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Influence of ocean salt water on mortar properties with substitution of sand by waste glass powder

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Abstract: The construction sector, particularly in countries bordering the ocean, is faced with a major challenge: effectively reusing waste of all kinds to limit pollution and build structures capable of withstanding the environment's long-term acidity (pH). Using waste glass as a finely ground mineral additive in a mortar is a promising recycling route based on the mechanical-chemical activation method. This article presents the research results into using glass powder, which is very recent and rare, as a partial replacement for sand, with a substitution level of 0% to 10%. This work studies the influence of waste glass powder (wgp) and salt water (sw) on mortar's flexural and compressive strength. The physical properties such as porosity, absorption rate, and their micro mechanical-chemical behaviour were also studied. The experimental results showed that the flexural strength of those with glass sand increased with salt water. On the other hand, the Unconfined compressive strength also increased, so the recycled glass aggregate can be used for producing coatings or self-compacting concrete.

1. Introduction

Mortar and concrete are the most widely used materials in the construction sector. They are renowned for their versatility and their essential role in infrastructure development. As a component of concrete and glass, and used in backfill, the construction sector is the biggest consumer of sand. But it's not just found in buildings and roads. It's a material from which our society has developed. However, these numerous applications involve massive extractions, closely linked to major environmental challenges, at the risk of exposing populations to increased risks of flooding, biodiversity loss and soil erosion. Sand production is a major source for construction and some other fields and innovative strategies are needed to reduce its impact on the environment, so searchers focused on the most waste materials that can be re-used. On such approach is to partially replace sand with alternative materials, such as waste glass powder (WGP). This substitution not only reduces environmental pollution, but also improves certain properties of mortar and concrete, such as durability and chemical resistance. The use of waste glass powder as a substitute for sand or aggregates has attracted increasing attention from researchers. Waste glass, a major component of municipal solid waste, is produced in large quantities around the world, but is often insufficiently recycled. For example, in 2017, China produced 20.25 million tons of waste glass, less than half of which was recycled [1]. Numerous studies have explored the incorporation of waste glasses into construction materials, demonstrating its potential to improve sustainability while maintaining or improving the performance of mortars and concretes[2-7]. In addition, studies have demonstrated the improved durability of concrete containing waste glass powder (WGP), particularly in terms of resistance to sulphate attack, chloride ion penetration and frost damage [8-10]. However, issues such as alkali-silica reaction (ASR) and limited reusability remain areas of concern. Despite this progress, the application of WGP in the construction industry faces obstacles such as inefficient recycling processes, high handling costs and the need for in-depth studies to optimize its integration into mortar and concrete. Metwally [11] reported that the use of fine glass screenings in concrete mixtures had a negative impact on workability but significantly improved the mechanical properties of concrete at older ages. To address these challenges, systematic research is needed to understand the influence of WGP on key properties such as porosity, compressive strength and water permeability. This paper investigates the use of WGP as a partial substitute for sand in mortar, with substitution levels ranging from 0% to 10%. The research focuses on analysing the effects of WGP on the mechanical properties and porosity of mortar, under curing conditions in two different pH environments. By employing experimental methods, this study aims to contribute to the sustainable use of WGP in the construction industry while addressing the challenges associated with its integration.

2. Material and methods

2.1. Test materials

The materials used in this study were Pure Portland Cement (PPC 45), river sand from China Road and Bridge Corporation (CRBC) stock in Lome, waste glass powder (WGP) and water (seawater and drinking water). The chemical compositions of these materials are presented in Table 1 as well as the grain size of waste glass powder and the sand . The seawater came from the Togolese ocean, while the drinking water came from the Togo Office of Water (TDE).

