



## GGBS And Fly Ash Effects on Compressive Strength by Partial Replacement of Cement Concrete

Azmat Ali Phul <sup>a</sup>, Muhammad Jaffar Memon <sup>a\*</sup>, Syed Naveed Raza Shah <sup>a</sup>,  
Abdul Razzaque Sandhu <sup>a</sup>

<sup>a</sup> Department of Civil Engineering, Mehran University of Engineering and Technology, Shaheed Zulfiqar Ali Bhutto Campus, Khairpur Mirs', Sindh, Pakistan.

Received 09 January 2019; Accepted 26 March 2019

### Abstract

This paper investigates the compressive strength properties of concrete with Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash in concrete by partial replacement of cement. The incremental demand of cement in the construction field is a concern for environmental degradation, in this regard; replacement of cement is carried out with waste materials by using GGBS and Fly Ash. On optimum level of GGBS and Fly Ash was assessed with varied percentage from 0 to 30% for different curing days. Replaced concrete were tested with the slump, compaction factor, Vee-bee and compressive strength. Cement to water ratio was maintained at 0.47 for all mixes. The compressive strength tests were conducted for 3, 7, 14 and 28 days of curing on a M25 grade concrete. The results obtained from the slump, compaction factor, Vee-bee and compressive strength of concrete containing GGBS and Fly Ash was increased as the curing time increases. The workability of replaced concrete improved when slump value achieved 30% as compared to controlled one SF0 and the compressive strength obtained 26.30% improvement at SF9 as compared to SF0. The outcomes indicated that the addition of GGBS and Fly Ash enhances the workability and compressive strength which eventually improved the mechanical properties of concrete.

*Keywords:* GGBS; Fly Ash; Compressive Strength; Slump; Compaction Factor; Vee-bee.

### 1. Introduction

Construction industry has become one of the most important part of a country's economic and social development [1]. Concrete has been utilized by the construction industry for the construction of most of the infrastructures which range from construction of foundations to retaining walls, dams to bridges, residential houses to tall skyscrapers [2]. The most predominately used binder in concrete is blended cement. Today, public and private organizations have been giving considerable importance to different construction materials on account of their environmental behavior. The growing use of cement made concrete in building projects and subsequent emission of harmful gases into the atmosphere causes a significant rise in earth's temperature [4]. One thousand kilograms of cement produce nearly similar amount of carbon dioxide (CO<sub>2</sub>) [5]. According to an estimate, around 6–8% of the total CO<sub>2</sub> globally emitted comes from ordinary cement production [6]. The concrete has been investigated currently in favor of depleting carbon dioxide emissions and enhancing the performance eventually reducing in the cost of construction [3]. Keeping in view eco-friendly approaches and utilization of industrial solid waste or by-product materials as replacement of cement has been considered under construction for the generation of cement and concrete because it shares less amount of consumption of natural resources

\* Corresponding author: [jaffar.memon@muetkhp.edu.pk](mailto:jaffar.memon@muetkhp.edu.pk)

 <http://dx.doi.org/10.28991/cej-2019-03091299>

➤ This is an open access article under the CC-BY license (<https://creativecommons.org/licenses/by/4.0/>).

© Authors retain all copyrights.

[7]. Moreover, quarrying for the raw materials to produce ordinary cement destroys wildlife sanctuaries. Hence, the main object of the responsible authorities is either to eliminate the wide spread use of ordinary cement or use some other environment friendly method for concrete making to reduce the danger posed by the extensive use of ordinary cement on environment [8, 9].

