards the restriction of reduction in compressive strength to greater extent. The new concrete's fibers pulled out effect and densification due to admixtures can also be observed, and PET bottle particles bridging can also be seen which bridges the mico-cracks due to

smaller in size.

- The reduction in the amount of $CO_2$ for S1 is 0.6% while for S2 and S3 shows 28% and 52.3% reduction when compared with PC, reduction in the $CO_2$ emission is observed which is polluting the environment.
- The rigid pavements using the optimized mix, reveals that the thickness of the rigid pavement can be reduced up to 25%-33% due to the increase in the modulus of rupture. Furthermore, the distress generation in rigid pavement designed using the optimized mix, is lesser as compared to the design using the conventional mix.

Hence, based on the above results, S1 concrete has great potential to be used in rigid pavements for more sustainability and greater performance, as it is environment friendly and cost friendly as well.

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