

Flexural Behavior of Reinforced Concrete Beams with High Performance Fibers

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Abstract: High-performance concrete is a specialized series of concrete designed to provide superior mechanical and physical properties that cannot be achieved through the conventional design. Using high-performance concrete in the construction field can reduce the dead weight, provide a longer span, and increase the service life. In this paper, a full experimental program is conducted to study the effect of glass and carbon fibers on the flexural behavior of reinforced concrete (RC) beams. A total of 15 RC beam specimens are prepared and divided into four main groups according to their added fiber materials, which are (S- Steel fiber), and E (E- Glass fiber), carbon fiber, and S-Glass with carbon fiber. All the reinforced fibers are used at 1.5% of the cement weight. The beams are reinforced using the fiber materials at the hinging zone then tested under concentrated static load placed at the mid-span. The results show that using high-performance fibers can improve the ultimate load capacity, ductility, and absorption energy of the RC beams.

Index Terms: Fiber reinforced concrete, structure elements, flexural behavior, cyclic loading

1. Introduction

Concrete is the most used building material around the world. Several studies indicate that it will continue to be used in the decades and years to come. Concrete has been used nearly in all types of constructions from highways, bridges, dams, towers, and canal linings, to the most beautiful & artistic buildings [1]. Long-term performance of concrete structure has become vital demand to developing countries. Therefore, several studies have focused on improving the performance and durability of the concrete structure to overcome many challenges such as; deterioration, long-term poor performance, and inadequate resistance to a hostile environment [2,3]. Conventional Portland cement concrete is found to be deficient in respect of; (a) durability in severe environment; shorter service life & requiring maintenance, (b) time of construction; longer release time of forms & slower gain of strength, and (c) energy absorption capacity for earthquake resistant structures [4]. High Performance Concrete (HPC) successfully meets the above requirements. HPC can give an excellent performance in the structures in which it is placed, in the environment to which it is exposed, and along the loads to which it is subjected during its design life [5].

Concrete is a brittle material, with little capacity to resist tensile stresses/strains without cracking. Thus, it requires reinforcement before it can be used as a construction material. Historically, this reinforcement has been in the form of continuous reinforcing bars which could be placed in the structure at appropriate locations to withstand the imposed tensile & shear stresses. Fibers, in contrast, are generally short, discontinuous, & randomly distributed throughout the concrete to produce a composite construction material known as Fiber Reinforced concrete (FRC). Steel Fiber (SF) is the most popular type of fiber used in reinforced concrete [6]. High-performance fiber-reinforced concrete often refers to concrete reinforced with a large number of fibers, from 4% to 20%, and attains tensile strain-hardening behavior along with a tensile ductility of around 1%. The large amount of fibers used in concrete significantly increases cost and reduces the workability of this material, sometimes leading to the requirement of different types of processing other than conventional casting [7]. Problems like early degradation reduced service life and increased repair costs of concrete structures. Thus, there is a pressing need to improve the concrete properties to overcome the mentioned problems and provide high strength, toughness, energy absorption, and durability [14]. One of the most promising materials that can be used to improve concrete properties is high-performance fibers including; steel, glass, and carbon fibers. During the past 30 years, High-Performance fiber reinforced concrete (HPFRC) has been increasingly used in structural applications. The brittle mode of failure is changed through the addition of steel fibers into HPC. The ductile design of reinforced concrete beams is generally related to flexural failure in bending, but very often the presence of high shear zones reduces their flexural capacity. Due to the cyclic action, the worst case of shear brittle failure occurs, while in the best case, ductile flexural failure occurs [15].

In this research, a fully experimental program is conducted to investigate the effect of two different fibers on the flexural behavior of RC beams. For this purpose, a total of 15 different RC beams are prepared by adding two different types of high-performance fibers namely; glass and carbon fibers. All the prepared RC beams were tested under monotonic and cyclic loading in order to investigate the influence of the reinforced fibers. The experimental results present a comparison between the different RC beams in terms of ultimate load capacity, ductility, and energy absorption.

