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PROPERTIES OF GREEN HIGH PERFORMANCE CONCRETE REINFORCED WITH DIFFERENT FIBERS

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BY

MOHAMMED NAJAT AHMED

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PROPERTIES OF GREEN HIGH PERFORMANCE CONCRETE REINFORCED WITH DIFFERENT FIBERS

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Civil Engineering

Gaziantep University

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by

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September 2021

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Mohammed Najat AHMED

ABSTRACT

PROPERTIES OF GREEN HIGH PERFORMANCE CONCRETE REINFORCED WITH DIFFERENT FIBERS

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M.Sc. in Civil Engineering
Supervisor: Assoc. Prof. Dr. Mehmet Tolga GÖĞÜŞ
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An experimental work was carried out to investigate the mechanical properties of Green High Performance Concrete (GHPC) reinforced individually with three different types of fibers such as polypropylene fiber (PPF) ,carbon fiber (CF), and glass fiber (GF) with volume fractions 0.3%,0.6%,and 1%. For this, GHPC mixtures were produced using silica fume (SF) at 20 percent as a partial substitute by cement weight, in addition to using the super plasticizer (SP) to obtain the appropriate workability with low w/b ratio. A constant w/b ratio of 0.35 was used for the produced mixtures, and in order to control the workability of the mixtures, the super plasticizer ratios were modified. Standard curing was used in this study, then the specimens were tested for compressive strength and flexural strengths. The results show that the blends reinforced with polypropylene fiber, carbon fiber, and glass fiber with fractions of volume of 1%, 0.6 %, and 0.3 %, respectively, demonstrated the highest compressive and flexural strength.

Key Words : Mechanical Properties , Green High Performance Concrete , Polypropylene Fiber , Carbon Fiber , Glass Fiber.

ÖZET

FARKLI ELYAFLARLA GÜÇLENDİRİLMİŞ YEŞİL YÜKSEK PERFORMANSLI BETON ÖZELLİKLERİ

AHMED, Mohammed Najat
Yüksek Lisans Tezi, İnşaat Mühendisliği
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67 sayfa

Polipropilen fiber (PPF), karbon fiber (CF) ve cam fiber (GF) olmak üzere üç farklı fiber türü ile tek tek güçlendirilmiş Yeşil Yüksek Performanslı Betonun (GHPC) mekanik özelliklerini hacim fraksiyonlarına sahip olarak incelemek için deneysel bir çalışma yapılmıştır %0,3, %0,6 ve %1. Bunun için, düşük w/b oranı ile uygun işlenebilirliği elde etmek için süper akışkanlaştırıcı (SP) kullanımına ek olarak, çimento ağırlığının kısmi ikamesi olarak %20 oranında silika dumanı (SF) kullanılarak GHPC karışımları üretilmiştir. Üretilen karışımlar için 0.35 sabit w/b oranı kullanılmış ve karışımların işlenebilirliğini kontrol etmek için süper akışkanlaştırıcı oranları modifiye edilmiştir. Bu çalışmada standart kürleme kullanılmış, daha sonra numuneler basınç dayanımı ve eğilme dayanımı açısından test edilmiştir. Sonuçlar, sırasıyla %1, %0,6 ve %0,3 hacim oranlarına sahip polipropilen elyaf, karbon elyaf ve cam elyaf ile güçlendirilmiş karışımların en yüksek basınç ve eğilme mukavemetini gösterdiğini göstermektedir.

Anahtar Kelimeler: Mekanik Özellikler, Yeşil Yüksek Performanslı Beton, Polipropilen Elyaf, Karbon Elyaf, Cam Elyaf.

''Dedicated to my family''

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LIST OF ABBREVIATIONS

HPC	High Performance Concrete
GHPC	Green High Performance Concrete
PPF	Polypropylene Fiber
CF	Carbon Fiber
GF	Glass Fiber
SF	Silica Fume
SP	Super Plasticizer
w/b	Water binder ratio
OPC	Ordinary Portland Cement
SCMs	Supplementary Cementitious Materials
PFA	Pulverized Fly Ash
GGBS	Ground Granulated Blast furnace Slag
W	Water
CA	Coarse Aggregate
FA	Fine Aggregate
ASTM	American Society for Testing and Materials
GHPFRC	Green High Performance Fiber - Reinforced Concrete
GHPPPFRC	Green High Performance Polypropylene Fiber Reinforced Concrete
ITZ	Interfacial Transition Zone

CHAPTER I

INTRODUCTION

1.1 General

High performance concrete (HPC) is a mixture of concrete that, compared to traditional concrete, has high toughness and high strength. HPC is the one of the best cementitious composites. It is intended to offer optimal performance qualities for the resources in the provided collection, exposure and conditions of use, according to the cost, durability and service life [1]. Engineers and designers around the world are discovering that using High-performance concrete enables them to create more durable constructions at same costs. HPC is used to resist harsh environmental conditions, pavements and highway bridges, coastal structures, precast units, tunnels, etc. [2]. The use of mineral and chemical admixtures is basically the main difference between traditional concrete and HPC. Chemical admixtures, such as super plasticizers are used to decreases the content of water and thereby lowers the porosity of the hydrated cement paste and gives high flow ability which allow to fill in congested reinforcement zones. Mineral admixtures ensure that the mortar matrix's porosity is further decreased and improved the Aggregate Interface [3]. So a (HPC) meets special requirements of consistency and regularity that cannot always be regularly accomplished by using only traditional materials and usual blending, placing and curing Improvements to features like placement and compacting without segregation, mechanical characteristics in the long term and young age or service life in harsh conditions can be considered in the requirements. Concretes often achieve high strength with many of these properties, High-strength concrete, on the other hand, may not always be high-performing. A high-performance classification related to strength is as is illustrated in the Table 1.1[4].

Table 1.1 High-performance concrete classifications [4]

High- Performance Concrete Class	I	II	III	IV	V
Compressive Strength , MPa	50	75	100	125	150

The term (Green High performance concrete) characterized as a concrete that utilizes waste materials as at least one of its constituents, The use of Supplementary Cementitious Materials (SCMs) as a partially substituted Portland cement (PC) to get the best concrete strength for usage in construction projects. It has been used to reduce the weight of cement in concrete mixes which leads to a significant reduction in CO_2 emissions per ton of cementitious materials. It is also a way of utilizing the by-products of industrial development Processes. The using of SCM, is very important to assure the concrete's long-term sustainability, given the growing usage of SCM, which expect large CO_2 emissions to be reduced, Mitigating the environmental effects of concrete processing [5- 7] .

1.2 Mineral admixtures

Cementitious materials, often known as mineral admixtures, function as both pozzolanic and fine filler materials, hence the hardened cement microstructure getting stronger and denser [8]. The use of mineral admixtures reduces the reaction velocity so the significance of treatment has decreased [9]. There are several types of Mineral admixtures, as listed below [10]:

- Waste Glass Powder (GP)
- Pulverized Fly Ash (PFA)
- Silica Fume (SF)
- Steel Slag
- Waste Ceramic Powder
- Quartz Powder
- Ground Granulated Blast furnace Slag (GGBS)

1.3 Fibers

High-performance concrete (HPC) is a brittle, high-strength concrete. The inverse connection between the two behaviors is a roadblock to high-performance concrete utilization. Discontinuous fibers can be used to produce a mix of strength and ductility [11]. The inclusion of fibers in the concrete mixes can substantially enhance the concrete's mechanical characteristics, particularly tensile strength. High-strength, toughness, and durability were created for high-performance concrete reinforced with fibers [12, 13]. Fiber reinforcement is thought to be a safe way to enhance the HPC cracking resistance. HPC's early-age behavior is influenced by type and content of fibers [14, 15]. There are various types of fibers that are widely used in construction as explained below [4]:

1.3.1 Glass Fibers

Glass fiber is made up of 200 to 400 separate filaments that are loosely linked to create a standing. Cut these supports to varied lengths or combine them to make a tape or fabric mat E-glass is a commonly used kind of glass fiber. In the case of reinforced AR glass and plastics, E-glass is less resistant to current alkalis in Portland cement, but AR-glass is more resistant. Polymers are frequently used in blends to enhance physical characteristics, like moisture transport.

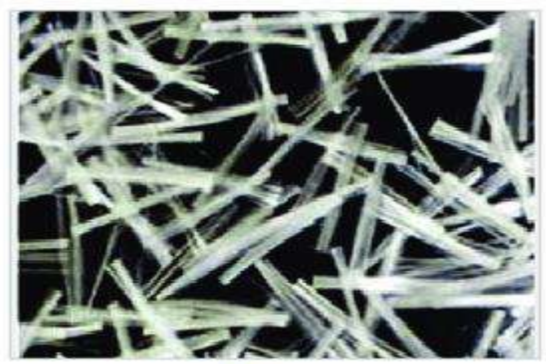


Figure 1.1 Glass Fibers [4]

1.3.2 Steel Fibers

Steel fibers come in a variety of forms that can be used as reinforcement. Round steel fiber is the most common kind, which is made by cutting round wire into small lengths. The average diameter varies from 0.25 to 0.75mm. Cutting or slicing the wire produces round steel fibers. Silting flat sheets produces flat sheet fibers with thicknesses ranging from 0.15 to 0.41mm and widths ranging from 0.25 to 0.90mm.

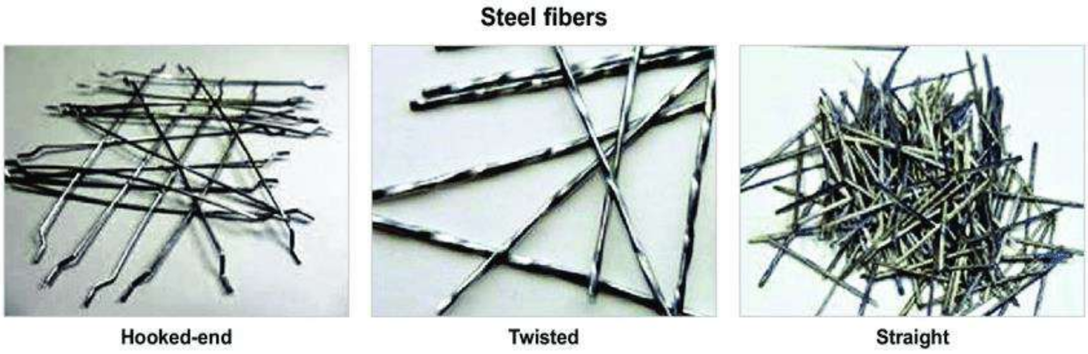


Figure 1.2 Steel Fibers [4]

1.3.3 Asbestos Fibers

Asbestos, a natural sources and low-cost mineral fiber, has been effectively collective with Portland cement paste to produce asbestos cement, a usually used product. Because of its mechanical, chemical, and thermal resilience, asbestos fibers are suitable for tiles, corrugated roofing components, and sheet product pipes. Unreinforced matrix is around two to four times the cost of asbestos cement sheet. The fiber, however, has low strength of impact due to its short length.

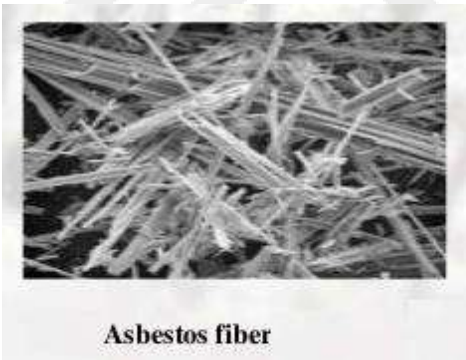


Figure 1.3 Asbestos Fibers [4]

1.3.4 Carbon Fibers

Carbon fibers are the newest and, most likely, one of the most remarkable additions to the commercially accessible fibers. Carbon fiber has an exceptionally high flexural strength and elasticity. These are very broad. Their stiffness and strength properties were shown to be preferable than those made of steel. However, since they are a lot more susceptible to harm in comparison to glass fiber, they are normally coated with resign.

Figure 1.4 Carbon Fibers [4]

1.3.5 Polypropylene Fibers

Polypropylene is one of the most inexpensive and commonly used polymers. Polypropylene fibers are chemically resistant, and it would be the cementitious binder that would degrade first under strong chemical assault. It has an extremely high melting point, so that a working temperature of 100 degrees Celsius may be maintained for short periods of time without affecting fiber characteristics. Since PPF are hydrophobic, they're simple to mix since they don't need to remain in touch for lengthy periods of time; all they require is to be evenly distributed in the mix. Commercially available polypropylene short fibers with tiny volume fractions are utilized in concrete.

Figure 1.5 Polypropylene Fibers [4]

1.3.6 Organic Fibers

Steel and glass fibers are chemically more inert than organic fibers like polypropylene or natural fiber. They are also less costly, particularly if they are natural. To make a multiple cracking composite, a large amount of vegetable fiber can be used. A super plasticizer can be used to overcome the problem of uniform dispersion and blending.

1.4 Objective of Thesis

The main objective of this thesis is to produce green high performance concrete by using the Supplementary Cementitious Materials (SCMs) as a partially substitute Portland cement (PC) such as silica fume as well as super plasticizer(SP) type high rate water reduce (HRWR). Then reinforced the produced GHPC by adding three different types of fibers (Polypropylene fiber ,Carbon fiber, Glass fiber) with different volume fractions 0.3%, 0.6%, and 1% individually for each green HPC mix Then investigate mechanical properties represented by testing compressive strength and flexural strength at age 7 and 28 days for the casted mixes and assess the effects of used fibers on the characteristics of best produced green HPC.

