Synthesis of Geopolymer Concrete Using Flyash

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Abstract. Geopolymer concrete (GPC) reduces the environmental impacts of conventional Portland cement concrete, therefore, this research aims to investigate the compressive characteristics of GPC by utilizing the readily available industrial waste i.e., coal based Flyash in the Khyber Pakhtunkhwa province of Pakistan. For the preparation of GPC, Na_2SiO_3 was used as an activator. After the preparation of GPC specimens, their compressive characteristics were investigated at different ages of specimens, Flyash content, curing time, and curing conditions. Moreover, the relationship between compressive strength and modulus of elasticity of GPC was also evaluated. From the testing of GPC specimens in a compression testing machine (CTM), their compressive strength was found to be similar to that of conventional Portland cement concrete i.e., in the range of 20-40 MPa tested at the age of 7 and 28 days respectively. Furthermore, elevated temperature curing was found to increase the compressive strength of GPC significantly as compared to that of ambient curing. From the cost analysis, Flyash-based GPC was found to be cost effective as compared to conventional Portland cement concrete

1. Introduction

After water, concrete is the second most frequently utilized substance on the planet [1] Its constituents such as cement require a higher amount of energy to be prepared, this energy is obtained by burning fossil fuels. Along with this, the hydration reaction of cement with water during the preparation of concrete is an exothermic process and it releases energy in the form of heat into the environment while forming bonds. These two are the main reasons that contribute towards the great carbon footprint of concrete. About 9 percent of carbon dioxide in the environment is due to the manufacturing or use of concrete and its constituents. [2]

In recent decades, attempts are being made to produce greener concrete with the lowest carbon footprint and highest strength and sustainability. One of these attempts, is to make green concrete known as geopolymer concrete (GPC) using geopolymer materials available abundantly throughout the globe. Mainly the materials having properties the same as cement are used for this purpose, called supplementary cementitious materials (SCMs). The SCMs include Flyash (FA), Condensed Silica Fumes (CSF), Ground Granulated Blast Furnace Slag (GG, BFS), and various other industrial and agricultural wastes that are rich in silica and alumina. [3] GPC attains its strength on the basis of polymerization of inorganic minerals i.e., the geopolymers. These geopolymers belong to a group of three-dimensional aluminosilicate materials made from sources like clay, red mud, and Flyash which were discovered by Davidovits in 1979.[4] The primary characteristics of geopolymers include their rapid development of compressive strength, low permeability, improved chemical and thermal resistance, better mechanical properties under both normal and extreme conditions, and tendency to significantly reduce the mobility of the majority of heavy metal ions contained within the geopolymer structure. [5]

The Flyash based GPC can have advantageous and varied qualities, according to numerous studies. For instance, GPC has demonstrated good performance in high temperatures, high early age strength, and good resistance to acid and sulphate attacks. [6], [7] In recent years, it has been demonstrated that GPC may produce high early and ultimate compressive strengths under ambient curing conditions, as well as good workability when additives like Portland cement, calcium hydroxide, or powdered granulated blast furnace slag are used. [8] Most experts agree that GPC is less harmful to the environment than Portland cement concrete, however further research is needed to support this conclusion. Moreover, the literature available on the mechanical and structural properties of GPC is still not enough to make it an industrial material like ordinary Portland cement (OPC) concrete.

Therefore, this research paper aims to investigate the mechanical properties (i.e., the compressive characteristics in particular) of GPC by utilizing locally available Flyash. For this, the compressive strength of GPC manufactured from different concentrations of Flyash to OPC i.e., 0%, 10%, 20%, 30%, 40%, and 50% (by mass) was evaluated using Na_2SiO_3 as an activator. The compressive characteristics of GPC were investigated at different ages of specimens i.e., 1 day, 3 days, 7 days, 14 days, and 28 days, curing time and curing conditions. Furthermore, the comparison between elevated temperature and ambient temperature was done. The cost analysis among the ordinary Portland cement concrete and geopolymer concrete was also compared.

