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Research Article

Comparative Study on High-Performance Concrete Using SBR And Enriched Fibers

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ARTICLE INFO | **ABSTRACT**

High performance concrete, due to its high strength and durability prevents the deterioration of reinforced concrete structures and can be utilized in the rehabilitation of structures. The objectives of this study are to compare the use of SBR and Polypropylene fibers with glass powder in Ultra-high-performance concrete (UHPC) blends. An investigation was conducted on the characteristics of both fresh and hardened UHPC blends. An investigation into the workability properties of UHPC in both its fresh and hardened states was carried out. An assessment of the performance of UHPC during compression, tension, and flexure was done. This paper aims to systematically assess the impact of SBR and enriched polypropylene fibers on the workability, compressive strength, tensile strength, and flexural strength of UHPC. The evaluation was conducted by laboratory experimentation. Tests were conducted on cast cubes, cylinders, and beams to determine qualities such as compressive strength, tensile strength, flexural strength, and durability.

Keywords: High performance concrete, Compressive strength, Slump test, Polypropylene fibers.

1. Introduction

Structures made of reinforced concrete (RC) that have been constructed correctly demonstrate great performance in terms of their endurance and their structural behavior in service conditions that are quite moderate. When they are, however, subjected to extreme mechanical or aggressive environmental conditions, this no longer holds. Both the people who are responsible for maintaining reinforced concrete structures, such as bridges, and the people who use those structures have been confronted with an ongoing and infuriating challenge in the form of premature deterioration of reinforced concrete structures. Concrete delamination and spalling are the most common forms of degradation, and they can be caused by several different causes. Some of these mechanisms include corrosion of embedded steel reinforcement, scaling caused by deicing salt, freezing and thawing cycles, or reactive aggregates. The rate at which this deterioration occurs is largely determined by the degree to which the concrete is permeable to water and other hostile substances. Because of this deterioration, the useful life of infrastructure is reduced, which in turn drives up the price of its long-term upkeep. Since HPC and VHPC/UHPC have high strength and durability, they could play important roles in mitigating the effects of this problem and be utilized in the rehabilitation of structures (Graybeal, 2014; Tayeh et al., 2013). High-performance concrete (HPC), very high-performance concrete (VHPC), and ultra-high-performance concrete (UHPC) all fall under the umbrella of high-performance concrete. Making the concrete less permeable is one strategy for reducing the impact that durability issues have on reinforced concrete structures. This decreased permeability is often accomplished by utilizing a lower water–cementitious materials ratio (W/CM) in conjunction with supplemental cementitious materials (SCMs) such as silica fume, powdered granulated blast furnace slag, fly ash, or metakaolin. Regardless of how low the permeability of the concrete is, however, if the concrete breaks, aggressive agents may penetrate the interior of the concrete and the reinforcing steel. Therefore, any suitable approach for the rehabilitation or strengthening of this kind of failing structure should have the characteristics of being reliable, effective, and cost-effective. Because HPC has better durability capabilities because of its low porosity and permeability characteristics, which give it its low porosity and permeability characteristics, it may be useful for the rehabilitation and retrofitting of reinforced concrete structures. The use of the technology of HPC in the process of repairing works has several advantages, including reducing the amount of working time required for the rehabilitation works; and increasing the serviceability and durability to such an extent that the repaired structures can meet the expected design life of the structures, with only minor preventative measures. These advantages can be summed up as follows: decreasing the amount of working time needed for the rehabilitation works, and increasing the quest for high-performance concrete can be traced back to the 1960s and may be credited to the "pioneering spirit" of a small group of designers and producers. This group was responsible for the development of a new type of concrete. The early 1960s saw the first use of high-strength concrete being utilized in substantial quantities. This application happened in the United States (Munoz et al., 2012). UHPC, which is often referred to as reactive powder concrete (RPC), is a highly high-strength, ductile material that is created by blending Portland cement, silica fume (or metakaolin), quartz flour, fine silica sand, a high-range water reducer, water, and either organic fibers or steel fibers. It is possible to achieve compressive strengths of up to 200 MPa (29000 psi) and flexural strengths of up to 50 MPa with this material (7000 psi). Powders (Portland cement, silica fume, metakaolin, quartz flour, and fine silica sand) pre-blended in bulk bags; superplasticizers; and organic fibers are the three components that are typically included in the premix that is used to supply these materials. Even after the material has initially cracked, it is still able to deform and support loads of flexural and tensile stress thanks to the ductile nature of this material, which is a first for concrete. Reinforcing steel is not required when using this material, which further reduces the complexity of the building process. Because of this, it has the potential to contribute to the solution of the problem of the deterioration of reinforced concrete infrastructures brought on by the corrosion of the implanted reinforcing steel. In the realm of construction, high-performance concrete (HPC), very high-performance concrete (VHPC), and ultra-high-performance concrete (UHPC) can all find applications. Some examples of these applications include repair materials (Graybeal, 2011), bridges (Graybeal, 2005; Hartwell, 2011; Shann, 2012; Bickley and Fung, 2006), pavements, tunnels, and high-rise buildings. This is because both of these materials can offer three advantages over regular concrete, including better strength, lower permeability, and a longer life expectancy in service. Formulations of HPC, VHPC, and UHPC that contain Supplementary Cementing Materials (SCMs) produced from waste products of industrial processes are also more environmentally sustainable.

