

**MECHANICAL PROPERTIES OF MORTARS MADE FROM GLASS POWDER AS
A PARTIAL REPLACEMENT FOR SAND****Gnilane THIAM**

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ABSTRACT

The various industrial activities of humans constantly generate large amounts of waste such as plastic, glass, wood, tires, and various types of waste, most of which inevitably end up in unsuitable landfills. Since the beginning of the 21st century, many industrial waste products and by-products have been recycled. This study is part of this recycling effort, aiming to repurpose waste in the development of construction materials as an alternative solution to the depletion of natural resources (sand) and to protect the environment. To do this, an experimental campaign was conducted to evaluate the effect on the mechanical properties (maximum stress and Young's modulus) of mortars to which finely ground glass powder from bottles was added. The sand was replaced with glass powder in proportions of 0, 5, 10, 15, 20, and 25 %. A water/cement ratio of 0.5 was used to make the mortars subjected to compression tests. The results were compared with those of the reference mortar. The maximum stress was obtained for a dosage of 25% glass powder at 28 days. Replacing sand with glass powder improves the performance of the produced mortars, thus opening an interesting avenue for recycling glass bottles into construction materials.

Keywords:

Glass powder¹, Recycling², Mortar³, Substitution⁴ and Young's modulus⁵

1. INTRODUCTION

Concrete is today recognized as the most widely used construction material worldwide. However, the production of cement causes major environmental impacts, notably significant energy consumption and a high carbon footprint. To limit these effects, forward-looking approaches aim to integrate waste into the cement mixture to

mitigate their ecological impact [1]. In addition, glass is essentially produced by melting very pure silica sand containing more than 99% silica, which gives it potential pozzolanic material properties. With the continuous growth in glass consumption, the amounts of waste generated increase proportionally. Several avenues for the valorization of this waste have been considered. However, according to some studies [2], the majority of methods for valorizing used glass require preliminary treatments, which limits their large-scale development and their capacity to absorb significant volumes of waste. In this context, a sustainable alternative is to reuse used glass in construction materials, particularly concrete. For both economic and environmental reasons, the incorporation of recycled glass into construction materials is attracting growing interest [3]. This approach not only limits the extraction of natural resources but also reduces energy consumption and costs associated with waste disposal, while decreasing the pressure on existing landfills. Indeed, the construction sector, due to its significant raw material needs, offers considerable potential for the integration of recycled materials, particularly glass waste. Thus, the use of mortars as a means of valorizing waste constitutes a broader strategy for reducing the ecological footprint of the construction sector. It is within this context that our study is framed, focusing on improving the compressive strength of mortar by incorporating glass powder. The aim of the study is to determine mechanical properties such as maximum compressive stress and Young's modulus.

2. MATERIALS AND MHETODS

2.1 Materials

For the production of the glass powder (GP) in our study, glass bottles were collected from the Mbeubeuss landfill (Dakar-Senegal). They were placed in saturated water for 24 hours to remove labels and all impurities. After drying, the used glass particles were manually broken into small pieces. Then, the pieces were ground into powder using a Los Angeles ball mill (G-128-424305/02). The physical properties of glass powder are summarized in Table 1.

Table -1: Physical properties of glass powder

Properties	Absolute Density (Kg/m ³)	Apparent Density (Kg/m ³)	Finess Modulus
GP	1325	1246	3.30

The microstructure of the powder shows that the material is glassy in nature and has an irregular shape. X-ray diffraction showed that the glass powder has an amorphous structure, with no identifiable peak (Figure 1).