2. Methodology

2.1. Materials

2.1.1. Flyash

The Flyash which was used in this research was obtained from the coal power plants located in Khyber Pakhtunkhwa province of Pakistan.

2.1.2. Cement

In this research Ordinary Portland Cement prepared by "Bestway, Pakistan" was also used to manufacture cubes which were used in comparison with Geopolymer cubes. The physical properties and chemical properties of OPC are shown in table 1. The chemical composition of OPC was obtained from a research article by Amin and Ali. [9] However, the standard laboratory tests were conducted in accordance with the ASTM guidelines [10]–[13] to determine the physical properties of above mentioned OPC.

Table 1: Physical Properties and Chemical Composition of OPC

Cement Composition		Physical Properties of Cement	
Constituents	**Content %**	**Parameter**	**Value**
CaO	61.7	Specific Gravity	3.01
SiO_2	21.0	Consistency	28.4%
Al_2O_3	5.04	Initial Setting Time	1 h and 39 min
MgO	2.56	Final Setting Time	3 h and 47 min
SO_3	1.51	Specific Surface	319.5 m^2/kg
Fe_2O_3	3.24		
IR	0.65		
Free Lime	0.98		
LOI[3]	1.83		

2.1.3. Activator
In this research Sodium Silicate (Na_2SiO_3) prepared by a South Korean company named "DAEJUNG" was used as an activator in powdered form. The purpose of using an activator is that it helps to activate silica and alumina content present in Flyash.

2.1.4. Aggregates
Using ASTM C136, [14] the nominal maximum size of coarse aggregate (inches) was determined to be 0.7 inches down. The sand originates from a nearby source which is Lawrencepur Pakistan. The computed sand fineness modulus was 2.47 as per ASTM C136. [14] Using ASTM C127, [15] the Available Moisture Absorption was 1.42 percent, the Available Moisture Content was 1.05 percent, the Bulk Specific Gravity was 2.493 g/cc, and the Apparent Specific Gravity was 2.685 g/cc.

2.2. Sample Preparation
For the investigation of the compressive characteristics of GPC using locally available Flyash in Khyber-Pakhtunkhwa (Pakistan), 3 cylindrical specimens were prepared to achieve each type of experimental assessment. To achieve the desired research objectives, GPC specimens were prepared by replacing Flyash with cement in the ratio of 0%, 10%, 20%, 30%, 40%, and 50%. Moreover, GPC specimens were also prepared to investigate the effect of curing conditions (ambient or elevated temperature curing) and curing time on their compressive strength.

2.3. Curing of Specimens
Two curing conditions were used in this experiment. The first type of curing was elevated temperature curing at 70 °C for 24 h. The other curing condition was ambient curing where specimens were kept at in open atmospheric temperature of about 23°C till the day of testing. GPC specimens subjected to different curing conditions were tested separately to investigate the effect of the type of curing on their compressive strength.

3. Results and Discussions
3.1. Compressive Strength of Flyash Based GPC
For the determination of the compressive behavior of all the GPC specimens, a compression strength test was conducted using a compression testing machine (CTM) according to the manual of ASTM C39. [16] The experimental findings of the GPC compressive strength used in this investigation are compiled in table 2. Their compressive strength was found to be similar to that of conventional Portland cement concrete i.e., in the range of 20-40 MPa tested at the age of 7 and 28 days respectively. The highest strength was attained i.e., 39.98 MPa when OPC was replaced with 30% of Flyash. It implies that fly ash concrete can generate significant strength due to the pozzolanic reaction after 28 days.