Among many additional minerals such as, waste materials, by-product and industrial solid waste have pozzolanic qualities that matched as a cement or concrete properties. In this case, ground granulated blast furnace slag (GGBS) and Fly Ash commonly used supplementary cementitious because of their pozzolanic properties. Slag and Fly Ash formed additional C-S-H gel after reaction with portlandite whose structure is similar type that is accrued by cement hydration. Therefore, GGBS and Fly Ash reaction makes a huge contribution to the characteristics and development of concrete [10]. The quantity of GGBS and Fly Ash waste from industries are increasing on daily basis and main issue of their disposal. GGBS is derived through metal ores during smelting procession. Iron is extracted in the form of iron silicate usually called so as slag. Disposal of slag may create toxic health hazards. Thermal power plants are one of the main sources and other new thermal power plants of electricity in our country due to which the utilization of coal is on rise to generate more energy consequently in producing plenty of ash. Round about 75-80 per cent of the total amount of ash by product is generated via power plant is Fly Ash. Currently plenty of research carried out on the application of cementitious material such as, silica fume, Fly Ash, ground granulated blast furnace slag, rice husk, and metakaolin [11], subtly utilized those cementitious materials in replacement for Portland cement. Impacts of those material can be judged through concrete durability also reduce thermal cracking risk in mass concrete, consumed less energy along with eco-friendly as compared to cement and are considered throughout world as a filling material, roofing construction, tiles making and concrete blocks [12]. Hence, reuse of industrial by-products or secondary materials has been motivated in construction as well as cement production because it contributes to reduce the consumption of natural resources [13].

In this research the two best choices of cementitious material GGBS and Fly Ash were assessed partially with ordinary Portland cement. The aim of this research is to examine the effects on fresh and hardened state when addition of blast furnace slag and Fly Ash in concrete with cement and the determination of concrete workability and compressive resistance at varied curing days that reduces the expenditure cost incurring than conceding the concrete strength.

## 2. Materials and Methods

The research methodology used in this experimental work is shown in Figure 1.



Figure 1. Flow chart of Research Methodology

### 2.1. Constituent Material

#### 2.1.1. Concrete

Concrete is mainly a mixer of materials composed of water aggregate and cement. Aggregates, Fine and Coarse combined occupy about 70% voids in a specified mass of concrete and residual 30% voids are occupied by water, cement and air voids. To achieve the desired physical properties of finished materials, commonly supplementary cementitious materials are added in a concrete mixture.

#### 2.1.2. Cement

Ordinary Portland cement (OPC) is the most preferred binder in the manufacturing of concrete due to its good adhesive and cohesive properties that facilitate it's bonding with other materials. Locally acquired Ordinary Portland cement of 53 grade of the ACC cement Branch conforming to ISI standards is used and standard tests were conducted according to IS:8112-1989. The physical and chemical elements of cement are given in Table 1.

#### 2.1.3. Supplementary Cementitious Materials (SCMs)

Supplementary Cementitious Materials (SCMs) GGBS and Fly Ash were used in various proportions described under:

### Ground granulated blast furnace slag (GGBS):

GGBS is collected from Steel Mill Karachi. Blast furnace slag is a by-product left as a residual product after the burning of coke, limestone and ore of iron in a combination at 1500 C. Molten iron and molten slag are obtained after heating the mix [14, 15]. The low-density molten slag comes up on the surface and easily separated from rest of the mass. Afterwards it is cooled down by the action of water. The water pressure during the cooling process breaks down the slag into a size less than five millimeters. Blast furnace slag powder is then obtained by grinding the dried slag mass [16, 17]. The chemical and physical properties of BBFS are shown in Table 1.

GGBS is derived from pig iron manufacturing process. When the molten slag cools, it changes into a fine, granular, almost fully non-crystalline, glassy form known as granulated slag. It has latent hydraulic properties. The finely ground slag, when mixed with Portland cement (PC), gives very good binding properties [18]. It has same chemical properties as that of cement, but it is less reactive than Portland cement (PC). It hydrates on adding water just like the Portland cement and mostly in combination with Portland cement, typically in the range 60 to 40 percent GGBS, depending on the application. The blends can either be factory made or formed in the mixer by adding Portland cement and GGBS each from its own silo. Concrete containing GGBS/PC mix may be slow in reacting than pure PC concrete, but it has improved durability [18]. The chemical and physical properties of BBFS are shown in Table 1.

### Fly Ash:

Fly Ash is the other choice. Locally available (Jamshoro, Pakistan) Class F Fly Ash was used. It was collected from Lakhra Power House, Jamshoro. It is obtained from coal power plants [19]. It creates serious environmental, disposal and health problems. Its grains are spherical in shape and are used in combination with ordinary cement to enhance the concrete workability. Also, it increases durability and strength of hardened concrete. The chemical and physical properties of Fly Ash are shown in Table 1.

