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Enhancing concrete strength and sustainability: the role of Medan Barangan banana skin powder as a cement substitute

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Abstract

Cement is commonly utilized as a binding agent in the construction industry, making it the most essential component in concrete production. Globally, cement production contributes to 8% to 10% of anthropogenic carbon dioxide (CO2) emissions. With the rapid expansion of the cement sector, CO_2 emissions are expected to rise. Therefore, reducing cement consumption is crucial to mitigate global warming. This study employed experimental research conducted in a laboratory (Civil Engineering Laboratory, Universitas Medan Area, Indonesia), creating 60 cylindrical and cubic test specimens. It investigates how agricultural waste can yield innovative, sustainable, and eco-friendly concrete, thereby decreasing environmental issues and CO_2 emissions. Agricultural waste contains pozzolanic materials that, when finely ground, initiate a pozzolanic reaction where calcium oxide (CaO) and silica combine to form calcium silicate, enhancing concrete's strength. In this research, banana skin powder (BSP) from Medan Barangan, a by-product of agriculture, was tested as a substitute for cement in 2.5%, 5%, and 7.5% variations. The high silica content in Medan Barangan BSP is likely to induce a pozzolanic reaction in the concrete mix, thus improving the concrete's strength. The results indicated that a 2.5% substitution of Medan Barangan BSP increased the concrete's compressive strength but decreased at 5% and 7.5% substitutions. Therefore, the concrete mix can feasibly include Medan Barangan BSP waste. These findings are particularly beneficial to the community, especially in Medan, for application in the construction sector. However, it is advised to limit the substitution to no more than 5% of the total cement weight.

Keywords

Banana skin powder, Cement consumption, Agricultural waste, Pozzolanic reaction, Compressive strength.

1.Introduction

The construction sector is experiencing rapid developments in various domains such as housing, offices, bridges, highways, dams, and ports. The predominant construction material employed in these projects is concrete, known for its high compressive strength, fire resistance, and extended operational lifespan [1]. However, the manufacturing process of concrete, involving cement, fine aggregate, water, and additives, poses challenges to environmental conservation [2]. The widespread use of cement, especially in industrial construction, contributes significantly to environmental issues.

These oxides interact in the kiln at high temperatures to form more complex compounds. Along with the pace of cooling and degree of grinding, the quality of various cements varies depending on the relative amount of their oxide composition. The estimated limits for the oxide concentration of standard Portland cement are shown in *Table 1*. Cement, primarily composed of lime, silica, alumina, and iron oxide, undergoes complex reactions in the kiln, leading to variations in the quality of produced cements. Global carbon dioxide (CO_2) emissions from cement production contribute to climate change, necessitating a reduction in cement usage to mitigate environmental impact. It is recorded that the world cement production produces 8% to 10% of anthropogenic global CO_2 gas emissions into the atmosphere as shown in *Figure 1*, which creates the

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weathering and climatic changes. Municipal solid waste, encompassing research, food, fruit, glass, and agricultural waste, poses a growing challenge due to urbanization, economic expansion, and changes in living standards [3, 4]. The motivation behind this research stems from the need to address environmental concerns by exploring sustainable alternatives to traditional concrete production, incorporating waste materials, and reducing CO_2 emissions. This research focuses on investigating banana skin powder (BSP) Barangan Medan, an agricultural waste with high silica content, as a substitute for cement in concrete production. The aim is to conduct a comprehensive examination of the potential benefits of utilizing BSP Barangan Medan to enhance concrete strength through a pozzolanic reaction. Additionally, the study seeks to promote innovative and sustainable solutions to environmental challenges in the construction sector. The primary contribution of this research lies in the exploration of BSP Barangan Medan as a novel and minimally utilized waste material for concrete production. By recycling this waste, the study aims to provide environmental and economic benefits to the local community, particularly in the city of Medan, North Sumatra. The research also contributes to the broader goal of developing environmentally friendly concrete that can reduce CO_2 gas emissions, addressing the urgent need for sustainable construction practices [5–8].