1.5 Layout of the Thesis

This thesis included five chapters as following described below:

Chapter One: Offers a general definition for High performance concrete (HPC) and green concrete also described mineral admixtures and its types as well as an overview of the fibers used in concrete and its types, with an overview of each quality.

Chapter Two: Reviews the several previous studied on influence of mineral admixtures on the properties of HPC and the effect of fibers on the properties of HPC and other types of concrete. And then finding the research gap in those studies to be filled in this study.

Chapter Three: This chapter deals with the laboratory experiments that worked in this study. The characteristics of the used materials, mix proportions, blending procedures, samples preparation, curing, and procedures of testing are mentioned.

Chapter Four: The experimental results are presented, and the influence of different types of fibers on the mechanical properties of HPC is discussed in detail.

Chapter Five: Conclusions are presented based on the results of comparative studies and indicated recommendations for subsequent studies.

CHAPTER II

LITERATURE REVIEW AND PREVIOUS WORKS

The development of high-performance concrete was caused by concrete buildings' early degradation in aggressive environments. The production of HPC necessitates careful selection and constituent proportioning in order to create a composite. It is primarily distinguished by its little porosity and fine texture structure of the pores These, in turn, increase concrete's resistance to harmful substances like chloride, carbon dioxide, sulfate ions, salt , and water as a result of the increased durability efficiency. Chemical and mineral admixtures are primarily used to enhance the high-performance concrete pore structure. Mineral admixtures reduce the mortar matrix porosity much more and strengthen the aggregate's interface [16]. Several studies attempted to enhance HPC's mechanical characteristics. And use the mineral admixtures as SCMs as partial substituted of cement. Although the use of SCMs can contribute to enhance the properties of concrete, it does not contribute to convert the brittle material to ductile material. Adding fibers to the plain cementitious matrix can improve greatly the toughness and impact behavior. Many previous studies have reported about the effect of fibers in the concrete and as shown:

2.1 Effect of mineral admixtures on properties of HPC

The primary goal of using combination of pozzolans with Portland cement to make high-performance concrete is to improve the microstructure.

Mehta and Atcin [17] report that the tiny particles of Pozzolans are a form of cement that is fewer reactions than Portland cement when mixed into the paste, As a result of this mechanism, the paste is made. As far as the distribution of information is concerned, it is more homogeneous and dense. Due to the reaction of pozzolanic amongst finer pores the mineral's amorphous silica inclusion and the calcium hydroxide formed as a result of cement hydration reactions, furthermore, the finer grains' physical effect allows for denser packing within the cement, which decreases weight. In the transition zone between the two, there is a wall impact paste, as well as

aggregates. This poorer area is bolstered,since these two phases have a stronger bond, improving the microstructure of concrete and the characteristics. In general the pozzolanic effect is controlled by the physical and chemical characteristics of the pozzolanic reaction as well as the pozzolanic reaction itself. Filler is created by the mixture's smaller particles. Adding pozzolans to cement improves its strength and durability in comparison to plain paste due to the contact fortification. As a result, the PE on the microstructure of the paste relies on a variety of factors, including pozzolanic responses on the finer particle's filler effect. The pozzolans' physical action results in a higher density, uniform paste, and more homogeneous. The substitution of Silica fume can add approximately 15% of the cement mass.
According to Roy [18], per cement grain, 2 million particles were substituted in that way that each cement grain was surrounded by fume particles, densifying the matrices and deeply hydrating the voids.

Berry [19] discovered that partially reacted fly ash particles can fill voids and increase paste density. As the quantity of fly ash in the paste increases, this effect becomes more noticeable.

Isaia's [20,21] research reveals that, there is a synergy between these pozzolans when a low reactive pozzolan is used in triple mixes with a more sensitive one, like rice husk ash or silica fume or, and the achieved result is better than the ones validated in the binary mixes.; This is known as the influence of synergy. This fly ash impact may be described by its physical impact, which is greater than that supplied by rice husk ash or silica fume particles. The precise cement surface touching water increases as the deflocculation increases. The electro kinetic potential among the particles is increasing. These procedures allow for a greater number of nucleation sites to initiate hydration reactions, resulting in a greater number of products that are hydrated and, as a result, increased consumption of calcium hydroxide, action of pozzolanic and united power or the improvement of other factors related to long-term durability. The physical activity complements the chemical action, resulting in improved overall efficiency.

G.C. Isaia et al. [22] reported when applied to Portland cement, pozzolans play a significant role in increasing the mechanical strength and longevity of concrete structures. Pore structure changes caused by particle size lowering as a result of

pozzolanic action and blockage of the pore are the most important influence on the microstructure of cementitious paste as well as voids as a result of the activity of the finer granules. Just a few studies have attempted to measure these two impacts.12 concrete mixes were evaluated in this research: one as control by PC, nine with PFA, rice husk ash, and limestone filler replacing 12.5 percent, 25%, and 50% of the cement, and two with 12.5 + 12.5 percent and 25% of PFA and rice husk ash, respectively, with w/b of 0.35, 0.50, and 0.65 were used to make all of the mixes. The residual water contents and calcium hydroxide were also examined. The findings reveal that as the mineral concentration in the mixture increased, the physical and pozzolanic effects improved furthermore, peaking at 91 days rather than 28 days. The filler impact rose more than the pozzolanic impact when the results were compared for the identical intensity values (35 and 65 MPa). In binary and ternary combinations including rice husk ash in 25 percent or greater amounts, the pozzolanic effect was improved.
Hassan et al. [23] looked at how 2 mineral admixtures, PFA, and SF affected the characteristics of super-plasticized HPC. The research showed that adding mineral admixtures to high-performance concrete enhanced its properties.

Aitcin [24] provided a study of the toughness characteristics of high performance concrete and concluded that HPC is more durable than conventional concrete, because of its low permeability and strong microstructure.

Bakharev et al. [25] recommended durability tests of acid-attacked alkali-activated slag concrete. As compared to conventional concrete of similar grade, they discovered that grade 40 alkali-activated slag concrete is more acid resistant and durable.

Shannag and Shaia [26] used visual observations to assess the degradation and relative sulphate resistance of high performance concrete, recommending the usage of silica fume in conjunction with natural pozzolana for improved performance in extreme sulphate environments.

Dakshina Murthy et al. [27] conducted an experiment on sulphate ion attack on common, standard, and greater grade concrete at young ages of 7 and 28 days. The utilize of fly ash in concrete improved the performance against sulphate attack, according to their results.

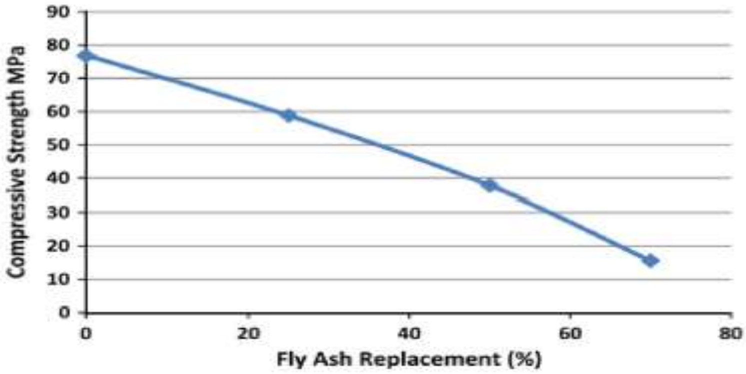
Jerath and Hanson [28] investigated the impact of using fly ash instead of Portland cement and using heavy aggregate gradation on the permeability of concrete blends. They discovered that growing the fly ash content from 35 to 40% and using dense graded aggregate improved the durability of concrete mixtures. When conducting rapid chloride ion permeability tests, they noticed a decrease in the charge transferred, suggesting increased durability. According to the literature, filling the voids with a supplemental cementitious material that is finer than cement is efficient in improving the packing density of cementitious materials.

According to research by J.J. Chena, et al. [29] per the concrete materials packing model, adding PFA microspheres to close the voids between cement particles and then adding SF to additional fill the voids among PFA microspheres would decrease the content of water and attain the required flow ability. This could make it possible to manufacture HPC with a lesser water/cementitious materials. The aim of this study was to see how PFA microspheres and SF affected cementitious materials packing density, as well as the flow ability and cement paste strength. The results revealed that adding PFA microspheres and SF to a mixture can greatly enhance the density of the packing, improving flow ability and strength efficiency at the same time.

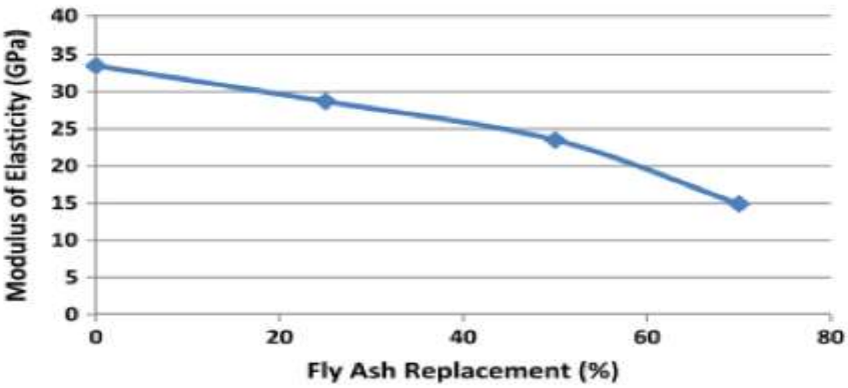
According to Joseph and Ramamurthy [30], increasing the replacement amount of cement by PFA reduces the fresh density of concrete while increasing its workability.

Solanki and Pitroda [31] tested the flexural strength of prisms with dimensions of 100 mm, 100 mm, and 500 mm. The IS10262:2009 method was used to create a concrete mix M20 grade. The water/cement ratio in all of the mixtures was 0.48,at the age of 28 days, a flexural strength test was performed. The 28 flexural strength of concrete was enhanced by 11.1 percent with a 20 percent replacement standard of PC by FA, according to the results.

Kayali and Ahmed [32] made concrete mixes by substituting Fly ash for PC in various proportions. For all of the concrete mixes, the water/cement ratio was 0.38, and the entire cementitious material content was maintained at 450 kg/m^3. After being fog cured for seven days, the concrete samples were air dried for 28 days before being tested. They found that the compressive strength of concrete produced with fly ash decreased over time, with a further decrease when the amount of fly ash used to replace it rose. When compared to PC, fly ash concrete's modulus of elasticity followed the same trend. Figure 2.1 depicts the fly ash's influence on compressive strength and modulus of elasticity. They recorded that these trends were for 450 kg/m^3 total cementitious content, and that these trends could differ considerably for other total cementitious components.



7a (Compressive Strength)



7b (Elastic Modulus)

Figure 2.1 Impacts of various PFA fractions on compressive strength and modulus of elasticity in binary cement concrete [32].

Khayat and Aitcin [33] found that adding 10 percent silica fume to a lean concrete reduced the amount of water needed. Also with 5% silica fume added to standard structure concrete, the water request is increased to sustain a steady slump The addition of up to 10% silica fume as an admixture, as well as the use of a super plasticizer to keep a specified slump, is found to be important for manufacturing concrete that is highly strong and durable.

Wong and Razak [34] investigated the impact of SF with content 5% , 10% , and 15% on concrete slump and Vebe time. The slump values of the mixtures ranged from 30 to 260 mm, with Vebe times varying from 1 to 15 seconds.

The constant super plasticizer amount used for mixes of the same w/cm ratio resulted in a wide difference in workability across mixtures.

Mazloom et al [35] established silica fume-containing high-performance concrete. The water–cementitious ratio was 0.35, and the concentration of silica fumes was 0, 6, 10, and 15%. It was discovered that mixes with a higher silica fume content needed higher super plasticizer doses. The very small silica fume particle size enables some super plasticizer to be deposited on its surface, resulting in a greater demand for super plasticizer in silica fume-containing concrete.

Igarashi et al. [36] investigated pore size distribution and capillary porosity in high-strength concrete at a young age, with 10% silica fume. Concretes with silica fume also had less coarse pores than conventional concretes at young ages of 12 and 24 hours. In silica-fume-containing concretes, the diameter at which porosity begins to rise quickly as pore diameter decreases was smaller at 12 hours than in ordinary concretes. The fact that silica-fume-containing concretes had a smaller criterion diameter meant that the binder particles in these concretes were packed very densely.

Khan [37] found that adding silica fume with 0–15 percent as a partial substitute for cement to mixtures caused in more substantial decreases in porosity. However, when silica fume was applied at a rate of up to 10 percent replacement, the decrease in porosity was higher, above which the decrease was negligible or reversed.

Mazloom et al. [35] looked at the influence of silica fume (0%, 6%, 10%, and 15%) on the compressive strength of high-performance concrete over a 400-day period. They discovered that concrete made with silica fumes was 21% better than normal concrete. After 28 days, and after 90 days, compressive strength growth of concrete blends containing SF was negligible. However, after one year, the control concrete's strength improved by 26% and 14%, respectively, relative to its 28 and 90-day strength.

The compressive strength of HPC was investigated by Sobolev [38] It was discovered that raising the super plasticizer dosage from 8% to 18% reduced the w/c from 0.31 to 0.26 and increased the compressive strength from 86 MPa to 97 MPa, and at 15% silica fume, The compressive strength with the greatest value was determined to be 91 MPa.

