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Optimization of Bagasse Fiber Mixture in the Manufacture of Precast Concrete Based on Pressure Test

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Abstract. The World Cement Association reported in 2024 that global demand for cement continues to rise, despite the material's non-renewable nature and significant environmental impact, contributing to 8% of total CO_2 emissions. This research explores the use of bagasse fiber as a partial substitute for cement in concrete production to reduce cement consumption, produce eco-friendly concrete, and repurpose sugar industry waste. The study aims to determine the optimal composition of bagasse fiber in precast concrete by evaluating compressive strength. Using a quantitative, experimental method, 30 concrete samples with varying bagasse fiber content—0%, 5%, 10%, 25%, and 30%—were tested for compressive strength, with six samples per variation. Bagasse fiber content was the independent variable, while compressive strength was the dependent variable, measured in accordance with SNI-7394-2008 standards. Results indicated that increasing bagasse fiber content decreased concrete compressive strength. Samples with 30% bagasse fiber achieved 0.62 MPa at 14 days and 0.91 MPa at 28 days, meeting the criteria for lightweight, low-strength concrete (0.35–7.00 MPa) suitable for heat-retaining walls. This study contributes to sustainable construction by reducing bagasse waste and promoting accessible, eco-friendly concrete production for small and medium-sized enterprises.

Keywords: Bagasse Fiber, Precast Concrete, Concrete Press Test

1. Introduction

The global demand for cement has surged significantly, even as its production faces challenges due to its reliance on non-renewable resources and high environmental impact. Cement production alone is responsible for 8% of global CO_2 emissions, prompting industry-wide initiatives to achieve carbon neutrality by 2050 [1]. In Indonesia, cement consumption reflects this demand increase, with 17.12 million tons used in the first quarter of 2022, marking a 5.5% growth over the same period in 2021 [2]. Indonesia's cement production capacity in 2023 reached 119.91 million tons, further increasing the potential for emissions [3]. As cement is a fundamental material in concrete production, the search for sustainable alternatives has become increasingly urgent.

With rising awareness about environmental issues and climate change, the push towards green technology has gained momentum. This movement aims not only to conserve natural resources but also to reduce energy consumption and minimize environmental harm, a critical goal for sustainable development, especially in Indonesia [4]. One of the primary objectives of green concrete production is to lower CO_2 emissions by reducing fossil fuel use and substituting harmful materials. Green concrete is characterized by a low clinker content and eco-friendly binders, incorporating materials that lessen environmental impact [5]. A promising approach to achieve green concrete involves replacing part or all of the cement in concrete with alternative materials such as silica fume, slag, fly ash, rice husk ash, bagasse ash, and notably, bagasse fiber.

Today's declining environmental quality underscores the importance of incorporating sustainable practices in construction. Architects play a crucial role in promoting eco-friendly materials and construction techniques, such as green concrete, which is formulated with materials that reduce environmental harm. The inclusion of pozzolan materials, natural or artificial additives that partially replace cement, can improve both the economic and mechanical properties of concrete. In particular, bagasse fiber, a by-product of the sugar industry, offers a renewable and cost-effective alternative to conventional cement, with potential for use in both interior and exterior applications in precast concrete.

Bagasse waste from sugar production, often left untreated, contributes to air pollution when dispersed into the environment. As bagasse fiber is abundant and inexpensive, it holds economic advantages and valuable material properties suitable for renewable concrete mixtures. In Indonesia, sugarcane production reached 2.41 million tons, with East Java contributing nearly 50% of the nation's total, generating substantial quantities of bagasse fiber and ash [6]. Utilizing bagasse fiber as a partial cement replacement addresses the dual goals of reducing traditional cement use and minimizing sugar industry waste. While prior research has explored the use of bagasse in various materials—such as composites, tiles, acoustic panels, and eco-friendly bricks—the potential for bagasse fiber in green concrete production remains largely untapped [7][8][9][10].