Table 1: The physical and mechanical characteristics of different materials

Material	Composition Parameter	Value
Cement CPA 45	Calcium oxide (CaO) [12]	63.9%
	Silicon dioxide (SiO_2)[12]	21.35%
	7&28-day flexural strength	7.6 & 8.2 MPa
	7&28-day compressive strength	34.3 & 40.3 MPa
River Sand	Fineness modulus	2.61
	Chlorides	0.019%
Waste Glass Powder	Fineness modulus	2.6
	Silicon dioxide (SiO2) [12]	71.0%
	lime [12]	10.25%
Water	pH (Seawater)	7.9
	Dissolved solids (Seawater)	742.44 mg/L
	pH (Potable Water)	6.63
	Dissolved solids (Potable)	20.8 mg/L

2.2. Experimental Design

Mortar samples were prepared with sand partially replaced by WGP at substitution levels of 0%, 5% and 10%. The water/cement ratio was maintained at 0.5 for all mixes. The samples were cured in seawater and drinking water for 7 and 28 days.

2.2.1. Test Methods

Absorption Rate: Measured by immersing cured specimens in water and calculating the percentage increase in weight.

Flexural Strength: Tested using a three-point bending method following ASTM standards.

Unconfined Compressive Strength: Determined using a universal testing machine, with results recorded at 7 and 28 days.

Porosity: Analysed by measuring the volume of voids in specimens using standard porosity tests.

2.2.2. Preparation and Curing

The mortar samples were poured into moulds, labelled and demolded after 24 hours. They were then cured in seawater or drinking water for 6 and 27 days. Regular monitoring ensured uniform curing conditions.

3. Results and discussions

There are different formulations according to the extra glass powder dosages and the type of treatment.

3.1. Mortar physical and its micro-mechanical-chemical behaviour

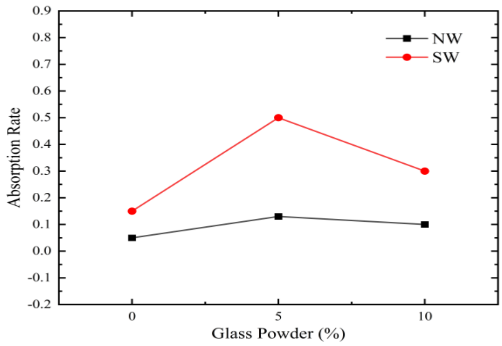

Figure 1. Comparative absorption rate curve of the mortar for drinking water and saltwater.

The water absorption rates of the mortar samples are shown in Figure 1. Samples cured in seawater show higher absorption rates than those cured in drinking water, particularly for 10% WGP substitution. This trend indicates an increase in porosity due to poor adhesion between the WGP and the cement matrix.

Figure 2 shows a peak in absorption at 5% of sand replenishment by glass powder. This peak, which is more pronounced in the case of salt water, demonstrates a chemical reaction between the glass and the salt water, which leads to alteration of the latter, resulting in greater hydration of the binder and retention of water in the pores. The less glass powder there is, the more quickly it alters, causing the mortar to retain moisture. To support the lack of microscopic experiments in this research, the results of previous studies are referenced. Salt water constituents, such as magnesium sulphate, react chemically with cement components, forming calcium sulphate, magnesium hydroxide and sulpho-aluminates, which are the main causes of chemical attack on concrete [13]. [14] used advanced techniques such as SEM, EDX and mapping to identify cracks, voids and locations of compounds in concrete samples. Their research showed that salt water-induced deterioration progresses inwards, breaking down calcium silicate hydrate (CSH) into magnesium silicate hydrate (MSH) and forming products such as gypsum, ettringite and Friedel's salt during sulphate and chloride attack. Siliceous aggregate particles are not affected, as the erosion mainly affects the mortar.

