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Review the Development of Geopolymer Technology to Enhance the Performance of Rigid pavement

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Abstract: Geopolymer cement is a sustainable material that serves as a viable alternative to ordinary Portland cement (OPC) in the construction of transportation infrastructure and buildings. The chemical activator, curing process, and sources of geopolymer materials are essential factors that significantly impact the strength, durability properties, and microstructure of the resulting geopolymer matrices. In contemporary construction practices, concrete is a widely used material that can be expensive to produce with adverse effects on the environment. In order to decrease the reliance on OPC, a novel form of concrete known as geopolymer concrete (GPC) has been developed. This review aims to present the development of geopolymer technology to enhance the strength and durability of rigid pavement. It is imperative for pavement engineers to comprehend and tackle the challenges associated with geopolymer construction methodologies, encompassing placement, curing, and pavement efficacy. Based on the literature survey, it can be concluded that geopolymer concrete is a viable substitute for OPC concrete (PCC) due to its superior physical, mechanical, and durability characteristics. Various types of GPC demonstrated satisfactory performance in terms of drying shrinkage and thermal expansion compared to PCC. Geopolymer concrete exhibits high resistance against acid, sulfate, and salt attacks. The utilization of geopolymer cement in the construction of rigid pavement has been identified as a potential solution to address concerns related to global warming and enhance the durability of such infrastructure.

Keywords: Rigid pavement, Geopolymer concrete, Performance, Global warming, Durability.

Introduction

Geopolymer is a novel construction material which can be an alternative binder to Portland cement. Geopolymer materials represent an innovative technology that is generating considerable interest in the construction industry, particularly in light of the ongoing emphasis on sustainability. It relies on minimally processed natural materials or industrial byproducts to significantly reduce its carbon footprint, while also being very resistant to the durability issues that can plague conventional concrete [1]. A source material that is high in silica and alumina reacts with alkaline liquids to produce geopolymer concrete. The soluble alkali metals that are used to make the alkaline liquids are typically sodium- or potassium-based. As shown in the figure 1, all alkali-activated materials are created by reacting an aluminosilicate material, which is typically provided in powder form as an industrial byproduct, with an alkaline activator, which is typically in the form of a concentrated aqueous solution of alkali hydroxide, silicate, carbonate, or sulfate [2]. Natural minerals such as kaolinite, clays, alternatively, by-product materials such as fly ash, silica fume, slag and red mud could be used as source materials [3].

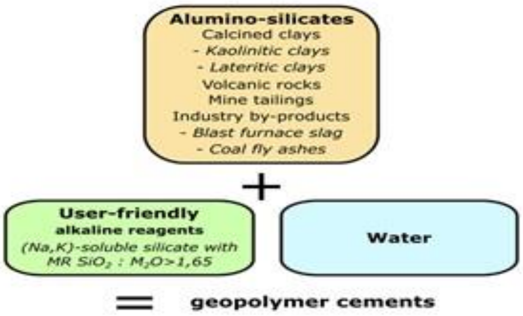

Fig. 1: The Process of Geopolymer Cement

Geopolymer-based concrete using fly ash has a high potential for the construction industry to replace OPC based concrete with comparable structural properties as shown in Figure 2 [4].

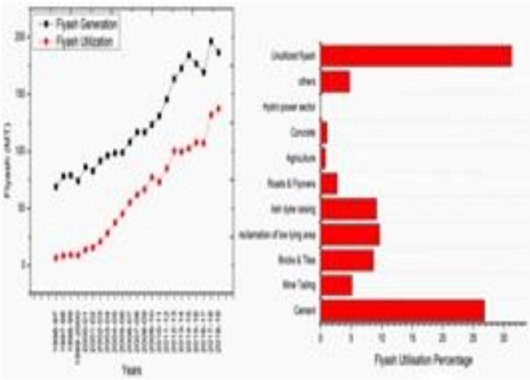

Fig. 2: Fly Ash Generation and Utilisation, as reported in reference [4]

Nowadays, the application of nano materials has received numerous attentions to enhance the Geopolymer concrete properties [5]. The choice of the source materials for making geopolymers depends on factors such as availability, cost, and type of application [6]. The construction of concrete pavements must be improved to ensure effective transportation, reduce cost, and promote environmental sustainability, considering the effects of weather, fuel use, cost of repairs and paving lifetime. Because the initial cost of rigid pavement is higher than that of flexible pavement; the latter has been preferred to date, even though the maintenance cost of rigid pavement is lower [7]. This paper aims to review individual studies conducted by researchers that have put their efforts into showing the properties of Geopolymer concrete materials, which will help us understand their behaviour as high-quality rigid pavement concrete and promote environmental sustainability.