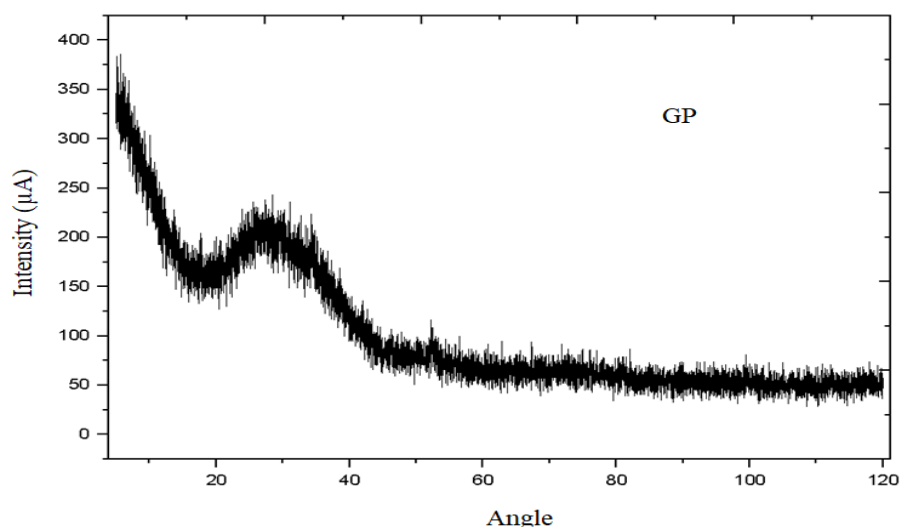


Fig -1: Crystalline structure of glass powder

2.2 Mortar Formulation

The cement, sand, water, glass powder, and equipment are kept at laboratory temperature. To carry out the weighing, a precision balance is used. Water is added using a graduated cylinder. The standard dosage for a cement mortar is generally one volume of cement to 3 volumes of sand, with about 0.5 volume of water [4].

The mortar mix is carried out using a mixer. Once this mixer is turned on, water is poured into the container, then the cement, and finally all the sand is added gradually according to the procedure of standard NF EN 196-1, 1995. The proportions of the mixtures are summarized in Table 2.

Table -2: Composition of mortar mixes

Mortars	Cement (g)	Sand (g)	Water (ml)	GP
MR	450	1350	225	0
5GP	450	1282.5	225	67.5
10GP	450	1215	225	135
15GP	450	1147.5	225	202.5
20GP	450	1080	225	270
25GP	450	1012.5	225	337.5

2.2 Methods

To determine the compressive strength or compressive stress, each half-specimen is positioned so that the load is applied on its molded lateral faces, that is, perpendicular to the casting direction. The compression area is limited to a square section of 40 mm x 40 mm, generally using steel or tungsten carbide plates of appropriate dimensions to ensure the load is distributed over the entire surface (Figure 1).

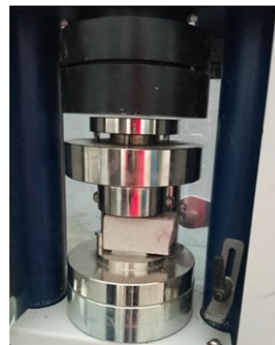


Fig -2: Compression device

The compressive load is applied continuously and at a constant speed until the specimen fails. The compressive stress is then calculated by dividing the maximum load carried by the compression area:

$$\sigma = \frac{F_c}{S} \quad \text{Eq -1}$$

σ is stress compressive (in MPa)

F_c is the maximum compressive breaking strength (en N)

S is the compressed section (in mm²).

The Young's modulus of a material is essential to know in order to design structures capable of withstanding applied forces. In this study, the CEB-FIP law [CEB 90] is used to define the evolution of compressive stress as a function of strain and then determine the Young's modulus according to equation 2.

$$E_c = 22[(F_{cm})/10]^{0.3} \quad \text{Eq -2}$$

With F_{cm} is the maximum compressive strength. This equation links the Young's modulus to the average compressive strength of concrete. The Young's modulus E_c thus obtained represents the initial stiffness of concrete in compression. It characterizes the linear elastic behavior of the material for low levels of stress and strain. Diop et al. [5] defined a mechanical behavior law that allows determining the stress-strain curve and the modulus from the maximum stress. In this study, we applied this law to determine the Young's modulus at 28 days of curing.

3. RESULTATS AND DISCUSSION

The results obtained are shown in Figures 3 and 4. In these figures, we notice that the stress increases as the percentage rate of glass powder increases. Also, the longer the curing time, the more the stress increases. The incorporation of glass powder in place of sand has a positive effect on the compressive strength of the prepared mortars. This effect may be related to the glass particles, which have a very varied chemical and mineralogical composition, combining an adhesion effect and a filling effect. The glass powder, composed of fine particles rich in amorphous silica, increases the contact surface between the cement and the sand grains, which improves adhesion within the mortar matrix.

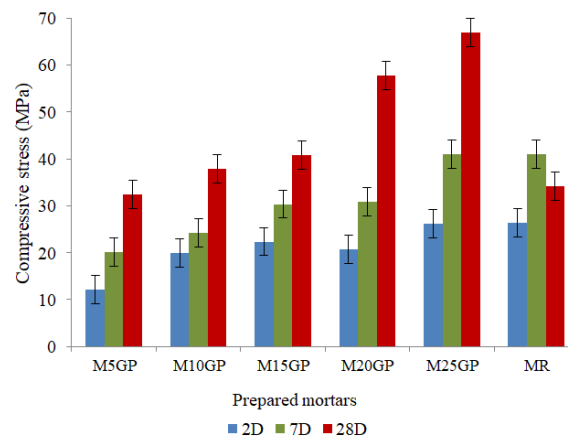


Fig -3: Young's modulus

Amorphous glass powder has a slow pozzolanic activity. In the short term (2 and 7 days), the interaction with calcium hydroxide (portlandite) is limited, as the optimal pH and moisture conditions for the pozzolanic reaction have not yet been fully reached. The amorphous glass powder gradually reacts with the calcium hydroxide released during cement hydration to form calcium silicate hydrate (C-S-H), which densifies the matrix. This reaction becomes more significant from 28 days onwards.