2. Literature Review

A Comprehensive review of literature related to fiber reinforced concrete is presented through ACI committee. Guidelines for design, mixing, placing & finishing steel fiber reinforced concrete are given in ACI. It was concluded that the addition of fibers increased the compressive strength & toughness. Some empirical equations were also proposed for compressive strength of concrete in terms of fiber reinforcing index.

Flexural strength of SFRC depends on the strength characteristics of fibers, the bond between matrix & fiber, the ductility of fibers, the volume of fibers & their spacing, the dispersion & orientation of fibers, their shape & aspect ratio in [1]. Addition of fibers in concrete increase tensile strength through arresting the propagation of cracks have been reported through [2,3].

It was reported that the workability of fresh SFRC decreases along increase in fiber content. Fiber content of the SFRC mix for minimum balling effect depends on the size & shape of the fiber & mix too [4]. The major factors affecting the flexural strength are the volume fraction & the length to diameter ratio of fibers. An increase in both these parameters leads to higher flexural strength.

In Carried out the fatigue performance of steel fiber reinforced concrete containing fibers of mixed aspect ratio. Steel fiber reinforced concrete containing 1% through volume fraction of fibers, gave the best fatigue performance in terms of number of cycles to fatigue as compared along maximum fatigue stress, expressed as a percentage of corresponding static flexural strength [5].

In examined that a fiber combination of 65% of 50 mm & 35% of 25mm long fibers can be taken as the most appropriate combination for compressive strength, split tensile strength & flexural strength of SFRC [6].

In [7] reported conservative reduction factors are introduced for using post-crack tensile strength in design & a conversion design chart is proposed for developing FRC systems equivalent to traditional reinforced concretes.

To have reported the fiber combination of 70% long fiber & 30% short looked end steel fiber at 1.5% volume fraction gives the most appropriate combination along regard to the highest in the flexural & split tensile strength [8].

Suggested that the addition of steel fibers in the concrete mix improves structural performance of the beam measured in terms of ultimate load carrying capacity, stiffness, crack width & deflection [9].

Concluded that along the increase in steel fiber content in concrete, there is a tremendous increase in flexural strength. Even at 1% of steel fiber content, flexural strength of 6.4 N/mm^2 is observed against the flexural strength of 5.36 N/mm^2 at 0%, the increase in 1.1% flexural strength is obtained [10].

Investigated that during compression failure, fibers restrain crack propagation leading to an increase in the post-peak nonlinearity of the high strength concrete [15]. It Showed that using high strength fibers results in a clearly better ductile behavior & higher load levels in the post cracking range compared to normal ones. also studied the influence of steel fiber in concrete provides a ductile concrete structure & hence increases the energy absorption capacity of concrete & a considerable increase in the splitting & flexural tensile strengths of the concrete & also investigated the effect of steel fiber aspect ratio on the HSC containing different percentages of silica fume. It has been shown that at the same silica fume content, the modulus of elasticity of the concretes was decreased along an increase in the steel fiber content for all the aspect ratio [16].

An experimental study was conducted [17]. On the high strength mortar (HSM) reinforced along steel fiber & hybrid fibers consisting of steel, palm & synthetic fibers. It was reported that the use of 2% steel fiber through volume of concrete led to an increase up to 36% on the static modules of elasticity. This can be explained as fact that steel fibers have a higher stiffness compared to non-metallic fibers, which resulting in a higher modulus of elasticity in HSM.

The conducted experiments for mix design of high strength concrete along admixtures, varying super plasticizer along a range 0.6 to 0.9% along an increment of 0.1% & concluded that addition of silica fume increases compressive strength & decrease the slump [18].

