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# Use of aluminum powder for the development of a sustainable paste used in the restoration of historical monuments

*Marianne Saba*[1,*], *Wahib Arairo*[2], *Ghina Sabalbal*[3] , Makram *El Bachawati*[4] , and *Joseph* Absi[5]

[1]Department of Civil and Environmental Engineering, University of Balamand, 110, Lebanon
[2]Issam Fares Faculty of Technology, University of Balamand, 100-Tripoli, Lebanon
[3]Department of Islamic Endowments, Tripoli, Lebanon
[4]Department of Chemical Engineering, University of Balamand, 110, Lebanon
[5]Institut de Recherche sur les Céramiques, CNRS, University of Limoges, 12 rue Atlantis, 87068 Limoges Cedex, France

**Abstract.** The preservation of historic sites requires the development of sustainable restoration materials.. This work examined the use of aluminum powder as a main component in the manufacturing of environmentally friendly pastes for historical monument repair. These pastes currently present a sustainable remedy by inserting the aluminum powder having special properties such as its light weight and size, resistance to corrosion, and excellent thermal conductivity [1]. By thoroughly examining the mechanical, aesthetic, and sustainability aspects of these materials, this study provides insights into the effectiveness and long-term preservation advantages of aluminum powder-based pastes. Results highlighted that the produced pastes have remarkable mechanical properties, such as high compressive strength, superb adhesion, and dimensional stability. Additionally, they are aesthetically compatible, making it possible to replicate the materials and surface textures of the originals. Aluminum powder-based pastes reduce waste and the carbon footprint of restoration projects from a sustainability standpoint. Case studies that successfully use these pastes in the restoration of historical monuments are included in the publication, showing their efficacy, tenacity, and aesthetic compatibility [1]. All things considered, the incorporation of aluminum powder in environmentally responsible pastes reveals to be a promising development in the preservation and restoration of historical monuments, assuring their preservation for future generations while keeping environmental responsibility.

## 1 Introduction

### 1.1 Geopolymer

In recent years, the construction sector has seen a rise in the need for eco-friendly and sustainable materials that can take the place of conventional cement-based materials. Geopolymer paste, a revolutionary material with tremendous potential in numerous construction applications, is one such promising alternative. When compared to traditional Ordinary Portland Cement (OPC) materials, geopolymer paste has several advantages, including greater strength, longer durability, and a lower environmental effect [2].

Aluminosilicate minerals and alkali activators undergo a chemical reaction known as geopolymerization that results in geopolymer paste, a cementitious substance that gives the necessary strength for the polymeric paste. It is commonly made by mixing alkali solutions (sodium or potassium based) with industrial waste materials like fly ash, slag, or metakaolin to create a polymeric network structure. The process of geopolymerization involves the activation of the aluminosilicate precursors via the alkaline solutions that are the activator. This activation process chemically transforms the precursors into a solid matrix. When comparing geopolymer (GP) with cement-based materials, the main advantages are the visible mechanical properties, thermal properties overruling OPC, and good durability properties thus making GP a promising alternative for various construction applications [3].

### 1.2 Use of geopolymer in historical monuments

The use of lime-based mortars and coatings are the leading materials used for building or repairing historical monuments, regardless of how long they date back. Numerous monuments assessed the use of lime-based materials in monumental buildings and restoration. Several researchers such as Paiva et al (2006), discussed the importance of ensuring long-term longevity when restoring mortars and surface coatings, while also ensuring that such repairs can withstand corrosion and environmental disasters such as seismic activities, while also maintaining the authenticity of the monuments [4]. Some advancements in historical monument repair have involved the inclusion of geopolymer in them. According to Kouamo, et al (2012), geopolymers composed of 70 to

