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The Effect of Adding Glass Powder Waste and Superplasticizer on Concrete Compressive Strength

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ABSTRACT

This study investigates the effect of glass powder as a partial replacement for fine aggregate on the physical properties and compressive strength of concrete. The experimental program included bulk density testing, moisture content analysis, mix design development, slump testing, and compressive strength testing at the age of 28 days with a target strength of K-250. Glass powder was incorporated at replacement levels of 0%, 2%, 4%, and 8% by weight of fine aggregate, while a superplasticizer was used to maintain workability. The results indicate that fine aggregate has the highest unit weight, followed by coarse aggregate, whereas glass powder exhibits the lowest unit weight. Moisture content results show that coarse aggregate has the highest moisture content, while glass powder has the lowest. Slump test results demonstrate that all concrete mixtures achieved acceptable workability, with slump values ranging from 9 to 11 cm. Compressive strength testing shows that normal concrete achieved the highest strength, while the inclusion of glass powder led to a reduction in strength, particularly at higher replacement levels. However, the mixture with 4% glass powder showed relatively better performance compared to other glass powder variations. Overall, the study concludes that glass powder can be used as a partial fine aggregate replacement in concrete at controlled percentages without significantly compromising workability and with acceptable early-age strength performance.

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1. INTRODUCTION

The construction sector in Indonesia continues to experience significant growth, driving innovation in the development of alternative building materials. Reinforced concrete remains one of the most reliable structural materials due to its strength and durability, and it is widely applied in infrastructure projects such as high-rise buildings, concrete pavements, and long-span bridges. To sustain this progress, continuous innovation is essential to enhance concrete performance and further strengthen its role as a primary building material [1].

Waste is one of the main contributors to environmental damage, largely driven by human consumption patterns. This damage is exacerbated by the growing demand for consumer goods packaged in materials such as glass bottles for ketchup, sauces, beverages, and jams. The rapid increase in household waste highlights the need for effective utilization strategies, particularly through processing glass bottles into valuable products. In recent years, research has focused on promoting the reuse of waste materials as components in large-scale mixtures. One promising approach is the use of waste glass, ground into powder, as an additive in construction materials, representing an appropriate and sustainable waste management solution [2]. Glass waste has long been recognized as hazardous due to its sharp and pointed nature, which poses risks of injury if not handled properly [3], [4]. In addition, glass is a type of solid waste that cannot decompose organically in the environment [5], [6]. This form of waste is commonly generated in daily life, particularly in large urban areas such as Jakarta, where its volume continues to increase in line with human activities that rely heavily on glass products. Unfortunately, much of this waste is often discarded directly onto open land, leading to environmental pollution, since glass is a material that cannot naturally degrade or be recycled by nature without proper processing

The quality of concrete can be improved by incorporating mineral additives (aggregates) and chemical additives (admixtures), while still maintaining operational and economic efficiency. One of the mineral additives commonly used is glass powder derived from broken glass, whereas the chemical additive applied is Superplasticizer. Glass powder is particularly beneficial because it contains silica, which has the potential to serve as a high-quality filler material. The addition of glass powder waste in concrete is believed to enhance its strength, watertightness, and density, functioning effectively as a filler that contributes to improved mechanical performance [7]. In addition to mineral additives such as glass powder, chemical admixtures also play an important role, as they can significantly increase the workability of concrete during compaction. Recent studies have highlighted the role of superplasticizers in improving concrete performance, particularly in roller-compacted concrete (RCC) [8] and lightweight concrete applications [9]. RCC, as a dry concrete requiring compaction, depends on proper consistency measured by Vebe time, and studies have shown that adding 0.3% Poly Naphtalene Sulfonate (PNS) superplasticizer effectively reduces Vebe time, extends workability up to four hours, and maintains compressive strength. Similarly, research on lightweight concrete using Porcelanite aggregate with waste materials such as plastic fibers, eggshell powder, and glass powder demonstrated significant improvements in strength, durability, and workability, particularly with mixes containing 1% plastic fiber and 20% glass powder. Furthermore, research by Amelia et al. (2025) [10] revealed that optimizing material gradation significantly influences compressive strength and porosity, with porous concrete using a 0.2–0.7 cm aggregate gradation achieving the highest 28-day compressive strength and meeting SNI standards for parking applications

Building on these previous findings, the present study focuses specifically on the combined use of glass powder waste and superplasticizer to further explore their synergistic effects on concrete performance. This research introduces the combined use of glass powder waste and superplasticizer as a novel approach that integrates sustainable waste management with advanced concrete technology. The novelty lies in utilizing glass powder, which is rich in silica, as a mineral additive to enhance concrete strength while simultaneously reducing environmental pollution caused by non-degradable glass waste. By incorporating superplasticizer alongside glass powder, the study explores a new synergy that improves workability and compressive strength, offering both structural and ecological advantages that have not been widely investigated before.