Table 1 Limitations of the standard Portland cement oxide content [9]

Chemicals	Cement (max %)
CaO	67
SiO_2	25
Aluminium oxide (Al_2O_3)	8.0
Ferric Oxide (Fe_2O_3)	6.0
Magnesium Oxide (MgO)	4.0
K_2O and Na_2O, alkalies	1.3
SO_3	3.0

The research is organized as follows: Section 2 provides a detailed background on the challenges associated with traditional concrete production and the environmental impact of cement usage. Section 3 discusses the motivation behind the research, emphasizing the need for sustainable alternatives. Section 4 outlines the specific objectives of the study, focusing on the utilization of BSP Barangan Medan in concrete mixtures. Section 5 highlights the contributions of the research to the field of environmentally friendly concrete. Finally, section 6 concludes the research by summarizing key findings and proposing future avenues for research in sustainable construction practices.

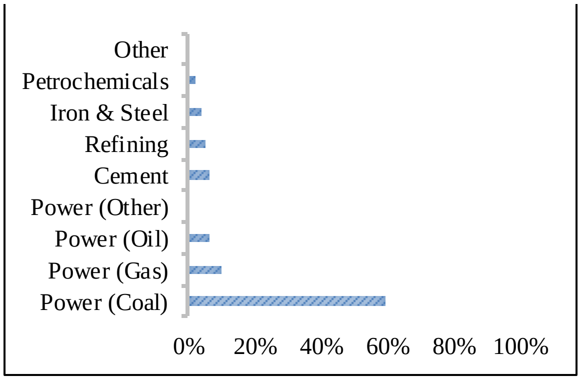

Figure 1 Emissions of CO_2 in the atmosphere [10]

2.Literature review

To create a solid mass, Portland cement and other hydraulic cement, fine aggregate, coarse aggregate, and water are combined. Normal concrete (NC) is concrete with a unit weight (2200 – 2500) kg/m^3 using natural aggregates broken down. Fine aggregate is natural sand due to the most significant grain size of 5.0 mm from the stone-crushing industry spontaneous disintegration of stone or sand. Coarse aggregate is gravel due to the natural stone disintegration or crushed stone with a grain size of 5 mm to 40 mm obtained from the stone crushing business. Technical requirements for materials: 1) Water must comply with applicable regulations. 2) The cement must comply with Standar Nasional Indonesia (SNI)-15-2049-1994 [11] regarding Portland cement. 3) Aggregates must comply with SNI-03-1750-1990 [12] concerning quality and method of testing concrete aggregates. Equation 1 calculates the standard deviation from on-the-job experience to determine the desired average compressive strength percentage.

$$S = \sqrt{\frac{\sum_{i=1}^{n}(X_1 - \bar{X})^2}{n-1}} \tag{1}$$

Where:
S is the standard deviation
X_1 represents the concrete compressive strength as determined by each specimen.
X is the average compressive strength according to Equation 2.

$$S = \sqrt{\frac{\sum_{i=1}^{n} Xi}{n}} \tag{2}$$

Where:

n is the minimum number of test results required is 30, and one test result is the average test value of two specimen tests. The added value is calculated according to Equation 3.

$$M = 1.64 \times Sr \quad (3)$$

Where:
M is the value added.
Statistical constant with a value of 1.64 that depends on the test findings' maximum 5% failure rate.
Sr is the plan's standard deviation.

Using Equations 4 and 5, the desired average compressive strength is determined.

