Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/17853
DOI URL: http://dx.doi.org/10.21474/IJAR01/17853

RESEARCH ARTICLE

MECHANICALS PROPERTIES OF MORTARS BASED ON GLASS WASTE AS A PARTIAL REPLACEMENT FOR CEMENT

Gnilane Thiam[1], Ndèye A. Sène[2], Pascale Balland[3] and Abdou A. Thiam[4]

1. Ecole Supérieure Polytechnique, Laboratoire Eau, Energie, Environnement et Procédés Industriels.
2. Université Cheikh Anta Diop de Dakar, Corniche Ouest BP : 5085 Dakar-Fann, Sénégal.
3. Université Savoie Mont Blanc, SYMME, FR-74000 Annecy, France.
4. Laboratoire Nationale de Reférence LNR ex CEREEQ, Route du Service Geographique, BP 189 Dakar-Hann, Senégal.

Manuscript Info

Manuscript History
Received: 15 September 2023
Final Accepted: 17 October 2023
Published: November 2023

Key words:-
Waste, Glass, Recycling, Mortar, Consistency

Abstract

The various activities of man continuously generate countless quantities of waste (plastics, glass, wood, domestic waste, etc.), a significant proportion of which inevitably ends up in inappropriate landfill sites. Since the beginning of the 21st century, many materials have been recycled. The present study is part of this recycling effort, with the aim of using construction waste to reduce the environmental footprint of cement. An experimental campaign was carried out to assess the effect on the physico-mechanical properties of mortars to which recovered and finely ground glass powder was added. Cement CEM II 32.5 R was substituted by glass powder in proportions of 5, 10, 15 and 20 %. The water/cement ratio was set at 0.26 to ensure consistency and set time, while a W/C ratio of 0.5 was used for the manufacture of mortars subjected to compression and bending tests. The results were compared with those obtained with the reference mortar. Maximum optimum strength was obtained at a dosage of 20 %. These comparisons show that the addition of glass powder has a beneficial effect on the mechanical and physical characteristics of the various mortars studied. This is a promising application for this waste, which still needs to be confirmed by further testing.

Introduction:-

For several decades now, the use of glass bottles in industry has been steadily increasing, resulting in a large quantity of glass waste being generated and abandoned in inappropriate landfill sites. For many decades, the increasing use of glass bottles by industry has led to the mass production and abandonment of glass waste in inappropriate landfills. In addition to these very large quantities, the search for new sources of materials in the construction industry is increasingly encouraging the recycling sector. Indeed, a number of research projects have been launched into the recycling of inert materials, particularly glass, for possible use in mortar, concrete and public works[1,2]. Glass is essentially composed of silica (SiO_2), which accounts for over 70 %, and a significant amount of lime (CaO), over 11%. These properties mean that glass is classified according to ASTM C618 [3] as class N pozzolan. However, it contains a quantity of sodium oxide (Na_2O), estimated at over 12 %. With these high levels of amorphous silica and sodium oxide, the use of glass in cementitious materials has led to extensive research. With

Corresponding Author:- Gnilane Thiam
Address:- Laboratoire Eau, Energie, Environnement et Procédés Industriels (LE3PI); EcoleSupérieure Polytechnique (ESP) de DAKAR, Université Cheikh AntaDiop (UCAD)-Sénégal.

glass powder, the CaO available in glass can react with SiO_2 and water to form calcium silicate hydrates (CSH), improving the mechanical properties and durability of cementitious materials [4,5]. Several studies have been carried out on the physical and mechanical properties of glass powder-based mortars.

