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Utilizing Waste Glass as Partial Replacement of Fine Aggregate in Cement Mortar Blend

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Abstract: Waste glass as fine aggregate replacement in mortar is an interesting possibility for the economy on waste disposal sites and conservation of natural resources. This paper experimentally investigates the potential of using crushed waste glass as fine aggregate replacement in mortar. The experimental work performed includes workability, water absorption, compressive strength, and flexural strength under different curing ages of 7, 14, and 28 days. Four mortar mixes with 0%, 10%, 15%, and 20% replacement by weight of sand with waste glass were prepared. The water absorption and flexural strength values increased with an increase in curing age but decreased with an increase in waste glass addition from 49% -31.5% and 7.68 MPa -3.90 MPa at 28 days, respectively. The compressive strength values showed a reasonable increase at 10% - 15% glass replacement (20.29 MPa -22.34 MPa) and experienced a decrease in strength from 15% - 20% (22.34 MPa-19.31 MPa). The highest compressive strength was obtained at 15% waste glass replacement after 28 days of curing which is higher than the control mix by 21.5%. This research highlights the potential for utilizing waste glass as a sustainable alternative in mortar matrix thereby contributing to waste reduction and resource conservation. Based on the results obtained, mortar containing up to 15% waste glass replacement of sand can be used in construction works.

Keywords: compressive strength, flexural strength, mortar, waste glass, sand.

1. Introduction

Glass is one of the oldest manufactured materials, the production of glass dates to ~2500BC in the Roman Empire (Rasmussen, 2012). By the late 1400s, and early 1500s glass had already become an important commodity in European countries (Alireza & Qiuyan, 2019). In 2004, the United Nations estimated that year 181.4 million tonnes of solid waste were disposed of which 12.7 million tonnes were glass (Ismail & Al-Hasmi, 2009). According to the U.S Environmental Protection Agency in 2013, Americans generated 10.37 million tonnes of glass in the municipal solid waste stream. In Nigeria, glass waste makes up 2.7% of municipal solid waste in Nigeria (Malu, et al, 2008).

The world's demand for aggregates in construction has been rapidly increasing in the last few years, the reason is mainly due to the drastic economic growth of Nations like Brazil, China, and India (Mandadapu et al, 2023). Traditional construction materials such as concrete, bricks, hollow blocks, solid blocks, pavement blocks, and tiles are being produced from existing natural resources. This is damaging the environment due to the continuous exploration and depletion of natural resources (Saffuidin, et al, 2010). The primary choice for fine aggregate in concrete production is typically natural sand obtained through riverbed mining. Nevertheless, the supply of river sand for concrete production is dwindling due to unsustainable mining practices in riverbeds, resulting in adverse consequences such as a declining water table and the increasing risk of bridge pier subsidence (Mageswari & Vidivelli, 2010).

In recent times, numerous research endeavors have concentrated on the utilization of waste glass as a partial substitute for natural aggregates in concrete. Mageswari and Vidivelli (2010) observed that the compressive strength of cubes of concrete increases as the percentage of sheet glass powder increases but decreases as the age of curing increases due to the alkali-silica reaction. The test results indicate that it is possible to manufacture concrete containing sheet glass powder (SGP) with characteristics like those of natural sand aggregate concrete provided that the percentage of SGP as fine aggregate is limited to 10-20% (Mageswari & Vidivelli, 2010).

Al-Akhras et al. (2011) observed that the compressive strength of mortar increased with the increase of waste glass powder (WGP) as a partial replacement of limestone sand under moist curing. The flexural strength of mortar increased with the increase of WGP as a partial replacement of cement or sand under moist curing.

Ketkukah and Mukaddas (2019) observed that with a mix ratio of 1:3 and a water-cement ratio of 0.48, the replacement of fine aggregates using 10% waste glass gave better results than the 20% replacement. The 28-day compressive strength increased by 8.5% using 10% waste glass content compared to the control mix. The 28-day flexural Strength decreased by 10.6% and 30.14% using 10% and 20% waste glass content respectively (Ketkukah & Mukaddas, 2019).