**Table 1. Physical and Chemical Properties of OPC, GGBS and Fly Ash**

Properties	Cement	GGBS	Fly Ash
Specific gravity	3.15	2.79	2.43
$SO_2$	20.6	34.4	63.5
$Al_2O_3$	4.0	9.0	11.1
$Fe_2O_3$	3.1	2.58	5.2
$CaO$	62.8	44.8	14.7
$MgO$	2.6	4.43	1.98
$SO_3$	3.1	2.26	0.35
$Na_2O$	–	0.62	0.48
$K_2O$	–	0.5	0.4
LOI	1.8	1.32	2.1

#### 2.1.4. Fine and Coarse Aggregates

Locally available river sand which is free from organic impurities is used and conformed to grading zone 2 as per IS: 2386 (Part-I – 1963). Sand passing through sieve is 4.75 mm and retaining on IS sieve no. 150  $\mu$  is used in this study. Sieves are thoroughly cleaned before use.

The coarse aggregate used in the experiments have maximum size of 20 mm. IS 383:1970 was used to find out the proportion mix of coarse aggregate, with 60% 10 mm size and 40% 20 mm. The physical properties are shown in Table 2.

**Table 2. Physical properties of Fine aggregate and Coarse aggregate**

Properties	Fine aggregate	Coarse aggregate
Specific gravity	2.65	2.80
Water absorption	2%	1%
Free surface moisture	2%	Nil

#### 2.1.5. Water

Higher water content imparts higher workability to the concrete mix. When water is added to the concrete, hydration reaction occurs, and hardening of the paste starts, subsequently. Water should have a pH value in the range 6-8. Water

should not contain salt in it if used for reinforced concrete, because it can cause the reinforcement steel material to corrode.

## 2.2. Experimental Investigation

### 2.2.1. Casting and Curing of Control Specimen

At each mix three cubes of 15×15×15 cm in size were casted in a moulds on each partial per cent GGBS and Fly Ash as given in Table 3. Each caste specimens were kept in temperature 25<sup>0</sup>C for 24 Hours and 60 to 70% humidity maintained. After 24 hours period demolded and placed in water for curing. Cubes were investigated for further tests after curing for various ages of 3, 7, 14 and 28 days as shown in Figure 2.



Figure 2. Compressive strength testing of samples

### 2.2.2. Mix Design Proportion

This mix design procedure adopted in present work to obtain M-25 grade is in accordance with IS 10262:2009 & 456:2000. The weight of each components/ingredients and the mix design proportion is represented in Table 3.

Table 3. Mix Design Proportions

Mix Proportion	Binder Content			Quantity of Each Component (kg/m <sup>3</sup> )					
	OPC	GGBFS	Fly Ash	OPC	GGBFS	Fly Ash	Fine Aggregates	Coarse Aggregates	Water
SF0	100%	0%	0%	435.41	0	0	653.38	1173.78	191.5
SF1	95%	2%	3%	413.64	8.71	13.06	653.38	1173.78	191.5
SF2	95%	2.5%	2.5%	413.64	10.89	10.89	653.38	1173.78	191.5
SF3	95%	3%	2%	413.64	13.06	8.71	653.38	1173.78	191.5
SF4	85%	5%	10%	370.10	21.77	43.54	653.38	1173.78	191.5
SF5	85%	7.5%	7.5%	370.10	32.66	32.66	653.38	1173.78	191.5
SF6	85%	10%	5%	370.10	43.54	21.77	653.38	1173.78	191.5
SF7	70%	10%	20%	304.79	43.54	87.08	653.38	1173.78	191.5
SF8	70%	15%	15%	304.79	65.31	65.31	653.38	1173.78	191.5
SF9	70%	20%	10%	304.79	87.08	43.54	653.38	1173.78	191.5

## 2.3. Testing

### 2.3.1. Sieve Analysis

It is process of evaluating the particles size distribution of fine and coarse aggregates. For sieve analysis, we go through different sieves as standardized by the IS: 2386 (Part 1)-1963 (80mm, 63mm, 50mm, 40mm, 31.5mm, 25mm, 20mm, 16mm, 12.5mm, 10mm, 6.3mm, 4.75 mm, 3.35mm, 2.36mm, 1.18mm, 600µm, 300µm, 150µm and 75µm) by passing aggregates through them and thus collected different size particles left over on different sieves.

