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EVALUATION ON THE POTENTIAL OF GEOPOLYMER AS TUNNEL REPAIRING MATERIALS

Repairing tunnels is an essential part of infrastructure upkeep that guarantees commuter safety and the durability of the tunnels. A variety of materials, including cement-based ones like concrete, shotcrete, and mortar, are needed for tunnel repairs. Yet, the hunt for substitute materials has been sparked by the negative environmental effect of cement manufacturing and the accompanying expenses. It has been suggested that geopolymers, a type of materials that develop from the reaction between aluminosilicate minerals and alkali activators, might replace cement-based materials in tunnel restoration. This review paper focuses on evaluating the potential of geopolymers towards applications for tunnel mending because they are a new material with many possible uses.

Keyword: Geopolymer; Tunnel Repairing; Construction Materials

1. Introduction

Tunnel repairing is a crucial aspect of infrastructure maintenance that ensures the safety of commuters and the longevity of the tunnels. Repairing tunnels require a range of materials, including cement-based materials such as concrete, shotcrete, and mortar [1]. However, the environmental impact of cement production and the associated costs have driven the search for alternative materials [2,3]. Geopolymer can be define as an inorganic polymeric cementitious Alumino-Silicate materials possessing an amourphous three-dimensional structure which comprises of SiO4 and AlO4 tetrahedral related by shared Oxygen atoms.

Geopolymers are formed by the reaction of aluminosilicate materials such as metakaolin, fly ash, and slag, with an alkaline activator such as sodium hydroxide (NaOH) or potassium hydroxide (KOH) [4-6]. The reaction between the aluminosilicate materials and the alkaline activator results in the formation of a polymeric network that can bind aggregates and fillers, resulting in a hard, durable, and chemically resistant material. Geopolymers, a class of materials that form from the reaction between aluminosilicate materials and alkali activators, have been proposed as a potential alternative to cement-based materials in tunnel repairing. This paper will provide an overview of the potential of geopolymer as tunnel repairing material.

2. Primary Factor for Tunnel Repair

The primary factor for repair of a tunnel can vary depending on the specific circumstances and conditions of the tunnel. However, there are a few common causes for tunnel repair. The most common causes were age and deterioration. Fig. 1 shows tunnel failure due to age and deterioration. As tunnels age, they can begin to deteriorate due to various environmental factors [7]. Over time, tunnels may deteriorate due to weathering, corrosion, seismic activity, or other environmental factors [8,9].

This can lead to structural issues such as cracking, spalling, and leaks that require repair. For example, exposure to weathering can cause the concrete or steel lining of a tunnel to deteriorate over time. Additionally, exposure to corrosive chemicals or gases can cause the tunnel to weaken and crack, leading to the need for repair.

Similarly, tunnels may also be affected by ground movement due to geological factors, changes in soil moisture, or seismic

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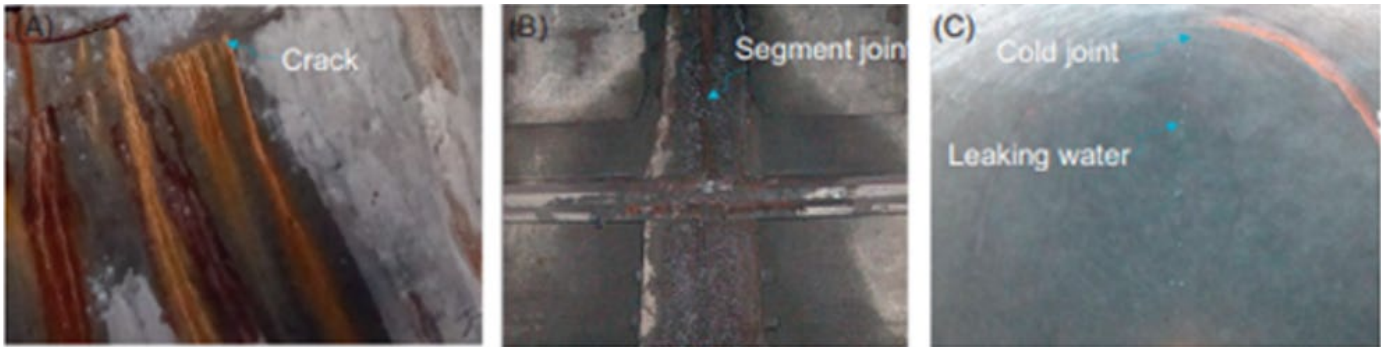

Fig. 1. Tunnel failure due to age and deterioration;(A) crack, (B) corrosion at segment joint, (C) leaking water [9]

activity. Fig. 2 shows the tunnel failure due to ground movement. Changes in soil moisture can also cause the soil to expand or contract, which can put pressure on the tunnel structure and cause cracking or deformation [10,11]. This can cause settlement, subsidence, or heaving, which can damage the tunnel structure and require repair. Whereas, water infiltration is a common issue in tunnels and can lead to deterioration and corrosion of the tunnel lining and structure. Water can seep through cracks or gaps in the tunnel lining, leading to corrosion and deterioration of the structure. In some cases, water infiltration can also lead to soil erosion around the tunnel, which can cause settlement or subsidence. This can be caused by poor drainage, groundwater infiltration, or leaks from adjacent structures.