This study seeks to identify the optimal composition of bagasse fiber in producing high-quality precast concrete. Through concrete compressive strength tests, the study aims to determine the most effective percentage of bagasse fiber as a cement substitute. The research explores practical aspects of bagasse fiber application, including sample preparation, concrete testing, and data analysis. We hypothesize that integrating bagasse fiber as a partial cement replacement will yield lightweight, aesthetic precast concrete products that meet Indonesian standards for concrete strength (SNI 03-2834-2000) [11].

2. Literature review

2.1. Bagasse Fiber

The mechanical properties of bagasse fibers are as follows: The fineness value of the fiber is 65.78 tex, and the length of the fiber sheave is 95.25mm. Based on tensile and creep strength testing using Instron, The tensile strength is 2 g/denier, the fiber creep is 9.47%, the moisture content is 0.331%, and the moisture regains is 0.333%. Meanwhile, the FTIR test was used on bagasse fibers from the chemical composition, namely the O-H, C-H, C=C, and =C-O-C groups. Based on the fineness value, it shows that bagasse fibers do not meet the requirements for fibers to be spun using ring spinning, so it will produce uncomfortable fabrics. Therefore, bagasse fiber is not recommended as an alternative raw material for spinning from natural fibers, but it is very suitable for sound-damping materials, heat absorbers, or composite material reinforcing fibers [12].

The results of ASTM D 638 M (M-I) standard tensile tests on bagasse fiber composite materials with polyester resin matrix show that the tensile strength will increase against the increase in fiber volume fraction. The test specimens that undergo strain and fracture at the load point have a volume fraction of 85% matrix: 15% fiber with a tensile strength value of 2.95 MPa, strain of 8% and a young modulus of 36.875 MPa[13]. The study results show that the bagasse fiber applied in composite has a good tensile strength, so it is very interesting to test it as a composite material with concrete material with low tensile strength. Based on the testing of the mechanical properties and tensile strength of bagasse fiber, research was conducted on its use as a concrete composite material. The composite was tested for optimal performance in concrete strength, demonstrating its potential to produce precast concrete that can function as a soundproofing wall and heat absorber.

2.2. Precast concrete

Precast concrete is concrete that is made in a special place before it is installed in the construction of the project. At the same time, precast concrete walls are thin panels printed with special printing tools. Precast concrete walls are unfinished concrete walls with original textures that are widely applied to building facades and interior walls. Concrete with raw finishing is environmentally friendly concrete. It is very good because there is no chemical finishing, so it is free of pollution and chemical disturbances in the morning of the user. Some of the advantages of using precast concrete walls include: a) Practical properties; Practically used for finishing building facades and room walls. It is efficient because it is a finishing material, so it saves the cost of finishing the façade or wall of the room. b) Easy maintenance: It does not require special maintenance, is resistant to weather, and is very easy to maintain. c) Aesthetic value: The shape and appearance have been designed with the beauty of the appearance in a natural concept, both in shape, texture, and neutral colour that can expose and combine other natural materials such as wood, stone, or plants. d) Able to withstand heat: Based on the basic properties of concrete, materials have cold properties and can reduce hot temperatures from the outside to lower the indoor temperature.

2.3. Lightweight Concrete

There are three types of lightweight concrete based on specific gravity and compressive strength, namely [14]: a) Low-Density Concretes for non-structures with a volume weight of 300-800 kg/m3 with a compressive strength of 0.35-7 Mpa, which can be used as a separation wall or sound insulation wall and heat insulation. b) Moderate Strength Concrete for lightweight structures with a volume weight of 800-1350 kg/m3 and compressive strength between 7-17 MPa (ASTM C331-81) used for load-bearing walls. c) Lightweight concrete with high strength or structural lightweight concrete is used for lightweight structures with a weight volume of 1350-1900 kg/m3 and a compressive strength greater than 17 MPa (ASTM C330-82a), which is applied like normal concrete.

2.4. Concrete pressure test based on SNI 1974:2011 [15]

2.4.1. Scope

It is the determination of the compressive strength of concrete against a cylindrical test specimen measuring 150mm x 300mm printed in the laboratory or the field. The standard is limited to concrete with a unit weight greater than 800 kg/m3.