### 2.3.2. Workability

Various tests of workability of concrete at construction sites such as slump, compaction factor and vee-bee were determined. The workability of concrete indicates the conditions through which the concrete is handled, transported and placed between the forms with minimum loss of homogeneity.

Slump test was assessed to determine the consistency of concrete mixture. The main function of slump is to indirectly utilized or testing of the correct amount of waste added in the medium paste. Furthermore, to justify slump test the compaction factor and Vee-bee tests were also determined.

### 2.3.3. Compressive Strength

For this test, cubic moulds of 15cm x 15cm x 15cm size in grade 25 ratios were used. Compaction was achieved via table vibrator of the hand filled concrete cubes for the compaction. After 24 hours the specimens were demolded and subsequently placed water tank basin for different ages for curing. Number of three specimens was used to get the mean value of each partial percentage for compressive strength and test was operated on compression testing machine having load capacity 200 MT. The cubes were placed under water for curing after keeping molded for 24 hours. Compressive strength tests of the cubes were carried out after curing at 3,7,14 and 28 days, respectively in confirmation with I.S. 516-1959.

## 3. Results and Discussion

### 3.1. Workability

#### 3.1.1. Slump

The mixed fresh concrete workability was measured immediately after mixing of the concrete according to IS: 1199-1959 and blended cement concrete specimens are given in Figure 3. It is clearly can be observed that the slump of OPC concrete specimen was 70 mm, whereas 100, 90 and 90 mm for specimens SF4, SF6 and SF7, which are higher than controlled one respectively. The specimens with more coal Fly Ash have better workability because of the spherical shape of coal Fly Ash particles. The spherical particles of Fly Ash caused to deplete the internal friction between the ingredients of concrete that likely influence a considerable fluidity of mix concrete. The SF1, SF2 and SF8 lose the workability collapse to lowest slump of 80, 85 and 75 mm. This may be attributed to the weight of slag affect the slump. According to Reddy et al. [20] had also got slump value increased by replacing cement with various percentage of GGBS and Fly Ash.

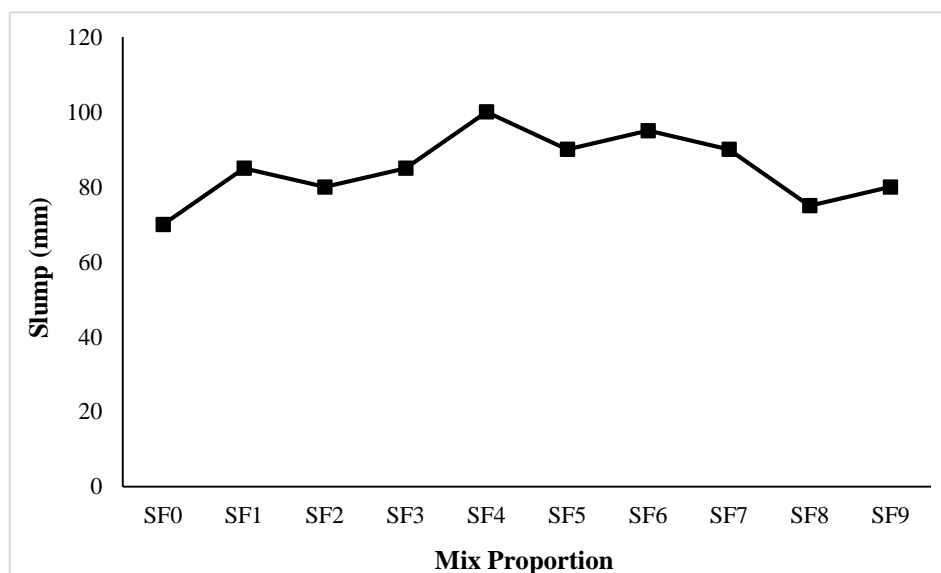


Figure 3. Slump of different mix proportion of GGBS and Fly Ash

#### 3.1.2. Compaction Factor

Compacting factor was assessed as per IS 456-2000. The Slump and compacting factor investigation are usually adopted test for fresh concrete. The degree of workability of concrete depends on the value of test results obtained from slump and compacting factor as shown in Figure 4. The compaction factor degree measured by the density ratio and all mixed ratio indicated well in medium state except one SF4 mix state showed high in compaction factor ratio.

