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GEOPOLYMER MORTAR WITH ALKALIACTIVATED FLY ASH AS THE BASE: STRENGTH AND DURABILITY STUDIES LITERATURE SURVEY

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Abstract:

This literature survey explores the strength and durability aspects of geopolymer mortar that incorporates alkali-activated fly ash as its base material. Geopolymer mortar, a promising alternative to conventional cement-based materials, utilizes industrial by-products such as fly ash to reduce carbon emissions and enhance sustainability. The study focuses on investigating the mechanical strength properties of geopolymer mortar, including compressive strength, flexural strength, and tensile strength. Various factors influencing the strength development of alkali-activated fly ash-based geopolymer mortar are discussed, such as activator composition, curing conditions, curing duration, and fly ash characteristics. Additionally, the durability performance of geopolymer mortar is examined, considering aspects such as water absorption, chemical resistance, carbonation resistance, and resistance to sulfate attack. The literature survey encompasses a comprehensive analysis of existing research articles, conference papers, and technical reports in the field. It aims to provide an overview of the current state of knowledge regarding the strength and durability studies of geopolymer mortar with alkali-activated fly ash as the base material. The findings highlight the potential of alkali-activated fly ash-based geopolymer mortar in terms of achieving comparable or even superior mechanical properties compared to traditional cement-based materials, while exhibiting enhanced durability performance. This literature survey serves as a valuable resource for researchers, engineers, and practitioners interested in the development and application of geopolymer mortar with alkali-activated fly ash, aiding in the advancement of sustainable and environmentally friendly construction materials.

Keywords — **Geopolymer mortar, Alkali-activated fly ash, Strength properties, Durability performance, Industrial by-products, Sustainable construction materials.**

1. INTRODUCTION

Throughout the course of human history, construction practices have continually evolved and improved. In the past century, it became evident that a significant portion of project costs was attributed to the preparation of mortar and concrete. In response to the need for cost-effective construction methods, there was a notable paradigm shift in technological advancements in the field. The scarcity of essential components like lime posed economic challenges to many construction projects. As a result, researchers began exploring alternatives to conventional Portland cement concrete and mortar. This led to the emergence of geopolymer concrete and mortar as viable alternatives. This study primarily focuses on various aspects related to geopolymer mortar. Geopolymer mortar utilizes innovative materials and techniques, aiming to enhance the efficiency and economy of construction projects. By replacing traditional materials with geopolymer-based alternatives, significant cost savings can be achieved. The research delves into key factors such as the composition and preparation of geopolymer mortar, as well as its mechanical properties and durability. Various studies and experiments are analyzed to determine the feasibility and effectiveness of geopolymer mortar in practical applications. By exploring the potential of geopolymer mortar, this study contributes to the body of knowledge in the construction industry. The findings offer insights into the benefits and limitations of geopolymer-based materials, enabling researchers and practitioners to make informed decisions regarding their implementation. Ultimately, the study seeks to promote the adoption of geopolymer mortar as a sustainable and cost-effective solution in construction practices.

2. NEED AND ADVANTAGES OF USE OF GEOPOLYMER MORTAR

Ordinary Portland cement and conventional mortar heavily rely on cement as a crucial component. The manufacturing process of cement involves the heating of limestone at temperatures around 1450°C in a kiln, known as the calcination process. This process releases carbon dioxide as a byproduct while converting calcium carbonate into calcium oxide. Additionally, the use of coal as a heating fuel in the kiln contributes significantly to carbon dioxide emissions. Numerous studies have revealed that approximately 1 ton of carbon dioxide is emitted for every 1 ton of cement produced (Bosoga et al., 2009). Considering that the global construction industry consumes around 2.6 billion tons of cement annually, and with an estimated 25% increase in demand over the next 10 years, there is a growing concern about potential shortages in natural limestone reserves within the next 25 years (Bosoga et al., 2009). To address these environmental challenges and reduce carbon footprints, the use of geopolymer has emerged as an optimal solution. Geopolymer offers several advantages: it utilizes waste materials such as fly ash and blast furnace slag generated by thermal industries, and it serves as a binder material, effectively replacing the need for cement in mortar preparation. By adopting geopolymer technology, the construction industry can effectively mitigate environmental impacts and reduce reliance on traditional cement-based materials. This shift not only facilitates the utilization of industrial by-products but also contributes to sustainable construction practices by minimizing carbon emissions and conserving natural resources.