The present study aimed to explore the potential for using waste glass as a partial replacement of fine aggregate on a cement and sand mixture. Natural fine aggregate is substituted by weight by weight of waste glass powder. A mix ratio of 1:6 (cement: sand) was used to prepare four types of mixtures, 0%, which is the control mix, 10%, 15%, and 20% mixtures with a water content ratio of 0.50. Compressive and flexural strength are evaluated for 7, 14, and 28 days of age curing. Also, the properties of fresh mortar were studied.

2. Methodology

2.1 Method and Material

The raw materials used for this study are natural sand, cement (type I), and waste glass powder. The ordinary Portland cement used was Ashaka cement, produced and manufactured by the Ashaka cement plant, Gombe state by the NIS 444.1: 2003 and EN 197.1: 2011 specifications. The crushed waste glass used for this study was obtained from the Soil laboratory of the Civil

Engineering Department, Federal Polytechnic Bauchi. The crushed waste glass was sieved using the 4.0 mm BS test sieve size to obtain smooth waste glass material without impurities and obstacles.

The controlled mortar mixes with 0% waste glass are calculated to be as follows: fine aggregate (1945.65 g), cement (324.35 g), and water (162.23 g). The density of cement mortar measured in kg/m^3 is known to be 2162 kg/m^3 or 2.162 g/cm^3 in g/cm^3 and was used to obtain the masses of the cement and fine aggregate materials at 0% control mix and other mix percentages. The other mixes contained waste glass (fine aggregate) of 10%, 15%, and 20% by weight as a partial replacement of sand (fine aggregate). The three mixes were cast and cured for 7, 14, and 28 days. The water-to-cement ratio was kept at 0.5 throughout.

2.2 Flow and workability test

The flow table test, conducted following BS EN 12350-5, assesses the consistency of fresh mortar in a laboratory setting. Meanwhile, the slump test provides insight into the uniformity of fresh mortar across different batches. The shape of the mortar's slump conveys information about the workability and quality of the fresh mortar, serving the purpose of evaluating how easy it is to work with after mixing. During the test, the mold was positioned at the center of the flow table apparatus and filled with the mortar material from a mixing tray. Subsequently, the material was compacted to ensure even filling and minimize voids. The mold was then removed, leaving the material in a truncated shape and the slump was measured.

2.3 Water absorption test

The water absorption test was conducted following the guidelines outlined in BS 1881: Part 122: 1983. This test involved measuring the average dry weight of mortar cube specimens once they were removed from their molds. The average weight of these cube specimens was measured after they had been submerged in water for the curing process. The water absorption for each specimen was determined, providing a metric to assess the durability of the material. The water absorption (A) was calculated as follows:

$$A (\%) = (W_2 – W_4/W_4) \times 100$$

Where,

A (%) = Water absorption percentage

W_2 = Weight of the saturated sample in air

W_3 = Weight of saturated sample in water

W_4 = Weight of the dry sample.

2.4 Compressive strength test

The compressive strength test was carried out according to BS 1881: part 116:1983. Specimen sizes of 100mm× 100mm× 100mm were used to carry out the compressive strength test. The average strength of three specimens was taken to determine the compressive strength for each age, the test on the cubes at various ages was carried out using a compressive strength test machine at the Civil Engineering Concrete Laboratory of the Federal Polytechnic Bauchi.

Each sample cube was crushed in the machine, and the crushing load (in Newton) was taken note of immediately after crushing. The value was divided by the cross-sectional area of the cube to get the compressive strength in Nmm^{-2} (MPa).

2.5 Flexural strength test

The flexural strength test was carried out according to BS 1881: part 118: 1983. The flexural strength was determined using a simply supported prism with a clear span under two-point loadings. The test was carried out at ages 7, 14, and 28 days on a prism of sizes 40 mm x 40 mm x 160 mm. An equation ($F = \frac{PL}{bd^2}$) was also adopted and made use of in the flexural strength calculations of the specimens.