$$fcr = f'c + M \quad (4)$$

$$fcr = f'c + 1.64\ sr \quad (5)$$

Depending on how water-cement and compressive strength interact with factors discovered through field testing using the suggested materials and working conditions, the water-cement factor needed to achieve the desired average compressive strength is chosen. SNI 03-1915-1992 [13] regarding standards for sulfate-resistant concrete and SNI 03-2914-1994 [14] regarding specifications for water-resistant reinforced concrete must be followed for specified situations if the maximum cement water factor is to be used. In order to produce concrete that is simple to procure, pour, and level, the slump is determined in accordance with the application of labor requirements. 1) One-fifth of the lowest distance between the side planes of the mould. This is the maximum aggregate grain size that may be used. 2) A third of the thickness of the plate. 3) Three-quarters of the minimum clear distance between bars or beams. The concrete mix proportions calculations must be made in kg per m^3 of (cement, water, fine and coarse aggregates) combination. Banana plantations are the most widely planted fruit [15–17]. Data from the Central Bureau of Statistics (BPS) indicate, banana waste in Indonesia produces nearly 2.09 tons annually and causes environmental pollution [18–20]. Of all fruits, bananas are the most frequently consumed. The amount of banana peel waste generated is enormous, and it contributes to environmental issues, including odour and wastewater, that impact the atmosphere and groundwater, respectively. Many researchers have experimented with utilizing cement substituted with banana leaves and bananas as reinforcement. The flexural performance of concrete containing banana fibers in various filler percentages, ranging from 8% to 10%, was examined by [21–23]. According to the findings, banana fiber reinforcement increased tensile and flexural strength by 2 to 3%. Banana stem ash's material properties and the mechanical characteristics of the concrete employed as a cementing ingredient were examined by [24]. Banana stem ash was added in 1% increments, ranging from 0% to 3%. The results reveal that the presence of the pozzolanic component in banana stem ash reduces compressive strength by 30% compared to NC. The chemical composition of BSP was analyzed to determine its pozzolanic content, revealing a significant presence of pozzolanic materials. This analysis of BSP's chemical properties was conducted by [25] in the analytical laboratory of the Faculty of Civil Engineering and Built Environment at Universiti Tun Hussein Onn Malaysia (UTHM). The findings of the study are detailed in *Table 2*. BSP is a Grade Pozzolanic substance defined by American Society for Testing and Materials (ASTM) C618 [26, 27]. As a result, pozzolanic material can be used to improve the mechanical quality of concrete as a substitute for cement, make it more affordable and environmentally friendly, and decrease agricultural waste. Employed a mix design optimization approach to study the effects of BSP in concrete, varying proportions to find the optimum blend [28]. The study demonstrated that an optimized mix of BSP significantly improved the compressive strength and workability of concrete, advocating for the sustainable use of banana skin waste and enhancing concrete properties [29]. However, it acknowledged a lack of information on long-term durability. BSP was posited as a green alternative in concrete, contributing to waste reduction and environmental sustainability, with a noted reduction in environmental impact and a potential economic advantage [29]. The mechanical properties of BSP-infused concrete were rigorously evaluated, highlighting improvements in tensile and flexural strength, thereby enhancing mechanical properties compared to traditional mixes [30]. The study provided a detailed look into the microstructural analyses of BSP and cementitious material interactions, offering insights at a molecular level, yet it mentioned limited practical application discussion [31]. Chemical compatibility studies conducted revealed the influence of BSP on the chemical reactions during cement hydration, providing an in-depth understanding of these interactions [32]. The versatility of BSP in diverse climates was showcased through performance assessments under various environmental conditions, though the study mentioned limited long-term exposure data [33]. Concerns related to the consistency of concrete mixes were addressed, with the study indicating improved workability in some cases depending on the mix proportions [34]. A durability assessment demonstrated enhanced resistance to various environmental factors over time, suggesting increased durability of BSP-infused concrete [35]. The economic viability of incorporating BSP was explored, considering material costs and potential long-term savings, offering a cost-benefit analysis, yet acknowledging that regional cost variations might not be fully accounted for [36]. The research presented results using standardized performance metrics, establishing benchmarks for the effects of BSP on concrete properties, contributing to a standardized understanding for industry-wide assessment [37]. Optimization strategies for incorporating BSP were explored, providing practical insights into achieving enhanced performance, with a focus on improved concrete properties through optimized mix design [38]. The influence of BSP on the setting time of concrete was also investigated, addressing practical construction constraints [39]. Comparative analyses benchmarked the performance of BSP-infused concrete against conventional mixes, evaluating the viability of BSP as a concrete additive, highlighting waste utilization and potential cost savings, but noting limited long-term exposure data [40]. The research emphasized how incorporating BSP aligns with broader sustainable construction practices, showcasing the environmental benefits of utilizing agricultural waste in construction and aligning with sustainable construction goals [41]. Finally, the positive impact of BSP in reducing the environmental footprint of concrete production was underlined, measuring the potential for reducing carbon emissions and enhancing environmental sustainability [42]. This comprehensive study provided a multifaceted view of BSP's potential, calling for further research to fully understand its long-term effects and broader environmental impacts.