The compressive strength of silica fume-containing concrete was studied by Wong and Razak [34]. They used w/cm ratios of 0.27, 0.30, and 0.33 to make concrete mixes. They noticed that SF did not instantly enhance strength; instead, after 7 days, the blended compositions were stronger than the control. Early strength loss was proportionate to the amount of cement replaced due to the diluting impact of the pozzolan and the sluggish nature of the reaction of pozzolanic; and after ninety days of curing, the increase in average strength with 10% silica fume reached a 17 percent increase. The expected enhancement in strength was not achieved when the w/c ratio was reduced from 0.30 to 0.27.

The impact of silica fume on HPC flexural strength was studied by Bhanja and Sengupta [39],five series of concrete mixes were rendered using SF as partial substitution of cement at 5, 10, 15, 20 and 25 percent at w/cm ratios of 0.26, 0.30, 0.34,0.38, and 0.42. Silica fume seems to have a considerable influence on flexural strength in addition to splitting tensile strength. Extremely high concentrations of silica fume also enhanced flexural strength substantially. Furthermore, increasing the proportion of silica fume replacement resulted in a continuous increase in flexural strength.

Hooton [40] examined the impact of SF on the splitting tensile strength of 182-day-old concrete. After 28 days, he discovered that the splitting tensile strength of SF concrete mixtures had not increased. It was also detected that the split tensile strength reduced as the amount of silica fume substituted increased.

Hooton also measured the modulus of elasticity of SF concretes up to 365 days of age. Although it tended to grow at later ages, the elastic modulus of PC concrete was nearly comparable to that of SF concretes at 28 days.

Mazloom et al. [35] examined the impact of SF on the secant modulus of elasticity. As the SF replacement amount was increased, the secant modulus of concrete improved. They also investigated the total, drying shrinkage, and auto genous of HPC containing silica fumes. With a w/c ratio of 0.35, the silica fume percentages were 0, 6, 10, and 15%.They found that SF had minimal effect on specimen drying shrinkage, but had a substantial impact on specimen shrinkage when sealed. Growing the silica fume inclusion has the clear consequence of increasing auto genous shrinkage, and auto genous shrinkage rose considerably at high levels of SF In actuality, adding 10% and 15% SF to concrete caused auto genous shrinkage to rise by 33 and 50%, respectively.

The pozzolanic reaction of SF, as well as its impact on the pore size and pore structure distribution of concrete, revealed its function in autogenous shrinkage.

According to Hooton [41], including SF to concrete decreases its permeability. The water permeability of the control mixture was 1.8*10-14 m/s, while the water permeability of the concrete mix containing 10% silica fume was less than 1*10-17 m/s. It was unable to estimate the permeability of SF concretes with a greater silica fume amount.

Gjrov [42] discovered that silica fume substantially lowered the lean concrete water permeability. The water permeability coefficient of concrete produced with 100 kg/m^3 of cement was lowerd from 1.6*10-7 to 4*10-10 m/s when 10 kg/m^3 of SF were utilized. The permeability of non- silica fume concrete including cement at a rate of 250 kg/m^3 was equivalent to the permeability of non- silica fume concrete containing cement at a rate of 250 kg/m^3.

Other studies have looked at the impact of GGBS on concrete characteristics. When comparing GGBS with PC concrete, Hooton [43] detected that the slump of GGBS concrete remains unchanged, but slag concrete is much simpler to compress by vibration, making it very workable. Because of its enhanced workability, slag concrete has less entrapped air. The higher fines concentration in GGBS concrete makes it simpler to finish. But at greater levels of replacement and ambient temperatures <15 ^oC, setting periods can be increased to 1 or 2 hours. GGBS concrete with a higher level of replacement(higher than 50%) or put at lesser temperatures requires more curing if mixing and finishing durations are considerably increased. When the replacement levels are high and the ambient temperature is low (15 ^oC), Hooton discovered that GGBS mixes may be left to set for 1 or 2 hours. The completion time might be increased by a few minutes when the temperature goes over 20 degrees Celsius. All concretes require additional curing to prevent moisture loss, but GGBS concrete installed at low temperatures requires more curing.

The compressive strength of slag-containing concrete at 7 and 28 days is compared to PC concrete in Fig. 2.2 from the Slag Cement Association SCA [44]. The flexural strength of Slag cement and PC concrete is compared in Figure 2.3.

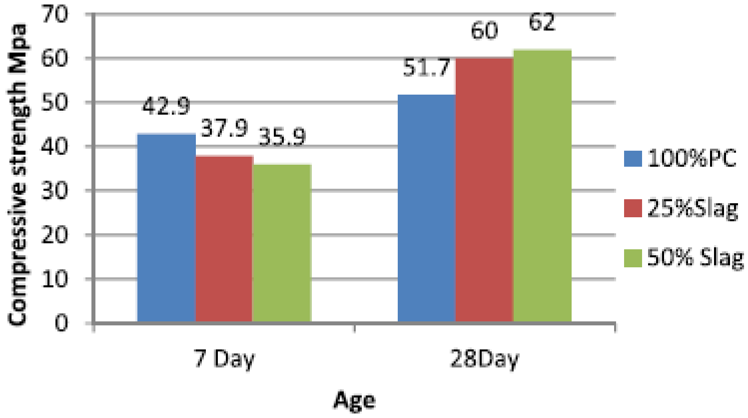


Figure 2.2 Slag's Effect on Slag Cement Concrete's Compressive Strength [44].

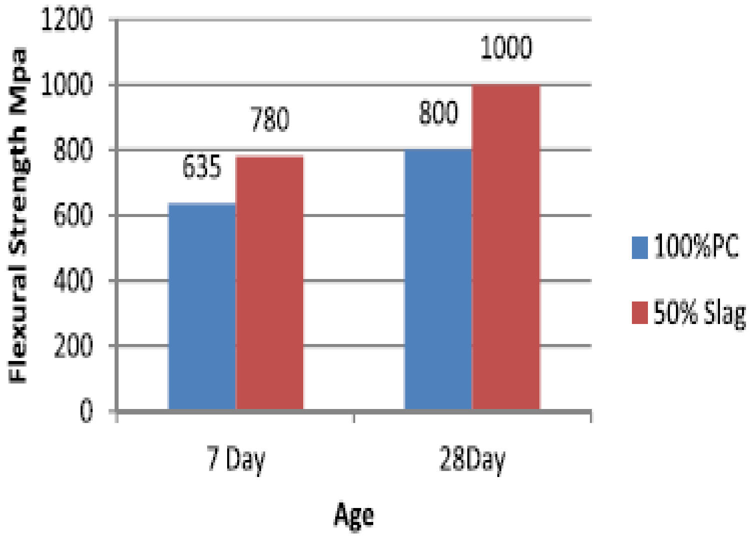


Figure 2.3 Slag's Effect on slag cement concrete's flexural strength [44].

At the age of one day, Johariet al [45] observed that the GGBS relative strength with 20%, 40%, and 60% substitution was 72 percent, 45 percent, and 4.6 percent of PC concrete, respectively. Because of GGBS's delayed reactivity and delusory impact, the early age intensity was reduced.

Khatib and Hibbert [46] observed that when the proportion of GGBS in concrete grows, the early age strength growth of GGBS-containing concrete falls, while the strength between 28 and 90 days rises when compared to PC concrete. The advantages of GGBS substitution were advantageous up to 60%, but the strengths were very bad above that. Figure 2.4 illustrates Khatib and Hibbert's comparison of compressive strength of GGBS and PC concretes at various ages. The samples were made of concrete with a 0.5 water/binder ratio and cured in water at 20 degrees Celsius. Compressive strength was improved when 60 percent GGBS was used instead of PC in concrete. The ninety day flexural strength values of various mixtures are shown in Figure 2.5, 60 percent GGBS concrete had a greater flexural strength than the control blend. The flexural strength of 40 percent GGBS concrete was lowered, whereas the flexural strength of 80 percent GGBS concrete was considerably reduced.

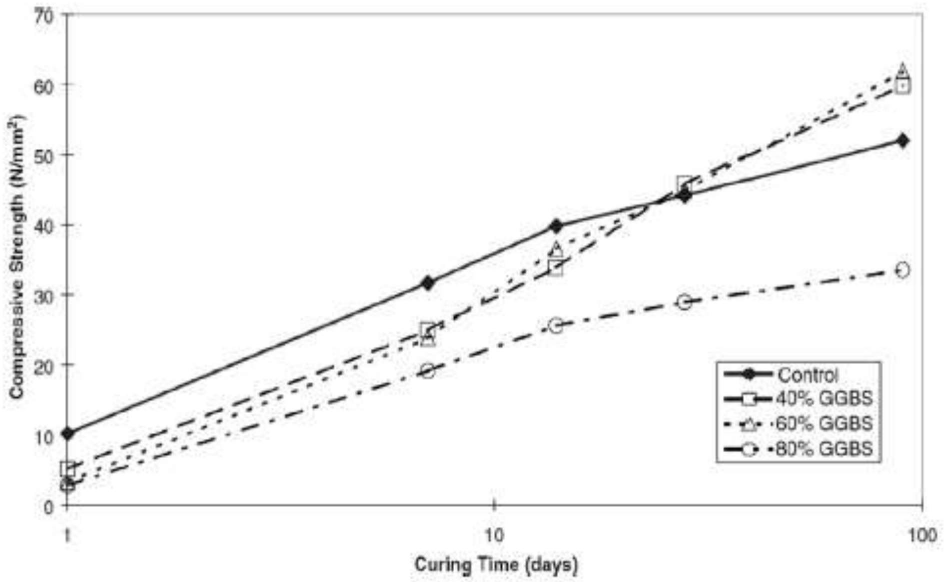


Figure 2.4 GGBS's impact on compressive strength [46]

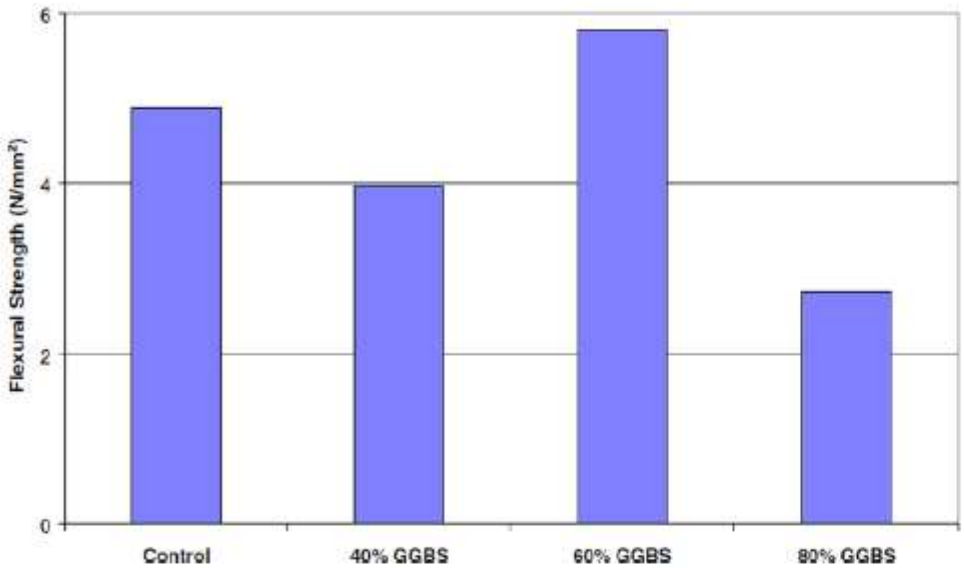


Figure 2.5 GGBS's impact on flexural Strength [46]

Several previous studies looked at the use of ceramic waste in concrete as a substitute for natural aggregates or cement. Wioletta et al. [47] discovered that after using powdered ceramic waste as an incomplete substitute for fine aggregate at a percentage ranging from 10% to 20% in concrete mortar, the compressive and flexural strengths improved slightly when compared to traditional concrete.

Halicka et al. [48] conducted research into the use of ceramic waste in concrete. The researcher used shattered waste ceramic aggregates made from ceramic waste instead of standard aggregates. They discovered that when the concrete contained ceramic waste, the abrasion resistance, as measured by height changes in the sample, was increased. Resistance to high temperatures, compressive strength, and splitting tensile strength all showed a similar pattern.

2.2 Effect of fibers on properties of HPC and other types of concrete

According to the literature, different fiber parameters like as type, length, aspect ratio, and content, influence the characteristics of FRC. As a result, it's critical to think about each factor's influence on concrete mixture. Many previous investigations have indicated about the effect of fibers Especially steel fibers in the concrete Song and Hwang[49] investigated the impact of steel fiber on HSC compressive strength at different fiber content levels, including 0.5, 1.0, 1.5, and 2.0 percent by concrete volume. The addition of 1.5 percent fiber resulted in the greatest compressive strength, which was calculated to be 15.3 percent greater than the fibreless HSC.

According to Eren and Celik [50], the quality and aspect ratio of fibers are important variables in determining the concrete compressive strength. In this investigation, increased content and aspect ratio steel fiber resulted in a larger growth in compressive strength.

Koksal et al. [51] examined the impact of steel fiber on the compressive strength of FRC containing silica fume. The impact was studied using three various amounts of silica fume, containing 5, 10, and 15%. Steel fiber was also utilized, with 65 and 80 aspect ratios, respectively, and fiber concentrations of 0.5 and 1%. Compressive strength values of concretes with an aspect ratio of 80 were found to be superior to that of concretes with an aspect ratio of 65 for the identical silica fume and steel fiber material. As 1% steel fiber content was added to steel FRCs with 15% SF and aspect ratios of 80 and 65, compressive strengths rose by up to 117.6 and 113.8 percent, respectively, when compared with control samples.