Table 1.0: Mix proportion of constituent materials

Mix	Constituent Materials Weight (g)			
(%)	Water	Cement	Sand	Waste glass
0	162.23	324.35	1945.65	0.00
10	162.23	324.35	1751.09	194.56
15	162.23	324.35	1653.8	291.84
20	162.23	324.35	1556.52	389.13

3. Results and Discussions

3.1 Flow and workability

Table 2.0: Workability (flow table test) of mortar with waste glass as sand

% Replacement	Workability
0	339.5
10	425.5
15	456.7
20	472.0

The result of the flow table test is presented in Table 2.0. the workability values had a slight increase as the waste glass ratio increased in comparison to the controlled mix. This means that the workability value increases with the increase in glass quantity. The values of the workability were obtained to be 339.5mm, 425mm, 456.7 mm, and 472mm for samples containing 0%, 10%, 15%, and 20% of waste glass respectively as shown in Table 2.0. This increase in the workability values can be related to the fact that waste glass does not absorb water and that the water layer over the surface of waste glass is thinner (Aseel & Ahmed 2016), hence the maximum flow was observed at 20% replacement of fine aggregate with waste glass.

3.2 Water Absorption

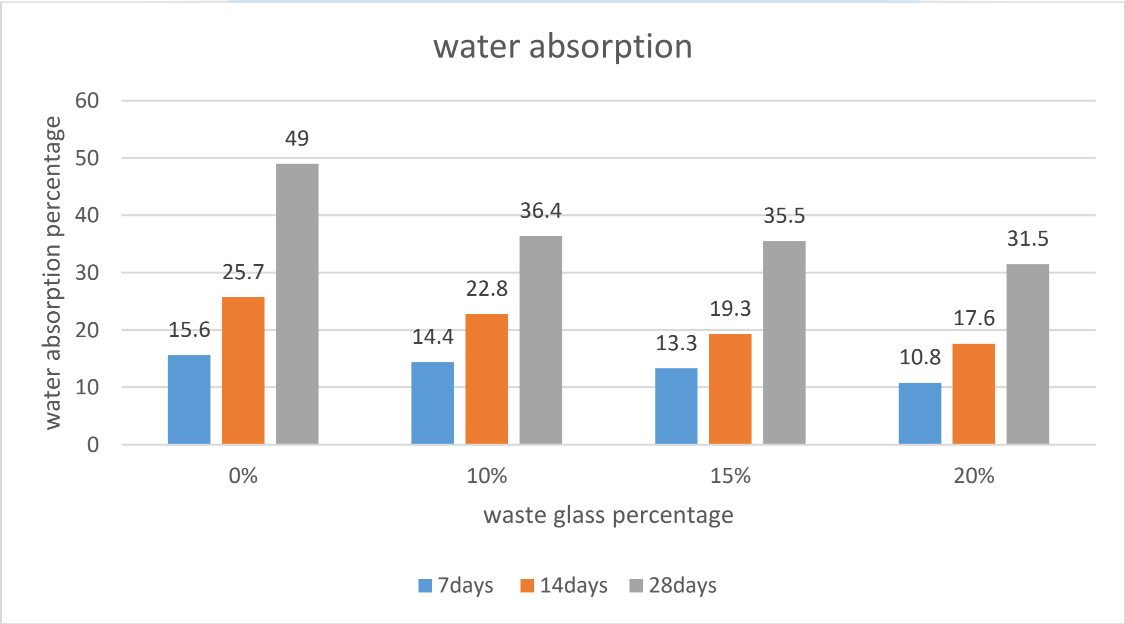

Fig 1: Water absorption behavior of mortar with waste glass as sand

A water absorption test was carried out for all mixtures and the percentage of water absorption was measured. The percentage of water absorption decreased with an increase in waste glass content. The lowest value of water absorption was found for mortar mix with 20% waste glass content.