* Corresponding author: marianne.saba@balamand.edu.lb

80% volcanic rock and 20 to 30% metakaolin showcased good mechanical and chemical computability requirements for historic buildings [5]. Another renovation work conducted by Maras et al (2021) for an old moment using geopolymer mortars concluded that by reducing the amount of alkali solution and by increasing the extraction rate of the aluminum that comes from the grinding process, the development of a geopolymer recovery mortar for natural stones gave promising results [6]. Lastly, Davidovits et al (2008). proposed a new but equally contentious idea about the Egyptian pyramids in the 1980s. It revolved around the probability that the blocks used in the Egyptian pyramids were cast in situ by the use of disaggregated limestone obtained from Egypt's Giza plateau that come altogether by the use of a binder that is made of either potassium or poly (sialate) [7]. After conducting several studies, scientists approved Davidovit's theory and realized the presence of geopolymer in those archeological sites. Hence, proving that the use of geopolymers as mortars or binders in historical monument restoration is likely probable.

### 1.3 Aluminum incorporation in repair pastes

The conservation and restoration of historical monuments are crucial endeavors that require the selection of materials, performance, and sustainability [8]. Traditional restoration materials frequently lack longevity, and their use can unintentionally result in unfavorable outcomes. As a result, there is a growing need for creative and long-lasting solutions to properly preserve our cultural heritage. Aluminum powder has a variety of distinctive qualities that have gained significant attention. It is considered an alternative option for a variety of applications, including the restoration of historical monuments, due to its lightweight properties, resilience to corrosion, and excellent thermal conductivity [3].

Historical monuments' structural durability and strength are crucially dependent on the mechanical characteristics of restoration pastes. When assessing the effectiveness of such pastes, shear strength, adhesion, and dimensional stability are crucial aspects to take into account. Geopolymer pastes made from aluminum powder have the advantage of enhancing mechanical qualities, making them a reliable option for the restoration procedure. A comparison to attain the characteristics and functionality of pastes based on aluminum powder by conducting comparison tests with conventional geopolymer paste materials is done.

The creation of restoration pastes using aluminum powder as a sustainable element holds considerable potential for the preservation and repair of ancient structures. The lightweight, corrosion-resistance, and high thermal conductivity of aluminum powder are just a few of the qualities that help restore the mechanical and aesthetically pleasing qualities of restoration pastes. Furthermore, the sustainability of pastes made from aluminum powder waste fits with the rising focus on environmentally friendly solutions for historic preservation Parathi, S et al., (2021) [9]. The impact of the aluminum powder on the geopolymerization reaction was first assessed by Jia, D. et al (2021) where it was concluded that aluminum has a major impact on the stimulation of the geopolymerization process [10]. It has been shown that a shorter curing time along with a uniform microstructure and an increased resistance to mechanical stress provided by the geopolymer derived from smaller molecules of metakaolin combined with an aluminum element [10].

The function of aluminum in the production of geopolymer has been investigated by Arriffin et al., (2021) [11]. Concerning the calculated group of ionic charge of aluminum silicate. They discovered that aluminum components have an essential function in the geopolymerization reaction, promoting in a certain way the process of this reaction.

In a study conducted by Onutai et al. (2020), it was demonstrated that the strength of the geopolymer was affected by the concentration of aluminum (Al) waste [12]. While the proportion of alumina determines the setting of the geopolymer, the concentration of silica exerts a more considerable impact on the mechanical strength of the geopolymer. This can essentially be attributed to the increased dissolution of aluminosilicates for higher Si concentration within the geopolymerization process. The final characteristics of geopolymers are substantially influenced by the concentrations of Si, Na, and Al.

The final characteristics of the geopolymerization are conditioned by the extent of this reaction, although most investigators have had the starting constitution of the mixture modified. Indeed, the different raw materials present apparent reactive phases, and the ability of each constituent combines in the system to constitute a solid and stable network. However, the majority of research studies have affirmed that the synthesis of geopolymer is constrained to a limited concentration range of Na, Al, and Si.

