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Study of the effect of glass powder on the mechanical properties and freeze-thaw resistance of sand concrete based on local materials

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ABSTRACT

This study falls within the framework of the valorization of local materials and the reuse of industrial waste in construction. Its aim is to improve the mechanical properties and durability of sand concrete. The hypothesis is the incorporation of glass powder as an industrial waste into the matrix in order to obtain a new sand concrete. This study therefore focused on the effect of adding glass powder in percentages ranging from 0 to 40%, with an interval of 10%, in order to target the right composition that provides a compromise solution among the characteristics studied. The results found show that the optimal addition that provides the best compromise between the properties studied is 10% glass powder. Improvements of up to around 9% in the case of flexural strength and around 18% in the case of compressive strength. In addition, the study shows that the addition of glass powder poses no major problems with regard to "freeze-thaw". The maximum reduction in the rate of mass loss was 2.89%, and the rate of strength loss was 1.47%. Finally, it should be noted that the results obtained in this study are very encouraging for the development of a new sand concrete capable of meeting the requirements of local construction.

1 Introduction

In southern Algeria, where large aggregates are scarce and costly due to transportation from other regions, it is essential to rationally exploit the aggregates available within the country and to enhance the existing resources. These include dune sand, river sand, and substantial deposits of natural and artificial fines. Consequently, we may need to consider substituting ordinary concrete with alternative types, such as sand concrete [1].

Additionally, waste glass has garnered significant interest from researchers because of its low recycling rate and high disposal costs. Utilizing waste glass in construction is viewed as a valuable solution for minimizing environmental impact [2]. In civil engineering, glass recycling has proven effective in various applications, such as using glass waste as a substitute for aggregate or as a partial replacement for cement [3, 4].

The hypothesis involves utilizing glass waste in powdered form to create a new type of sand concrete for construction purposes. The aim is to enhance the mechanical properties and freeze-thaw resistance of the sand concrete. This study specifically examines the impact of incorporating varying dosages of glass powder, from 0% to 40% in 10% increments, to identify the optimal formulation that achieves the best balance between the desired properties.

2 Materials and methods

2.1 Sands

Two sands are used in this study; dune sand (DS) and river sand (RS), the first one coming from the southern region of the city of El Oued (Algeria) and it has a maximum grain diameter of about 0.63 mm; the proportion of grains smaller than

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0.08 mm is below 5%. The second sand comes from the north-western region of the city of El Oued and has a maximum diameter of 5 mm. The mixture of the two sands is prepared according to a mass ratio determined by correcting the grain size curve of the river sand, in its fine part, by adding dune sand (RS/DS = 1.7) [5].

2.2 Cement

The type of cement used to develop the studied composite is CEM II/B-L 42.5N Composed Portland Cement according to NA 442. Table 1 shows the main chemical elements of the cement used.

Table 1 - Chemical analysis of the used cement.

Element	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	SO_3	K_2O	Cl^-	Na_2O	Free CaO	P.A.F	Insoluble Residues
Quantity (%)	18.84	60.03	1.81	4.90	3.21	2.65	0.68	0.017	0.09	0.67	8.49	1.13

2.3 Limestone filler

The filler used is limestone nature obtained by sieving the remains of crushing (80 µm sieve) of a quarry located at the northern exit of the city of Hassi Messaoud (Algeria). The filler is used to complete the grading curve of the sand in its fine part to fill the intergranular voids [6]. The absolute and apparent density of the filler used are 2500 kg/m^3 and 981 kg/m^3 respectively.

2.4 Glass powder

The glass powder is an alternative addition of white color. It is obtained after the collection and crushing of glass fragments. The glass used in the composition of the sand concrete for is in fact from industrial glass waste. The absolute density and the specific surface Blaine are respectively 2570 kg/m^3 and 288 m^2/kg.

2.5 Admixture

The admixture used is a high water-reducing superplasticizer of the "MEDAFLOW 30" type. It is a liquid solution easily diluted in the mixing water and of a light brown color, in conformity with the EN 934-2 standard.

2.6 Elaboration of the studied concretes

The mixtures are prepared with glass powder percentages ranging from 10% to 40% with a 10% step, relative to the mass quantity of cement. Five sand concrete compositions were selected to determine the influence of the glass powder content. The different values of the materials used for the elaboration of the studied concretes are mentioned in the Table 2.

Table 2 - Different compositions studied.

Composition	Sand (RDS) (kg/m^3)	Cement (kg/m^3)	Limestone Filler (kg/m^3)	Glass powder (%)	Mixing water (l/m^3)	Super-plasticizer * (%)
SC-WGP	1296	400	150	0	235	1.5
SC-GP10%	1296	360	150	10	235	1.5
SC-GP20%	1296	320	150	20	235	1.5
SC-GP30%	1296	280	150	30	235	1.5
SC-GP40%	1296	240	150	40	235	1.5

* The percentage of superplasticizer is calculated, in mass, relative to the mass of cement.

3 Results and discussions

3.1 Mechanical properties

3.2.1 Flexural strength

The Fig. 1. shows the results of the flexural strength measured at 28 days and 90 days for the different types of concrete studied.

