SHORT SCIENTIFITIC COMMUNICATIONS

Valorization of glass waste into glass powder in the manufacture of concrete

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Abstract:

Introduction/purpose: The valorization of waste in civil engineering is an essential practice due to its environmental and economic benefits. In many countries, various waste materials are incorporated into construction, particularly in cement and concrete, in the form of powders, fibers, or aggregates. This study focuses on reusing glass waste, a material that poses a significant environmental challenge. The primary objective is to evaluate the feasibility of partially replacing sand with glass waste in concrete production and analyzing its impact on the material's properties.
Method: Different types of glass waste are added to concrete as a partial replacement for sand, using varying percentages. The resulting concrete

samples undergo testing and are compared to conventional (control) concrete to assess their physical and mechanical properties.
Results: The analysis indicates that incorporating recycled glass into concrete is feasible, although the material's properties vary depending on the type and amount of glass used. In some cases, certain characteristics of the concrete improve, while in others, challenges related to strength and durability may arise.
Conclusion: Using glass waste in concrete is a sustainable alternative that helps reduce waste and conserve natural resources. Despite some limitations, this technique represents a promising solution for the construction sector, promoting sustainable development and a circular economy.

Key words: valorization, glass powder, concrete, substitution, mechanical properties.

Introduction

Concrete is the most widely used construction material worldwide due to its availability, relatively low cost, and ease of use. It is employed in a wide range of applications, from residential buildings to infrastructure projects such as bridges and roads. Its standard composition generally includes cement, sand, gravel, and water, although numerous variations exist depending on specific requirements for mechanical strength, durability, and workability.

In the context of sustainable development and responsible resource management, the construction industry faces several environmental challenges. Cement production is particularly energy-intensive and significantly contributes to CO2 emissions. Furthermore, the massive extraction of sand and gravel causes severe ecological disturbances, including habitat destruction, air and water pollution, and increased greenhouse gas emissions.

Recycling waste materials presents a promising solution to mitigate the environmental impact of the construction sector. Among recyclable materials, waste glass is an underutilized resource despite its abundance and potential in various applications, including concrete production. Recycled glass can be ground into fine powder and used as a partial sand replacement in concrete mixtures, thereby reducing landfill waste and conserving natural resources.

This study aims to evaluate the impact of incorporated glass powder on the mechanical properties of concrete. To achieve this, we used the Dreux-Gorisse mix design method to formulate a control concrete and six modified concrete mixes containing different proportions of glass powder

(5%, 10%, 15%, 20%, 25%, and 30%) as a partial replacement for sand. The main focus is to assess how this substitution affects the mechanical behavior of concrete, particularly in terms of its strength and durability over time.

The incorporation of recycled glass in concrete has been extensively studied due to its unique properties, including its silica-rich composition and potential pozzolanic reactivity when finely ground. A review of previous research helps to contextualize this study within the scientific framework and identify current advancements and limitations in this field. Glass can be classified into various categories based on its application and chemical composition, including container glass, lamp glass, and cathode ray tube (CRT) glass (Topcu et al, 2004). Specialized glass types, such as borosilicate glass, are known for their chemical resistance and high softening points, making them suitable for cookware and laboratory equipment (Samtur, 1974). However, impurities and contaminants in mixed-color glass waste can affect the properties of recycled glass and, consequently, the performance of glass-containing concrete (Isa, 2008). The cement industry is one of the most energy-intensive industries, with energy costs representing up to 40% of variable production expenses and even 50–60% in some countries (Jani, 2014). The valorization of glass waste in construction materials, including concrete, presents a promising approach to reducing these costs while enhancing sustainability. A comprehensive review of glass recycling methods in building materials, including concrete, has been provided in (Lu et al, 2019). Several studies have investigated the performance of concrete containing recycled glass in various forms. An in-depth analysis of the use of recycled glass powder in concrete has been presented in (Mallum et al, 2022), highlighting its influence on mechanical strength and durability. Other studies have examined the advantages and limitations of glass powder as a supplementary cementitious material (Federico et al, 2009) or as a fine aggregate substitute (Ismail et al, 2009; Harrison et al, 2020). Research indicates that glass powder, due to its fine particle size and silica content, can exhibit a pozzolanic reaction, improving the long-term strength of concrete. The shortage of natural sand and the environmental consequences of its extraction have led to the search for sustainable alternatives. The use of crushed glass powder as a partial sand substitute in concrete is a viable solution that reduces natural aggregate consumption while repurposing industrial waste. Studies have demonstrated that glass powder effectively fills voids between larger aggregates, enhancing the compactness and mechanical performance of concrete.