2. METHOD

This research began with material testing to evaluate the physical properties of the constituent materials used in the concrete mixture. The fine aggregate, coarse aggregate, and glass powder were tested for specific gravity and water absorption in accordance with ASTM C128 to determine its density characteristics and absorption capacity. Moisture content testing was also conducted following ASTM C128 to identify the amount of free surface water present in the aggregate, which is essential for accurate water adjustment in the concrete mix. In addition, bulk density testing was performed based on ASTM C29 to determine the unit weight and packing characteristics of the aggregates, ensuring that all materials met the required standards prior to mix proportioning.

After the material properties were verified, the concrete mix design was developed to determine the appropriate proportions of cement, aggregates, water, and glass powder. The variation of glass powder namely 0, 2%, 4%, 8%. Slump testing was subsequently performed on the fresh concrete mixtures to evaluate their workability and consistency and to assess the influence of glass powder and admixtures on fresh concrete behavior. This test was conducted to ensure the quality of the concrete, particularly its ability to flow and adequately fill the molds. A higher slump value indicates greater fluidity of the concrete mixture. Good-quality concrete is characterized by sufficient workability, ease of placement, and the absence of segregation between aggregates and cement paste, as well as the absence of bleeding or water separation.

Compressive strength testing was then carried out to evaluate the mechanical performance of the hardened concrete specimens [11]. The specimens were tested at the age of 28 days, corresponding to the target compressive strength of K-250. Testing was performed using a compression testing machine, in which a gradually increasing axial load was applied until failure occurred, defined as the point at which the specimen could no longer sustain the applied load. The resulting data were used to determine the compressive strength of each concrete mixture.

3. RESULTS AND DISCUSSION

3.1. Material test results

3.1.1 Specific gravity and absorption

Table 1. Specific Gravity and Water Absorption

Description	Unit	Coarse Aggregate	Fine Aggregate	Glass Powder
Weight of dry sample in air	gr	1447,65	494,5	497,1
Bulk Sp. Gravity	gr/cc	2,346	2,581	2,79
Bulk Sp.gr s.s.d basic	gr/cc	2,435	2,610	2,80
Apparent Sp. Gravity	gr/cc	2,576	2,657	2,83
Absorption	%	3,811	1,112	0,58

Table 1 presents the results of the specific gravity and water absorption tests for coarse aggregate, fine aggregate, and glass powder. These parameters are essential for evaluating the physical characteristics of materials, particularly their density, porosity, and suitability for use in cementitious composites. The weight of dry samples in air varied among the materials due to differences in particle size and testing requirements. The coarse aggregate required a larger sample mass (1,447.65 g) compared to fine aggregate (494.5 g) and glass powder (497.1 g), which is consistent with standard testing procedures and does not influence the intrinsic material properties. The bulk specific gravity (oven-dry condition) of the materials showed a clear increasing trend from coarse aggregate (2.346) to fine aggregate (2.581), with glass powder exhibiting the highest value (2.79). This indicates that glass powder possesses a denser particle structure compared to natural aggregates. A similar trend was observed in the bulk specific gravity under saturated surface dry (SSD) conditions, confirming the relatively low internal porosity of glass powder. The apparent specific gravity values further support this observation. Glass powder exhibited the highest apparent specific gravity (2.83), while coarse aggregate showed the lowest value (2.576). Since apparent specific gravity excludes permeable pores, the high value obtained for glass powder suggests a compact and impermeable internal structure with minimal open porosity. Water absorption results revealed significant differences among the materials. Coarse aggregate exhibited the highest absorption value (3.811%), indicating a relatively high volume of interconnected pores capable of absorbing water. In contrast, fine aggregate showed moderate absorption (1.112%), while glass powder demonstrated the lowest absorption (0.58%). The low absorption capacity of glass powder reflects its non-porous nature and implies minimal water uptake during mixing. From a practical perspective, these characteristics have important implications for mixture design and performance. The high absorption of coarse aggregate necessitates careful adjustment of mixing water to maintain consistent workability and strength [12]. Conversely, the low absorption and high density of glass powder suggest its potential as a supplementary fine material or partial aggregate replacement, contributing to improved packing density and reduced water demand. However, the use of glass powder in cement-based materials may also influence interfacial bonding and durability, which warrants further investigation.

