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DEVELOPMENT OF ALKALI ACTIVATED CONCRETE USING FLY-ASH FOR REDUCING CARBON FOOTPRINT

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ABSTRACT

The consumption of cement is increasing day by day due to the remarkable development in the infrastructure. One tonne of cement produced emits approximately one tonne of carbon dioxide into the atmosphere. To reduce the use of cement, new-generation concretes such as Alkali Activated Concrete, also known as geopolymer concrete (GPC), have been developed. Geopolymer is a novel material with the potential to replace conventional Portland cement. It is an inorganic material with an amorphous to semi-crystalline polymeric structure that is manufactured by alkali activation of amorphous aluminosilicates at ambient or slightly higher temperatures. In this study, geopolymer concrete was made with low-calcium fly ash. The geopolymer was created by combining sodium silicate and sodium hydroxide solutions with fly-ash. Other materials used for GPC include locally obtainable coarse aggregate and fine sand that is surface dried. Mettur Thermal Power Plant's low-calcium, Class F fly ash was used to make geopolymer concrete. Alkaline solution to fly ash ratio was varied from 0.3 to 0.45. The sodium hydroxide solution concentration was kept constant at 12M (Molars). After being cast in moulds; the specimens were placed in a 60°C oven for 24 hours before being allowed to air dry at room temperature. The compressive strength of geopolymer concrete was tested at 7 and 28 days of age. The test results show that compressive strength increases with an increase in alkali ratio and alkali-to-fly-ash ratio. The slump value for GPC is very less compared with conventional concrete.

Keywords: geopolymer aggregate, geopolymer concrete, sodium hydroxide, sodium silicate.

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1. INTRODUCTION

Concrete is not simply the greatest common building material worldwide, it is the second-most-used material in the world after water. Together with the increase in demand for concrete as a building material, Portland cement demand is also rising. Within 20 years, it's expected that cement production will rise from around 1.5 billion tonnes to 2.2 million tonnes. However, the effects of global warming on the climate have grown to be a major concern. Human actions that discharge greenhouse gases into the atmosphere, such as carbon dioxide (CO_2), are the primary causes of global warming. CO_2 accounts for around 65% of the greenhouse gases' contribution to global warming. Cement manufacture uses a lot of energy, emits a lot of greenhouse gases into the atmosphere, and is thought to be responsible for almost 5 to 7 percentage CO_2 emissions worldwide (Masoule M. *et al,* 2022). Three to four percent of the world's carbon dioxide is made by burning fossil fuels and for the production of cement, which causes various environmental issues (Hanle *et al*., 2004). Considering the high consumption of concrete and the rising demand for cement, there is a need to pay close attention to how this affects the environment and also need to do adequate measures to reduce the environmental problems. A new generation of concrete, such as geopolymer concrete (GPC) or Alkali Activated Concrete, has been created to reduce the need for cement (AAC). Chains, networks, or inorganic molecules are characteristics of geopolymers. Waste products like fly ash and ground-granulated blast furnace slag (GGBS) are taken to produce geopolymer concrete. Fly ash is a waste product of thermal power plants, and GGBS is a waste material of steel plants. Both fly ash and GGBS are processed using suitable technology and used in geopolymer concrete construction. By lowering the demand for Portland cement, the use of this geopolymer concrete minimises both the waste stock and carbon emissions. Because geopolymer concrete is made from industrial by-products, it is an excellent substitute for cement concrete. Industrial by-products such as fly-ash, wood-ash, GGBSetc, and mainly used in GC construction and they will replace 100% of cement in concrete. The lower environmental impact of geopolymers is one of their main advantages. Geopolymers are preferred for green buildings since they utilise industrial wastes, mine tailings, and ashes. Additionally, they replace cement and reduce the dangerous quantity of CO_2 that is emitted during cement manufacture. (Masoule M. *et al*, 2022)