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2.4.2. Implementation steps

The treatment of the compression test piece is very important; the test piece must be maintained in humid conditions and tested in humid conditions at room temperature. The specified test life is tested within the allowable time tolerance among others: For the test specimen, 7 days with the allowed time ± 6 hours or 3.6 % and the life of the test specimen 28 days with the allowed ± 20 hours or 3.0 %.

2.4.3. Loading

Loading is performed until the test piece is destroyed, and the maximum load the test piece receives during loading is recorded. Record the type of destruction and visual condition of the concrete test piece.

2.4.4. Calculation

Calculation of the compressive strength of the test piece by dividing the maximum load received by the test specimen during the test by the flat cross-sectional area. Compressive strength of concrete = P/A, Compressive strength of concrete with the cylindrical test piece, expressed in MPa or N/mm2; P is the axial compressive force, expressed in Newton (N); and A is the cross-sectional area of the test piece, expressed in mm^2.

3. Method

The study applied an experimental quantitative method to find a cause-and-effect relationship between variables, namely to measure the influence of the optimal composition of bagasse fiber mixture as a partial substitution of cement on the results of concrete pressure tests in the manufacture of quality precast concrete. The population of the research data consisted of the composition of concrete aggregate according to the standard SNI 03-2834-2000 (BSN, 2000) on the procedure for making concrete mixture plans. For the concrete pressure test, 5 variations of composition were made in the manufacture with a mixed percentage of bagasse fibers, namely 0%, 5%, 10%, 25% and 30%, and each of these variations was made 6 cylindrical concrete test pieces with a diameter of 15cm x 30cm, so that the total number of samples for the pressure test was 30 test pieces. The sampling technique was taken from each variation, and the percentage of the mixed bagasse fiber was taken from 6 samples. The concrete test will be tested for concrete compressive strength based on the concrete age, 14 days and 28 days, and three samples of test concrete will be taken from each area.

The variables in this study are independent, namely the variation in the percentage of partial replacement of cement with bagasse fibers, namely 0%, 5%, 10%, 25% and 30% on the volume of the fine aggregate of concrete (cement) and the quality of the mixture, namely water binding/vicat, and adhesion/slump. The bound variable, namely the concrete compressive strength test, was based on SNI-7394-2008 for the class 1 concrete standard (non-structural). The research was carried out in four stages, namely: 1). preparation of tools and materials, 2). Making bagasse fiber, 3). Design and making concrete samples and 4). Concrete press testing. Data is taken from the accumulation of test results, and the average test score is tabulated based on the variables used. The validity technique is carried out by determining the deviation of the sample test results. Data analysis technique using the statistical test with linear regression analysis.