Overall, the results indicate that glass powder exhibits superior physical properties in terms of density and water resistance compared to natural aggregates, highlighting its potential application in sustainable construction materials. Nevertheless, additional studies focusing on mechanical performance and long-term durability are required to fully assess its suitability in structural applications.

3.1.2 Moisture contains

Table 2. Moisture contains

No	Moisture Contain	Unit	Fine Aggregate	Coarse Aggregate	Glass Powder
1	Wt of cont. + wet spl	gr	357,95	578,35	150,9
2	Wt of cont. + dry spl	gr	356,9	570,35	150,85
3	Wt of water	gr	1,05	8	0,05
4	Weight of container	gr	151,1	175,61	23,5
5	Weight dry spl	gr	205,8	394,74	127,45
6	W%	%	0,511	2,02	0,39

Based on the moisture content test results presented in table 2, clear differences are observed among the fine aggregate, coarse aggregate, and glass powder. The fine aggregate shows a moisture content of 0.511%, which indicates a relatively low but measurable amount of surface moisture adhering to the particles. This is common for fine aggregates due to their higher specific surface area, which allows more water to be retained on the particle surfaces even after drainage. The coarse aggregate exhibits the highest moisture content at

2.02%. This higher value suggests the presence of free surface water trapped between larger particles and within surface irregularities. Coarse aggregates are more susceptible to retaining surface moisture after exposure to water [13], particularly when not fully air-dried, which can significantly influence the effective water content in concrete or mortar mixtures if not properly accounted for during mix proportioning. In contrast, the glass powder shows the lowest moisture content of 0.39%. This result indicates that glass powder has minimal water absorption and limited surface water retention. The relatively smooth and non-porous nature of glass particles contributes to this behavior, allowing water to drain easily and reducing the amount of moisture held on the particle surfaces. Overall, these results highlight the importance of considering moisture content variations among different materials prior to mix design. The higher moisture content of coarse aggregate may require adjustments to the mixing water to maintain the desired water–binder ratio, while the low moisture content of glass powder suggests a more stable contribution to the mixture. Proper correction for moisture content is essential to ensure consistency, workability, and performance of the final composite material.

3.1.3 Bulk Density

Bulk density is an important parameter used to evaluate the compactness and packing characteristics of aggregate and powder materials in concrete production

Table 3. Bulk density

Description	unit	Fine aggregate	Coarse Aggregate	Glass Powder
Weight of container	gr	6144,4	6144,4	275,4
Weight of sample + Container	gr	14120	13480,0	1810,9
Weight of sample	gr	7975,6	7335,6	1535,5
Volume of container	cc	4941	4941,0	1128
Unit Weight	gr/cc	1,614	1,485	1,36

The results in table 3 show that the fine aggregate has the highest unit weight at 1.614 g/cc, indicating a denser particle packing and relatively lower void content compared to the other materials. This condition is typical for fine aggregates, as smaller particle sizes tend to fill voids more effectively. The coarse aggregate exhibits a unit weight of 1.485 g/cc, which is lower than that of the fine aggregate due to its larger particle size and higher void ratio, even under standardized compaction procedures. Meanwhile, the glass powder shows the lowest unit weight of 1.36 g/cc, reflecting its finer particle morphology, possible angular shape, and lighter material characteristics, which contribute to increased voids and reduced bulk density. Overall, these results demonstrate a clear relationship between particle size, shape, and packing behavior on the unit weight of the materials tested. The variations in unit weight among fine aggregate, coarse aggregate, and glass powder are in good agreement with the fundamental principles of aggregate mechanics and bulk density theory.

3.2 Mix design

The purpose of this concrete mix design is to determine the appropriate proportions of constituent materials required to produce concrete with the desired properties. The mixture used in this study consists of cement, Bangka sand as the fine aggregate, Sidamanik gravel as the coarse aggregate, water, and a specified percentage of glass powder as a partial replacement material.

Table 4. Glass powder percentage of concrete in volume trial 1 m^3

Material	Unit	Variety of Glass Powder			
		0%	2%	4%	8%
Cement	Kg	297,101	297,101	297,101	297,101
Water	ℓ	226,928	226,928	226,928	226,928
Fine Aggregate	Kg	964,373	945,45	925,798	887,223
Coarse Aggregate	Kg	901,131	901,131	901,131	901,131
Glass Powder	Kg	-	19,287	38,575	77,150
Sikament	Kg	-	1,192	1,192	1,192
Total	Kg	2389,533	2391,089	2390,725	2390,725