With this in mind, Arab et al [6] studied the normal consistency and the setting start and end times of the different mixes using a Vicat apparatus. The results show that the addition of glass powder has a slight effect on setting times, with a difference of 30 minutes between the control mix without PV and the mix in which 20% of the cement was replaced by glass powder. On the other hand, the consistency decreased with the amount of glass powder substituted for the cement. This observation could be of practical interest when concreting in hot weather. Aliabdo et al [7] determined the standard consistency and the setting start and end times using the Vicat test method. Test results showed that replacing the glass cement powder reduced water requirements by 0.4 %. However, Nihat et al [8] studied the compressive strength of mortars at 3, 7 and 28 days of age on 50mm cubic samples using ASTM C109. The test results showed that comparable compressive strength could be achieved up to a replacement rate of 20 % for fine pumice and glass microbubble materials compared with the reference mix, allowing a reduction of up to 20 % in cement content. In this way, water absorption and void content are systematically reduced by replacing cement paste with pumice and glass waste. Ling et al [9] carried out the three-point bending strength test in accordance with ASTM C 3248 at 1, 3, 7, 28 and 90 days after casting. A universal testing machine with a load capacity of 50 kN and a displacement speed of 0.20 mm/min was used for this test. The results are the average values of three specimens. Compressive strength was determined using a conventional compression machine with a load capacity of 3000 kN on the broken pieces (parts of the prisms broken in the bending strength test). The results showed a progressive reduction in strength with increasing glass content. Chen et al [10] also agree that glass exhibits beneficial behaviour associated with pozzolanic reaction when used in powder form. The aim of our study is to evaluate the physico-mechanical properties of mortars based on glass powder.

This article is organised as follows. Section 1 describes the methodological approach of the study. Section 2 presents and discusses the results, before concluding in Section 3.

Materials and Methods:-

The cement

The cement used is a CEM II/B 32.5, with an apparent density (ρ app = 1020 kg / m^3), an absolute density (ρ abs = 3000 kg / m^3), a Blaine fineness (3480 cm² / g) and a mineralogical composition is presented in table 1.

Glass glass

Glass powder is obtained by recovering, cleaning and crushing coloured bottles from the Mbeubeuss/Senegal landfill. Green glass was used. X-ray analysis shows that glass powders are essentially composed of silica, sodium and calcium. The results are summarised in Table 1.

Table 1:- Mineralogical composition of cement and glass powder.

oxides in (%) of mass	SiO_2	Na_20	Ca0	Fe_2O_3	Al_2O_3	MgO	SO_3	Fire loss
CEM II	21.29	0.17	64.68	3.49	4.72	0.44	2.06	1.93
Waste glass powder	67.24	14.01	11.37	0.44	2.34	1.28	0.13	2.47

Standard Sand

CEN standard sand (ISO standard sand) is a natural, siliceous sand, particularly in its finest fractions. It is clean, with grains that are generally isometric and rounded in shape. It is dried and screened. The granulometric composition is determined by sieving complies with the requirements of standards EN 196-1 and ISO 679: 2009.

Preparation, manufacture and conservation of study pastes and mortars

Formulation of cement pastes

The pastes were made with a W/C ratio equal to 0.27 for all the mixes. Table 2 summarises the different prepared pastes. The W/C ratio represents the quantity of water used in relation to the quantity of cement or binder.

Table 2:- Composition of paste mixes.

Paste	Cement (g)	Water (ml)	Glass powder (g)
P0	500	123	0
P5%	475	120	25
P10%	450	118	50
P15%	425	115	75
P20%	400	113	100

Manufacture and conservation of study pastes and mortars

45 specimens were made to study flexural and compressive strength at 2, 7 and 28 days. The specimens were developped in a standard mixer (Figure 1a) prescribed by standard EN 196-1 (NF EN 196-1, 1995) [11]. The specimens were placed in accordance with the procedure described in the standard. In order to monitor the mechanical behaviour of the mortars, we considered the different compositions illustrated in Table 2. The following conditions were applied: a PV dosage (0 %, 5 %, 10 %, 15 % and 20 %), a W/C ratio set at 0.5. The mortars were kept in water (20 °C ± 2) and air-dried inside the laboratory 24 hours before testing. The different mortars produced are summarised in Table 3.