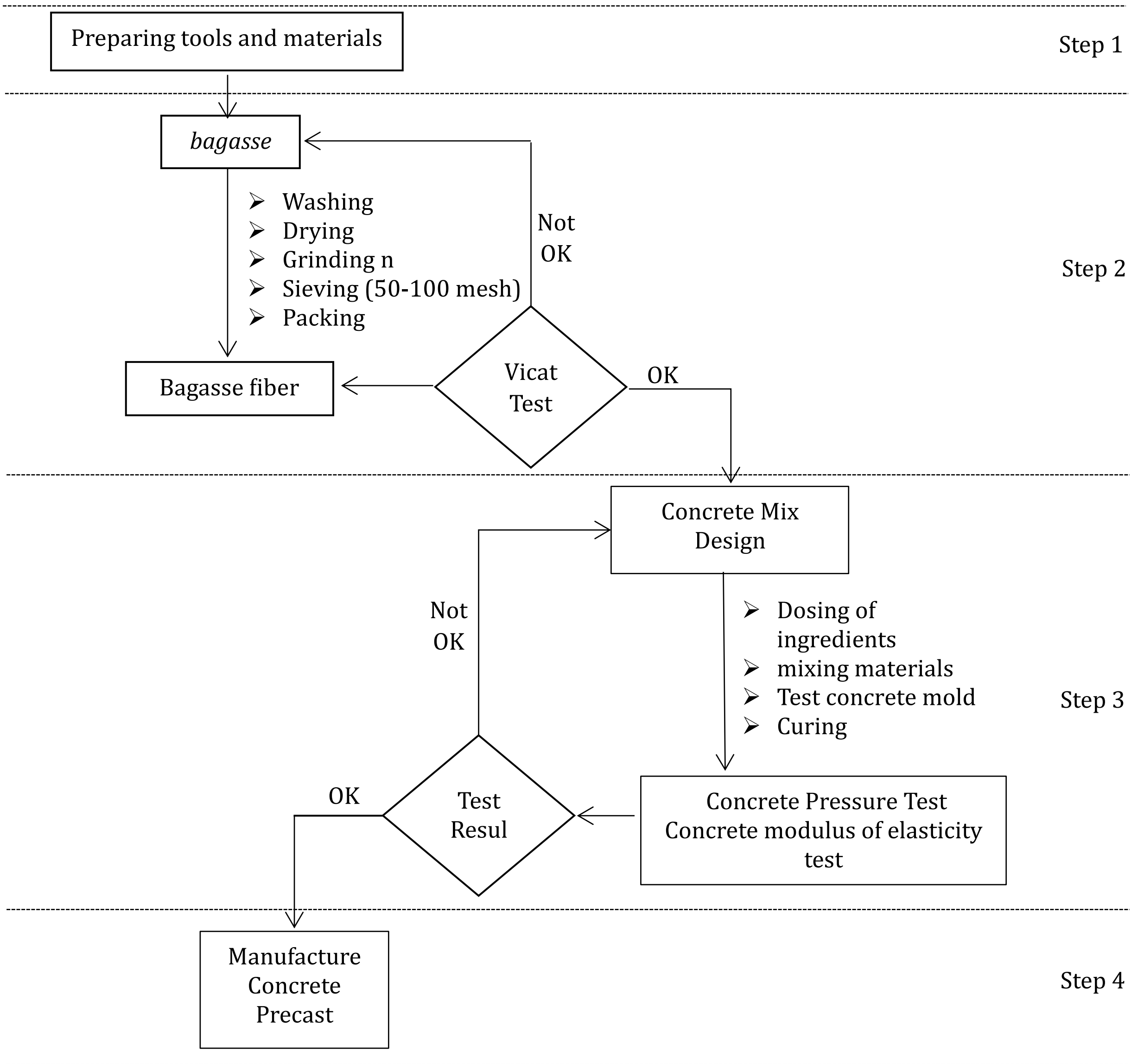

Figure 1. Step of the experiment

4. Result

The research on the optimal bagasse fiber mixture in the manufacture of quality precast concrete aims to determine the percentage of bagasse fiber as the optimal substitute for part of cement in the sense of meeting the standards of non-structural precast concrete based on the results of the concrete pressure test. The research is based on the composition of concrete aggregate according to SNI 03-2834-2000 (BSN, 2000). The percentage of bagasse fiber blend made and tested is 0%, 5%, 10%, 25%, and 30%. From each of these variations, six samples of concrete test specimens were made and tested for compressive strength at the age of 14 days and 28 days of concrete, three test samples each. The following are the results of the concrete pressure test based on the percentage of bagasse fiber composition and the age of the concrete.

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Table 1. Concrete pressure test results (14 days old)

No	% Bagasse Varian	Day to	Weight (gr)	Average Weight (gr)	Surface Area (cm²)	Average Density (kg/m³)	14 days Press Strength (KN)	Kilo Newton /M²	Mpa	Average Compressive Strength (Mpa)
1	0	14	10605	10621,33	176,7	2038,47	85,5	4275	4,28	4,53
			10670				114,5	5725	5,73	
			10589				71,5	3575	3,58	
2	5	14	10447	10413,67	176,7	1998,62	74	3700	3,70	3,61
			10422				63	3150	3,15	
			10372				79,5	3975	3,98	
3	10	14	9596	9625,00	176,7	1847,25	42	2100	2,10	1,66
			9604				32	1600	1,60	
			9675				25,5	1275	1,28	
4	25	14	8296	8580,00	176,7	1646,69	14,5	725	0,73	0,78
			8642				18	900	0,90	
			8802				14,5	725	0,73	
5	30	14	9087	8861,67	176,7	1567,88	12,5	625	0,63	0,62
			8742				11,5	575	0,58	
			8756				13	650	0,65	