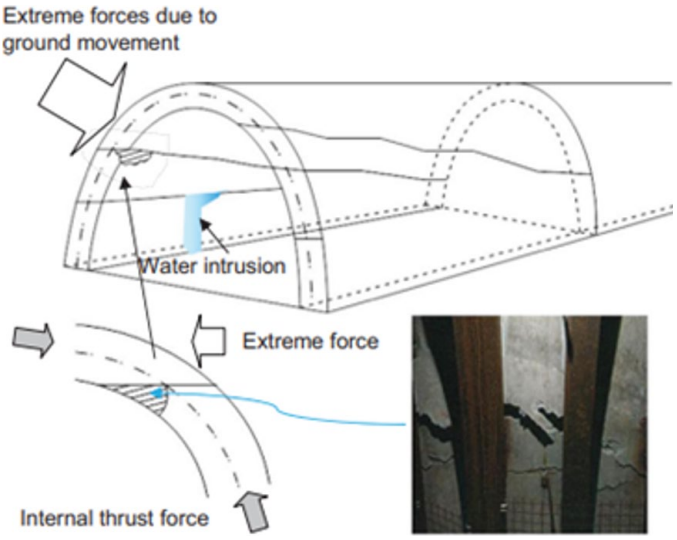

Fig. 2. Tunnel failure due to ground movement [9]

In addition, tunnels may also be subject to heavy traffic loads, which can cause wear and tear on the structure and lead to cracking or deformation of the tunnel walls or roof [12]. Tunnels are designed to withstand heavy traffic loads, but over time, the repeated stress of vehicles passing through can cause the tunnel to deteriorate. This can lead to cracking or deformation of the walls or roof, or even collapse if the tunnel is not properly maintained. Besides that, in some cases, design or construction deficiencies may lead to issues with the tunnel structure, such as inadequate reinforcement, poor materials, or improper installation of tunnel lining [13]. For example, inadequate reinforcement can cause the tunnel to be unable to withstand heavy traffic loads, while poor materials or improper installation of the lining can cause the tunnel to deteriorate more quickly than expected.

In order to prevent the need for major repairs or reconstruction of a tunnel, regular inspections and maintenance are crucial. This can include routine inspections of the structure, as well as measures to prevent water infiltration, such as improving drainage or sealing cracks and gaps in the lining. By identifying potential issues early and taking steps to address them, it is possible to extend the lifespan of a tunnel and ensure that it remains safe and functional for years to come.

3. Conventional Tunnel Repairing Materials

There are several conventional materials that are commonly used for tunnel repairs, including:

Concrete

Concrete is a common material used in tunnel construction and repair. It is strong, durable, and can be easily molded into different shapes and sizes [14]. However, it can be prone to cracking and deterioration over time.

Steel

Steel plates and beams are often used to reinforce or repair tunnels. Steel is strong and can withstand significant weight and pressure, but it can be prone to corrosion and may require frequent maintenance [15].

Shotcrete

Shotcrete is a type of concrete that is sprayed onto a surface using a high-pressure hose [14,16]. It is often used for repairing tunnel linings, as it can be applied quickly and can adhere to a range of surfaces.

Grout

Grout is a type of cement-based material that is used to fill voids or cracks in concrete or masonry [16]. It can be injected into the affected area using a pump, and it hardens quickly, proiding a strong and durable repair.