Geopolymer Concrete

Geopolymer concrete is a type of concrete that is formed by using inorganic aluminosilicate materials. The use of cement has been found to have a negative impact on the environment and deplete natural resources. The production process of Ordinary Portland Cement (OPC) necessitates substantial fuel consumption for combustion and the breakdown of limestone, leading to notable CO_2 emissions. Cement manufacturing facilities emit approximately 1.5 billion tons of carbon dioxide into the atmosphere on an annual basis. Geopolymer concrete has been introduced to reduce this problem. Geopolymer concrete is an inorganic polymer concrete that can be produced at ambient temperature by utilizing industrial waste or by-products as source materials to create a solid binder. It serves a comparable purpose to OPC.

As illustrated in Figure 3, binders such as fly-ash and ground granulated blast furnace slag (GGBS) are utilized, along with alkali activators such as sodium hydroxide and sodium silicate, to enhance the binding characteristics of the concrete [8-9]. Geopolymer binder may be used in applications to totally or partially replace OPC for environmental and technological reasons. A previous study found that geopolymers had no adverse alkali-aggregate interaction, high early strength, low shrinkage, sulphate, corrosion, acid, and fire, and resistance to freeze-thaw and corrosion [10].

Fig. 3: The Manufacturing Geopolymer Concrete [9].

Properties of Geopolymer Concrete

– Non-toxic and bleed free.

– Sets at room temperature.

– Light in weight.

– Higher compressive strength

– Higher resistance to heat and all inorganic solvents. Moreover, GPC source materials provide promising ways to convert waste into resources, thereby contributing to and producing low carbon footprint concrete. The obstinate characteristics of GPC are mentioned in Figure 4 [11].

Fig. 4. Desirable Properties of Geopolymer Matrix [11]

In comparison to regular Portland cement concrete, geopolymer concrete has a very high compressive strength. The early strength of geopolymer concrete was quite high [12].

Under ideal mix design conditions, geopolymer concrete's compressive strength and mechanical characteristics outperform OPC concrete's [13]. The geopolymer is an environmentally benign and sustainable alternative to conventional Portland Cement (OPC)-based concrete because it has the advantages of rapid strength growth, elimination of water curing, good mechanical and durability properties. Portland cement manufacture results in the emission of air pollutants, which causes environmental pollution in the construction sector. It lowers CO2 emissions by 80–90% [14]. Water is a crucial component throughout the geopolymerization process since it helps the initial paste work better but is excluded from the final geopolymer structure. Water does not significantly influence the primary chemical processes of polymerization, in contrast to hydration reactions in ordinary concrete. The mechanical and chemical characteristics of geopolymer concrete are significantly impacted by its excretion during heat treatment and subsequent drying. According to M. S. Eisa (2021), employing geopolymer concrete (GPC) based on metakaolin is more efficient at implementing stiff pavement slabs than Portland cement concrete (PCC) and performs better in terms of drying shrinkage than geopolymer concrete based on slag or fly ash [15]. Several geopolymer pastes (GPPs) compressive strength is mostly influenced by the type of binder, as depicted in Figure. 5 [11]. According to Farooq, F. (2021), as the concentration of GGBFS rises, so will the compressive strength of the sodium silicate (NS), sodium hydroxide (NH), and sodium hydroxide plus sodium silicate solution (NHNS) series [16]. According to researchers who studied the mechanical properties of GPC based on recycled concrete aggregate (RCA) with 50% and 100% RCA content, the compressive strength of GPC increases by more than 10% from 7 to 28 days [17]. According to Palomo et al.'s findings, different FA samples that have been cured at 85 °C for 1 day create materials with compressive strengths ranging from 35 to 40 MPa [18].

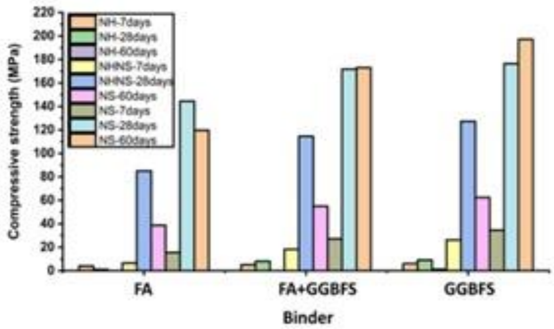

Fig. 5. Effect of Waste Material with Activator on Compressive Strength [11]**.**

Rigid pavements

As a crucial component of the transportation infrastructure, pavement is crucial to contemporary society. Concrete constructed of Portland cement, either plain, reinforced, or prestressed, is used to create rigid pavements. According to Figure 6 [19], the rigid pavement is made up of three layers: the base course, the subgrade, and the cement concrete slab. A solid base or subbase course layer placed beneath the cement concrete slab greatly extends the pavement's life and, as a result, is ultimately more cost-effective. The elastic theory is used to construct rigid pavements and analyze stresses [20]. A rigid pavement tends to spread the load across a somewhat broader area of soil due to its rigidity and high tensile strength, and the majority of the structural capacity is provided by the slab itself. The rigid pavements are used for heavier loads and can be constructed over relatively poor subgrade [21].