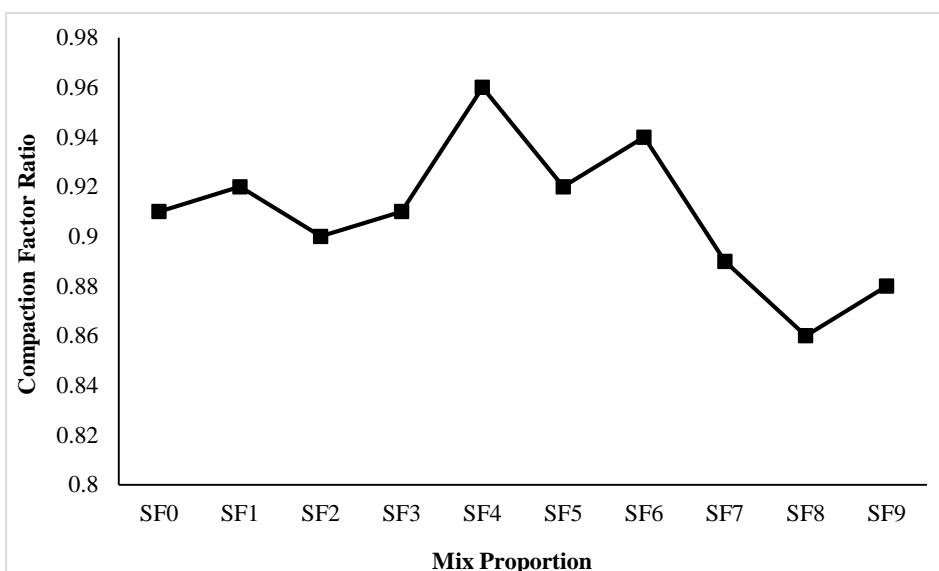


Figure 4. Compaction Factor of Different Mix Proportion of GGBS and Fly Ash

### 3.1.3. Vee-Bee

Vee-bee main objective is to find out the workability of the fresh mixed concrete as shown in Figure 5. Vee-bee was conducted according to IS: 119-1959 which gives intimation about the mobility and the compatibility aspect of freshly mixed concrete. The measurement of Vee-Bee holds the relative efforts to change the mass of concrete from definite shape to the other. The amount of measurement time defines its remolding effort and the required time to complete the remolding is measured through the workability and expressed in the Vee-Bee seconds. It clearly indicated the time taken in seconds when addition of GGBS & Fly Ash percent increases.