According to Yazici et al. [52], the SFRCs compressive strength rose from 4% to 19% after steel fiber was introduced. SFRCs with fiber concentrations of 1.5, 1.0, and 0.5 percent were also found to have the maximum compressive strength at 45, 65, and 80 aspect ratios.

Koksal et al. [51] examined the impact of aspect ratio of steel fiber on HSC with various amounts of SF. For all aspect ratios and SF levels, the concretes modulus of elasticity decreased as the steel fiber content raised.

Steel fiber reinforced concrete with an aspect ratio of 80 was found to have a higher modulus of elasticity than concrete with an aspect ratio of 65. Gul et al [53] discovered the following.

According to Atis and Karahan [54], the elastic modulus of concrete with 0.25 and 0.5 percent steel fiber content was somewhat higher than that of unfibered concrete.

According to Song and Hwang [49], adding up to 2% steel fiber enhanced the modulus of rupture. Depending on the fiber concentration, the increase in modulus of rupture was predicted to vary from 28.1 to 126.6 percent when compared to plain concrete.

Balaguru et al. [55] examined the impact of fiber type, length, and content on the flexural toughness of high strength concrete. The usage of steel fiber with hooked-end in concrete has been found to be highly effective in improving toughness when compared to other types of fiber. A fiber content of (30–60) kg/m^3 was also stated as being adequate to induce ductile tendency. However, it was observed that for deformed-end fibers and corrugated; a larger fiber volume percentage is required to obtain the equal toughness degree. In the case of steel fiber with hooked-end, the lengths of a fiber seemed to have no effect on the hardness of the concrete.

Soroushian and Bayasi [56] examined the influence of type of steel fiber on the flexural behavior of HPC. For aspect ratios of around 60 and 75, and a 2 percent fiber content, concrete with steel fiber with hooked-end provided flexural strength and energy absorption capabilities which were greater than concrete with crimped and straight steel fibers.

According to Yazici et al. [52], the steel fiber aspect ratio had a substantial influence on the enhancement of concrete flexural strength. The flexural strength of the control concrete was determined to be 5.94 MPa. Flexural strength values for aspect ratios of

45, 65, and 80 were 6.13, 6.22, and 6.40 MPa and 7.74, 9.31, and 10.73 MPa, respectively, for 0.5, 1.0, and 1.5 percent fiber content.

Kakea et al. [57] tested the influence of mineral admixtures and content of steel fiber on the HPCs drying shrinkage. In this research, additional cementitious materials of 10% or 20% SF or slag were used to replace the cement weight. At 1 and 2 percent fiber volume fraction, corrugated steel fiber with (D = 0.8 mm) and (L = 55 mm) was added to concrete. The w/b ratio was 0.27. Figure 2.6 indicates that increasing the fiber percentage reduced concrete shrinkage strain significantly, especially at the 28-day. Samples with 1% fiber content exhibited a 4 to 9% decrease in shrinkage when compared to plain concrete samples. Shrinkage reductions of 15 to 24 percent were achieved by adding 2% fiber content to concrete.

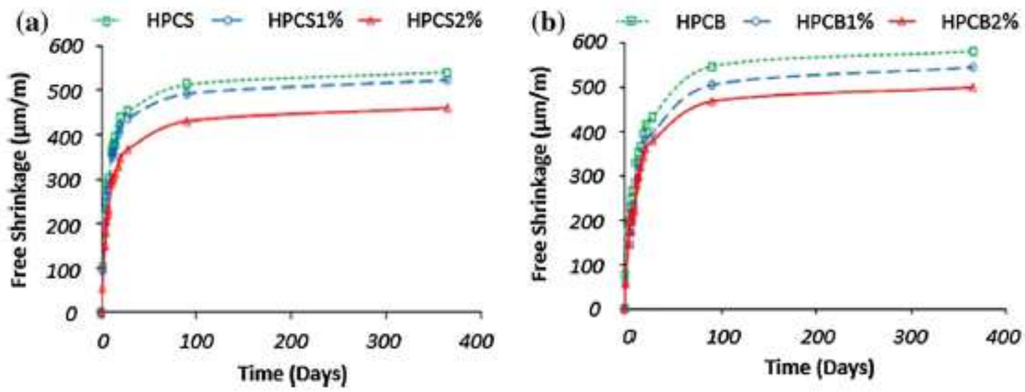


Figure 2.6 Free shrinkage of HPFRC: **a.** include SF, **b.** include GGBS [57].

Polypropylene fibers have been examined by other researchers in relation to traditional concrete and HPC. According to Peng and Qing.58], the concrete workability containing fly ash and SF diminishes when PPF is added. They also observed that when the volume fraction of fiber rises, new concrete fluidity falls and fresh concrete composite cohesiveness increases.

Influence of polypropylene fiber on fracture characteristics of HPC was investigated by Peng and Qing. [59]. Five volume fractions of fibers (0.04 %, 0.06 %, 0.08 %, 0.1 %, and 0.12 %) were utilized with SF and PFA. The findings show that adding PPF to HPC composites containing SF and PFA reduces their workability. Furthermore, adding PPF to a concrete composition that contains 6% SF and 15% PFA improved the fracture parameters significantly like, fracture energy, fracture toughness the critical crack opening displacement, maximum mid span deflection , the maximum crack opening displacement of the three-point bending specimens, and the effective crack length. As the volume fraction of fiber rises from 0 to 0.12%, the fracture characteristics progressively enhance. According to the fracture parameters variance rules, the capacity of the PPF to resist the development of cracks in a concrete composite containing 6% silica fume and 15% fly ash rises with the growth in volume fraction of fiber not exceeding 0.12%.

Dejian et al [60] investigated the impact of PPF length on HPC cracking resistance at a young age. Temperature Stress Test Machine is a machine that measures temperature stress. According to the findings of the tests, increasing PPF length decreased the temperature drop during HPC cracking; increasing PPF length decreased the absolute value of HPC auto genous shrinkage; The cracking stress to axial tensile strength ratio and HPC stress reserve were reduced as the PPF length increased; the HPC basic tensile creep was reduced as the PPF length increased; and the HPC cracking resistance was reduced as the PPF length increased.

Banthia and Gupta [61] discovered that PPF reinforcement was highly efficient in minimizing cracking in concrete. They claim that polypropylene fibers reduce the breadth and quantity of fractures in general. According to them, thinner fibers are much more efficient than thicker fibers, and longer fibers are much more efficient than shorter ones.

Aly et al [62] inspected the impact of PPF on normal strength concrete shrinkage and cracking. After 1 day of curing and then exposure to a relative- humidity of 50 percent and a temperature of 23 degrees Celsius, the shrinkage of samples made of fiber reinforced concrete containing 0.50 percent by volume of PPF risen by 15%; and by 22 percent after 7 days of curing and exposure to a relative- humidity of 50 percent and a temperature of 23 degrees Celsius. On the other hand, they claimed that their findings differed from those of a number of other researchers; they justified their findings by pointing out that fiber reinforced concrete has a higher porosity than concrete without fibers, as well as a faster rate of moisture loss in fiber reinforced concrete.

Saje et al [63] investigated the shrinkage of PPF reinforced HPC. The volumetric content of PPF in the tested concretes ranged from 0 to 0.75 percent. In this respect, the influence of dry and previously wet PPF added to concrete on composite shrinkage was studied. When the content of fiber was raised to 0.5 percent of the volume of the composite, shrinkage was considerably decreased, but when the fiber content was increased further, the shrinkage reduction rate became negligible. The concrete reinforced with previously wet PPF, which acted as an internal water reserve, showed less early autogenously shrinkage than the concrete reinforced with dry PPF. HPC reinforced with previously wet PPF, on the other hand, shrank double as much as HPC reinforced with dry PPF.

The impact of reinforcing fibers on the compressive strength of normal strength concrete with fiber reinforcement was studied by Bayasi and Zeng[64], they discovered that concrete compressive strength enhanced by 15% when reinforced with 1.27 cm long PPF with a volume fraction of 0.1 percent, and by 19% when reinforced with a volume fraction of 0.3 percent. It decreased by 2.5 percent when compared to concrete without reinforcing fibers at a volume fraction of 0.50 percent.

Alhozaimy et al. [65] looked at the impact of different PP fiber content 0% , 0.05% , 0.1% , 0.2% , and 0.3%, on the plain concrete compressive strength and concrete with different binders (fly ash, slag, and silica fumes), Plain concrete showed no significant impact, but concrete exposed to silica fumes showed a 23 percent increase in strength. They also looked into the effects of various PPF content (0 percent , 0.05 percent , 0.1 percent , 0.2 percent , and 0.3 percent) ,on the plain concrete flexural strength and concrete with different binders (fly ash, slag, and silica fumes) ,with the inclusion of 0.3 percent content of fiber, strength increased by 42 percent.

Toutanji [66] investigated the impact of PPF at various volume fractions of fiber on concrete flexural strength. It has been demonstrated that increasing the volume fraction of fiber increases concrete's post peak flexural resistance, rising the volume fraction 0.1–0.3% resulted in a significant increase in flexural strength, although adding 0.5 fiber content resulted in a much smaller increase.

Some researchers studied the mechanical characteristics of normal and high performance- carbon fiber- concrete. For example, Chen and Chung [67] found that using chopped CF with nominal lengths ranging between 3.0mm and 12.7mm and a volume fraction of 0.189 percent in normal strength concrete, along with a silica fume, chemical agents, and dispersant, obtained the following results: 22 percent improve in compressive strength, 205 percent improve in flexural toughness, 85 percent improve in flexural strength, 90 percent reduction in drying shrinkage. The slump has shrunk from 152mm to 102mm. They got to the conclusion that the carbon fiber content in concrete must be at least 0.1 by volume to be effective in enhancing flexural strength.

Chen and Chung [68] investigated the impact of chopped silica fume and carbon fibers on concrete of a normal strength with low drying shrinkage (with fine and coarse aggregates). The carbon fibers were divided into different volume fractions, and the silica fume dosages were varied. They discovered that combining 0.19 vol. percent chopped CF (10μm diameter, nominally 5mm length) with 15 % silica fume in concrete reduces drying shrinkage strain by 84 percent while also improving, flexural toughness, flexural strength, and freeze-thaw durability. They also discovered that using silica fume and fibers together preserves chemical resistance and compressive strength

Wasan & Akar[69] investigated the mechanical characteristics of high performance carbon fiber concrete, Producing HPC with super plasticizer and concentrated silica fume combined with various volume percentages of carbon fiber (0 percent , 0.2 percent , 0.3 percent , 0.4 percent , and 0.5 percent) is part of the research. The impact of chopped CF on the mechanical characteristics of HPC such as compressive strength, splitting tensile, modulus of elasticity, and flexural strengths was also investigated. The findings show that adding carbon fibers to high-performance concrete enhances its mechanical properties. The findings also show that adding concentrated silica fume to the cement as an additive by weight raises the compressive strength more than replacing it by weight. The percentage improvements in compressive strength of concrete containing 15 percent SF as substitute and addition by cement weight, respectively, are around 14 and 26 percent. As CF are applied to high performance concrete, the modulus of elasticity and compressive strength increase marginally, when compared to the control high performance concrete, the flexural strengths and splitting tensile rise considerably. For high performance concrete with a 0.5 % fiber volume fraction, the percentage increase in flexural strengths and splitting tensile after 28 days is about 45 % and 46 %, respectively.

Deng[70] used three-point bending experiments to analyze carbon fiber reinforced concrete. The test findings revealed that when pre-cyclic loading stress levels above a specific threshold, the fracture characteristics of concrete with carbon fiber reinforcement and normal concrete are dropped, with the threshold value for concrete with carbon fiber reinforcement being greater than that of normal concrete. Regardless of fatigue life or pre-cyclic loading history, concrete with carbon fiber reinforcement has a significantly longer critical effective fracture length than conventional concrete. A concrete beam with carbon fiber reinforcement with a central notch has a significantly longer flexural fatigue life than the matrices, i.e., concrete with carbon fiber reinforcement with a maximum fraction volume of 0.3 % has a fatigue life of approximately 2.8 times that of normal concrete with such a fatigue stress value of 0.9.

Others have looked at the impact of glass fibers on concrete. Selin et al [71] found that adding 0.5 percent glass fiber volume fraction increased flexural strength by 42 percent, and adding 1 percent volume fraction increased flexural strength by 75 percent. Also they found that 0.5 percent glass fiber volume fraction addition resulted in a 20 percent rise in tensile strength, and 1 percent volume fraction addition resulted in a 37 percent rise in tensile strength. They also tested heated GF reinforced concrete for two hours with various volume fractions 0, 0.5%, and 1 %. For 0 percent, 0.5 percent, and 1 percent fiber volume fractions, the reduction in compressive strength compared to its initial strength is 32%, 25%, and 10%, respectively.

The performance of glass fiber reinforced concrete was investigated by Yogesh Murthy et al [72]. The study found that using GF in concrete not only enhances the characteristics of the concrete, but it also provides an easy way to dispose of the glass as industrial waste. According to the results of the study, the beam flexural strength with 1.5% GF increased by nearly 30 percent. Slump decreases as the amount of glass fiber in the composites increased.