Table 3:- Composition of mortar mixes.

Mortars	Cement (g)	Sand (g)	Water (ml)	Glass powder (g)
M0	450	1350	225	-
M5	427,5	1350	225	22,5
M10	405	1350	225	45
M15	382,5	1350	225	67,5
M20	360	1350	225	90

Physical and mechanical characterization methods for cement pastes and mortars

Consistency and setting times of cement pastes

The determination of the normal consistency and the setting start and end times of the various mixes were studied with a Vicat apparatus (Figure 1b). The mixes were first made using a mixer (figure 1a), then quickly introduced into a mould placed on a glass plate, without settling or excessive vibration, and the whole assembly was placed on the plate of the Vicat apparatus. The needle placed on the surface of the sample is released and sinks into the paste. When it stops (or after waiting 30 seconds), the distance d between the end of the needle and the base plate is recorded. A mixture (or dough) is considered to be of normal consistency if d = 6mm ± 1mm. If d > 7 mm, it is considered that there is not enough water and conversely if d < 5 mm, it is considered that there is too much water [12].

Figure1:- a. TECNOTEST mixer, b. Vicat equipment.

Mechanical properties of mortars
Mechanical tests were carried out in accordance with standard EN 196-1 (NF EN 196-1, 1995) to determine the mechanical properties of the different types of mortar: Three point bending (3 pts) on three 4×4×16 cm^3 specimens (Figure 2a) and compression on the half-test specimens from the previous test (figure 2b).

Results and Discussion:-
Consistency and setting time
Replacing cement with glass powder reduces setting time as the glass content increases, up to 15% where the control mortar achieves the same setting time. The paste made with 20% glass powder has a slightly longer setting time than the control mortar. However, the consistency decreases with the increase in glass powder in pastes made with a reduction in water requirement of around 0.35 %. Studies carried out on raw glass powder show that the material absorbs little water [6,7]. This may be due to the smooth, non-porous surface or to the fact that the grains of glass particles are larger than the cement. This behaviour may be due to the vitreous surface of the glass powder grains and may improve concrete with the same water content. Replacing cement with glass powder has a negligible effect on initial and final setting times and complies with the limits of the Egyptian standard ESS No 2421 and ASTM C 150 [7].

Flexural and compressive strength
The results presented in (Figure 3) show that mortars with glass powder obtain flexural strengths that increase progressively with the percentage of PV. In fact, at 28 days, mortars with glass powder develop flexural strengths almost equal to those of the control mortar and evolve proportionally to the percentages up to 20% [13]. This phenomenon can be explained by increased adhesion between cement and sand grains in the presence of glass powder [6].

Figure 2:- a. Three-point bending machine, b. Compression machine.

However, it can be seen (Figure 4) that the addition of glass powder reduces the compressive strength measured at 2 and 7 days, compared with the control mortar for all the ratios studied. Thus, at 28 days, the mortars develop a strength approximately equal to that of the control mortar. At 20% glass powder, the mortars develop a slightly lower strength than the reference mortar.

This can be attributed to two chemical reactions:
Hydraulic reaction and pozzolanic reaction, which mainly improve long-term strength. It has been shown that, in the longer term, the calcium hydroxide (CH) produced during cement hydration reacts with silica to produce additional

calcium silicate hydrate (CSH) through a latent hydraulic reaction [14]. The pozzolanic effect, which has a slow action at an early age, also develops progressively over time [15]. This phenomenon is explained by the interaction between the reactive silica in the glass powder and the CH released by the hydration of the cement, which gives the glass the property of fixing the lime to form an intense CHS gel. The pozzolanic reaction is predominant in the long term, which leads to less intense hydration at younger ages, resulting in low strengths. In both types, the gels produced are of the same nature and are not very different from those produced by the hydration of portland cement. Since the formation of these CSH leads to an overall increase in solid volume, the porosity of the paste will eventually be reduced and the microstructure more densified, resulting in high compressive strength [16].
In addition, waste glass powder is also able to reduce the permeability of concrete which ultimately leads to a more durable building material against the corrosive environment according to the work of Seyed Esmaeil et al [17].