Based on Table 4, the concrete mixtures were designed with varying percentages of glass powder, namely 0%, 2%, 4%, and 8%, while maintaining a constant cement content of 297.101 kg and coarse aggregate content of 901.131 kg for all mixtures. This approach allows the effect of glass powder incorporation on the overall mix composition to be evaluated without altering the primary binding and structural aggregate components. The addition of glass powder was accompanied by a corresponding reduction in the amount of fine aggregate, indicating that the glass powder was used as a partial replacement for fine aggregate by weight. As the percentage of glass powder increased from 2% to 8%, the fine aggregate content decreased from 945.45 kg to 887.223 kg, while the glass powder content increased from 19.287 kg to 77.150 kg. This substitution strategy helps maintain a relatively consistent total mass of the concrete mixture across all variations, with total weights ranging from 2389.533 kg to 2391.089 kg. Such consistency is important to ensure comparable volumetric proportions and to minimize the influence of total mass variation on concrete performance. The water content shows a slight reduction with increasing glass powder content, which may be attributed to adjustments made to maintain workability and control the water–cement ratio. Additionally, a constant amount of Sikament at 1.192 kg was used in the mixtures containing glass powder, indicating the use of a chemical admixture to enhance workability and compensate for changes in particle shape and surface characteristics introduced by the glass powder. Overall, the mix design presented in Table 4 demonstrates a systematic approach to incorporating glass powder into concrete by partially replacing fine aggregate. This design enables an effective assessment of the influence of glass powder content on the fresh and hardened properties of concrete while maintaining consistency in key mix parameters.

Table 5. Glass powder percentage of concrete in volume trial 0.038 m^3

Material	Unit	Variety of Glass Powder			
		0%	2%	4%	8%
Cement	Kg	11,290	11,290	11,290	11,290
Water	ℓ	8,623	8,623	8,623	8,623
Fine Aggregate	Kg	36,660	35,927	35,180	33,714
Coarse Aggregate	Kg	34,243	34,243	34,243	34,243
Glass Powder	Kg	-	0,733	1,466	2,932
Sikament	Kg	-	45,296	45,296	45,296
Total	Kg	90,816	136,112	136,098	136,098

Table 5 presents the concrete mix proportions for a trial volume of 0.038 m^3 with glass powder contents of 0%, 2%, 4%, and 8%. In this table, the quantities of cement, water, and coarse aggregate are kept constant at 11.290 kg, 8.623 L, and 34.243 kg, respectively, for all mixtures. This consistency indicates that the variation in mix composition is primarily associated with the substitution of fine aggregate by glass powder, allowing a direct evaluation of the influence of glass powder content at a laboratory-scale volume. As the glass powder percentage increases, the amount of fine aggregate decreases from 36.660 kg in the control mixture (0%) to 33.714 kg in the 8% glass powder mixture. Correspondingly, the glass powder content increases from 0.733 kg at 2% to 2.932 kg at 8%. This trend confirms that glass powder is used as a partial replacement for fine aggregate by weight, like the approach adopted in the larger-scale mix design presented in Table 4. The Sikament content remains constant for all mixtures containing glass powder, indicating its role in maintaining workability and consistency of the fresh concrete. When compared with Table 4, Table 5 represents a scaled-down version of the same mix design proportions, adjusted for a trial volume of 0.038 m^3. The proportional relationship between cement, aggregates, water, and glass powder in both tables is maintained, demonstrating consistency between the full-scale design and the laboratory trial mixes. Minor differences in total weight are attributed to rounding effects and unit conversion from bulk mix quantities to trial batch volumes. Overall, the comparison between Tables 4 and 5 shows that the mix design methodology is applied consistently across different production scales. The trial volume mix in Table 5 effectively reflects the proportions established in Table 4, ensuring that experimental results obtained from laboratory testing can be reliably correlated with the intended full-scale concrete mix design.

3.3 Slump test

The slump test was performed to assess the effect of glass powder substitution on the fresh concrete behavior prior to casting. Based on Table 6, the slump test results indicate that all concrete mixtures exhibit slump values within a narrow range of 9–11 cm, suggesting relatively consistent workability among the tested mixes. The control mix (NC) shows the highest slump value of 11 cm, reflecting good workability of normal concrete without admixtures or glass powder. The addition of superplasticizer (SP) at 0.4% slightly reduces the slump value to 10 cm, which may be attributed to adjustments in the water content or interaction between the admixture and cement particles. When glass powder is incorporated at 2% and 4% in combination with SP, the slump values remain at 10 cm and decrease slightly to 9 cm, respectively. This reduction indicates that the inclusion of glass powder tends to slightly reduce workability, likely due to its fine particle size and angular shape, which increase internal friction within the fresh concrete mixture. At a higher glass powder content of 8%, the slump value increases again to 10 cm. This behaviour suggests that the presence of superplasticizer is effective in maintaining adequate workability even at higher levels of glass powder substitution. Overall, the results demonstrate that the use of glass powder up to 8%, in combination with a superplasticizer, does not significantly compromise the workability of the fresh concrete, as all slump values remain within an acceptable and workable range for practical applications.

