Раздел 2. «Информационно-коммуникационные технологии»

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Investigation of Geopolymers characteristics made from Kazakhstani industrial byproducts for consistent buildability with 3D printer

This paper investigates the characteristics of geopolymer developed from industrial byproducts in Kazakhstan. The geopolymer is aimed to be used for 3D construction printing for sustainable development. According to the data obtained after compression test, the geopolymer obtained with the addition of calcined clay is better than using metakaolin from the European manufacturer Metaver.

Keywords: Geopolymer, 3D Printing, buildability, byproducts

1.0 Introduction

The rising interest in 3D printing technology and its application in construction, particularly with geopolymers, is a phenomenon of the end of the 20th century [1]. Geopolymers, composed of substances like fly ash and blast-furnace slag, are sustainable alternatives to traditional cement due to lower carbon emissions and comparable or superior structural properties [2]. The growing cost and stricter regulations on conventional Portland cement (OPC) necessitate sustainable alternatives like geopolymers. However, research on optimal printing parameters and material properties is limited [3]. The potential for using local by-products from Kazakhstan for geopolymer production is largely unexplored.

This study seeks to understand how geopolymer properties influence their 3D printability and the importance of consistent buildability across different materials. The outcomes could widen the range of industries using 3D printing applications. The research examines the properties of geopolymers synthesized from Kazakhstani industrial byproducts for 3D printing uses. Objectives involve analyzing these byproducts, determining optimal geopolymer composites, assessing mechanical strength testing methods, and developing a superior strength geopolymer for efficient 3D printing.

The study comprises five chapters that include research methodology, experimental results concerning geopolymer physical and mechanical properties, conclusions drawn from the study's outcomes and suggestions for future research areas.

2.0. Methodology

The methodology of this research involves investigating the 3D printer buildability consistency of geopolymers made from industrial waste in Kazakhstan. Materials from mining, processing facilities, and laboratories, such as metakaolin and fly ash, will be gathered and treated. Preparation involves ball milling for size reduction, and sieving to remove contaminants. XRF analysis is then used to identify the materials' oxide content. Based on XRF results, four mixture designs will be created: one based on fly ash, one on metakaolin, and two combining both. These will aim for a specific final oxide composition in the geopolymers. The mixing process uses molding and demolding techniques to ensure the geopolymer's mechanical properties of mold-casted samples. The last stage is testing, where the compressive and flexural strength of the geopolymers are evaluated to confirm their suitability for 3D printing. Compressive strength testing determines the maximum compressive load before failure, while flexural strength testing determines the maximum load a material can bear before breaking or bending.

3.0. Results and discussion

3.1. Calcined clay preparation

Kaolin clay is widely used in geopolymer compositions due to its high aluminum content, which is essential for strong and stable geopolymer bonds. In this study, kaolin clay was obtained from the Altyntau field near Kokshetau city in Kazakhstan and processed in Astana. The clay was heated in a furnace at 750 degrees Celsius to remove impurities and then crushed in a ball mill to achieve a consistent powder form for use in geopolymer compositions.

The use of processed kaolin clay has been shown to improve the mechanical and physical properties of geopolymer materials. It can increase compressive strength, reduce water absorption, and enhance microstructural qualities [4]. The high aluminum content in handled kaolin clay is crucial for the development of strong geopolymer bonds. The crushing process ensures a uniform particle size distribution, which is necessary for homogeneous geopolymer formation.

XRF analysis, a widely employed method for identifying the elemental makeup of solid substances, involves a series of steps. Initially, the material is finely ground and subsequently compacted into circular tablets. The process entails two distinct phases: tablet fabrication using the provided materials, followed by the utilization of the XRF Axios Max PANalytical machine to obtain chemical composition information. Tables 1 and 2 present the results of XRF analysis

Table 1- Kokshetau calcined clay XRF Result.