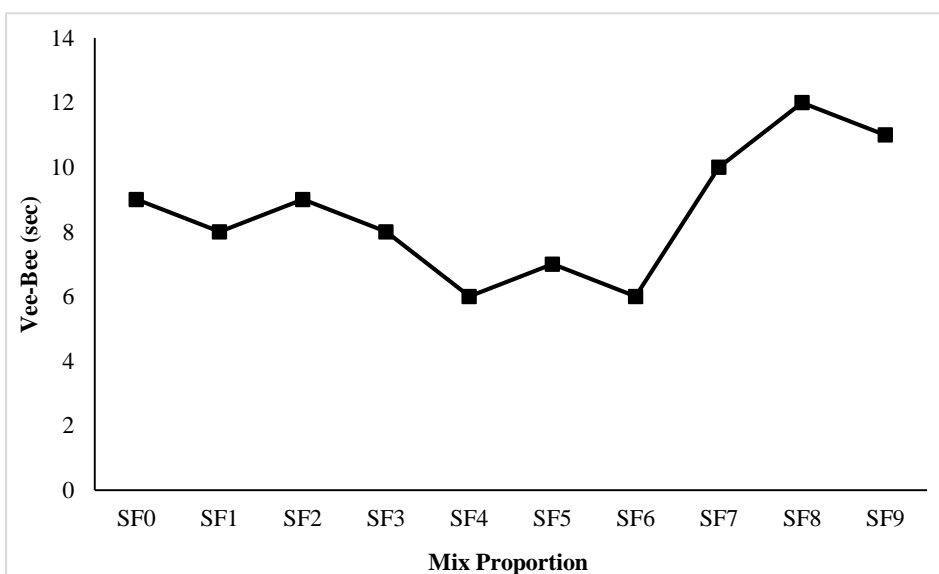


Figure 5. Vee-bee of different mix proportion of GGBS and Fly Ash

### 3.2. Compressive Strength

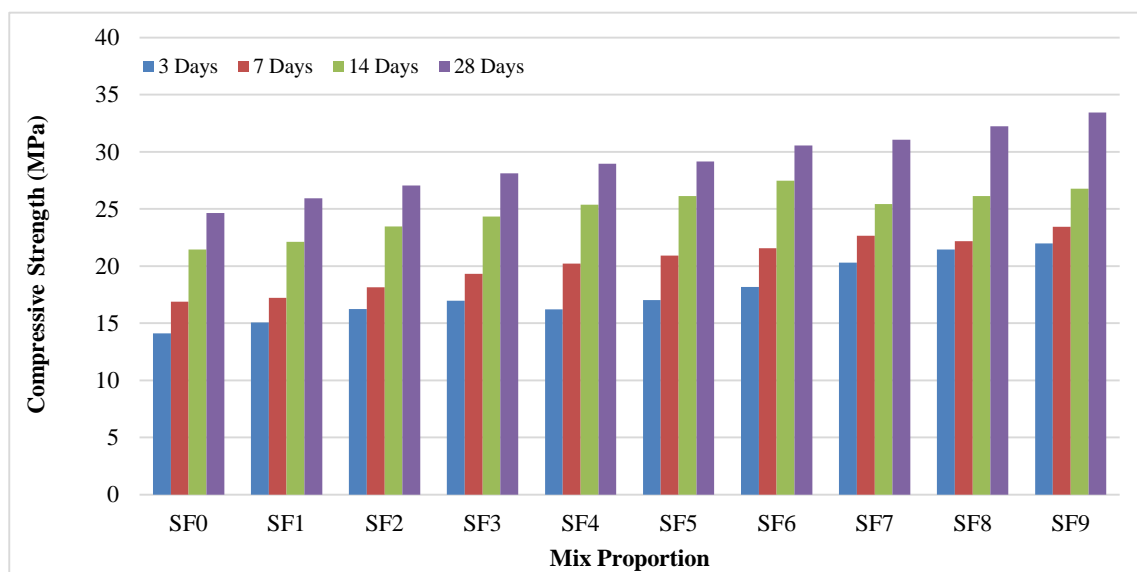
The compressive strength of GGBS and Fly Ash were determined at 3, 7, 14, and 28 days. Figure 6 shows the compressive strength results obtained by the addition of varied partial percentage of GGBS and Fly Ash on 5%, 15% and 30%. The results showed increased of the strength with time coherently with all partial percentage in comparison to the controlled one. This is because mainly two reasons behind the strength development of GGBS and Fly Ash. First and foremost, reason is the higher percentage of slag content, which trigger higher strength and secondly is the gel formation which increases with curing time and results in higher strength [21, 22]. Depending on the variables of GGBS and Fly Ash properties on source their performance with high volume of mixes utilizing varied material sources may vary accordingly. In comparison, GGBS likely be more consistent in chemical composition and physical characteristics [23]. Therefore, GGBS tend to cater more gradually uniform results. Whereas, Fly Ash chemical and physical characteristics depends on the source availability and performance of high-volume Fly Ash may vary accordingly [22].

In contrast, ground granulated blast furnace slag GGBS tends to be more uniformed in chemical and physical characteristics [21] therefore, tend to give more likely consistent results.

The compressive strength has clearly shown improvement as the curing days gradually increased from SF1 to SF9 than the control one (OPC) as shown in Table 4. Furthermore, SF9 achieved 26.30% more compressive strength than the control one as well as the targeted strength on 25 grade concrete being 31 MPA as clearly shown in Figure 6. The targeted compressive strength readily crossed by SF7, SF8 and SF9. These results are in line with Prince et al. [24] who achieved 39 MPa at 30% replacement of Copper slag and 20% Fly Ash with M40 grade. Therefore, it can be said that 30% is optimal percentage on which safely achieved the desired hardened of concrete and reduce the cost of cement and recycling of unwanted waste.