It was determined that the high performance fiber reinforced micro concrete can have larger compressive & tensile strength but the same modulus of elasticity as normal concrete, which makes this material very interesting for the use in repair & strengthening of concrete structures [19]. To proposed HPFRC has developed in relatively short time to material along a recognized high potential of application. In order to facilitate design along HPFRC existing codes for conventional design of concrete structures should be used as much as possible as basis & it should be compatible [20]. It was observed that incorporation of steel fibers in HPC can reduce the brittleness of concrete & alter the mode of failure of the concrete structure. reported that the instead of adding single fiber, the combination of different types of fibers, hybrid fibers, increases the energy absorption capacity substantially [21]. The structural performance is improved

along the inclusion of steel fibers along different aspect ratio. It was examined that the addition of fibers bridges the cracking effects & delays the formation of the first crack [22].

3. Research Methodology

Experiment & numerical modelling are the research methods used in the present research. The experimental research is divided in to two different parts which include the study of the behavior of simply supported & continuous beams along crimped & hooked end steel fibers under monotonic & cyclic loading. Initially, the materials used in the current research are tested for their properties. Two types of beams, namely HPC & HPFRC, have been cast & tested under cyclic loading as well as monotonic loading. Two conventional concrete beams are cast as HPC beam & three types of HPFRC beams are cast, namely hooked end fiber reinforced HPC beam, crimped fiber reinforced HPC beam & hybrid fiber reinforced HPC beam. For each mix, two specimens are cast. In the case of hooked end & crimped fiber reinforced concrete beam, the beams are incorporated into hooked end fibers & crimped fibers respectively. In hybrid fiber reinforced concrete beam, the specimen is incorporated along 70% of hooked end & 30% of crimped fibers through volume of total fraction of 1.5%. Then the eight beams are subjected to cyclic loading. Similarly, the other eight beams are cast & subjected to monotonic loading. The load is applied along the help of screw jack & the deflection is measured through means of deflector meter.

3.1 Limit States for Reinforced Concrete (RC) & Fiber Reinforced concrete (FRC) in Flexure

Beyond the cracking limit, the following two limit states have been identified for both RC & FRC beams.

1. The limit states of incipient yield of the section indicated through the yielding in the steel & concrete or fibrous concrete reaches a maximum strain limit of 0.002. The yielding of steel has been considered as a prerequisite for this limit state, because steel percentage is to be chosen so as to prevent the concrete from reaching a limit strain of 0.002 in compression before the onset of yield in steel, i.e. over reinforced beam failure at limit state is avoided through carefully selecting the percentage of tension steel.
2. The limit state of ultimate load indicated in concrete or fibrous concrete reaches a strain limit of 0.0035 or 0.0095 respectively. While 0.0035 is an accepted strain limit for reinforced concrete at ultimate limit, the value of 0.0095 for fibrous concrete is chosen based on the stress strain curves of fibrous concrete.