Table 2 Chemical of BSP

Chemicals	**BSP (%)**
CaO	8.95
SiO_2	55.98
Al_2O_3	2.71
MgO	1.08
SO_3	0.10
K_2O	28.75
Fe_2O_3	1.356
Loss On Ignition (LOI)	1.121

3.Methods

The research methodology involves experiments in a laboratory setting. The steps of the research are visually presented in a flowchart (*Figure 2)*. The NC mix includes fine aggregate, coarse aggregate, Portland cement type 1, and pure water. In addition to the standard components, BSP Barangan Medan is introduced as an innovative material for concrete. The chemical composition of BSP Barangan Medan is tested in the laboratory, and the results are presented in *Table 3*. BSP Barangan Medan is integrated into the concrete mix along with Portland cement type 1, fine aggregate, coarse aggregate, and pure water. Different percentages of BSP Barangan Medan (2.5%, 5%, and 7.5% relative to cement) are used in the concrete mix. A study on the grain size gradation is conducted, assessing the properties of both fine aggregates and coarse aggregates. The results of these assessments are visualized in *Figure 3* and *Figure 4*. Various tests are conducted to examine the characteristics of aggregates: specific gravity, water absorption, mud content, water content, mass density, fineness modulus, roughness testing using a Los Angeles machine for coarse aggregates.

The evaluation of concrete properties is categorized into two types:

Fresh Properties Inspection: This involves conducting a slump test, a prevalent technique used to assess the workability of fresh concrete during the mixing stage. The slump test is essential for ensuring that the concrete maintains an appropriate consistency for handling and placement.

Hardened Properties Inspection: This typically includes analyzing the concrete's characteristics after it has undergone curing and has set. Additionally, slump loss testing is performed to determine the viable working time of the concrete mix prior to the initial setting time. The inspection of hardened properties primarily focuses on measuring the concrete's compressive strength.

The test for compressive strength uses a cylindrical specimen with a height of 30 cm and a diameter of 15 cm, and cubes specimen with a size of 15 cm × 15 cm × 15 cm, where the compressive strength test refers to ASTM C39 [43]. The process of compacting the concrete mixture into a cylindrical or cube-shaped Mold is divided into 3 compaction parts, where the mixture is put into the Mold approximately 1/3 of the way and then compacted by dropping the compactor stick 25 times on each part. Hardened properties testing was carried out on the concrete, aged 7, 14, and 28 days with the results being the average of 5 test objects. The curing method used in this research is water curing, where water curing is carried out by immersing the test object in a tub filled with water at a temperature adjusted to room temperature. During the experiment, concrete compressive strength test data was systematically collected by testing a total of 60 samples at regular intervals, with testing conducted 7, 14, 28 days and meticulous attention was given to identifying and addressing any deviations or anomalies encountered in the testing process to ensure data accuracy and reliability.