This work will focus on investigating the use of geopolymer paste as a repairing material for a Mosque named Attar Mosque ( Figure 1). It is currently being renovated and reinforced with the use of carbon sheets, concrete, and cement plaster. It is situated in Tripoli City in Lebanon. It is a place that dates back several eras, specifically to the year 751 Hijri/1350-51 AD, and is known to have inscriptions inside of it that praise the creator of the early Mamluk and many local legends. It was built using sandstone and mortar with a lime base, and there is evidence of lime plastering on sandstone walls.

This article aims to promote the understanding and acceptance of aluminum powder-based pastes as a workable and sustainable choice for the restoration of historical monuments through extensive work on mechanical properties and varying the rate of Al powder and its size.

It emphasizes how the aluminum powder is used in geopolymeric binders as a sustainable component in the creation of repair pastes, thus improving the mechanical properties of restorative pastes while maintaining an environmentally friendly aspect.

**Fig. 1:** View of the dome structure in Al Attar Mosque.

## 2 Methodology

The first part of the work consisted of preparing the raw materials: Metakaolin and aluminum powder. The essential precursor of silica was acquired by grinding and calcinating the Lebanese kaolin to turn it into Metakaolin. This dehydrated clay-based material is a mineral containing high amounts of silicate and aluminum. Kaolin is found in abundance in Lebanese soil and geological formations making its sourcing easy and eco-friendly since it does not require the same process of production as OPC. Figure 2(a) illustrates the natural form of Kaolin obtained from the initial rocks. The Los Angeles apparatus is used to grind the Kaolin rocks, which are later then crushed using hammers, and passed through a No.200 mesh sieve to obtain the adequate fineness of the Kaolin desired. The fine Kaolin is then placed in a furnace at 750°C for 7 hours to calcinate it, thus turning it into dehydrated Metakaolin observed in Figure 2(b).


**Fig. 2:** (a) Coarse Kaolin & (b) Fine Metakaolin

The second material used in the mix was the waste aluminum powder. The latter was used under fine and coarse sizes to evaluate the impact of size on the mechanical performance of the geopolymer binder. Obtained from a local aluminum industry that produces doors and windows in North Lebanon, the aluminum passed 2 different mesh sieve sizes that are later on used in the formulation of the samples. The first batch of aluminum is of the very fine type, having a similar fineness to the metakaolin, that passes the mesh sieve No. 200. As for the second size, a coarse aluminum was obtained after grinding it in a machine, that reaches a size of 400 µm. The addition of aluminum occurred at 2 different percentage additions, one being 5% and the other being an addition of 20% of aluminum in mass to the mix designs to evaluate the impact of the increase of aluminum content and size variation in the paste on sandstone rocks. Such addition can help in enhancing the mechanical properties of the geopolymer paste because the aluminum reacts with the alkali activator which then produces hydrogen gas and causes foaming to appear. The foaming observed renders the material to become lightweight and porous, also making it a great thermal insulator. This phenomenon decreases the paste's density and makes it act as a lubricant, facilitating the application process. A Sodium-based alkaline solution was also prepared by mixing sodium-hydroxide pellets with a sodium silicate solution to obtain a $Na_2O/SiO_2$ ratio of 1.8. A ratio of 1:3 was assigned between the Lebanese metakaolin to Normalized sand for the preparation of the geopolymer samples. In addition, the admixture gel was inserted to achieve a porosity of 0%, 0.1%, and 0.2% in the samples according to a mass addition. The alkali solution was gradually added to the mix, after mixing the solid powders with the admixtures altogether, where a homogeneous-like state was observed. The following was mixed for an additional 5 minutes and was, later on, poured into molds and vibrated for 60 seconds with the use of a vibrating table to leaze the air bubbles escape and ensure good settlement. The samples were set aside to dry for 24 hours. The several steps involved in the sample preparation are shown in Figure 3.