The utilization of Ultra-High Performance Concrete (UHPC) in combination with Glass Fiber Reinforced Polymer (GFRP) was proposed as a hybrid concept that inspired numerous researchers in the cutting-edge field. Elmahdy et al. [85] conducted an experimental investigation on a novel design that incorporates Ultra-High Performance Concrete (UHPC) in hybrid beams. Chen & El-Hacha [86] conducted an investigation on another hybrid beam, which had a similar design to a GFRP hollow box section, under static flexural pressure. The study demonstrated the indispensability of UHPC in attaining greater strength while reducing the weight and size of structural parts. Iskander et al. [87] conducted an investigation on a hybrid UHPC-GFRP hollow box section, which had a base made of SFRP or CFRP sheets. The analysis uncovered that the failure was partially attributed to the configuration of the fiber orientation at the corner areas of this hybrid beam. In their study, Gretz and Plank (2011) examined the process of film generation in a latex dispersion in water and cement pore solution using Environmental Scanning Electron Microscopy (ESEM) and other supporting techniques. In their 2009 study, Wang et al. examined the micro-mechanical properties of cement pastes modified with styrene-butadiene rubber (SBR) latex. They used the nanoindentation (NI) technique to identify these features. Ru Wang et al. (2006) examined the impact of styrene–butadiene rubber (SBR) latex on the formation of cement hydrates, specifically Ca(OH)2, ettringite, C4AH13, and C–S–H gel. They utilized various measurement techniques to assess the extent of cement hydration. In their study, Parghi and Alam (2016) examined the impact of varying polymer cement (P/C) ratios (0, 5, 10, 15, and 20%) on the mechanical and durability parameters of modified mortar under different curing circumstances. In a study conducted by Shaikh Faiz Uddin Ahmed in 2011, the impact of using polymers in combination with supplementary cementitious materials on specific mechanical and durability properties of modified mortars was investigated. Konar et al. (2011) investigated the interaction between styrene-butadiene rubber (SBR) film and the ions released during the hydration of C2S and C3S in Portland cement mortar composites. They used Fourier Transform Infrared Spectroscopy (FTIR) to analyze the interaction and scanning electron microscopy (SEM) to examine the morphology of the composites. In their 2009 study, Zhengxian Yang et al. investigated the chloride permeability and microstructure of Portland cement mortar that was treated with styrene-butadiene rubber (SBR) latex. They used mortar samples with different polymer/cement mass ratios. In their study, Alessandra et al. (2007) investigated the utilization of a polymer and silica fume blend in the production of mortars. This combination yielded outstanding qualities that are well-suited for repairs and revetments that demand superior performance. In 2006, Ru Wang and colleagues conducted an experiment to investigate the impact of styrene-butadiene rubber (SBR) latex on the physical characteristics of SBR latex-modified mortars. The experiment involved maintaining a constant water/cement ratio or a constant flow.

The literature suggests that although individual research concentrates on certain additives (such as Metakaolin, silica fume, and SBR latex), little is known about the synergistic effects that occur when these additives are used together in concrete mixtures. Although micro silica enhances UHPC and UHP-GPC's mechanical qualities and long-term performance, more research is required to determine how best to incorporate it. More research is needed to pinpoint the precise microsilica fraction in UHP-GPC that strikes a balance between improved mechanical characteristics and workability.

2. Methodology

This section includes details of all materials, equipment, materials compositions, and replacements that will be discussed. A detailed description of the constituent materials of UHPC is given here.

2.1 Materials:

2.1.1 Polypropylene (PP)

Polyethylene terephthalate (PET) and polybutylene terephthalate (PBT) are examples of linear polyesters that are composed of repeating units containing numerous ester groups and unsaturated carbon–carbon double bonds. As per the IS 10909 (2001), Polypropylene shall mean homopolymers of propylene, copolymers of propylene with ethylene, and/or one or more alkene-1-olefines containing C_4 to C_8. The propylene content must constitute not less than 50 percent by mass and monomers with C_4 to C_8 shall constitute not more than 15 percent by mass.

Fig. 1 Polypropylene Fibers

Table 1: Physical properties of Polypropylene Fibers

S. No	Property	Value
1	Specific Weight	960 kg/m^3
2	Modulus of Elasticity	295000 MPa
4	Softening Temperature	80 °C
5	Melting Temperature	160-170 °C
6	Water Absorption	0

2.1.2 Glass fibers powder

Glass is a silica-rich amorphous substance that can exhibit pozzolanic properties when its particle size is smaller than 75 µm. Research has indicated that the use of finely pulverized glass does not have a significant impact on the alkali-silica interaction. Glass powder is locally obtainable in Hisar shops, having been gathered and processed from glass. Glass trash is an extremely durable substance. The glass powder was pulverized in a pulverizer for a duration of 60 - 90 minutes, resulting in particle sizes smaller than 75 µm.

Fig. 2 Glass Fiber powder

Table 2 Physical properties of Polypropylene Fibers

S. No	Property	Value
1	Specific Weight	960 kg/m3
2	Modulus of Elasticity	295000 MPa
4	Softening Temperature	80 °C
5	Melting Temperature	160-170 °C
6	Water Absorption	0
7	Failure Strain	3.7

2.1.3 Styrene Butadiene Rubber

Styrene Butadiene Rubber (SBR) is a copolymer of styrene and butadiene monomers. Its long life, resilience to abrasion, and low price make it a popular choice for many uses. SBR may be refined into a wide variety of powders and other forms to meet a wide range of industrial applications. SBR is the synthetic elastomer that is produced in the biggest amount worldwide is called SBR.