For a developing country like India, coal is the most useful material. About 65% of India's installed capacity for electricity production comes from coal-based thermal power plants. In the Future coal-based thermal power generation is anticipated to continue to dominate to meet the nation's increasing energy demand. The thermal power plant is dependent on coal-fired warm power plants, which produce a large amount of fly ash, expected to be around 170 million tonnes per year. As a result, a large amount of fly-ash is produced in our country, posing a risk to the general public because fly-ash residues are hazardous to our health. A small part of the fly-ash residue is used for swamp dumping as well as in the production of fly-ash blocks and other products. The process of

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geopolymerisation using fly-ash and alkaline materials for the production of cement-less concrete will leads to diminishing the environmental problems by fly-ash. An aluminosilicates material, such as fly ash, GGBS, metakaolin, rice husk ash, activated bentonite, clay, red mud, etc., is alkaline activated to produce geopolymers. The majority of these raw ingredients are industrial wastes or by-products, and the production and use of waste-based geopolymers can have significant positive effects on the environment and the economy. The most effective raw material for geopolymer concrete is fly-ash. Large-scale cement production has a major negative influence on limestone reserves and the environment. It is also a highly fuelled or energy-intensive process that produces 1 tonne of CO_2 for every tonne of cement produced. The manufacturing process of cement requires high fuel consumption and energy consumption and it generates almost 1 ton of CO_2 to produce 1 ton of cement causing severe environmental issues. An alternative sustainable solution for the replacement of cement without negotiating the strength and durability to avoid the greenhouse gases effect. Production of geopolymer concrete using alkali activated materials is one of the best solutions to substitute ordinary concrete (Ramesh V & Srikanth K., 2020).

Strength, durability, and morphology tests are to be done to study the properties of geopolymer concrete. Durability tests consist of water sorptivity tests, Rapid chloride penetration test, sulphuric acid & hydrochloric acid immersion test, etc. The morphology of the GPC is studied by SEM analysis. XRF and XRD analysis is conducted to examine the chemical constituents and mineralogical characteristics of materials. 80% amount of CO2 emission was noticed in geopolymer compared to ordinary cement. (S. Unnikrishnan & H. M Tanu, 2022). The fundamental benefit of lightweight geopolymers over traditional OPC is their higher durability characteristics. Lightweight geopolymer concrete is a sustainable material that can be used in thermal insulation applications (Masoule M. *et al*, 2022).

1.1 Research Significance

The need for a sustainable environment necessitated the creation of fly ash geopolymer concrete, an OPC concrete substitute. One of the key elements influencing concrete structural applications is the fly-ash geopolymer concrete's mechanical characteristics (Abdulrahman H., *et al,* 2022). Slag, fly ash, and rice hush ash are examples of industrial solid waste that GPC uses to reduce its carbon footprint. For every tonne of cement manufactured, approximately one tonne of carbon dioxide emissions are released into the atmosphere, which directly harms the environment and raises global temperatures by increasing greenhouse gas emissions. GPC is cost-effective, consumes little energy, is thermally stable, is simple to work with, is cement-less, and is durable. GPC minimises the amount of cement used in buildings and offers an alternative for the binding properties of the material and it is useful for sustainable construction. GPC is more resistant to acid, sulphate, and salt attack than Portland cement concrete and has greater physical, mechanical, and durable properties. In light of this, geopolymer concrete is a natural alternative to Portland cement concrete and a substance with considerable commercial potential for ecological development in the construction sector (Verma m, *et al*, 2022).

2. EXPERIMENTAL PROGRAM

The materials properties, mixing techniques, concrete preparation, and experimental tests performed to evaluate the mechanical properties of fly-ash geopolymer concrete are summarised in this experimental program.