Table 2. Concrete pressure test results (28 days old)

No	% Bagasse Varian	Day to	Weight (gr)	Average Weight (gr)	Surface Area (cm²)	Average Density (kg/m³)	28 days Press Strength (KN)	Kilo Newton /M²	Mpa	Average Compressive Strength (Mpa)
1	0	28	10942	10808,67	176,7	2074,43	116,9	5845	5,85	5,65
			10802				103	5150	5,15	
			10682				119	5950	5,95	
2	5	28	10601	10609,33	176,7	2036,17	98,5	4925	4,93	4,99
			10666				99	4950	4,95	
			10561				102	5100	5,10	
3	10	28	9093	9169,33	176,7	1759,80	35	1750	1,75	1,95
			9161				42,5	2125	2,13	
			9254				39,5	1975	1,98	
4	25	28	8365	8390,33	176,7	1610,29	22	1100	1,10	1,03
			8612				20,5	1025	1,03	
			8194				19	950	0,95	
5	30	28	8976	8772,33	176,7	1552,08	15,5	921	0,92	0.91
			8865				14,6	911	0,91	
			8476				16,3	897	0,90	

The results of the concrete pressure test at the age of 14 days and 28 days on concrete with the addition of 0% bagasse fiber with an average of 4.53Mpa and 5.65Mpa, 5% bagasse fiber with an average of 3.61Mpa and 4.99Mpa. The addition of 10% bagasse fiber averages 1.66Mpa and

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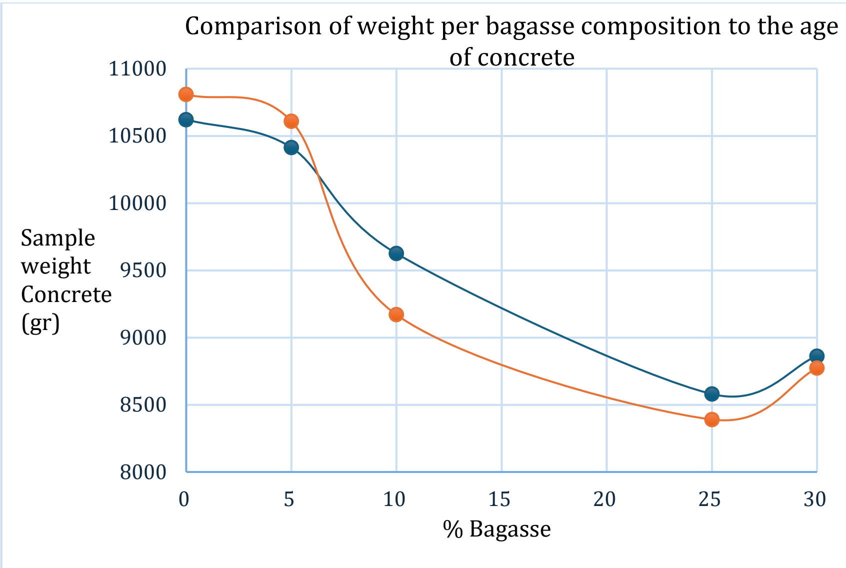
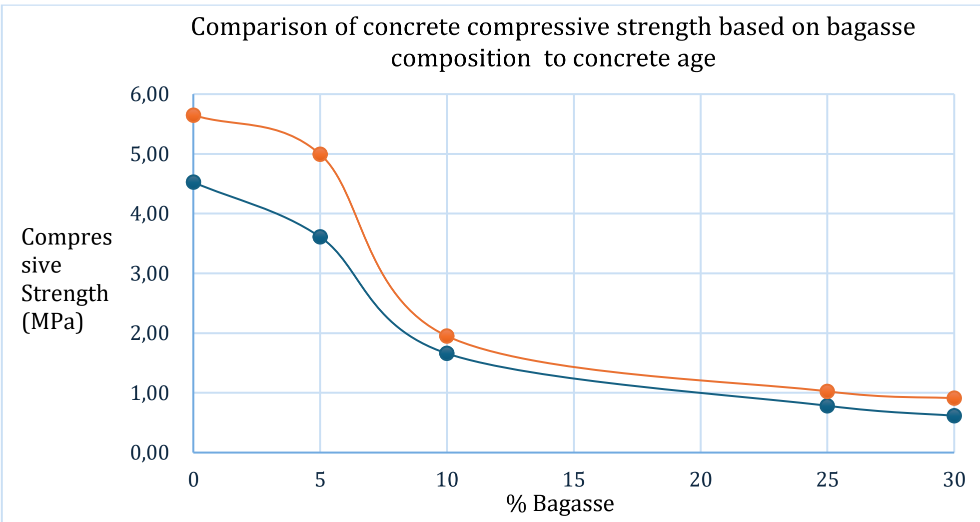
1.95Mpa, and 25% bagasse fiber averages 0.78Mpa and 1.03Mpa. 30% bagasse fiber addition averages 0.62Mpa and 0.91Mpa. Based on the comparison of bagasse fiber composition to concrete weight, concrete age, concrete strength, and concrete density value can be seen in the following figure:



—: Concrete life 14 days
—: Concrete life 28 days

Figure 2. Comparison of weight per bagasse composition to the age of concrete

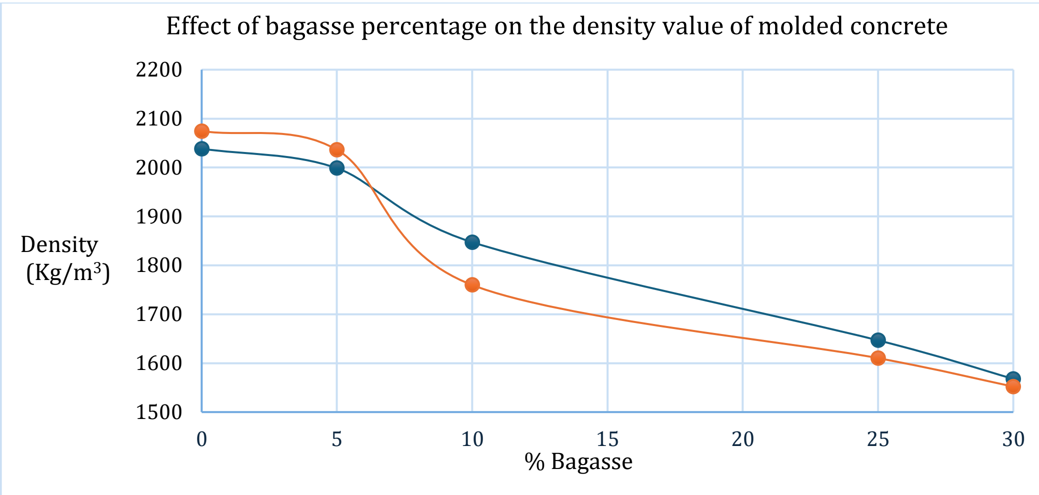
Based on Figure 2, the weight per the composition of bagasse fiber to the concrete age shows that the greater the percentage of bagasse fiber, the lighter the concrete and the more mature the concrete age, the lighter the concrete.



—: Concrete life 14 days
—: Concrete life 28 days

Figure 3. Comparison of compressive strength of concrete based on the composition of the bagasse against the age of the concrete

Based on Figure 3, the comparison of concrete compressive strength against the composition of *bagasse* fiber with the concrete's age shows that the concrete's compressive strength increases as the concrete ages. However, with an increase in the percentage of *bagasse* fiber in the concrete mix, the compressive strength of the concrete decreases.



—: Concrete life 14 days
—: Concrete life 28 days

Figure 4. Effect of bagasse percentage on concrete mixture on the density value of moulded concrete

Based on Figure 4, The effect of bagasse fiber percentage on the density value of printed concrete shows that the larger the percentage of bagasse fiber in the concrete mixture, the smaller the density value, and as the concrete ages, the smaller the density value.

