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M. Sc. in Civil Engineering

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UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL AND APPLIED SCIENCES

INVESTIGATION OF FLEXURAL BEHAVIOR OF FIBERS REINFORCED GEOPOLYMER CONCRETE HALLOW BEAMS

M. Sc. THESIS

IN

CIVIL ENGINEERING

BY

SAAD TALAL KAMIL ALSAHOOKI

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Supervisor

Prof. Dr. Mustafa ÖZAKÇA

By

Saad Talal Kamil ALSAHOOKI

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Saad Talal Kamil ALSAHOOKI

ABSTRACT

INVESTIGATION OF FLEXURAL BEHAVIOR OF FIBERS REINFORCED GEOPOLYMER CONCRETE HALLOW BEAMS

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This study is focused influence of steel and glass fibers on mechanical and structural properties for geopolymer concrete. Furthermore, the effect of hybrid fiber of steel and glass fibers on same these properties was studied also. Where test specimens were manufactured from the geopolymer concrete composites contain of alkaline liquids, 50% fly ash and 50% ground granulated blast furnace slag. The mixtures were designed for 14M molarity and the proportion of sodium silicate equivalent 2.5 than sodium hydroxide and used for producing geopolymer concrete. With this mixture, fibers were added (1%) steel, (0.5%) glass to the full volume of concrete and obtained hybrid fiber by mixing half of amount from both types. The material tests were done for workability, compressive strength (f_c') and tensile strength (f_{sp}) for 7, 28 and 56 days. For structural parameters were casted 12 beams (4 solid, 4 circular-hollow and 4 square-hollow) and tested under 3-points monotonic test, for investigation and comparison in terms of Flexural strength, ductility and failure patterns. The experimental test results indicated that there were improved compressive and tensile strength of geopolymer concrete due to use the steel, glass and hybrid fibers. Also these fibers led to improvements in resistance the first crack and ultimate load, ductility increasing, best control on crack patterns and an appropriate converge in the behavior of solid and hollow beams.

Key words: Fly ash, Glass fiber, Geopolymer concrete, Hybrid fibers, Steel fiber.

ÖZET

GEOPOLİMER BETON İÇİ BOŞ KİRİŞLERİN EĞİLME DAVRANIŞLARINA LİFLER ETKİSİNİN İNCELENMESİ

ALSAHOOKI, Saad Talal Kamil
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Bu çalışma, çelik ve cam elyafların geopolimer betonun mekanik ve yapısal özelliklerine olan etkisine odaklanmıştır. Ayrıca, aynı özelliklerde çelik ve cam elyafın hibrit etkisi de incelenmiştir. Test numuneleri, alkali sıvılar olan % 50 uçucu kül ve % 50 öğütülmüş yüksek fırın cürufu içeren jeo-polimer beton kompozitlerinden üretilmiştir. Karışımlar 14M molarite için tasarlanmış ve sodyum silikatın oranı 2.5 sodyum hidroksittir ve jeopolimer beton üretmek için kullanılmıştır. Bu karışımlarda, her iki lif türünden yarıları oranında karıştırılarak hibrit lif elde etmek için tüm hacimdeki betona % 1 çelik ve % 0.5 cam elyaf olarak eklenmiştir. Testler, 7, 28 ve 56 günlerde işlenebilirlik, basınç dayanımı (fc') ve gerilme mukavemeti (fsp) için yapılmıştır. Yapısal parametreler için 12 kiriş (4 dolu, 4 dairesel boşluklu ve 4 kare boşluklu) üretilmi, eğrilme mukavemeti, süneklik ve kırılma modellerinin araştırılması ve karşılaştırılması için 3 noktalı monotonik test altında test edilmiştir. Sonuçlar, çelik, cam ve hibrit liflerin kullanımından dolayı jeopolimer betonun basınç ve çekme dayanımının arttığını göstermektedir. Ayrıca bu lifler, ilk çatlağa ve nihai yüke, süneklik artışına, çatlak desenleri üzerinde en iyi kontrole, dolu ve boşluklu kirişlerin davranışında iyileşmelere yol açmıştır.

Anahtar kelimeler: Uçucu kül, cam elyaf, geopolimer beton, hibrit lifler, çelik elyaf

DEDICATION

This Thesis Is Dedicated To…

My dear parents…

My beloved wife…

My children...

My brothers and my sisters and their families…

SAAD AL-RAWI

2018

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First and foremost, I am grateful for Allah that he award me patience and power to overtake all obstacles and I arrive to this stage by his grace.

Then, I would like to express my special appreciation and all thanksgiving for my supervisor, Professor Dr. Mustafa ÖZAKÇA, who providing all the necessary facilities for this research, supervision time, also his kindness and support to complete this study.

I take this opportunity to express my gratitude and my reverence for my dear parents whom were nurtured me until I become a righteous and useful person. As well as, I can't hide feelings of love and respect consideration for my beloved wife who was succor for me at hardest conditions of life.

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There lots of feelings to think everyone in this world, but I am sure, none what these feelings will be sufficient to thank my brothers, my sisters and their families, and my children are my hope at the life, but I don't have a method, only saying all appreciation and respect for you.

Lastly, Special thanks to my friends in graduate study in civil department of engineering for their encouragement for me, their great sympathy with me.

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LIST OF SYMBOLS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
GPC	Geopolymer Concrete
OPC	Ordinary Portland Cement
FRC	Fiber Reinforced Concrete
GF	Glass Fiber
HYFRC	Hybrid Fiber Reinforced Concrete
FA	Fly Ash
GGBFS	Ground Granulated Blast Furnace Slag
LVDT	Linear Variable Displacement Transducers
RC	Reinforcement concrete
S-beam	Solid beam
SH-beam	Square hollow beam
CH-beam	Circular hollow beam
CFRP	Carbon fiber reinforced polymer
f_c'	Compressive strength of concrete
f_{sp}	Tensile strength for concrete
f_y	Yield stress of steel
Δ	Displacement
Δ_{cr}	Displacement at first crack
Δ_u	Displacement at ultimate load
P	Maximum applied load
P_{cr}	First crack load
P_u	Ultimate load
P_y	Load at yield point
F	Flexural strength
F_{cr}	Flexural strength at first crack load
F_u	Flexural strength at ultimate load
ε_c	Concrete strain

ε'_c	Strain corresponding to the maximum compressive stress
14M	14 molarity of alkaline solution
μ	Ductility factor
ρ	Reinforcement ratio
L	Length of specimen
D	Diameter of specimen
b	Width of beam section
d	Depth of beam section

CHAPTER 1

INTRODUCTION

1.1 General Introduction

During the last 100 years rapid manufacturing led up to interesting changes to method of construction and in materials; where more 11 billion tons of concrete are being used annually [1] making it used construction materials vastly. The Ordinary Portland Cement (OPC) concrete is still a predominant material for construction due to its features such as workability, inexpensive, and fire resistance in addition its modest upkeep cost. It's a hardened admixture from aggregate, cement and water.

However, the developmental activities were accompanied by investment of normal resources in the production of concrete. The overuse of naturalistic resources as ore materials in concrete production had alarmed the entire world to minimize the research of natural materials. Where construction manufacture has been become the greatest consumer of naturalistic resources in the world, accordance with United Nations reports, it is foreseeable that population ratio in large cities will raise about 65% by 2050 [2]. The growth rates in the evolving countries would lead to more using of electricity, expansion of infrastructures and abodes, in another meaning, electricity and concrete. The OPC is a construction material utilized for concrete fabrication. It is well-known that the 1 ton production of cement releases an identical quantity of carbon dioxide (CO_2) into the atmosphere. Mostly, the cement manufacture accounts about 5-8% of the CO_2 emissions globally [3].

In lighting of the above facts, wide-prevalence innovative studies are being carried out all over the world for the high-valued utilization of suitable industrial byproducts for the high amount or complete replacement of the OPC from the concrete. One of recent attempts in this direction was Geopolymer Concrete (GPC).

As well a lot of various theoretical and experimental studies related to the analysis of structural elements focused on reducing of self-weight for a given load carrying capacity. For example, Hollow elements could utilize reducing of dead load which diminishes the seismic effect contribution in high elevation structures and also valid at the heat isolation and vibration dampers. Moreover, that structural material optimization can conduct by usage of these alternative options which we will highlight on their advantages in this chapter.

1.1.1 Structural behavior of geopolymer concrete

Almost all experimental studies on geopolymers have specified that this innovative binder has significant potential as an alternative to OPC. Geopolymers have acquired considerable concern because geopolymer materials may result in environmental characteristics such as reduction in consumption of naturalist resources and ran-down in the net production of CO_2. GPC is a newfangled binder material that could totally replace OPC.

The GPC has many superior characteristics compared with its counterpart OPC concrete. The chemical compounds of GPC and the curing circumstances play important roles in its mechanical properties. GPC is an environmentally friendly sustainable construction material which became mounting popular. For a particular compressive strength, GPC exhibits higher tensile strength compared to OPC concrete, which is appropriate for structural applications. Higher bond strength is shown between reinforcement and GPC. It has outstanding resistance to sulphate attack, fire and suitable resistance to acids. It has low creep and lessens shrinkage of drying [4]. At the moment, standards and codes for OPC concrete are being used in the design of GPC structural members. Nevertheless, more concern should be given to the structural design in regards to brittleness of GPC.

Until recently, the perception of structural GPC was quite limited. Some of the research conducted has been comparative study of experimental and analytical aspects of GPC members. It was mentioned that the behavior of GPC column-beam joints was analogous to the members of OPC concrete [5] and reinforced GPC beams was performed a flexural response. Both experimental data and ANSYS modeling were compared, and exposed that the results were appeared a little deflection due to meshing of elements in the model [6].

1.1.2 Advantages of hollow members

Structural elements improvement can be achieved by decreasing of dead load which minimize the seismic effect contribution in high altitude structures and also convenient at the vibration inhibitors and heat isolation. There are methods for increasing the concrete effectiveness under neutral axis like pre-stressing and the ordinary beams substitution with other shapes such as T-beams. But these methods cause in change of the structural geometry and increase the construction cost [7]. An alternate method of replacing the zone below the neutral axis with inert weightless substances this un-utilized concrete is removed by making circular and square hollowness at the neutral axis of beams. This is a substitutional by reducing the use of concrete. The stress in the part over neutral axis is less effect on the concrete than below axis which serves as a shear relocate media. It should be ensured that no sliding will occur between the both layers [8].

Experimental work was conducted on the reinforced GPC beams with square and circular cavities along neutral axis in center, with the observation that ultimate compressive are at the top zone of beam and zero at the beam bottom, Other than tensile. So that can be used a cheap and light material or made cavity in near the neutral zone. Sustainability can be carried out by replacing the partly used concrete. Therefore, it's provided concrete; at the self-time we can save cement, which reduces the greenhouse gases emissions. So it is considered as environment friendly.

1.2 Influence of Fibers Reinforced Concrete

Recent research concentrated on new composite materials relatively are inserted in mortar as micro reinforcement so as to get better resistance of tensile cracking and other concrete properties are called Fiber Reinforced Concrete (FRC) [9]. There are different fibers that are used in the concrete namely Glass Fiber (GF), Steel Fiber (SF), natural and synthetic fibers. The amelioration in the material behavior of the FRC depends on dosage and characteristics of the used fibers [10]. The properties of FRC rely upon many parameters such as elastic properties, volume fraction of fiber, aspect ratio, size and type. For each application it requires to locate which fiber type is exemplary in achievement the aim. The fibers are able to prevent surface cracking through their job as nexus bridges and this leads to an optimization of the concrete resistance. With larger ratio usage of fibers for concrete members will get an uniform distribution of fibers within the compound well, thereby producing a composite material has homogeneous mechanical behavior. They provide a cohesive mix, creating a three dimensional reinforced net system [11].

Amongst the fibers mentioned, steel fibers are wide use in applications of experiment researches and more practical too. Steel FRC is a concrete type that contains randomly oriented discrete SF. The major aim of SF addition in concrete is assisting to control widening and propagation of cracks after occurring of cracking in concrete matrix. By control of the mechanical cracking properties inside the composite material as a result will be improved significantly. Also the randomly distributed of SF ameliorates concrete properties, like static strength and toughness of flexural, and ductility [12-15]. The GF is extremely fine fibers, suitably strong and durable material, a lightweight, and much less cost. Due to these properties in terms of strength and weight, wherefore GF became very favorable when compared to metals. Also from GF advantages can be easily formed it and use it for the crack control during processes of concrete molding in-situ, to enhance the toughness of precast concrete [16].

Recently fibers have been significantly used by combining two types of fibers or more as reinforcing compounds in traditional Reinforced Concrete (RC) to benefit of properties variety for each fiber. This new material is called *hybrid fibers reinforce concrete*.

1.3 The Objectives of Research and Tasks

The main objectives represent to carry out experimental and analytical investigation to discuss the following issues:

I. Creating of clear envisage about reinforced GPC efficiency may be instead of OPC concrete in the structural buildings.

II. The relation extent experimental results for reinforced GPC with prognostication modes currently utilized for reinforced OPC concrete structural members.

III. Analytical comparison between hollow beams of produced from GPC and those solid beams in term of flexural strength, ductility and failure patterns.

IV. Study of FRC effect on the mechanical and structural properties for GPC.

1.4 Layout of Thesis

The study has been divided into five chapters.

- A general introduction, use GPC in structural construction, advantages of hollow members and effect add fibers to concrete are given in Chapter I.
- A comprehensive literature survey is presented in Chapter II. Literature survey has been grouped in parts; studies about the flexural behavior of reinforced GPC beams, studies of hollow beams comparison with solid beam, studies Structural Properties of FRC beams.
- In Chapter III, gives a detailed describing of the experimental work in this study
- Covers the analysis of the experimental results and a discussion regarding the beam test in Chapter IV.
- General conclusions about the results are offered in Chapter V.

CHAPTER 2

LITERATURE REVIEW

2.1 The Geopolymers Concrete

Most studies on using GPC in structural members are mainly concentrated on the RC columns and beams, in addition to the steel-concrete bond interaction. Generally, reinforced GPC members shown similar performances compared with those the ordinary reinforced cement-based concrete members, if a load-bearing capacity was not enhanced. Because of this, that many researchers suggested that codes of conventional RC members are used for design of GPC members like AS 3600 [17] and ACI 318 [18], due to these codes are generally reasonable in strength estimation of reinforced GPC members.

In order to create an appropriately economic design of structural for GPC members, there are opportunities into search either determine the design parameters meant specifically for GPC or develop alternative design manner for GPC structures. Moreover, due to similarity at the general behavior of structural elements like cracking characteristics, load deflection, and failure manner of the GPC members with members of traditional concrete. Generally, researchers came to a recap that design of GPC members could be conducted in the same mode as ordinary concrete members [19].

2.1.1 Structural behavior for reinforced geopolymer concrete beams

The GPC has a various mechanism of strength development compared to OPC concrete mixtures; hence, the available procedures for design and analysis of cement concrete elements should be appraise and verification before use in GPC structures.

The specialized literatures in the GPC field concentrated considerably on producing process, durability, physical, and mechanical characteristics. Available literature on GPC concentrated considerably on production, durability, and mechanical and physical characteristics.

Ernst [20] conducted out an experiential work on the structural demeanor of GPC beams. They watched that the performance of GPC beams was similar to OPC beams in term of comparable strength and aggregate content. The failure manner of GPC beams was more brittle than the OPC concrete beams. The researchers proposed that the same design and analysis procedures which styled for OPC concrete beams can be utilized for the case of GPC beams to check flexural and shear strength. The performance of GPC columns has been deliberated also to secure that this material is capable to perform as a structural material in columns.

The GPC beams were convergent with OPC concrete beams in terms of longitudinal reinforcement ratio effect on flexural capacity and ductility factor. In other researches; as well, a Fly Ash (FA) based GPC beam was indicated that under-reinforced behaved similarly (flexural stiffness, load-deflection relationship, first cracking and ultimate load, failure mode and crack width) as OPC concrete beams were submitted under flexing load [21–25].

Furthermore, Dattatreya et al. [21] watched decline ductility of post-peak for GPC beams, and this was reiterated by Yost et al. [22] who detected that failure through concrete crushing was a more brittle compared to OPC concrete. In return, Jeyasehar et al. [26] revealed higher middle-span deflection, first crack and ultimate load, also smaller crack width for the situation of reinforced GPC beams as compared to OPC concrete beams.

Similar to the preceding realization in Hardjito et al. [27], Sumajouw et al. [28] estimated the flexing load amplitude of the 16 beams from reinforced GPC according to AS 3600 [17] and the prediction ratio average of test was obtained to be 1.11. With consideration that the GPC beams were under-reinforced and the compressive strength influence was marginal. Moreover, the maximum deflection in mid-span at service load prognosis specified in AS 3600 [17] was disclosed to be moderate, with rate test-to-prediction ratio of 1.15.