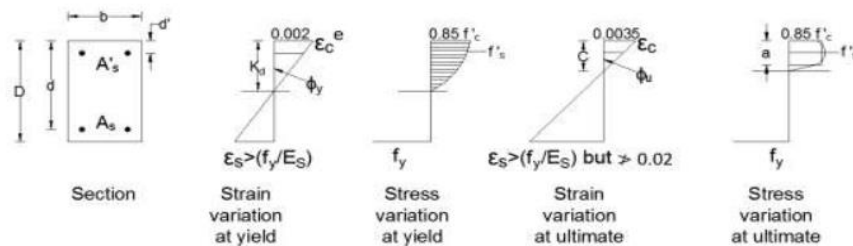


Fig. 1. Reinforced concrete beam section in flexure

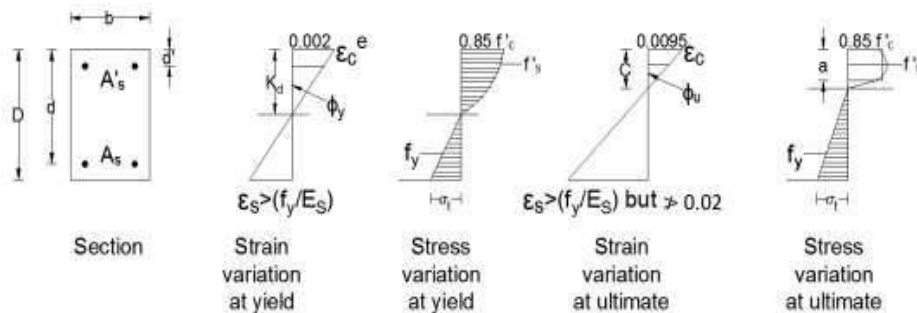


Fig.2. Fiber reinforced concrete Beam section in flexure.

3.2 Plastic Curvature, Rotation & Displacement

Figure 3 shows the curvature distribution of simply supported beam along its span at ultimate moment. The distribution of curvature along the member is apparent. The region of inelastic curvature is spread over a small length of beam. In this region, the bending moment exceeds the yield moment of the section. The curvature fluctuation shown in Figure 3 in full lines is due to cracking. The dotted lines show the idealized curvature diagram.

In ductility predictions, it is necessary to determine the deformations that have occurred when the ultimate moment is reached. The actual curvature distribution at ultimate can be idealized into elastic & inelastic regions as shown in Figure 3. The elastic contribution to rotation & deflection on one side of the beam is calculated from elastic rotation.

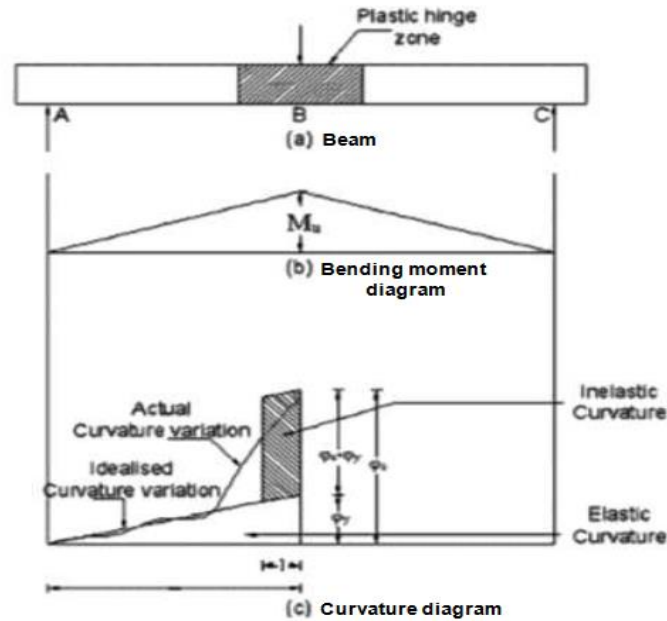


Fig.3. Curvature distribution of simply supported Beam along its span at Ultimate moment

Tables 1 & 2 give a single span beams under monotonic loading & single span beams under monotonic loading at hinged zones of the experimental & theoretical results. The theoretical values reported in the table have been computed using the equations developed in section 2.

Table 1. Single span beams under monotonic loading

No.	Designation	SHPC	SH	SC	SH+C
1.	Curvature at cracking ($\times 10^{-6}$)	3	3.457	3.33	3.45
2.	Cracking moment (kN m)	1.152	2.15	1.997	2.189
3.	Curvature at yield ($\times 10^{-4}$)	1	1.09	1.15	1.2
4.	Curvature at ultimate ($\times 10^{-4}$)	4.016	6.462	6.844	7.18
5.	Ultimate moment (kN m)	6.7	10.48	10.41	10.89
6.	Deflection at cracking (mm)	0.867	0.669	0.6249	0.788
7.	Deflection at service load (mm)	1.669	1.856	2.1	2.215
8.	Transformed area (mm^2)	10605.3	10143.06	10172.22	10129.99
9.	Ultimate load (T) (kN)	24.36	40.47	40.25	41.47
10.	Ultimate load (E) (kN)	24	27	26	33
11.	Ratio of ultimate load (E/T) kN	0.98	0.66	0.64	0.79

