ENVIRONMENTALLY FRIENDLY CONCRETE USING WASTE GLASS POWDER (WGP) AS A PARTIAL SUBSTITUTE OF CEMENT

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Abstract: The utilization of waste materials in concrete production is gaining significant attention as a means to mitigate environmental issues and promote sustainable construction practices. This study investigates the potential of waste glass powder (WGP) as a partial replacement for cement in concrete. The aim is to evaluate the effects of WGP on the properties and performance of concrete, with a focus on enhancing sustainability and reducing the environmental impact associated with cement production. The experimental investigation involved preparing concrete mixtures with varying proportions of WGP, ranging from 10% to 25%, as a partial replacement for cement. Based on the research findings, it can be concluded that the substitution of 20% WGP for cement is the optimal dosage. The results of various tests and evaluations show that the concrete has desirable properties and performance characteristics at this level of replacement. This 20% substitution ratio strikes a balance between maintaining adequate compressive strength and improving the concrete's sustainability. In conclusion, the incorporation of WGP as a partial replacement for cement in concrete shows promise as an environmentally friendly and sustainable approach.

Keywords: sustainable construction, waste glass powder, cement, concrete, compressive strength

1. INTRODUCTION
The potential harm that glass waste could do to the environment has made it a pressing concern [1]. Glass is a material that is frequently used in
many different industries, including packaging, building, and household goods [2]. However, improper management and disposal of glass waste have had a negative impact on the environment [2]. Glass waste's non-biodegradable nature is one of the main environmental issues it raises [3]. Glass accumulates in landfills and other disposal facilities because, in contrast to organic materials, it takes an extremely long time to decompose naturally [4]. Ecosystems on land and in water are in danger as a result of this prolonged persistence in the environment [5].

Sustainable building techniques place an emphasis on ecology and resource efficiency while designing and managing a healthy built environment [3]. Throughout a building’s lifecycle, this method focuses on reducing the environmental impact of construction activities. It entails utilizing energy-efficient designs and systems, incorporating renewable energy sources, and using sustainable building materials, such as recycled or locally sourced materials. Furthermore, sustainable construction places a strong emphasis on waste management best practices, waste reduction, and water conservation [6].

Concrete is still one of the most widely used building materials because of its toughness and adaptability [7], [8]. Even so, the use of cement as a key ingredient in the production of concrete poses serious environmental problems [9]. The production of cement uses a lot of energy and emits a lot of carbon dioxide (CO2), which increases greenhouse gas emissions and contributes to climate change [10]. Furthermore, habitat destruction and biodiversity loss may result from the extraction of raw materials like clay and limestone used in the manufacture of cement [11]. Additionally, proper recycling and waste management are made more difficult by the disposal of concrete waste following construction or renovation projects [12]. Innovative strategies are needed to address these environmental issues, such as the creation of substitute cementitious materials [3], [5], [13]. An effective way to lessen the industry’s negative effects on the environment is to use supplementary cementitious materials (SCMs) to replace some of the cement in concrete [13], [14]. Several industrial by-products have proven to be successful supplementary cementitious materials (SCMs) in construction applications such as Silica fume (SF), Ground Granulated Blast Furnace Slag (GGBS), and Rice Husk Ash (RHA), fly ash and bottom ash (FABA) [15]. These materials are used to create blended cements which can improve concrete durability, early and long term strength, workability and economy [3]. Waste glass powder (WGP), though it has the potential to be an SCM, has not yet seen the same commercial success. WGP has a high pozzolanic reactivity and contains amorphous silica, both of which are desirable in SCM, which is used in concrete because they may increase the chemical resistance and durability of the latter [16]. Glass milling to micron scale particle size to improve reactions between glass and cement hydrates [17]. Cement is partially replaced with WGP in the production of concrete, significant energy, environmental, and economic benefits can be realized [18]. The properties that influence the pozzolanic behavior of WGP and most of the pozzolans in concrete are fineness, chemical composition, and the pore solution available for reaction [10], [19].

In recent years, WGP has become increasingly popular for concrete production in civil engineering applications [20]. Despite the fact that many studies have been conducted on this subject, the results obtained from the literature differ [10]. As a result, there is still a need to investigate the mechanical behavior of concrete with partial substitution of WGP, as well as the optimal dosage of it. The objective of this study is to examine the impact of utilizing waste glass powder (WGP) as a partial replacement for cement on the strength properties of concrete.