Yost et al. [22] discovered that the ultimate load of the under reinforced GPC beams complied with the application of ACI 318 [18] to foretell theoretically. Furthermore, according to IS 456 [29], in spite of there is harmonization between prognosticated and experimental values for the cracking, service, and capacity of ultimate moment, as well as the reinforced GPC beams deflection. Dattatreya et al. [21] offered that optimization could be conducted to prophesy the structural behavior for the GPC beams. Prachasaree et al. [30] noticed this and inserted specified parameters of equivalent stress block for GPC which allowed good conformity with laboratory results for GPC beams.in the capacity of nominal moment was obtained a rate of 13% difference, this led to reduce the variation between expected and experience results by nearly 1.4 times. Prachasaree et al. [30] mentioned that the parameters of submitted design could be applied accordance in the styling steps in ACI 318 [18] and AS 3600 [17]. In the suggested method, onset, a facilitator model of stress-strain pattern was suggested for GPC using modification of Popovics as Equation (2.1) below:

$$\frac{f_c}{f_c'} = \varepsilon_c n / \left[\varepsilon_c' \left[n - 1 + \left(\frac{\varepsilon_c}{\varepsilon_c'} \right)^{nk} \right] \right] \tag{2.1}$$

Where f_c is the compressive stress (MPa), ε_c is the concrete strain, ε_c' is the corresponding strain to the ultimate compressive stress which is calculated by ε_c' = 0.0051- 4(f_c')/10^5 based on experiential data, n is factor of the curve fitting specified by n = 0.5 + (f_c'/14.3)-[3(f_c') 2/10^4] and where k is constant factor equal 1 when $\varepsilon_c/\varepsilon_c'$ < 1 and k > 1 otherwise. Anew, by depending on the modified equation for stress-strain, Prachasaree et al. [30] suggested that parameters of flexural design are following k_1, k_2 and k_3 Equation (2.2) and (2.3) for the determinations of the block of equivalent stress for the GPC condition, and hence the capacity of nominal moment for GPC beams could be determined by steps using of standard design these proposed parameters.

$$\mathrm{k}_2 = 0.384 - \left(\frac{f_c'}{10^3} \right) \tag{2.2}$$

$$\mathrm{k}_1\mathrm{k}_3 = 1.070 - \left(\frac{f_c'}{76.3} \right) + 9(f_c')^2/10^5 \tag{2.3}$$

Where $k_1$and k_3 are the parameters of equivalent stress block and k_2 determines the centroid compressive forces. The ANSYS program was utilized to precede numerical analysis for prediction of the flexural behaviors of under-reinforced GPC beams, Kumaravel et al. [31] and Thirugnanasambandam et al. [23] detected useful comparison of the experimental and predicted load-deflection relationship. Likewise, in the research carried out by Nguyen et al. [32], despite simulation of finite elements with ABAQUS software appears slight variance in the predicted deflection values, but still there was suitable agreement between the experiential and simulated load-deflection behavior of reinforced GPC beams. Adoption on these studies, it was proposed that the ABAQUS and ANSYS programs could be a helpful way in simulating the structural members behavior for GPC, and this may be assists design engineers of dealing with reinforced GPC members in the future.

Researchers discovered that the structural behavior of under reinforced GPC beams which contain diverse concrete materials. For example, Andalib et al. [33] inserted 30% of palm oil fuel ash into the GPC to make GPC beams. They noticed failure and cracking pattern in addition to ultimate moments where was similar as OPC concrete beams. Furthermore, despite the flexural capacity of the reinforced GPC beam was grown by 23% with the recycled concrete molding by 75% replacement of coarse aggregate, but identical first crack load was monitored for all statuses of recycled concrete by (0, 25, 50, 75 and 100%) [34]. An available design in ACI 318 code [18] was explored to allow conservative prediction of the utmost moment of the GPC beams with expected test proportions are ranging by (1.02 - 1.25). In another context, there same paper by Kathirvel et al. [34], that the GPC beams which included larger quantity of recycled aggregate exhibited increasing ductility and deflections, larger crack widths and also more number of cracks.

Kumaravel et al. [35] conducted experiential work the flexing behavior of beams which were casted by usage of GPC which cured by 60°C for 24 hours, with grade 40 concrete and the dimensions were width 125 mm, height 250 mm and length 3000 mm. Where, flexural test were carried out for these beams under the 4 points loading. Thereafter, comparison of results was conducted for the control beams of ordinary cement concrete of the same concrete grade. The reinforced GPC beams appeared identical load-deflection curves to those obtained from the reference OPC concrete beams; yet, the reinforced GPC beams exhibited higher bearing capacity in terms of ultimate load, service load, and the appearance of first crack. Moreover, the ultimate load, yield load, and maximum load for the reinforced GPC exhibited higher values than the reference beams of OPC concrete by 2.7, 3.57, and 11.25% respectively. Figure 2.1 explains resemblance at cracking modes for both reinforced GPC and OPC concrete beams under flexural test. After yielding-point, the beams appeared failed in the tension region and followed it crushing stage of the concrete in the compression area. While, the ANSYS software was used to expect the results for all the beams and they had been appeared relatively concurrence with those experimental.

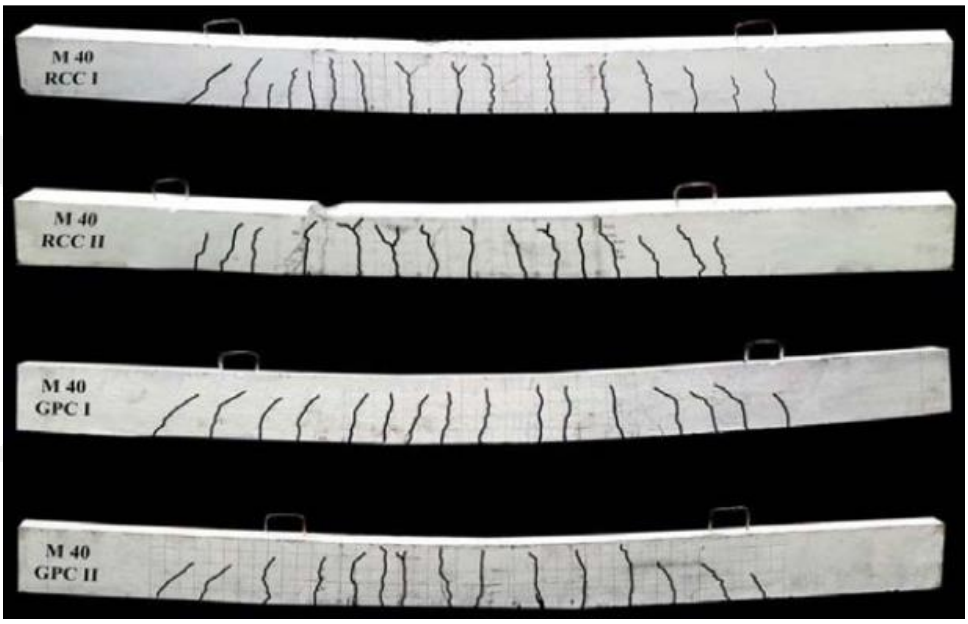


Figure 2.1 Failure patterns of reinforced cement concrete and reinforced GPC beams [35]

Un et al. [36] clarified that utilized rational ways, like effective modulus mode and age-adjusted effective modulus method which were primarily advanced for concrete structures of ordinary cement-based, the long-range deflection of reinforced GPC beams could be evaluated. Despite, Un et al. [36] suggested that more search requires conducting for determination of the long-range behavior in other structural members, also identifying the input parameters for the GPC condition in predicting the long-range deflection of the GPC structures.

The flexing behavior of reinforced GPC beams subjected to erosion was also evaluated by beams inundation in the solution of sodium chloride under accelerated corrosion effect, Wanchai [24] found that the reinforced GPC beams appeared more retraction than the control beam from OPC concrete in term of the flexural capacity, after immersion of beams in sulphuric acid and commixture of sulphuric acid with solutions of hydrochloric acid for 180 days. Also Kannapiran et al. [37] noticed little decline in the flexural strength of RC beams was less than 8% and no significant alteration to the relationship of load-deflection.

There was comparable paper by Dattatreya et al. [38], but the beams were not cured by oven temperature at laboratory conditions. The dimensions of beams were 100mm x 150 mm x1500 mm, and suggested the change of tensile reinforcement ratio as parameter by comparing with the balanced reinforcement to study influence of longitudinal reinforcement ratios on the structural behavior of GPC, where ratios varied between 82-110%. There was increase in the first crack loads for the reinforced GPC beams as a percentage was ranging by 13-16% of the OPC concrete beams, and also 9-11% of their ultimate loads. But the service loads rates for the reinforced GPC beams retreated by 12% compared to the OPC concrete beams.

The failure modes include crack width, spacing, and number and cracking patterns were almost similar. Equations of the ACI 318 code [39] were used to prognosticate the cracking and utmost moment, and max-displacement. The theoretical results awarded appropriate relationship and relative unison with the experiential results; therewith, the concurrence degree was not similar for all conditions. It was proposed to include an extra reduction factor. Moreover, studies advised investigating of stress block state for the reinforced GPC members.

Another significant search by Yost et al. [22, 40] conducted an investigation of the flexural behavior for reinforced GPC beams. These beams were casted by utilizing of the FA with dimensions 305×152×3200 mm which cured by 60°C for 24 hours by usage of advanced system which known as “environmental curing room”. Where, this system adopt on the temperature raise by the utilizing of halogen lights. The compressive resistance was ranging of 52-57 MPa. These beams were reinforced with three various ratios and divided to three groups: the shear critical reinforcement, over-reinforced, and under-reinforced. Whereby the experiment system was the 4-point loading and the testing results were compared with the OPC concrete beams. As for under-reinforced beams, the all curves of OPC concrete and reinforced GPC beams exhibited approximate resemblance for the load-displacement relationship.

The yielding loads reinforcement was a little larger than supposed values for both concrete types. A ductile manner was noticed after the crushing of concrete in compressive area. Anyway, the reinforced GPC beams clarified a more brittle behavior which lead to the concrete dismantling, and the directly load fell at the failure instant; whilst the OPC concrete beams continued after a short period of failure. The deflection values were recorded reinforced GPC beams at the utmost load. There three phases were described by usage of a dial-gage under neutral axis of beam: transition, elastic, and inelastic. The equations ACI 318 code [38] implied that the stress block of Whitney rectangular can be applied for the design of reinforced GPC beam. As for over-reinforced beams, they exhibited a linear manner of load-displacement relationship until failure, while the OPC concrete beams manifested a simple curvature pre-failure. The ultimate load of beams was almost 8% and larger than the expected data. Either, shear critical reinforcement beams, the failure manner was by the diagonal shear manner. Cracking modes were observed identical for both the OPC concrete and reinforced GPC beams, which propose the similarity of the shear transfer mechanism for both concrete types.

2.1.2 Limitations and challenges

In spite of the huge researches that have been conducted, the GPC confronts several challenges that require to be cured. One of these essential challenges is lack of standards which should be conducted by a global committee. The adaptation method of as such new materials will be finite because the institutional issues and flexibility absence of specifications, or rather, the impediments of the technical issues. For evaluation of concrete performance have to use appropriate standards, which can be most suitable solution for the conditioning of such new materials. Furthermore, the "geopolymers" term includes a wide ambit of source materials, which can perturb the designers or specifiers; hence; hence, a valid category of the source materials have to pick out for the concrete manufacture [41].

The issuance of newfangled codes will be high costly; therefore, it requires the cooperation of governmental institutions, researchers, and industries. The major incentive for the relying of such new materials is the environmental issues and sustainability cost. Nevertheless, these troubles are not enough to encourage the unwilling markets; this requires providing of a demand market for new material. This can be done by increment the universal awareness and the new regulations adaptation for the greenhouse gas emissions. The improved essential properties like strength and durability make end users are more preparing to dealing with GPC as an ideal choice of the environmental issues. Above all this, from expected, that GPC will be contribute in decrease the cost up to 10-30% compared to OPC concrete because the raw materials of GPC are relatively inexpensive [42].

In actuality, the cement companies can support controlling with production of such raw materials by long period contracts. For reducing of the activating solutions, or producing of cheaper activating solutions have to utilize modern effective mechanisms, with taking consider the efficiency improvement of gases emission. In light of the currently prospected prices, GPC commercialization is most probably to be limited to the high-performance implementations which include dangerous waste management and the resistance of heat, fire and chemical materials [43].

There another intrinsic issue suggests significant question about long-term performance of GPC in an acceptable quality.in order to verification before such new materials are conducted suitable for construction technique, there are several design engineers need at least 20-30 years at reality. Absence of as such data makes it inappropriate when the user safety may be a critical concern. The durability tests provide allusions about the predictable performance; therewith, there urgent necessity of a definitive approach. Other obstacles to be overcome are more specifically related to the change in the physical and mechanical characteristics which are related to the compounds diversity and the source materials quality [44].

Through directly comparison of prior dilemmas with the available studies results appear difficulty issues. The predictability and reproducibility of the hardened and fresh properties can be indications as determinants for conditioning of any new material. It's necessary to depend on a new engineering and chemical viewpoint for evaluation of the GPC product in term of the rheological properties and the chemical composition. As well as, high temperature curing of the GPC subtract another challenge which reduces using GPC of precast applications. In order to the wide admission of GPC products have to conduct ambient cured for geopolymer binder. Some researchers attempted to raise the FA reactivity by increment the fineness [45] or a calcium source material addition [46, 47]; perhaps, this may affect the durability cost and cost of the GPC.

Heidrich et al. [41] carried out an investigation in Australia about the obstacles that are confronting the acceptance of usage of GPC. The survey covered a extensive domain of the concrete industry specialists. Primarily, most respondents appeared hesitation about utilizing of GPC and have attributed main reason to standards absence, While Others expressed of their concerns regarding the GPC efficiency at long-term as second challenge, and safety, maintainability and productivity issues came in the third place. Therewith, there were fewer concerns as for liability and cost.

2.2 Experimental Researches of Hollow Beams

The use of RC hollow members for civilian facilities has continuously increased around the world during the last decade. In spite of efficiency of concrete construction around the world, but there are still many problems on the table, among these problems, the concrete weight and the brittleness of the concrete members are in the tops list. The RC members are largely utilized in engineering practice in a diversity of situations and applications.

In general, these RC beams are designed following simplified procedures based on the data produced by laboratory tests which are extracted from laboratory tests. Although conventional experiential solution methods remain adequate for normal design of RC beams, since the late 1960's, the finite element technique has been applied extensively for the nonlinear analysis of the RC beams. The finite element strategy development has provided means for the analytic thinking of a great deal more complex systems in a much more realistic technique. Referable to the complexity of the nature of material composite, right modelling of such structure systems is still a challenging chore.

This section in chapter two, previous experimental works are reviewed, this include introducing the available researches on the investigating the behavior of RC members with longitudinal openings was presenting and without hollowness.

2.2.1 Flexural behavior of hollow beams

Many experimental studies showed that both hollow and solid beams with same reinforcement and same cross-section failed nearly under the same load when subjected to pure torsion with lower impacts of the interior concrete core. However, fewer reports were detected in the literature comparing the failure loads and behavior in the case of beams subjected to combine bending [48].

Several experimental researches have been realized in the behavior of hollow and solid members under different loads [49]. Karthik et al. [50] experimental research was done the concrete conductance with variation of grade in the compression and tension region of RC beams. They reached theoretic concept that the RC beam with simply supported doesn't need to concrete in tension zone, where concrete function in this zone is an as transportation media to strain; hence, the lessening of concrete grade in the tension section for RC beams. This will be lead to decrease the construction expenditure.

Govindan et al [51] reported that maximum stresses in the beams are at the bottom and top of neutral axis and equal zero at axis-center. Therefore, a light and cheap material can be utilized near neutral region, what making it economic and constructivist value. It is noticed that the bearing capacity in the hollow beam decreased to range by 80 - 90% of the solid beams capacity.

Bhatt et al [52] tested on a group of beams, twelve beams of two pairs solid and hollow RC beams are tested under both combined bending and torsion action. The RC beam were designed by utilize direct design-technique that is depend on the plasticity theory under lower bound consideration which is considered to contribute to the progress of RC concrete theories . In this technique, any stress field, this could preserve equilibrium with external load and calculated the required reinforcement by using the ultimate limit state. In their research the elastic stress field has been utilize. The RC solid members were designed as hollow by supposing that the resisted of torsion is by 50 mm thickness. From these results, they could be observed that both hollow and solid members failed approximately 10% less than the design loads in pure torsion and dominant bending tests.

Soman et al [53] studied experimental and analytical investigation on partial replacement of concrete in the tension zone. Air voids were formed by using PVC pipes and polyethylene balls. Dimensions of all specimens were 150×200×1250 mm and the concrete grade was M25. The plastic balls and PVC pipe were used in neutral axis by 3.7 and 3.8cm diameter respectively. The partial replacement was 4, 8 and 16% of concrete amount and below neutral axis. It tests result that partial replacement up to a range of 8% can be done and beyond that replacement leads to detract in the loading capacity.

2.3 Effect of Fiber on Concrete Behavior

It is worth mentioning that the ductility has advantages but the most important feature of the dominant safety in the structure because it provide an indication on the resistance of the structural member to with keeping the maximum strength. Ductility commonly used to delay the local failure of structures that are not fixed by allowing the redistribution of stresses from one critical division to other [54].

Moreover, RC is exposed to cracks that begin with tensile stress when exposed to bending load and the main weaknesses of concrete as a structural material are the low tensile strength and brittleness. The insertion of fiber may lead greatly the mechanical properties enhancement of concrete such as the bearing capacity of the residual carrier (toughness) and ductility [55]. Where adding fiber to the conventional concrete materials, is enhanced the behavior beyond the peak load due to its post peaking reinforcing that can called as toughness. From the structural view, the fibrous concrete toughness initiation of the small multi-cracks that lead to increase the durability. The importance of the mentioned properties can be developing at the service level. Furthermore, FRC applying may be assists to diminish or even completely remove reinforcement of shear [56].