4. Results & Discussion

Two types of beams, namely HPC & HPFRC, have been cast & tested under cyclic loading as well as monotonic loading. Two conventional concrete beams are cast as HPC beam & three types of HPFRC beams are cast, namely hooked end fiber reinforced HPC beam, crimped fiber reinforced HPC beam & hybrid fiber reinforced HPC beam. For each mix, two specimens are cast. In the case of hooked end & crimped fiber reinforced concrete beam, the beams are

incorporated into hooked end fibers & crimped fibers respectively. In hybrid fiber reinforced concrete beam, the specimen is incorporated along 70% of hooked end & 30% of crimped fibers through volume of a total fraction of 1.5%. Then the eight beams are subjected to cyclic loading. Similarly, the other eight beams are cast & subjected to monotonic loading. The load is applied along the help of screw jack & the deflection is measured through means of deflect meter.

The load deflection curve of fiber reinforced concrete beam has longer plateau at the peak load & the descending part of the curve is less steep compared to normal reinforced concrete beams. The crack mouth opening displacement & the corresponding deflection are computed using the energy needed to propagate the crack. For flexural strength, two values are significant: the first, known as first crack strength is primarily controlled through the matrix. The second, known as the ultimate flexural strength, is determined by the maximum load. From Figure 4 fibers along hybrid fibers can be observed to perform better than the other fibers. The optimum volume fraction for post crack ductility depends on fiber properties, volume fraction & matrix composition. For example, the matrix that contains SF provides higher density & better bond; the same fiber volume can yield different results.

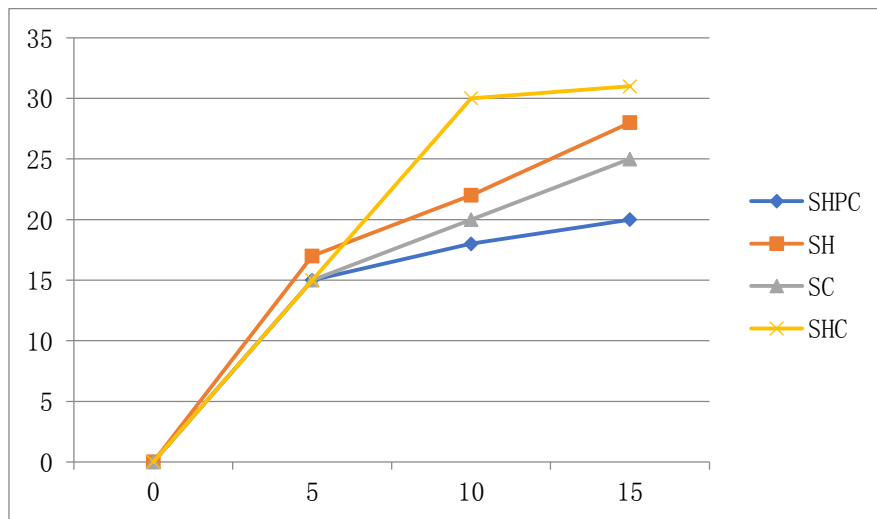


Fig.4. Comparison of load deflection response envelopes of beams

At the ultimate stage, all types of HPFRC beams show high load carrying capacity compared to conventional RC beam. The reason is that the addition of steel fibers in to the concrete improves the load carrying capacity. The first crack load is increased along the use of steel fibers to the concrete. When the fibers are added to concrete, crack propagation gets arrested. The comparison of first crack load & ultimate load for various specimens is shown in Figure 5. The initial cracking load for each beam ranges between 10 kN & 16 kN The beam SHPC has the smallest cracking load of 10 kN while the beam SH+C has the largest cracking load of 16 kN.