Compound	Value	Unit	Status
Na2O	0,000	%	BgC;DC;
CuO	0,030	%	BgC;DC;
Al2O3	27,978	%	BgC;DC;
SiO2	52,026	%	BgC;DC;
SO3	0,105	%	BgC;DC;
K2O	0,002	%	BgC;DC;
CaO	0,000	%	BgC;DC;
TiO2	0,785	%	BgC;DC;
MnO	0,003	%	BgC;DC;
Fe2O3	0,032	%	BgC;DC;

Table 2- Metaver Metakaolin XRF Result

Compound	Value	Unit	Status
Na2O	0,000	%	BgC;DC;
CuO	0,040	%	BgC;DC;
Al2O3	35,108	%	BgC;DC;
SiO2	64,025	%	BgC;DC;
SO3	0,097	%	BgC;DC;
K2O	0,057	%	BgC;DC;
CaO	0,049	%	BgC;DC;
TiO2	0,862	%	BgC;DC;
MnO	0,000	%	BgC;DC;
Fe2O3	0,025	%	BgC;DC;

Overall, utilizing processed kaolin clay in geopolymer synthesis is a significant step towards creating high-quality materials with excellent properties. It offers a more sustainable and environmentally friendly alternative to conventional concrete-based materials, potentially impacting the field of construction materials.

3.2. Mixing

After careful consideration of various mixing methods and their impact on geopolymer properties, we have opted to utilize the gradual addition method for our purposes. This approach entails adding components in increments and allowing each addition to mix for a specific duration before introducing the next one.

Previous research has demonstrated the effectiveness of the gradual addition method in producing geopolymers with exceptional mechanical properties. For instance, a study was conducted that revealed that the gradual addition of fly ash and metakaolin yielded higher compressive strength compared to the one-step addition method [5].

In our G2 mix designs, we will initiate the process by mixing sodium silicate with metakaolin for 5 minutes at a rotational speed ranging from 150 to 250 rotations per minute. Subsequently, we will introduce fly ash and continue mixing for 15 minutes before incorporating GGBS and mixing for an additional 3 minutes. Finally, sand will be added and mixed for 5 minutes. The procedure for G1 mix designs remains similar, except for variations in the addition of fly ash, mixing durations of other components, order of addition, and speed of mixing.

3.3. Preparation of an alkaline activator.

Two alkaline solutions were prepared for geopolymer formation. The first solution had a ratio of 11.5 NaOH to 100 Na2SiO3, while the second solution had the same ratio but was diluted with water at a ratio of 10 to 4. Solutions were mixed until homogeneous and free of undissolved particles. The alkaline solution is crucial for geopolymerization, controlling properties like microstructure and mechanical strength [6]. The experiment tested two solutions with different water dilution levels. The second solution had increased water content to accommodate fly ash in the mix. Mixing caused an exothermic reaction, requiring a 24-hour reaction time. Overall, alkaline solution preparation is vital for geopolymer materials, with the NaOH to Na2SiO3 ratio being a key factor.

3.4. Mixing process

The geopolymer concrete mixing process followed the specifications outlined in the project's mix design. Two types of molds, cube-shaped and parallelogram-shaped, were used to determine the volume of geopolymer needed for mechanical property tests. The overall volume of concrete required was 0.004572 m3. To simplify measurement, the geopolymer mix was determined by mass rather than volume. The approximate density of the mixes was found to be 2200 kg/m3 [7].

Based on the density calculation, approximately 10 kg of geopolymer was needed. The mixing process involved combining metakaolin and sodium silicate for 5 minutes, followed by the addition of GGBS and mixing for an additional 3 minutes. After adding sand, the mixture was mixed for another 5 minutes.

Once mixed, the geopolymer concrete was ready for molding. The molding process included mold assembly, oiling, filling, and wrapping with polyethylene film. Oiling the molds served multiple purposes such as facilitating easy demolding, creating a smooth surface finish, and protecting the molds from damage. Half-filled molds were tapped with a resin mallet to remove air bubbles and voids, followed by filling the rest of the mold. Each mold was then wrapped with polyethylene film to retain moisture.

After 24 hours of curing at ambient temperature in a dark place, the samples were demolded. This process required precision to ensure the proper shape and condition of the samples. The samples were carefully removed using a resin mallet and putty knife due to their strong adhesion to the molds. Some samples experienced minor damage during demolding but did not significantly affect subsequent tests. After demolding, the samples were wrapped again and further cured.