The literatures provide some specific information and research results on the calculation of FRC reinforced beams. The preferable methodology of testing for assessing the materials properties is the toughness in the flexural test of the cracks initiate after peak load. The code of practice adopted two methods to determine the flexural capacity; these are one point, and two points for flexural test [57].

2.3.1 Structural properties of fiber reinforced concrete beams

The mechanical demeanor of a structure is very affected by the formed materials utilized. Based on tensile response from load-displacement relation, mostly engineering materials may be classified to three groups are quasi-brittle, brittle and ductile (without or with strain-hardening) as explained in Figure 2.2 [58].

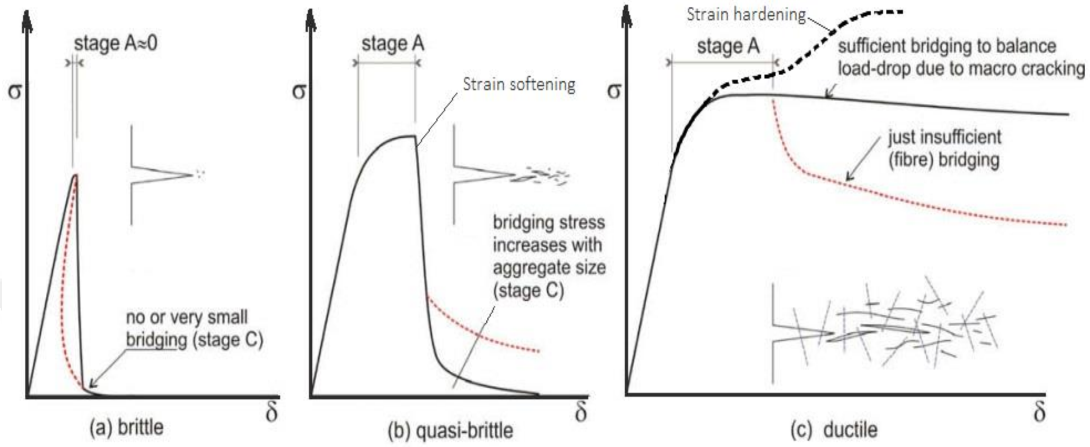


Figure 2.2 Three kinds of failure modes observed in materials

Brittle failure could be seen that in strengthened cement material, this failure type as is clarified in Figure 2.2a, where it is described as a linear load-deflection curve followed by a load subsidence at first cracking and a strain of ultimate tensile in the mentioned order by 0.01% [59]. The failure of quasi-brittle can be noticed that in concrete and most fiber reinforced cementations composites, which is described as a linear relation for stress- strain curve followed with a softening curve after first cracking. The quality of the softening part depends upon the matrix components. This softening mostly happens during bridging action of cement ligaments, aggregates and/or fibers as is shown in Figure 2.2b.

As graphically shown in Figure 2.3, conventional concrete, avoiding fiber, demonstrates limited strain softening behavior after peak load; however, a proper softening with an acceptable ductility can be observed in the case of FRC depending on fiber type and volume fraction. Ductile strain-hardening materials (Figure 2.2c); moreover, are capable of maintaining increasing levels of bearing after first crack happens while beyond the peak value with mounting deformation [59].

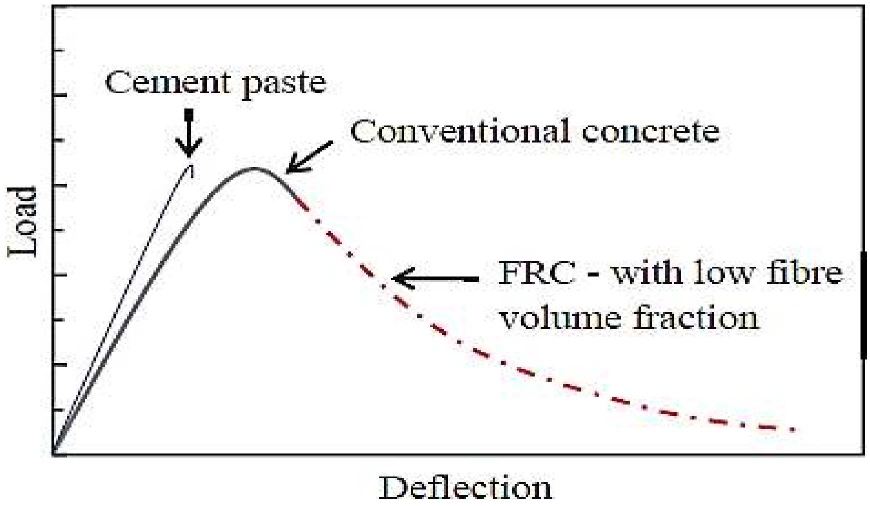


Figure 2.3 Schematic failure modes for concrete

On the utilizations of different kinds of fibers in concrete to measure the structural behavior, studies are epitomized in the following items:

Sathish et.al [60] detected the density result of GPC composites was approximately equivalent to those conventional concrete. The raise at compressive strength was about 10 and 20% for GPC. It can be utilized in zones which need faster strength performance. The reinforced GPC with fiber leads to completely exclude the usage of cement in concrete and assists to prevent global warming and to utilize the FA effectively.

For instance, Soulioti et al. [61] a investigation was conducted on concrete specimens under the four-point bending tests and that contained the SF by 1, 1.6, 3 and 5%; where the results were checked and evaluated in terms of peak load, post-peak behavior, and residual strength, and also comparison them. The distribution of fiber was assessed and their contribution in pattern of first fracture. As well as, the SF effects volume were highlighted on the index of ductility, strength, and utmost strain for steel FRC, in order to give a guide for structural utilizing. Lastly, the fiber geometry was detected to be a major factor affecting the material mechanical performance.

Altun et al [62] tested and evaluation nine steel FRC beams under two point monotonically load, with a cross section 300×300 mm. Six of them are box beams divided two group depending on the size of longitudinal hole, three of them of box beam with central hollow part of 100×100 mm and the other three-box beam with

200×200 mm. They found that results clearly indicate that box beams with some hollow parts around their neutral axes work efficiently against bending. For the thinner steel FRC box beams, two times wall thickness over height of box beam (e/h=0.33) , the loss in resistance of ultimate load about 29% is fewer than both gains in the mass of concrete 44% and amount of tensile steel reinforcements 39%. The reduced transverse loads of the earthquake due to reduced weights of the box beams of a possible structure may impose minor loads and bending moments on those hollow beams, which may stay in commensurate with their slightly smaller load-carrying capacities. They also presented the three-dimensional relationship of the measured loads versus the mid-section displacements and the cross-sectional moments of 10 inertias as explained in Figure 2.4, Which are clarifies the behavior of RC hollow beams.

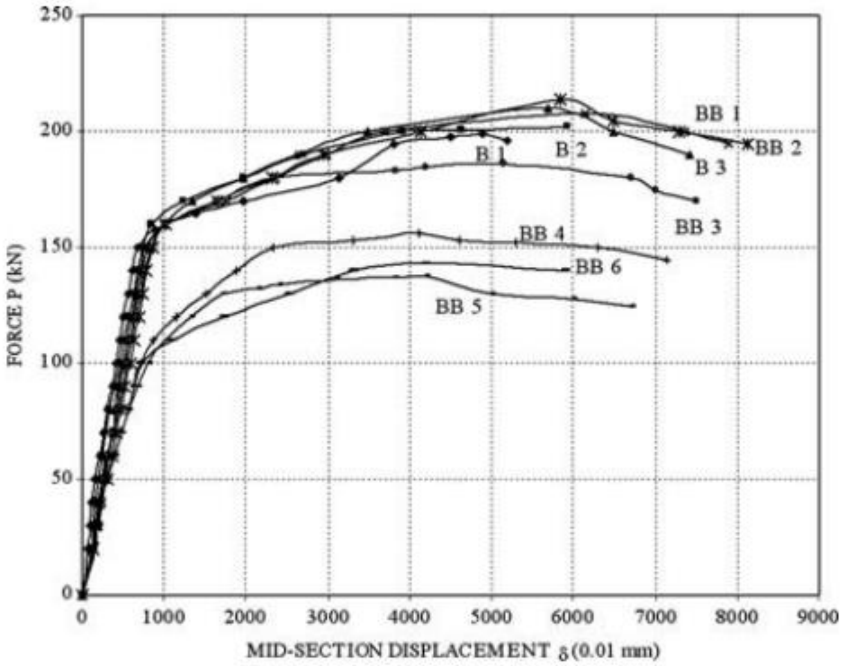


Figure 2.4 The relationships of loads versus mid-displacements [62]

Rinaldi et al [63] have investigated the effect of adding 1% volume fraction of SF (l_f = 30 mm, d_f = 0.6 mm) to a concrete beam (f_c = 25 MPa) reinforced with steel bars (f_{sy} = 460 MPa, f_{su} = 550 MPa) with geometry. The obtained results are agreed that adding fiber to the RC beams improves the ductility by 166 %.

Banthia et al. [64] explained that deformed steel macro-fibers in term of production hybrids were greatly best than those with less deformation. Lastly, compounds of reinforced by a lower Volume Fraction (V_f) of fibers were noticed that have a better chance for hybridization than those high V_f of fibers. In other words, whenever toughness of FRC was less, that elected fibers are better for the hybridization. Furthermore, the maximum of V_f in the hybrids should be doesn't transcend 1.3%.

Bhalchandra A et.al [65] the compressive strength and the flexural resistance of reinforced GPC increases with GF inserting at concrete mixture, with respect to increase in percentage volume portion of GF and addition of 0.3% volume fraction of GF exhibited maximum increment in flexural strength and compressive strength by 57 and 20.2% respectively with respect to mix without fibers.

Jagannadha Rao et al. [66] specified the appropriateness of GF for applying with the recycled aggregate in the structural concrete of high strength. Where, this study conducted comparison of the ordinary concrete aggregate with the partially replaced recycled concrete aggregate in term of hardened state properties, with taking into consideration, addition of GF with varying percentages. The split tensile, compressive and flexing resistances had increased for percentages are 0% recycled concrete aggregate and 50% recycled concrete aggregate with increment of fiber content. The utmost values of all these strengths were acquired by 0.03% of GF content for both the concretes of 0% recycled concrete aggregate and 50% recycled concrete aggregate. Before beams failure, the great deflections denoted ductility improvement with the GF insertion

Banthia et al [67] depended on hybrid fiber task, one of fiber kind lead to enhance the early age and fresh properties such as plastic shrinkage and ease of production, while the other fiber improves mechanical characteristics. Some hybrids are available such a high (>0.5%) dosage of SF is incorporated with a low (< 0.2%) of the polypropylene fiber.

One kind of fiber is smaller, where this fiber has as bridge to connect micro-cracks and hence, dominates their development and delays overlap. This results to a larger tensile strength of the compound. The other fiber is longer and is aimed to inhibit the spread of macro-cracks and hence results in a significant amelioration in the fracture toughness for compound [65].

Banthia et al. [68] conducted experimental investigation to enhance concrete admixtures by insertion high modulus steel fibers and low modulus pitch-based carbon in forms of mono and hybrid. On a comparative basic, the SF exhibited higher tensile strengths to the base cement matrices than carbon fibers, in term of the toughness or energy absorption, the carbon fibers led up to improve more than SF. In view of the above research findings, many reference mixtures were considered with diversified volume fibers (V_f) of steel and polypropylene in this study to determine impact of fiber modulus variation on the flexural toughness behavior for concrete.

CHAPTER 3

SPECIMENS PREPARATION AND METHODOLOGY OF TESTS

3.1 General

This chapter presents a preparation of the specimens for casting and curing process. Also, the Characteristics of materials applied in this study are depicted together with specifying their mix proportions. This experimental work was accomplished at the Structural and Materials Laboratories at Gaziantep University.

3.2 Material Specification

3.2.1 Fine materials

The utilized main materials as source for the producing of GPC are:

The low calcium fly ash is from class F normally produced of bituminous coal or burning anthracite according to (ASTM C618-12), which usually consists of silica and alumina mainly, this class has a most loss on ignition than C class. It was assembled from a local supplier and stored in large locked bags at designated laboratory storage place. The specific gravity of FA is 2.2 Kg/m3.

Ground Granulated Blast Furnace Slag (GGBFS) is a non-metallic product where acquired it from wastes of Iron manufacturing processes. It's a glassy granular material because it consists of alum-inosilicate of calcium, silicates and other bases according to (AS 3582.2) [69]. The used slag in this study was bought from a local supplier and its specific gravity is 2.88 kg/m^3. Tables 3.1 list the chemical components for the both materials.

Table 3.1 Specification of FA and GGBFS

Characteristics	FA	GGBFS
Silicon dioxide (SiO_2)	62.53	40.42
Aluminum oxide (Al_2O_3)	21.14	10.60
Magnesium oxide (MgO)	2.40	7.63
Calcium oxide (CaO)	1.60	34.19
Sulphur trioxide (SO_3)	0.10	0.68
Iron oxide (Fe_2O_3)	7.85	1.28
Potassium oxide (K_2O)	3.37	-
Sodium oxide (Na_2O)	2.45	-
Loss on ignition (%)	2.04	2.74
Specific gravity (Kg/m^3)	2.20	2.88
Blaine fineness (m^2/kg)	379	575

3.2.2 Alkaline solution

Alkaline solution takes a significantly function in GPC for the alumina and silica dissolution; Moreover, for the polymerization response catalysis [70]. In this experimental study, materials to prepare alkaline solutions activator for geopolymerization were provided from local suppliers. Where sodium silicate (Na_2SiO_3) is available in the semblance a gelatinous liquid and sodium hydroxide (NaOH) in the shape of flakes as are clarify in Figure 3.1. The sodium hydroxide solution was prepared with 14 molarity consternation by dissolving the flakes in deionized water. After that, the solution is mixed with sodium silicate (Grade A53). It is important to alert that the two solutions can't mix together before 24 hours [71].

3.2.3 Aggregate

Coarse aggregate: A crashed stone with a gap graded of crashed stone are used. The maximum size of the particles was 9.5 mm. It is shown that there are a gap between particles of 4.75 mm and 9.5 mm, this means that even the coarse aggregate has higher fine aggregate.

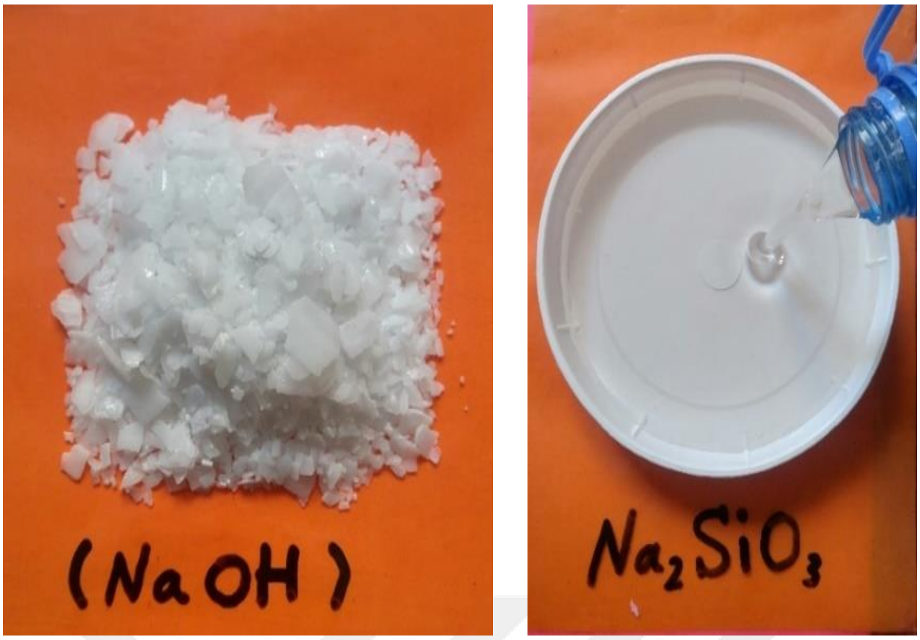


Figure 3.1 Components of alkaline solution

Fine aggregate: A graded river sand brought from local source. The size of particles are ranging from 0.075 mm to 4.75 mm was used.

Table 3.2 and 3.3 explain the sieve analysis of the used coarse and fine aggregate. Also in Figure 3.2 there are curve for seive anlysis.

