Impact of Washed and Unwashed Beach Sand on Geopolymer Mortars

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Abstract. This research examines how the choice of sand aggregates (fine or coarse) affects the mechanical characteristics of geopolymer mortars, particularly emphasizing the use of two types of beach sand: washed and unwashed. Different sets of geopolymer mortars were made using various types of sand: Egyptian sand, unwashed Beach Sand (coarse, & fine), and Washed Beach Sand (coarse & fine). Standard curing techniques were followed to evaluate mechanical properties. The results show apparent differences in the mechanical performance of geopolymer mortars according to the fineness of the aggregates used and the impact of the washing. The compressive strengths of mortars made with unwashed beach sand differed significantly from those made with cleaned sand [2]. As such, this study advances the knowledge of the complex interactions between various fine aggregates and the functionality of geopolymer mortars. It highlights the relevance of fine aggregate selection and the optimization of mortar formulations to improve mechanical qualities and durability [3]. This will help to promote the broader use of geopolymer-based materials for more sustainable, eco-friendly construction projects. This study researched the relationship between the mechanical properties of geopolymer mortars and various kinds of sand. The aim was to acquire the fundamental knowledge to choose eco-friendly and sustainable building materials. Egyptian sand and fine, regular beach sand were seen to have consistent and dependable compressive strength characteristics.

1 Introduction

Construction materials are fundamental components of any building or infrastructure project. Over many centuries and until the present day, civilizations have always relied on various natural and synthetic substances to use in their shelters, roads, bridges, and other structures. The most prevalent categories of building materials include steel, wood, masonry, concrete, and geopolymers. The most common foundation material in modern buildings is concrete, created by combining cement, aggregates, and water. Its advantages include a high compressive strength, low cost, and the ability to be formed into any shape [4]. Since it can be casted into any shape and has a high compressive strength, it has been a vital component of our built environment for centuries. Its historical relevance can be found in the employment of crude concrete forms in ancient civilizations' construction of long-lasting structures. Technological developments have characterized the evolution of concrete, leading to the creation of high-performance concrete formulas with exceptional strength, durability, and adaptability.
However, the construction industry faces unparalleled problems at this crossroads in the twenty-first century, especially concerning sustainability and environmental impact.

1.1 Impacts of Concrete Production

Concrete is by far the most used material in the construction industry because of its strength, durability, and affordability. However, the process behind its production raises many concerns about its impact on sustainable development. These concerns include energy consumption, carbon emissions, resource depletion, waste generation, and many more.
The production of concrete is extremely high, and it is an energy-consuming process. This is mainly due to the high temperatures required to manufacture cement, one of concrete's primary ingredients. Manufacturing just one ton of cement requires 60-130 Kg of fuel oil or its equivalent and 110 kWh of electricity. Cement production reaches over 4 billion tons annually worldwide, so the associated energy consumption is massive. Traditional concrete production is known for its high carbon footprint, accounting for around 8% of worldwide CO_2 releases. This is caused mainly by the production of Ordinary Portland Cement (OPC), the key binding ingredient in standard concrete mixes. Making Portland cement requires immense heat from burning limestone and clay in kilns, resulting in CO_2 emissions from both the industrial process and chemical reactions. Add to that, concrete still emits CO_2 long after its initial production and curing, and this is due to the process of carbonation that occurs over the lifetime of concrete structures, during which the concrete re-emits large amounts of CO_2 that it had previously absorbed during production.

This has led to a surge in the search for alternatives that can maintain or surpass the Portland cement performance in the concrete mix while minimizing its ecological and environmental impact. It allowed the development of eco materials such as geopolymers[4-5].