Muna M. and Eman[73] outlined an experimental study of the tensile, compressive, and young's modulus of mortar reinforced with GF and concrete. The aim of the study is to see how different GF content (0, 600, 1000, and 1400) gm/m^3 affects the mechanical characteristics of concrete and mortar reinforced with GF after 14 and 28 days. The findings demonstrate that concrete compressive strength increased by ratios of 3.6% ,7.1% , and 9.3%, the compressive strength of mortar improved by 2% ,0.8% , and 0.4% when the fiber content was 600,1000,1400 gm/m^3 respectively..According to this study, because concrete contains glass fibers, the GFRC young modulus rose by 9.7%, 56.6 %, and 84 %, respectively. The addition of(600, 1000, and 1400) gm/m^3 GF to mortar and concrete improved the splitting tensile strength by approximately (5.4,7.7,17) and (1,4.3,125) percent, respectively.

Deshmukh S.H.et al [74] explores the influence of GF on OPC concrete. Using an experimental approach, the impact of glass fibers in various percentages ranging from 0 to 0.1 percent on the mechanical characteristics of concrete was investigated using, splitting tensile, flexural, compressive strength tests. The result indicates the proportion of glass fibers increases the compressive strength, when 0.03 percent glass fiber is added to normal M-20 concrete, the 28-day compressive strength increases by 8.81 percent. They discovered that adding 0.06 percent glass fiber to normal M-20 concrete increased compressive strength by 11.15 percent after 28 days. In comparison to normal M-20 concrete, the 28-day compressive strength is increased by 23.44 percent with the addition of 0.1 percent glass fiber. When it comes to the proportion of glass fibers added, 0.1 percent provides better results. Flexural strength improves as the proportion of glass fibers increases. When compared to normal M-20 concrete, the inclusion of 0.03 percent glass fiber, the 28-day flexural strength is improved by 7.27 percent. With the inclusion of 0.06 percent glass fiber, the 28-day flexural strength of M-20 concrete is enhanced by 9.27 percent, in addition, when 0.1 percent glass fiber is added to normal M-20 concrete, the flexural strength increases by 19.31 percent after 28 days. They also discovered that when 0.03 percent glass fiber is added to normal M-20 concrete, the 28-day Splitting tensile strength increases by 2.8 percent. In comparison to normal M-20 concrete, the 28-day Splitting tensile strength is improved by 12.73 percent with the addition of 0.06 percent glass fiber. In comparison to normal M-20 concrete, splitting tensile strength after 28 days is improved by 42.23 percent with the addition of 0.1 percent glass fiber. When it comes to the proportion of glass fibers added, the addition of 0.1 percent produces better results.

2.3 Concluding Remark

- Through previous studies on the impact of mineral additives on the characteristics of high-performance concrete, silica fume (SF) has a higher reactivity than other mineral admixtures in the design and development of HPC due to its tiny particle size, it can more effectively fill in voids between cement grains without loosening the cement grains' packing, resulting in a denser concrete mixture with finer pore structure. Therefore, in this study, green high performance concrete was produced by using silica fume in mixtures as supplementary cementitious material.

- It is noted that most of the previous studies focus on the impact of fibers, especially steel fibers, on the properties of ordinary concrete and some other types of concrete, and there are few studies on the impact of other types of fibers on the characteristics of green high-performance concrete. Therefore, this study, investigated the influence of three different types of fibers and in different contents on the mechanical properties of green high performance concrete.

CHAPTER III

EXPERIMENTAL STUDY

The experimental program included two stages. The first stage includes the production of GHPC mixture as a reference mixture using silica fume at 20% as a partial substitution by cement weight, in addition to using the super plasticizer to obtain the appropriate workability with low w/b ratio. The second stage included adding three different types of fibers (Polypropylene fiber, Carbon fiber, Glass fiber) individually to the components of the reference mixture with volume fractions 0.3%, 0.6%, and1%. Then, the mechanical properties of the above-produced mixtures were investigated.

A constant w/b ratio was used for the produced mixtures, and in order to control the stable workability for the blends, the super plasticizer ratios were modified to investigate the effect of different types of fibers on the mechanical properties of GHPC.

In this study, standard curing was used. The specimens were tested for compressive strength and flexural strengths.

3.1 Raw Materials

3.1.1 Cement

Ordinary Portland cement (OPC) was used in the current work meeting the Iraqi Specification (IQS: No5, 1984) requirements [75]. Tables 3.1 and 3.2 display the chemical and physical properties, respectively. All tests were carried out by the Center Agency for standardization and quality control, Iraq.

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Table 3.1 Chemical properties of OPC

Property	Test result (Percentage)	Standard IQS, No.5
1.Oxide composition:		
Alumina, Al_2O_3	6.6	3-8
Silica, SiO_2	22.32	17-25
Ferric Oxide, Fe_2O_3	3.78	0.5-6
Lime, CaO	63.58	60-67
Sulphuric Anhydride, SO_3(%)	2.57	Max. 2.8 %
Magnesia, MgO(%)	3.27	Max. 5%
2. Compound composition:		
C_3A	12.09	11.96-12.3
C_2S	33.22	28.61-37.9
C_3S	35.48	31.03-41.05
C_4AF	7.97	7.72-8.02

Table 3.2 Physical properties of OPC

Property	Test result	Standard IQS, No.5
Fineness(%)	3	Max. 10%
Specific surface(cm^2/gm)	3359.5	Min. 2250
Initial setting time(minute)	150	Min.45
Final setting time(minute)	390	Max.600
Specific gravity	3.14	—
Compressive strength at 3days(MPa)	20	Min.16.0
Compressive strength at 7days(MPa)	29	Min.24.0

3.1.2 Silica Fume

U.A.E. produces silica fume (SF), in accordance with ASTM C1240-05 specifications [76] was used as supplementary cementitious material. The chemical and physical properties are shown in tables 3.3 and 3.4, respectively. A photographic view of the SF is shown in Figure 3.1.

Table 3.3 Chemical properties of SF

Parameter	Content %
SO_3	0.50
Mg O	1.00
Alkalis like Na_2O	0.70
AL_2O_3	1.60
Fe_2O_3	1.30
Loss on ignition(LOI) (includes Carbon)	2.90
Moisture Content	1.00
SiO_2	91.0
Ca O	0.10

Table 3.4 Physical properties of SF

Parameter	Results
Specific Density, kg/m^3	1780
Oversize on 45 µmm. %	0.77
Accelerated Pozzolanic Activity (7 day)	115
Specific Surface Area, m^2/gm	23.8
Loose Bulk Density, kg/m^3	638.2

Figure 3.1 Photographic image of the SF

3.1.3 Mixing Water

Tap water (W), which is considered safe to drink, was used for concrete mixes.

3.1.4 Super plasticizer

A new third generation super plasticizer (SP) that made of apoly carboxylic Ether based high range water reducing, was used in various quantities to keep the mixtures' workability at the desired level. According to the producer's gift technical data sheet, the used SP conforms with ASTM C 494/C494M-99a Type A, E, F, G requirements. The super plasticizer's properties and photographic view are mentioned in Table 3.5 and Figure 3.2 , respectively.

Table 3.5 Properties of the Super plasticizer

Basis	Aqueous solution of modified poly carboxylates
Appearance	Light Brownish Liquid
PH Value	5-7
Density at 20 °C , kg/lt.	1.07 ± 0.01
Solid content , %	29-31

Figure 3.2 Photographic image of the SP

3.1.5 Coarse Aggregate (CA)

The aggregate used was Normal River aggregate with a maximum size of 12.5mm. It was graded according to ASTM C 33-C 33M-13[77]. Table 3.6 displays the sieve analysis; Figure 3.3 illustrates a photographic view of the CA.

Table 3.6 Sieve analysis of CA

Sieve size(mm)	% passing	Specification Limit (ASTM C 33-C 33M-13)
19	100	100
12.5	92	90-100
9.5	52	40-70
4.75	8	0-15
2.36	3	0-5

Figure 3.3 Photographic image of the CA

3.1.6 Fine Aggregate (FA)

River sand with 3.94 fineness modulus was utilized according to the ASTM C 33-C 33M-13[77]. Table 3.7depicts the sieve analysis. Figure 3.4 illustrates a photographic image of the FA.

Table 3.7 Sieve analysis of FA

Sieve size (mm)	% passing	Specification Limit (ASTM C 33-C 33M-13)
9.5	100	100
4.75	97	95-100
2.36	88	80-100
1.18	63	50-85
0.6	31	25-60
0.3	18	5-30
0.15	8	0-10
0.075	1	0-3

Figure 3.4 Photographic view of the FA

3.1.7 Polypropylene Fibers

Micro polypropylene fiber (PPF) with a length of 12 mm and a diameter of 18 microns were used as fiber reinforcement, Table 3.8 lists the properties of micro polypropylene fibers as given by the manufacturer. Figure 3.5 portrays a photographic image of the PPF.

Figure 3.5 Photographic image of the PPF

Table 3.8 Properties of PPF

Appearance/ Colours	White
Chemical Base	% 100 polypropylene fiber
Fiber Length, mm	12
Fiber Diameter , micron-nominal	18
Aspect ratio (L / D)	667
Specific Density , gm/cm^3	0.91
Water Absorption	Nil
Ignition Point , °C	365
Melt Point , °C	160
Thermal Conductivity	Low
Electrical Conductivity	Low
Acid Resistance	High
Specific Surface Area , m^2/kg	250
Alkali Resistance , %	100
Modulus of Elasticity , N/mm^2	~ 4000
Tensile Strength , N/mm^2	300 – 400

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3.1.8 Carbon Fibers

In this study, chopped carbon fiber filaments with a length of 5-6 cm were used as fiber reinforcement. The properties of carbon fibers are mentioned in Table 3.9, according to the manufacturer. Figure 3.6 depicts a photograph of the CF.

Table 3.9 Properties of CF

Carbon content , %	98
Filament length , mm	5-6
Filament diameter , µm	7
Specific Density , gm /cm^3	1.7
Tensile strength , MPa	3440
Modulus of elasticity, GPa	235
Elongation , %	1.5
Electrical resistivity, Ω.cm	3 x 10^{-3}

Figure 3.6 Photographic image of the CF

3.1.9 Glass Fibers

The glass fiber (GF) type E was used, with a length varies randomly from 12 to 20 mm. Table 3.10 lists the properties of glass fibers as a fiber reinforcement as defined by the manufacturer. A photograph of the GF is shown in Figure 3.7.

Table 3.10 Properties of GF

Filament length, mm	12-20
Filament diameter, µm	14
Filament, millions / Kg	212
Specific Density, gm/cm^3	2.56
Tensile strength , MPa	2445
Modulus of elasticity, GPa	72
Elongation,%	2.4
Electrical resistivity, Ω.cm	10^{14}
Moisture content,%	< 0.3

Figure 3.7 Photographic image of the GF

3.2 Mixture Proportioning

A reference mixture was developed for the purpose of obtaining GHPC by partially saving the amount of cement by using silica fume at a rate of 20% as an alternative to the weight of cement. Super plasticizer was also used to achieve a suitable workability with a low w/b ratio, the symbol for this mixture was coded (OR). After that, the reference mixture was reinforced individually with three different types of fibers (Polypropylene fiber, Carbon fiber, Glass fiber) with volume fractions 0.3%, 0.6 %, 1%. Where the w/b ratio for all mixtures was fixed and the super plasticizer ratios were adjusted according to the slump test results for the trial mixtures to maintain the same workability for all mixtures. The symbols for Polypropylene fiber, Carbon fiber, and Glass fiber reinforcement mixtures were coded as (PPFR, CFR, GFR), respectively. The volume ratios of the fibers are indicated next to the symbol. For example, PPFR 0.3 indicates the mixture of 0.3% volume of polypropylene fiber.

In addition to the reference mixture, 3 mixes were developed for each fiber type based on its volume ratio, resulting in a total of 10 mixtures, as shown in Table 3.11.

Table 3.11 Mix proportions (kg/m^3)

Mixture symbol	PC	SF	FA	CA	W	SP	w/b	PPF	CF	GF
OR	400	80	726	1088	168	4.32	0.35	0	0	0
PPFR0.3	400	80	726	1088	168	6.96	0.35	2.73	0	0
PPFR0.6	400	80	726	1088	168	8.16	0.35	5.46	0	0
PPFR 1	400	80	726	1088	168	9.6	0.35	9.1	0	0
CFR0.3	400	80	726	1088	168	6.72	0.35	0	5.1	0
CFR0.6	400	80	726	1088	168	7.92	0.35	0	10.2	0
CFR1	400	80	726	1088	168	9.36	0.35	0	17	0
GFR0.3	400	80	726	1088	168	7.2	0.35	0	0	7.68
GFR0.6	400	80	726	1088	168	8.4	0.35	0	0	15.36
GFR1	400	80	726	1088	168	9.6	0.35	0	0	25.6

3.3 Sample Preparation

A pan mixer with a capacity of 0.1m^3 was used to mix the ingredients. The mixing procedure follows ASTM C192/C192M – 15 specifications [78]. For producing GHPC first, CA, a portion of the blending water, and the super plasticizer were placed in the mixer and blended for 1 minute; then, FA, cement, SF, then the rest of the water were added to the mixer and blended for 3 minutes, followed by a 3 minute pause to search for any unmixed materials, and finally, 2 minutes of final mixing. After the ingredients have been fully blended, individually fibers were gradually applied to the produced mixture spraying by hand, while the mixer was running. The mixing was kept going for another three minutes to ensure that the fibers in the mixture are uniformly distributed as shown in Figure 3.8. After that, the fresh mixtures were poured into oiled molds and compacted with a vibrator machine, as shown in Figure 3.9.

For each mixture, sets of six cubes of (150×150×150) mm^3 for compressive strength and six prisms of (400×100×100) mm^3 for flexural strength are prepared, totaling 120 specimens.