Table 3.2 Coarse aggregate grading (crashed stone)

Sieve opening (mm)	**Retained weight** (gm.)	**Passing** %
12.50	0.0	100
9.50	186.6	89
4.75	1690.8	5
2.00	1749.7	2
1.18	1754.9	1
0.60	1758.5	1
0.30	1763.8	1
0.15	1770.0	0
0.075	1770.0	0

Table 3.3 Fine aggregate grading (river sand)

Sieve opening (mm)	**Retained weight** (gm.)	**Passing** %
12.50	0.0	100
9.50	186.6	100
4.75	1690.8	93
2.00	1749.7	63
1.18	1754.9	45
0.60	1758.5	29
0.30	1763.8	16
0.15	1770.0	5
0.075	1770.0	4

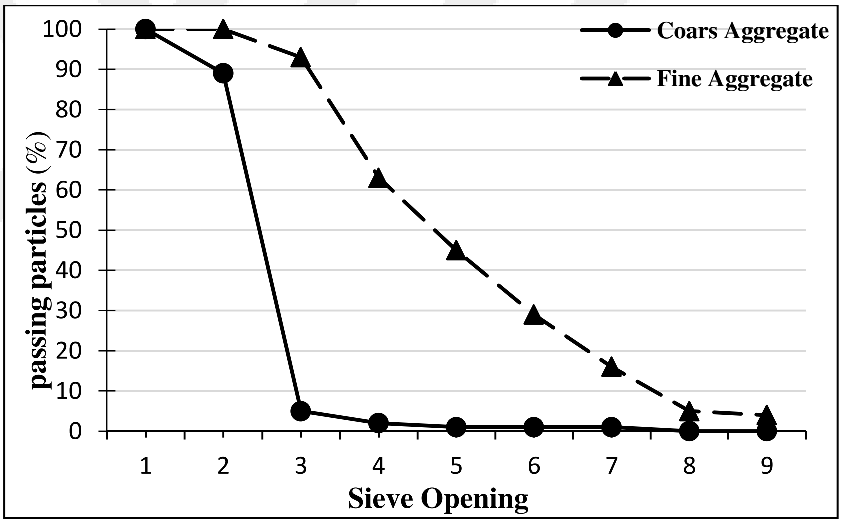


Figure 3.2 Sieve analysis

3.2.4 Fibers specification

The fibers are designed for using in concrete or cement mortar to improve the internal quality, prolong service age of concrete and cement mortar and reduce maintenance cost. The fiber may form a guided support system in concrete randomly which can thus control the formation and development of non structural cracking effectively such as drying cracking cracking and plastic shrinkage cracking, effectively reducing the separation of aggregates and forming cracking settlements.

The utilized SF in this study is cold-drawn wire from type I according to a classification of common kinds of SF which provided by a standard limitation for steel FRC in (ASTM A820) [72].

While that used glass fiber is electrical glass fibers from type E-glass, the most widely utilized, has comparably inexpensive and excellent strength and stiffness, but it is somewhat weak in impact endurance [73]. Generally, that GF is an inorganic and fusionable product which has cooled to a solid condition without crystallizing due to glass is amorphous, it is isotropic and has a glass transition point instead of fusion point according to (ASTM C167) [74]. Its tensile strength in fibers appearance is almost overtaking ten times more than in bulk form There are numerous characteristics of GF come from their specifiation which makes them ideal enhancements [75].

Both fibers sourced from Turkey and Table 3.4 show the specifications of both fibers in this experimental work. Also there is Figure 3.3 clarify utilized fibers employed in casting process.

Table 3.4 Fibers specification

Fiber	**D** (µm)	**L** (mm)	**L/D**	**Modulus Elasticity** (GPa)	**Specific Gravity** (kg/m^3)	**Tensile Strength** (MPa)
Steel	55	30	55	200	7820	1500
Glass	13	12	92	89	2490	4750

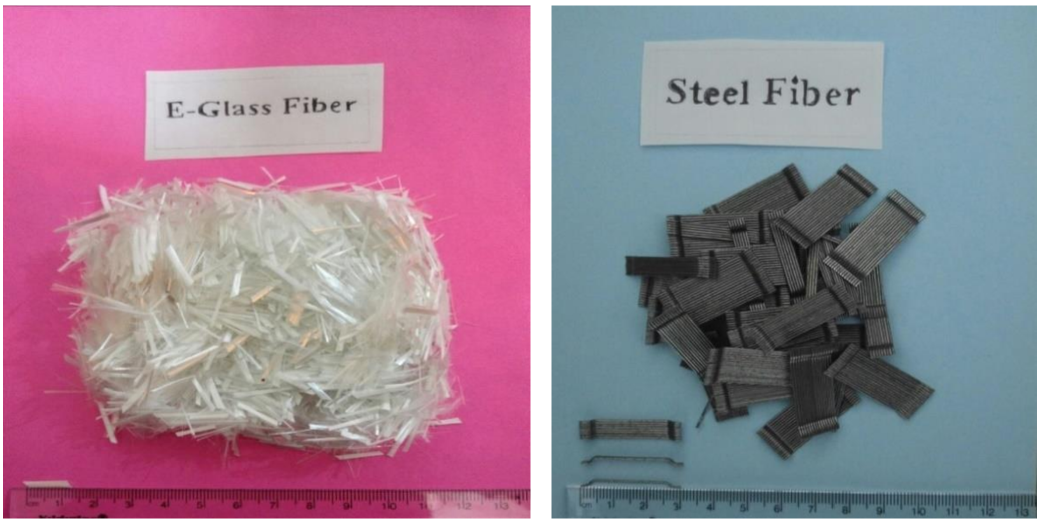


Figure 3.3 Fibers types

3.2.5 Super plasticizer

Master Glenium51® is a type of poly carboxylic ether. This super plasticizer was depended in every mixture. The specific gravity of 1.07 Kg/m^3 was utilized every concrete mix. The detailed characteristics of used high range water reducing admixture.

3.3 Mix Design and Materials Properties

The mineral and aggregates used for GPC production are shown in Figure 3.4. In the GPC mix design, both fine and coarse aggregates were used as 70.6% of whole admixture by mass. Fine aggregate was represent 49% the entire aggregates of mass. According to earlier researches and studies, it is clear that a density of GPC equal (2300 kg/m^3) and it's similar to that of OPC concrete. The GPC composites contain of alkaline liquids, 50% FA and 50% GGBFS. The mixtures were designed for 14M molarity and the proportion of sodium silicate equivalent 2.5 than sodium hydroxide and used for producing GPC. Where fibers were added (1%) steel fiber, (0.5%) glass fiber to the full volume of concrete and obtained hybrid fiber by mixing half of amount from both types. In Table 3.5 mix proportion is given.

Table 3.5 Concrete mixture amount per cubic meter

CODE	**FA** (kg)	**Slag** (kg)	**WG** (kg)	**NaOH 14M** (kg)		**Fibers** (kg)		**Coarse Agg.** (kg)	**Fine Agg.** (kg)	**Sup.** (lt)
				Flakes	**Water**	**Steel**	**Glass**			
SF0-GF0	225	225	144.64	23.36	34.48	0	0	826.2	793.8	20
SF1-GF0	225	225	144.64	23.36	34.48	78.2	0	826.2	793.8	20
SF0-GF0.5	225	225	144.64	23.36	34.48	0	13	826.2	793.8	20
SF0.5-GF0.5	225	225	144.64	23.36	34.48	39.1	6.5	826.2	793.8	20

Where WG is a water glass or (Na_2SiO_3), SF0-GF0 is code for mix design without fiber, SF1-GF0 is code of mixing consists of 1% steel fiber, SF0-GF0.5 is code of mixing has of 0.5% glass fiber and SF0.5-GF0.5 is code for hybrid fiber mix by mixing half of amount from both fibers.

(a)

(b)

Figure 3.4 (a) Fine materials for matrix (b) Fine and Coarse aggregate

3.4 Preparation of Specimen

3.4.1 Reinforcement of beams

All beams are reinforced on tension zone by two deforme bars ϕ 8 mm in bottom of section for flexural reinforced, and two bars in compression zone from section. For shear reinforcement was used ten stirrups of ϕ 5.2, the yielding strength of the ϕ 8 mm and the ϕ 5.2 mm bars were 503 MPa and 558 MPa respectively. Reinforcement cages were constructed at Gaziantep University Lab and Figure 3.5 shows the details of reinforcement for the beams used in test.

Figure 3.5 Details of reinforcement

3.4.2 Moulds for casting test specimens

Plastic cylinder moulds (100×200 mm) were used for casting specimens of compressive and split tensile strength. Every mould was properly cleaned before casting and the interior mould surface was painted by a specific oil to assist demoulding process after concrete solidify.

For casting samples of flexural tests, three molds were designed from plywood plates. All moulds had same cross section dimensions (150×150mm) and length is 850mm. One of mould was prepared to cast solid beams. The two other moulds were put a square and circle pipe in them before casting for obtaining specimens of hollow beams. Before each casting process, pipes are lubricated by machines grease, and then are covered by plastic wraps to help demoulding process after hardening of concrete and opening moulds. Figure 3.6 shows moulds used in specimen preparation.

Figure 3.6 Moulds for flexural test samples.

3.4.3 Mixing process and specimens casting

The components of GPC consist of mixing the dry solid composites are FA, slag, fine and coarse aggregate together in the mixer for about 3.5 minutes. Then after that alkaline solution is added above this dry mixture. The super-plasticizer was added after solution is mixed thoroughly to achieve the workability. The wet mixing duration was not less than 3 minutes [76]. The mixing for GPC was undertaken using an 80-litres mixer. The mixing process is shown in Figure 3.7. Instantly after mixing, the fresh concrete was cast into the moulds.

Figure 3.7 Mixing process for GPC

According Table 3.5 there are four mixing groups. First group is control mix without fiber. As for three other groups, they contain of different types from fibers as are explained in the same table. From each group was casted 9 cylinders (100mm x 200mm) for compressive strength test at ages 7, 28 and 56 days where was assigned three samples for each age. Also split tensile strength test, was taken same number from specimens for every groups and ages.

Concurrently with casting of cylinders, 12 beams were casted and divided to the same four groups for flexural strength test. Each group included three beams, one of them solid beam and two others beams are square and circle hollow beams. Figure 3.8 shows freshly mixed concrete placed in cylinders and beams and Figure 3.9 clarifies beam geometry and groups details. The net distance of concrete covers about reinforcement was 15mm on all faces.

After pouring the concrete in the mold, concrete surface was leveled and smoothed using a trowel, due to a limited mixer tub capacity each mixture group was casted in three batches. The vibration was applied to consolidate the mix in order to have a uniform allocation of the fibers and prevent segregation occurrence.

Figure 3.8 Freshly mixed concrete placed in cylinders and beams

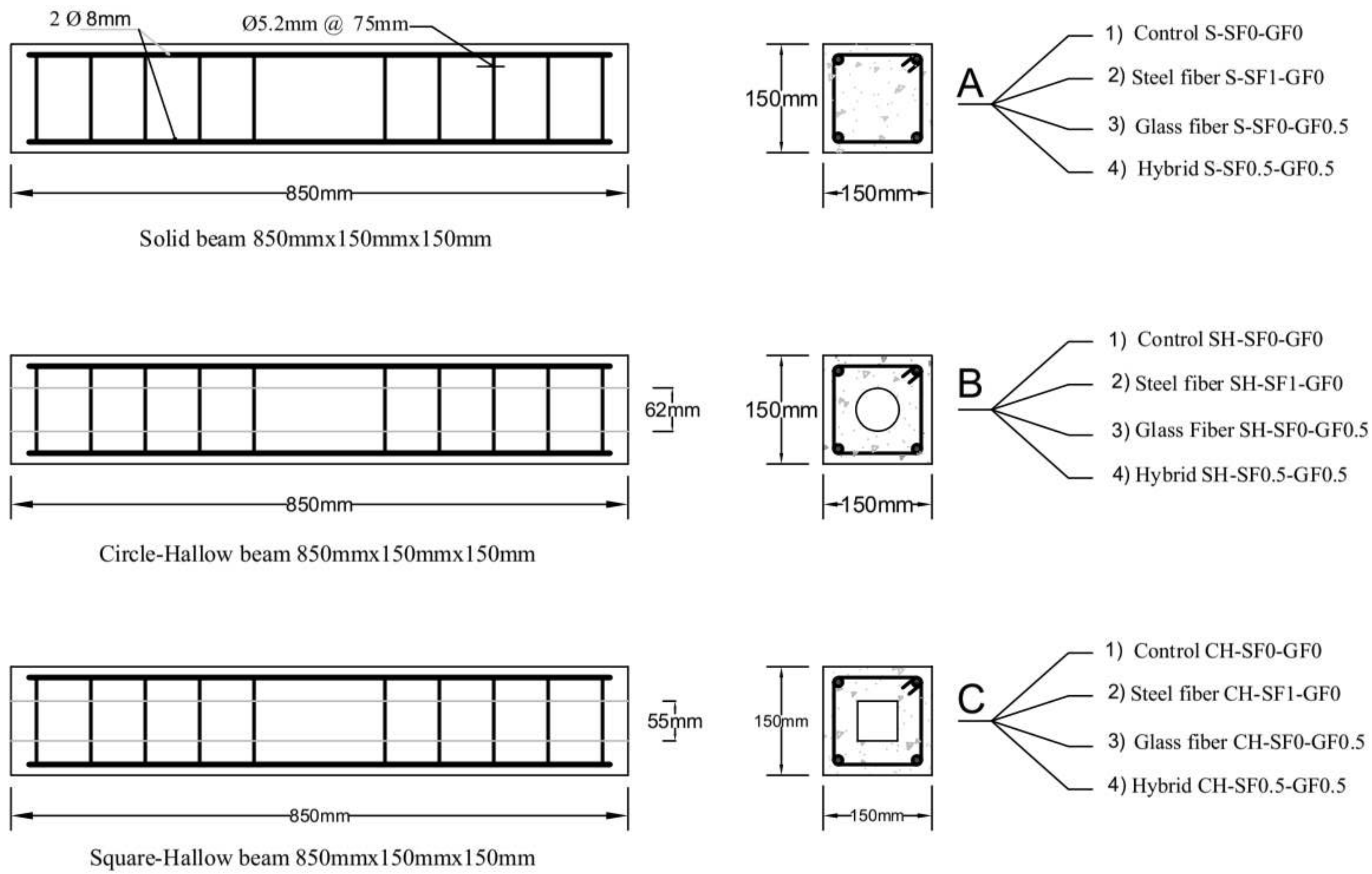


Figure 3.9 Beam geometry and groups details

3.4.4 Curing system

After 24 hours from casting, the specimens along with molds were placed inside the oven for curing under temperature of 80°C and for 24 hours. Next they were demoulding and returned again to the oven and also for 24 hours to complete curing process at same temperature. Moreover, to obviate condensation above the concrete surface, thin plastic sheets were utilized to cover the exposed concrete face from start of casting process to curing end as are appeared in Figure 3.10. At last stage samples were kept in laboratory temperature conditions between 25°C to 30°C until the test day as shown in Figure 3.11.

Figure 3.10 The curing of GPC in oven

Figure 3.11 Specimens after curing and demoulding

3.5 Tests of Mechanical Properties

3.5.1 Slump test

According to ACI 116R-00, the workability is freshly concrete mixing property which determines concrete homogeneity and involves several correlated terms, such as flow ability, consistency, mobility, pump ability, plasticity, compatibility, stability, and finish ability. Hence, it's essential to consider workability in the mix design to ensure casting ease and durability of concrete. Slump test was used to measure fresh concrete workability which done in accordance with ASTM C 143 [77]. For the test was used a conical mould with the dimensions of 100mm top diameter, 200mm bottom diameter and 300mm in height. The next procedures were followed during the testing:

Initially the interior mould surface and base plate was cleaned and wiped out with a wet rag. Then, the mould was firmly fixed above the base plate in place by hand catchers and standing on the both feet pedals. The mould was packed in equally three layers and each layer was compacted with 25 strikes, a temping rod was used for compaction and its dimensions are 600 mm length and 15mm diameter, where,each layer was compacted by this rod which penetrate the previous layer at least 25 mm.

After compacted and levelled the upper layer, surplus concrete was removed from mould base. Then the mould was raised vertically in about 3 ±1 seconds with avoiding any torsional pull causes side displacement. Finally the vetrtical distance between the mould height and the edges of top concrete surface was measured. The these measurements average is the slump value. Figure 3.12 show slump test.

Figure 3.12 Fresh GPC and slump measurement

3.5.2 Compressive strength test

The compressive strength test is the most widespread of all tests on concrete hardness because application of this test is very easy. Moreover,compressive strength determine many desirable properties of concrete which related it qualitatively [78]. A Besmak digital series compression machine was utilized to find compressive strength in accordance with ASTM C 39 [79] and applied to test the samples is as follows:

For each mixture group was selected three specimens (100mm x 200mm) at ages 7, 28 and 56 days respectively ASTM C172 [80]. The samples were made cover of sulphur for load surface to provide uniform load distribution according to ASTM C 617-12 [81]. The cylinder was set in the centroid of down plate of compression testing machine and subjected under load with a constant rate of 0.2 kN/sec until failure. Load carrying capacity and strength were recorded after the failure of the specimen from system of equipment directly by a flash drive. Figure 3.13 shows test setup.

Figure 3.13 Cylinder compressive test

3.5.3 Split tensile strength test

The splitting tensile test (indirect or ‘Brazil’ test) is a simple and indirect procedure of determining the tensile strength, which gives more consistent results than other tension tests. The measured strength in the split test of concrete is supposed to be higher the direct tensile strength by 5 to 12 % approximately [78]. Besmak digital series compression machine was utilized to get value of split tensile strength was conducted following ASTM C496 [82] and explained to test the samples is as follows:

For each mixture group was selected three specimens (100mm x 200mm) at ages 7, 28 and 56 days respectively ASTM C172 [80]. The cylinder was placed in a axis horizontal between the plates of testing machine with put 15-25 mm wood strips to ensure that the center lines of the specimens were loaded on its longitudinal axis and vertically at the both test face sides as illustrated in Figure 3.14.