5. Discussion

The study results demonstrated that adding bagasse fiber to a concrete mixture consisting of cement, sand (as coarse aggregate), and water significantly impacts the weight, density, and compressive strength of the concrete. Additionally, the age of the concrete also influences these properties. A higher percentage of bagasse fiber in the mixture results in a lighter concrete weight. As the concrete ages, its weight tends to decrease further. For instance, concrete without bagasse fiber (0%) at 14 days of age has an average weight of 10,621.33 g, increasing slightly to 10,808.67 g at 28 days. In comparison, concrete with 30% bagasse fiber has an average weight of 8,861.67 g at 14 days and 8,772.33 g at 28 days. This reduction occurs because bagasse fiber is a lightweight material, and a larger proportion of it in the mixture replaces heavier aggregate components, thereby decreasing the overall weight of the concrete [16].

Higher percentages of bagasse fiber in the mixture also reduce the density of the concrete. For concrete with 0% bagasse fiber, the average density is 2,038.47 kg/m^3 at 14 days and 2,074.43 kg/m^3 at 28 days. In contrast, concrete with 30% bagasse fiber shows an average density of 1,567.88 kg/m^3 at 14 days and 1,552.08 kg/m^3 at 28 days. These results indicate that density is primarily influenced by the composition of the mixture rather than the age of the concrete. The addition of bagasse fiber reduces the volume of denser materials, such as cement and sand,

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leading to a lower density. Consequently, as the percentage of bagasse fiber increases, both the weight and density of the concrete decrease, which also reduces the demand for cement and sand in the mixture.

The compressive strength test results reveal that an increased proportion of bagasse fiber decreases the concrete's compressive strength, whereas aging improves it. For example, concrete with 0% bagasse fiber achieves an average compressive strength of 4.53 MPa at 14 days and 5.65 MPa at 28 days. However, concrete with 30% bagasse fiber achieves only 0.62 MPa at 14 days and 0.91 MPa at 28 days. These findings confirm that the compressive strength of concrete increases with age, reaching its peak at 28 days [17]. High-quality concrete exhibits improved compressive strength due to a reduced water-to-cement ratio. The combination of materials in the mixture significantly affects the compressive strength, with the best results observed at 28 days [18][19][20]. Additionally, increasing fiber content reduces both the slump and density of the concrete.

The compressive strength of concrete with 30% bagasse fiber at 28 days (0.91 MPa) classifies it as lightweight concrete with low strength. Such concrete, with a volume weight of 300–800 kg/m^3 and compressive strength ranging from 0.35–7 MPa, is suitable for non-structural applications like partition walls or insulation walls [21]. Lightweight concrete can also be categorized as insulating concrete, characterized by its density (300–800 kg/m^3) and compressive strength (0.69–6.89 MPa). This type of concrete is particularly suitable for applications such as heat-insulating walls, soundproof panels, lightweight brick walls, or decorative wall panels (rosters) [22].

6. Conclusion

Based on the results of the experiment with the basic reference of the percentage of concrete quality composition K-200, with the addition of bagasse fibers (5%, 10%, 25% and 30%) shows that if the percentage of bagasse increases, the weight of concrete and density will decrease so that the weight of cement and sand distribution also decreases which results in the need for cement and sand will decrease. The results of the concrete pressure test show that the higher the percentage of bagasse in the concrete mixture, the lighter the weight of the concrete will be, and the density level will decrease, resulting in a decrease in the compressive strength of the concrete. The compressive strength result of the largest percentage of bagasse concrete, which is 30% with a concrete life of 28 days, is 0.91 MPa and is included in the category of lightweight concrete with low strength that can be used for insulin concrete, namely sound absorption and heat retention.

The research contributes to the development of the theory, namely producing concrete composition with an optimal mixture of bagasse fibers (30%) and non-structural concrete that can function as insulation concrete for sound absorption and heat retention. Research contributes to the environment by using bagasse waste and producing environmentally friendly concrete to reduce carbon emissions. In addition, the research results can be applied at a local and grassroots level because they apply simple technology that can be implemented directly by the community and small, micro, and medium enterprises. Concrete tests are limited to concrete pressure tests, so it is necessary to conduct further research for other tests such as the concrete modulus of elasticity, concrete tensile, temperature, moisture, etc.

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