3. VARIOUS MECHANISMS INVOLVED IN FORMATION OF GEOPOLYMER MORTAR

The strength and various properties of geopolymer are obtained through a process known as polymerization. This polymerization occurs between two amorphous materials, namely fly ash, metakaolin, slag, and geopolymer gel. To gain a comprehensive understanding of geopolymer behaviour, it is crucial to grasp the different mechanisms that are involved in the polymerization process.

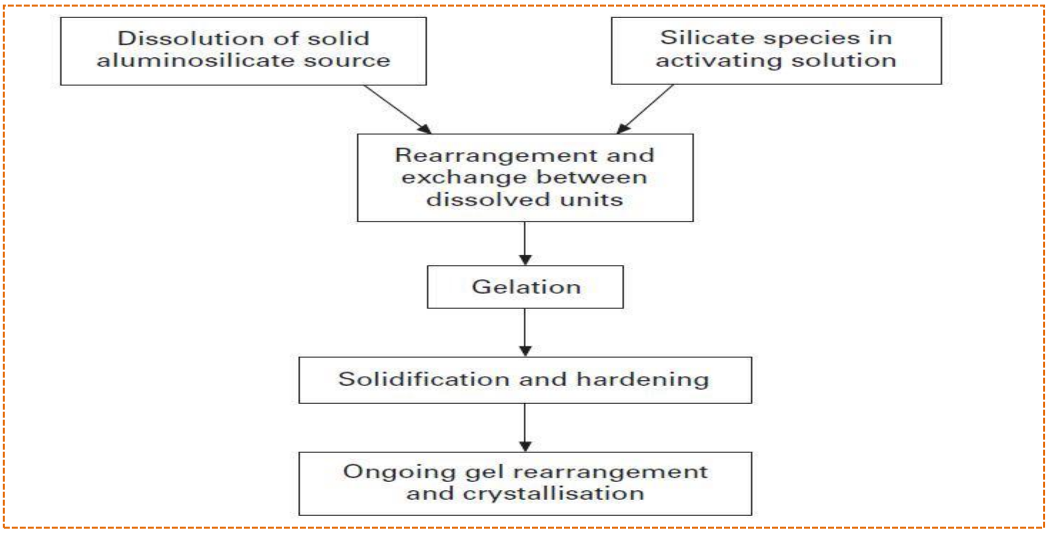

Figure 1: Schematic diagram of various steps of Geopolymerization (Source: Google image)

4. REVIEW OF LITERATURE

The production of geopolymer involves a complex process that requires the application of various engineering knowledge. A comprehensive study of geopolymer should encompass all aspects of the manufacturing processes, drawing from different engineering backgrounds. To assess the contribution of each component to the performance of geopolymer, it is crucial to analyze the influence of individual elements on the overall product. Thus, an extensive literature review was conducted to gain a deeper understanding of geopolymer performance. Various research books, articles, notes, and state-of-the-art publications were consulted for this purpose. Researchers have employed diverse methodologies to investigate the behavior of geopolymer and comprehend its properties and characteristics.

In their study**, Duxson et al. (2007)** investigated the process of geopolymerization and elucidated the mechanism involved in the formation of geopolymer. The researchers outlined several distinct steps involved in geopolymerization: dissolution, speciation equilibrium, gelation, reorganization, and polymerization and hardening. Initially, alkali attacks the fly ash, leading to the dissolution of fly ash particles on their surface. This dissolution results in the creation of reaction products, which can either remain isolated or adhere to the surface of the fly ash particles. Consequently, complex morphologies are formed within the mortar matrix, including unreacted particles, partially dissolved particles attacked by the alkaline solution, and reaction products. The formation of the geopolymer gel, denoted as [Ma(AlO2)a(SiO2)b.nMOH.mH2O], is dependent on the dissolution of the Si/Al source material, which, in turn, is influenced by the quality of the Si/Al source and the concentration of the alkaline solution **(Xu, 2002)**.