While numerous studies have explored the incorporation of glass powder in concrete, several questions remain open, particularly regarding optimal dosage and its effects on mechanical performance. The unique contribution of this study includes:

- Rigorous application of the Dreux-Gorisse method to develop an optimized concrete mix with varying proportions of glass powder, ensuring precise formulation;
- Systematic experimental comparison between a control concrete and six modified mixes containing 5% to 30% glass powder as a sand replacement;
- Comprehensive mechanical evaluation, focusing on the evolution of tensile and compressive strength over time; and
- Identification of the optimal glass powder dosage that improves concrete performance while maintaining an economically and environmentally viable formulation.

This research enhances the understanding of how recycled glass affects concrete properties, providing valuable insights for sustainable construction practices.

This study aligns with sustainable development objectives by reducing the environmental impact of concrete production while improving its performance. Using glass powder as a sand substitute not only recycles an abundant waste material but also optimizes concrete formulation in terms of compactness and strength. The experimental findings will contribute to advancing knowledge on recycled glass in construction materials and guide future research on optimizing concrete mixtures for sustainability.

Materials and methods

Concrete is a building material made from a mixture of cement, gravel, sand, water, and various additives that alter its properties. The components must be appropriate to produce concrete that satisfies the necessary specifications.

The aggregates subject to this study are located in the Sidi Bel Abbes region in Algeria, and their source is as follows:

Cement

CEM II/A-L 42.5N cement is a Portland limestone cement, composed mainly of clinker (80 to 94%) and pure limestone (6 to 20%), with the addition of gypsum (0 to 5%) as a setting regulator.

The cement used in producing different types of concrete complies with standards NF P15-301(Yaragal et al, 2017) and NF EN196-1. It is Portland cement of class CEM II 42.5N, produced at the ZAHANA cement plant. Its strength at 28 days is (≥42.5 MPa).

Sand

The sand utilized in our study is quarry sand sourced from Hasnaoui Sidi Ali Ben Youb. Its cleanliness was evaluated through the sand equivalent test and the sand grain size analysis is presented in Figure 1. According to the results of the sand equivalent test, our sand is clean sand.

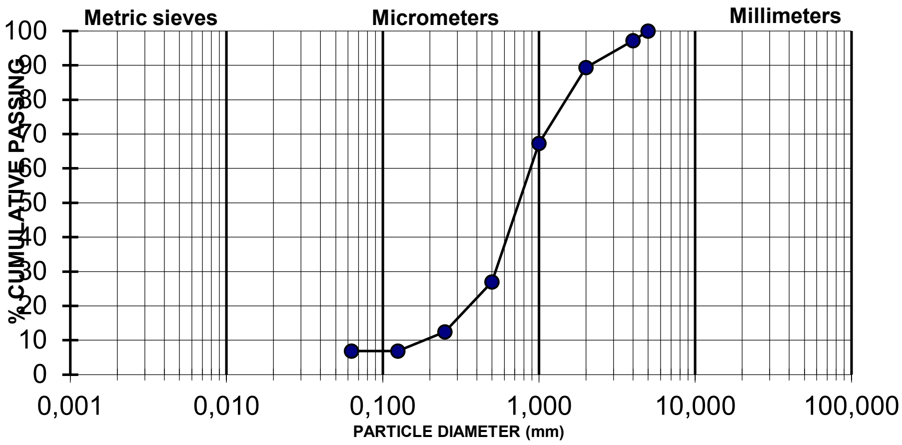

Figure 1 – Grain size analysis curve of the used sand

Gravel

The aggregates utilized in this study are sourced from the Hasnaoui Sidi Ali Ben Youb quarry situated in the Sidi Bel Abbes province of Algeria.