3.3 Compressive Strength

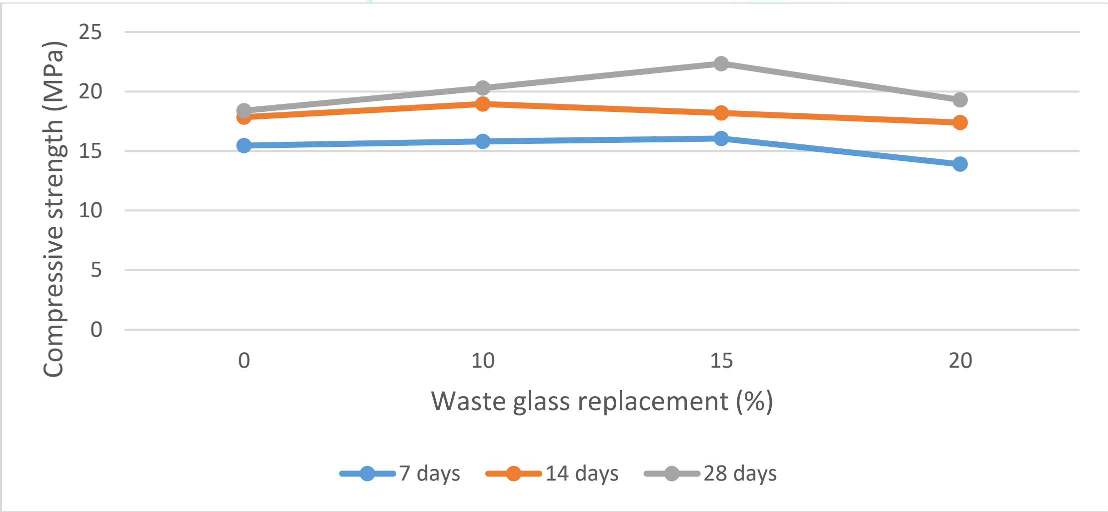

Figure 2: Compressive strength of mortar with waste glass as sand

The compressive strength of the controlled and waste glass mortar mixes at 7, 14, and 28 days are presented in Figure 2. With the increase in waste glass quantity, the compressive strength of mortar increases except for 20% at 28 days of curing age. From the results obtained, it is obvious that the compressive strength of mortar increases with replacements of fine aggregate from 10%-15%. The maximum compressive strength i.e., 22.34 Mpa was obtained at 15% replacement of fine aggregate with waste glass. The difference in compressive strength at 15% and 0% (control) is up to 21.5%.

3.4 Flexural Strength

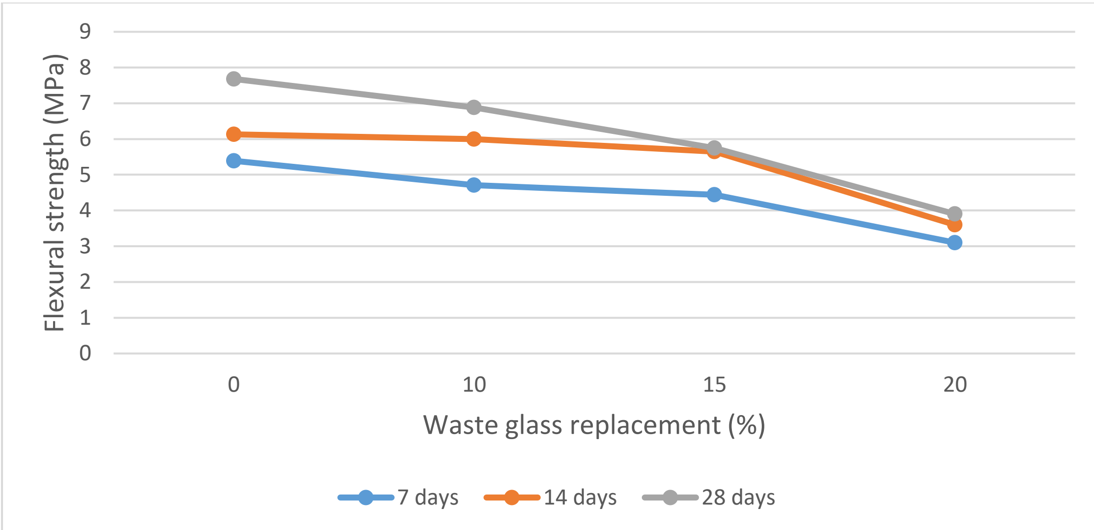

Figure 3: Flexural strength of mortar with waste glass as sand

The results of flexural strength tests at 7, 14, and 28 days are given in Figure 3. It is seen that all mixes show a continuous decrease in flexural strength with an increase in glass waste. According to the experiment results, the best flexural strength value was obtained at 0% (control mix) after 28 days of curing.