Thakur and Ghosh (2009) demonstrated variations in the alkali content, specifically the Na2O to Al2O3 ratio (Na2O/Al2O3), ranging from 0.46 to 0.62. Additionally, they explored the effects of other parameters, such as silica content (3.7 to 4.3), alkali activator to fly ash ratio (0.4 to 0.6), water to geopolymer solid ratio (0.157 to 0.366), and sand-fly ash ratio (0.5 to 3.0), on the performance of geopolymer mortar. **Rattanasak and Chindaprasirt (2009)** focused on the influence of Na2SiO3/NaOH ratio and the concentration of NaOH on geopolymer performance, utilizing ranges of 0.5 to 2.0 for Na2SiO3/NaOH ratio and 5 to 15 for NaOH concentration. In a separate study, **Temuujin et al. (2010)** investigated the impact of the sand-binder ratio on the engineering properties of geopolymer mortar, varying the sand-binder ratio from 10% to 50% and analyzing the effect of increased sand content on compressive strength. The study of geopolymer mortar and its performance also involves the examination of processing parameters. These parameters have been found to be crucial in the mix design of geopolymer mortar and have a significant impact on its final compressive strength and durability. Curing time, curing temperature, and the type of mixing have been identified as influential factors (**Thakur and Ghosh, 2009; Rovnanik, 2010; Rattanasak and Chindaprasirt, 2009**). **Thakur and Ghosh (2009) and Rovnanik (2010)** investigated the effect of curing temperature on the compressive strength of geopolymer mortar, varying the temperature within the range of 45°C to 120°C. Similarly, the influence of curing time was examined by varying it from 6 to 72 hours. **Rattanasak and Chindaprasirt (2009)** explored different mixing methods for geopolymer preparation, comparing separate mixing and normal mixing techniques, with separate mixing yielding better results. The literature review provides a range of values for these parameters; however, the selection of specific values often requires a trial and error approach and engineering judgment in experimental studies.

Composition parameters in geopolymer mortar, such as alkali content, silica content, and Na2SiO3/NaOH ratio, have a significant impact on the engineering properties of the final product. **Thakur and Ghosh (2009)** studied the effect of alkali content on the compressive strength of geopolymer mortar and found that increasing alkali content led to higher compressive strength at 3 days, 7 days, and 28 days. This was attributed to the increased formation of aluminosilicate gel resulting from higher alkali content. Similarly, **Thakur and Ghosh (2009)** examined the influence of silica content (ranging from 3.7 to 4.3) on compressive strength. They observed that compressive strength initially increased up to an optimum silica content, after which further increases in silica content caused a decrease in compressive strength due to hindered polymerization within the geopolymer mortar. **Rattanasak and Chindaprasirt (2009)** investigated the effect of the Na2SiO3/NaOH ratio on the mechanical strength of geopolymer mortar. They varied this ratio from 0.5 to 2 and found that it played a crucial role primarily at lower concentrations of NaOH. The concentration of NaOH in geopolymer mortar was found to have an impact on its compressive strength, as discussed by **Rattanasak and Chindaprasirt (2009).** They observed that for a lower water glass to NaOH ratio, increasing the NaOH concentration resulted in higher compressive strength. For example, geopolymer mortar prepared with a water glass to NaOH ratio of one and a 15 M NaOH concentration exhibited a compressive strength of approximately 70 MPa. The water-to-geopolymer solid ratio in geopolymer mortar was studied by **Thakur and Ghosh (2009)**. They explained that the addition of water helps in the increased dissolution of Si and Al sources, promoting polymerization. It was reported that the compressive strength increases with an increase in the water-to-solid ratio up to a certain limit. However, beyond the optimum value, the compressive strength starts to decline due to paste supersaturation and delayed gel formation. The sand-fly ash (FA) ratio was investigated by **Thakur and Ghosh (2009)** in relation to the compressive strength of geopolymer mortar. They found that the compressive strength decreases significantly with an increase in the sand-FA ratio beyond a value of 1.5. The influence of the sand-binder ratio, expressed as a percentage, on the compressive strength of geopolymer mortar was described by **Temuujin et al. (2010)**. They varied the aggregate content from 10% to 50% in the preparation of geopolymer mortar and concluded that there was little to no effect on the compressive strength within this range. Overall, these parameters play a crucial role in determining the compressive strength of geopolymer mortar and should be carefully considered in the mix design process.