2.1 Material

Fly ash from coal-burning power plants with low calcium content (ASTM Class F) can be used to make geopolymer concrete. The majority of fly ash that is readily obtainable in the world is low-calcium fly ash, which is a by-product of burning bituminous or anthracite coal. Even though coal-burning power plants are viewed as being unfriendly to the environment, the amount of power produced by these facilities is growing as a consequence of the vast quantities of high-quality coal that are readily available throughout the world and the low cost of the electricity generated from these sources. As an alternative to Portland or other hydraulic cement paste, a low-calcium fly ash-based geopolymer is used as the binder in the production of concrete. Fly ash must be reacted with alkaline activators for the geopolymer reaction. The alkaline activator can be created by mixing sodium hydroxide (NaOH) solution with sodium silicate solution. With or without admixtures, the coarse aggregates, fine aggregates, and other materials are bound by the fly ash-based geopolymer paste to create the geopolymer concrete. Geopolymer concrete is produced using conventional concrete technology methods.

2.1.1 Fly ash

Any substance that is primarily composed of amorphous silicon and aluminium could be used as source material to create geopolymers. Cass F fly-ash contains more amounts of Silicon and aluminium. In this study, Class F fly-ash attained from Mettur Thermal Power Station, Tamil Nadu is used for the production of geopolymer concrete. Mainly class F fly-ash is used for geopolymer concrete construction because owing to the presence of SiO_2, Al_2O_3 and Fe_2O_3 is more than 70 %. The geopolymer paste is made when the silicon and aluminium oxides in the low-calcium fly ash react with the alkaline liquids. The chemical composition of fly-ash obtained from the source is given in Table-1. Test results for specific gravity and XRD of fly-ash are given in Table-2 and Figure-1.

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Table-1. Properties of fly-ash.

S. No	Chemical composition	%
1	SiO_2	53.64
2	Al_2O_3	22.93
3	Fe_2O_3	4.28
4	MgO	1.86
5	Loss of Ignition	2.11

Table-2. Specific gravity of fly-ash.

Test	Specific Gravity
Specific gravity	2.18

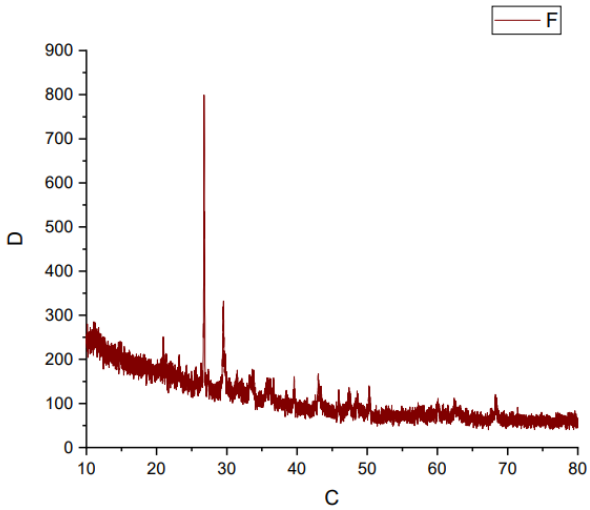

Figure-1. XRD test result for class F fly-ash.

2.1.2 Alkaline activators

In the process of geopolymerization, sodium hydroxide (NaOH) and sodium silicate are combined to create an alkaline activator. To make the sodium hydroxide (NaOH) solution, the flakes were dissolved in water. The concentration of NaOH solids in a solution varied with solution concentration, which was expressed in the molar or "M" units. The alkaline liquid is essential in the polymerization process. The molarity of sodium hydroxide is taken as 12 M. The sodium silicate to sodium hydroxide ratio is taken as 1.5 & 2.0.

2.1.3 Aggregates

Locally available M-sand and coarse aggregates are used for this research work. Grading is the distribution of particles among various sizes usually expressed in terms of percentage passing on each test sieve. Taking into consideration of workability, strength, and economy of concrete and practicability IS 383 recommends grading limits for various coarse and fine aggregates.

Sieve analysis for fine aggregate is done by following the code IS 2386 part-1.

Table-3. Sieve analysis of fine aggregate.