2. RESEARCH SIGNIFICANCE

This research looks into the feasibility of using WGP as a sustainable alternative to cement in concrete production. The goal of using WGP is to address the environmental concerns associated with its disposal while also reducing the harmful CO2 emissions caused by traditional cement production processes. This study’s findings are expected to provide valuable insights and serve as a useful resource for a variety of stakeholders, including the general public, academia, and industry, by providing additional knowledge and references to further advance scientific development in this field.

3. MATERIALS AND METHODS

a. Material

In this study, type I cement with a strength class of 42.5N was used. According to ASTM C187 (ASTM, 2011) and ASTM C786 (ASTM, 2016d), the percentages of clinker and gypsum in the cement were 95-100% and 0-5%, respectively, while the specific gravity and fineness of OPC were 3.15 and 99.3% (#200 sieve).

Waste glass powder (WGP) is used as a partial replacement for cement using syrup bottles. After the collection process, the bottles are washed and cleaned to remove paper labels and dust or other
unwanted material. The next step is to store them in water to remove organic contaminants then dry and crush them in the laboratory using a Los Angeles Machine for getting the same size of GWP, which passes a #50 sieve and is retained in a #100 sieve (0.150 mm).

Machine crushed coarse aggregates were used in these experiments as gravel with five different sizes (4.75 mm, 9.50 mm, 12.7 mm, 19.1 mm, and 25.4 mm in diameter). To find out gradation of coarse aggregates based on standard ASTM C136M-14 sieve analysis was performed and controlled by ASTM C33M-16. Properties of coarse aggregate are shown in Tables 1.

Natural sand was used as a fine which was obtained from the local market in Gorontalo with maximum size of 4.75 mm in diameter. To find out gradation based on ASTM standard, C136M-14 sieve analysis was performed and controlled by C33/C33M-16 of ASTM standard. Results of its physical property were shown in Tables 1.

The experimental casting procedure was carried out in two stages. A control sample was cast in the first stage using ordinary Portland cement and natural fine and coarse aggregates. A modified set of samples was prepared in the second stage by replacing a portion of the cement with WGP. Instead of starting the mixing procedure right away, the required amount of ingredients was precisely weighed using a precise weighing system. The speed of the mixer was then set to 30 rev/min. The coarse aggregates were first placed in the drum, followed by the fine aggregates. Each ingredient was dry blended before adding the appropriate amount of Portland cement and water. For all batches, the blending process took approximately 10 minutes. WGP was used as a cement replacement in amounts of 10%, 15%, 20%, and 25%. Table 2 also showed the material quantification per m³.

c. Compressive Strength

The compressive strength of concrete refers to its ability to resist a compressive force or load without undergoing significant deformation or failure based on ASTM standards. It is one of the essential properties used to assess the structural performance and durability of concrete in various construction applications. Compressive strength is typically measured by subjecting concrete specimens to a compressive force until failure occurs. The resulting maximum load or stress at failure is recorded as the compressive strength of the concrete. It is commonly expressed in units of force per unit area, such as megapascals (MPa) or pounds per square inch (psi). The specified compressive strength requirements for concrete vary depending on the intended application and structural design considerations.

4. RESULTS AND DISCUSSION

Results

Figure 1a shows compressive strength of concrete with different proportion ration of WGP. The compressive strength values of the reference concrete without WGP series at 28 days were found as 24.6 MPa. The lowest compressive strength values were also found to be 18 MPa in the concrete produced with cement including 10% WGP and and the highest compressive strength value is 26.3 Mpa with 20% WGP for 28 days periods, respectively. As observed in Figure 1a, it has been detected that the compressive strength of concrete combinations including WGP utilization as a fractional