1.2 Geopolymers as a Sustainable Alternative

Geopolymers are being considered as an environmentally friendly substitute for concrete. Geopolymer binders yield 80% less greenhouse gases, harden more quickly than OPC (Ordinary Portland Cement), and have better durability and heat resistance properties. Geopolymers can be made from a range of aluminosilicates and industrial by-products. The most common sources are fly ash, bottom ash, slag, and metakaolin. They can be used as a binder instead of the OPC in concrete mixes. Fly ash is a by-product of coal combustion in thermal power plants; it is made out of fine particles that rise with flue gases during combustion and is rich in reactive silicon and aluminum. Bottom ash is the coarse particles that collect at the bottom of coal furnaces after combustion; it has a porous structure and contains iron oxides and silicates; however, it has a lower reactivity than fly ash in geopolymers. Slag is a by-product of steel production in furnaces; it is rich in calcium, alumina, and silica compounds that come from impurities in the iron ores. Finally, metakaolin is derived from a natural clay mineral called kaolinite, which is obtained by heating the purified kaolinite to temperatures between 500 °C and 800°C. It also contains trace amounts of quartz and other minerals. With the help of geopolymers, it is possible to repurpose industrial waste products more usefully, lowering waste streams and producing building materials with improved performance and a smaller carbon footprint. Geopolymers provide an enticing green substitute for traditional concrete for many building applications involving decreased environmental impacts and enhanced technical capabilities [4]. The production of geopolymers requires significantly less energy than the manufacture of conventional cement. This is primarily due to the lower temperatures needed for geopolymer synthesis. While cement production requires kiln temperatures of around 1450°C, geopolymers can be synthesized at room temperature or slightly elevated temperatures under 100°C. The raw materials for geopolymers also require less preparatory processing than OPC. Sources of aluminosilicates like metakaolin must not be decarbonated or ground into a fine powder before use. The lower energy needs for both processing raw materials and activating geopolymer synthesis mean the embodied energy of these novel binders can be 60% to 80% lower than conventional cement. Another sustainable benefit of geopolymers is that they utilize abundant aluminosilicate materials that are considered wastes or by-products of other industrial processes. In contrast, the production of traditional Portland cement requires the intensive mining and processing of raw ingredients like limestone. The availability of suitable sources of materials like limestone is declining in many regions, forcing increased haul distances and higher costs. Geopolymers are not dependent on scarce natural resources and make use of industrial by-products that would otherwise represent a waste disposal challenge. They provide an opportunity to recycle metakaolin by calcining kaolin clay, fly ash, and bottom ash from coal combustion, as well as slag from steel manufacturing, rather than landfilling these waste products. It has been estimated that producing one ton of geopolymer concrete can use 80-90% less raw materials and avoid landfilling up to 1.5 tons of fly ash compared to traditional concrete. The processing and synthesis of geopolymers also generate minimal waste since the reactions occur near ambient temperatures [6].

1.3 Applications of Geopolymers

Geopolymers have also been proposed as a greener alternative to ordinary Portland cement due to their production significantly lower carbon emissions. Traditional cement manufacturing releases high levels of CO_2, both from the limestone calcination process and the combustion of fuels in the kiln. Geopolymers derived from aluminosilicate sources like fly ash and Slag do not require energy-intensive decarbonization or heating above 100-200°C. Estimates suggest the synthesis of geopolymers generates only 0.184 tons of CO_2 per ton of binder, whereas Portland cement production emits up to 1 ton of CO_2 for each ton made. Using waste-derived ingredients, geopolymers offer a substantial opportunity to decrease the carbon emissions of traditional concrete production[4-6].

One of the most promising applications of geopolymers is in developing sustainable, environmentally friendly concretes and cement. Geopolymer concretes have been shown to have comparable or superior mechanical properties and durability compared to traditional Portland cement concretes while being significantly more sustainable regarding energy consumption, resource depletion, waste generation, and CO_2 emissions during production.

However, this is not the only application in which geopolymers are taking over; geopolymers are also being used as sustainable alternatives to traditional ceramic materials and composites. They can be formed into ceramic materials through the reaction of aluminosilicate-cate powders with alkaline activators, followed by shaping and curing at relatively low temperatures compared to the sintering of conventional ceramics. Like geopolymer concrete, a major advantage of geopolymer ceramics is the ability to achieve high mechanical strength, thermal and chemical stability, and other desirable properties at temperatures around 500-800°C lower than required for ordinary ceramic production. This results in significant energy savings and more cost-effective manufacturing. Geopolymers have been successfully synthesized into a variety of ceramic materials, including fire insulation, refractory linings, ceramic tiles, porous ceramic composites, and more [4-5].