Figure 3 SBR Powder used in UHPC

Table 3 Properties of SBR Powder

S. No.	Property	Value
1	Total Solids	99.2 %
2	Ash Content at 600 °C	14 %
3	MFFT (min. film-forming temperature for re-dispersed in 50% solid concentration)	8 °C
4	Specific Gravity	0.50 g/cm3
5	Particle Size	87 μm

2.1.4 Binder materials (OPC)

Ordinary Portland Cement (OPC) is the predominant type of cement utilized for grade 53, which complies with the specifications outlined in IS 12269 -1987 (Reaffirmed 2004). This study examines the physical parameters of Ultratech OPC 53 grade cement in order to establish its suitability for various applications as tabulated in Table 4.

Table 4 The test results of OPC Grade 53 Cement

S. No	Property	Value	As per 12269 – 1987
1	Specific gravity	3.12	3.10 – 3.15
2	Standard consistency (%)	30 %	30 – 35
3	Initial setting time	35 minutes	30 Minimum
4	Final setting time	247 minutes	600 Maximum
5	Compressive strength 7 days (MPa)	45.50	43 MPa
6	Compressive strength 2 8 days Mpa	60.10	53 MPa

2.1.5 Silica Fumes

A by-product of making silicon metal or ferrosilicon alloys is silica fume, sometimes referred to as microsilica. It is made up of spherical particles that are a hundred times smaller than the typical cement particle size. Silica fume added to concrete has the potential to greatly improve the material's mechanical and durability qualities.

Figure 4 Silica Fumes used in UHPC mix

Aggregates

2.1.5.1 Fine aggregate

The materials within the size range of 4.75 mm to 0.075 mm are classified as fine aggregate. The river sand available locally was used for the test. The sand conforms to the IS 383-1970 and belongs to zone II. Table 5 shows the physical properties of the river sand.

Table 5 Physical properties of fine aggregate

Property	Value
Specific gravity	2.67
Fineness modulus	2.37
Bulk density (kg/m^3)	1650
Water absorption	0.84

2.1.5.2 Coarse aggregate

The crushed quarry stones were used as course aggregates. The classification of CA was done as per the IS 383-1970 standard. The coarse aggregate used in this research was obtained from a crusher near Jaipur, Rajasthan. To produce the UHPC mixes nominal maximum size of the aggregate chosen is 10 mm and below. The water content as per IS 10262:2019 is 208 kg/m^3 for 10 mm size aggregates. The physical characteristics of the coarse aggregate have been evaluated and presented in Table 6.

Table 6 Physical properties of coarse aggregate

S. No	Property	Value	Method of testing
1	Specific gravity	2.70	As per IS 383 - 1970
2	Bulk density	1510	As per IS 2386 - 3 (1963)
3	Water absorption (%)	0.45	As per IS 2386 - 3 (1963)
4	Elongation index	34.80	As per IS 2386 -1 (1963)
5	Flakiness index	14.70	As per IS 2386 -1 (1963)
6	Impact value	12.5	As per IS 2386 – 4 (1963)

2.1.6 Water

Water is an essential component of concrete because it affects the reaction between cement and water. When preparing the concrete mixture, the water that is used should be free of any substance that contains oil, acid, alkalis, clay, loam, or any other vegetable matter. To prepare the concrete mixture, pure water is added to the mixture of cement, fine aggregates, and coarse aggregates.

Table 7 Properties of water

S.No	Properties	Observed Value	Limitation as per IS 456:2000
1	pH Value	7.00	Not less than 6.00
2 a. 2 b.	Dissolved Solids Organic mg/lit Inorganic mg/lit	10 1084	Not to exceed 200 Not to exceed 3000
3	Suspended solids mg/lit	30	Not to exceed 2000
4	Chlorides as Cl mg/lit	36	Not to exceed 2000 for PC, 500 for RCC

2.1.7 Superplasticizer

FAIRFLO is made available in the form of a brown liquid that is composed of sulphonated Nepthalene condensates. The superplasticizer's powerful dispersion action can be used in various ways to achieve compact and very robust concrete with exceptional strength and durability. FAIRFLO's exceptional water reduction qualities make it an excellent choice for precast concrete applications that require good early strength. It does not contain any chloride. Figure 5 shows a picture of the superplasticizer used in the production of the UHPC mix.

Figure 5 Superplasticizer used in the production of UHPC mix

Table 8 Properties of Superplasticizer

S. No.	Properties	Observed Value
1	Physical State	Brown liquid
2	Chloride Content	0.2% Max.
3	Ph	7.5 ± 0.5
4	Air Entrainment	Less than 1% additional air entrained

2.2 Mix Design of UHPC

Ultra-High Performance Concrete (UHPC) is a type of advanced concrete with exceptional mechanical properties, durability, and a very low permeability. The mix design for UHPC is carefully formulated to achieve these superior characteristics. Here's a detailed explanation of the components and steps involved in designing a UHPC mix. Figure 6 Flow Chart Representation For Experimental Investigation.