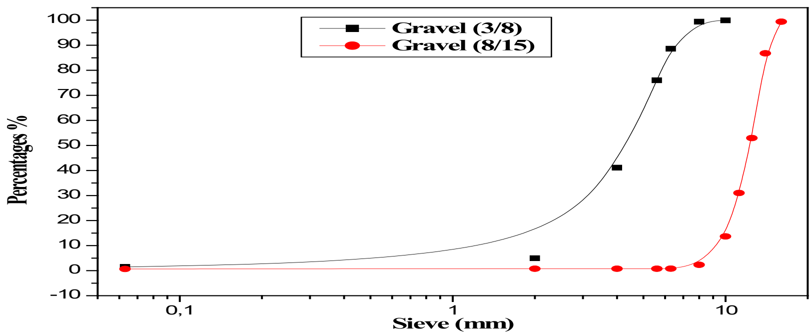

Figure 2 – Grain size analysis curve of the aggregates

These aggregates are available in two size ranges: 3/8 and 8/15 (Figure 2). The concrete is prepared using a mixer with a capacity of 500 liters.

Water

Water plays a crucial role in concrete, as it directly contributes to the chemical reaction with cement (Federico et al, 2009). The quantity of water used should be enough to ensure both the hydration process and the workability of concrete. Potable water is typically used for this purpose.

Glass powder

The glass powder used in our concrete is a finely ground material obtained from recycled glass. The LOS ANGELES machine used for our tests grinds this glass into powder with a diameter of (D ≤ 0/3) (Figure 3).

Figure 3 – Glass powder (0/3) sample

Methodology

To guarantee clarity and precision in our study, we decided to use a reference concrete (RC) as a standard for comparison in our tests. We use the Dreux-Gorisse method to optimize the filling of voids for denser and more resistant concrete and to control workability and durability. Our concrete was designed using the Dreux-Gorisse method, based on a 1 m³ formulation, providing a continuous granular skeleton with a target strength of 40 MPa and a slump of 12 cm. We adopted different compositions of concrete without and with the addition of glass powder at different percentages in all that follows (Table 1).

In this paper, we present the characteristics of the materials and the formulation of the concretes to be studied. We conducted several experimental tests on these concretes (Table 2). The crushing of the cubic specimens (15*15*15 cm³) is presented in Figure 4.

Figure 4 – Concrete made in 15x15x15 cm³ cubic test specimens

Table 1 – Concrete conventions with and without glass powder

Concrete type	Composition
BT	Control concrete with 0% glass powder
BV01	Concrete with 5% glass powder
BV02	Concrete with 10% glass powder
BV03	Concrete with 15% glass powder
BV04	Concrete with 20% glass powder
BV05	Concrete with 25% glass powder
BV06	Concrete with 30% glass powder

Table 2 – Formulation and composition of concrete based on glass powder

Types	Cement (Kg/m^3)	Sand (Kg/m^3)	Gravel (Kg/m^3)	Gravel (Kg/m^3)	Water (L/m^3)	Glass powder (Kg/m^3)
			3/8	**8/15**		
BT	350	**445.00**	356	534	175	**0**
BV01	350	**422.75**	356	534	175	**22.25**
BV02	350	**400.00**	356	534	175	**45.00**
BV03	350	**378.25**	356	534	175	**66.75**
BV04	350	**356.00**	356	534	175	**89.00**
BV05	350	**333.75**	356	534	175	**111.25**
BV06	350	**311.50**	356	534	175	**133.50**

Results and discussions

This section presents the outcomes of the experimental tests conducted on these concrete samples, specifically focusing on compressive and tensile strength assessments.

As stated in (Ismail et al, 2009), the average compressive strengths of various concrete mixtures were measured at intervals of 7, 14, and 28 days using a compression machine.

