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Comparative Analysis of Fly Ash-based Geopolymer Concrete and Ordinary Portland Cement Concrete

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ABSTRACT. *In Pakistan, the high year-over-year growth in the construction industry has led to a significant increase in the cost of construction materials, particularly cement. To reduce the cost of construction, alternative materials need to be sought. In Pakistan, approximately one million tons of fly ash are generated each year from coal-fired thermal power stations. A sample of fly ash was obtained from the 125 Megawatts Coal Fired Power Station Lakhra in Khanot, Hyderabad, Sindh Pakistan.A study was conducted on fly ash-based geopolymer concrete, using test data to identify the factors that influence its properties and to develop a simple method for designing geopolymer concrete mixtures. The mix design for fly ash was carried out using the standard ACI method. Various trial mixes were prepared using arbitrary ratios of cementitious materials, fine and coarse aggregates. The compressive strength of ordinary Portland cement (OPC) concrete was 64% and 57% for geopolymer concrete (GPC) after 7 days. At 14 days, the strength of OPC was 83% and 76% for GPC. The strength of OPC reached 97% after 28 days, while GPC reached 91%.*

Keywords: Geopolymer Concrete, Ordinary concrete, fly ash concrete, CO_2 emission, Cement

1. INTRODUCTION

Concrete is the most commonly utilized artificial material globally and is composed of standard Portland cement (OPC). In terms of usage, it is second only to water in the world [1]. Ordinary Portland cement (OPC) concrete is utilized for infrastructure development. In 2015, the construction sector in Pakistan experienced a growth of 11.31% year-over-year[2]. The annual demand of cement is expected to reach 53 million tons per annum [3]. In Pakistan, the production of cement accounts for 5.5% of total industrial output [4]. The necessity for ordinary Portland cement (OPC) concrete would increase further in the future worldwide[5]. The cement production exhausts notable amount of natural sources and releases high volumes of carbon-dioxide[6]. The cement production is also highly energy-intensive. The release of carbon dioxide during cement production influences the environment with global warming. The cement production is approximated to be responsible for about 5% of the all the global CO2 emission[7]. It is estimated that about one ton of Portland cement produce one ton of CO_2 [8]. Concrete production industry also faces issue to fulfil the increase demand of concrete due to slow manufacturing process, limited reserves of limestone and increased taxed due to carbon [9]. Blending (mixing of supplementary material with clinker) is believed to be very efficient way to minimize the emission of CO2[10].

On the other hand, a significant amount of fly ash is generated from the burning of coal in power plants. According to statistics from WAPDA, about 4811 MW of power is generated through thermal means, and coal is used as fuel in most of these stations [11]. As the demand for power increases, the volume of fly ash also increases. Fly ash is typically considered as waste and disposed of in landfills. To address this issue, alternative binders need to be developed for concrete production. The American Society of Testing Material (ASTM) has classified fly ash into "Class C" and "Class F". The specifications for fly ash are outlined in ASTM C-618 [12]. Geopolymers reduce energy consumption and CO_2 emissions by approximately 60% and 80%, respectively [13]. Geopolymer is a sustainable and cost-effective alternative to ordinary Portland cement, due to its high strength, superior durability, and low energy consumption, as well as reduced CO_2 emissions during production. The water stability of geopolymer concrete is largely influenced by the curing temperature and type of curing mold used, with the latter affecting the evaporation rate of the alkali solution during curing [14]. The term "Geopolymer" was invented to describe these binders, which are created through a polymerization process. Geopolymer concrete is a type of concrete that uses fly ash-based geopolymer as a binding material instead of ordinary Portland cement (OPC). Geopolymer concrete has been widely studied and found to be a suitable substitute for OPC concrete. In 2001, the authors adopted Davidovits's original concept of geopolymer for the production of geopolymer concrete [15]. Concrete is an essential building material that is in increasing demand. The demand for ordinary Portland cement (OPC), the most widely used type of cement and a key ingredient in concrete, is expected to grow. The Global Cement Volume Forecast Report 2019 predicts that the world's cement production capacity will reach 5.8 billion tons by 2024.

2. MATERIALS and METHODOLOGY

The properties of material used in mix preparation are given in Table 1. These properties were find using standard ASTM procedures.

