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GEOPOLYMERS – SUSTAINABLE MATERIALS FOR ADVANCED TEXTILES, A SHORT REVIEW

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Abstract: *Geopolymers are inorganic polymers synthesized from alumino-silicate materials, presenting unique advantages such as high thermal stability, fire resistance, and low environmental impact. These properties make geopolymers highly suitable for applications in textiles, particularly in enhancing fabric performance while addressing sustainability challenges. This work investigates the potential of geopolymers as a coating or additive to textile fibers. It explores their role in providing textiles with improved fire resistance, durability, and moisture management. The incorporation of geopolymers into textiles could reduce the need for toxic and unsustainable chemical treatments traditionally used in the textile industry. The sustainability of geopolymers, coupled with their functional properties, offers significant potential for eco-friendly textile solutions. Furthermore, this paper discusses the challenges involved in the incorporation of geopolymers into textiles, such as issues with processing techniques, scalability, and compatibility with existing textile manufacturing processes. The paper also highlights emerging innovations and the ongoing research aimed at improving the properties of geopolymers, making them more adaptable to various textile applications. Additionally, the economic and environmental benefits of incorporating geopolymers in textile production are explored, offering insights into their long-term impact. The application of geopolymers in textiles is a promising area of research that could revolutionize the industry by providing environmentally friendly alternatives and improving fabric performance.*

Key words: *coatings, adhesion strength, fiber reinforcement, thermal stability, mechanical performance*

1. INTRODUCTION

The textile industry is continuously evolving to meet the growing demands for functional, durable, and eco-friendly fabrics. Traditional textile treatments, such as chemical finishes, often involve harmful substances that pose environmental and health risks. In response, the need for sustainable alternatives has led to the exploration of geopolymers, a class of inorganic polymers that exhibit promising characteristics such as high thermal stability, fire resistance, and low environmental impact. According to [1-3], geopolymers are formed via polymerization from alumino-silicate precursors, and their unique properties make them ideal candidates for enhancing the functionality of textiles. Geopolymers offer significant advantages when applied to textiles, especially in providing superior flame retardancy, moisture management, and enhanced durability. Textiles treated with geopolymers can resist high temperatures, reduce the risk of combustion, and offer protection in hazardous environments. Additionally, their ability to improve fabric strength and resistance to environmental factors like UV radiation and chemical exposure makes them highly valuable for industrial applications. Geopolymer coatings can also enhance fabric resilience against wear and tear, leading to a longer lifespan for textiles used in demanding environments. Moreover, geopolymers are considered a more sustainable option compared to conventional textile treatments. Papers [3-4] highlight that, as green materials, geopolymers are derived from abundant natural resources and their production typically involves lower energy consumption and reduced carbon emissions compared to traditional materials, according to the works of [5-6]. Therefore, incorporating geopolymers into textiles aligns with the growing push for eco-friendly alternatives in the textile industry. This paper explores the various applications of geopolymers in textiles, focusing on their ability to enhance fabric properties and reduce the environmental impact of textile production. Furthermore, it addresses the challenges of integrating geopolymers into textile manufacturing processes and discusses future directions for research in this innovative area.

2. SUSTAINABILITY

The environmental sustainability of geopolymers is another key advantage, as their production process is considered more eco-friendly than traditional textile treatments. Geopolymers are synthesized using low-energy processes and abundant raw materials, such as fly ash and clay, which are often waste by-products from industrial activities, as described by papers [3, 5, 7-8]. This makes geopolymers a more sustainable choice for textile manufacturers looking to reduce their carbon footprint, having almost no carbon atoms in their structure as well, thus not being able to release huge amounts of CO_2. Additionally, geopolymers do not contain harmful volatile organic compounds (VOCs) or other toxic substances commonly used in conventional textile coatings, ensuring that treated fabrics do not release pollutants during their lifespan. This sustainability is in line with the global shift towards greener manufacturing practices and the reduction of harmful chemicals in textile production. In **Fig. 1**, the life cycle assessment (LCA) of the geopolymers obtained using mine waste is presented.

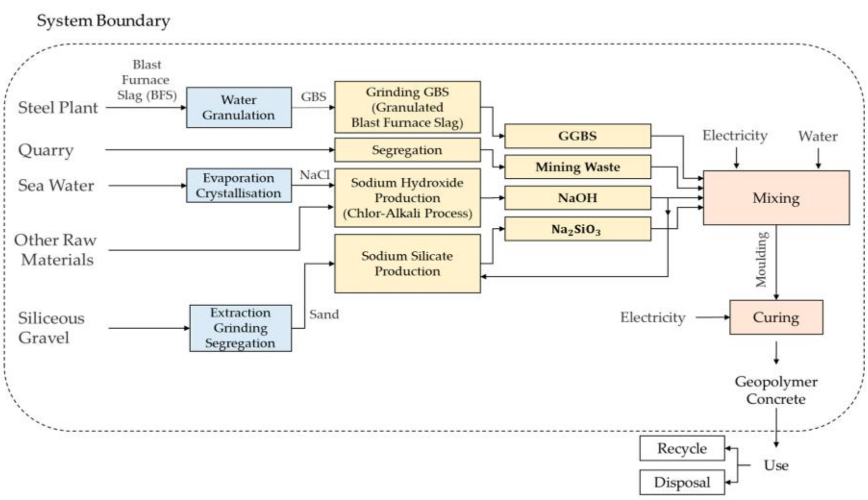

Fig 1*: The LCA diagram of the geopolymerization process when mine waste is used [12]*

3. PROPERTIES AND APPLICATIONS

Geopolymers are increasingly being utilized in the textile industry to improve fabric performance, with applications primarily focused on providing textiles with enhanced properties such as fire resistance, strength, and durability. Depending on the Si:Al ratio, geopolymers can be used in various fields, as described in **Fig. 2**.

