Jurnal Mesil (Mesin Elektro Sipil) **E-ISSN : 2723-7052**
Vol. 7, No.1, Juni 2026, Hal 50-66
https://doi.org/10.53695/jm.v7i1.1575

The effect of adding *Fly Ash* from Labuhan Angin PLTU and bagasse ash from Kwala Madu sugar factory on the compressive strength of high performance concrete

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ABSTRACT
Construction development in Indonesia continues to increase rapidly, particularly in building, road, and bridge infrastructure. Concrete is one of the most widely used construction materials, and the development of high-performance concrete using locally available materials is essential to improve structural performance and sustainability. This study aims to determine the effect of incorporating fly ash from the Labuhan Angin Power Plant and bagasse ash from the Kwala Madu Langkat Sugar Factory on the compressive strength of high-performance concrete using locally available materials. An experimental study was conducted in a concrete laboratory involving material preparation, mix design, specimen casting, curing, slump flow testing, and compressive strength testing. Nine variations of concrete mixtures were prepared using cube specimens measuring 50 mm × 50 mm × 50 mm. Compressive strength tests were performed at curing ages of 3, 7, 14, and 28 days to evaluate the performance of each mixture variation. The results showed that the highest early-age compressive strength was obtained in Variation H, reaching 50.58 MPa at 3 days, while the highest compressive strength at 28 days was also achieved in Variation H, reaching 84.67 MPa, indicating high-performance concrete characteristics. The highest compressive strength for mixtures containing both fly ash and bagasse ash was obtained in Variation I, reaching 82.33 MPa at 28 days. Compared with the reference mixture (Variation A, 72.85 MPa), the use of supplementary cementitious materials increased the compressive strength by up to 16.2%. These findings demonstrate that the utilization of local industrial and agricultural waste materials, such as fly ash from the Labuhan Angin Power Plant and bagasse ash from the Kwala Madu Langkat Sugar Factory, can significantly enhance the compressive strength of concrete while contributing to environmental sustainability through the reduction of industrial waste pollution.

Kata Kunci: *Bagasse Ash*; *Compressive Strength*; *Fly Ash*; High-Performance Concrete; Local Materials.

1. PENDAHULUAN

Indonesia is experiencing significant growth in construction activities, particularly in building, road, and bridge infrastructure. Concrete remains one of the most widely used construction materials due to its strength, durability, and versatility. The development of high-performance concrete (HPC) has become increasingly important to meet the demands of modern infrastructure requiring high strength, durability, and long service life. High-performance concrete is typically characterized by low water–cement ratios, dense microstructures, and improved mechanical properties compared to conventional concrete [1].

The use of supplementary cementitious materials (SCMs) has become a major development in modern concrete technology. Materials such as silica fume, fly ash, and fine silica sand are widely used to enhance compressive strength, durability, and

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https://doi.org/10.53695/jm.v7i1.1575

workability of concrete mixtures [2]. Previous studies have shown that silica fume significantly improves the compressive strength and durability of concrete by refining pore structure and enhancing cement hydration reactions. Similarly, the addition of superplasticizers allows the reduction of water content while maintaining adequate workability, resulting in higher compressive strength performance [3].

Concrete with higher performance is called Ultra High Performance Concrete, which is a new generation of concrete characterized by its very dense material, with a compressive strength of up to 150 MPa–250 MPa. Concrete with this new technology allows the creation of slender and high-strength concrete structures while saving materials. In many developed countries, ultra high performance concrete is often used as a structural material in various buildings, such as bridges, high-rise buildings, construction decoration and various other civil constructions. Ultra high performance concrete is usually quite expensive, so researchers often use local materials to save costs, so there has been a lot of research on ultra high performance concrete [4]. Ultra-high-performance concrete is designed to produce high-density packaging, optimal pore structure, and high compressive strength. Proper mix design promises good quality and effectiveness for the sustainable development of ultra-high-performance concrete. A good concrete mix is one whose ingredients have been tested before use. Testing the materials in the concrete is necessary to determine the concrete mix design [5].