### Table 1. Physical properties of fine aggregate and coarse aggregate

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Unit</th>
<th>Fine Aggregate</th>
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</tr>
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<tbody>
<tr>
<td>Particle size</td>
<td>mm</td>
<td>2.36 - 0.0075</td>
<td>4.75 - 25.4</td>
</tr>
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<td>Fineness modulus</td>
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<td>2.51</td>
<td>8.41</td>
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<tr>
<td>Absorption capacity</td>
<td>%</td>
<td>2.60</td>
<td>1.93</td>
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<tr>
<td>Moisture content</td>
<td>%</td>
<td>2.04</td>
<td>0.60</td>
</tr>
<tr>
<td>Volume weight</td>
<td>kg/m³</td>
<td>1518</td>
<td>1550</td>
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### Table 2. Mix proportion of materials per m³

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<th>Compositions</th>
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<td>Water</td>
<td>kg</td>
<td>212</td>
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<td>Cement</td>
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<td>281</td>
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<tr>
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<td>kg</td>
<td>1118</td>
<td>111</td>
</tr>
<tr>
<td>Fine Agg.</td>
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<td>Total</td>
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### Testing procedure and concrete mix proportion.

The workability of concrete was determined using an ASTM slump cone test. The ASTM standard procedure for compressive strength testing is used for cylindrical specimens with standard dimensions of 150 mm diameter and 300 mm length. For drying shrinkage tests, ASTM standards were used. After 28 days of curing, all tests were performed. For each mix, five samples were drawn, and the mean value was used to determine the outcome of the test.

The experimental casting procedure was carried out in two stages. A control sample was cast in the first stage using ordinary Portland cement and natural fine and coarse aggregates. A modified set of samples was prepared in the second stage by replacing a portion of the cement with WGP. Instead of starting the mixing procedure right away, the required amount of ingredients was precisely weighed using a precise weighing system. The speed of the mixer was then set to 30 rev/min. The coarse aggregates were first placed in the drum, followed by the fine aggregates. Each ingredient was dry blended before adding the appropriate amount of Portland cement and water. For all batches, the blending process took approximately 10 minutes. WGP was used as a cement replacement in amounts of 10%, 15%, 20%, and 25%. Table 2 also showed the material quantification per m³.

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replacement for cement was lesser than those of the corresponding concrete mixes lacking WGP. As observed in Figure 1b, statistical investigation of test values shows the noteworthy impact of WGP (as a fractional replacement for cement) on the compressive strength of concrete.

It is shown in Figure 1b, the coefficient of determination ($R^2$) is 0.8101. This means that 81.01% of the compressive strength of the 28 days periods was determined by the use of WGP as the partial cement substitute through the polynomial equation of $Y = -0.103x^2 + 3.799x - 10.295$. Meanwhile, 18.99% of the concrete’s compressive strength is determined by other factors.

It is due to fact that WGP is a SCM that reacts with calcium hydrate (CH) which is form during hydration process of cement. calcium hydrate (CH) is by product which remain uncreative forming weak zone in concrete. It has been also reported that, calcium hydrate (CH) react with different chemical present in cement cause degradation of concrete. Silica present in WGP react with calcium hydrate (CH) and convert it in calcium silicate hydrate (CSH) gel which Provide additional binding property, leading to more compressive strength.

Discussions

Several studies have been conducted to determine the optimal percentage of WGP that can be used as a partial replacement for cement in concrete. Kumar et al. in [21] discovered that as the percentage of cement replaced by GWP increased, the density of concrete at 28 days decreased. This is because the GWP used has a lower density (2.58) than cement (3.15). Bhat & Rao in [22] confirmed the same result. Keerio et al in [23] discovered that replacing 5%, 10%, and 15% of the cement with WGP increases the density of hardened concrete; the maximum increase of 1.25% in the control concrete was observed when replacing 10% of the cement with WGP. According to Aliabdool et al in [24], the use of WGP as a partial cement replacement has a significant effect on concrete density.

The compressive strength at a given age is the most important property of hardened concrete. Because of the pozzolanic activity of WGP, Martina Martina et al in [14], and Olanfinnade et al in [25] reported that the concrete containing WGP showed a significant improvement in the development of compressive strength at 28 days compared to the control concrete. Vandhiyan et al in [26] concluded that cement replacement increases the compressive strength of concrete by up to 10%. Mounika et al in [27] discovered that the optimum compressive strength was obtained in the mixture containing 10% WGP and increased by 28.3%, 31.1%, and 36% at 7, 14, and 28 days, respectively. Gahoi & Kansai in [28] replaced cement WGP in percentages ranging from 0% to 25%. They discovered that increasing the percentage of WGP in concrete to 10% resulted in a significant increase in compressive strength. Zeybek et al in [10] obtained different results. 20% substitution of WGP as cement can be considered the optimum dose. Mechanical properties increased up to a certain limit in concrete produced with combined WGP and crashed glass particles, but then decreased due to poor workability. As a result, 10% can be considered the optimal replacement level, as combined WGP has significantly higher strength and workability properties.