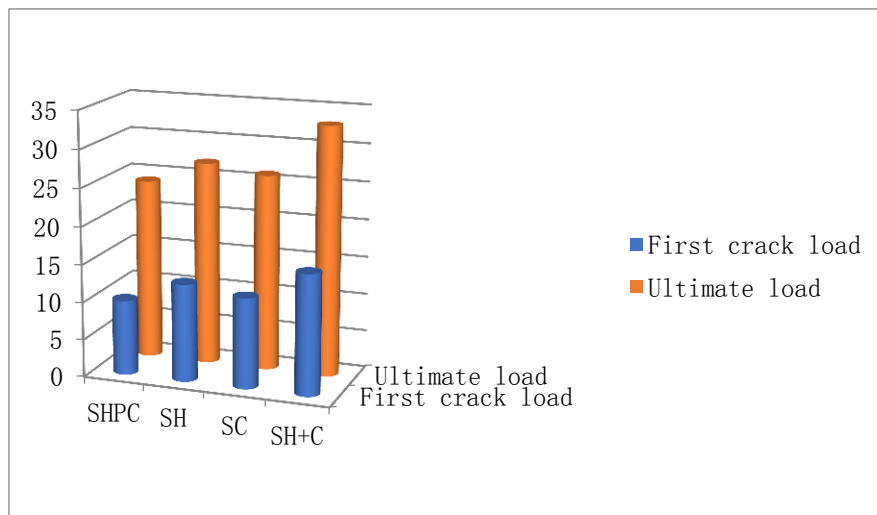


Fig.5. Comparison of first crack load & ultimate load

Stiffness Characteristics Stiffness is defined as the load required causing unit deflection of the beam. A tangent is drawn at initial load level. The slope of the tangent, thus drawn, gives the initial stiffness of the beam. The 1.5% volume fraction of fibers in HPFRC increases the stiffness of the beams. The comparison of stiffness characteristics for all the beams is shown in Figure 6.