This mixing, molding, and the demolding process was repeated for other mix variations (G2, G1.KT, G2.KT) according to their respective mixing specifications.

3.5. Testing process

Geopolymer concrete can be tested for mechanical properties through methods such as compressive strength and flexural strength tests. These tests were conducted on cube-shaped samples for compressive strength and parallelogram-shaped samples for flexural strength. The tests were performed at different curing periods, including 1 day, 3 days, 7 days, and 28 days, with three samples tested for each period.

The results of the tests obtained using the "Servo-Plus Evolution E183N" machine, showed that the metakaolin-based composition exhibited increasing compressive strength from 2.5 MPa at 24 hours to 18 MPa at 7 days and up to 32 MPa after 28 days of curing. The flexural strength also increased from 0.9 MPa to 7 MPa during the same period.

Similar trends were observed for the "G2" composition, with compressive strength increasing from 1.4 MPa after 1 day to 32.6 MPa after 28 days, and flexural strength reaching 5 MPa.

The results of the "G1_KT" composition, which used kaolin clay from Kokshetau, showed significantly better performance. After 1 day of curing, compressive strength was measured at 25.5 MPa and flexural strength at 3.6 MPa. These values increased to 63 MPa and 9.5 MPa, respectively, after 28 days of curing. The results of the "G2_KT" composition were similar to those of "G1" and "G2".

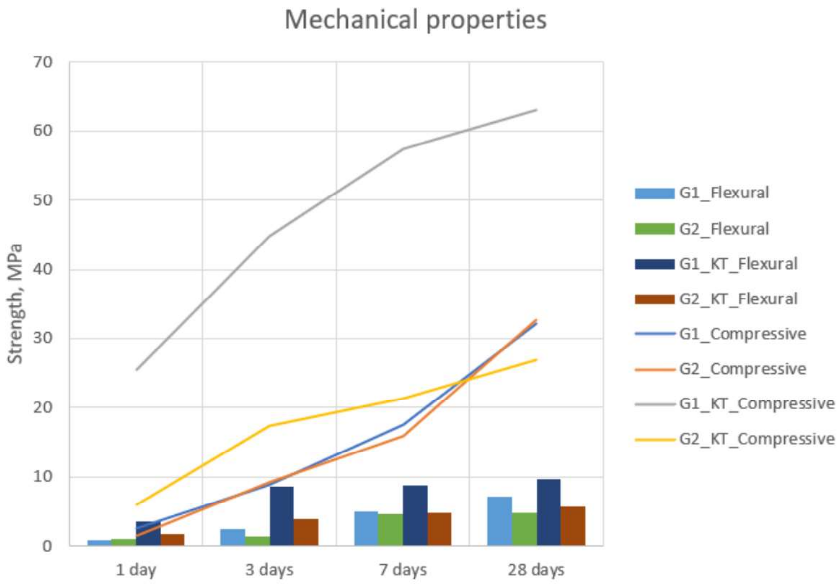

Figure 3 - Results of compressive and flexural strength of four geopolymer compositions

Comparing these results to the requirements for regular concrete set by the American Concrete Institute (ACI), it can be concluded that all four geopolymer mixes met the minimum compressive strength requirement of 2500 psi (17.24 MPa) and had flexural strength equal to 10-15% of the compressive strength [8]. Other sources suggest that concrete used in residential and commercial buildings should have compressive strength ranging from 4000 to 10000 psi (27.58-68.95 MPa) [9], which indicates that all four geopolymer mixes also meet these requirements.

The finding that geopolymer compositions made with Kazakhstani kaolin clay performed better than those made with European kaolin clay is significant. This can be attributed to the unique mineralogical composition of the Kazakhstani kaolin clay, which may include minerals such as quartz, feldspar, mica, and iron oxides in varying concentrations. The processing procedure, including heating the kaolin clay and grinding it in a ball mill, may also have contributed to its superior performance.

These findings have important implications for the development of sustainable construction materials. By utilizing regional resources like Kazakhstani kaolin clay and improving processing techniques, it may be possible to create high-quality, eco-friendly geopolymer compositions. Further research is needed to fully understand the factors influencing geopolymer composition performance and optimize their formulation for specific applications.