Table -1: Properties of material

Coarse Aggregate(CA) obtained	**Crushed stones from a local construction site**
Coarse Aggregate(CA) use with	mix of 1” down and 1/2” down but above No. 4 Sieve
Sand fineness modulus	2.3 to 3.1 AASHTO [18]
Ordinary Portland Cement	Type-I confirms with ASTM C-150[19]
Fly ash	low-calcium ASTM Class F dry fly ash[14]
Fly ash obtained from	local power station
Fly ash composition	Si= 50% , Al= 25%, Fe=10 to 18% Ca=2% by mass
Fly ash particles	80% fly ash particles of less than 38 to 55 μm in size.

The details of the chemical composition of various batches of the fly ash, as determined by X-Ray Fluorescence (XRF) analysis. Fly ash is pozzolanic in nature. Fly ash was collected from Thermal Power Station Lakra at Khanot District Dadu of Sindh Province, Pakistan. It is 150 MW coal fire power station located at about 30 km from Hyderabad. The ash passing through flues is collected by electrostatic collectors and removed through mechanical separator and dumped at site.

Fig -1: Fly ash

The physical and chemical analysis of the material was carried out at “KOHAT CEMENT PLANT” Kohat and results are given in Table 2.

Table -2: Properties of fly ash compared with standard ranges

Constituent	Fly ash	ASTM C-618[14]	Favorable Range
Al_2O_3	30.5%	-	14.3%----27.5%
CaO	12.47%	-	16.8%----29.5%
Fe_2O_3	9.3%	-	4.2%---9.5%
MgO	1.04%	5% max	3.70%----8.5%
SiO_2	32%	-	24.1%----43.1%
Loss on ignition	14%	12%	--------
$SiO_2+Al_2O_3+Fe_2O_3$	71.8%	70% min	47.9%----72.4%

This study describes the development of a methodology for preparing flyash-based geopolymer concrete and comparing its properties with ordinary Portland cement (OPC) concrete. The chemicals used are purchased in 1 kg bottles from a local supplier in Khyber Bazar, Peshawar, Pakistan and are in powder form. The study follows ASTM codes and the ACI Mix Design method is used to calculate the mix quantities for 4000 psi concrete. The mixing process for OPC concrete follows a general method, while the flyash sample for geopolymer concrete was collected from the Kohat Cement Factory in Khyber Pakhtunkhwa. The study conducted preliminary tests to investigate the effect of using flyash with chemicals such as NaOH and Na2SiO3 as a cement substitute in concrete. The testing was carried out at the Concrete Laboratory in the Civil Engineering Department at UET Peshawar. Three different test specimens were used; Cylinders for compression test and tensile test. For a concrete to meet the job specification and quality control requirements, concrete compressive strength was measured. Cylindrical test specimens of size 6 x12-inch (150 x 300 mm) are cast for testing the concrete compressive strength, according with the ASTM C 31[17], "Standard practice for Making and Curing Concrete Test Specimens in the Field."

The study mixes the ingredients of concrete in specified quantities and pours the mixture into mold. The concrete samples are removed from the molds after a day and undergo curing at specified temperatures. After the curing period, the samples are removed from the chamber and allowed to air dry at room temperature for one day before undergoing compression testing in a Universal Testing Machine (UTM). The compressive and tensile strengths test results are plotted in various graphs and correspond to the average values of three test cylinders and two beams in each series. The fineness modulus of the fine aggregate is approximately 2.3, and the w/c ratio was selected for 4 ksi and 6 ksi concrete according to the ACI Table of mix design and was 0.48 and 0.33, respectively. The bulk density of the coarse aggregate was 96.79 lb/ft. The coarse and fine aggregate for the 6 ksi concrete is the same as that used for the 4000 psi concrete.

Aggregates and fly ash were dry mixed for 3 minutes in a pan mixer. After dry mixing, the activator solution, and the extra water were also added to the solid particles in pan mixer and the mixing continued for another 3 to 5 minutes. A total of 72 cylinders were prepared. 18 [9 compressions (3 for each 7, 14 and 28-day testing), 9 tensile (3 for each 7, 14 and 28-day testing)] cylinders for each standard, 25% replacement, 100% replacement [(NaOH: Na_2SiO_3: Flyash=1:4:40), (NaOH 6M, Na_2SiO_3 4M)] and 100% replacement [(NaOH: Na_2SiO3: Flyash=1:4:40), (NaOH 12M, Na_2SiO_3 4M)] for each test variable such as for 7 days, 14 days and 28-days testing respectively. Experimental program shown in Figure 2.