Figure 3.14 Split tensile strength test in progress

Lastly, load was applied to the samples without any shock and constantly increased with a constant average of 1.5 kN/min. With testing finish, the failure load was registered to calculate the utmost tensile stress by the usage of equation (3.1).

$$f_{sp} = \frac{2000\,P}{\pi\,L\,D} \tag{1.3}$$

Where,

f_{sp} = Split tensile strength (MPa),

P = Maximum applied force (kN),

L = Length of specimen (mm),

D = Diameter of specimen (mm).

3.6 Test of Structural Properties

3.6.1 Instrumentation and test set-up

Flexural beam test is another indirect method of testing and evaluating for tensile strength of the concrete. All beams were placed on simple supports with net span is 750 mm. The loading framework was utilized to check the GPC beams under three point loading by applying of the hydraulic jack load at the middle of beam until the ultimate failure. The casting and testing procedure as per the specifications provided were followed by ASTM C1609 [83]. Figure 3.15 clarifies the test configuration.

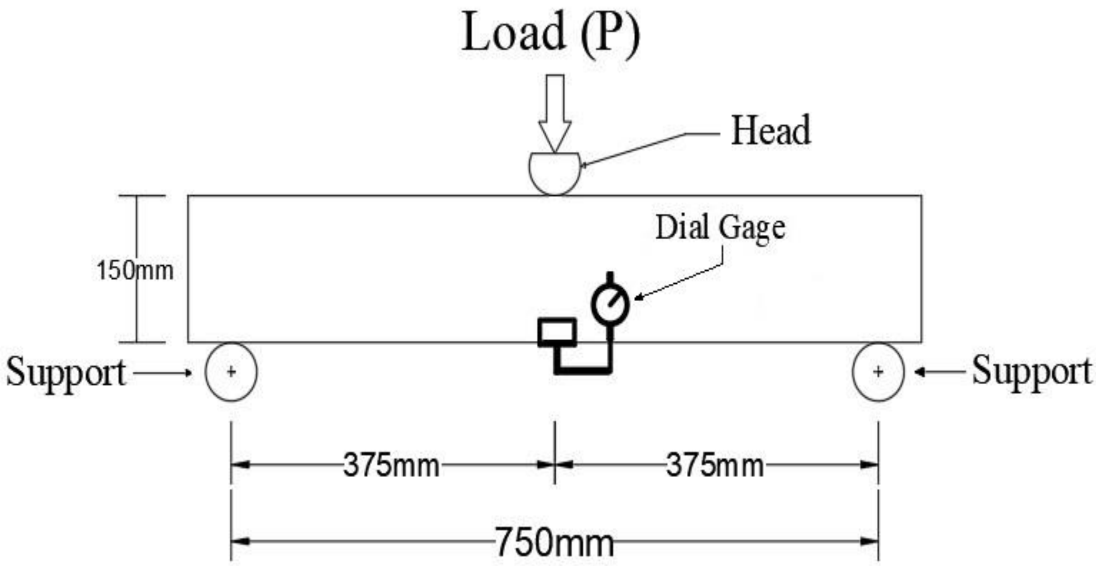


Figure 3.15 Beam test configuration

A testing machine (Instron 5590R) with utmost capacity of 250 kN was applied in experiment.Table 3.6 shows the details of the testing machine and specimen.

Table 3.6 Details of the INSTRON testing machine

Model No	85
System ID / SN	85L2125
Configuration	-F1-G1
Capacity	0 KN (56250 Ib)
Wight	2 Kg (1949 Ib)
Date of Manufacture	ly - 2011
Voltage	0 Volts
Frequency	– 63 Hz
Maximum Power	00 VA
Circuit Breaker	AMP

3.6.2 Test procedure

Prior to placement the testing specimens in the machine, for disparity removing, the beam surfaces were fully rubbed to be smoothly at the locations of supports and loads. Each beams were dyed with white colour to facilitate discern of micro-cracks and marking.

The test was done by the loading movement stability for the testing machine platen on the beam as a rate by 0.4 mm/min. The data capture rate differented by 10-20 a result read per second. The loading continued on tested beam until reaching to the expected peak-load, atmost rate was utilized to ensure that capture of sufficient data to followe the curve of load-deflection near failure.

Digital data recording unit was applied to compile the data during the test. Linear Variable Data Transformers (LVDT) was utilized to obtain the deflection values at determined locations along the beam span. LVDT was calibrated before any test conducting. The relationship of LVDT outputs in milli-volts (mV) with actual movement by millimetres (mm) is considered as linear relation. LVDT was placed at selected position under the beam span center to monitor the deflection. prior to the loading, the accuracy of full data recording system was insured and the firstly readings were specifed until failure. The ascendant and descend data of the load-displacement curve were registered for each test beam. After peak-load stage, the results reading continued until either the limit of LVDT at mid-span was reached or no extra information was recorded by data logger due to the whole specimen failure. Figure 3.16 shows these procedures.

Figure 3.16 Flexural beam test and beam failure

CHAPTER 4

PRESENTATION AND DISCUSSION OF RESULTS

4.1 General

This chapter displays the experimental program results on the cylinders and beams of GPC. It is explained effect fibers on behaviour of mechanical properties are workability and the resistance of compressive and split tensile. Also their influnce on structural characteristics are flexural strength, dectility and the cracks patterns at moment of first crack load, ultimate load and compression zone.

4.2 Mechanical Properties Results

4.2.1 Workability

The fresh GPC workability was determined by slump testing where scaled after the concrete mixing immediately, based on ASTM C 143 [77]. Generally, all the admixtures were coherent, shiny in appearance and sticky due to the existence of sodium silicate. Wherefore a observed slump of GPC refers a higher workability and less stickiness than OPC concrete mixture.

It was observed that the values of workability are decreasing gradually with addition of fibers. Generally, the causes of decrease in workability because the high viscous nature of GPC and uneven distribution of fibers in the admixture [84]. Table 4.1 Figure 4.1 explains the workability curve.

Table 4.1 Slump test results

	SF0%-GF0%	**SF1%-GF0%**	**SF0%-GF0.5%**	**SF0.5-GF0.5**
slump	50	35	26	31

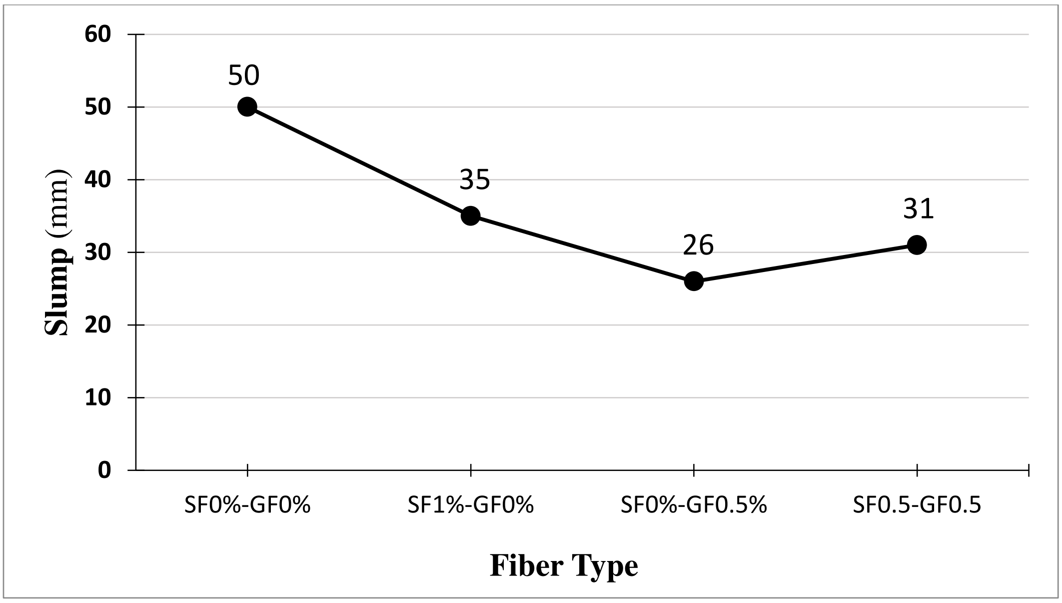


Figure 4.1 Workability curve for fibers reinforced GPC

4.2.2 Compressive strength results

The various factors such as the source of FA, GGBFS, NaOH solution concentration in terms of molarity, the curing in normal room temperature and oven temperature at 80oC, the concrete age into the testing date and addition of fibers are affecting on the GPC compressive strength, are investigated and calculated data averages. In Table 4.2 is presents compressive strength results.

Table 4.2 The compressive strength data averages

Code Mix/Age	**7 days** (MPa)	**28 days** (MPa)	**56 days** (MPa)
SF0-GF0	43.26	48.62	48.97
SF1-GF0	47.17	51.57	51.89
SF0-GF0.5	46.62	50.89	51.48
SF0.5-GF0.5	45.08	49.88	50.52

Generally, compressive strength of GPC was increased with use steel and glass and hybrid fibers. In early age, SF was observed that their effect more than late age. The Figure 4.2 describes compressive strength at Ages 7, 28, 56 days.

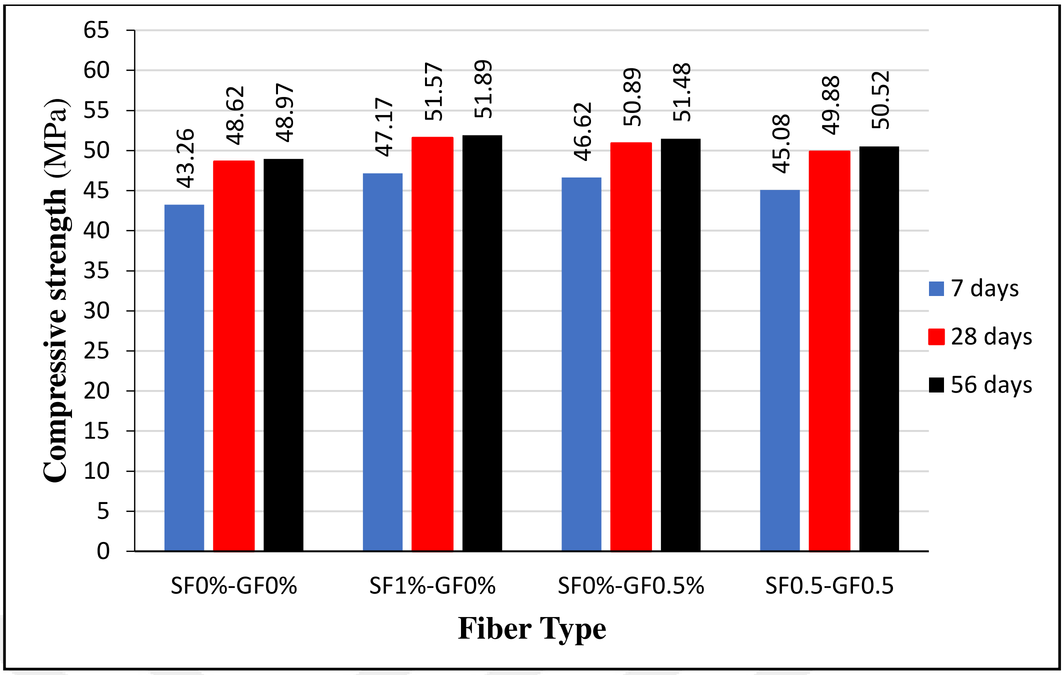


Figure 4.2 The GPC compressive strength at ages 7, 28 and 56 days

Based on the results of these monotonic tests, clarify in Figures 4.3 can observe that the increases in the compressive strength of GPC due to use the fibers which led to reduce the interior cracks [85]. Utilizing of steel fiber was clarify effect and had observed increasing in the strength of concrete about (6 - 9 %) with NaOH concentration of molarity at (14M). Also GF improvement the compressive strength of GPC about (4.7 - 7.7 %), but hybrid fibers gave improvement between (2.6 – 4.2 %) in the strength.

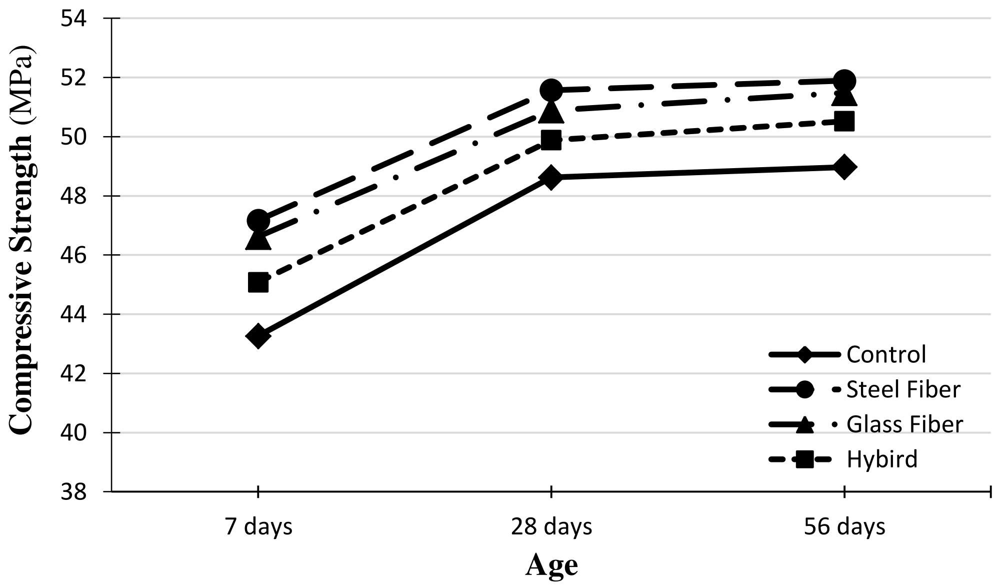


Figure 4.3 Effect fibers on compressive strength

4.2.3 Split tensile strength results

After occurs of the first crack, the plain concrete loses their tensile bearing capacity immediately. The SF addition to concrete mix result in significant improvement in strength of GPC in direct tension, with increases of about (30-40%) for the addition of (1-1.5%) by volume of SF in mixing of concrete [86]. This study is concentrating on specimens that were reinforced only with steel and GF from each batch were tested under constant compression loading. Table 4.3 shows the data averages of split tensile strength.

Table 4.3 The data averages of split tensile strength

Code Mix/Age	**7 days** (MPa)	**28 days** (MPa)	**56 days** (MPa)
SF0-GF0	4.6	4.8	4.91
SF1-GF0	6.48	6.88	7.02
SF0-GF0.5	5.12	5.31	5.38
SF0.5-GF0.5	5.21	5.51	5.59

The present experimental program consists of a series of tensile tests performed on (100 mm x 200 mm) cylindrical specimens of steel, glass, and hybrid fibers concrete. Three specimens from each batch were tested under monotonic compressive loading. Figure 4.4 describe bar chart of split tensile strength at Ages 7, 28, 56 days.

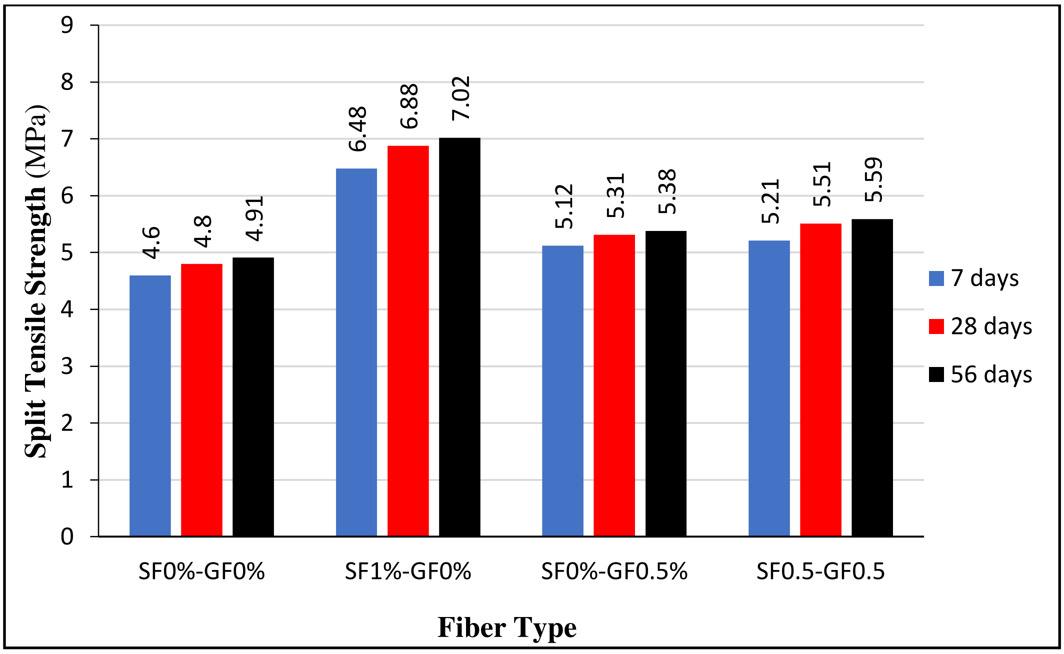


Figure 4.4 Split tensile strength of GPC at 7, 28 and 56 days

But in this study, addition of steel fibers let to the significant improvement in tensile strength of GPC indirect tension, where it was increasing by (40.86 - 42.97%), also addition GF improve the strength of GPC about (9.57 - 11.30%), but there was improving between (13.26 - 13.85%) in tensile strength due to use hybrid fibers as is clarified in Figures 4.5.