Fly ash, a by-product of coal combustion in power plants, has been extensively studied as a supplementary cementitious material in high-performance concrete. Several studies reported that the incorporation of fly ash can improve workability, reduce heat of hydration, and increase long-term compressive strength due to pozzolanic reactions [6]. In high-performance concrete applications, fly ash is commonly used to enhance durability and mechanical properties while reducing cement consumption and environmental impact. [7].

In addition to fly ash, agricultural waste materials such as bagasse ash have attracted attention as potential cementitious additives. Bagasse ash is a by-product of sugarcane processing and contains a high percentage of silica, making it suitable as a pozzolanic material in concrete mixtures. Previous research has shown that the addition of bagasse ash in concrete can increase compressive strength and improve durability characteristics. For example, the incorporation of 5–6% bagasse ash has been reported to increase compressive strength by approximately 6.43% compared to conventional concrete [8]. These findings demonstrate the potential of bagasse ash as an alternative material for improving concrete performance while promoting waste utilization.

Furthermore, the use of fine silica materials such as silica sand with different mesh sizes contributes to improved particle packing density, resulting in denser concrete microstructures and enhanced compressive strength [9]. In concrete mixes, the use of fine mesh silica sand can increase the compressive strength of concrete by up to 13% compared to ordinary concrete sand. Materials such as silica sand are waste products from mineral mining that contain the chemical compound silica (silicon dioxide, SiO_2), which is widely used in concrete mixes. Silica sand is often used as a substitute and additive in concrete mixes, with the aim of producing superior compressive strength compared to standard concrete. Research using a mix design plan for a compressive strength of 40 MPa with the addition of silica sand showed that the highest concrete compressive strength test results occurred in the 10% silica sand variation of 42.09 MPa at the age of 28 days, for the highest concrete splitting tensile strength results occurred in the 10% variation of 4.48 MPa at the age of 28 days [10]. To get the density of the concrete, silica sand is ground with different mesh sizes, the finer the size of the silica sand, the stronger the compressive strength of the concrete that will be produced. This is because silica sand will fill the cavities in the concrete. In addition, other functions of silica sand are to increase the compressive strength of concrete, reduce porosity & permeability, increase the durability of concrete, improve the bond between cement paste and aggregate, generally the use of silica sand is 5-10% of the weight of cement [11].

The addition of polypropylene fiber has also been reported to improve crack resistance, ductility, and mechanical performance of concrete by controlling microcrack propagation within the cement matrix [12]. Although numerous studies have investigated the use of fly ash and bagasse ash individually as supplementary cementitious materials, limited research has examined their combined utilization in high-performance concrete, particularly using locally available industrial and agricultural waste materials. Moreover, studies focusing on the combined effect of fly ash from the Labuhan Angin Power Plant and bagasse ash from the Kwala Madu Sugar Factory on compressive strength development of high-performance concrete are still limited.

Therefore, this study aims to investigate the effect of incorporating fly ash from the Labuhan Angin Power Plant and bagasse ash from the Kwala Madu Langkat Sugar Factory on the compressive strength of high-performance concrete using locally available materials. The results of this study are expected to contribute to the development of sustainable concrete technology through the utilization of industrial and agricultural waste materials while improving the mechanical performance of concrete.

2. METHODS

This research uses experimental methodology from previous journals conducted in concrete laboratory and civil engineering structure laboratory of University of North Sumatra. The research begins with analysis of problem background based on material data research, followed by literature review on concrete structure materials that can increase concrete compressive strength and can be found around researchers based on previous research journals to facilitate researchers to obtain conclusions from material mixtures on concrete compressive strength based on Indonesian National Standard (SNI) 2847-2019: Structural Concrete Requirements for Buildings [13]. In the manufacture of high-performance concrete, the research utilizes waste from the surrounding area as a concrete additive. The concrete manufacturing stage using *Fly Ash* and bagasse ash waste involves providing concrete mix materials and the tools needed for the research. Furthermore, during the experimental phase, the research tools and materials will be inspected, concrete mix composition planning, concrete mix preparation, slump flow testing, concrete specimen molding, concrete specimen curing or soaking, and concrete compressive strength testing will be carried out.