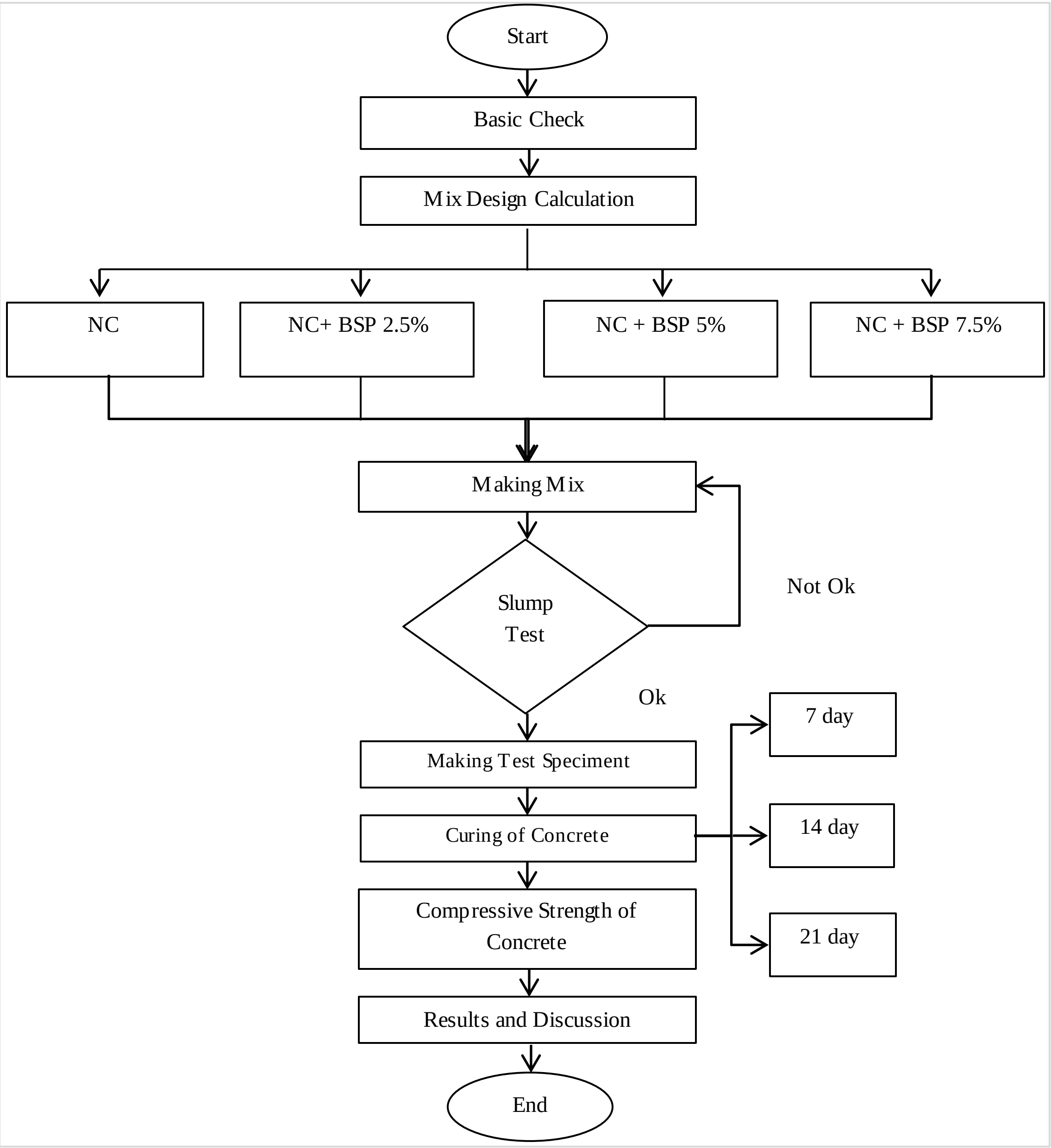

Figure 2 Flowchart for the complete step

Table 3 Chemical of BSP Barangan Medan

Chemicals	**BSP Barangan Medan (%)**
CaO	6.95
SiO_2	57.98
Al_2O_3	2.5
MgO	1.29

Chemicals	**BSP Barangan Medan (%)**
SO_3	0.05
K_2O	28.7
Fe_2O_3	1.26
LOI	1.24

Table 4 Physical property of aggregate

Property	**Fine aggregate**	**Coarse aggregate**
Specific gravity	2.56	2.66
Water absorption (%)	2.04	1.63
Moisture content (%)	6.5	1.06