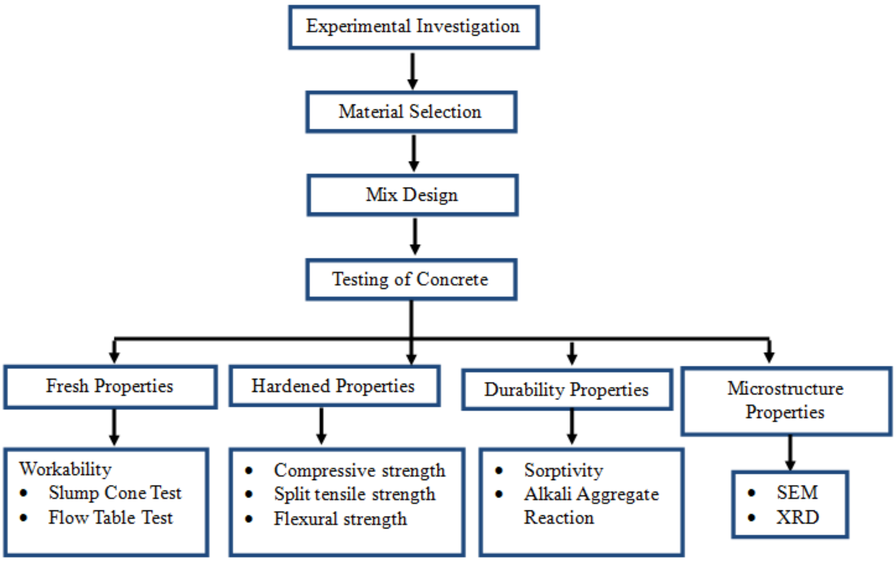

Figure 6 Flow Chart Representation For Experimental Investigation

Final Mix Design Summary (per cubic meter)

- Cement (OPC 53): 491.88 kg
- Silica Fume: 65.58 kg
- Glass Powder: 98.37 kg
- Water: 150.64 kg
- Superplasticizer: 7.21 kg
- Fine Aggregates: 529.62 kg
- Coarse Aggregates: 1141 kg

2.3 Mix Proportions

To attain its higher mechanical qualities and endurance, Ultra-High-Performance Concrete (UHPC) requires particular quantities of different components in its mix proportions. Table 9 shows the mix proportions used in concrete.

Table 9 Mix proportions used in concrete

Mix	Cement (kg/m³)	Silica Fume (kg/m³)	SBR (kg/m³)	Superplasticizer (kg/m³)	Glass Powder (kg/m³)	Coarse Aggregates (kg/m³)	Fine Aggregates (kg/m³)	Water (kg/m³)
Control mix	491.88	65.58	0	7.21	98.37	1141	529.62	150.64
G10	441.69	65.58	0	7.21	98.37	1141	529.62	150.64
G20	391.5	65.58	0	7.21	98.37	1141	529.62	150.64
G30	341.31	65.58	0	7.21	98.37	1141	529.62	150.64
G40	291.12	65.58	0	7.21	98.37	1141	529.62	150.64
G50	240.93	65.58	0	7.21	98.37	1141	529.62	150.64
SF6	491.88	39.35	6	7.21	98.37	1141	529.62	150.64
SF8	491.88	52.47	8	7.21	98.37	1141	529.62	150.64
SF10	491.88	65.58	10	7.21	98.37	1141	529.62	150.64
SF12	491.88	78.7	12	7.21	98.37	1141	529.62	150.64
SF15	491.88	98.37	15	7.21	98.37	1141	529.62	150.64
SF18	491.88	118.04	18	7.21	98.37	1141	529.62	150.64
G10/SF12	441.69	78.7	0	7.21	98.37	1141	529.62	150.64
G20/SF12	391.5	78.7	0	7.21	98.37	1141	529.62	150.64
G30/SF12	341.31	78.7	0	7.21	98.37	1141	529.62	150.64
G40/SF12	291.12	78.7	0	7.21	98.37	1141	529.62	150.64
G50/SF12	240.93	78.7	0	7.21	98.37	1141	529.62	150.64

Mix Identification: Each row represents a different mix design identified by a label such as "Control Mix", "G10", "SF6", etc.

3. Tests Performed

3.1 Slump Test

Concrete workability relates to its ease of handling, laying, and compacting during construction. It is essential to mixing, transporting, and finishing concrete and ensuring product quality. Workability depends on water, aggregate size and shape, cement, admixtures, and ambient conditions. The slump test was performed in accordance with the specifications outlined in IS 1199-1959. IS 1199:1959 (Reaffirmed 2016). The fresh concrete's workability was assessed by the traditional slump test.

3.2 Compressive Strength Test

Concrete cube samples measuring 150 mm were cast for the purpose of conducting a uniaxial compressive strength test. The tests were performed at intervals of 1, 3, 7, 28, and 56 days under typical water curing conditions, in accordance with the Indian Standard Code IS: 516-1976 IS 516:1959. The compressive strength of cube specimens was determined by calculating the average value of three examples at each age. The specimens are cast and stored in molds for a duration of 24 hours at the ambient temperature. After 24 hours, a set of specimens was taken out of the mold and subjected to elevated temperature curing at 60°, 90°, and 120° C in an oven for 48 hours. Once thermal equilibrium was achieved, the compressive strength test was conducted 72 hours later. The remaining specimens that have undergone heat treatment are submerged in water until they reach the desired testing age. Three cubes underwent testing, and average values were obtained for each age.