In making a concrete mixture composition, the following concrete materials are needed:

1. Cement Type Portland Composite Cement (PCC)

Cement material is a chemically active mixture when in contact with water, functioning as an aggregate binder. Portland Composite Cement (PCC) is a hydraulic cement made from Portland cement clinker that is ground together or mixed with additional inorganic materials such as Pozzolan (*Fly Ash*, volcanic ash), Limestone, Silica. The General Composition of PCC is Portland Clinker: ± 65–80%, Additional materials (pozzolan/limestone): ± 20–35%, Gypsum: ± 3–5%. The characteristics of PCC are lower hydration heat, slower compressive strength development at early age, good long-term compressive strength, more environmentally friendly and better concrete workability. In Indonesia, PCC is very commonly used for building & infrastructure construction. The cement used in this study is PCC, which is produced by PT. Three Wheels, with a packaging of 50 kg and 40 kg sacks.

2. *Silica Fumes*

Silica fume material is a mineral additive in the form of a very fine powder commonly used to improve the quality of concrete, especially high-quality concrete. The advantages of silica fume are Producing high-quality concrete (≥ 60 MPa), Very effective in closing concrete pores, and Suitable for aggressive environments. The characteristics of Silica Fume are a very fine powder form, dark gray to blackish color, particle size: ± 0.1 µm (± 100 times finer than cement), SiO_2 content ≥ 85–95%, highly reactive pozzolanic. The function of Silica Fume in the Concrete mixture is to increase compressive strength, increase durability, strengthen cement-aggregate bonds, and make concrete denser. The silica fume used in this study is the Sikafume brand, weighing 20 kg/bag, produced by PT Sika Indonesia.

3. *Silica Sand Mesh* 35-60

Silica sand mesh 35–60 is silica sand with a grain size that passes through a 35 mesh sieve and is retained on a 60 mesh, so it has a medium–fine grain gradation. This material is dominated by silicon dioxide (SiO_2). The characteristics of this silica sand are high SiO_2 content: ≥ 90–99% and relatively sharp grain shape. Silica sand also functions as an additional fine aggregate in concrete. in concrete mixes General Requirements Sand must be clean, hard, and sharp, free from mud, clay, organic materials, does not contain salt (sea water), the grains are not easily destroyed. The sand used must not contain more than 5% mud, because mud will inhibit the bond between sand and cement. If the mud content is >5%, it must be washed. The sand used is clean sand obtained from Bangka Belitung with a mesh size of 35-60 (500-250 microns) or 0.5–0.25 mm from CV Nagamas, Bangka Belitung province.

4. Silica *Mesh* 325

Silica mesh 325 is a very fine silica powder that passes through a 325 mesh sieve, with a particle size approaching that of a micro-filler. This material consists mostly of silicon dioxide (SiO_2) and is chemically inert. The particle size of silica mesh 325 is much finer than silica sand mesh 35–60, approaching the size of cement (even finer). The role of Silica Sand in Concrete is as a micro-filler, filling micropores in cement paste, increasing the density and compactness of concrete, improving the texture and quality of the concrete surface, supporting an increase in physical compressive strength (filler effect), denser concrete, high hardness, suitable for high-quality concrete. This natural sand/industrial processed product contains the chemical compound SiO_2 ≥ 90% (can even be > 95%), the shape of the grains is generally sharp & hard, light white-gray color. Things to Note are the dosage is generally 5–15% of the weight of cement, can reduce workability → need SP and must be mixed evenly. The specification for silica powder is 325 mesh (44 microns) or 0.044 mm. The fine silica used in this study was obtained from Bangka Belitung, Indonesia.

5. Water

Water for concrete is water used in the mixing and curing process of concrete. It functions to activate the cement hydration reaction, provide workability, and determine the quality and durability of the concrete. Water requirements for concrete are: In general, drinking water (clean water) is also suitable for use in concrete. Technical requirements for water that can be used in concrete mixtures are clear, odorless, free from mud, oil, and organic materials, and does not contain substances harmful to concrete and reinforcing steel. Chemical Content Limits (general reference SNI / ASTM) are pH: ≥ 6, Total dissolved solids (TDS): ≤ 2,000 mg/L, Chloride (Cl^-): (Reinforced concrete: ≤ 500 mg/L and Prestressed concrete: ≤ 250 mg/L), Sulfate (SO_4^{2-}): ≤ 1,000 mg/L, and Oil & grease: ≤ 50 mg/L. And in carrying out this research, the water used came from the concrete laboratory and water available in the structural laboratory at the University of North Sumatra which had been visually checked before being used.