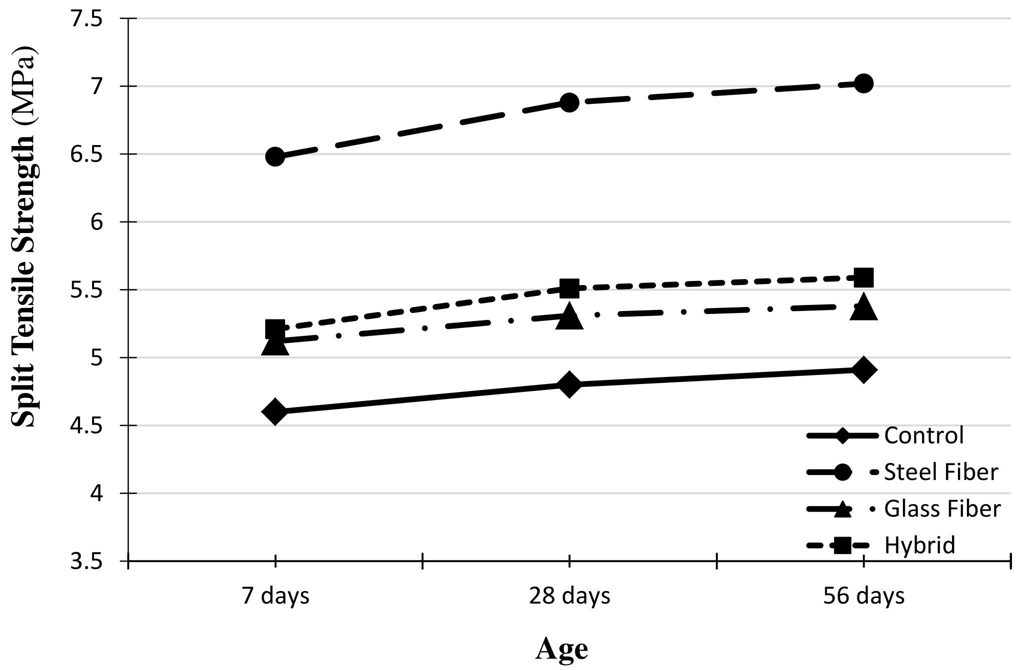


Figure 4.5 Effect fibers on split tensile strength

In this research work, the primary advantages of fiber addition to concrete which improve the tensile response after cracking and improve crack control, also showed that any SF addition to improve Significantly the tensile toughness of concrete [87].

4.3 The Results of Structural Properties

Although obtaining of an engineered construction material is of great achievement, it must also be applied to structures to acquire the benefits from a structural standpoint. Accordingly, the structural properties of reinforced GPC beams incorporating fibers as intrinsic reinforcement are investigated. As mentioned earlier, twelve reinforced GPC beams constructed for three types from fibers consist of 1% steel, 0.5% glass and 0.5% hybrid, where they are compared with control beams of hollow of solid beams. Table 4.4 presents results of tested twelve beams.

Table 4.4 Numerical values for the parameters of the flexural behavior

			First Crack		Ultimate	
Group No.	Beam Type	Code No.	P_{cr} (KN)	Δ_{cr} (mm)	P_u (KN)	Δ_u (mm)
A	Solid	S-SF0-GF0	14.494	1.115	47.458	20.308
		S-SF1-GF0	18.852	1.319	52.814	25.658
		S-SF0-GF0.5	20.981	1.795	49.718	22.844
		S-SF0.5-GF0.5	18.526	1.184	50.203	23.425
B	Circular -Hollo	CH-SF0-GF0	13.920	1.032	46.393	19.102
		CH-SF1-GF0	18.704	1.318	50.764	19.619
		CH-SF0-GF0.5	20.161	1.806	48.576	15.812
		CH-SF0.5-GF0.5	18.057	1.061	48.301	18.799
C	Square -Hollo	SH-SF0-GF0	12.861	0.916	45.368	15.37
		SH-SF1-GF0	18.532	1.528	48.477	19.431
		SH-SF0-GF0.5	19.648	2.409	46.257	20.862
		SH-SF0.5-GF0.5	16.617	1.095	47.04	16.117

4.3.1 The general behavior of beams

Every samples were tested under continuously mounting load until failure happening. The beam initiated to bend whenever the load increased and flexural cracks evolved along the beams span. Lastly, all beams reached failure stage in a typical flexure pattern. Figure 4.6 appears the curve of idealized load-deflection at the span middle. The gradual increasing of deflection exhibited at mid-beam as a load increment function. The load-displacement curves denote distinct events that occurred during the test. These events are specified as first cracking (A), the tensile reinforcement yield (B), the GPC crushing at the compression face paired with concrete cover crumbling (C), a modest incline in the load which follow the ultimate load (C'), and disintegration of concrete in compression region as a result to the longitudinal steel buckling in the compressive zone (D). These characteristics are typical of flexure behavior in reinforced GPC beams [88].

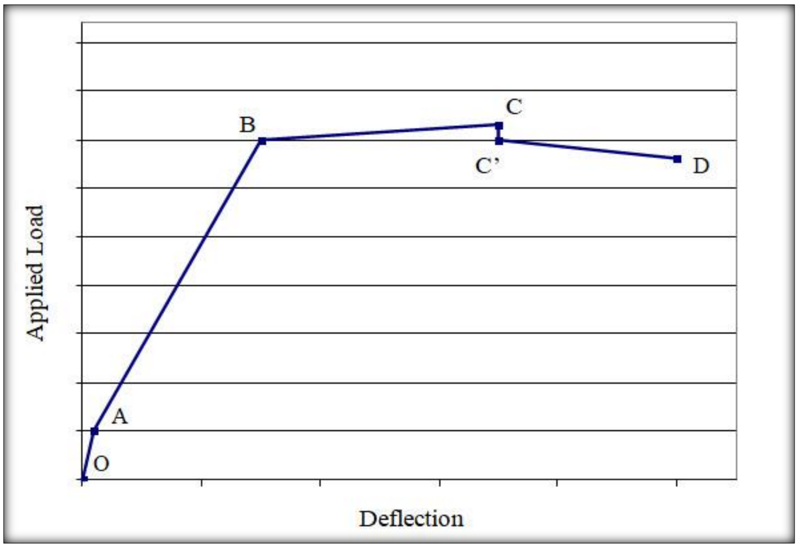


Figure 4.6 A typical curve of idealized load-displacement at mid-span

Table 4.5 appears values of flexural strength with depend on test results in table 4.4, where flexural strength was calculated by Equation (4.1)

$$F = \frac{P.L}{b.d} \tag{4.1}$$

Where F = Flexural strength, MPa

P = Central point through two point loading system, KN

L = Span of beam (mm)

b = Width of beam section (mm)

d = Depth of beam section (mm)

Table 4.5 Flexural strength values

Code No.	First Crack		Ultimate	
	F_{cr} (MPa)	F_{cr} Change (%)	F_u (MPa)	F_u Change (%)
S-SF0-GF0	4.83	0	15.822	0
S-SF1-GF0	6.28	30.07	17.61	11.28
S-SF0-GF0.5	6.99	44.76	16.58	4.76
S-SF0.5-GF0.5	6.17	27.82	16.74	5.78
CH-SF0-GF0	4.64	0	15.47	0
CH-SF1-GF0	6.24	34.37	16.92	9.42
CH-SF0-GF0.5	6.72	44.83	16.20	4.71
CH-SF0.5-GF0.5	6.02	29.72	16.10	4.11
SH-SF0-GF0	4.29	0	15.13	0
SH-SF1-GF0	6.18	44.09	16.16	6.85
SH-SF0-GF0.5	6.55	52.77	15.42	1.96
SH-SF0.5-GF0.5	5.54	29.20	15.68	3.69

4.3.2 The load-deflection responses of beam

The load-displacement data are recorded from the loading cell of machine with LVDT amounted at the beam bottom. It's known that the typical relationship of load-displacement (P-Δ) of a regular RC beam may essentially compose of three Patterns of behavior: pre-cracking stage, post-cracking stage, and post-yielding stage. In Figures 4.7 - 4.9 clarifies the load- displacement response of each beam.

It was noted that while the extreme tension bars in beam reached tensile strength, there was a significant deviation of the curve from the original slope, implying a relative reduction in the beam flexural strength beyond the working load level. This is representing the pre-cracking stage, where the deflection mounts linearly with the loading almost. In the elastic part the strain is expected to be approximate and relatively small for concrete and steel materials.

From Figures 4.7 to 4.9 there were nonlinear extraneous displacements because they are often associated to such a test. Up to the first initiation crack, the displacement is commensurate to the applied load linearly; the first cracks are hardly and carefully located on the curve. After the first crack take place, the curve slope was slightly changed, but looks to be in linear increasing rate, the increasing rate continues up to yield point. After yielding of the reinforcement, the curves are increasing in nonlinear manner up to the maximum resistance load, the test is continuing until the beam is collapsed.

As soon as the strain in the tensile steel reached yield level, the beam was considered to have failed structurally. The test samples continued to drift rapidly until the secondary compression failure developed, resulting in crushing the total concrete in the maximum moment zone, followed by a large-scale cracking afterwards and a large widening of the stable cracks.

4.3.3 The strength of first crack load

The test results summary for all beams, which were noticed the load (P_{cr}) and deflection (Δ_{cr}) at first crack load, and deflection at the failure point, is available in Table 4.4. The all types of tested beams from solid beams, square and circular hollow beams, also with various kinds of fibers are as given in Table 4.4 It shows that these fibers addition have a significant impact on the cracking load that induced first crack, which may be defined as the crack that occurs at the initial change of slope of the (P - Δ) curves. However, on the other hand, it is clearly shown that the concrete beams which have fibers are more resistance in the initial loading stages (elastic) before the significant change of slopes.

For the ranges bounded by the point of the first crack and ultimate load, reinforced specimens with fibers exhibited less deformation and also larger load-carrying capacity from that of conventional concrete, as seen in the Table 4.5 This is due to the ability of FRC in arresting crack growth and crack widening. Figure 4.9 also explained that FRC influence in increment the ultimate strength is less significant than its effect in reducing the vertical deformation. The main reason for such behavior is influence of FRC addition to the reinforcement of beam, which lies in improving in control of cracking and deformation [89].

Anywise, That the resistance of first crack load was increased with every beams kinds which were added fibers to their mixtures, although, the first crack resistance loads is take place before the participation of the exterior fiber, but the effectiveness of the interior fiber on the micro-crack is play important role in whole resistance.

For group A (solid beams), where the resistance of first crack loads for S-SF1-GF0, S-SF0-GF0.5 and S-SF0.5-GF0.5 increased 30.07%, 44.76% and 27.82% respectively. With regard to group B (circular hollow beams) and group C (square hollow beams), there are almost similar increasing at percentages for group A, where increment percentages of P_{cr} for CH-SF1-GF0, CH-SF0-GF0.5 and CH-SF0.5-GF0.5 were 34.37%, 44.83% and 29.72%, in the same manner the increment percentages of P_{cr} for SH-SF1-GF0, SH-SF0-GF0.5 and SH-SF0.5-GF0.5 were 44.09%, 52.77% and 29.20% respectively.

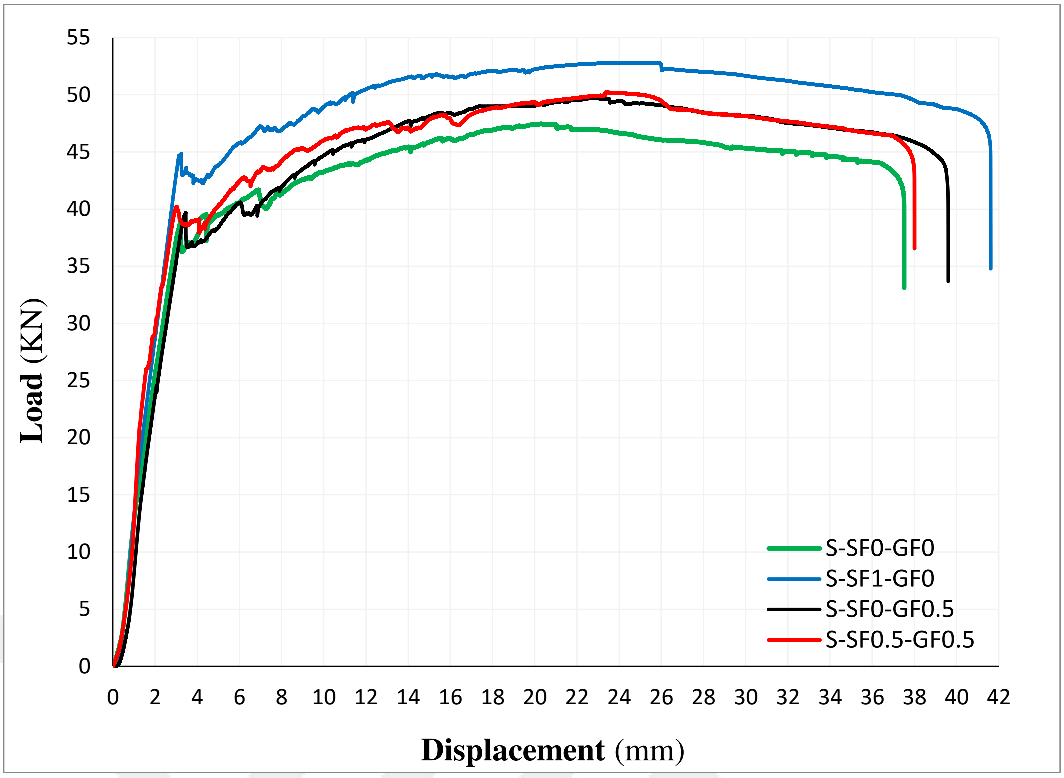


Figure 4.7 Load-deflection curves for group A tested S-beams

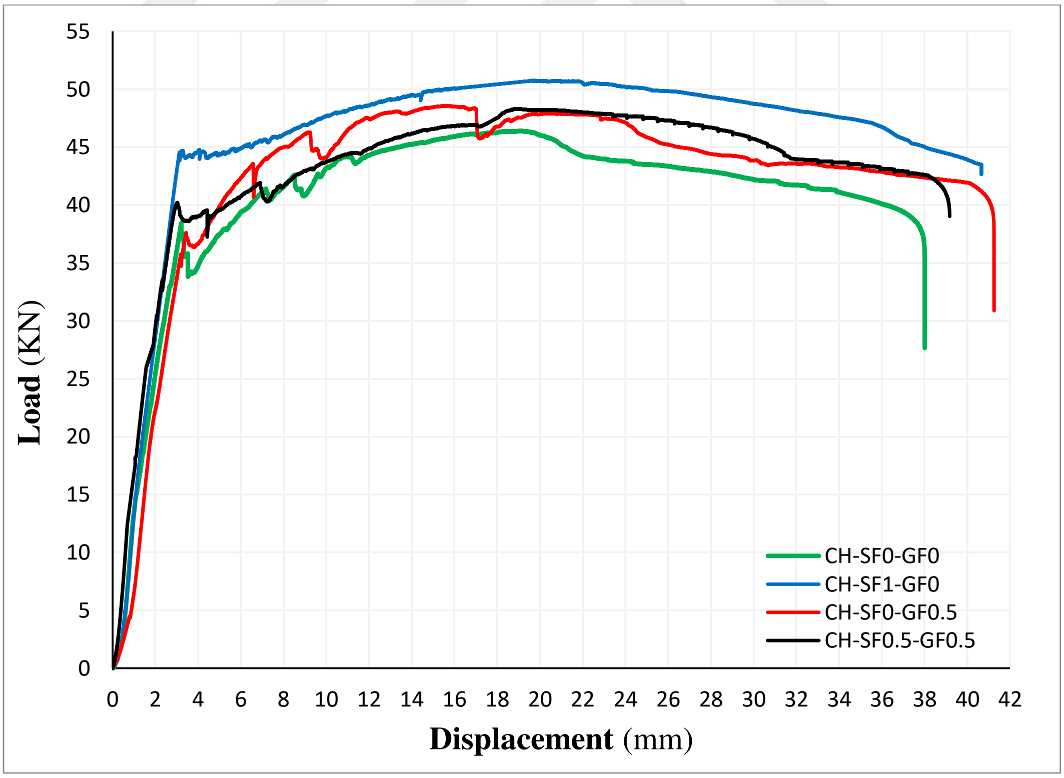


Figure 4.8 Load-deflection curves for group B tested CH-beams

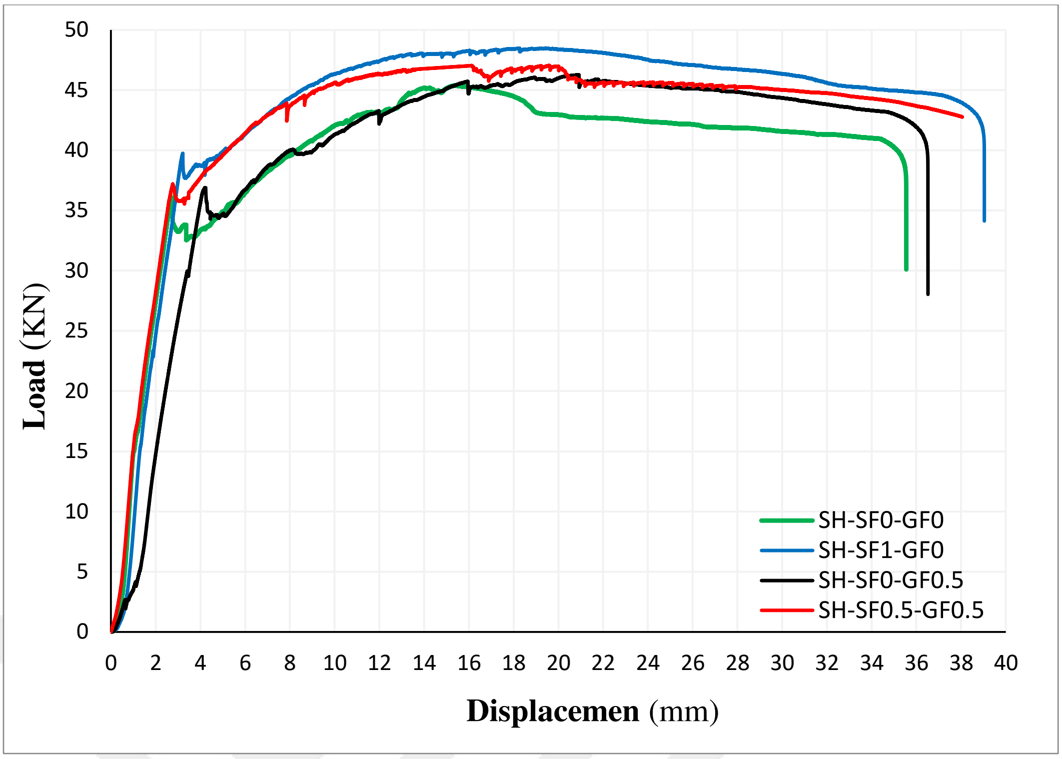


Figure 4.9 Load-deflection curves for group C tested SH-beams

Figure 4.10 is representing diagram of relationship the load at first crack between normal specimens and specimens were containing various fibers in their mixture. This diagram is used to compare results for each type of beams and effect of fiber addition on the GPC behavior at moment of first crack. In all reinforced specimens with fibers, increasing load and central deflection were observed when occurs of first crack, this explains reason of delay appearance of first crack and larger resistance with comparison to normal samples.