4. Results and Discussion

4.1 Mixture Proportion

The UHPC mixes were proportioned using the guidelines provided in IS 10262-2019. The concrete was mixed in accordance with the specifications outlined in IS 456-2000. The composition ratio of UHPC mixes, which consist of binary and ternary blends, is presented in Table 10.

Table 10 Mix Proportions

Mix	Cement (kg/m³)	FGP (kg/m³)	PP (kg/m³)	SBR Powder (kg/m³)	Silica Fumes (kg/m³)	CA (kg/m³)	FA (kg/m³)	Water (kg/m³)
Control Mix	760	0	0	9.62	114	1106	525	152
FGP 1	666	0	76	9.62	114	1103	523	152
FGP 2	592	0	152	9.62	114	1100	522	152
FGP 3	518	0	228	9.62	114	1097	520	152
FGP 4	444	0	304	9.62	114	1094	519	152
FGP 5	370	0	380	9.62	114	1091	518	152
FGP 6	696	44.4	456	9.62	114	1099	522	152

FGP 1 + 0.5 PP	681	59	0	9.62	114	1092	518	152
FGP 2 + 0.5 PP	666	74	0	9.62	114	1085	515	152
FGP 3 + 0.5 PP	651	89	0	9.62	114	1081	513	151
FGP 4 + 0.5 PP	629	111	0	9.62	114	1075	510	151
FGP 5 + 0.5 PP	607	133	0	9.62	114	1069	507	151
FGP 6 + 1 PP	577	89	74	9.62	114	1078	511	151
FGP 1 + 1 PP	681	59	0	9.62	114	1092	518	152
FGP 2 + 1 PP	666	74	0	9.62	114	1085	515	152
FGP 3 + 1 PP	651	89	0	9.62	114	1081	513	151
FGP 4 + 1 PP	629	111	0	9.62	114	1075	510	151
FGP 5 + 1 PP	607	133	0	9.62	114	1069	507	151
FGP 6 + 1 PP	577	89	74	9.62	114	1078	511	151
FGP 1 + 1.5 PP	681	59	0	9.62	114	1092	518	152
FGP 2 + 1.5 PP	666	74	0	9.62	114	1085	515	152
FGP 3 + 1.5 PP	651	89	0	9.62	114	1081	513	151
FGP 4 + 1.5 PP	629	111	0	9.62	114	1075	510	151
FGP 5 + 1.5 PP	607	133	0	9.62	114	1069	507	151
FGP 6 + 1.5 PP	577	89	74	9.62	114	1078	511	15 1
FGP 1 + 2 PP	681	59	0	9.62	114	1092	518	152
FGP 2 + 2 PP	666	74	0	9.62	114	1085	515	152
FGP 3 + 2 PP	651	89	0	9.62	114	1081	513	151
FGP 4 + 2 PP	629	111	0	9.62	114	1075	510	151
FGP 5 + 2 PP	607	133	0	9.62	114	1069	507	151
FGP 6 + 2 PP	577	89	74	9.62	114	1078	511	151
FGP 1 + 2 PP + 10 %SBR	681	59	0	9.62	114	1092	518	152
FGP 2 + 2 PP + 10 %SBR	666	74	0	9.62	114	1085	515	152
FGP 3 + 2 PP + 10 %SBR	651	89	0	9.62	114	1081	513	151
FGP 4 + 2 PP + 10 %SBR	629	111	0	9.62	114	1075	510	151
FGP 5 + 2 PP + 10 %SBR	607	133	0	9.62	114	1069	507	151
FGP 6 + 2 PP + 10 %SBR	577	89	74	9.62	114	1078	511	151
FGP 1 + 2 PP + 20 %SBR	681	59	0	9.62	114	1092	518	152
FGP 2 + 2 PP + 20 %SBR	666	74	0	9.62	114	1085	515	152
FGP 3 + 2 PP + 20 %SBR	651	89	0	9.62	114	1081	513	151
FGP 4 + 2 PP + 20 %SBR	629	111	0	9.62	114	1075	510	151

4.2 Slump Test Results

Upon visual examination, it was seen that the mixes containing Polypropylene, Fiber Glass Powder and SBR Latex Powder exhibited both mobility and cohesiveness. The graph in Figure 7 demonstrates that increasing the replacement of cement with GGBS led to a notable improvement in the slump values. The results demonstrated that the workability was enhanced at all degrees of cement replacement with GGBS when compared to the control mix. The average increase in slump of Ultra-High Performance Concrete (UHPC) mixes including Ground Granulated Blast Furnace Slag (GGBS) was around 15% compared to the control mix. The crystalline composition and the precise surface area of GGBS decrease the requirement for water, hence enhancing the ease of handling and manipulation. Conversely, the binary combinations of UHPC with SF exhibited a reduction in slump compared to the control combinations. The reduction, in comparison to the control mixture, amounted to nearly 7%. This is a result of the extensive surface area of silica particles, which leads to an elevated water need for UHPC mixtures.