1.3.1 Impact of Sand Type on The Mortar Mix

The type of sand used as fine aggregate in concrete can significantly influence the fresh and hardened properties of the concrete mix. The mineralogical composition, particle shape, gradation, and cleanliness of the sand all affect workability, strength development, and durability. When unwashed beach sand is directly incorporated into concrete mixes, salt (sodium chloride) can have several impacts. The salt's chloride ions can delay the cement's setting and hydration process, prolonging the time required for the concrete to gain strength initially[7]. Over the long term, these chlorides can penetrate through the concrete cover and initiate corrosion of any reinforcing steel present, leading to structural issues. Additionally, residual salt remaining in the concrete can dissolve in moisture and migrate to the surface, leaving behind unsightly white salt deposits known as efflorescence. In high concentrations, chlorides can also negatively impact cement hydration, resulting in reduced ultimate strength for the concrete [2- 8].

To mitigate the issues caused by the salt in the beach sand, the sand can be washed with fresh water and then dried in the oven before being incorporated into concrete production. Using correctly washed and dried beach sand can provide several key benefits, as the washing process reduces the chloride content to minimal levels, significantly minimizing the risk of corrosion, efflorescence, and retardation caused by those chlorides. Clean Sand without contaminants can also improve the workability and flow of the fresh concrete mix. Furthermore, the cement hydration process is not disturbed with chlorides removed, allowing the concrete to develop its full potential strength properties [9-10]. In the case of geopolymers, very little has been done on the impact of applying beach sand, washed or unwashed, on the properties of geopolymer mortars. As such, the study aims at creating an approach to the feasibility of using the beach sand in all sizes and assessing the impact of its being washed and unwashed on the geopolymerization reaction. All that will be renowned in the compressive strength results.

2 Methodology

For the mix design, Egyptian sand, known to have a similar granulometry to normalised sand, was compared with two different sizes of beach sand sieved to attain coarse and fine sieve characteristics. The beach sand was collected on-site from Anfeh, a coastal city in the North of Lebanon. The beach sand was first sieved according to ASTM specifications to separate the coarse and fine particles. The first one was made of the sand retained on sieve #50, and in the final tray, and is identified as beach sand Type 1. As for the second type of sand, it consisted of the sand retained on sieves #30 and #40, and is identified as Beach Sand Type 2.
In the coming step, the beach sand Type 1 was washed as it was humid and contained water. The drying process was done in the CIEL laboratory at the University of Balamand at 100 degrees in the oven, resulting in the beach sand type 3. The exact sieving process that was done with beach sand type 2, which is identified as beach sand type 4. The granulometry of the beach sand and the Egyptian sand is represented in Figures 1 and 2 to simply visualize and compare the fineness and passing grade of the sand.

2.1 Mix Designs

Five significant mix designs were developed for the elaborated research. The solid phase of the material was composed of metakaolin purchased from Imerys, and its granulometry is seen in Figure 3, and sand; the overall composition makes up the precursor. The sand characteristics and sources varied from one mix to the other; as such, the specifications are summarized in Table 1. The liquid part of the geopolymer (activator) is a sodium-based alkali solution. This solution was prepared one day before the mixes to avoid exothermic reactions following an $SiO_2/Na_2O = 1.5$.

Table 1. Sand Types

Elements	Sand
Mix 1	Egyptian Sand
Mix 2	**Fine** Wash Beach Sand (Type 1)
Mix 3	**Coarse** Beach Sand (Type 2)
Mix 4	**Washed**, **Coarse** Beach Sand (Type 3)
Mix 5	**Washed**, **Fine** Beach Sand (Type 4)

2.2 Sieve Analysis

Sieve analysis is a method used to assess the sample gradation, showing the distribution of particle sizes.