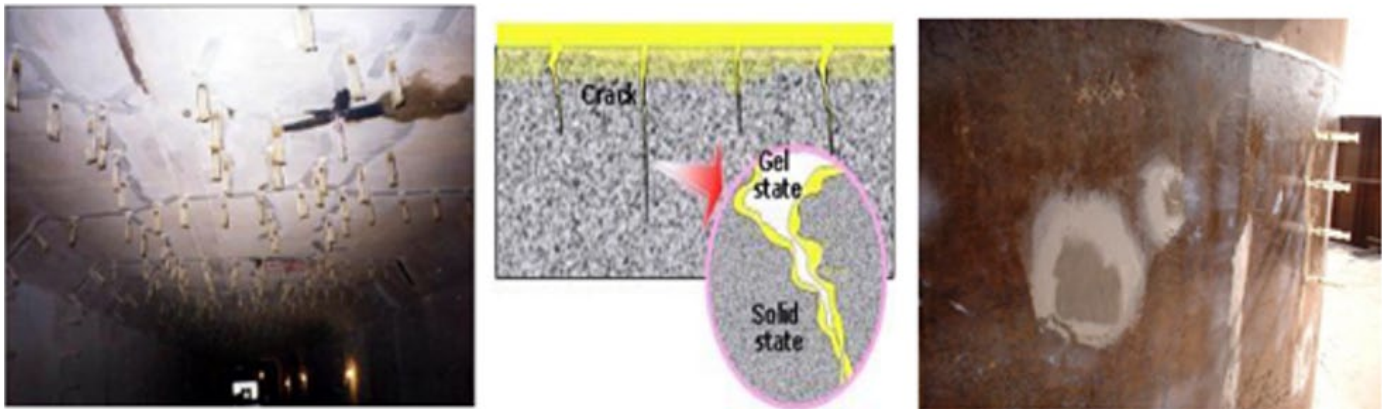

Fig. 3. Crack repairing by injection, sealant and packing [14]

Epoxy

Epoxy is a type of adhesive that is often used for bonding and repairing concrete and steel. It is strong, durable, and can bond to a range of materials [17]. However, it can be expensive and may require specialized equipment for application. Fig. 3 shows crack repairing with epoxy by injection, sealant and packing.

While these materials have been used successfully for many years, they each have their own drawbacks, such as being prone to deterioration or requiring frequent maintenance. This has led to the development of alternative materials, such as geopolymer, which offer improved durability, environmental benefits, and ease of application.

4. Geopolymer as an Alternative Materials

Geopolymer can be as an alternative materials in many applications. It refers to a type of inorganic polymer made from the reaction of aluminosilicate materials with an alkaline activator solution [18,19]. Fig. 4 shown the classification of aluminosilicate source materials available. Unlike traditional cement-based materials that rely on the use of Portland cement, geopolymers utilize a different chemical reaction to create a binding material.

Geopolymers are formed by the reaction of a source material, typically a natural or industrial waste material such as fly ash, slag, or clay, with a strongly alkaline solution, typically made of sodium or potassium hydroxide or silicate [20-23]. The resulting reaction forms a three-dimensional polymer network that provides the material with its strength and durability.

Geopolymer technology offers several advantages over traditional materials such as concrete, including lower greenhouse gas emissions, greater durability, and reduced energy consumption during production [24]. Additionally, geopolymer can be made from a wide range of raw materials, including waste materials, which can help to reduce waste and pollution. Geopolymers have several advantages over traditional cement-based materials, including lower carbon dioxide emissions, greater durability, and resistance to chemical attack [25]. They have been used in a variety of applications, including construction materials, coatings, and composites.

Research into geopolymers is ongoing, and there is potential for their use to expand as more sustainable building materials are sought after. Geopolymers have been studied and developed for several decades, and their properties and applications have been extensively researched [18-25]. Today, geopolymer technology is becoming increasingly popular in the construction industry, as it offers a sustainable alternative to various application including as tunnel repairing material.

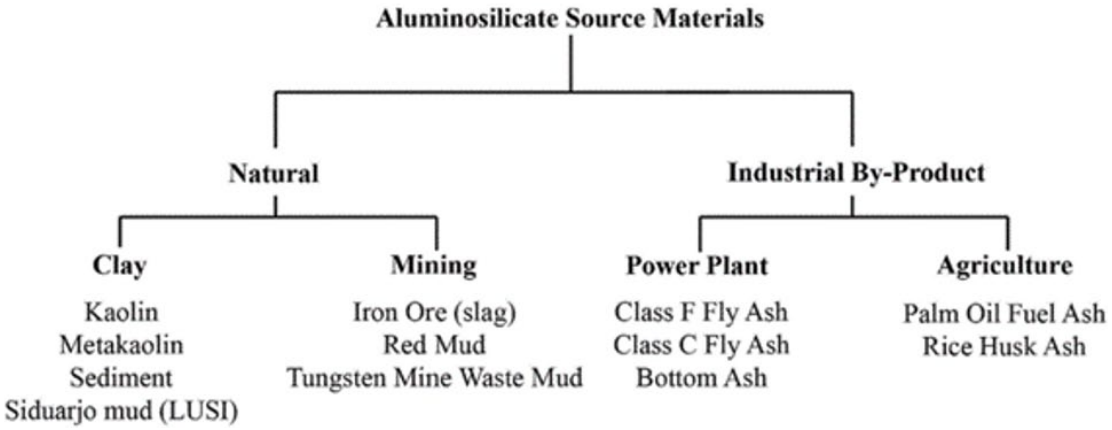

Fig. 4. Classification of aluminosilicate source materials [19]