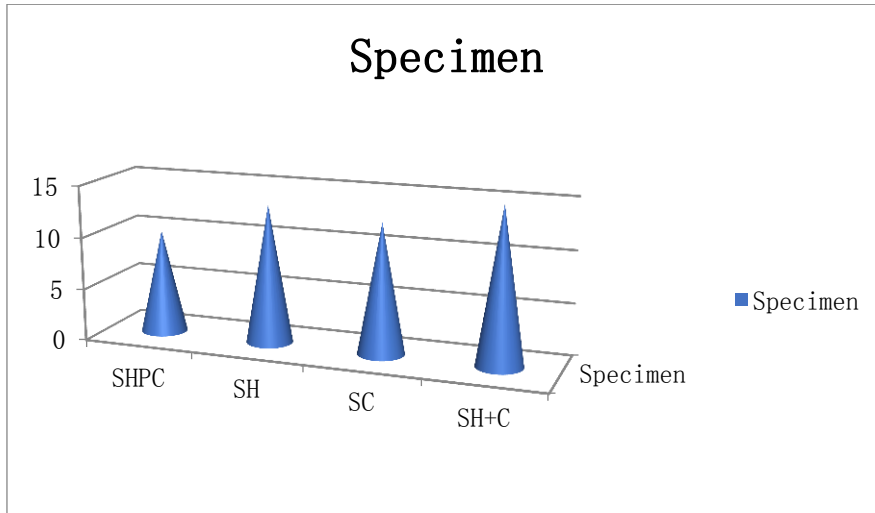


Fig.6. Comparison of stiffness characteristics for all the beams

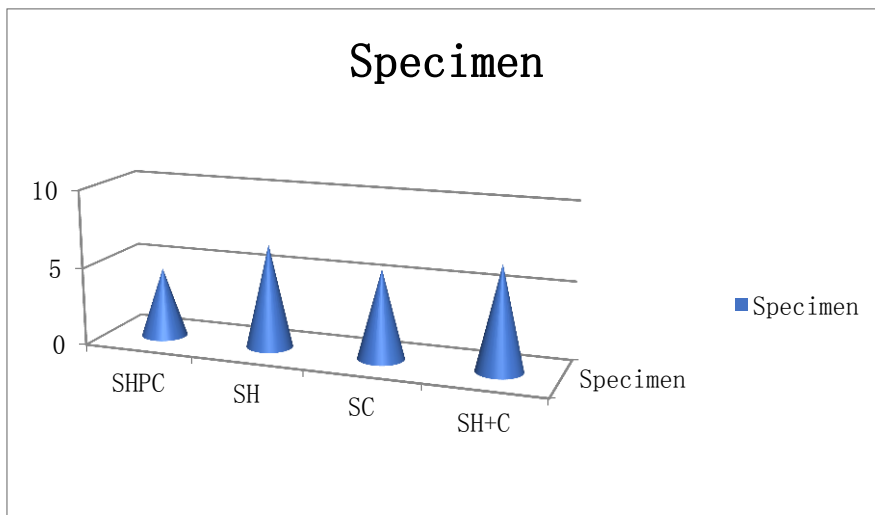


Fig.7. Comparison of ductility factor

The area under the load-deflection curve represents the energy absorption capacity of the specimen. The cumulative energy absorption capacity of SH+C beam is 280kNmm while that of SH, SC & SHPC beams have the values of 220 kNm, 244 kNm & 118 kNm respectively. The SH+C (hybrid) beam is higher than that of the other beams. The comparison of energy absorption capacity for the entire specimen is shown in Figure 8.

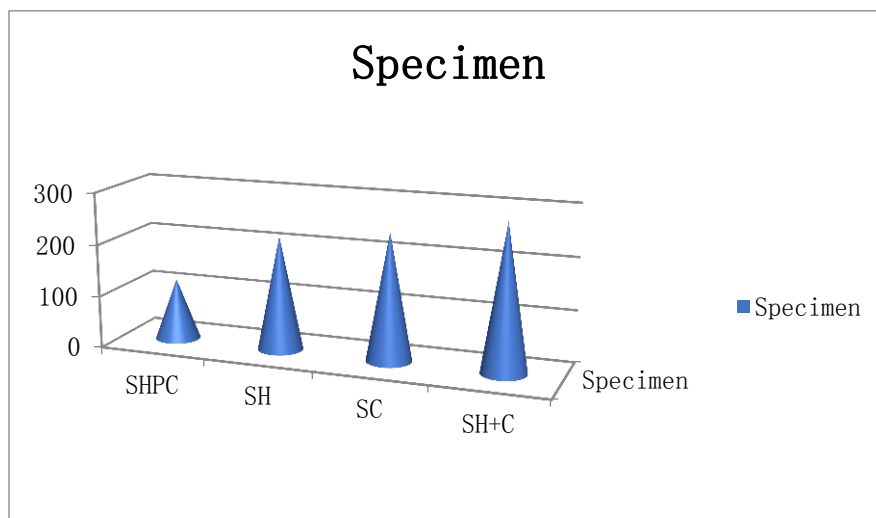


Fig.8. Comparison of energy absorption capacity

5. Conclusion & Future Work

In this research, four groups of concrete beams are tested under concentrated load at the middle of the beams. Each group contains fiber material added at 1.5% of the cement weight. These fibers include; S- Glass fiber, E- Glass fiber, carbon fiber, and S-Glass with carbon fibers. The study proved that adding the fibers to the concrete mix can increase the ductility of reinforced concrete beams beside the ultimate load value by 10%. On the other side, the results demonstrated the using high-performance fibers can improve the water absorption resistance of the simply supported RC beams.

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- Construction Materials Laboratory
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