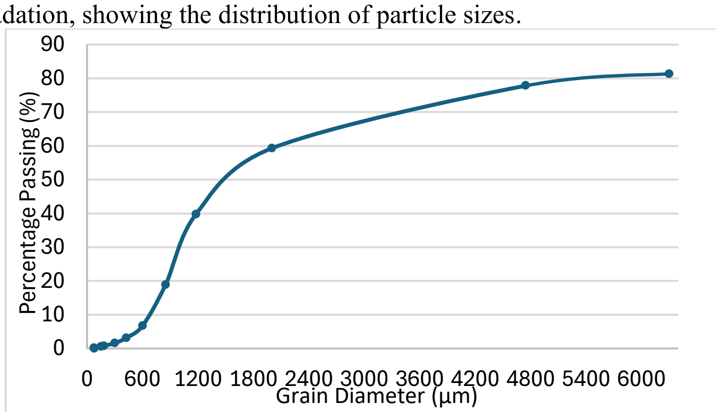

Fig. 1. Granulometry of Beach Sand

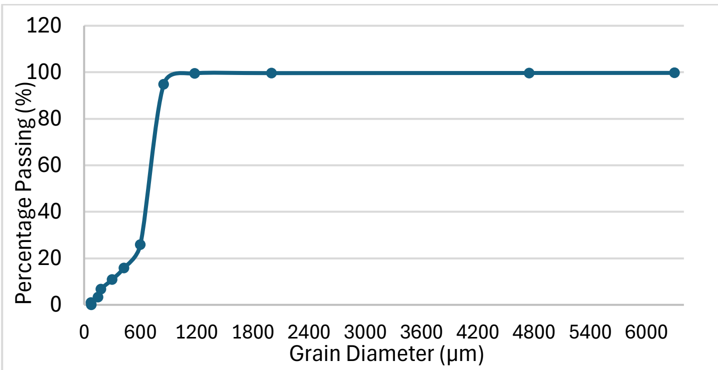

Fig. 2. Granulometry of Egyptian Sand

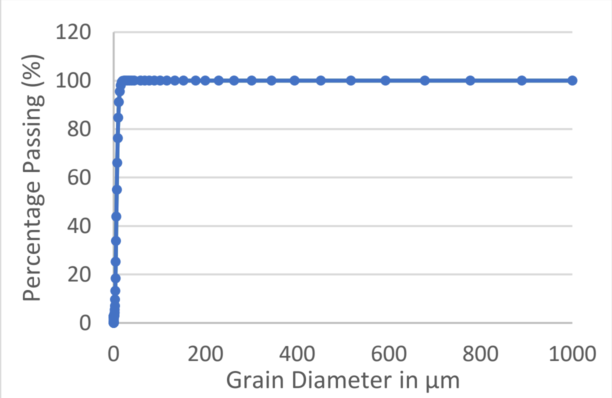

Fig. 3. Granulometry of Metakalolin

2.3 Tests

Five mix designs were elaborated for this investigation, each varying a physical property of the sand as mentioned in Table 1; ie, Egyptian Sand was used in Mix 1, and two other batches of beach sand with differing fineness and coarseness were used in Mixes 2 and 3. The particle size distribution of the two batches of beach sand used in Mixes 4 and 5 also varied. The basic mechanical properties of the mortars elaborated were tested on days 7, 28, and 90 to understand and assess the behavior and impact of the beach sand (washed and unwashed) on the compressive results. The 4*4 cm cubical samples were tested on a UTM Compression test machine. To assess repeatability, an average of 5 cubes was tested for each mix at each curing age.

3 Results and Discussion

The mix designs were evaluated to determine their compressive characteristics. The results obtained are analysed to assess each mix formulation's performance attributes. The results of the 4x4x4 cm cubical samples are presented in Figure 4 for samples tested from an early age (7 days) up to 90 days.

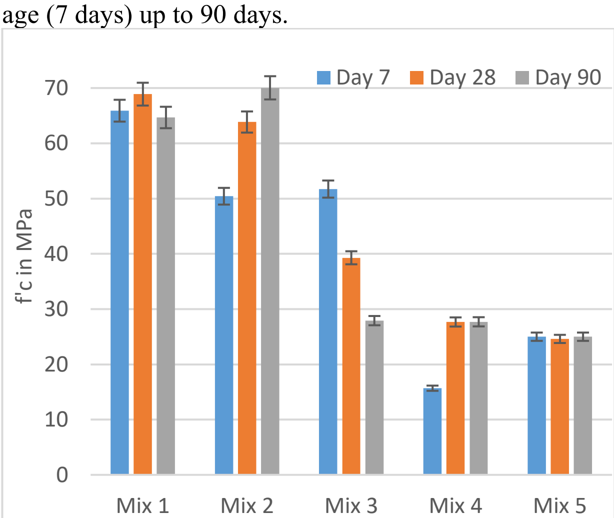

Fig. 4. Compressive Strength for Cubical Samples

The experimental investigation's findings on the mechanical characteristics of geopolymer mortars shed light on the complex interaction between the different types of Sand used and the granulometry. The observed differences in compressive strength between the five mix designs highlighted the complex relationship between sand characteristics and mortar performance, considering both the sands' features and their interactions within the mortar matrix. Throughout the curing time, mix 1, which contained Egyptian sand with similar behavior to normalized sand, showed comparatively high compressive strength values, revolving around 67 MPa. This finding implies that Egyptian Sand allowed strong interparticle bonding and adequate packing inside the mortar matrix, potentially as a function of its mineralogical composition and particle size distribution. These qualities are essential for creating mortar constructions that are long-lasting and able to sustain applied loads and environmental conditions. This implies that the granulometry of the samples has highlighted that the f'c of the samples was high due to the fine and compacted samples.