Table 2: Compressive Strength of Flyash Based GPC

Flyash (%)	1 day	3 days	7 days	14 days	28 days
0	5.6	14.36	21.4	31.4	34.9
10	5.92	14.8	22.1	32.95	36.6
20	6.08	15.2	23.15	34.2	37.93
30	6.4	16.54	24.95	36.1	39.98
40	5.92	14.8	22.45	32.44	36.7
50	5.44	13.6	20.2	31.73	33.85

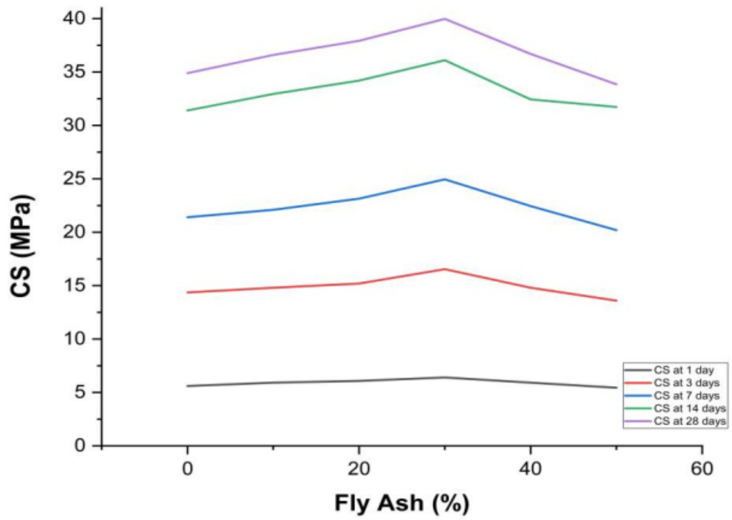

Figure 1: Comparison of FA and CS on different days *CS: Compressive strength

3.2. Compressive Strength of GPC and Curing Conditions

The GPC compressive strengths at 7 and 28 days for elevated temperature curing (70 °C) ranged from 10 to 45 MPa, whereas the compressive strengths of GPC at 7 and 28 days for ambient curing ranged from 05 to 40 MPa, respectively. Since the geo-polymerization process needed heating to speed up the interaction between the alkali activator and Flyash, it can be noted that the heat curing temperature had an impact on the early strength of GPC. When compared to ambient curing, the compressive strength of GPC that was cured at 70 °C increased by 35% after 7 days. At 28 days, the strengths of samples cured at elevated temperatures were 8% greater than those cured at room temperature.

Table 3: Compressive Strength of GPC Subjected to Ambient and Elevated Temperature Curing

Age of Specimens	Compressive Strength (MPa)	
	Ambient Curing	Elevated Temperature Curing
1	6.4	11.24
3	16.54	31.74
7	24.95	33.58
14	36.1	39.99
28	39.98	43.26

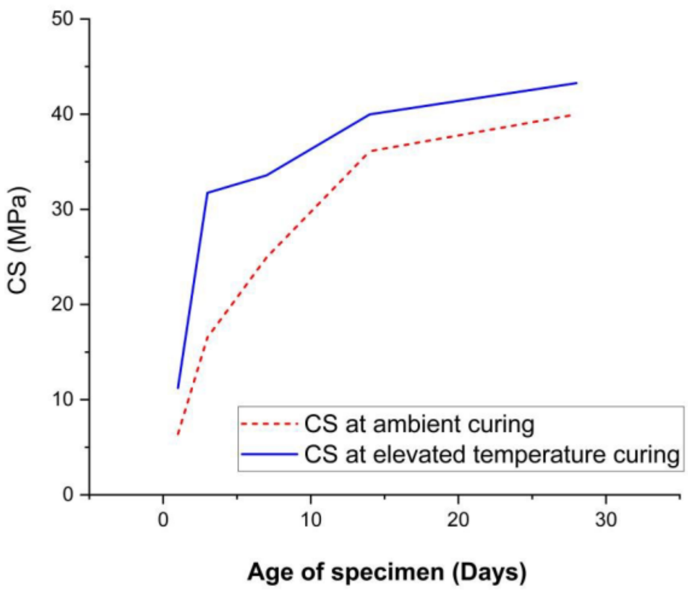

Figure 2: Ambient curing vs elevated temperature curing

3.3. Compressive Strength of GPC and Curing Duration

The compressive strength increased as curing time increased, as indicated in table 4. The results suggest that for the synthesis of geopolymers with higher compressive strengths, a longer period of low-temperature curing is preferred. This is due to the fact that getting a geopolymer without cracks depends a lot on the water that is contained in geopolymers and how it is removed when it evaporates. As a result, curing at a lower temperature is preferred rather than drying quickly during the process.