6. *Superplasticizer Viscocrete*® 8670 MN

Viscocrete® 8670 MN is a concrete chemical additive (superplasticizer) based on Polycarboxylate Ether (PCE) produced by Sika, used to increase the workability of concrete without adding water. The main function is to significantly reduce water requirements, improve workability and slump flow, increase concrete compressive strength, enable the manufacture of high-quality concrete and Self-Compacting Concrete (SCC). General Characteristics: Liquid Form, Light Brown Color, Specific Gravity: ± 1.08 ± 0.02, pH: ± 4 – 6, Chloride-free (safe for reinforced concrete). Cement Particle Dispersion Working Mechanism, Main Effect: High Water Reduction & Good Slump Retention. Function & Benefits: Reduces water by ±20 – 35%, Low w/c ratio increases compressive strength, High Workability, High Slump without adding water, Suitable for high-quality concrete & reinforced concrete, maintains concrete workability longer, Ideal for long-distance casting. The Usage Dosage is Generally 0.8 – 2.0% of the cement weight, The optimal dosage is determined through trial mix, and excess addition can cause segregation. Use 0.6 – 1.5% of the cement weight, Mixed with water or after initial mixing, mixed with PCC cement. Viscocrete® 8670 MN is very effective in producing high-quality, workable, and durable concrete, especially when combined with PCC, silica fume, and PP fiber [14]. The superplasticizer used in this study was Viscocrete 8670 MN, a product of SIKA Indonesia.

7. Bagasse Ash

Bagasse ash is the ash resulting from burning bagasse from sugar factories. After the burning and refining process, this ash can be used as a mineral additive (pozzolan) in concrete mixtures. The chemical characteristics of bagasse ash are high SiO_2 content (generally 60–80%, can be higher after processing), amorphous if the burning is controlled, pozzolanic reactive, and blackish gray color. Bagasse Ash Processing To be effective in concrete, the ash needs: Controlled burning (±600–700°C),

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Milling/screening (passing sieve No. 200 / mesh 75 μm), and Reduction of unburned carbon (low LOI). The dosage is generally 5–20% as a partial replacement for cement, the optimum dosage is often found at 10–15%, and trial mix is needed for best results. The bagasse ash used in this study was obtained directly from the waste disposal source at the sugar factory (PG) managed by PT Perkebunan Nusantara II (PTPN II) located in Kwala Begumit Village, Stabat District, Langkat Regency, North Sumatra. This sugar factory processes sugar cane into white crystal sugar. Bagasse ash contains chemical compounds namely Silica SiO_2 + Alumina Al_2O_3 + Iron oxide Fe_2O_3 ≥ 70% which meets the criteria for pozzolanic materials (ASTM C618) so that it can increase the compressive strength of concrete and meet quality standards as a concrete mixture. The advantages of using bagasse ash in concrete mixtures are Utilizing industrial waste (environmentally friendly), Reducing cement use, Reducing hydration heat and More economical material costs [15].