5. Geopolymer as Tunnel Repairing Materials

Tunnels are a critical part of transportation infrastructure, enabling people and goods to move quickly and efficiently through urban areas and across the country. However, tunnels are subject to wear and tear over time, and they require periodic maintenance and repairs to ensure their safety and longevity. One material that is gaining popularity for tunnel repairs is geopolymer, a type of synthetic material made from industrial by-products that offers a range of benefits over traditional materials.

Geopolymer has several properties that make it well-suited for use in tunnel repairs. First, geopolymer is extremely durable and can withstand a wide range of environmental conditions, including extreme temperatures, humidity, and exposure to chemicals [26,27]. This durability makes geopolymer an ideal material for use in tunnels, which are subject to significant wear and tear over time. Besides that, geopolymer is an excellent adhesive, meaning that it can effectively bond to a range of substrates, including concrete, steel, and other materials commonly used in tunnel construction [1]. This bond strength is critical in tunnel repairs, as it ensures that the repaired area will remain stable and secure over time.

Moreover, geopolymer is easy to apply and can be molded into a variety of shapes and sizes, making it well-suited for repairs to tunnels of different sizes and shapes. Additionally, geopolymer can be sprayed or poured into place, allowing for quick and efficient repairs. Geopolymer also offers several environmental benefits over traditional repair materials. Geopolymer can be made from a range of industrial by-products, including fly ash, which is a waste product of coal-fired power plants [28,29]. This means that geopolymer can help to reduce waste and pollution by repurposing these materials for use in infrastructure projects.

Overall, geopolymer is a promising material for tunnel repairs due to its durability, adhesive properties, ease of application, and environmental benefits. As the need for infrastructure repairs continues to grow, geopolymer offers a sustainable and effective alternative to traditional repair materials that can help to ensure the safety and longevity of critical transportation infrastructure

6. Application of Geopolymer in Tunnel Repairing

Geopolymer has a range of applications in tunnel repairing due to its properties of durability, adhesive strength, ease of application, and environmental benefits. Some specific applications of geopolymer in tunnel repair include:

Tunnel linings

Geopolymer can be used to repair and reinforce tunnel linings, which are subject to wear and tear over time. Tunnel linings are exposed to harsh environmental conditions such as moisture and chemicals, which can lead to deterioration and structural damage. Geopolymer can be applied to the lining surface as a thin layer, providing a durable repair that can withstand these harsh conditions [30]. This material can also help to prevent further damage to the lining by providing an added layer of protection. Geopolymer can be sprayed or poured onto the lining surface, providing a strong and durable repair that can withstand harsh environmental conditions.

Crack and joint repair

Cracks and joints are common issues in tunnel structures that can compromise their safety and structural integrity. Geopolymer is an effective material for repairing these issues because of its ability to fill voids and bond to a range of materials [31]. The material can be injected into the affected area, filling the void and creating a strong bond that can withstand stress and movement. The material can be injected into the affected area, filling the void and providing a strong bond that can withstand the stress and movement of the surrounding materials.

Reinforcement

Geopolymer can be used to reinforce tunnel structures, such as concrete or steel beams, by applying a layer of the material onto the surface [32]. This can improve the structural integrity of the tunnel and prevent further damage. This is achieved by applying a layer of geopolymer onto the surface of the structure. The geopolymer creates an additional layer of support, helping to prevent further damage to the structure and improving its overall durability.

Tunnel roof repair

Geopolymer can be used to repair and reinforce tunnel roofs, which are subject to damage from water infiltration and other environmental factors [33]. The material can be applied in a thin layer, providing a durable and waterproof repair. Tunnel roofs are also subject to damage from environmental factors such as water infiltration. Geopolymer can be used to repair and reinforce these roofs, creating a waterproof barrier that protects against moisture and other environmental damage. This helps to extend the life of the tunnel structure by preventing corrosion and deterioration.

Tunnel waterproofing

Geopolymer can be used as a waterproofing agent for tunnels, providing a protective barrier that prevents water from infiltrating the structure. This can help to prevent corrosion and deterioration of the tunnel structure over time. Geopolymer can be used as a waterproofing agent for tunnels, which is important for preventing water infiltration and the resulting structural damage [34]. By applying a thin layer of geopolymer to the surface of the tunnel, it can help to prevent the ingress of moisture and chemicals. This protects the structure and prolongs its lifespan, reducing the need for frequent repairs and maintenance.