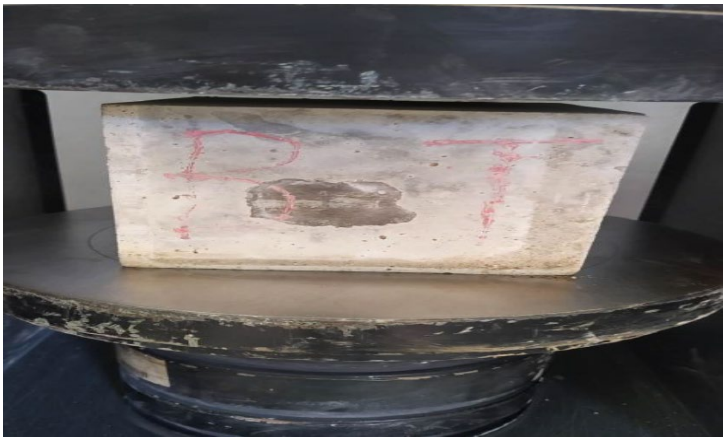

Figure 5 – Crushing of a cubic specimen of witness concrete

Based on the compression tests conducted in the RAH laboratory, the results are as follows:

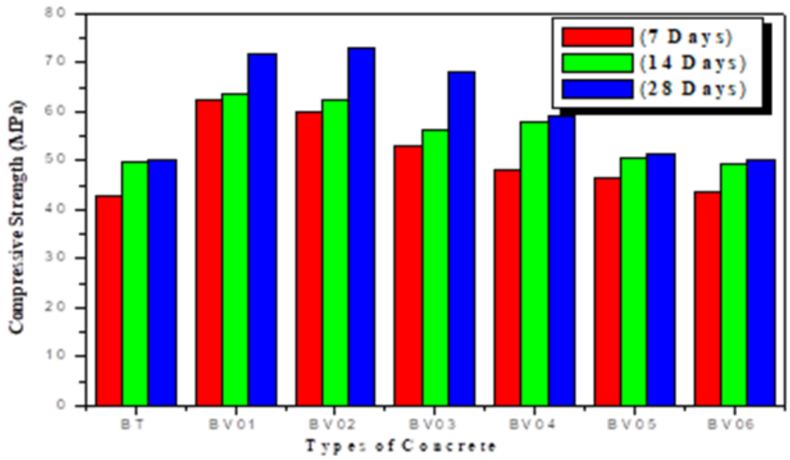

Figure 6 – Results of the compressive strength test

Figure 6 presents the results of the compression tests conducted on the standard concrete (BT) and the concrete containing varying volumetric fractions of glass powder at 5%, 10%, 15%, 20%, 25%, and 30%. The compressive strength was assessed at 7, 14, and 28 day intervals, based on the percentage of glass powder relative to the conventional concrete mix. The compressive strength of the cubic specimens measuring 15 cm x 15 cm x 15 cm, incorporating 5% glass powder, showed a 42.52% increase compared to the standard concrete after 28 days. In contrast, the specimens containing 10% glass powder exhibited a 44.95% increase in compressive strength. However, for the specimens with 15%, 20%, 25%, and 30% glass powder, there was a decline in their compressive strength, with reductions of approximately 35.88%, 17.62%, and 2.07%, ultimately reaching 0%. The findings indicate that incorporating just 10% glass powder (BV02) enhances the concrete strength to 72.88 MPa. This suggests a strong bond between sand and a binder, reflecting the effective integration of glass powder within the matrix. However, increasing the glass powder content to 15%, 20%, 25%, and 30% results in a decline in concrete strength. This decrease is attributed to inadequate implementation and management, resulting in the creation of voids that contribute to the lower strength relative to the standard concrete. Substituting 10% of sand with glass powder is considered a viable option.