In light of the growing concern over climate change and the occurrence of acid rains in urban areas, it becomes crucial to assess the performance of geopolymer mortar when subjected to acid attack, especially as a potential replacement for ordinary Portland cement (OPC) mortar. Researchers, such as **Thokchom et al. (2009) and Thokchom et al. (2011)**, have conducted studies to investigate the impact of acid attack on the engineering properties of geopolymer mortar using nitric acid and sulfuric acid. The findings revealed that the influence of acid attack on the performance of geopolymer mortar exhibited a similar pattern for both acids. This particular study focuses on examining the effects of nitric acid on fly ash-based geopolymer mortar and discusses the observed consequences.

In their study, **Thokchom et al. (2011)** investigated the impact of acid attack on the microstructure of the mortar. To analyze this, they compared traces of both the unexposed and exposed surfaces using the SEM-EDX technique. Micrographs of the geopolymer mortar were captured, and the elemental composition was evaluated. The findings indicated that the microstructure of the mortar deteriorated as a result of acid attack. Additionally, the calcium content in the traces of the exposed surface decreased when subjected to acidic substances.

In a study conducted by **Bijeljic et al. (2020)**, the physical-mechanical, durability, and microscopic properties of geopolymer mortar mixtures based on fly ash and ladle slag were investigated. The mixtures were alkali-activated using sodium silicate and sodium hydroxide solution. Initially, the study examined the effects of different particle sizes of fly ash (classified as "F" type) on the characteristics of the mortar mixtures. The binder and alkali activator were cured at 95ºC for 24 hours, and parameters such as pozzolanic activity and strength activity index were evaluated. Subsequently, the study replaced the fly ash with ladle slag, ranging from 0% to 20% of the mass, with replacement steps of 5%. The specimens were then cured under ambient conditions, and various tests were conducted to assess water absorption, flexural and compressive strength, freeze-thaw resistance, sulfate attack, ultrasound velocity, FT-IR spectroscopy, and leaching of heavy metals. The results of compressive strength tests on geopolymer mortars exposed to sulfate solution indicated that the mortar made with a combination of fly ash and ladle slag exhibited better resistance to sulfate attack compared to the mortar made with fly ash alone.

In a comprehensive study by **John et al. (2021)**, the properties of fly ash and fly ash-slag geopolymer mortar were thoroughly reviewed. The study examined various aspects including microstructural properties, fresh properties (such as setting time and workability), hardened properties (including compressive strength and tensile strength), and durability properties (such as thermal resistance, shrinkage, acid resistance, chloride resistance, and sulfate resistance). The influence of different factors was discussed, including the types of alkaline solutions, their concentrations, combinations of alkaline activators, fine aggregate to binder ratio, alkaline solution to binder ratio, curing temperature and duration, and the presence of superplasticizers. The study also investigated the impact of additives such as silica fume, alccofine, quartz powder, alumina, epoxy, bio-additives, various types of fibers, and nano-materials in both fly ash and fly ash-slag geopolymer mortar. A comprehensive analysis of the effect of mix proportioning on the fresh, hardened, and durability properties of fly ash geopolymer and fly ash-slag geopolymer mortar was presented in this study.