Overall, geopolymer offers several advantages over conventional materials for tunnel repair, including improved durability, ease of application, and environmental benefits. As such, it is becoming an increasingly popular choice for repairing and maintaining critical transportation infrastructure.

7. Advantages and Disadvantages of Geopolymer as a Tunnel Repairing Materials

Geopolymer as a tunnel repairing material offers a range of advantages, particularly when compared to traditional cement-based materials. TABLE 1 shows the Advantages and disadvantages of geopolymer as tunnel repairing materials. One of its main advantages is its durability [27]. Geopolymer has a high resistance to corrosion, abrasion, and chemical attack, which means it can withstand the harsh environmental conditions that tunnels are exposed to [35]. This ensures long-lasting repairs that can withstand the test of time.

Another advantage of geopolymer is its adhesive strength. This material can bond to a range of materials such as concrete, masonry, and steel, creating strong and durable repairs that can withstand stress and movement [36]. This makes geopolymer particularly useful for repairing cracks and joints in tunnel structures, which are common issues that can compromise the safety and structural integrity of the tunnel [37].

In addition to its durability and adhesive strength, geopolymer is also an eco-friendly material. Its production produces less CO_2 emissions than traditional cement-based materials, making it a sustainable option for tunnel repair [25]. This is particularly important in today‘s world, where there is a growing focus on reducing the carbon footprint of infrastructure projects [29]. Another advantage of geopolymer is its ease of application. It can be applied using standard equipment such as sprayers, pumps, and mixers, making it easy to use and apply. This reduces the amount of time and resources required for tunnel repairs, making it a cost-effective option in the long run.

However, despite these advantages, geopolymer also has some limitations. One of its main challenges is its cost [38]. Geopolymer is currently more expensive than traditional cement-based materials, which can make it less economically feasible for some tunnel repair projects. Additionally, there is currently limited availability of geopolymer, and there are only a limited number of suppliers and manufacturers [39].

Another challenge is its lack of standardization. As geopolymer is a relatively new substance, there aren‘t any officially established standards for its use or quality assurance [40]. There is a lack of standardization in its application and quality control, which means that there is still some variability in the quality and effectiveness of repairs using geopolymer.

Despite these challenges, geopolymer remains a promising option for sustainable and durable infrastructure repair and maintenance. As research and development continue, geopolymer is likely to become more widely available, cost-effective, and standardized in its application, making it an increasingly attractive option for tunnel repair.

8. Conclusions

As a conclusion, geopolymer has the potential to be a highly effective material for tunnel repair. It offers several advantages over traditional cement-based materials, including its durability, adhesive strength, eco-friendliness, and ease of application. While there are some challenges to overcome, such as its cost and longer curing time, ongoing research and development are likely to make geopolymer more widely available, cost-effective, and standardized in its application.

As the need for sustainable and durable infrastructure grows, geopolymer has the potential to become a widely used material for tunnel repair, contributing to the longevity and safety of critical infrastructure. Geopolymer has the potential to be a game-changing material for tunnel repair, offering significant advantages over traditional cement-based materials. Its durability, adhesive strength, and eco-friendliness make it an attractive option for infrastructure projects seeking sustainable and long-lasting solutions.

While there are some challenges to overcome, including its cost and limited availability, geopolymer‘s potential to revolutionize the way we repair and maintain critical infrastructure cannot be overlooked. As research and development continue, geopolymer is likely to become more cost-effective, widely available, and standardized in its application, paving the way for a safer and more sustainable future for tunnel repair and infrastructure maintenance.

TABLE 1

Advantages and disadvantages of geopolymer as tunnel repairing materials

Advantages	Disadvantages
Durability: Geopolymer has a high resistance to corrosion, abrasion, and chemical attack, making it a durable material for tunnel repair.	**Cost:** Geopolymer is currently more expensive than traditional cement-based materials, making it less economically feasible for some tunnel repair projects.
Adhesive strength: Geopolymer has excellent adhesive properties, allowing it to bond to a range of materials such as concrete, masonry, and steel. This ensures a strong and long-lasting repair.	**Limited availability:** Geopolymer is not yet widely available, and there are currently only a limited number of suppliers and manufacturers.
Environmentally friendly: Geopolymer is a sustainable material that produces less CO_2 emissions during its production than traditional cement-based materials, making it an eco-friendly choice for tunnel repair.	**Lack of standardization:** Geopolymer is a relatively new material, and there are currently no standardized procedures for its application and quality control.

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