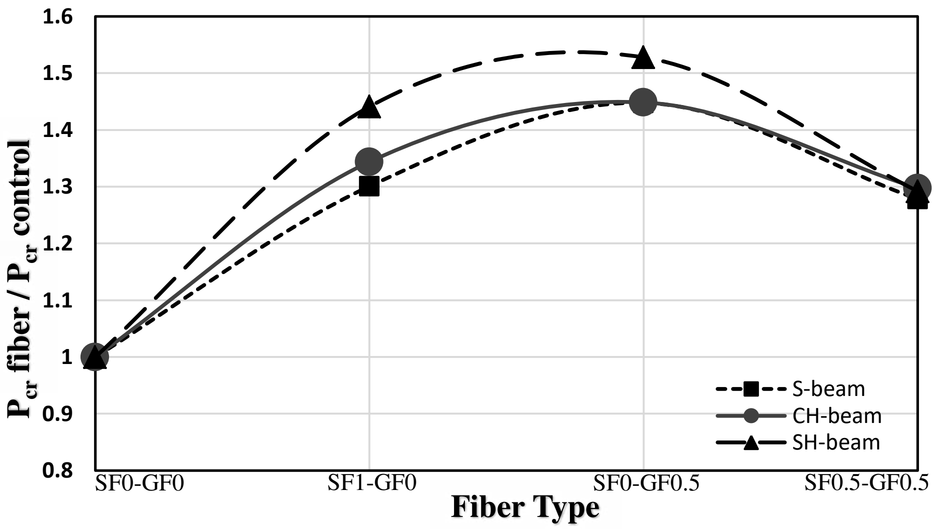


Figure 4.10 The normalized the first crack resistance loads

4.3.4 Ultimate beam strength

Table 4.5 summarized the result of three points test, the cracked and ultimate beam strength are listed with its corresponding displacement. For all reinforcement ratios, it shows that addition of fibers is significantly enhanced the resistant of the beams.

Generally, addition of steel, glass and hybrid fibers led to improve the strength of ultimate loads (Fu) for all groups compare to control specimen of each beam type. For reinforced specimens by SF, the results were given ultimate strength about (6.85 - 11.29%). Also addition GF given improvement of the strength about (1.96 - 4.76%) and there was growing between (3.69- 5.78%) in the strength due to use hybrid fibers as is clarified in Figure 4.11.

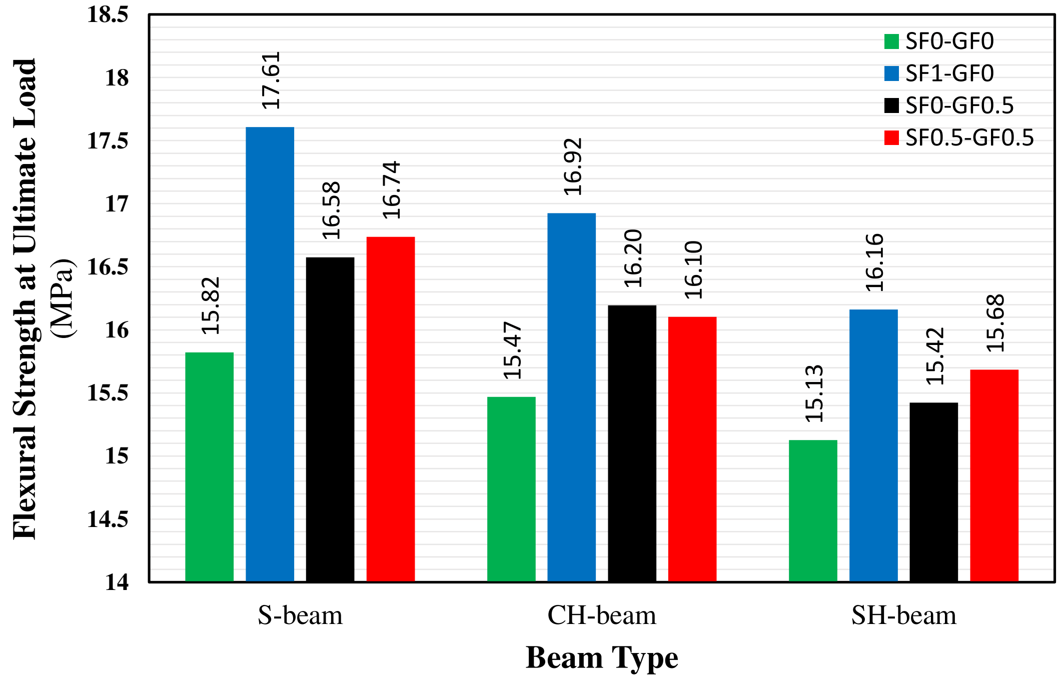


Figure 4.11 The effect of fibers on the ultimate beam strength

4.3.5 Comparison of beam type effect

Experimental researches focused replacing the zone below the neutral axis with inert weightless substances like polythene balls or cavities will not greatly affect. These studies appeared that solid and hollow beams with same reinforcement and same cross-section fail almost at an asymptotic load when undergo to pure torsion with minimal effects of the internal concrete core [90].

Moreover, this paragraph studies effect of cavity existence in centroid axis of beam and its form, which is investigated as second parameter to compare the behavior and failure loads in the solid and hollow beams made of GPC.

Figure 4.12 is diagram represents regression curve where R^2 values were significant about (0.9425 - 0.9981), and these values show rapprochement in behavior the strength of first crack load and central deflection for solid and hollow beams.

For Figure 4.13 the post-yielding stage due to the yielding of the tensile steel, all the (P-Δ) curves experience some change in slope. At a sectional level, the depth of the neutral axis is reduced significantly, thereby increasing the deflection immediately after yielding. Each beam exhibited different post-yielding load-deformation response, depending upon the type of beam but didn't take place significant variation at the behavior and ultimate load.

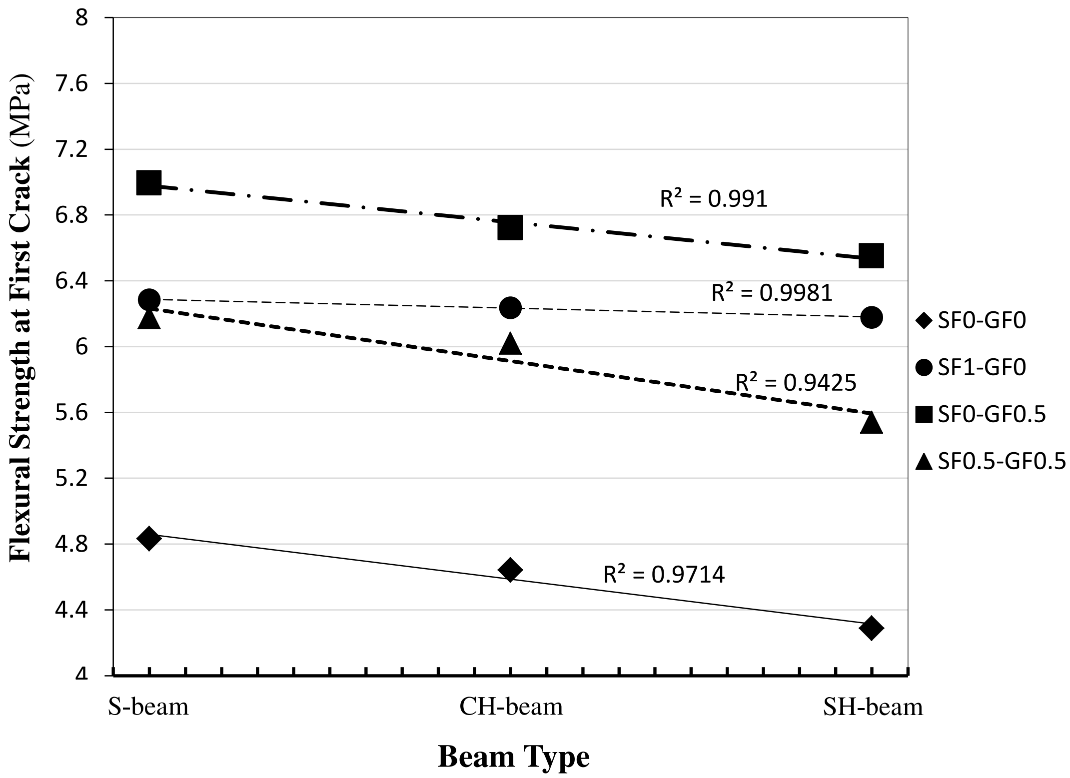


Figure 4.12 The regression value for solid and hollow beams

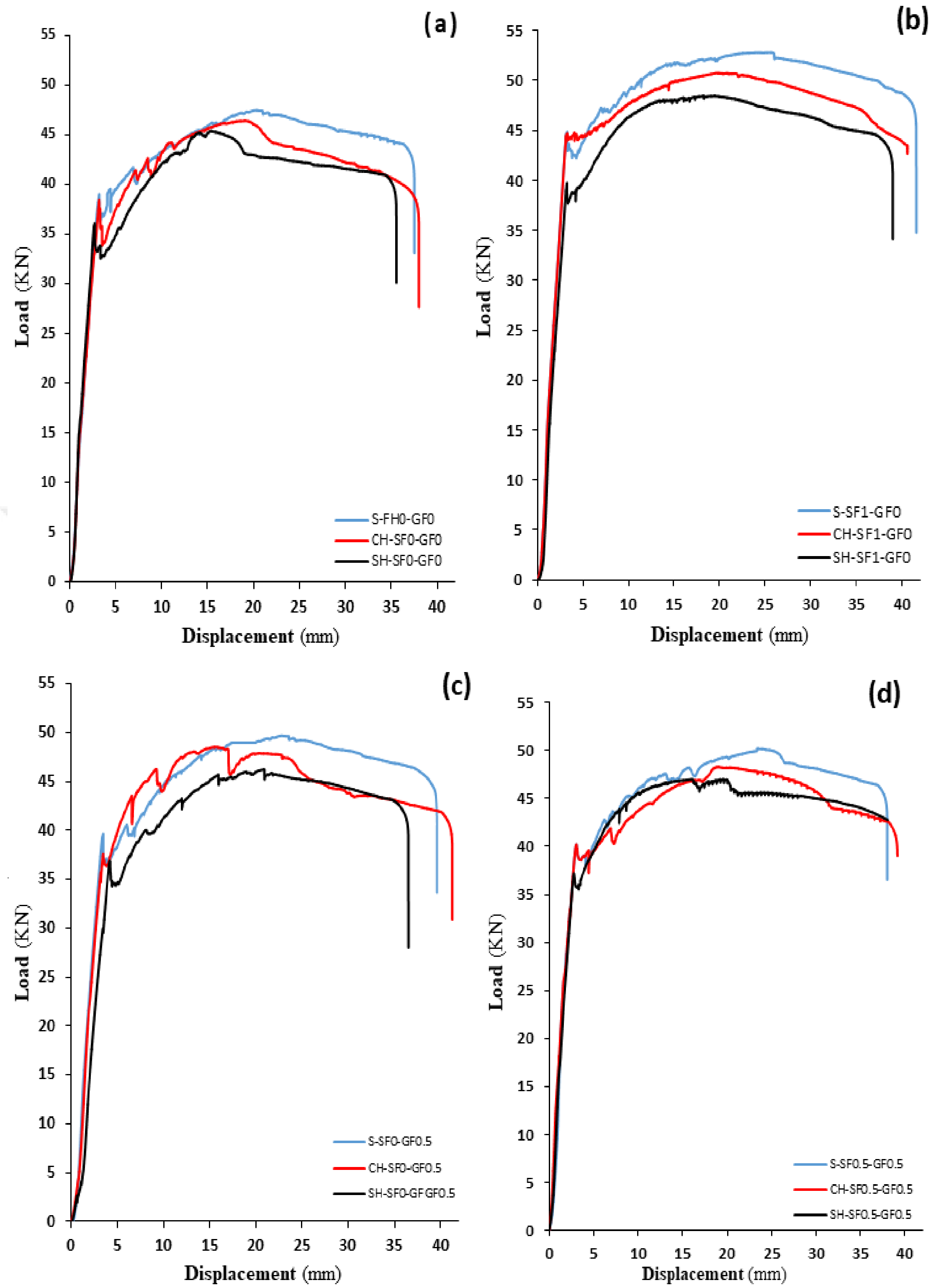


Figure 4.13 (a, b, c and d) Effect of beam type on Load-deflection

As for effect of cavity shape in the beam, the curves of load-displacement in figure 4.13, that circular-hollow beams curves indicate progress in the flexural behavior larger than square-hollow beams in terms of the first crack resistance and ultimate load strength for control and fiber reinforced beams. Despite this cracks mode and ductility factors in the square-hollow beams best than the circular, as it will come later.

4.4 Effect Fibers and Beam Type on the Ductility

Ductility is a term used in the design of seismic to demonstrate the structure ability to resist periodic deformities amplitude in an inflexible scope without strength diminishing [91]. The ductility factor (μ) known, as the proportional of utmost deformation (Δ_u) to the yield deformation (Δ_y). This can be utilized as a predictor for the non-elastic deformation of seismic analysis and design. The ductility index is communally defined as the many parameters such as deformities, curvature, rotation and namely displacement [91].

Typically, the factor of displacement ductility (μ) is determined at a time of non-flexible dynamic date analysis [91]. The displacement ductility factor can be estimate using Equation (4.2).

$$\mu = \frac{\Delta_u}{\Delta_y} \tag{4.2}$$

Where Δ_u is the ultimate deformation is that the deformation corresponding to the maximum resistance load and Δ_y is the yield deformation. The yield deformation definition can cause a significantly confusing, because that relationship the applied load and the central displacement may have many defined yield points. This may happen due to different angle of view. Moreover, different flexural stages that need to make the reinforcement bars at along the member thickness to reach yield [91]. Mathematically the ductility index is the displacement ratio at the yield point (Δ_y) to the ultimate displacement (Δ_u) as in Figure 4.14.

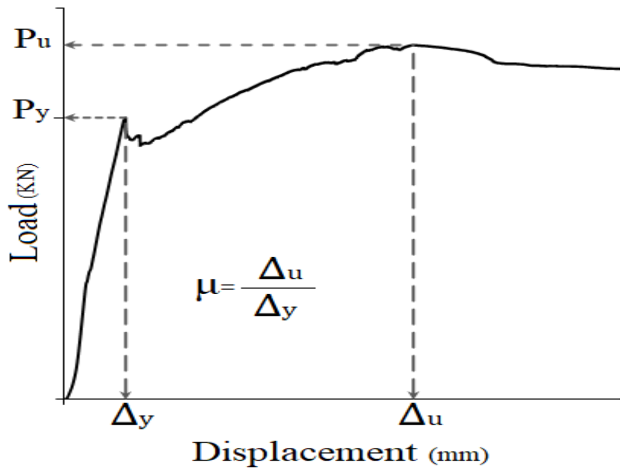


Figure 4.14 Definition of the ductility factor (μ) of the beams

Generally, the results appear in Table 4.6, that the GPC gave fairly good ductility factors (μ) for all beams. Their values are ranging (4.58 - 7.91). From Figure 4.15, the test results have been done comparison between the ductility factors (μ) of fibrous concrete with that of plain concrete. In group A, all solid beams shown improvement for beams included steel, glass and hybrid fibers 22.45%, 5.21% and 25.7% respectively.