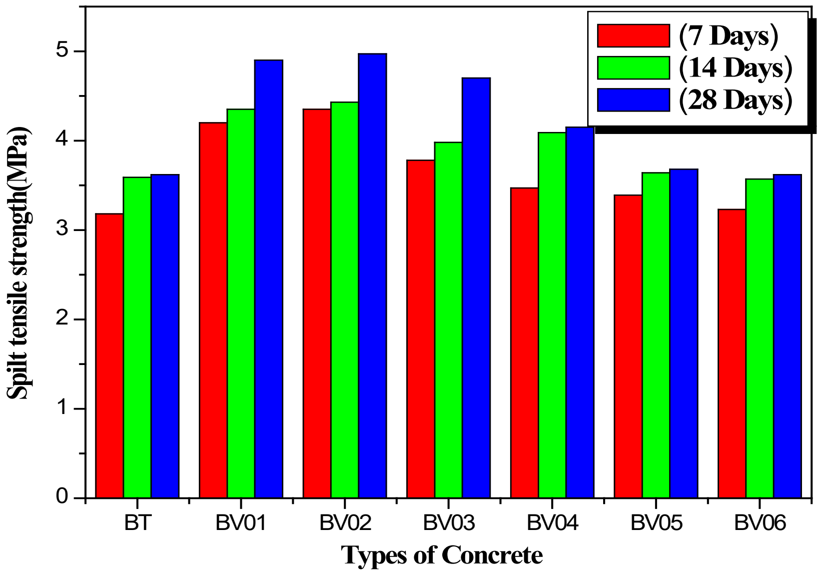

Figure 7 – Tensile strength of the concrete used

Spilt tensile strength was tested in the compressive testing machine. Cylinder specimens of 300mm*150mm were used. The split tensile strength of the cylinder is calculated using:

L = 30cm, length of the cylinder, and

D = 15cm, diameter of the cylinder.

As illustrated in Figure 7, the inclusion of glass powder can significantly improve the tensile strength of concrete. The data indicates that concrete mixed with glass powder exhibits a tensile strength increase ranging from 5% to 30% compared to that of conventional concrete across all ages. Specifically, at 28 days, the tensile strength of concrete containing glass powder shows increments of 35.47% and 37.49% for 5% and 10% glass powder content, respectively. In contrast, for the 15%, 20%, 25%, and 30% glass powder mix, the tensile strength increases by 29.93%, 14.70%, 39.83%, and remains unchanged at 0%.

Conclusions

This research presents findings on the mechanical properties of glass powder in relation to the compressive and tensile strength of concrete, including a comparison with conventional concrete. The key conclusions are as follows:

- The compressive strength of concrete increases with the inclusion of 5% and 10% glass powder (samples BV01 and BV02) compared to standard concrete.
- Concrete mixtures containing 15%, 20%, 25%, and 30% glass powder demonstrate lower compressive strength than the 10% glass powder concrete (BV02).
- The incorporation of glass powder positively influences the strength of concrete, indicating that glass powder concrete fulfills construction requirements and serves as a viable option for the industry.
- While resistant glass powder is valued for enhancing the strength and ductility of concrete, excessive amounts may lead to segregation issues and an overall decrease in concrete strength.
- High concentrations of glass powder can also pose workability challenges due to their increased surface area. However, the performance of glass powder in locally produced concrete shows marked improvements in overall strength and toughness compared to traditional concrete.
- Glass powder is used in various fields, such as coatings manufacturing, construction materials, abrasives, ceramics, etc.

- Glass powder is an environmentally friendly material. Its manufacturing and infinite recyclability make it a sustainable choice for the environment.
- The glass powder is an innovative material. New technologies enable the development of glass powders with increasingly higher performance properties.

This research expands knowledge on alternative materials in concrete, promoting innovation for more eco-friendly, durable, and high-performance concrete.

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Valorización de residuos de vidrio en polvo de vidrio en la fabricación de hormigón

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CAMPO: materiales, ingeniería civil
TIPO DE ARTÍCULO: breve anuncio

Resumen:

Introducción/objetivo: La valorización de residuos en la ingeniería civil es una práctica esencial debido a sus beneficios ambientales y económicos. En muchos países, diversos materiales de desecho se incorporan a la construcción, especialmente en cemento y hormigón, en forma de polvos, fibras o agregados. Este estudio se centra en la reutilización de residuos de vidrio, un material que representa un importante reto ambiental. El objetivo principal es evaluar la viabilidad de sustituir parcialmente la arena *por residuos de vidrio en la producción de hormigón y analizar su impacto en las propiedades del material.*

Métodos: Se añaden al hormigón diferentes tipos de residuos de vidrio como sustituto parcial de la arena, en porcentajes variables. Las muestras de hormigón resultantes se someten a pruebas y se comparan con el hormigón convencional (de control) para evaluar sus propiedades físicas y mecánicas.