4.0. Conclusion

In this project, the aim was to design, mix, and test geopolymer concrete (GPC) mixes using Kazakhstani by-products to achieve outstanding mechanical properties that can compete with regular Portland cement concrete. Different GPC mixtures were presented, including metakaolin-based and fly ash-based mixes using European metakaolin and Kokshetau kaolin. The results showed that the metakaolin-based mixtures performed better, with Kokshetau kaolin showing significantly higher compressive strength (63 MPa) and flexural strength (9.5 MPa) compared to "MetaVer" metakaolin.

The superior performance of GPC made entirely from Kazakhstani by-products, particularly Kokshetau kaolin, demonstrates its potential to meet the mechanical strength requirements for residential and commercial buildings, where compressive strength requirements start from 28 MPa. This indicates that GPC can be a suitable alternative for construction applications.

In addition to the construction industry, GPC has other potential applications. It can be used in 3D printing due to its ability to solidify rapidly and maintain shape. Moreover, geopolymer concrete can be utilized in environmental remediation efforts by immobilizing and stabilizing contaminants in soil or water, thereby minimizing waste [10].

However, certain constraints during the project hindered optimal outcomes. Insufficient power and rotation speed of the mixer led to overheating and inadequate mixing. Additionally, air bubbles in the mixture posed challenges during mold filling, resulting in decreased strength due to cracks in bubble-rich areas. Improvements in equipment, such as using a better mixer and vibration table, can address these issues in future projects.

In conclusion, GPC proves to be a viable alternative to regular Portland cement concrete with comparable compressive and flexural strength values. Furthermore, considering its reduced environmental impact and lower-cost components, GPC has the potential to replace conventional cement in the near future.

5.0 Future works

In this project, we have investigated the properties of geopolymer derived from industrial byproducts in Kazakhstan. However, there are still areas that warrant further exploration in future studies. One potential avenue for future research is to explore the feasibility of utilizing a 3D printer to assess the buildability of our geopolymer material. Although we were unable to access a 3D printer during this project, it would be intriguing to observe how our geopolymer performs in terms of consistency and structural integrity when printed in various shapes and sizes.

Another area that could benefit from future investigation is the examination of different curing parameters and their impact on the compressive and tensile strength of our geopolymer. By manipulating variables such as curing temperature, duration, and other factors, we can determine the optimal conditions for curing that yield the desired mechanical properties for our geopolymer material. This line of inquiry will contribute to enhancing our understanding of how curing influences the overall performance and durability of geopolymer structures.

Overall, these suggested avenues for future work will expand upon our current findings and provide valuable insights into optimizing the use of geopolymer made from Kazakhstani industrial byproducts.

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Темірзақұлы Б., Мухаметкалиев Т., Мд Хазрат Али

Қазақстандық өнеркәсіп қалдықтарынан жасалған геополимерлердің сипаттамаларын олардың 3D принтермен үйлесімділігін зерттеу

Бұл мақалада Қазақстандағы жанама өнеркәсіптік өнімдерден алынған геополимердің сипаттамалары зерттеледі. Геополимер тұрақты даму үшін құрылыс 3D басып шығаруда қолдануға арналған. Қысу сынақтан кейін алынған мәліметтерге сәйкес, кальцийленген сазды қосу арқылы алынған геополимер еуропалық Metaver өндірушісінің метакаолинін қолданғаннан гөрі жақсы.

Түйін сөздер: Геополимер, 3D басып шығару, құрастыру мүмкіндігі, қалдықтар

Раздел 2. «Информационно-коммуникационные технологии»

Темірзақұлы Б., Мухаметкалиев Т., Мд Хазрат Али

Исследование характеристик геополимеров, изготовленных из промышленных отходов казахстанской промышленности, на предмет их совместимости с 3D-принтером

В данной статье исследуются характеристики геополимера, разработанного из побочных продуктов промышленности в Казахстане. Геополимер предназначен для использования в трехмерной строительной печати для устойчивого развития. По полученным данным после теста сжатие, геополимер, полученный с добавлением кальцинированной глины, лучше чем с использованием метакаолина от европейского производителя Metaver.

Ключевые слова: Геополимер, 3D-печать, строительная пригодность, отходы

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