The objective of the study conducted by **Kawalu et al. (2022)** was to explore the impact of using glass-waste aggregate on the mechanical properties of fly ash-based geopolymer and OPC mortars. The research involved the preparation of mortar mixtures using glass-waste as fine aggregate, alongside control mixes using silica sand in both geopolymer and OPC mortars. An alkali activator consisting of a blended solution of sodium silicate and sodium hydroxide was utilized for the fly ash geopolymer mixtures. The workability of the fresh mixtures was assessed, while compressive strength testing was performed on 50 mm cubes. Additionally, mortar prisms sized 25 x 25 x 285 mm were prepared for drying shrinkage testing. The results revealed that the inclusion of glass-waste aggregate had a detrimental effect on the compressive strength of the mortars, regardless of the type of binder used. Geopolymer mortars incorporating glass-waste aggregate exhibited a 55% reduction in compressive strength compared to those containing silica sand.

The aim of the study conducted by **Kandoria et al. (2022)** was to explore the potential applications of geopolymer mortar in the construction industry as a greener and more environmentally friendly alternative. Given the increasing concerns over pollution and climate change, it is crucial to identify sustainable materials that can reduce reliance on traditional cement. Geopolymer mortar, which is produced from alumina and silica-rich by-products like fly ash and rice husk ash, offers a promising solution. These materials are activated using an alkaline solution. The study focused on investigating the compressive strength of geopolymer mortar with various modified alkaline solution ratios. By promoting the use of geopolymer mortar, the study highlights the potential to decrease reliance on cement, thereby contributing to environmental sustainability in the building sector.

In a recent experimental investigation by **Kumar et al. (2023)**, the behavior of bituminous mixes, specifically Stone Matrix Asphalt (SMA) and Bituminous Concrete (BC), was studied. The study revealed several significant findings. Firstly, all three types of fillers used in BC met the required specifications, indicating their suitability for use. BC with a cement filler exhibited the highest stability, while alternatives such as fly ash and stone dust fillers proved to be viable and cost-effective options. The addition of fibers up to a concentration of 0.3% enhanced the stability of BC, although further incorporation of fibers did not result in substantial improvements compared to SMA. The inclusion of fibers in BC led to a decrease in its flow value, but when 0.5% of fibers were added, the flow value increased. SMA exhibited superior tensile strength compared to BC, and the introduction of fibers reduced deformation in both types of mixes. Notably, SMA incorporating sisal fiber demonstrated excellent performance, particularly for flexible pavement applications, highlighting its potential in various construction projects.

This study conducted a comprehensive literature review to gain insights into the behavior of fly ash-based geopolymer mortar. The findings suggest that various industrial waste by-products can be effectively utilized in geopolymer mortar production. The strength of fly ash-based geopolymer is primarily influenced by mix compositions, including alumina and silica content, as well as the concentration of alkali activator. Processing parameters such as curing period and temperature also play a role in determining strength. However, it is important to note that research in this area has predominantly focused on geopolymer concrete, with limited exploration of mix composition effects on geopolymer mortar. Furthermore, there is a lack of detailed studies on the carbonation effects in geopolymer mortar and a need for guidelines for its preparation and performance assessment.

5. SUMMARY

Literature Survey presents a comprehensive summary of studies investigating the strength and durability properties of geopolymer mortar using alkali-activated fly ash as the main constituent. The paper provides an overview of various research findings in this field and highlights key insights and trends. The literature survey reveals that geopolymer mortar, produced by activating fly ash with alkali solutions, offers promising potential as a sustainable alternative to conventional cement-based mortar. Several studies have investigated the effects of various parameters on the strength and durability of geopolymer mortar. Regarding strength properties, the research indicates that the compressive strength of geopolymer mortar can be influenced by factors such as the composition of the mix, including the alumina and silica content, as well as the concentration and type of alkali activator used. Curing conditions, such as temperature and duration, also play a significant role in determining the final strength of geopolymer mortar. In terms of durability, the literature survey demonstrates that geopolymer mortar exhibits good resistance to acid attack, sulfate attack, and chloride penetration. The incorporation of supplementary cementitious materials and additives, such as silica fume and fibers, has been found to enhance the durability performance of geopolymer mortar. Overall, the literature review highlights the potential of geopolymer mortar as a sustainable and durable alternative to conventional cement-based mortar. However, further research is needed to optimize mix design parameters, understand long-term performance, and develop standardized guidelines for the production and application of geopolymer mortar in practical construction scenarios.

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