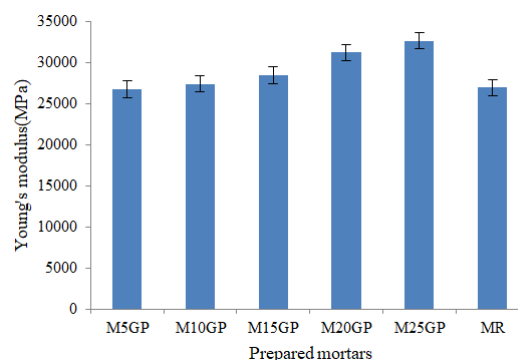


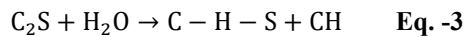
Fig -4: Young's modulus

In Figure 4, the modulus of elasticity followed a trend similar to that of compressive stress, reaching maximum values of about 35000 MPa. This variation can be explained by the action of fine glass powder particles, which

fit into the gaps between particles, thus reducing the voids in the mortar matrix. As a result, the mortar structure becomes more compact, contributing to an increase in the modulus of elasticity [6]. However, a larger increase was observed with 25% glass powder. In the evolution of the mechanical performance of cementitious materials with added minerals, two reactions occur: hydration and pozzolanic reactions

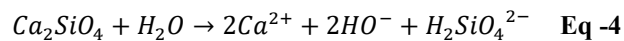
- The hydration and pozzolanic reaction

The hydration reaction is noted in the following equation:

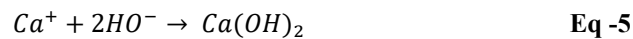


During the initial phase, rapid reactions occur between C_2S and water right from the start of wetting, generating a strong exothermic signal in isothermal calorimetry tests [7]. This signal is partly due to the heat released by wetting the cement powder, but also to the energy released during the dissolution of C_2S . The enthalpy of congruent dissolution of C_2S (Ca_2SiO_4) is 138 kJ/mol, according to the reaction [8]:

❖ Dissolution of dicalcium silicate



❖ Precipitation of portlandite



❖ Precipitation of hydrated calcium silicates CSH

- Pozzolanic reaction



In the early stages of cement hydration, glass powder mainly acts as a filler material, characterized by the stability of the SiO_4 tetrahedra. However, over time, the increased production of calcium hydroxide $Ca(OH)_2$ leads to a gradual rise in Ph [9]. This highly alkaline environment activates the glass powder, causing the formation of gels rich in Si-O bonds [10].

At the same time, the pozzolanic effect gradually develops. This reaction, although slow, plays a crucial role in the long-term evolution of cement properties. However, it involves less intense hydration in the early stages, resulting in relatively low initial strengths. Therefore, the beneficial impact of glass powder on the mechanical performance of cement only fully appears at later ages. The formation of C-S-H (calcium silicate hydrate) leads to an increase in the total solid volume, which reduces the porosity of the cement paste and makes its microstructure denser. This densification results in higher compressive strength, which could be explained by the low Ca/Si ratio of the gel from the pozzolanic reaction, lower than that of the gel formed by conventional cement hydration [11][12]. This low Ca/Si ratio might be linked to the high mechanical performance observed, potentially giving the gel specific properties, like better strength or a more stable structure.

CONCLUSIONS

This study looked at evaluating the effect of adding glass powder as a partial substitute for sand in cement mortar mixes. The results showed that gradually adding glass powder, from 5% to 25%, significantly improves the compressive strength of the mortars, with a peak performance observed at 25%. This improvement is attributed to two main factors: first, the filler effect of the fine glass particles, which helps densify the cement matrix by reducing voids, and second, the pozzolanic activity of the amorphous glass, which slowly reacts with calcium hydroxide to form calcium silicate hydrate (C-S-H) gels, thereby strengthening the mortar's microstructure. The study also showed an increase in the Young's modulus with the glass powder content, indicating greater stiffness and compactness in the modified mortars. This development confirms that glass powder contributes to improving the mechanical properties of the material.

Environmentally, using glass powder as a substitute material is part of a sustainable development approach. It allows for the recycling of an abundant, non-biodegradable waste while reducing the consumption of natural sand, which is becoming increasingly rare and sought after. This approach thus offers a double benefit: limiting the ecological footprint of mortar production and reducing the amount of glass waste sent to landfills.

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