8. *Fly Ash*

Fly Ash from Labuhan Angin Power Plant is *Fly Ash* from coal combustion at Labuhan Angin Power Plant (Central Tapanuli Regency, near Sibolga). This material has the potential to be used as a mineral additive (pozzolan) in concrete. *Fly Ash* classification based on ASTM C618, *Fly Ash* from PLTU in Indonesia (including Labuhan Angin) generally includes: Class F *Fly Ash*, namely low CaO content, high SiO_2 + Al_2O_3 + Fe_2O_3 content (≥ 70%), and pure pozzolan properties so it is suitable as a concrete mixture material. Physical Characteristics are Particle shape: spherical, Size: finer than cement, Color: blackish gray, Specific gravity: ± 2.2 – 2.6. The role of *Fly Ash* in Concrete is as a partial replacement for cement, Increasing concrete workability, Reducing hydration heat, Increasing concrete durability, and Reducing porosity and permeability. Dosage of Use is General: 10 – 30% of the weight of cement, High quality concrete: 15 – 25%, Mass concrete: can be > 30%. *Fly Ash* of Labuhan Angin PLTU is very good combined with: PCC, Silica fume and Superplasticizer (Viscocrete® 8670 MN). *Fly Ash* The method used in this study was obtained directly from the waste disposal source at Labuhan Angin PLTU. Labuhan Angin PLTU is one of the electricity suppliers in the Tapian Nauli I area, Tapian Nauli, Central Tapian Nauli Regency, North Sumatra. Based on X-Ray Fluorescence (XRF) analysis, *Fly Ash* has a $SiO2+Al2O3+Fe2O3$ content of 81.86% which indicates that *Fly Ash* meets the quality standards as a concrete mixture.

9. *Polypropylene Fibers*

Polypropylene fiber (PP fiber) is a synthetic fiber made from polypropylene polymer which is added to the concrete mixture in small amounts to improve the mechanical performance and durability of the concrete. The characteristics of PP Fiber are Material: Polypropylene, Form: monofilament / fibrillated, Fiber length: 6 – 20 mm (generally 12 mm), Diameter: ± 18–40 microns, Specific gravity: ± 0.91 (lighter than water), Resistant to alkali & chemicals, Does not rust. The function of PP Fiber in Concrete is to Control plastic shrinkage cracks, Reduce premature cracks, Increase impact resistance, Increase concrete ductility, Reduce bleeding and segregation. The working mechanism of Polypropylene fiber (PP fiber) is that PP fiber works as a micro binder

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that restrains the movement of micro cracks in fresh concrete and hardened concrete, so that cracks do not develop into large cracks. The polypropylene fiber used is SikaFibre (Polypropylene Fiber for Concrete) with a diameter of 18 microns and a length of 12 mm. This fiber is resistant to acids and bases, with a fiber melting point of 160°C. The density of polypropylene fiber is ~900 kg/m3, tensile strength 700 N/mm2, and modulus E 5000-15000 N/mm2. Sika polypropylene fiber (such as SikaFibre or SikaFiber) is a high-quality polypropylene monofilament microfiber added to concrete to control and minimize plastic shrinkage cracks, reduce permeability, increase durability, and improve impact and abrasion resistance in concrete. In this study, the Polypropylene fiber (PP fiber) used was obtained from PT SIKA Indonesia.

2.1. Material Characterization

The chemical compositions of fly ash and bagasse ash used in this study were determined using X-Ray Fluorescence (XRF) analysis. The fly ash obtained from the Labuhan Angin Power Plant was classified as Class F fly ash based on ASTM C618 requirements, with a combined content of SiO_2, Al_2O_3, and Fe_2O_3 of 81.86%, indicating strong pozzolanic characteristics.

Bagasse ash collected from the Kwala Madu Sugar Factory was processed through controlled burning at a temperature of approximately 600–700°C, followed by grinding and sieving through a No. 200 sieve (75 µm). The chemical composition of bagasse ash showed a high silica content, with the total content of SiO_2, Al_2O_3, and Fe_2O_3 exceeding 70%, which meets the pozzolanic material requirements according to ASTM C618.

The physical properties of the materials, including particle size distribution and fineness, were evaluated to ensure suitability for use as supplementary cementitious materials in high-performance concrete.

2.2. Mix Design of High-Performance Concrete

The mix design of high-performance concrete was prepared based on Indonesian National Standard SNI 2847-2019. The water-to-cement ratio (w/c) used in this study was maintained at 0.21, while the water-to-binder ratio (w/b) was 0.19 for all mixture variations.

Nine concrete mixture variations (A–I) were prepared with different proportions of fly ash and bagasse ash as supplementary cementitious materials. The dosage of fly ash and bagasse ash varied between 3.5% and 7% of the total binder content. A polycarboxylate-based superplasticizer (Viscocrete® 8670 MN) was added at a dosage of approximately 2% of the cement weight to achieve the required workability.

The composition of the concrete mixture materials can be seen in Table 1.