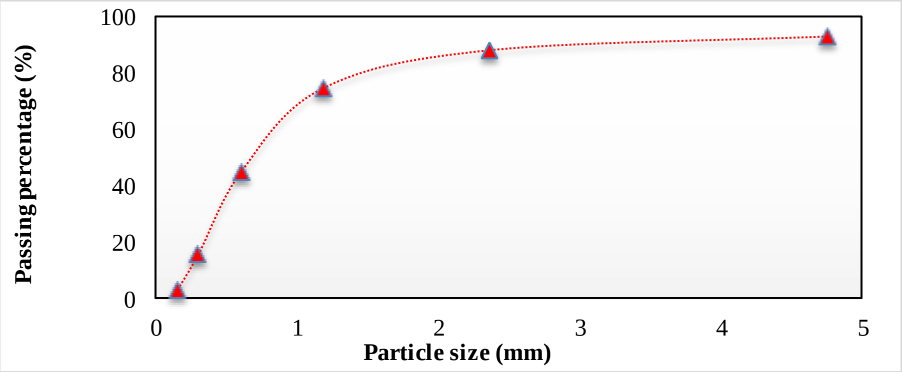

Figure 3 Size distribution of fine aggregates

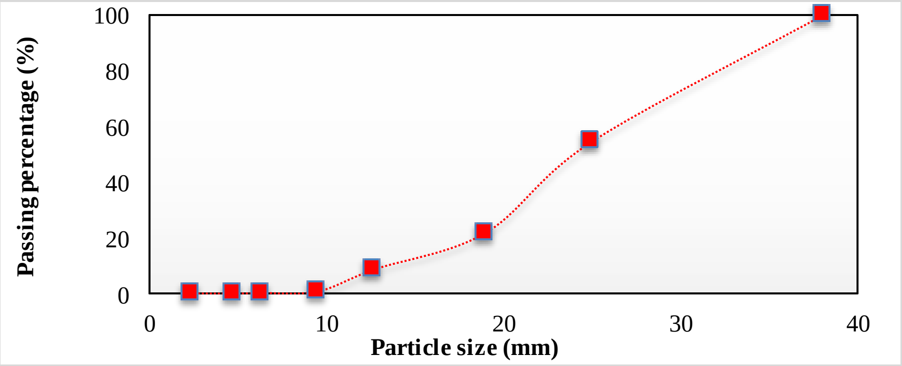

Figure 4 Size distribution of coarse aggregates

For the mix design calculation, there is a correction for the based on the information in *Table 4*, the proportions of the mixture, specifically, information gleaned from aggregates' physical properties testing results. For the manufacture of NC, *Table 5* displays the mix design's outcomes, and it is adjusted to the mix design calculations based on SNI 03-2834-2000 regarding methods for creating NC mix designs.

Table 5 Concrete mix design

Concrete must have the necessary compressive strength at 28 days of age (f'c)	22 Megapascal (MPa)
Defects 5 %, k	1.64
The plan standard deviation is set, sr	7 MPa
Added value (M)	8.64 MPa
Targeted average compressive strength, (f'cr)	31.14 MPa
Type of cement	Portland type 1
Type of aggregate : Gravel Sand	 Crushed stones Uncrushed stones

(Ratio W/C)	0.5
(Ratio W/C) maximum	0.6
Slumps set	30-60 mm
Aggregate size maximum	40 mm
Free moisture content : Crushed stones Uncrushed stones So the amount of free moisture content required	190 kg/m^3 160 kg/m^3 170 kg/m^3
Content of cement	340 kg/m^3
Content of cement minimum	275 kg/m^3
Fine aggregate percent	28-35%
Fine aggregate percent is used	31.5%
So that the percent of coarse aggregate	68.5%
The aggregates' combined relative specific gravity	2.61
Weight of concrete	2280 kg/m^3
Aggregate content combined	1770 kg/m^3
Content of fine aggregate	558 kg/m^3
Content of coarse aggregate	1212 kg/m^3
From the results of the calculation above, the proportion of theoretical concrete mix for each m^3 of concrete is obtained, as follows: Cement Water Aggregate of fine Aggregate of coarse	340 kg/m^3 170 kg/m^3 558 kg/m^3 1212 kg/m^3
Correction of mix proportions based on aggregate physical properties data	
Cement Water Fine aggregate Coarse aggregate Total	340 kg/m^3 152 kg/m^3 582 kg/m^3 1206 kg/m^3 2280 kg/m^3