Figure 3.8 produced mixture

Figure 3.9 Sample Preparation

3.4 Sample Curing

The specimens' molds were removed one day after casting, and the process of curing was completed by fully immersing the samples in a water tank until testing time as shown in Figure 3.10. The water temperature (23±2°C) was maintained using an automated control thermometer that met ASTM C 511-13 requirements [79].

Figure 3.10 Curing tank

3.5 Testing Procedures

3.5.1 Slump Test

The slump test parameters can be used to determine the workability of fresh GHPC composites. A slump cone constructed of thin steel sheet with dimensions in accordance with ASTM C143/C143M- 15 requirements[80], as shown in Figure 3.11, can be used to measure slump values. Cone of Slump should be located on a flat plate before filling it with fresh GHPC composite in three layers. A tamping bar should be used to tamp each layer 25 times. A trowel can be used to clean off any excess fresh GHPC composite. After raising the slump cone vertically, place it on the flat plate next to slumped fresh GHPC blend. The value of the slump was calculated as the difference between the maximum fresh GHPC blend height and the slump cone height as shown in Figure 3.12. .

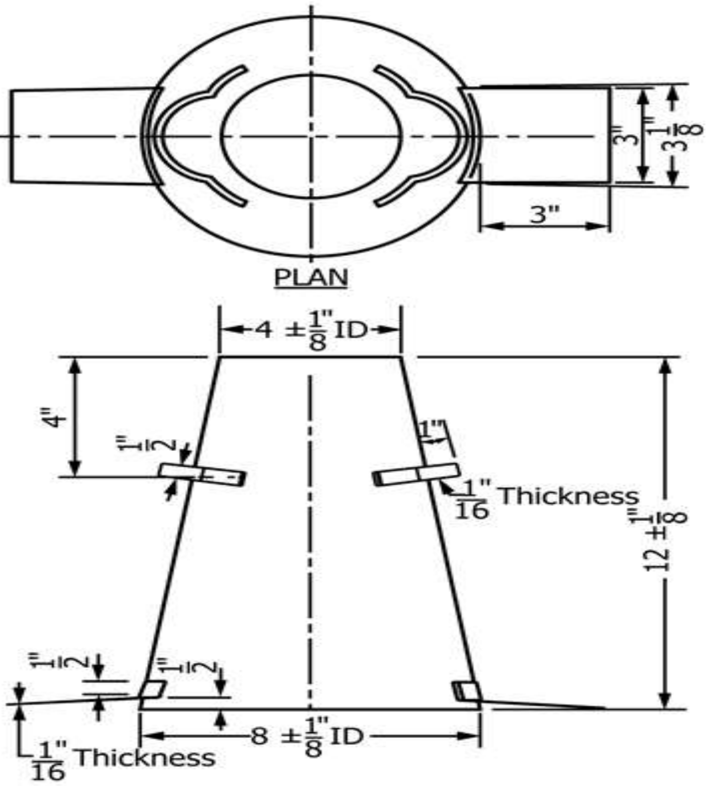

Figure 3.11 Slump test mold[80]

Figure 3.12 Slump test

3.5.2 Mechanical Property Tests

3.5.2.1 Compressive Strength Test

Compression tests were performed on 150 mm cubes at 7 and 28 days, in accordance with ASTM C39/C39M -15 specifications [81], at a rating load of 0.9 KN/s, on a digital testing machine with a capacity of 2000 KN, as shown in figure 3.13. Compression tests were performed for the treated samples as quickly as possible after being removed from wet storage. During the period between removing them from wet storage and testing, their moisture was maintained to be placed in the test machine while it is wet, then an axial compressive load at that rate was applied to the casting cubes until they failed. The specimen's compressive strength determined by dividing the maximum load obtained during the test by the specimen's cross-sectional area. The results in this study were assessed using an average of three samples for each age.

Figure 3.13 Compressive strength testing machine

3.5.2.2 Flexural Strength Test

Flexural strength, also known as modulus of rapture, is the tensile strength of concrete in bending. The aim of a flexural strength test is to determine the maximum load at which a bending concrete member can crack due to tension. It gives an idea of concrete's tensile strength.

In this study prism samples of 400x100x100mm were tested under simply supported conditions at 7 and 28 days, according to ASTM C78/C78M – 15 specifications[82] A third point load test is carried out on a digital testing machine with a capacity of 150 KN, with a span of 300 mm and a rating load of 50±10 N/s, as shown in Figure 3.14.

Figure 3.14 Flexural strength testing machine

The bending moment at failure is divided by the section modulus of the beam under consideration to determine flexural strength. According to the above specification, there are three cases for calculating flexural strength according to the fracture initiates of the examined prisms, as mentioned below.

Case one: The modulus of rupture is calculated as an indicated in the Equation 3.1, if the fracture starts in the tension surface within the middle third of the span's length.

$$R = MC/I = PL/bd^2 \quad \textbf{(3.1)}$$

Where:
R: modulus of rupture, MPa
M: maximum bending moment, N.mm
C: cross-sectional centroid = d/2, mm
I: moment of inertia = $bd^3/12$, mm^4
P: maximum applied load, N
L: length of span, mm
b: the specimen's average width, mm (at the fractured section)
d: the specimen's average depth, mm (at the fractured section)

Case two: The modulus of rupture is calculated as an indicated in the Equation 3.2, if the fracture occurs in the tension surface outside the middle third of the span length, by < 5 % of the span's length.

$$R = 3Pa / bd^2 \quad \textbf{(3.2)}$$

Where:

a: the average distance between a fracture line and the nearest support on the tension surface of the prism, mm.

Case three: Modulus of rupture test results should be discarded, If the fracture occurs outside of the middle third of the span length, by >5% of the span's length.

Since all of the fracture cases in this study were similar to the first case as shown in Figure (3.15), so the flexural strength was calculated using Equation 3.2. The results of three specimens were averaged and recorded.

Figure 3.15 Fracture initiates of the examined prisms

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Fresh properties

The effect of fibers types and content on the workability was assessed through the results of the slump test. Slump values for all GHPFRC mixtures were fixed at 130±10 mm. When adding different types of fibers with different volume fractions to the components of the reference mixture, it was observed that the amount of slump of the mixtures decreased significantly with the increases of fibers volume fractions, as shown in Figure 4.1 .This can be attributed to the fibers' small diameter, which will offers a large surface area, and reducing workability. The percentages of reduction in workability after adding Polypropylene fibers are 42.3%, 61.5%, 88.5%, for Carbon fibers are 38.5%, 57.7%, 80.1%, and for Glass fibers are 46.2%, 65.4%, 88.5% when volume fractions are 0.3%, 0.6%, and 1% respectively.

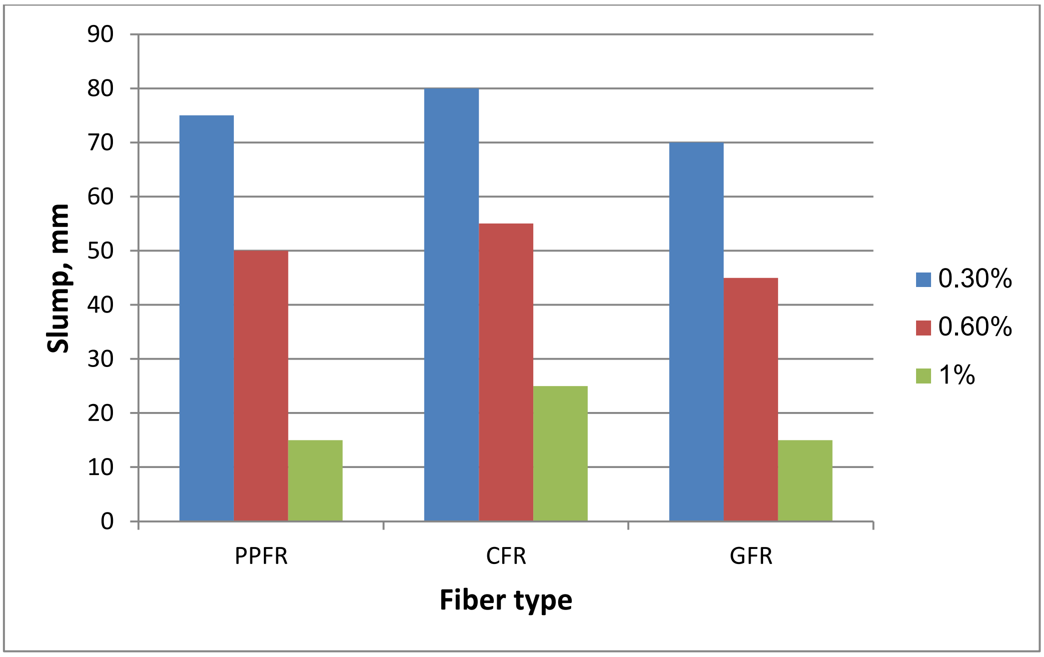

Figure 4.1 Slump values for GHPFRC mixtures

In order to maintain the same slump range for all mixtures, super plasticizer ratio was adjusted for any fiber type and content, as shown in Figure 4.2. As can be shown, the rate of super plasticizer increases as the amount of slump decreases to compensate for the loss of workability and keep it within the required range. According to the manufacturer's guidelines, the maximum percentage of super plasticizer is 2% by weight of binder.

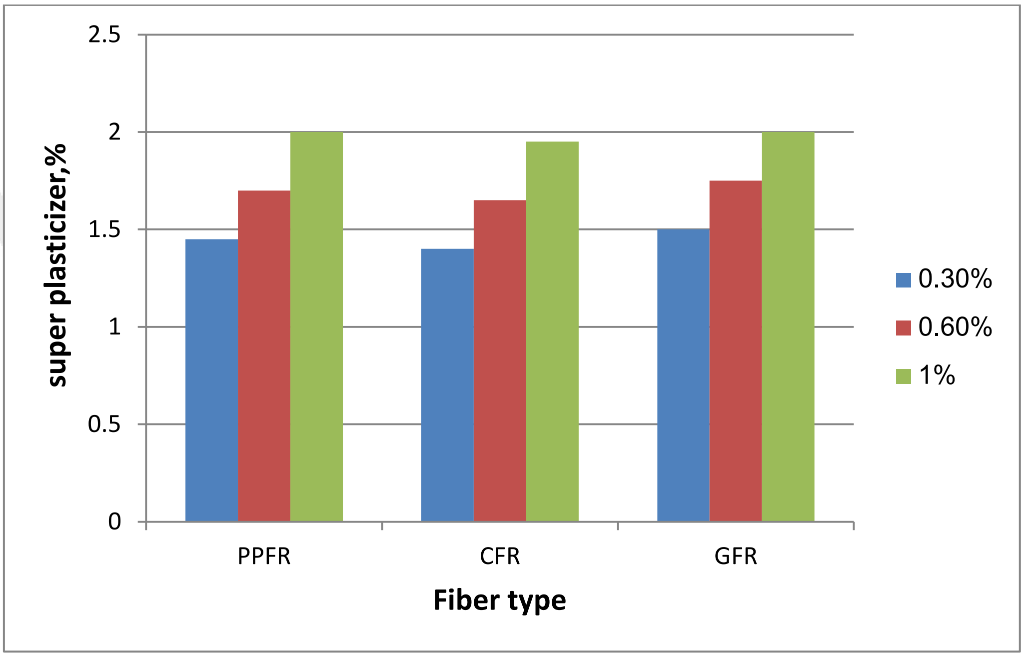

Figure 4.2 super plasticizer ratios versus different fibers types

4.2 Compressive strength

4.2.1 Effect of Polypropylene fibers on compressive strength of GHPC

The compression test results after 7 and 28 days of standard curing are presented in Figure 4.3, which shows the mean compressive strengths of three GHPC specimens with different polypropylene fibers content. It was observed that increasing the fiber content led to a systemic increase in strength at both ages. An early age development of strength was also observed at 7 days, which can be attributed to the combined activity of silica fume and super plasticizers. A reference GHPC samples has a 28-day compressive strength of 53 MPa which is 36% greater than the 7-day strength, while fiber reinforced GHPC samples has a 28-day compressive strength that ranges from 31% to 35%. Also it can be observed those 28 days compressive strength is increased by 7.1%, 13.4%, and20.3% compared to reference GHPC samples, when polypropylene fibers volume fractions are 0.3%, 0.6%, and 1% respectively. As a consequence, a 1% volume fraction produces maximum mean compressive strength of 63.8MPa. These findings are close to those reported by other HPC researchers [65],but it differs from those reported by researchers on normal strength concrete[64] , where gave higher results, This is due to silica fume's role in early and late strength growth, because of the high pozzolanic reaction of its grains with calcium hydroxide emitted from cement hydration , pore size and grain size refining approaches may be used to improve the microstructure and reduce micro cracking.