In group B and C, the ductility increased a slightly for reinforced beams with steel and hybrid fibers more than control beams from 3.68% to 7.43%. While in the both beams were reinforced with GF, the ductility remarkably decreased for circular hollow beam and meager desecrating in the ductility of square hollow beam. Despite they displayed greater carrying capacity of ultimate load as compared to the reference beams; this may be due to previously steel yielding over the middle-span [92].

Table 4.6 Ductility factor of fibers and beams type

Group No.	Beam Type	Code No.	P_y (kN)	Δ_y (mm)	P_u (kN)	Δ_u (mm)	μ
A	Solid	S-SF0-GF0	39.006	3.224	47.458	20.308	6.3
		S-SF1-GF0	44.861	3.244	52.814	25.658	7.91
		S-SF0-GF0.5	39.693	3.456	49.718	22.845	6.63
		S-SF0.5-GF0.5	40.212	3.037	50.203	23.425	7.71
B	Circular -Hollow	CH-SF0-GF0	38.437	3.214	46.393	19.102	5.94
		CH-SF1-GF0	44.566	3.129	50.764	19.619	6.27
		CH-SF0-GF0.5	37.619	3.447	48.576	15.812	4.58
		CH-SF0.5-GF0.5	40.212	3.037	48.301	18.799	6.19
C	Square-Hollow	SH-SF0-GF0	36.07	2.732	45.368	15.37	5.63
		SH-SF1-GF0	39.746	3.215	48.477	19.431	6.04
		SH-SF0-GF0.5	36.895	4.201	46.257	20.862	4.97
		SH-SF0.5-GF0.5	37.199	2.763	47.04	16.117	5.83

The summary, that ductility depends on the reinforcement ratio (ρ) and fiber volume fractions. This may be reason that steel and hybrid fiber gave ductility factors higher than GF, regardless of reinforcement ratio of steel bars because same ratio is equal in all beams.

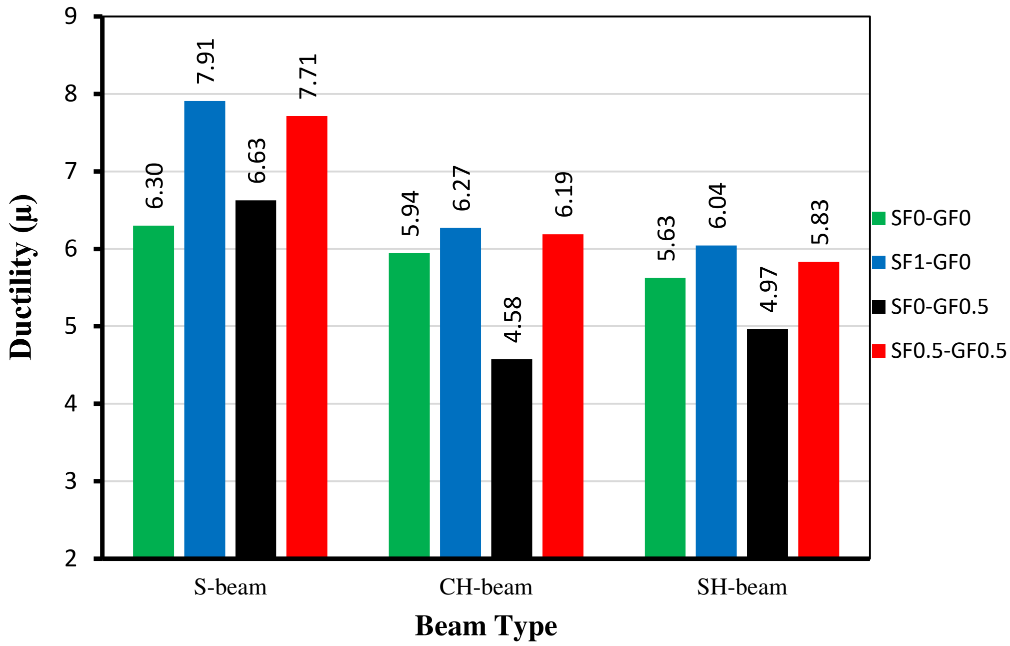


Figure 4.15 Effect fibers and beam type on the ductility

4.5 Failure Patterns

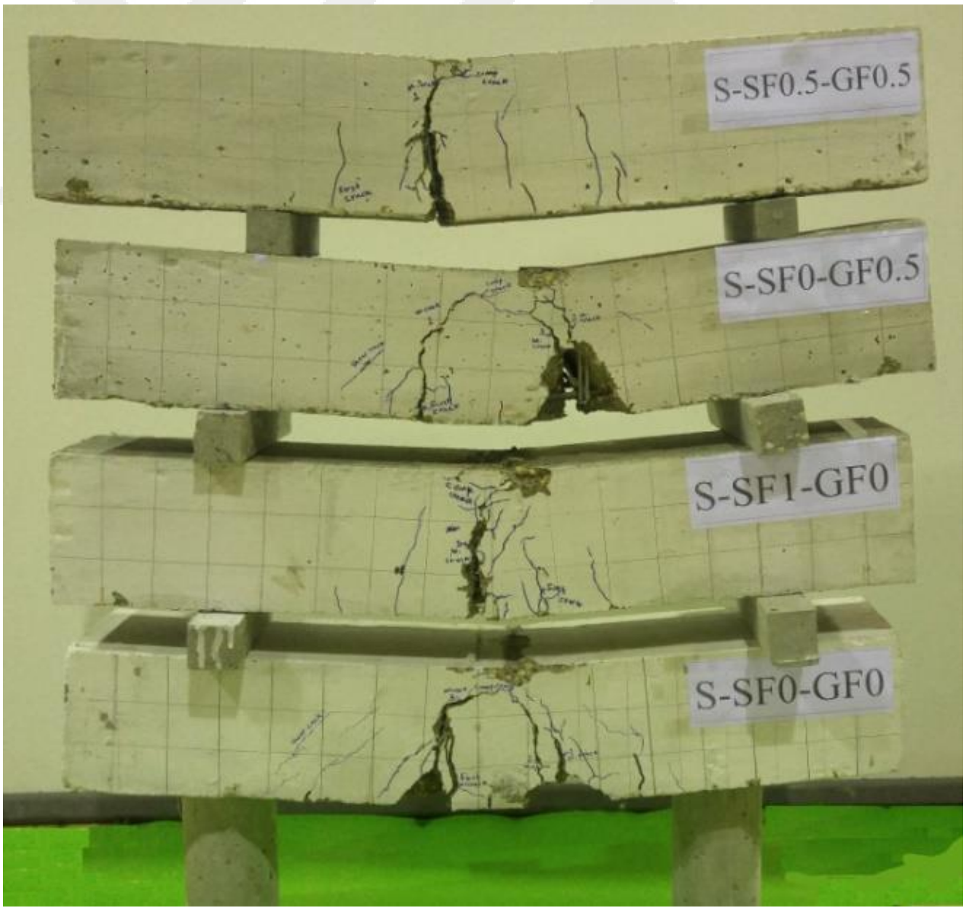
The all beams were tested until failure for acquire data about the fibers influence and beams types on the flexural behavior of GPC beams. In Figure 4.16 shows failure patterns for tested beams.

Generally, the crack pattern of all beams indicated that the crack is initiated in the tension zone at bottom part of beam middle almost at post-cracking stage. But when the post-yielding stage begins, flexural failure crack occurs directly in beam centroid and extends from the lower edge and stopes at compression zone. Then compression zone of concrete is crushed coinciding with resistance of longitudinal reinforcement bars for flexural load before occurring of compression failure and after that accompanied with a sudden, loud noise at failure moment.

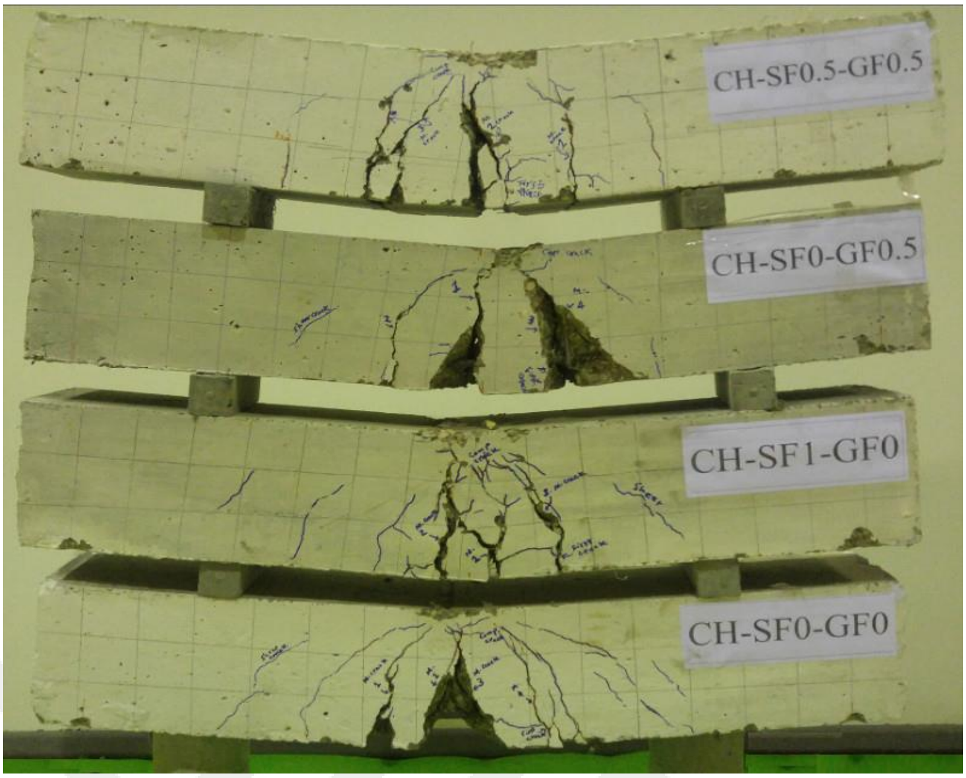
For control beams, the first crack shows at early time comparison with other beams, with load increment, other cracks appeared within the middle third of beam clear span, and then extended to cause cracks of flexural-shear towards the loading point with the shear cracks of connected to it.

For GFR beams, the occurrence of first crack delayed at longer period than similar beams in the type. Also in stage of post-cracking, appearance of cracks is fewer number than other beams. But after post-yielding stage, behavior of these beams become like other fiber reinforced beams, where more than one main crack is formed and propagate as load increase and they begin from first crack. The cracks are confined within the third in middle of beam only. At other positions, the surface kept not harmed in beams with the bonded anchorage, except some shear cracks are too micro due to these fibers.

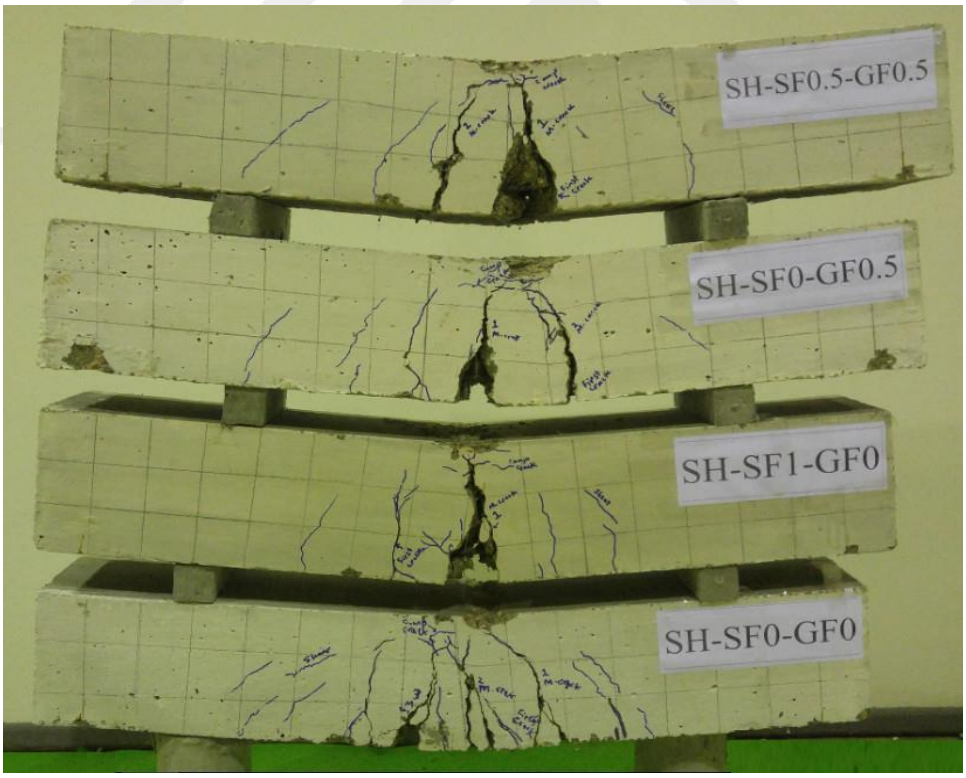
solid and square-hollow beams of reinforced by steel and hybrid fibers, the main crack was formed of only one crack extend from tension failure crack and expand with loading increase to ultimate failure and it has nothing to do with the first crack. The failure mode, by yielding tension of reinforcement bars followed, by concrete compression failure, but the compression concrete failure by multilayers delamination. The SF addition can be enhancing the compression zone beside its contribution to tension zone.



Group (A)



Group (B)



Group (C)

Figure 4.16 Crack pattern and failure mode for tested beams (groups A, B, C)

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

A systematic and comprehensive investigation has been undertaken on the influence of steel, glass and hybrid fibers addition on mechanical and structural properties of GPC was prepared of FA based, slag and alkaline solution . It is encompassed studies of experimental and analytical on the workability, compressive and split tensile strength for cylinder specimens. Also, this study include realization of behavior three types of beams under flexural test.

In this chapter are presented the outcomes of the current research according to mechanical and structural properties.

5.1.1 Mechanical properties

The following conclusions could be extracting from the present investigation:

- According the results, the workability decrease due to use fibers at 14 molarity concentration and also additional fibers, also can observed the large effect of glass fiber on the workability more than effect of steel and hybrid fibers.

- Based on the results of obtained tests, one can observe that the increases in the compressive strength of GPC, the hybrid fibers were less effect than steel and glass fiber on the compressive strength.

- Depending on the results, can observe use fibers improve tensile strength of GPC, but the glass fibers has less effect than steel and hybrid fibers on the tensile strength.

5.1.2 Structural properties

The test parameters were the reinforcement of GPC beams by fibers addition for the flexural strength at ultimate load. From the experimental and analytical studies the following conclusions are made:

- Using of fibers in concrete made from high fine aggregate percentages lead to increase the strength of first crack load is ranging (27.82 - 52.77%). It is striking that reinforced beams with GF appeared remarkable improvement in resistance of first cracks load, and before post-yielding stage, the cracks number were fewer than other beams types.
- All fibers shown ameliorate the strength of ultimate load up to 11.29%. In the same manner, compression resistance is increased with addition of different fiber. But SF gave best values than other fiber types.
- From diagrams of relationship (p - Δ), that SF curves show clear differentiation and uniform deformation with load growing until full failure happening. This proves that inclusion of SF gave best results than other specimens in all tests.
- The hybrid fiber had approach behavior between steel and GF in terms impact on flexture strength, ductility and failure patterns.
- The fibers addition led up to ameliorate GPC resistance by from lessening of cracks in compression part and shear zone for beam.
- The reinforcement ratio was used minimum and constant ratio for all beams, in order to conceptualize about fibers influence on the GPC ductility. Improvement was observed in ductility factors for specimens included steel and hybrid fibers, while they retreated in those containned of GF. generally, the all types of GPC beams appeared reasonable values for ductility factors.
- By this research, it could deduction that hollow members of produced from GPC have an converged response to those solid from where flexural strength, ductility and failure patterns.
- As for effect of cavity shape in the beam, that circular-hollow beams curves indicate progress in the flexural behavior larger than square-hollow beams in terms of the strength of first crack and ultimate load for control and fiber reinforced beams. Despite this cracks mode and ductility factors in the square-hollow beams best than the circular.

- The most important conclusion is the failure patterns noticed for reinforced GPC beams were analogous to those indicated in the literature for reinforced OPC concrete beams. Where there was a similar behavior of ductile which accompany concrete crushing in compression zone for all beams at flexural test.

5.2 Recommendations

There are future proposals for researches, that can be beyond this study extent as in below:

- This same study can be conducted but without curing of GPC in oven then investigate of structural properties at 28 or 56 days and comparison them with a cured specimen.
- Investigation of the structural properties enhancement of GPC beams by usage of glass fiber reinforced polymer bars instead of steel bars with immersion of specimens in hydraulic acids, sea water and wastewater for 180 days.
- In order to investment the maximum achievable capacity of FRC composites, the fiber matrix interaction is of significance. Hence, a supplementary study investigating the effect of coated fibers of larger diameters and longer length.
- Utilizing of Carbon Fiber Reinforced Polymer (CFRP) strips on the torsional behavior of GPC beams with weak sections or hollow beams.
- Experimental research can be conducted for investigation of GPC beams performance with openings in shear zone strength and rehabilitated with CFRP under repeated loading.

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