4.Results

The normal proportion of concrete needed to make a cylindrical specimen with a 15×30 cm dimension and an additional 10% volume of the volume of the test object to avoid shortages. It is planned that cylindrical and cube test objects for NC are 15 specimens each, where 7 days of curing are 5 specimens each, 14 days are 5 specimens each, and 21 days are 5 specimens each. Then the proportion of the mixture for 15 cylindrical specimens with a size of 15×30 cm is as follows:

1. Cement: 30 kg;
2. Water: 13 kg;
3. Aggregate of fine: 51 kg;
4. Aggregate of coarse: 105 kg;
5. Total: 199 kg.

The proportions of the mixture for 15 specimen cubes with a size of 15×15×15 cm are as follows:

1. Cement: 19 kg;
2. Water: 8 kg;
3. Aggregate of fine: 32 kg;
4. Aggregate of coarse: 67 kg;
5. Total: 127 kg.

The proportion of concrete innovation with BSP Barangan Medan percentages of 2.5%, 5%, and 7.5% to cement is shown in detail in *Table 6*. The mixture was then shaped, and the concrete was left to set in water for 7, 14, and 28 days before compressive strength testing. Complete results of concrete compressive strength testing are displayed in graphical form as in *Figures 5* for cylindrical test specimens and cube test specimens.

Table 6 Concrete mix proportions in kg

Mix	**NC**		**NC+BSP 2.5 %**		**NC+BSP 5 %**		**NC+BSP 7.5 %**	
	Cylindrical	**Cubes**	**Cylindrical**	**Cube**	**Cylindrical**	**Cubes**	**Cylindrical**	**Cubes**
Cement (kg)	30	19	29.25	18.25	28.5	17.5	27.75	16.75
Water (kg	13	8	13	8	13	8	13	8
Fine aggregate (kg)	51	32	51	32	51	32	51	32
Coarse aggregate (kg)	105	67	105	67	105	67	105	67
BSP Barangan Medan (kg)	-	-	0.75	0.75	1.5	1.5	2.25	2.25