3.2. Flexural strength of mortars

Flexural tests showed that glass cement mortars cured in seawater achieved higher strength at 7 days (6.17 MPa) than those cured in drinking water, but that strength decreased at 28 days (5.23 MPa). This behaviour is attributed to the interaction between the waste glass powder and the seawater, which improves resistance to chemical attack. The glass powder fills the voids in the granular skeleton, improving flexural strength, although its fineness limits mechanical strength. Optimum performance was observed at a 10% substitution of waste glass powder, while chemical reactions with seawater constituents contributed to variations in strength over time found that adding waste glass powder to sand concrete improved flexural strength by up to 9% when the optimal dosage of waste glass powder was 10%. The resistances evolve normally, except the one with 5% waste glass powder, which decreases at 7 days of age and whose value at 28 days is higher than the other compositions. As shown in Figure2, those results can be explained by the fineness of the glass powder, which is mechanically less resistant than the sand but fills the latter's particle size curve well and interacts with the cementitious matrix to increase its resistance.

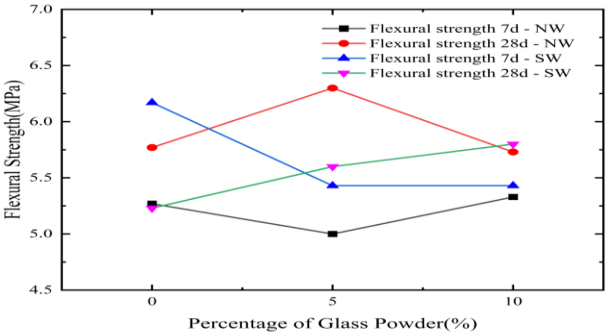

Figure 2. Comparative flexural strength curve of the mortar samples for drinking water and salt-water

3.3. Compressive strength of mortars

The compressive test results show in Figure 3 that glass cement mortars cured in salt water generally achieved higher strength at 28 days than mortars cured in drinking water, attributed to the pozzolanic reaction and improved strength at an early stage in the salt water. However, mortars containing 5% glass powder showed reduced strength at 28 days due to poor adhesion and non-uniform granular skeletons. The smooth surfaces of the glass particles weakened adhesion in the interfacial transition zone (ITZ), which affected overall strength development. Despite the variations, the differences in compressive strength between the samples were minimal. As Achal and Chandak [15] mentioned, the fine aggregate plays a vital role in imparting the strength to the concrete. Indeed, Du and Tan [16] reported that the interaction between aggregates and cement paste in concrete at the interfacial zone is vital for developing concrete strength and found that while using waste glass particles as fine aggregates compromised some mechanical properties of mortar, it particularly enhanced resistance to chloride ion penetration. However, Ammash, Muhammed et al.[17] reported a reduced compressive strength with increasing fractions of sand replacement by waste glass powder.

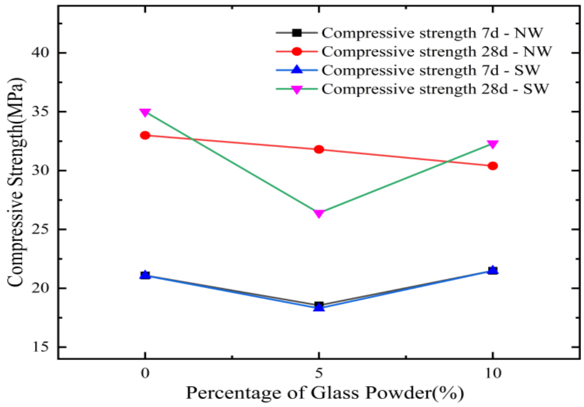

Figure.3. Comparative compressive strength curve of the mortar samples for drinking water and salt-water

4. Conclusion

This study demonstrates the feasibility of using waste glass powder as a partial sand replacement in mortar. While WGP enhances mechanical properties at optimal substitution levels (5%), higher levels increase porosity and reduce strength. The influence of seawater curing underscores the potential for improved resistance to salt water-induced deterioration. The paper collectively suggests that substituting sand with waste glass powder in a mortar and the characteristics of cure water can have both positive and negative effects. As concluded by [18], sodium chloride and sea-water salts on concrete, at a certain salinity level, increased compressive. Future research should explore extended curing durations and advanced analytical methods (X-ray diffraction, The thermogravimetric, fresh test on mortar, tensile test, etc.) to better understand WGP’s long-term effects in diverse environmental conditions.

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