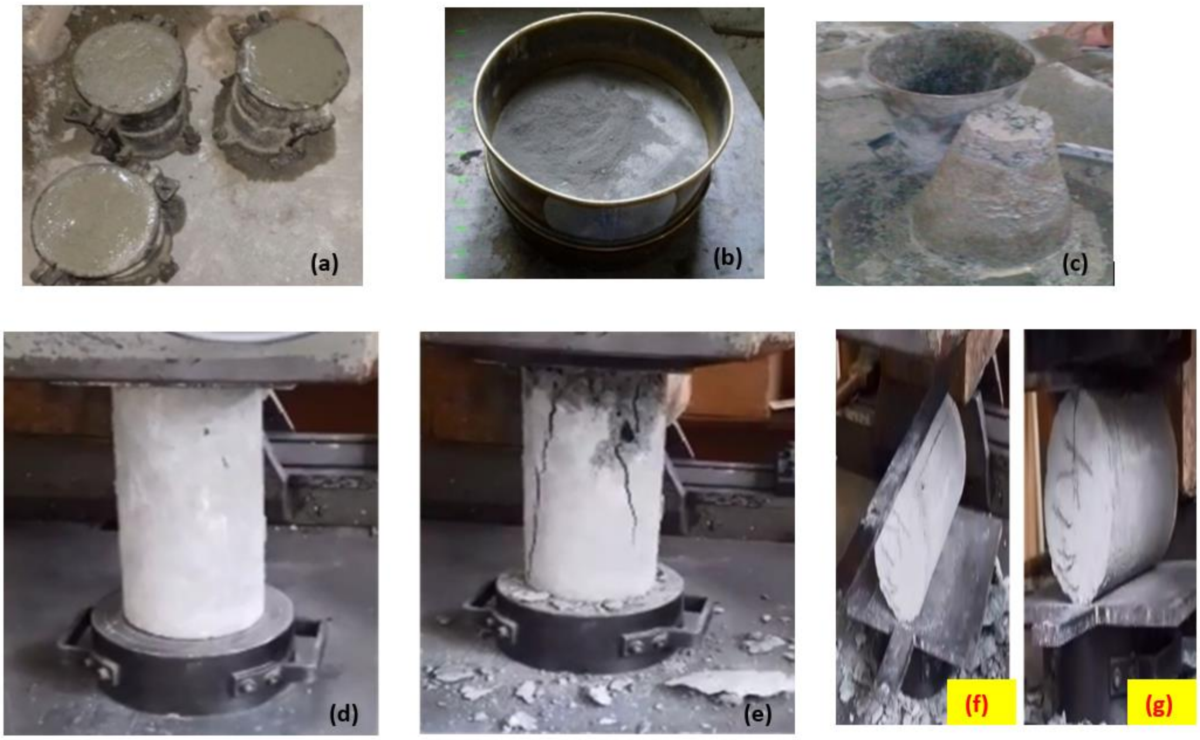

Fig-2: (a) Casting of concrete cylinders (b) Particle size of cement/fly ash (c) slump test (d) Compression testing (e) Compression testing (f) and (g) Split tensile testing

3. RESULTS AND DISCUSSION

3.1 Slump

The variation of slump values concern GPC and OPC. The water content is less than 6000 (psi) and also the workability of concrete is low therefore, the slump values decrease shown in Figure 3.