**Table 4. Average Compressive Strength**

Mix Proportion	Compressive Strength (MPa)			
	3 days	7 days	14 days	28 days
SF0	14.12	16.87	21.45	24.65
SF1	15.07	17.23	22.11	25.93
SF2	16.23	18.14	23.46	27.05
SF3	16.98	19.32	24.33	28.12
SF4	16.21	20.22	25.37	28.96
SF5	17.02	20.93	26.14	29.14
SF6	18.17	21.56	27.46	30.56
SF7	20.31	22.65	25.44	31.07
SF8	21.45	22.17	26.13	32.22
SF9	21.97	23.43	26.78	33.45



**Figure 6. Compressive Strength on Different Ages with Mix Proportion**

#### 4. Conclusions

The following observations and conclusions were drawn based on the results obtained from the investigation of Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash as a partial replacement of cement in concrete.

- The workability of concrete tends to increase initially with increasing replacement percentage up to an optimum limit, but then decreases partially.
- GGBS and Fly Ash content increases the workability reduces at the same water containing and w/c.
- The optimum workability was observed at replacement percentage of 15% as compared to control one that achieved 30%.
- The concrete specimens with 30% replacement of cement with GGBS and Fly Ash SF9 obtained the highest compressive strength 33.45 MPA than the control one SF0.

- The partial replacement of cement with GGBS and Fly Ash in concrete gradually increases the compressive strength as percentage of replacement raised.

## 5. Acknowledgements

The authors would like to acknowledge and appreciate the support received through the experimental work from department of Civil Engineering, Shaheed Zulfiqar Ali Bhutto Campus, Mehran University of Engineering and Technology, Khairpur Mirs', Sindh, Pakistan.

## 6. Conflicts of Interest

The authors declare no conflict of interest.