According to Du & Tan in [30], a 30% replacement of cement by WGP is optimal for the development of concrete compressive strength after seven days. Khan et al. in [31] discovered a decrease in compressive strength over time. The strength achieved at constant rates and after 84 days of testing of 10% WGP, 15% WGP, and 20% WGP mixtures was 88% of the control concrete's compressive

![Figure 1. Compressive strength results](image-url)
strength. According to Bhat & Rao in [22], the compressive strength of concrete containing 20% WGP has a maximum strength when compared to control concrete; this result is consistent with Sakale et al in [32].

An increment in the mechanical properties could be noted when the WGP is used to partially replace the binder. The increased strength can be attributed to the increased aluminum and silica dissolution, which results in an efficient Pozzolanic reaction and curing age [4]. It is important to note that the conclusions of these studies may vary due to factors such as the specific properties of the WGP used, the mix design, curing conditions, and the testing methods employed. Therefore, further research is needed to establish consistent guidelines and recommendations for the optimal use of WGP in concrete to ensure its effective and sustainable application in the construction industry.

The concept of environmentally friendly concrete with waste glass powder (WGP) involves integrating recycled glass into the concrete mixture, typically as a partial replacement for traditional cement. This approach addresses several environmental challenges simultaneously. First, it promotes the recycling of waste glass, diverting it from landfills and reducing the environmental impact associated with glass disposal. Secondly, it decreases the demand for cement, a material known for its significant carbon emissions during production. Cement manufacturing involves high-temperature processes that release substantial amounts of carbon dioxide (CO2) into the atmosphere. By substituting WGP for some of the cement content, this innovation helps lower CO2 emissions and conserves finite natural resources like limestone and clay, which are primary cement ingredients [4]. Furthermore, the use of WGP can enhance the thermal and insulating properties of concrete, potentially improving energy efficiency in buildings [1]. Overall, environmentally friendly concrete with WGP is a sustainable construction solution that minimizes waste, reduces carbon emissions, and contributes to a more eco-conscious and resource-efficient building industry, all while maintaining the essential structural qualities of traditional concrete [6].

5. CONCLUSION AND SUGGESTION

Conclusion

The use of pozzolanic materials as a partial replacement for cement affects the concrete's compressive strength. WGP is used as an artificial Pozzolana in this study. The WGP was mixed into the cement at various percentages (10, 15, 20, 25, by weight of cement), and the compressive strength of these blended mixes was tested. The blended mix results were compared to the Control Mix. Compared to the reference sample, 10%, 15%, and 25% replacement of WPG reduced the compressive strength by 26.8%, 11.8%, and 19.9%, respectively, and 20% WGP can increase the compressive strength of concrete by 6.90%. The current study defines WGP as suitable, accessible in large quantities, a local eco-material, inexpensive, and suitable for concrete construction from an economic and environmental standpoint.

Suggestion

The research on environmentally friendly concrete using WGP aims to investigate the optimal content of WGP as a cement replacement, assess its performance in various applications, investigate its compatibility with chemical admixtures, investigate the influence of particle size and shape, evaluate its environmental impact through life cycle assessments, analyze durability performance and economic viability, and contribute to the development of standardized methods. The research aims to advance sustainable construction practices and promote the use of waste materials such as WGP in concrete production by addressing these issues.

Author Contributes

All authors have made significant contributions to this experimental research. MRO and ASH were responsible for conceptualizing the research project and designing the experimental methodology. MS, TS, and MAH conducted the laboratory experiments. RP helped in the writing and editing of the manuscript. All authors participated in the reviewing and approving the final version for publication.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgments

We would like to extend our sincere appreciation to all those who have supported and contributed to the completion of this research project. We are also grateful to the Engineering Faculty of Universitas Gorontalo for providing the necessary funding, resources, and facilities to facilitate our research process.

6. REFERENCES