The slump test results are shown in Figure 7, Figure 8 and Figure 9. The mixes with GGBS on visual observation were found to be mobile as well as cohesive. The cohesiveness of the mix was due to the presence of SiO2 in GGBS. From the graph presented in Figure 9, it can be noted that the increase in the replacement of level of cement by GGBS resulted in a significant enhancement in the slump values. In comparison to the control mix, the findings revealed that all levels of cement substitution by GGBS improved workability. In contrast, the binary mixes of UHPC with SF showed a decrease in slump when compared to the control mixes. The decrease, when compared to the control mix, was almost 7%. This is due to the large surface area of silica particles which increases the water demand of the UHPC mixes.

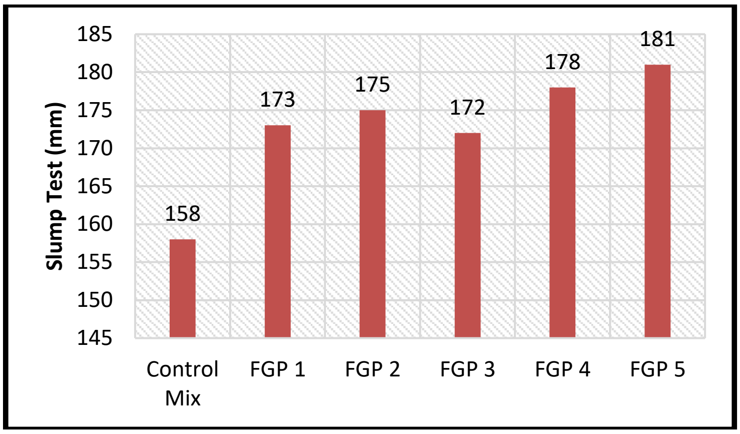

Figure 7 Slump test for FGP1-5

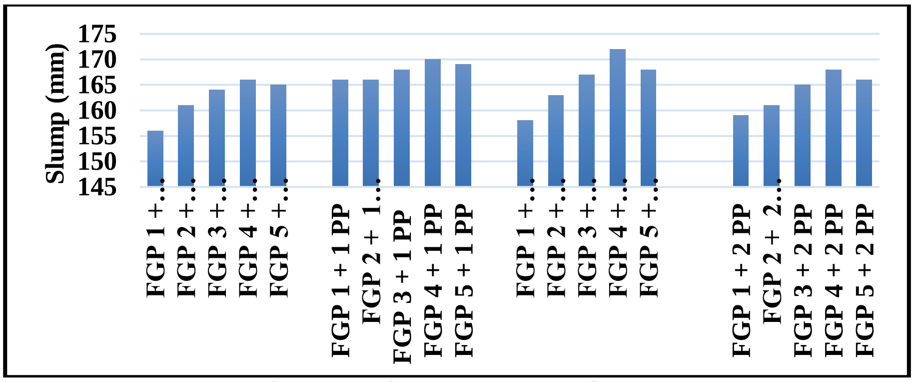

Figure 8 Slump test FGP1 plus PP

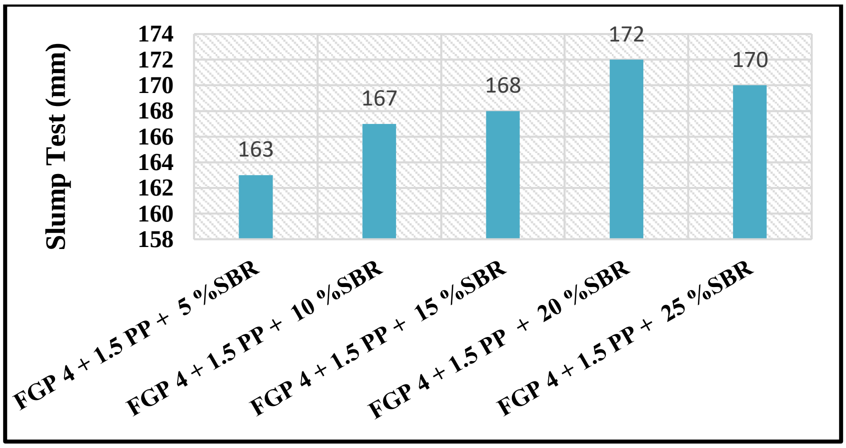

Figure 9 Slump test for FGP4 Plus PP

4.3 Compressive Strength Test

The cubes specimens for different mix proportions were cast and tested at 7, 14 and 28 days of curing. There was a significant increase in the compressive strength of stem cured specimen as compared to normal curing done in air. From the past literature review similar strength development of polymeric UHPC at early and later stages has been reported [38]. What is interesting in the compressive strength measurements is that incorporating polymers into UHPC prompts insignificant improvement in the compressive strength after 7 and 28 days. Nevertheless, a considerable increase in the compressive strength of the mixture containing 20 wt.% polymer (i.e., P20%-S) at 90 days was achieved by 5–8% enhancement. The results have shown that the SBR reacts with $Ca(OH)_2$ to form a new network structure. Hence it is concluded that the addition of polymers enhances the long-term compressive strength. Interestingly, although the 7- and 28-day compressive strengths of mixtures incorporating steel fibers are higher than those without steel fibers, the 90-day compressive strength of mixtures with and without steel fibers is comparably improved with 49% enhancement. The UHPC specimens were subjected to a compressive strength test at 3,7,14 and 28 days after water curing. The results of all the UHPC mixes are depicted in Table 4.2 and Figure 10. From Table 4.2 it can be seen that for all the