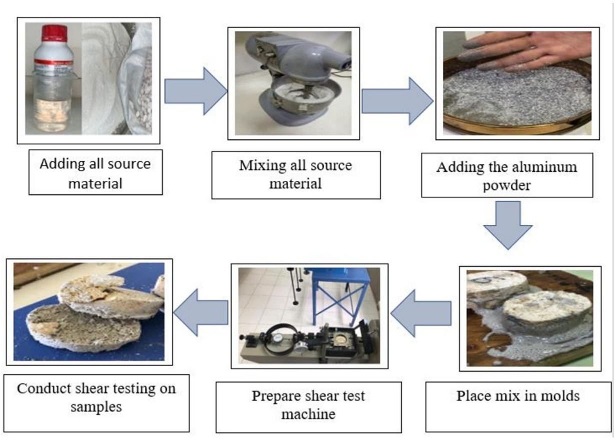


**Fig. 3:** Mix Design Process.

The mechanical properties of the geopolymer concrete samples, where specific IDs were assigned to each type of mix made are identified in Table 1. The properties of the several batches were assessed by conducting shear tests on the machine provided by the CIEL Laboratory at the University of Balamand. ASTM D 3080 standards were followed to conduct the testing with aging (day 90) since it is crucial to understand the relationship between shear stresses and normal strain as illustrated in Figure 4 [13].

**Fig. 4:** (a) Closeup view of the sheer test machine and tested samples (b)

**Table 1**. ID Samples.

| Name | Composition |
| --- | --- |
| GP-0 | Reference mix |
| GP-5-F | 5% Fine Al |
| GP-20-F | 20% Fine Al |
| GP-5-C | 5% Coarse Al |
| GP-20-C | 20% Coarse Al |

## 3 Results and Discussion

The findings of the shear tests performed on the pastes made from aluminum powder offer useful information about their mechanical capabilities and appropriateness for restoring ancient monuments. These pastes' capacity to withstand stresses and preserve the structural integrity of the rebuilt monuments depends critically on their shear strength.

The results show that the shear strength of the pastes made with aluminum powder is superior to that of conventional paste materials GP-O. The distinctive qualities of aluminum powder, such as its light weight and exceptional bonding abilities, can be credited for this high shear strength. A stronger interlocking structure is created by the aluminum particles in the paste, increasing shear resistance.

The aluminum powder-based pastes' exceptional shear strength ensures the stability and endurance of the rebuilt monuments, especially in the presence of even in difficult environmental circumstances. This is crucial for sites situated in areas vulnerable to earthquakes or strong winds. The ancient structures are long-term protected by these pastes' capacity to withstand shear stresses, which reduces the chance of structural failure. The adhesive qualities of the pastes based on aluminum powder are shown by the shear tests. Due to the paste's and the substrate's tight bond, there will absence of delamination or separation is assessed. For the restored surface to remain intact, especially in places subject to moisture or temperature changes, this adhesive strength is essential.

The aluminum powder-based pastes' dimensional stability under shear stress is another benefit. The pastes barely distort or creep, maintaining their original form and shape. This quality is essential to maintaining the architectural integrity of historical structures and assuring the accuracy of replicas. The shear test findings confirm that pastes based on aluminum powder are appropriate for restoring historical monuments. They are the perfect option for withstanding external stresses and guaranteeing the long-term stability of the rebuilt structures because of their high shear strength, good adhesive qualities, and dimensional stability. Figure 5 examines the interactions between the pastes at various masses addition of Al and various sizes types. It highlights that the reference mix had the lowest properties ( day 90) thus indicating that the Al powder in coarse and especially fine graded ( GP-5-F and GP-20-F) have great shear properties thus shedding light on the pastes' suitability and performance in particular restoration scenarios. The shear tests performed on the pastes made from aluminum powder show that they have superior mechanical and adhesive capabilities. As a result of these pastes' exceptional shear strength, renovated historical monuments will be stable and long-lasting. The accuracy of replication and preservation of architectural integrity is further aided by the pastes' dimensional stability. The findings demonstrate the potential of pastes made from aluminum powder as a dependable and efficient method for preserving and restoring ancient sites is feasible specifically when used in a small amount and applied in fine grinding in the paste. In conclusion, two major points were assessed in this study. The first assertion observed in Figure 5, was that the samples GP-5-F gave higher properties than the GP-20-F thus emphasizing the importance of the amount of waste powder in the paste. Second, it was seen that the impact of coarse materials had similar effects on the shear giving very similar values.