Resultados: El análisis indica que la incorporación de vidrio reciclado al hormigón es viable, aunque las propiedades del material varían según el tipo y la cantidad de vidrio utilizado. En algunos casos, ciertas características del hormigón mejoran, mientras que en otros pueden surgir desafíos relacionados con la resistencia y la durabilidad.

Conclusión: El uso de residuos de vidrio en el hormigón es una alternativa sostenible que ayuda a reducir los residuos y a conservar los recursos naturales. A pesar de algunas limitaciones, esta técnica representa una solución prometedora para el sector de la construcción, promoviendo el desarrollo sostenible y la economía circular.

Palabras claves:. valorización, polvo de vidrio, hormigón, sustitución, propiedades mecánicas.

Переработка стеклоотходов в стеклянный порошок и его использование в производстве бетона

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РУБРИКА ГРНТИ: 81.09.00 Материаловедение
ВИД СТАТЬИ: краткое заявление

Резюме:

Введение/цель: Валоризация отходов в гражданском строительстве является важной практикой из-за экологических и экономических преимуществ. Во многих странах различные *отходы используются в строительстве, особенно в цементе и бетоне, в виде порошков, волокон или заполнителей. Данное исследование посвящено вторичному использованию стеклянных отходов − материала, представляющего серьезную угрозу для окружающей среды. Основная цель статьи заключается в оценке возможности частичной замены песка стеклянными отходами при производстве бетона и анализе его влияния на свойства материала.*

Методы: В ходе исследования различные виды стеклоотходов были добавлены в бетон в качестве частичной замены песка в разных процентных соотношениях. Затем полученные образцы бетона были испытаны и сравнены с обычным (контрольным) бетоном для оценки их физических и механических свойств.

Результаты: Анализ показал, что добавление переработанного стекла в состав бетона возможно. Однако свойства полученного материала различаются в зависимости от типа и количества используемого стекла. В некоторых случаях характеристики бетона улучшаются, в то время как в других случаях могут возникнуть проблемы с прочностью и долговечностью.

Выводы: Добавление стеклоотходов в бетоне является экологичной альтернативой, которая помогает сократить количество отходов и сохранить природные ресурсы. Несмотря на некоторые ограничения, этот метод представляет собой многообещающее решение в строительной отрасли, способствующее устойчивому развитию и экономике замкнутого цикла.

Ключевые слова: валоризация, стеклянный порошок, бетон, замещение, механические свойства.

Валоризација стакленог отпада у стаклени прах у производњи бетона

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ОБЛАСТ: материјали, грађевинарство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: кратко саопштење

Сажетак:

Увод/циљ: Валоризација отпада у грађевинарству представља суштински важну праксу због користи како за *економију, тако и за животну средину., Различити отпадни материјали употребљавају се у многим земљама као додатак грађевинским материјалима, нарочито цементу и бетону, у облику праха, влакана или агрегата. Стога се у овом раду разматра поновно коришћење стакленог отпада, материјала који представља значајан еколошки изазов. Основни циљ јесте да се процени изводљивост делимичне замене песка стакленим отпадом у производњи бетона, као и да се анализира утицај који таква замена има на својства материјала.*

Методе: Бетону су додаване различите врсте стакленог отпада као делимичне замене за песак, у различитим процентима. Узорци тако добијеног бетона тестирани су и упоређени са стандардним (контролним) бетоном ради оцене њихових физичких и механичких својстава.

Резултати: Анализа показује да је изводљиво уградити рециклирано стакло у бетон, иако својства тако добијеног материјала варирају зависно од врсте и количине коришћеног стакла. У неким случајевима одређене карактеристике бетона се побољшавају, док се у другим могу јавити проблеми у вези с чврстоћом и трајношћу.

Закључак: Коришћење стакленог отпада у бетону представља одрживу алтернативу којом се смањује отпад и чувају природни ресурси. Упркос неким ограничењима, ова техника може да буде једно од решења у грађевинском сектору којим се промовише одрживи развој и циркуларна економија.

Кључне речи: валоризација, стаклени прах, бетон, супституција, механичка својства

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