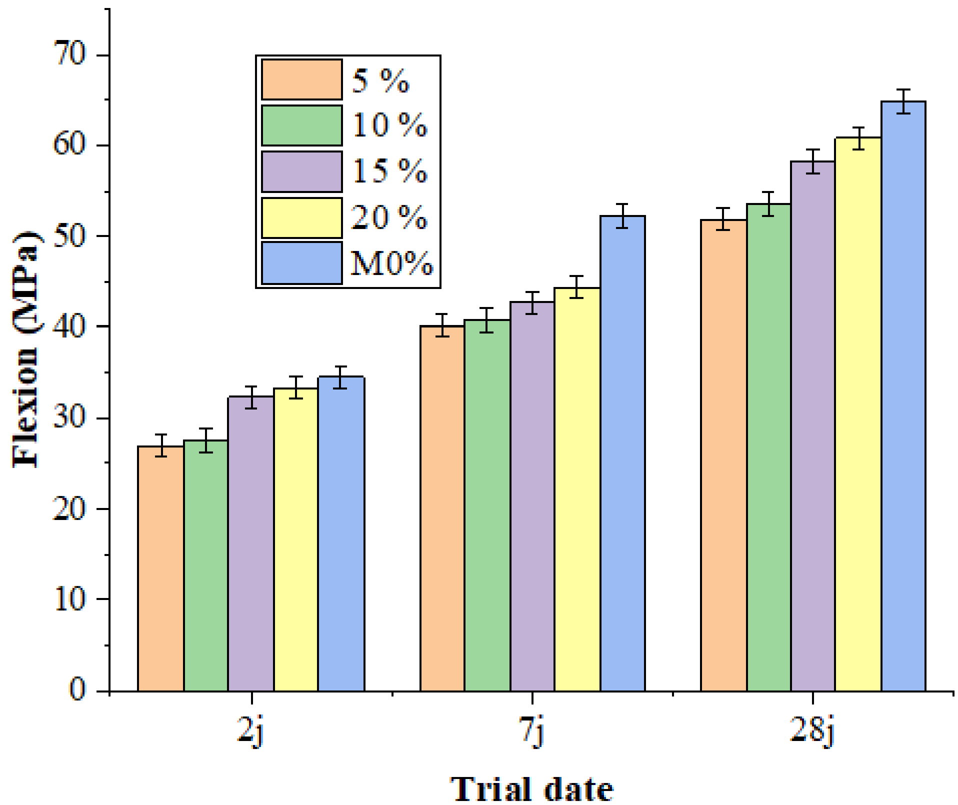

Figure 3:- Flexural strength.

Conclusion:-

The general objective of this work was to evaluate the physical and mechanical properties of mortars substituted for cement by (0, 5, 10, 15 and 20 %) glass powder, using a W/C ratio set at 0.5. These characterisation tests on the mortars will make it possible to determine the best combinations of cement and glass powder substitution in order to assess the proportions of concrete to be made.

The partial substitution of cement by glass powder reduces setting time and water requirements compared with the reference mix (except for 20 %). On the other hand, the consistency decreases with the percentage of glass powder for all schedules. This may be related to the difference between the glass powder particles and the cement, which tends to weaken the amount of bound water and increase the amount of free water in the mix [4].

Flexural and compressive strength increase progressively with the dosage of glass powder and over time, this parameter is linked to the pozzolanic reaction which causes a hydrated gel of calcium silicate. However, the most satisfactory results are obtained for a percentage of 20 to 28 days. According to Zeghichi et al [18], maximum compressive strength is achieved at 90 days with 20 % glass powder.