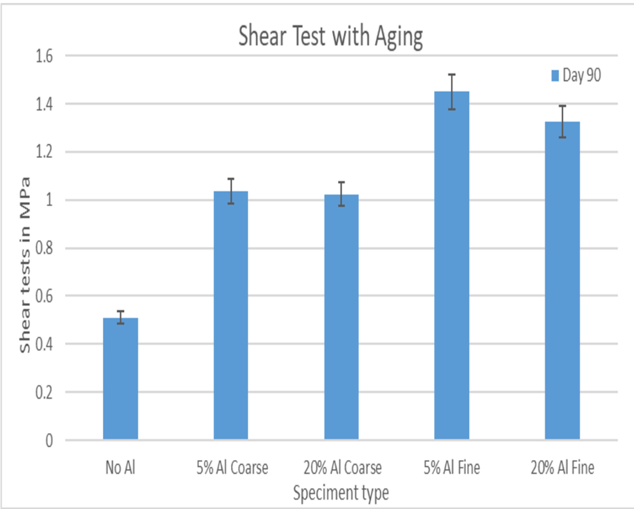


**Fig. 5:** Shear tests of the various mortars produced with aging.

## 4 Conclusion

Innovative and sustainable methods are needed for the conservation and restoration of historical sites to assure their long-term preservation. The use of aluminum powder as a crucial component in the creation of a sustainable paste for the restoration of historical monuments has been examined in this article, providing light on its mechanical, aesthetic, and sustainable characteristics. This study is the first of its kind to evaluate the incorporation of geopolymer with aluminum powder in sandstone blocks, offering novel perspectives on the restoration of old monumental buildings and showcasing a special combination that improves durability and preserves authenticity.

There are numerous benefits of using aluminum powder in repairing pastes. The lightweight design, excellent thermal conductivity, and other distinctive qualities of it improve the mechanical performance of the pastes. The aluminum powder-based pastes' excellent shear strength, adhesive qualities, and dimensional stability have been shown through shear testing, confirming their appropriateness for withstanding outside forces and maintaining the structural integrity of rebuilt monuments. When restoring historical monuments, aesthetic concerns are crucial, and pastes based on aluminum powder excel in this area as well. These pastes are an interesting option for establishing visual accuracy because they may mimic the appearance of original materials, make color matching easier, and offer surface textures that closely reflect the historic substrate.

Any restoration project must consider sustainability and pastes based on aluminum powder fit the trend toward more environmentally friendly solutions. The waste reduction and reduced carbon footprint associated with restoration activities are made possible by the recyclability and reusability of these pastes. Their sustainability profile is further improved by their compatibility with numerous historical materials. The case studies provided in this article serve as real-world illustrations of how aluminum powder-based pastes can be used successfully to restore historical monuments. In various restoration settings, these case studies have demonstrated the efficiency, robustness, and aesthetic compatibility of the pastes, highlighting their potential for wider use.

As a conclusion, the conservation and restoration of historical monuments can be accomplished with the use of pastes based on aluminum powder. These pastes' exceptional attributes have been demonstrated by careful examination of their mechanical performance, aesthetic compatibility, and sustainability aspects. We can guarantee the long-term preservation of our cultural legacy while upholding environmental responsibility by using aluminum powder in restoration procedures. The development of sustainable monument repair techniques will be aided by ongoing study and practical use of pastes based on aluminum powder, preserving these priceless historical structures for future generations.

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