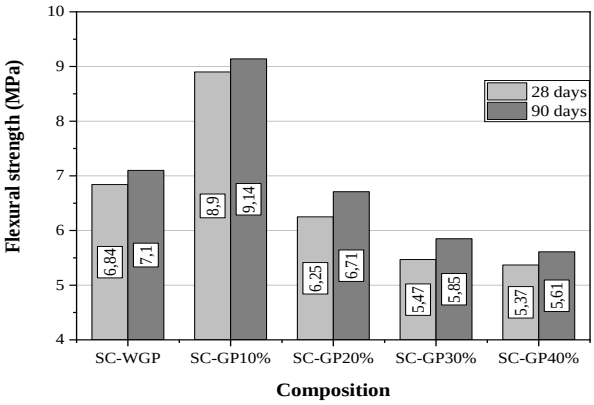

Fig. 1 –Evolution of the flexural strength at 28 and 90 days according to the proportion of glass powder.

From the results, it can be seen that the addition of glass powder in the sand concrete improved the flexural strength compared to the reference concrete SC-WGP. The addition of 10% glass powder (SC-GP10% case) recorded the maximum value of flexural strength i.e., 8.90 MPa (at 28 days) and 9.14 MPa (at 90 days), with an increase rate of about 30% (at 28 days) and 29% (at 90 days); this is probably due to the fineness of glass powder which increased the pozzolanic reaction to form additional calcium silicate hydrates (C-S-H); the combination (SC-GP10%) seems to be the most effective. On the other hand, beyond 10% glass powder, it is noted that the flexural strength values tend to decrease. The decrease recorded can be explained by the poor compaction in the cementitious matrix.

3.2.2 Compressive strength

The values of the compressive strength measured at 28 and 90 days of the different types of concrete studied are presented by the Fig. 2.

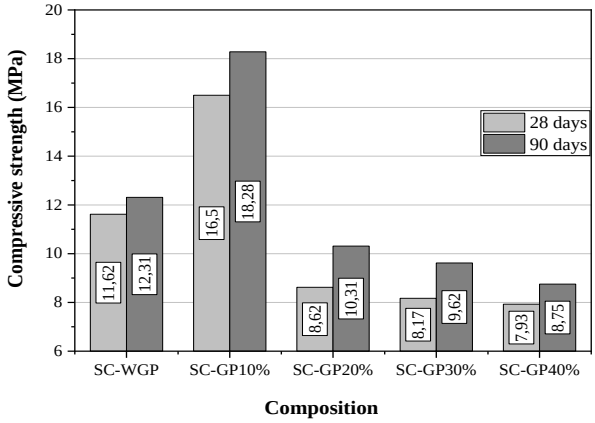

Fig. 2 –Evolution of the compressive strength at 28 and 90 days according to the proportion of glass powder.

The results obtained show that the glass powder amplifies the compressive strength. It is clear that the concrete with 10% glass powder is better than the other concretes studied. The maximum value of compressive strength was recorded as 16.50

MPa (at 28 days) and 18.28 MPa (at 90 days). This strength improvement can be explained by the physical and chemical effect of the glass powder. The glass powder adjusts the granulometry of the cement, which leads to the increase of the compactness of the paste (physical effect). Moreover, it participates in a pozzolanic reaction with the hydration products of the clinker to form dense C-S-H responsible for the strength (chemical effect). Also, it can be announced that the cement matrix with 10% of glass powder gave a more compact microstructure and therefore more resistant.

3.2 Freeze-thaw test

From a durability perspective, resistance to freeze-thaw cycles is an essential characteristic for exterior structures in cold regions. It is correlated with a number of concrete properties, such as porosity, permeability, pore structure and aggregate characteristics. To assess strength and mass losses, we recorded the variations caused by freeze-thaw cycles for all the compositions analyzed. The results obtained are presented in Table 3.

Table 3 - Influence of "freeze-thaw" cycles on compressive strength and mass of concrete studied.

Compositions	Resistance loss λ_R^g (%)	Mass loss τ_g (%)
SC-WGP	3.19	5.98
SC-GP10%	2.89	3.58
SC-GP20%	4.52	2.51
SC-GP30%	5.10	1.85
SC-GP40%	6.13	1.47

The results indicate a general decline in compressive strength after the freeze-thaw test across all compositions studied. Furthermore, the inclusion of 10% glass powder (SC-GP10%) results in a smaller reduction in compressive strength compared to the reference case (SC-WGP) and the other compositions containing glass powder.

On the other hand, the presence of glass powder reduces the rate of mass loss in concrete. In particular, an increase in powder dosage results in a clear reduction in mass loss rates. Clearly, the 40% powder dosage gave the lowest rate (1.47%).

Finally, it should be noted that the results show that the effect of this test is still remarkable. This effect can be attributed to the addition of glass powder to the sand concrete, which creates random pores within the matrix; these pores are filled by the water absorbed at the time of testing, and it is this water that causes the internal degradation of the concrete through the effect of freeze-thaw cycles.

4 Conclusion

The main points that can be concluded are:

- In terms of mechanical properties, the incorporation of 10% of glass powder in the compositions of the sand concrete studied improves the flexural strength and compressive strength compared to the reference composition.
- The freeze-thaw cycle test study recorded a slight reduction in compressive strength for all compositions studied, as well as a slight loss in mass. PV10 gave the best result in terms of compressive strength.

In general, the percentages of glass powder used gave a positive improvement on all the characteristics studied.

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