The main aim of glass recycling is to reduce environmental pollution and reduce the footprint of cement in construction materials. It has been reported that substituting 20 % cement with glass powder reduces CO_2 emissions by 18 %, according to Islam et al [19].

Acknowledgements:-

We would also like to thank the National Reference Laboratory LNR ex CEREEQ and the World Federation of Scientists (WFS) for all their support.

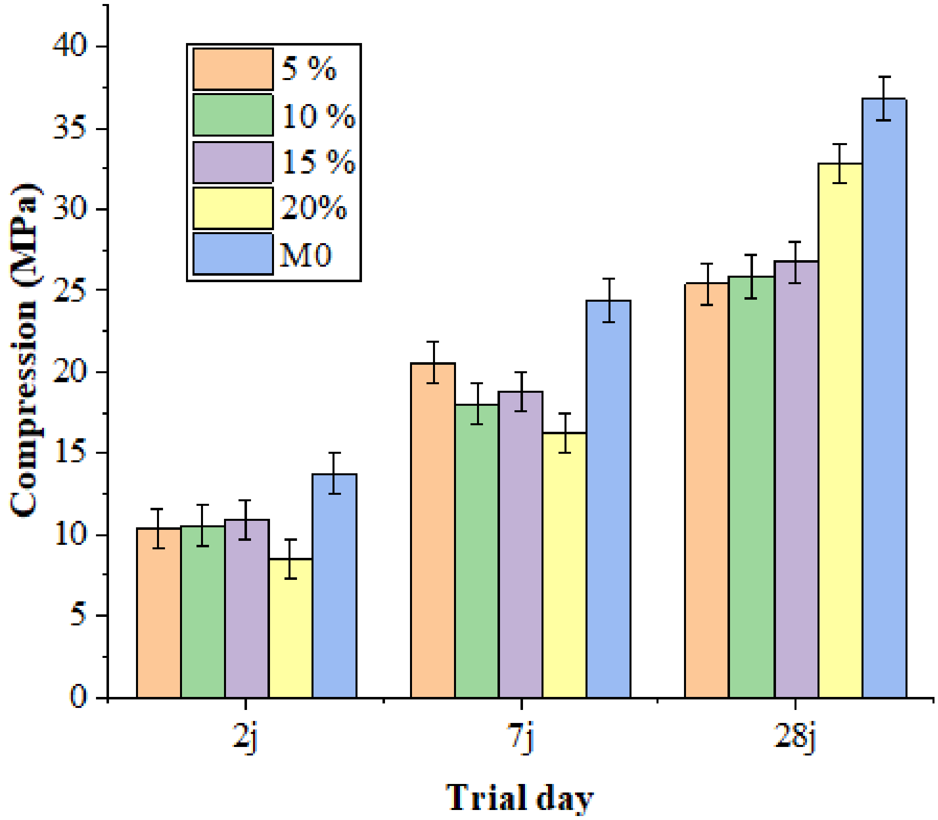

Figure 4:- Compressive strength.

Reference:-

[1] Zidol A. (2014) Durabilité en milieux agressifs des bétons contenant de la poudre de verre. Thèse de Doctorat, Université de Sherbrooke, Canada, 234 p.

[2] Topçu I. B., Canbaz M., (2004) Properties of concrete containing waste glass. Cement and Concrete Research. 34(2), p. 267-274. https://doi.org/10.1016/j.cemconres.2003.07.003.

[3] ASTM C 618-12, Spécification standard pour les cendres de houille et la pouzzolane naturelle brute ou calcinée à utiliser dans le béton. ASTM International, West Conshohocken, PA, États-Unis, 2012.

[4] C. Shi, Y. Wu, C. Rie fl erb, H. Wang, Caractéristiques et réactivité pouzzolanique des poudres de verre, Cem. Béton. Res. 35 (5) (2005) 987–993,https://doi.org/ 10.1016 / j.cemconres.2004.05.015.