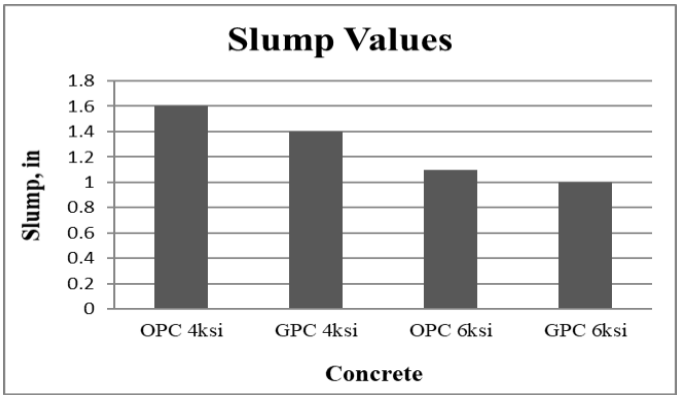

Fig -3: Slump Values

3.2 Compressive Strength

Compressive Strength the compressive strength of OPC is 64 % and for GPC is 57 % similarly for 14 days the compressive strength of OPC is 83% and GPC 67% and for 28 days compressive strength of OPC is 97 % and GPC is 91 %. Which showed that the compressive strength increases with the number of days of curing as shown in Figure 4.

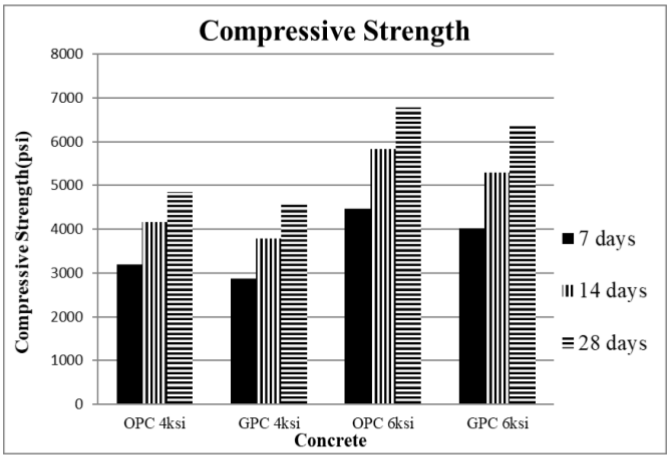

Fig -4: Compressive strength at 7, 14, 28 days

3.3 Tensile Strength

Tensile strength of GPC is quite more than the ordinary concrete. Moreover, the strength of GPC is more at the 7, 14 and 28 days. Result is shown in Figure 5.

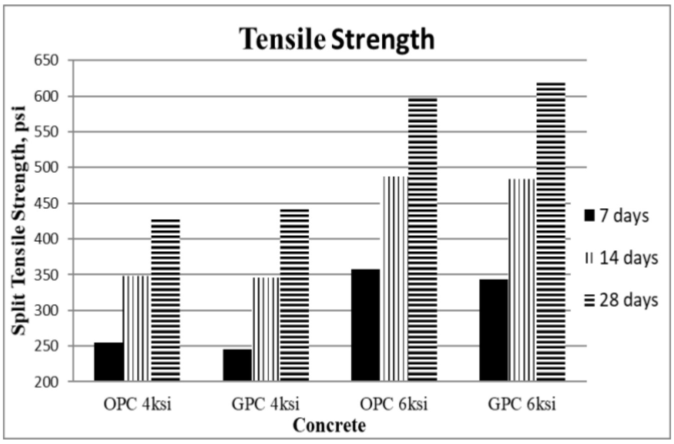

Fig -5: Tensile strength at 7, 14, 28 days

4. CONCLUSIONS

The research concluded that the slump values for geopolymer concrete (GPC) are lower for both 4000 psi and 6000 psi, due to the lower water content in the 6000 Psi mixture, which results in less workability and lower slump values. At 7 days, ordinary Portland cement (OPC) achieved 64% of its compressive strength, while GPC achieved 57%. At 14 days, OPC achieved 83% of its compressive strength, and GPC achieved 76%. The maximum results were achieved at 28 days, with OPC reaching 97% and GPC reaching 91%. The research found that an increase in the water-to-cement ratio increases the workability of the concrete but decreases its compressive strength. Concrete was found to be weak in terms of tensile strength, but GPC showed a 3.5% increase in tensile strength compared to OPC after 28 days of curing. The research showed that the presence of air in concrete affects its compressive strength more than its tensile strength but fly ash-based geopolymer concrete still provides relatively high strength even after more days of curing. The decrease in compressive and split tensile strength is relatively small compared to the amount of waste that is generated.

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