## 7. References

- [1] Jhatial, Ashfaque Ahmed, Samiullah Sohu, Nadeem-ul-Karim Bhatti, Muhammad Tahir Lakhari, Raja Oad, et al. "Effect of Steel Fibres on the Compressive and Flexural Strength of Concrete." *International Journal of ADVANCED AND APPLIED SCIENCES* 5, no. 10 (October 2018): 16–21. doi:10.21833/ijaas.2018.10.003.
- [2] Sandhu, A.R., Lakhari, M.T., Jhatial, A.A., Karira, H. and Jamali, Q.B. "Effect of River Indus Sand and Recycled Concrete Aggregates as Fine and Coarse Replacement on Properties of Concrete", *Engineering, Technology & Applied Science Research* vol. 9, no. 1, (2019), 3832 – 3835.
- [3] Kajaste, Raili, and Markku Hurme. "Cement Industry Greenhouse Gas Emissions – Management Options and Abatement Cost." *Journal of Cleaner Production* 112 (January 2016): 4041–4052. doi:10.1016/j.jclepro.2015.07.055.
- [4] O'Rourke, Brian, Ciaran McNally, and Mark G. Richardson. "Development of Calcium sulfate–ggbs–Portland Cement Binders." *Construction and Building Materials* 23, no. 1 (January 2009): 340–346. doi:10.1016/j.conbuildmat.2007.11.016.
- [5] Ogbeide, S. O. "Developing an Optimization Model for CO2 Reduction in Cement Production Process." *Journal of Engineering Science and Technology Review* 3, no. 1 (June 2010): 85–88. doi:10.25103/jestr.031.15.
- [6] McLaren, Robert J., and A. M. DiGioia. "The typical engineering properties of fly ash." In *Geotechnical Practice for Waste Disposal'87*, pp. 683-697. ASCE, 1987.
- [7] Davidovits, Joseph. "Properties of geopolymer cements." In *First international conference on alkaline cements and concretes*, vol. 1, pp. 131-149. Scientific Research Institute on Binders and Materials Kiev, Ukraine, (1994): 131-149.
- [8] Habert, G., J.B. d'Espinose de Lacaillerie, and N. Roussel. "An Environmental Evaluation of Geopolymer Based Concrete Production: Reviewing Current Research Trends." *Journal of Cleaner Production* 19, no. 11 (July 2011): 1229–1238. doi:10.1016/j.jclepro.2011.03.012.
- [9] Yang, Keun-Hyeok, Jin-Kyu Song, and Keum-Il Song. "Assessment of CO2 Reduction of Alkali-Activated Concrete." *Journal of Cleaner Production* 39 (January 2013): 265–272. doi:10.1016/j.jclepro.2012.08.001.
- [10] Yang, Keun-Hyeok, Yeon-Back Jung, Myung-Sug Cho, and Sung-Ho Tae. "Effect of Supplementary Cementitious Materials on Reduction of CO2 Emissions from Concrete." *Journal of Cleaner Production* 103 (September 2015): 774–783. doi:10.1016/j.jclepro.2014.03.018.
- [11] Pitroda, Jayeshkumar, L. B. Zala, and F. S. Umrigar. "Experimental Investigations on Partial Replacement of Cement with Fly ash in design mix concrete." *International Journal of Advanced Engineering Technology, IJAET* 3, no. 4 (2012): 126-129.
- [12] Berndt, M.L. "Properties of Sustainable Concrete Containing Fly Ash, Slag and Recycled Concrete Aggregate." *Construction and Building Materials* 23, no. 7 (July 2009): 2606–2613. doi:10.1016/j.conbuildmat.2009.02.011.
- [13] Han, Fanghui, Xuejiang He, Zengqi Zhang, and Juanhong Liu. "Hydration Heat of Slag or Fly Ash in the Composite Binder at Different Temperatures." *Thermochimica Acta* 655 (September 2017): 202–210. doi:10.1016/j.tca.2017.07.002.
- [14] Sun, Zhihui, and Coty Young. "Bleeding of SCC Pastes with Fly Ash and GGBFS Replacement." *Journal of Sustainable Cement-Based Materials* 3, no. 3–4 (January 6, 2014): 220–229. doi:10.1080/21650373.2013.876373.
- [15] Wang, Shao-Dong, and Anthony S. Read. "Slag Blended Cement and Concrete." *HKIE Transactions* 3, no. 1 (January 1996): 27–34. doi:10.1080/1023697x.1996.10667693.
- [16] Kumar, Sanjay, Rakesh Kumar, A. Bandopadhyay, T.C. Alex, B. Ravi Kumar, S.K. Das, and S.P. Mehrotra. "Mechanical Activation of Granulated Blast Furnace Slag and Its Effect on the Properties and Structure of Portland Slag Cement." *Cement and Concrete Composites* 30, no. 8 (September 2008): 679–685. doi:10.1016/j.cemconcomp.2008.05.005.
- [17] Bellmann, F., and J. Stark. "Activation of Blast Furnace Slag by a New Method." *Cement and Concrete Research* 39, no. 8 (August 2009): 644–650. doi:10.1016/j.cemconres.2009.05.012.



- [18] Ali, S.A. and Shaikh, A. "Experimental Study on Partial Replacement of Cement by Fly Ash and GGBS", *International Journal for Scientific Research & Development* 2, issue 07, (2014): 304-308.
- [19] Sathawane, Satish H., Vikrant S. Vairagade, and Kavita S. Kene. "Combine Effect of Rice Husk Ash and Fly Ash on Concrete by 30% Cement Replacement." *Procedia Engineering* 51 (2013): 35–44. doi:10.1016/j.proeng.2013.01.009.
- [20] Reddy, A. Narender, D. Anitha, and U. Venkata Tilak. "Performance of alkali activated slag and alkali activated slag+ fly ash with various alkali activators." *International Journal of Engineering and Technical Research* 2, no. 1 (2014): 73-78.
- [21] Neville, A.M. *Properties of Concrete* (4th ed.). London: Pearson, (2010).
- [22] McCarthy, M, and R Dhir. "Development of High Volume Fly Ash Cements for Use in Concrete Construction." *Fuel* 84, no. 11 (August 2005): 1423–1432. doi:10.1016/j.fuel.2004.08.029.
- [23] Barnes, Paul, and John Bensted. *Structure and performance of cements*. CRC Press, 2002.
- [24] John Robert Prince, M., and Bhupinder Singh. "Bond Behaviour of Deformed Steel Bars Embedded in Recycled Aggregate Concrete." *Construction and Building Materials* 49 (December 2013): 852–862. doi:10.1016/j.conbuildmat.2013.08.031.