Sieve size	Percentage of passing (%)	Grading limits for Zone II	
		Lower Limits	Upper Limits
0	0	0	0
0.15	5.4	0	10
0.3	15.2	8.0	30
0.6	42.4	35	59
1.18	68.9	55	90
2.36	96.8	75	100
4.75	100	90	100

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Table-4. Sieve analysis of Coarse aggregate (12.5 mm).

Sieve size	Percentage of passing (%)	Grading limits for 12.5 mm	
		Lower limits	Upper limits
0	0	0	0
4.75	5.52	0	10
10	53.02	40.0	85
12.5	97.58	90	100
16	99.09		
20	100	100	100

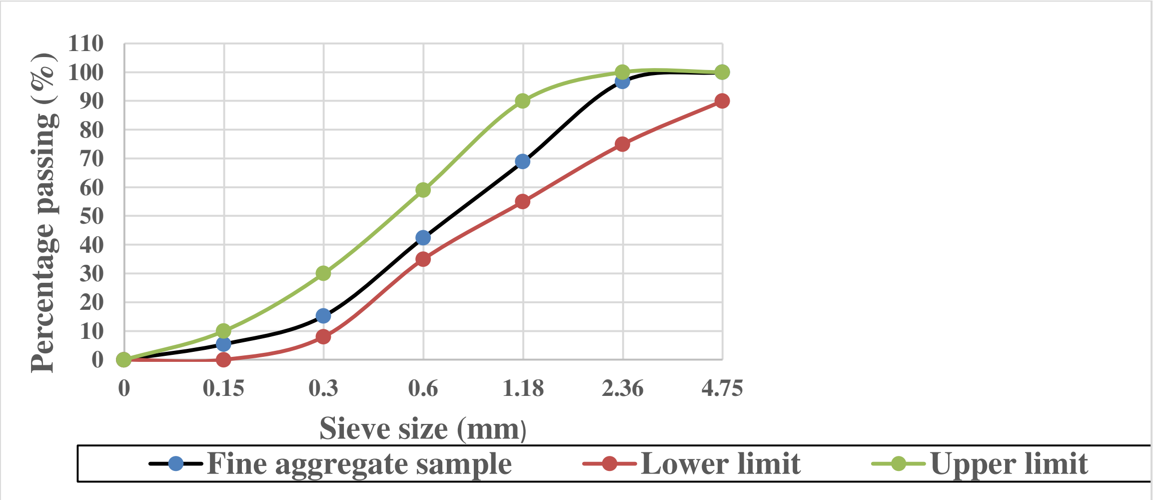

Figure-2. Gradation curve for Fine aggregate.

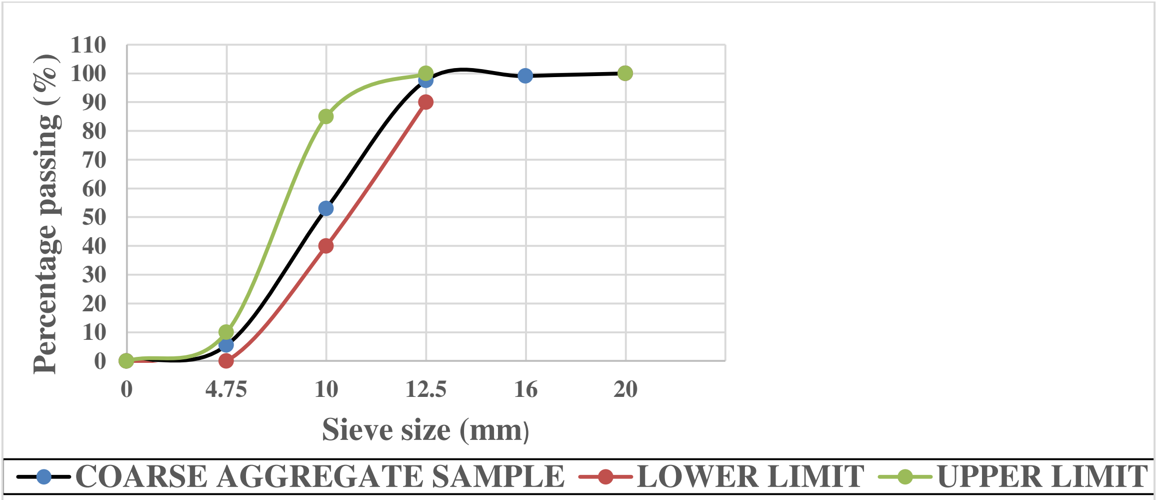

Figure-3. Gradation curve for coarse aggregate.