mixes, the compressive strength increases with age. Compared to UHPC mixes with FGP, the increase in early age strength was less for UHPC mixes with Enriched Fibres. The compressive strength for UHPC mixes with GGBS decreased by almost 15% at 10% replacement level and 12% at 20% replacement level of cement by GGBS at 1 and 3 days of normal curing. The results here are in line with the findings of previous researchers [74]. From Figure 10 it can be interpreted that the increment observed at 3, 7 days was almost 15% and 20% respectively for UHPC mixes with SF compared to that with GGBS.
As it can be seen from Table 4.2 GGBS contains more SiO_2 and less lime compared to OPC. According to Neville and Aitcin [261], [262] “the initial hydration of GGBS is slow as it depends upon the breakdown of the glass by the hydroxyl ions released during hydration of Portland cement”. Further, it has been reported [263] that only 30-37% of GGBS hydrates at 28 days hence low early-age gain in strength is reported for concrete containing GGBS. However, at later ages a gain in strength is observed for UHPC mixes with GGBS this may be due to the progressive release of alkalis by the GGBS, together with the formation of $Ca(OH)_2$ by Portland cement.
From the results depicted in Table 4.2, it is clear that for binary blended UHPC mixes with GGBS and SF respectively, the compressive strength increases with an increase in the content of SCMs. At all the testing ages the gain in strength was observed to be up to a certain level of replacement. The optimum replacement level recorded for GGBS and SF was 40% and 12% respectively and beyond this level, a slight decrease in compressive strength was seen. This might be owing to a paucity of free $Ca(OH)_2$, which caused the SCM particles to form a low-density C-S-H gel during the hydration process. The early age strength of all the UHPC mixes with GGBS improved with the incorporation of SF in the concrete mixture. The improvement in compressive strength was almost 10% when compared with binary blended UHPC mixes with GGBS. In addition to this, the ternary blended mixes with GGBS and SF showed a 17% enhancement in compressive strength over binary blended UHPC mixes with SF. The early age gain in strength for ternary mixes can be due to excess SiO_2 present in the mixture which further contributed to the acceleration of the hydration process by SF alone in the concrete mix. Further, later age gain in strength was also noticed in the case of ternary blended mixes, the 56 days strength for ternary blended mixes showed approximately 17% increment above the binary blended mixes with SF. The results presented here for the ternary blended UHPC mixes indicate synergy between SF and GGBS. The synergetic effect is also evident in Figure 3.16. The synergetic effect is also evident from the Scanning Electron Microscope (SEM) image present in Figures 4.11 and 4.12. The SEM image clearly shows the formation of ettringite and calcium silicate hydrate (C-S-H) gel at 28 days.