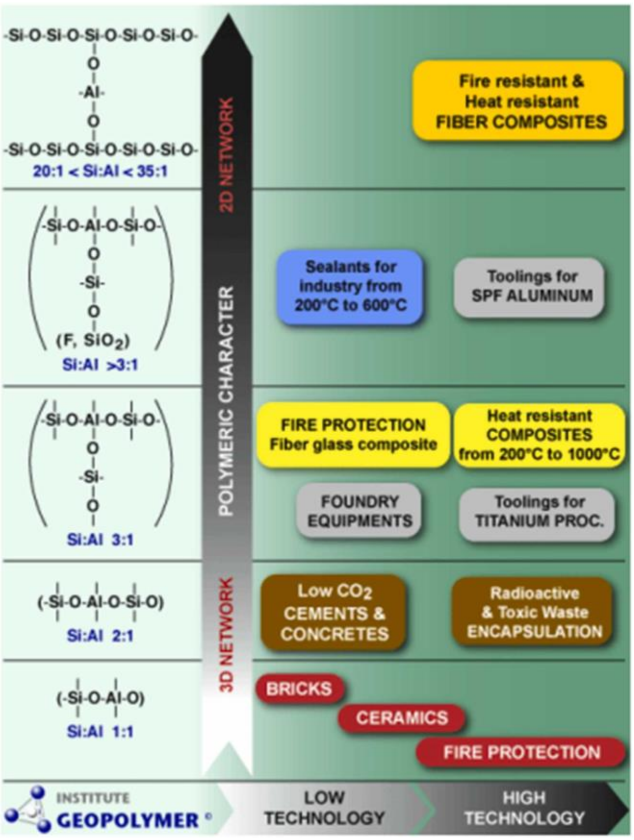

***Fig 2**: The applications of geopolymers according to their structure [13]*

3.1 Fire resistance

The most notable use of geopolymers in textiles is as a flame-retardant coating. Textiles coated with geopolymers show remarkable resistance to fire, making them suitable for protective clothing, upholstery, and industrial fabrics exposed to high heat. One such example is the achievement of the contribution [5], where a geopolymer composite with polyvinyl alcohol fibers and manganese slag was obtained and applied on pine wood boards. The incorporation of PVA fibers lead to a crack-resistant fireproof material. This application is especially crucial in industries such as aerospace, manufacturing, and emergency response, where flame-resistant materials are vital for safety. Geopolymers act as a protective barrier, preventing ignition and reducing the spread of flames, thereby improving overall safety.

3.2 Strength and durability

In addition to fire resistance, geopolymers can enhance the mechanical properties of textiles, making them more durable and resistant to environmental degradation, since their have a multi-metal-oxide structure. By integrating geopolymers into fabrics, textile manufacturers can create materials that are not only strong but also highly resistant to chemical and UV degradation. **Fig. 3** shows how curing age contributes to the compressive strength of the product.

