Optimizing the mechanical properties of geopolymer paste containing calcined clay and Dust clinker by Taguchi method

Alireza rezvani[a][1], Abouzar jalalkamali[b], Sania saheli[c]

a.Professor, Faculty of Basic Sciences, University of Sistan and Baluchistan, Zahedan, Iran

b.Student, Faculty of Basic Sciences, University of Sistan and Baluchistan, Zahedan, Iran

c. Instructor, Faculty of Basic Sciences, University of Sistan and Buchestan, Zahedan, Iran

Abstract:

Given that environmental pollution is one of the major concerns in today's societies, geopolymer cement is an innovative material in the construction industry with high performance and favorable efficiency. The production of geopolymer cement using pozzolans and aluminosilicate wastes, which are environmentally friendly, can serve as an alternative to conventional concrete production, addressing the pollution associated with Ordinary Portland Cement (OPC) production. This research focuses on synthesizing geopolymer cement based on calcined clay from the Bidester region in Khash city, enhancing its mechanical strength by adding fine clinker from rotary kilns. The experiments were designed using the Taguchi method. Taguchi's L16 array was proposed, and 16 experiments were designed. The Al/Na ratio was set at one. Various levels of silica modulus of the activating solution (0, 0.9, 1, and 1.1), the percentage of fine clinker addition (0, 5, 10, and 15), and the water-to-solid ratio (0.25, 0.3, 0.35, and 0.4) were assessed as influencing factors, with the a28-day strength as the response factor. Samples were maintained under 70% humidity at 23°C in a humidity cabinet. Results indicated that with optimal factors of a silica modulus of 1.1, a water-to-solid ratio of 0.25, and a 15% additive percentage, an average compressive strength of 81.24 MPa can be achieved, exceeding that of conventional OPC paste.

Keywords: Geopolymer synthesis, calcined clay, fine clinker, Taguchi, green cement.

Introduction:

The high energy consumption and significant dust production lead to the use of Portland cement and its products being less justifiable. Consequently, a new class of cement with the potential for high durability and reduced greenhouse gases, known as geopolymers, has gained attention. The term "geopolymer" was first used by Professor Davidovits, a renowned French chemist, in 1978 [1]. Geopolymerization is a geosynthesis process that chemically integrates mineral materials. During geopolymerization, silicate and aluminate tetrahedra polymerize by sharing all oxygen

[1] . **Alireza rezvani:** ali@hamoon.usb.ac.ir

atoms to form amorphous or semi-crystalline molecular structures [2]. Mechanical properties are a key indicator for geopolymers as cementitious binders for construction materials. It has been observed that geopolymers exhibit varying uniaxial compressive strengths (ranging from a few MPa to over 100 MPa) depending on their chemical composition, curing temperature, curing time, and raw material sources. Additionally, the compressive strength of geopolymers is influenced by water content, alkaline activator, and curing humidity [3].

The main objective of this study, considering the available native mineral resources, is to produce calcined clay-based geopolymer cement. To improve its properties and leverage the characteristics of Portland cement, fine clinker was mixed with varying percentages, and the influential parameters on its mechanical properties were optimized using the Taguchi method.

Methodology:

Samples were conditioned in a humidity chamber (at 23°C and 70% relative humidity) for 28 days, followed by compressive strength testing. The same environmental conditions were applied to all samples. The experimental data collection was done using the Taguchi method with Minitab 16 software. Based on prior works in the field and various reviewed articles, three factors were selected: the silica modulus of the activating solution, the water-to-solid ratio, and the percentage of the additive. Four levels were considered for each factor for a more detailed examination. The signal-to-noise (S/N) ratio was used as the response variable, and the “Larger is better” option was selected for this ratio in the software. Each sample had to be repeated at least three times, leading to a total of 48 samples.

Results and Discussion:

The compressive strength measurements from Trial 1 represent the initial test of each sample, while Trial 2 and 3 represent repeated measurements in the same test sequence. The optimal test results came from sample 13 (table 1).

Table 1. Corresponding orthogonal array and results

NO.	Si/Na	W/S	%Additive	Trial 1	Trial 2	Trial 3	SNR	STDV	MEAN
1	0	0.25	0	10.1	6.3	16.6	18.90	5.21	11.00
2	0	0.3	5	20.16	15.23	20.02	25.10	2.81	18.47
3	0	0.35	10	14.2	8.64	10.9	20.49	2.80	11.25

4	0	0.4	15	16.97	19.3	16.03	24.75	1.68	17.34
5	0.9	0.25	5	59.26	70.27	67.9	36.29	5.79	65.81
6	0.9	0.3	0	53.31	47.9	51.8	34.13	2.79	51.00
7	0.9	0.35	15	34	42.6	46.7	32.04	6.48	41.10
8	0.9	0.4	10	34.36	41.5	36.9	31.42	3.62	37.59
9	1	0.25	10	97.7	86.7	82.1	38.90	8.02	88.83
10	1	0.3	15	65.5	64.1	54.6	35.56	5.09	60.40
11	1	0.35	0	16.38	15.93	17.44	24.37	0.78	16.58
12	1	0.4	5	40.4	35.6	46.7	32.08	5.57	40.90
13	1.1	0.25	15	77.63	88.8	77.3	38.14	6.55	81.24
14	1.1	0.3	10	52.86	46	47.9	33.75	3.54	48.92
15	1.1	0.35	5	50	66.7	60.4	35.23	8.43	59.03
16	1.1	0.4	0	25.28	33.9	39.2	29.88	7.03	32.79

The Taguchi method can predict experimental results by employing optimal levels. Predicted optimal results from Taguchi compared with test results under optimal conditions are presented in the table 2.

Table 2 Comparison between the predicted optimal results and the result of the test performed under optimal conditions.

Sample	**Si/Na**	**W/S**	**%Additive**	**SNR**	**MEAN**	**STDV**
predicted	1.1	0.25	15	38.53	81.98	8.2
1.1M15-25	1.1	0.25	15	38.14	81.24	6.55

Conclusion

The lowest strengths were observed in samples with Si/Na = 0, highlighting the importance of sodium silicate solution in the preparation of kaolinite-based geopolymers. The higher alkalinity of the activating solution in materials with a high Si/Al ratio does not necessarily lead to the formation of geopolymer paste with higher resistance. Regardless of the material used, a high W/S ratio increases the distance between particles and minimizes their interactions, thus reducing the particle interface in the geopolymer matrix and improving the workability of the geopolymer mixture. The use of dust clinker as a partial replacement for metakaolin leads to a reduction in setting time due to the increased calcium content, which accelerates the setting and hardening of geopolymer pastes.

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