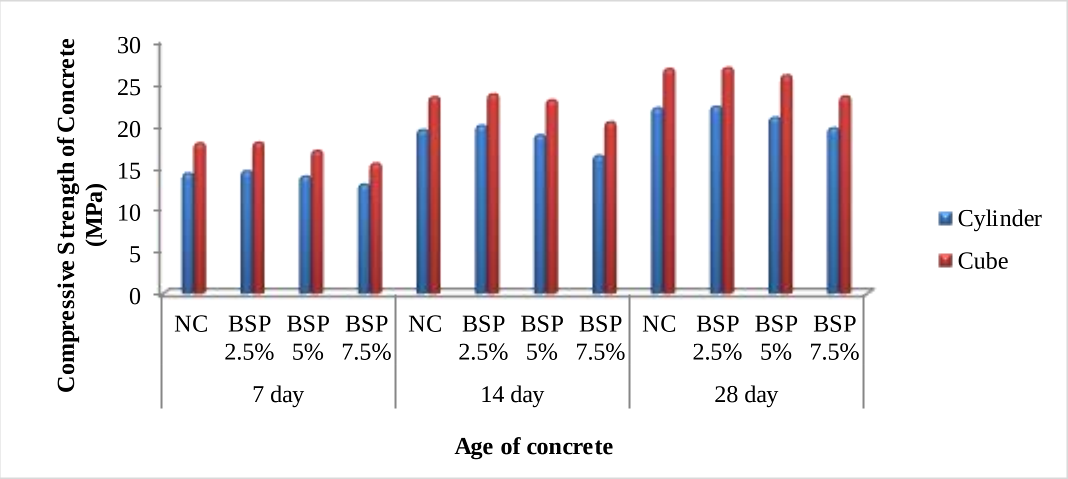

Figure 5 Results of concrete's compressive strength comparison graph in MPa

5.Discussion

The average compressive strength test results for NC cylinders aged 7 days, 14 days, and 28 days were 14.15 MPa, 19.31 MPa, and 21.91 MPa, respectively. Similarly, the average compressive strength test results for NC cylinders with 2.5% BSP replacement were 14.44 MPa, 19.82 MPa, and 22.08 MPa at 7 days, 14 days, and 28 days, respectively. For NC with 5% BSP substitution, the results at 7 days, 14 days, and 28 days were 13.81 MPa, 18.68 MPa, and 20.78 MPa. The average compressive strength test results of NC cylinders with 7.5% BSP replacement were 12.86 MPa, 16.25 MPa, and 19.53 MPa at 7 days, 14 days, and 28 days, respectively. The replacement of BSP at these ages led to a 2.5% increase in the compressive strength of cylindrical concrete. However, at 5% and 7.5% BSP substitution, the compressive strength began to decrease, with the lowest decrease of 13% occurring at 14 days for 7.5% BSP substitution. The average compressive strength test of NC cubes with 2.5% BSP substitution yielded values of 23.53 MPa, 26.67 MPa, and 17.82 MPa at 7 days, 14 days, and 28 days, respectively. For NC cubes with 5% BSP substitution, the average compressive strength test values at 7 days, 14 days, and 28 days were 16.85 MPa, 22.84 MPa, and 25.78 MPa. With 7.5% BSP substitution, the average cube compressive strength test values at these time points were 15.33 MPa, 20.22 MPa, and 23.29 MPa. Notably, at 5% and 7.5% BSP substitution, the compressive strength values began to decrease, with the lowest decrease of 11.5% occurring at 14 days for 7.5% BSP substitution. It is important to acknowledge that while the increase in compressive strength at 2.5% BSP substitution is evident, the subsequent decrease at higher substitution rates is attributed to the slower reaction of BSP Barangan Medan compared to cement, resulting in a slower hardening process. Therefore, the findings suggest that careful consideration of BSP Barangan Medan replacement percentages is crucial to balance the environmental benefits with the potential reduction in compressive strength. The limitations of this study stem from the particular conditions in which the experiments were carried out. Further research is necessary to investigate how varying environmental conditions and concrete compositions might affect the results. A complete list of abbreviations is shown in *Appendix I.*

6.Conclusion

The study has presented and discussed findings from evaluating the standard compressive strength and the compressive strength of concrete with varying substitutions of BSP Barangan Medan. Research results indicated that a 2.5% substitution of BSP Barangan Medan led to an increase in the concrete's compressive strength, while substitutions at 5% and 7.5% resulted in a decrease. Consequently, the concrete mix shows potential for incorporating BSP Barangan Medan waste. These findings can be particularly beneficial for the community, especially in Medan, for implementation in the construction sector. However, it is advised that the BSP substitution should not exceed 5% of the total cement weight.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Samsul Abdul Rahman Sidik Hasibuan: Conceptualization, data collection, data curation, writing – original draft, writing – and editing. **Hakas Prayuda**: Data curation, conceptualization, writing – review, analysis and interpretation of results. **Muhammad Khahfi Zuhanda**: Conceptualization, writing – review. **Yuan Anisa:** Data collection and writing – review.

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Appendix I

S. No.	Abbreviation	Description
1	ASTM	American Society For Testing and Materials
2	Al_2O_3	Aluminium Oxide
3	BPS	Bureau of Statistics
4	BSP	Banana Skin Powder
5	Cao	Calcium Oxide
6	cm	Centimeter
7	CO_2	Carbon Dioxide
8	F'c	Compressive strength of concrete (MPa) after 28 days of curing
9	Fe_2O_3	Ferric Oxide
10	kg	Kilogram
11	K_2O	Potassium Oxide
12	LOI	Loss On Ignition
13	MgO	Magnesium Oxide
14	MPa	Megapascal
15	m	meter
16	NC	Normal Concrete
17	Na_2O	Sodium Oxide
18	SO_3	Sulfur Trioxide
19	SNI	Standar Nasional Indonesia
20	Sio_2	Silicon Dioxide
21	UTHM	Universiti Tun Hussein Onn Malaysia
22	W/C	Water/Cement