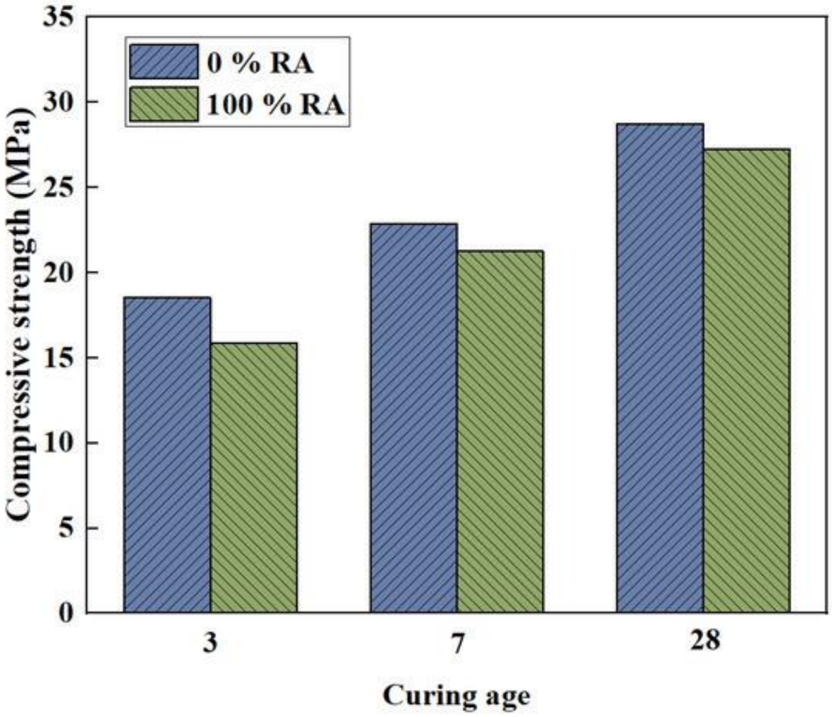

Fig.3*: The effect of curing age upon compressive strength [14]*

This is particularly useful for outdoor textiles exposed to harsh environmental conditions, such as tents, awnings, and outdoor furniture. Geopolymers are somewhat hydrophilic due to their ionic structure. Moreover, their rigid structure is prone to cracks, which facilitates the infiltration of water, thus extending the existing cracks and promoting fungal growth, according to paper [9]. In order to address these issues, geopolymers are blended with hydrophobic materials such as polydimethylsiloxanes (PDMS), which was demonstrated by the works of [9-11]. **Fig. 4** describes the method through which a fly-ash-based geopolymer was coated with PDMS in order to obtain a hydrophobic material. Paper [10] has managed to achieve a contact angle of 113º on the geopolymeric surface, which exceeds the minimum value of 90º that is needed in order for a material to pass the hydrophobicity assesssment. Moreover, upon enhancing the hydrophobicity of the surface even more using calcium stearate and polytetrafluoroethylene (PTFE), the contact angle increased to 140º and 159º, respectively, which means that PTFE turned the geopolymer into a superhydrophobic material, the minimum contact angle value being 150º.

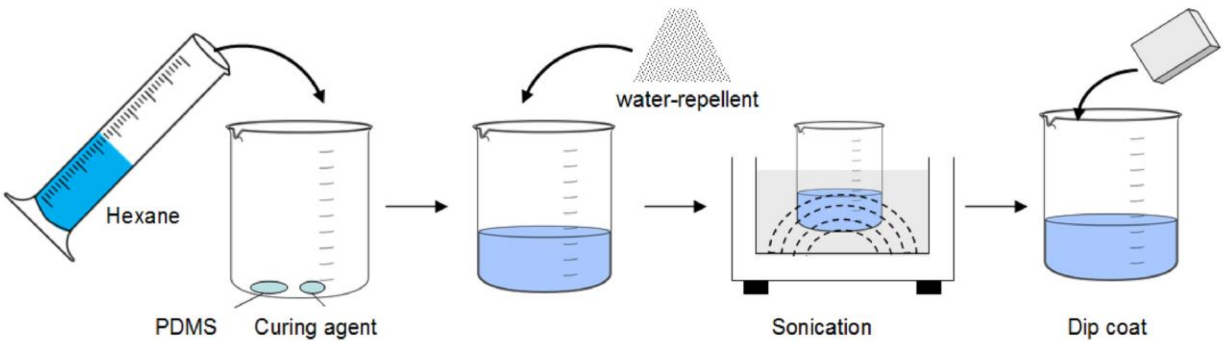

Fig.4: *Synthesis of a water-repellent geopolymer composite [10]*

Contribution [11] used two different coating materials – methylsilicone oil and an organic silicon agent, concluding that the first option is the best one, with a noticeable increase in the contact angle of the geopolymeric surface by almost 70º, which led to a value that is higher than 90º (enough to acknowledge the hydrophobicity of the geopolymeric surface).

4. CHALLENGES

Despite the promising advantages of geopolymers, their implementation in textile materials faces several challenges. One of the main obstacles is the difficulty in achieving uniform coating or integration of geopolymers with textiles due to their rigid, inorganic nature. Unlike organic polymers, geopolymers tend to form hard, brittle films that may not be flexible enough for certain fabric applications, as explained in work [2]. This inflexibility can limit their use in textiles that require high levels of elasticity or softness, such as clothing. Additionally, the integration of geopolymers into existing textile manufacturing processes poses challenges in terms of scalability. Many textile manufacturers are accustomed to using organic, more malleable materials and may need to adjust their processes to incorporate geopolymer-based treatments efficiently. Another challenge is ensuring compatibility between geopolymers and different textile fibers, as some fabrics may react differently to the geopolymer coating, affecting the final product's performance. Furthermore, the cost of producing and applying geopolymers to textiles is often higher than traditional treatments, which can deter widespread adoption in mass-market textile production.

5. CONCLUSIONS

Geopolymers present a promising alternative to traditional textile treatments, offering enhanced performance characteristics such as flame resistance, durability, and moisture management. Their eco-friendly nature, derived from natural and abundant resources, positions them as a sustainable option in the quest for greener textile manufacturing. Although challenges remain in terms of scalability and the integration of geopolymers into textile manufacturing processes, their potential to revolutionize the textile industry is evident. Future research into optimizing their properties and processing methods will likely pave the way for their widespread adoption in textile applications, contributing to both functional and sustainable advances in the industry. With increasing demand for environmentally responsible solutions, geopolymers could play a crucial role in the transformation of the textile sector towards more sustainable practices.

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