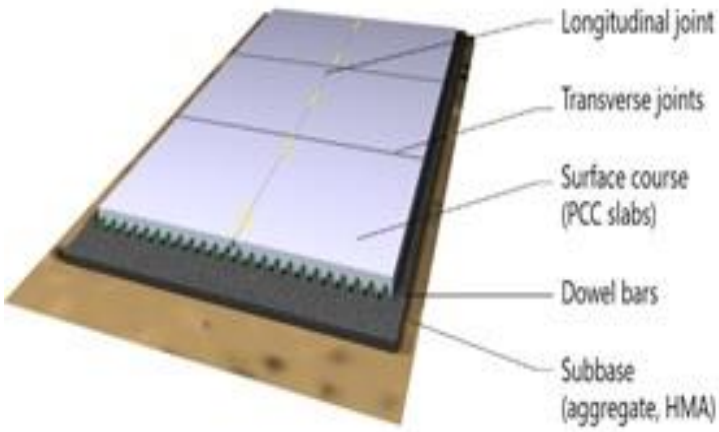

Fig. 6: Geopolymer Concrete [19].

Advantage of Rigid Pavements: [22,23]

- Because rigid pavements have a service life of up to 30 years and do not get deteriorated in wet weather, routine and periodic maintenance expenses are very cheap because only joint repair is needed.
- Rigid pavements have a lower life cycle cost than flexible pavements.
- In especially for the construction of highways passing through weak soils and carrying strong traffic loads, rigid pavements require less total thickness less than flexible pavements.
- Good night visibility even under wet weather conditions.

Rigid Pavement Types

To control the forces acting on concrete pavement, various pavement types require a variety of joints and reinforcement. Four types of rigid pavements can be distinguished:

•Jointed plain concrete pavement (JPCP),

•Jointed reinforced concrete pavement (JRCP),

•Continuous reinforced concrete pavement (CRCP), and

•Pre-stressed concrete pavement (PCP).

Continuously Reinforced Concrete Pavement (CRCP)

Both longitudinal and transverse steel is included in CRCP. Except at construction joints, the CRCP lacks transverse joints. The standard reinforcing steel configuration for CRCP is shown in Figure 7 [24]. The longitudinal steel's purpose is to control temperature and moisture-related changes in concrete volume as well as to maintain transverse fissures well sealed, not to reinforce the concrete slab. The transverse steel's purpose is to maintain the integrity of longitudinal joints and cracks. Concrete stresses in the concrete slab due to traffic loading are decreased if the steel performs its intended purpose and prevents fractures from enlarging [25].

Fig. 7: Continuously Reinforced Concrete Pavement [21]

Concrete Pavement Contraction Design (CPCD)

Transverse joints on CPCD are spaced regularly. The concrete's temperature-related contraction and expansion are managed by the transverse joints. To transfer load, smooth dowel bars are employed at the transverse joints. The transverse joints are separated by 15 feet. Random longitudinal cracking is managed using longitudinal joints. Tie bars are used to secure longitudinal joints. Figure 8 depicts the usual CPCD arrangement [26].

Fig. 8: Concrete Pavement Contraction [26]

The majority of joint failures in concrete pavement are brought on by joint failures rather than slab breakdowns. Cohesive and adhesive failures, in general, and faulting, pumping, blowups, spalling, corner breaks, and mid-panel cracking, in particular, are among the failures. A suitable frequency for maintenance, or joint resealing, can be established since finite element analysis has been used to study the mechanisms of sealant damage [27].

Rigid Pavement Failures

Fatigue cracking has been regarded as the primary requirement for rigid pavement design. The ratio of flexural tensile stress to the concrete modulus of rupture determines the maximum number of load repetitions that can occur before fatigue cracking starts. Pumping has recently been recognized as a crucial failure criterion. Pumping is the downward movement of the slab under heavy wheel loads that results in the ejection of soil slurry through the joints and fractures of cement concrete pavement. Faulting, spalling, and degradation are additional forms of discomfort on rigid pavements [28].

Conclusion

The studies undertaken in the area of applying geopolymer technology to transform raw materials or different wastes into green and sustainable materials, as well as in the direction of sustainable urban development, are briefly discussed in this review article using the life cycle assessment technique. Research shows that the geopolymer production method combines processed natural minerals, wastes, and industrial by-products to manufacture bonding agents, unlike Portland cement. Contrarily, Geopolymer Concrete is extensively used in the building sector due to its superior performance and environmental benefits. Due to their application in bridge construction, high-rise structures, and rigid-paved highways, geopolymer materials can be utilised as eco-friendly and sustainable building materials in future cities.

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