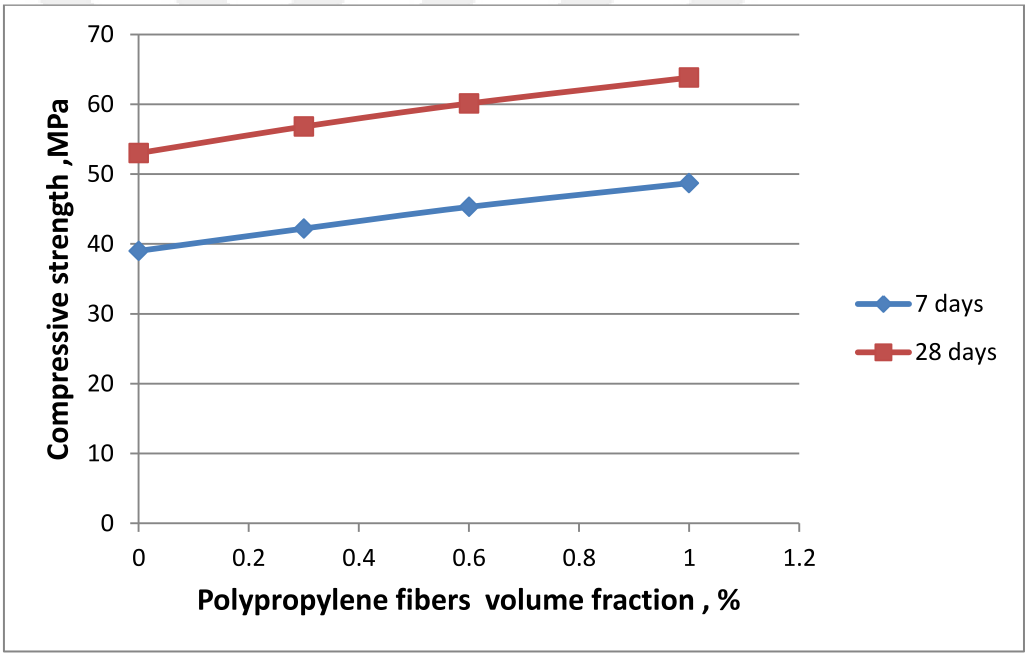

Figure 4.3 Effect of PPF content on compressive strength of GHPC

4.2.2 Effect of Carbon fibers on compressive strength of GHPC

Figure 4.4 depicts the mean compressive strengths of three GHPC specimens with varying carbon fiber content after seven and twenty-eight days of standard curing. It was observed that the compressive strength increases gradually, as the fiber volume fraction increase up to 0.6%, and then it gradually decreases. The rise in compressive strength was as high as 8.9% and 20.8% than the reference GHPC samples, when the fiber volume fraction was increased from 0% to 0.3 % and 0.6 %, respectively. Furthermore, the findings revealed that rising carbon fibers to 1% had little effect on enhancing compressive strength. This is most probably due to the large weight of fibers per any percentage content due to its specific density which equals 1700 Kg / m^3, which may be much greater than the weight required to enhance the plain GHPC by enhancing the micro structure of GHPC matrix and increasing its density and the bond strength between GHPC matrix and fibers. As a result, a volume fraction of 0.6 percent provides a maximum mean compressive strength of 64 MPa. The obtained results in this study were greater than those recorded by other researchers [69], because of the higher content of silica fume, which plays an important role in enhancing strength.

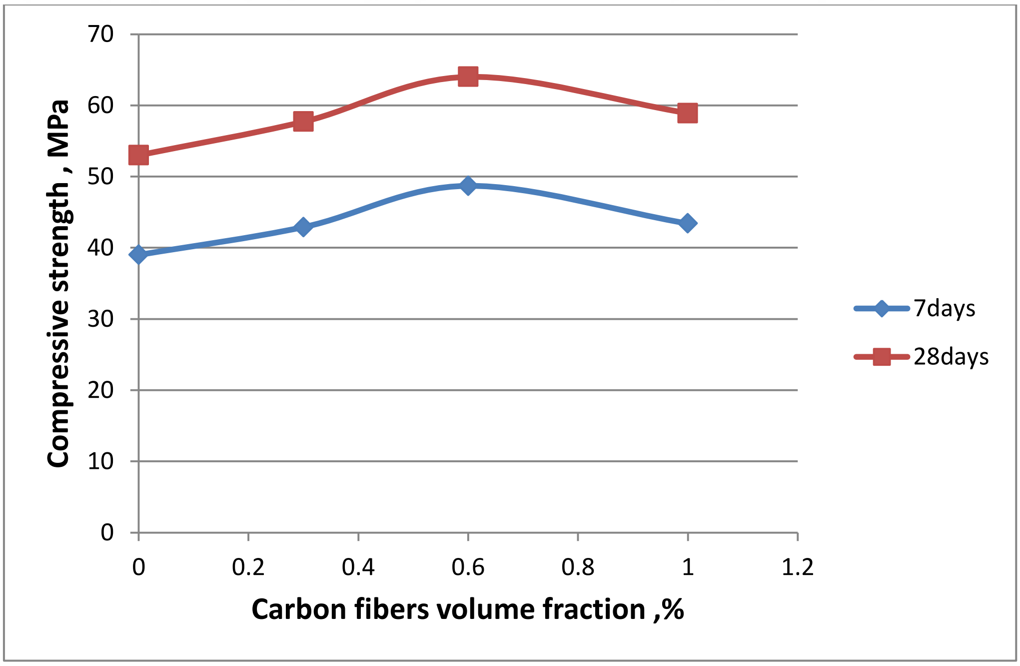

Figure 4.4 Effect of CF content on compressive strength of GHPC

4.2.3 Effect of Glass fibers on compressive strength of GHPC

The compression test results after 7 and 28 days of standard curing are presented in Figure 4.5, which shows the mean compressive strengths of three GHPC specimens with different glass fibers content. It was observed that the compressive strength steadily increases as the fiber volume fraction increases up to 0.3 %, and then gradually decreases. When the fiber volume fraction was increased from 0 to 0.3 %, compressive strength increased by 18.7%, then decreased to 14.7 %, when the fiber volume fraction was 0.6%, and finally, when the fiber volume fraction was 1 %, compressive strength was 2.3 % lower than the reference GHPC samples. This may be attributed to the large weight of fibers per any percentage content due to its specific density which equals 2560 Kg / m3, which may be much greater than the weight required to enhance the plain GHPC. As a consequence, a 0.3% volume fraction produces maximum mean compressive strength of 62.9MPa. These findings are differs from those reported by researchers [73], because they used less fiber, since the fiber content was less than 0.3%.

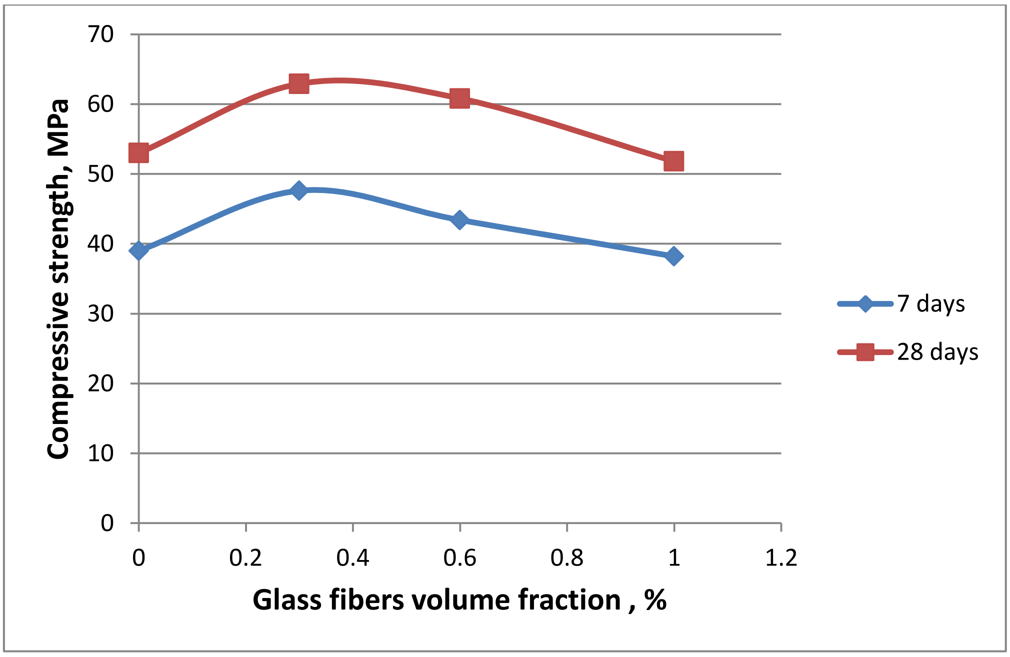

Figure 4.5 Effect of GF content on compressive strength of GHPC

4.2.4 Summary of an investigation of the impact of various fiber types and contents on compressive strength of GHPC

When comparing the effect of different types and contents of fibers on the compressive strength of GHPC, it found that the Polypropylene fibers, Carbon fibers, Glass fibers, gave the highest compressive strength compared to plain GHPC, when their volume fractions were 1%, 0.6%, 0.3%, respectively, as shown in Figure 4.6.

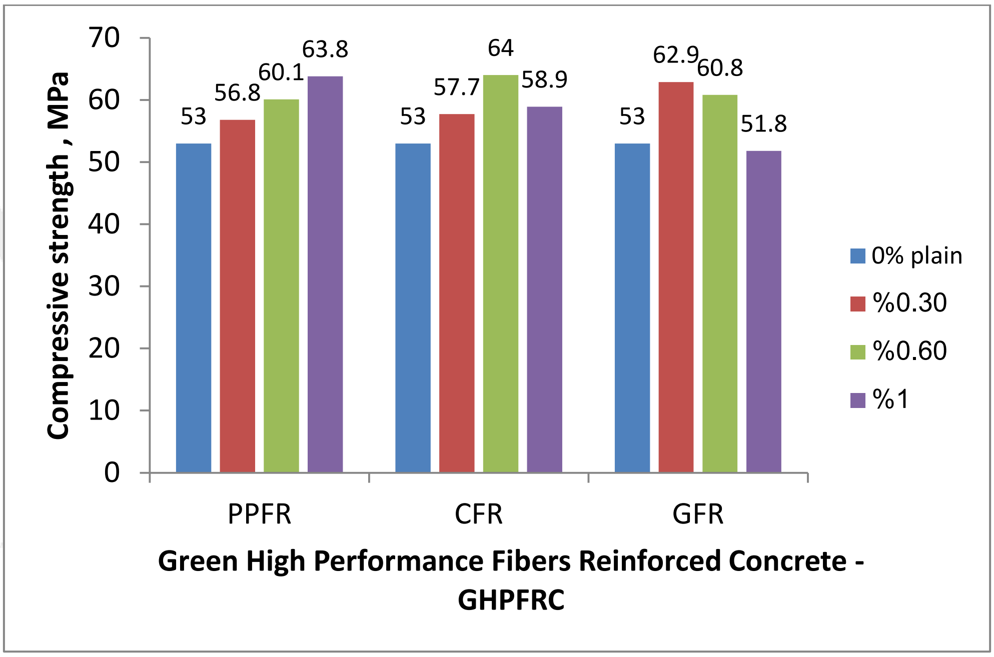

Figure 4.6 Compressive strength of GHPFRC

4.3 Flexural strength (Modulus of rupture)

4.3.1 Effect of Polypropylene fibers on flexural strength of GHPC

The flexural test results at 7 and 28 days are presented in Figure 4.7, which shows the average flexural strengths of three GHPC specimens with different polypropylene fibers content.. It can be seen that increasing the fiber content led to increase in strength at both ages. Plain GHPC samples (reference GHPC samples) has a 28-day flexural strength of 5.5 MPa which is 41% higher than that of 7-day samples, while polypropylene fiber reinforced GHPC samples has a 28-day flexural strength that varies from 38.5 to 43 percent.. Also it can be observed that 28 days flexural strength is increased by 8.6%, 19.5%, and 31.7% compared to reference GHPC samples, when polypropylene fibers volume fractions are 0.3%, 0.6%, and 1% respectively. As a consequence, a 1% volume fraction produces maximum flexural strength of 7.2 MPa. The assistance of polypropylene fibers in improving the bond between cement mortar and aggregate may be responsible for the increase in flexural strengths. GHPPPFRC samples need more energy to crack due to the high volume of polypropylene fibers, which increases the capacity to absorb more energy under bending. These findings differs from those reported by researchers on normal strength concrete [66], where gave higher results, this is due to the interfacial-toughening effect of silica fume in the GHPC matrix, which improved the fiber-matrix bond characteristics. This influence of silica fume causes densification of the GHPC matrix due to improved particle packing, which improves the microstructure of the GHPC matrix and increases its density.