Table 6. slump test

Test Object	Slump Value (cm)
NC	11
NC + SP 0,4%	10
NC + SP 0,4% + GP 2%	10
NC + SP 0,4% + GP 4%	9
NC + SP 0,4% + GP 8%	10

3.4 Compressive strength

Table 7. Compressive strength

Test		Normal Concrete (Kg)	Load (KN)	Compressive Strength (MPa)	Average	Ratio
NC	1	12.25	459,5	26,00	26,07	106%
	2	12,23	461,9	26,14		
	3	12,22	460,7	26,07		
NC + SP 0,4%	1	12,28	454,8	25,74	24,28	99%
	2	12,34	390,2	22,08		
	3	12,38	442,2	25,02		
NC + SP 0,4% + GP 2%	1	12,38	387,0	21,9	22,17	90%
	2	12,34	365,8	20,7		
	3	12,18	423,3	23,9		
NC + SP 0,4% + GP 4%	1	12,48	414,1	23,43	23,16	94%
	2	12,26	398,8	22,56		
	3	12,26	415,0	23,48		
NC + SP 0,4% + GP 8%	1	12,32	371,1	21,00	21,55	87%
	2	12,38	380,5	21,53		
	3	12,32	390,9	22,12		

Based on the compressive strength test results presented in the table 7, the normal concrete (NC) exhibits the highest average compressive strength of 26.07 MPa, which is taken as the reference value (100%). This result indicates that the control mix achieved the expected strength performance without the inclusion of superplasticizer or glass powder. The individual test results for NC show consistent compressive strength values, reflecting good uniformity in specimen preparation and testing. The concrete mixture with the addition of 0.4% superplasticizer (NC + SP 0.4%) shows a slightly lower average compressive strength of 24.28 MPa, corresponding to 99% of the control mix strength. This minor reduction suggests that the use of superplasticizer did not significantly affect the compressive strength, while potentially improving workability. When glass powder is introduced at 2% along with the superplasticizer, the average compressive strength decreases further to 22.17 MPa (90% of NC). This reduction may be attributed to the partial replacement of fine aggregate by glass powder, which can influence the particle packing and the bond between the cement paste and aggregates. At a glass powder content of 4%, the average compressive strength slightly increases to 23.16 MPa, or 94% of the normal concrete strength. This indicates that an optimal level of glass powder may exist, where the filler effect of fine glass particles improves the microstructure and partially compensates for strength loss. However, when the glass powder content is increased to 8%, the average compressive strength decreases again to 21.55 MPa, representing 87% of the control mix strength. This significant reduction suggests that excessive glass powder content may lead to weaker interfacial bonding and increased voids, negatively affecting the mechanical performance of the concrete. Overall, the results demonstrate that the incorporation of glass powder influences the compressive strength of concrete, with moderate replacement levels showing more favourable performance compared to higher percentages. The findings indicate that glass powder can be used as a partial replacement material in concrete; however, its percentage should be carefully controlled to achieve an optimal balance between workability and compressive strength.

4. CONCLUSION

Based on the results of this study, several conclusions can be drawn. The bulk density test results show that fine aggregate has the highest unit weight compared to coarse aggregate and glass powder, indicating denser particle packing and lower void content, while glass powder exhibits the lowest unit weight due to its finer particle size and material characteristics. The moisture content test indicates that coarse aggregate has the highest moisture content, whereas glass powder has the lowest, highlighting the need for proper moisture correction in mix proportioning. The concrete mix design incorporating glass powder as a partial replacement for fine aggregate was successfully developed for variations of 0%, 2%, 4%, and 8%. Slump test results demonstrate that all mixtures maintained acceptable workability, with slump values ranging from 9 to 11 cm, indicating that the use of superplasticizer effectively controlled workability despite the inclusion of glass powder. Compressive strength testing at the age of 28 days shows that normal concrete achieved the highest average compressive strength of 26.07 MPa. The addition of glass powder resulted in a reduction in compressive strength, particularly at higher replacement levels. However, the mixture containing 4% glass powder exhibited relatively better strength performance compared to the 2% and 8% variations, suggesting the presence of an optimum glass powder content. Overall, glass powder can be utilized as a partial replacement material in concrete; however, its proportion must be carefully controlled to balance workability and mechanical performance.

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