4. Conclusion

Finely crushed waste glass was used as a partial replacement for sand in cement mortar. Despite the reduction in the slump values of mixes containing glass aggregate, they possess good workability. The 10%, 15%, and 20% replacement of natural fine aggregate show an increase in the value of workability as compared to the control mix. The consistency of mortar increased generally with an increase in waste glass content. Water absorption of mortar decreases as the dosage of waste glass is increased. The decrease in the water absorption of mortar cubes is much at 7 days of curing.

The compressive strength of mortar with partial replacement of fine aggregate by crushed waste glass increased with an increase in glass percentage up to 15%.

From the results of the tests conducted on the prisms, it was shown that the controlled mix gives the maximum value for flexural strength at 28 days of curing age.

The result suggests that waste glass can be used as a partial replacement for sand in construction works to a certain percentage i.e., up to 15% replacement.

References

Al-Akhras, N., Ababneh, A., & Al-Qasem, I. (2011). Recycling of waste glass in mortar mixtures. *The Journal of Solid Waste Technology and Management*, *37*(3), 157–167.

Al-Zubaidi, A. B., & Al-Tabbakh, A. A. (2016). Recycling Glass Powder and its use in Cement Mortar applications. *Int. J. Sci. Eng. Res*, *7*, 555–564.

BS 1881 part 122 (1983). Methods of testing concrete. Method for determination of water absorption. *British Standards Institution Publication, London*.

B.S (1881). Part 118 (1983) Method for determination of flexural strength. *British Standards Institution Publication, London*.

BS 1881 Part 116. (1983). Code of Practice for Determination of Compressive Strength of Concrete Cubes. *British Standard Institution*.

BS EN 12350-5 (2019). Testing Fresh Concrete Part 5: Flow Table Test. *British Standard Institute, London.*

BS EN 197-1 (2011). Cement Part 1: Composition, specifications, and conformity criteria for common cement. *London: European Committee For Standardisation*.

Ismail, Z. Z., & Al-Hashmi, E. A. (2009). Recycling of waste glass as a partial replacement for fine aggregate in concrete. *Waste Management*, *29*(2), 655–659.

Ketkukah T.S., & Mukaddas A. M. (2019). The properties of mortar with waste glass as partial replacement of fine aggregates. *Journal of Science and Engineering Production, 1(1), 123-128.*

Mageswari, M., & Vidivelli, D. B. (2010). The use of sheet glass powder as fine aggregate replacement in concrete. *The Open Civil Engineering Journal*, *4*(1).

Majdinasab, A., & Yuan, Q. (2019). Post-consumer cullet and potential engineering applications in North America. *Resources, Conservation and Recycling*, *147*, 1–9.

Malu, S. P., Ogri, O. R., Tawo, E. N., & Ita, B. I. (2008). The Management of Industrial Glass Waste and Its Impact on The Nigerian Environment. *Global Journal of Environmental Sciences*, *7*(1/2), 19.

Mandadapu, S. N., Rao, V. N. P., & Ch, S. R. (2023). A review of fresh and hardened properties of concrete reinforced with waste materials. *IOP Conference Series: Earth and Environmental Science*, *1130*(1), 12046.

NIS 444.1. (2003). Methods of Testing Cement: Chemical analysis of Cement. *Nigerian Industrial Standard*, 1534–1650.

Rasmussen, S. C. (2012). *How glass changed the world: The history and chemistry of glass from antiquity to the 13th century*. Springer Science & Business Media.

Safiuddin, M., Jumaat, M. Z., Salam, M. A., Islam, M. S., & Hashim, R. (2010). Utilization of solid wastes in construction materials. *International Journal of Physical Sciences*, *5*(13), 1952–1963.