2.2 Specimen Preparation and Curing Regime

Geopolymer concrete is made in the same way as cement concrete. In the dry state, coarse aggregates, sand, and fly ash were primarily mixed. Then, add the arranged mixture solution of sodium hydroxide and sodium silicate, as well as extra water based on the water-to-geopolymer binder ratio, and thoroughly mix for 3-4 minutes to achieve a consistent mix. A different set of mixes are prepared and tested. Sodium hydroxide is in solid form and it should be dissolved to make the solution with the required concentration. The concentration of sodium hydroxide solution is 12 Molarity. Sodium silicate is also made into solution form. Geopolymer concrete is prepared by varying the ratio of sodium silicate solution to sodium hydroxide solution as 1.5, 2.0 and varying the ratio of binder to alkali solution was 0.3, 0.35, 0.4 & 045.

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2.3 Testing Methods

The compressive strength tests were done by compression testing machine, applying a load with a rate of 3 kN/sec. The loading capacity of the compression testing machine was 3000 kN. The workability test was done by slump cone test.

3. RESULTS AND DISCUSSIONS

3.1 Compressive Strength of Concrete Mixes

On a standard compression testing machine, the compressive strength of hardened fly ash-based geopolymer concrete was tested. A total of 16 cubical specimens with dimensions of 100mm x 100mm x 100mm were cast and compressed strength was tested after 7 and 28 days. The mean value of the compressive strength of three test concrete cubes is represented by each of the compressive strength test data. More than 20 MPa of compressive strength are achieved for almost all mixes. Geopolymer concrete can attain M20 concrete with different mixer proportions.

Table-5. Result for 7-day compressive strength geopolymer concrete.

S. No	Designation	Fly-ash (Kg/m^3)	Alkali ratio	Alkali to fly-ash ratio	Compressive strength, 7 days (Mpa)
1	GCNA 1 1	280	1.5	0.3	21.4
2	GCNA 1 2	280	1.5	0.35	21.45
3	GCNA 1 3	280	1.5	0.4	21.50
4	GCNA 1 4	280	1.5	0.45	21.65
5	GCNA 2 1	280	2	0.3	21.40
6	GCNA 2 2	280	2	0.35	21.45
7	GCNA 2 3	280	2	0.4	21.60
8	GCNA 2 4	280	2	0.45	21.70
9	GCNA 3 1	410	1.5	0.3	20.60
10	GCNA 3 2	410	1.5	0.35	20.90
11	GCNA 3 3	410	1.5	0.4	21.10
12	GCNA 3 4	410	1.5	0.45	21.0
13	GCNA 4 1	410	2	0.3	20.8
14	GCNA 4 2	410	2	0.35	21.3
15	GCNA 4 3	410	2	0.4	22.2
16	GCNA 4 4	410	2	0.45	21.9