[5] H. Du, KH Tan, Propriétés du béton en poudre de verre à grand volume, Cem. Béton. Compos. 75 (2017) 22-29, https://doi.org/10.1016/j. cemconcomp.2016.10.010.

[6] B. Arab, R. Mehaddene, and Y. Bouchnab, "Substitution du ciment CPA par la poudre de verre dans les mortiers à hautes performances," Déchets, Sci. Tech., no. N°75, pp. 1–8, 2017, doi: 10.42687/dechets-sciences-techniques.3665.

[7] A. A. Aliabdo, A. E. M. Abd Elmoaty, and A. Y. Aboshama, "Utilization of waste glass powder in the production of cement and concrete," Constr. Build. Mater., vol. 1824, pp. 866–877, 2016, doi: 10.1016/j.conbuildmat.2016.08.016.

[8] N. Kabay, N. Miyan, and H. Özkan, "Utilization of pumice powder and glass microspheres in cement mortar using paste replacement methodology," Constr. Build. Mater., vol. 282, p. 122691, 2021, doi: 10.1016/j.conbuildmat.2021.122691.

[9] T. C. Ling and C. S. Poon, “A comparative study on the feasible use of recycled beverage and CRT funnel glass as fine aggregate in cement mortar,” J. Clean. Prod., vol. 29–30, pp. 46–52, 2012, doi: 10.1016/j.jclepro.2012.02.018.
[10] CH Chen, R. Huang, JK Wu, CC Yang, Déchets de particules de verre utilisées dans les mélanges à base de ciment, Cem. Béton. Res. 36 (3) (2006) 449–456,https: // doi. org / 10.1016 / j.cemconres.2005.12.010.
[11] AFNOR., (1995) Méthodes d’essais des ciments - Partie 1 : détermination des résistances mécaniques. NF EN 196-1.
[12] AFNOR., (1995) Méthodes d’essais des ciments - Partie 3 : détermination du temps de prise et de la stabilité. NF EN 196-3.
[13] G. Lee, T. C. Ling, Y. L. Wong, and C. S. Poon, “Effects of crushed glass cullet sizes, casting methods and pozzolanic materials on ASR of concrete blocks,” Constr. Build. Mater., vol. 25, no. 5, pp. 2611–2618, 2011, doi: 10.1016/j.conbuildmat.2010.12.008.
[14] AM Matos, T. Ramos, S. Nunes, J. Sousa-Coutinho, Amélioration de la durabilité du SCC avec de la poudre de verre de rebut, Mater. Res. 19 (1) (2016) 67–74,https://doi.org/ 10.1590 / 1980-5373-MR-2015-0288.
[15] Idir R., Cyr M., Tagnit-Hamou A., (2011) Potential pozzolanicity of glass cullet fines and aggregates. Annales du Bâtiment et des Travaux Publics, 1, p. 28-34.
[16] S. Mindess, Durabilité du béton, développements dans la formulation et le renforcement du béton. (2019) 3-17, DOI: 10.1016 / B978-0-082-102616- 8.00001-0.
[17] M.S. Esmaeil, G. Alireza, Experimental investigation of waste glass powder, basalt fibre, and carbon nanotube on the mechanical properties of concrete,Constr. Construire. Mater. 252 (2020) 119115, https://doi.org/ 10.1016/j.conbuildmat.2020.119115.
[18] Zeghichi L., Mezghiche B., Benghazi Z., (2012) Contribution à l’étude des propriétés du ciment blanc et compos. Communication Science & Technologie, 10, p. 27-35.
[19] Islam G. M. S., Rahman M. H., Kazi N., (2017). Waste glass powder as partial replacement of cement for sustainable concrete practice. International Journal of Sustainable Built Environment. 6(1), p. 37-44. https://doi.org/10.1016/j. ijsbe.2016.10.005.