Moreover, mix 2, made of fine, normal beach sand, demonstrated a significant increase in compressive strength during the curing time. Increased interparticle cohesion and mechanical integrity are the results of the microstructure's progressive refinement and the geopolymer binder's ongoing geopolymerization reaction, which are responsible for the observed enhancement in f'c. The observed strength improvement is attributed to the enhanced packing and interlocking within the geopolymer matrix due to the fineness of the used aggregates.

On the other hand, mix 3, which included coarse normal beach sand, showed a decrease in compressive strength over time, suggesting that using coarser aggregates in geopolymer mortars may present some difficulties. Coarser sands frequently have less effective particle packing and less surface area available for interfacial bonding, which results in mortar structures that are weaker and have worse mechanical qualities. The observed reduction in strength emphasizes how crucial it is to maximize aggregate particle size distribution for the best mortar performance.

As for sample mixes 4 and 5, which respectively included coarse and fine-washed beach sands, the compressive strength values were relatively lower than the f'c of the mix designs in samples 1 and 2. As such, the sand's properties and the effect of being washed or not affect quite a lot of the sand's surface properties. As such, the effect of the sand washing has relatively compacted the f'c and thus impacted the interaction with the geopolymer binder and other particles inside the mortar matrix. In general, this observation reveals how complex sand types affect the binding potential and the mechanical properties of the geopolymer mortar and affect the geopolymer reaction. Comprehending these correlations is essential to optimizing mixed designs and enlarging sustainable building materials' mechanical attributes and longevity. Additional investigation into the basic principles controlling the interactions between sand and binder and

how they affect mortar performance is essential for increasing the f'c of geopolymer samples.
This implies that the sand quality, being washed or not, greatly impacts the mechanical performance of the material. The results highlighted that the pores and interconnecting bonds are quite affected by the size of the aggregates (fine or coarse) and the source type, and highlighted, at last, the intricate correlation between mortar qualities and sand characteristics, underscoring the need for mixed design optimization to improve the mechanical properties of the geopolymer mortars.
Eventually, it is highly important to note that very few studies have assessed the impact of beach sand, and none have studied the effect of the washed and unwashed beach sand with a variation in particle size distribution. Nevertheless, when comparing the results of this study with the work conducted by Truong et al., it was shown that the beach sand had no negative effect on compressive strength [11]. It was seen that using marine sand improved the mechanical properties in some cases [11]. As such, the present work highlights the mechanical and environmental benefits and opens up opportunities for wider application in the construction industry.

4 Conclusion

This study researched the relationship between the mechanical properties of geopolymer mortars and various sand types. Its objective was to acquire the fundamental knowledge to choose eco-friendly and sustainable building materials. The sands employed as the primary source of aggregates differed in either type of fineness, and this paper presented five distinct mix patterns. Careful testing and analysis were used to determine how aging will affect compressive strength. Egyptian Sand and fine, regular beach sand were seen to have consistent and dependable compressive strength characteristics, which made them desirable options.
However, there were challenges when utilizing typical beach sand, which was coarser than desired, and this ultimately caused the material to deteriorate. Furthermore, the cleaning process applied to beach sands affects the mortar's performance. These findings demonstrate the necessity of meticulous mix design optimization and knowledgeable sand selection in developing long-lasting geopolymer-based construction materials.
In conclusion, this study emphasizes how crucial the kind of sand is in defining the mechanical properties of geopolymer mortars, offering details critical to environmentally responsible construction projects. Egyptian Sand and fine, regular beach sand are strong enough to retain compressive strength, indicating their ability to sustain durable mortar matrices. However, the challenges presented by coarse beach sand and the unfavorable effects of sand-washing highlight how crucial it is to pick sand wisely and use treatment methods. A complete understanding of material properties can help enable the widespread use of geopolymer mortars in the construction industry by creating ideal mix designs. To develop environmentally friendly building systems, this research emphasizes the need for continued investigation and innovation in sustainable building materials.

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