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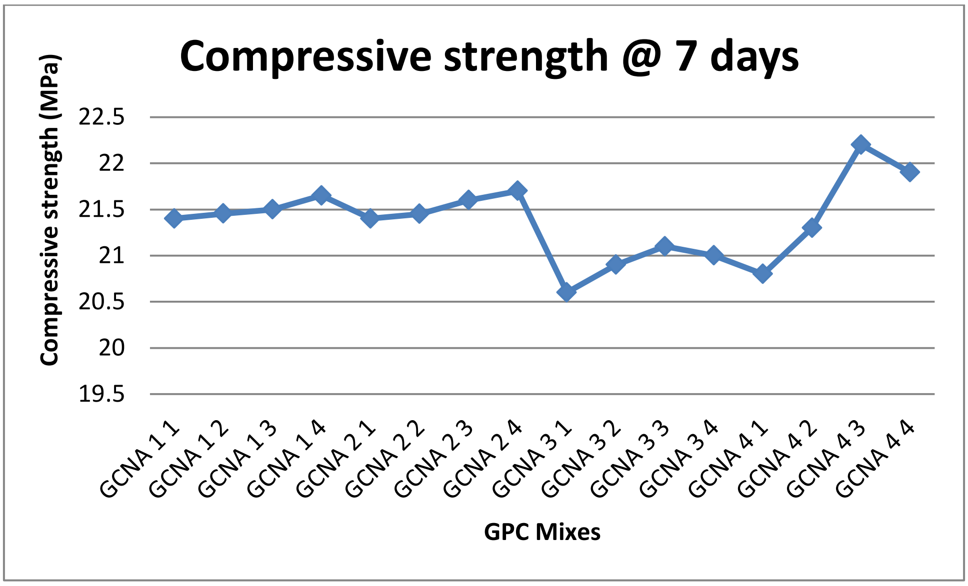

Figure-4.

Table-6. Result for 28-day compressive strength geopolymer concrete.

S. No	Designation	Fly-ash (Kg/m^3)	Alkali ratio	Alkali to fly-ash ratio	Compressive strength, 28 days (Mpa)
1	GCNA 1 1	280	1.5	0.3	23.2
2	GCNA 1 2	280	1.5	0.35	22.1
3	GCNA 1 3	280	1.5	0.4	21.9
4	GCNA 1 4	280	1.5	0.45	22.8
5	GCNA 2 1	280	2	0.3	23.9
6	GCNA 2 2	280	2	0.35	24.5
7	GCNA 2 3	280	2	0.4	23.6
8	GCNA 2 4	280	2	0.45	23.45
9	GCNA 3 1	410	1.5	0.3	22.7
10	GCNA 3 2	410	1.5	0.35	22.8
11	GCNA 3 3	410	1.5	0.4	22.9
12	GCNA 3 4	410	1.5	0.45	22.5
13	GCNA 4 1	410	2	0.3	23.5
14	GCNA 4 2	410	2	0.35	23.2
15	GCNA 4 3	410	2	0.4	23.5
16	GCNA 4 4	410	2	0.45	23.6

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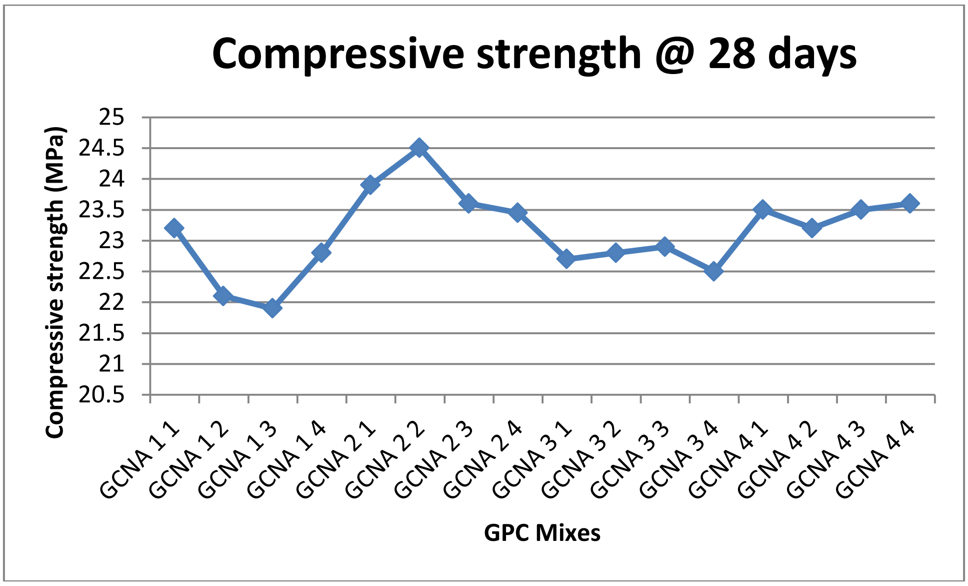

Figure-5.