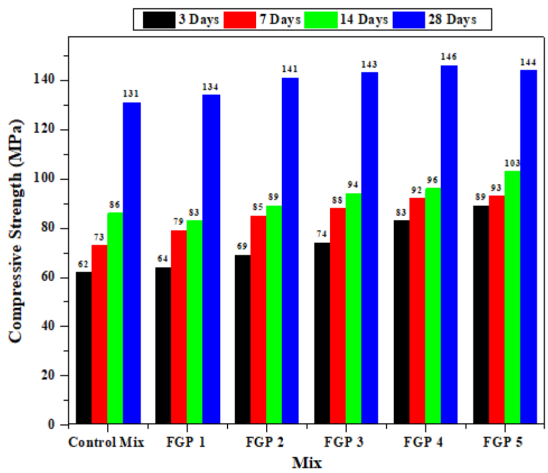

Figure 10 Compressive strength test result FGP

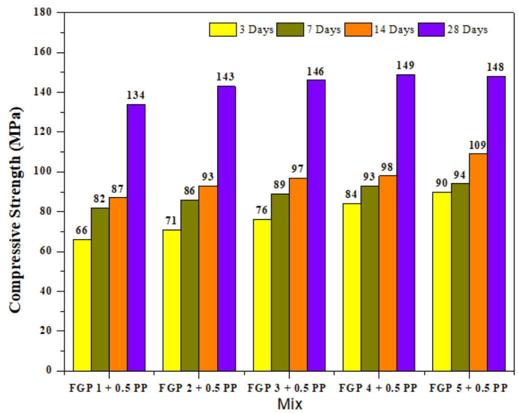

Figure 11 Compressive strength test result FGP PLUS 0.5 PP

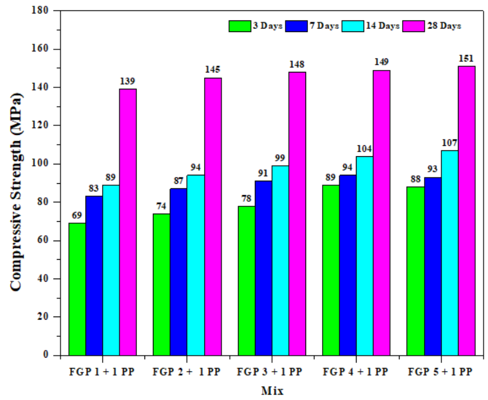

Figure 12 Compressive strength test result FGP Plus 1 PP

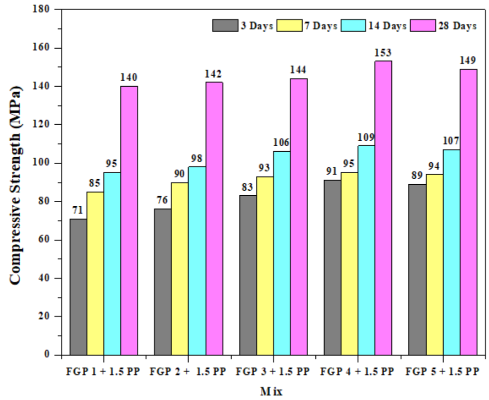

Figure 13 Compressive strength test result FG PLUS 1.5 PP

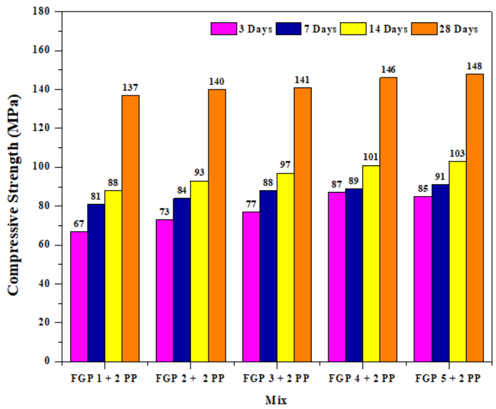

Figure 14 Compressive strength test result FG PLUS 2 PP

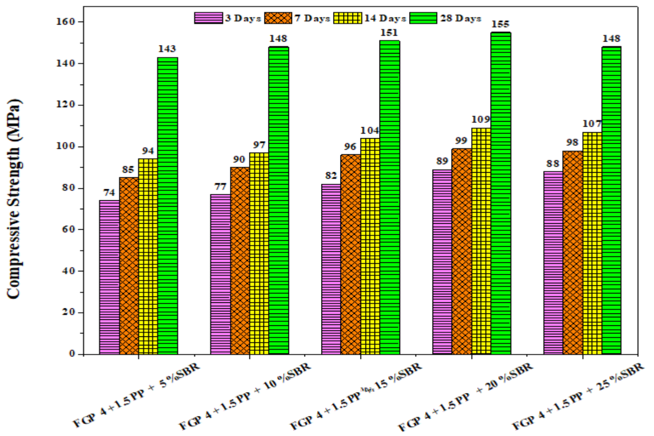

Figure 15 Compressive strength test result FG PLUS 1.5 PP and SBR

5. Conclusion

The conclusion of the current study can be highlighted through the following points:

1. The compressive strength (fc) values for the reference combination after 91 days of normal curing (NC) and 2 days of high-temperature curing (HC) were 179 and 204 MPa, respectively. In comparison, the fc values for the mixtures with 90% cement and 10% ground granulated blast furnace slag (90C/10GP) were 213 MPa at 2 days of HC and 198 MPa after 91 days of NC. Similarly, the mixtures with 80% cement and 20% ground granulated blast furnace slag (80C/20GP) had fc values of 216 MPa at 2 days of HC and
2. The compressive strength (fc) of the Ultra-High Performance Concrete (UHPC) with 30%, 40%, and 50% Ground Granulated Blast Furnace Slag (GP) replacement (70C/30GP, 60C/40GP, and 50C/50GP, respectively) dropped by 10-20% at early ages (1, 7, and 28 days) compared to the reference mixture containing no replacement. The outcomes varied in the later stages (56 and 91 days) of NC and likewise following HC.
3. The graph in Figure 4.1 demonstrates that increasing the replacement of cement with GGBS led to a notable improvement in the slump values. The results demonstrated that the workability was enhanced at all degrees of cement replacement with GGBS when compared to the control mix.
4. The mixes with GGBS on visual observation were found to be mobile as well as cohesive. The cohesiveness of the mix was due to the presence of SiO2 in GGBS. It can be noted that the increase in the replacement of the level of cement by GGBS resulted in a significant enhancement in the slump values. In comparison to the control mix, the findings revealed that all levels of cement substitution by GGBS improved workability.

References

1. Graybeal, B. (2014). Ultra-high-performance concrete connections for precast concrete bridge decks. *PCI J*, *59*(4), 48-62.
2. Tayeh, B. A., Bakar, B. A., Johari, M. M., & Voo, Y. L. (2013). Utilization of ultra-high performance fiber concrete (UHPFC) for rehabilitation–a review. *Procedia Engineering*, *54*, 525-538.
3. Muñoz, M. Á. C. (2012). *Compatibility of ultra high performance concrete as repair material: bond characterization with concrete under different loading scenarios*. Michigan Technological University.
4. Graybeal, B. (2011). *Ultra-high performance concrete* (No. FHWA-HRT-11-038).
5. Graybeal, B. A. (2005). *Characterization of the behavior of ultra-high performance concrete*. University of Maryland, College Park.
6. Hartwell, D. (2011). *Laboratory testing of Ultra High Performance Concrete deck joints for use in accelerated bridge construction* (Doctoral dissertation).
7. Shann, S. V. (2012). *Application of ultra high performance concrete (UHPC) as a thin-bonded overlay for concrete bridge decks*. Michigan Technological University.
8. Bickley, J. A., & Fung, R. (2006). Optimizing the Economics of high performance concrete. In *HPC: Build Fast, Build to Last. The 2006 Concrete Bridge ConferencePortland Cement AssociationFederal Highway AdministrationNevada Department of TransportationAmerican Concrete Institute (ACI)*.