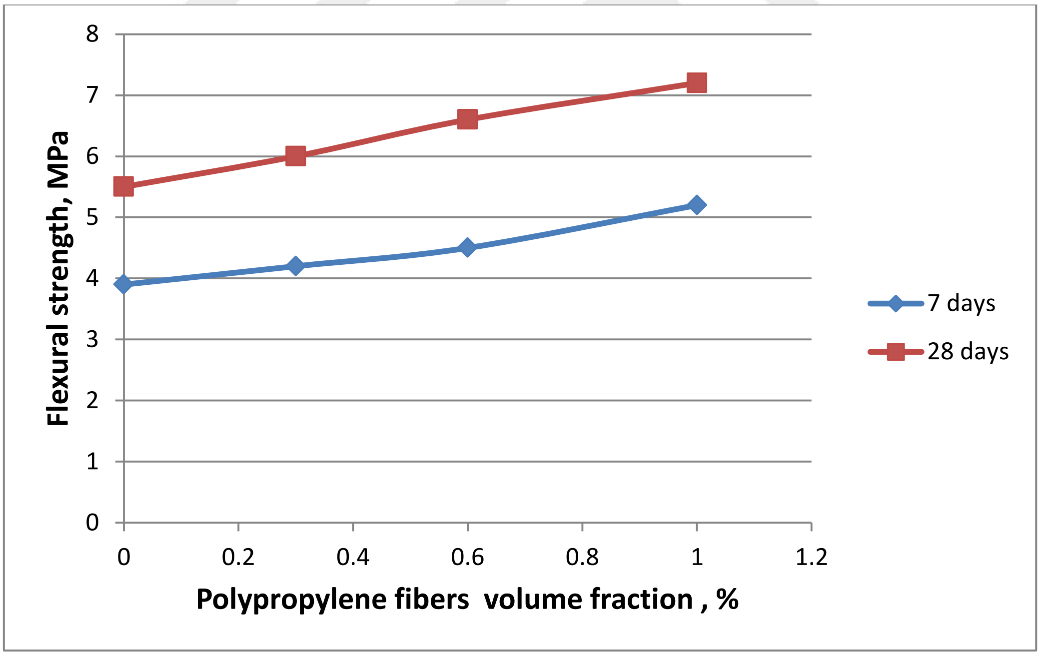

Figure 4.7 Effect of PPF content on flexural strength of GHPC

4.3.2 Effect of Carbon fibers on flexural strength of GHPC

The average flexural strengths of three GHPC specimens with differing carbon fiber content at seven and twenty-eight days are shown in Figure 4.8. Flexural strengths increased significantly as the fiber volume fraction increased up to 0.6 percent, and then steadily decreased. When the fiber volume fraction was 0.3 percent, 0.6 percent, and 1%, the growth in flexural strengths at 28 days was 43.2 percent, 81.7 percent, and 77.6 percent, respectively, when compared to plain GHPC. This behavior may be explained by the dismantling properties of fibers during the mixing phase, which resulted in the formation of massive tiny particles. However, these small particles can improve ITZ with a logic scale, after which they will not contribute to improving it, particularly when particle sizes are much larger than the other concrete constituents, especially at fiber contents of 1%. As a result, a volume fraction of 0.6 percent provides maximum flexural strengths of 10 MPa. The obtained results in this study were greater than those recorded by other researchers [69], because of the higher content of silica fume, which plays an important role in enhancing strength.

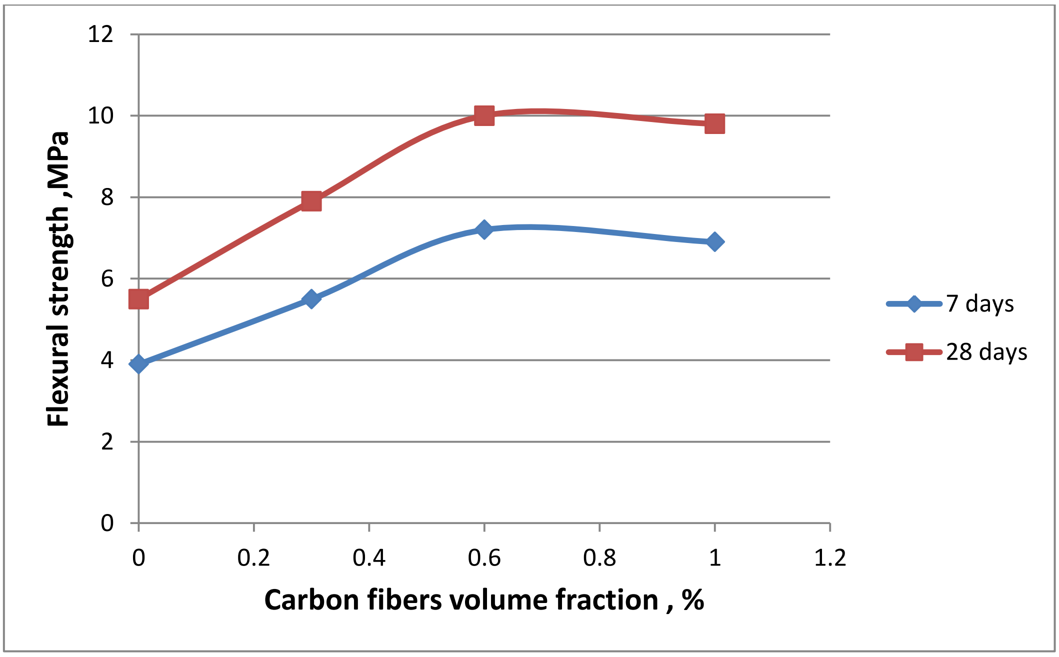

Figure 4.8 Effect of CF content on flexural strength of GHPC

4.3.3 Effect of Glass fibers on flexural strength of GHPC

The flexural strength test results at 7 and 28 days are presented in Figure 4.9, which shows the average flexural strengths of three GHPC specimens with different glass fibers content. A considerable increase in flexural strength was recorded when the fiber content was 0.3 %. Furthermore, the findings revealed that addition of more glass fibers had little effect on improving flexural strength, which began at 0.6% and increased to 1 % after that. When the fiber volume fraction was 0.3 %, 0.6 %, and 1 %, the increase in flexural strengths at 28 days was 67.3%, 53.1%, and 58.4%, respectively, when compared to plain GHPC. This can be attributed to the same reasons mentioned in 4.3.2 because this behavior is closer to that of carbon fibers, but the highest improvement here was in the volume fraction of 0.3% due to the high specific density of glass fibers which equals 2560 Kg / m3. As a consequence, a 0.3% volume fraction produces maximum flexural strength of 9.2MPa. These findings are close to those reported by other researchers [71].

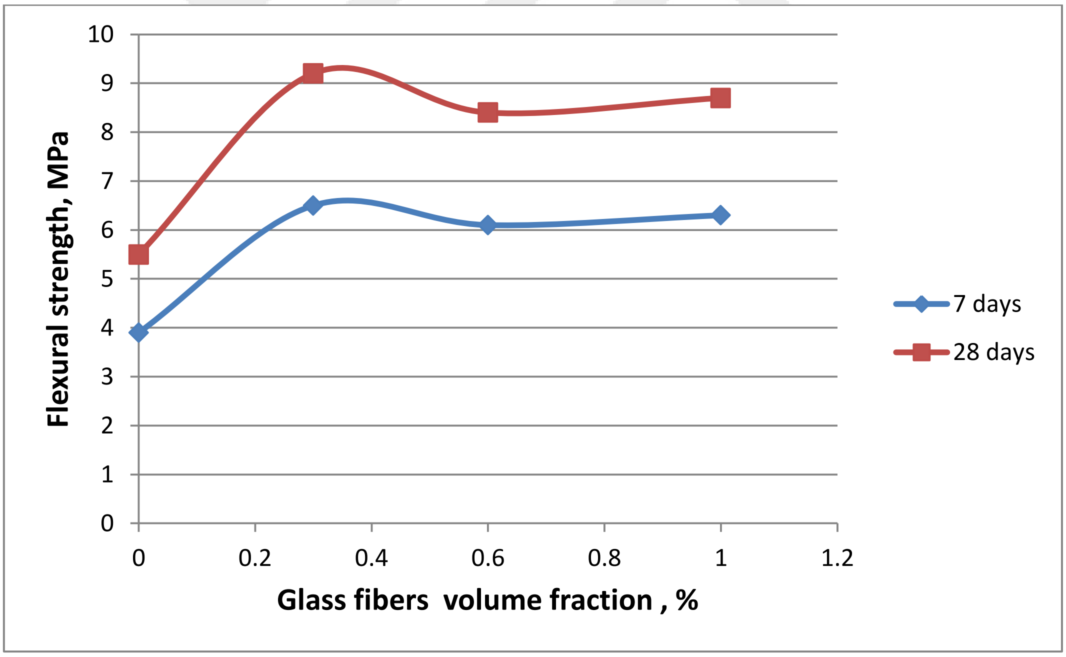

Figure 4.9 Effect of GF content on flexural strength of GHPC

4.3.4 Summary of an investigation of the impact of various fiber types and contents on flexural strength of GHPC

In general, it is evident that adding fibers to GHPC increases its flexural strength significantly. This is due to the fact that fibers can block and delay the spread of tensile cracks, as well as pass stress through the cracks and prevent crack development. Furthermore the experimental test revealed that plain GHPC specimens (without fiber) collapsed suddenly in a brittle manner and split into two pieces as shown in Figure 4.10 , while fiber reinforced specimens had cracks in the tension face prior to failure as shown in Figure 4.11. This is due to the fibers' action in the matrix, which prevents the initiation and propagation of arbitrarily directed micro - cracks, resulting in enhanced strength and ductility.

Figure 4.10 Failure mode of plain GHPC

Figure 4.11 Failure mode of fiber reinforced GHPC

When comparing the effect of various types and contents of fibers on the flexural strength of GHPC, it observed that when their volume fractions were 1 %, 0.6 %, and 0.3 %, respectively, the polypropylene fibers, carbon fibers, and glass fibers, gave the maximum flexural strength relative to plain GHPC , as shown in Figure 4.12.

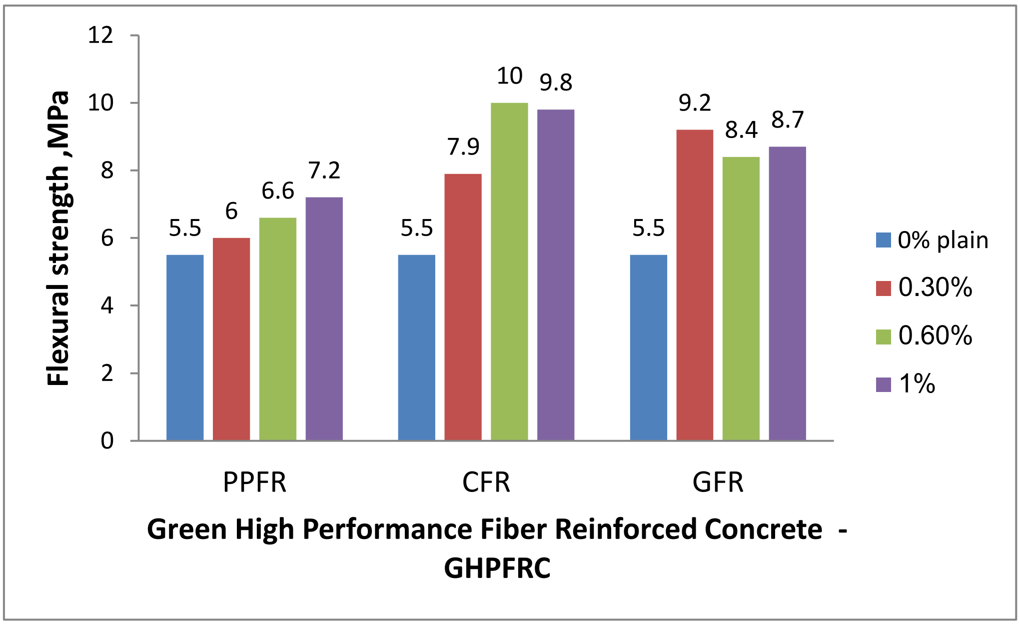

Figure 4.12 Flexural strength of GHPFRC

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The effects of various types of fibers on the mechanical properties of Green High Performance Concrete were investigated using an experimental program. The following conclusions were drawn based on the results of this study:

1. In order to obtain GHPC, Supplementary Cementitious Materials (SCMs), such as silica fume, have been used at a rate of 20% as a partial replacement for Portland Cement (PC) in HPC blends to minimize the weight of cement, making it more environmentally friendly and sustainable.
2. In general the inclusion of fibers reduces the workability of GHPC mixtures significantly, and the decrease in workability rises as the fiber volume fraction increases.
3. All GHPC specimens had early strengths, which increased with curing age. This may be due to the importance of silica fumes in improving both short- and long-term strengths.
4. It has been found that fibers have a greater impact on enhancing flexural strength than compressive strength; this can be explained by the fact that after matrix cracking, the interfacial bond between the matrix and the fibers would support the same load that the concrete did before cracking. As a result, the fibers tend to reduce specimen sudden failure and prevent crack propagation, resulting in an increase in concrete's load-bearing ability.
5. The addition of fibers to non-fibrous GHPC changed the non-fibrous matrix's brittle behavior to ductile behavior.
6. The addition of carbon and glass fibers improves flexural strength considerably. This may be due to their main properties, such as high tensile strength and aspect ratio, which made it possible to use a lot of energy to fracture the prisms.

7. Addition of polypropylene fibers causes increase in compressive and flexural strength of GHPC as the fiber volume fraction increases. Therefore the optimal polypropylene fiber content ratio was 1%, which gave a maximum compressive strength of 63.8 MPa and a maximum flexural strength of 7.2 MPa.
8. It was noticed that raising the carbon fiber content up to 0.6 percent resulted in a systemic increase in strength, after which the findings showed that the carbon fiber content had little effect on compressive and flexural strength, therefore the optimal carbon fiber content ratio was o.6%, which resulted in a maximum compressive strength of 64 MPa and a maximum flexural strength of 10 MPa.
9. It was observed that there was a significant growth in the both of compressive and flexural strengths when the glass fiber contents was 0.3% and then the results indicated a meaningless effect, therefore the optimal glass fiber content ratio was o.3%, which resulted in a maximum compressive strength of 62,9 MPa and a maximum flexural strength of 9.2 MPa.
10. According to experimental findings, plain GHPC has a flexural strength of 10.4 percent of its compressive strength, whereas fiber reinforced GHPC has a flexural strength of 11 to 17 % of its compressive strength.

5.2 RECOMMENDATIONS

Further studies are recommended to investigate the effect of fibers on other GHPC properties such as: durability characteristics, resistance to shrinkage, fracture properties, and fire resistance properties.

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