3.2 Workability

The workability of freshly mixed concrete is the ease with which it can be suitably mixed, placed, consolidated, and completed without segregation. For getting the workability of the fresh concrete, the slump test was used. The slump value of the fresh concrete was measured using a slump cone earlier it was cast into the mould. The workability is varying according to the mixer proportions.

Table-7. Result for slump value for geopolymer concrete.

S. No	Designation	Fly-ash (Kg/m^3)	Alkali ratio	Alkali to fly-ash ratio	Slump value (mm)
1	GCNA 1 1	280	1.5	0.3	50
2	GCNA 1 2	280	1.5	0.35	40
3	GCNA 1 3	280	1.5	0.4	30
4	GCNA 1 4	280	1.5	0.45	35
5	GCNA 2 1	280	2	0.3	25
6	GCNA 2 2	280	2	0.35	20
7	GCNA 2 3	280	2	0.4	35
8	GCNA 2 4	280	2	0.45	40
9	GCNA 3 1	410	1.5	0.3	35
10	GCNA 3 2	410	1.5	0.35	30
11	GCNA 3 3	410	1.5	0.4	35
12	GCNA 3 4	410	1.5	0.45	25
13	GCNA 4 1	410	2	0.3	20
14	GCNA 4 2	410	2	0.35	25
15	GCNA 4 3	410	2	0.4	35
16	GCNA 4 4	410	2	0.45	30

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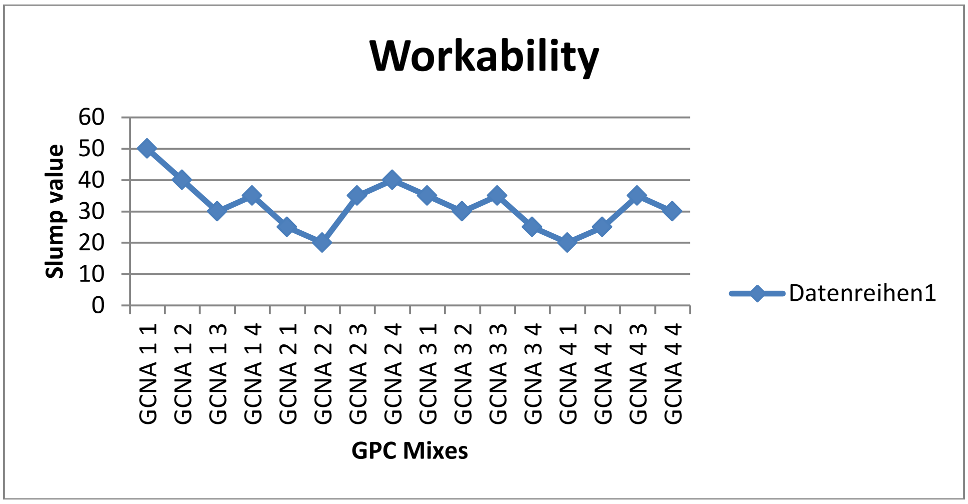

Figure-6.

4. CONCLUSIONS

Based on the test results, the subsequent conclusions are drawn. The alkaline liquid to fly ash ratio affects the compressive strength of geopolymer concrete. Compressive strength increases as the mass ratio of alkaline solution to fly ash increases. The difference between 3-day and 7-day compressive strength is only marginally increasing. At the age of 7 days, GPC attains its major compressive strength. It is very useful in rapid construction and precast structures. When compared to conventional concrete, GPC has a much lower slump value, so the addition of a good superplasticiser is needed to enhance the workability.

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