Table 4: Impact of Curing Time on GPC Compressive Strength

Curing Time (Days)	Compressive Strength (MPa)
5	17.86
7	24.95
9	28.96
12	34.21
15	37.36

3.4. Modulus of Elasticity of GPC

Specimens of different grades of concrete were cast and a compressive strength test was done on these specimens. The compressive strength test yields a stress-strain curve for each concrete grade. From the initial elastic portion of the stress strain curve, we determine the slope and this slope gives us the value of the modulus of elasticity. The compressive strength and modulus of elasticity of every grade of concrete were now determined. The ACI provides a relationship between the modulus of elasticity and the compressive strength of conventional concrete. However, as per the author's knowledge no such relationship exists for the GPC, therefore this research has worked to provide the relationship between the modulus of elasticity and the compressive strength of GPC. This relationship is presented in equation 1.

Table 5: Modulus of Elasticity of Various Grades of GPC

S. No	Compressive Strength (MPa)	Modulus of Elasticity (MPa)
1	16.37	19251
2	21.48	21435
3	26.89	21002
4	32.74	24244
5	36.84	26409
6	39.98	27113

$$E = 4312\sqrt{f'_c} \tag{1}$$

3.5. Cost Analysis of GPC

The ingredients in OPC Concrete and GPC Concrete are shown in table 6 and table 7 respectively along with their prices. The price of ingredients are local prices and varies from region to region. These prices were taken from a local material supplier in the district of Mansehra, Khyber Pakhtunkhwa province of Pakistan. From the cost analysis, GPC was found to be 11% cheaper as compared to OPC concrete. The GPC is cheaper as compared to OPC Concrete because Flyash is a byproduct and there is no usage of it, so it cost less as compared to OPC Concrete.

Table 6: Cost analysis of 1 m^3 of OPC concrete

Material	Rates in (PKR)	Unit	Quantity in Kg	Amount in PKR
Cement	1080	50 Kg	350	7560
Fine Aggregate	1716	T	642	1102
Coarse Aggregate	1839	T	1270	2335
SuperPlastizer	300	Kg	7.5	2250
Total		PKR		13247

PKR: Pakistani Rupee, T: 1000 kg.

Table 7: Cost analysis of 1m^3 of GPC concrete

Material	Rates in (PKR)	Unit	Quantity in Kg	Amount in PKR
Flyash	300	50 Kg	378	2268
Fine Aggregate	1716	T	554	950
Coarse Aggregate	1839	T	1294	2379
Na_2SiO_3	50	Kg	124	6200
Total		PKR		11797

PKR: Pakistani Rupee, T: 1000 kg.

4. Conclusions

Based on the experimental investigation of compressive characteristics of GPC utilizing locally available Flyash from the coal power plants located in Khyber Pakhtunkhwa province of Pakistan, the subsequent conclusion may be drawn.

- The optimum concentration of Flyash was revealed to be 30% to achieve the maximum compressive strength of GPC.
- The elastic modulus was found to be 4312 times the square root of compressive strength of GPC.
- In comparison to ambient curing, elevated temperature curing was discovered to be increasing the compressive strength of GPC. Moreover, increasing the curing time was also found to increase the compressive strength of GPC.
- From the cost analysis, GPC was found to be cost effective than OPC concrete. It was found to be 11% cheaper as compared to OPC concrete.

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