Table 1. Concrete Material Mix Variation A-Variation I.

Material Description Concrete	Variation A (kg)	Variation B (kg)	Variation C (kg)	Variation D (kg)	Variation E (kg)	Variation F (kg)	Variation G (kg)	Variation H (kg)	Variation I (kg)
Portland Composite Cement (PCC)	865,00	865,00	865,00	865,00	865,00	865,00	865,00	865,00	865,00
Silica Fume	207,60	207,60	207,60	207,60	207,60	207,60	207,60	207,60	207,60

Silica Sand Mesh 35-60	822,79	822,79	822,79	822,79	822,79	822,79	822,79	822,79	822,79
Silica Sand Mesh 325	190,30	190,30	190,30	190,30	190,30	190,30	190,30	190,30	190,30
Water	181,65	181,65	181,65	181,65	181,65	181,65	181,65	181,65	181,65
Superplasticizer Viscocrete® 8670 MN	17,30	17,30	17,30	17,30	17,30	17,30	17,30	17,30	17,30
Bagasse Ash from Kwala Madu Sugar Factory	120,40	-	60,20	146,00	-	73,00	172,20	-	86,10
Fly Ash from the Labuhan Angin PLTU		120,40	60,20		146,00	73,00		172,20	86,10
Polypropylene Fibers	2,46	2,46	2,46	2,46	2,46	2,46	2,46	2,46	2,46
W/c	0,21	0,21	0,21	0,21	0,21	0,21	0,21	0,21	0,21
W/b	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19

For variations A, B, C, D, E, F, G, H, and I of concrete mix composition, 5 specimens were made for each test. The tests were conducted at 3 days, 7 days, 14 days, and 28 days of age. The concrete specimens were cube-shaped with a side size of 50 mm to test the concrete's compressive strength.

2.3. Specimen Preparation and Testing Procedure

For each mixture variation (A–I), five cube specimens were prepared for each testing age. A total of 180 specimens were produced (9 variations × 4 testing ages × 5 specimens). The specimens were cube-shaped with dimensions of 50 mm × 50 mm × 50 mm.

After casting, the specimens were cured in water at room temperature until the testing age. Compressive strength tests were conducted at curing ages of 3, 7, 14, and 28 days using a digital compression testing machine in accordance with relevant testing standards.

Slump flow tests were performed to evaluate the workability of fresh concrete mixtures prior to casting.

3. RESULTS AND DISCUSSION

3.1 Flowability Tests

Flowability tests are tests to assess the flowability of fresh concrete, especially for high-strength concrete, Self-Compacting Concrete (SCC), and concrete with superplasticizers. This study used a Slump Flow Test to measure concrete flowability. The relationship between Flowability and Materials is that Flowability is influenced by the water-cement ratio (w/c), Superplasticizer (e.g., Viscocrete® 8670 MN), *Fly Ash*, silica fume, and PP fiber (which reduces flow). Flowability tests are important for: Ensuring ease of casting, Preventing segregation and honeycomb formation, and Determining the quality of fresh concrete. The Slump Flow Test was conducted to determine the workability of concrete made from a mixture of *Fly Ash* from the Labuhan Angin power plant, bagasse ash from the Kwala Madu sugar factory, water, 35-60 mesh silica sand, 325 mesh silica sand, polypropylene fiber, PCC cement, silica

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Vol. 7, No.1, Juni 2026, Hal 50-66
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fume, and Viscocrete 8670 MN superplasticizer [16]. The results Slump Flow Test are presented in Table 2 and the Slump Flow Test graph is presented in Figure 1.

Table 2. Slump Flow Test Results.

NILAI SLUMP FLOW				
No	Description	Diameter A	Diameter B	Slump Flow Test Average
1	Variation A	19,05	19,20	19,13
2	Variation B	19,10	19,05	19,08
3	Variation C	19,00	19,10	19,05
4	Variation D	19,10	18,90	19,00
5	Variation E	18,90	19,00	18,95
6	Variation F	18,90	19,10	19,00
7	Variation G	19,10	19,05	19,08
8	Variation H	19,00	19,10	19,05
9	Variation I	18,90	19,10	19,00

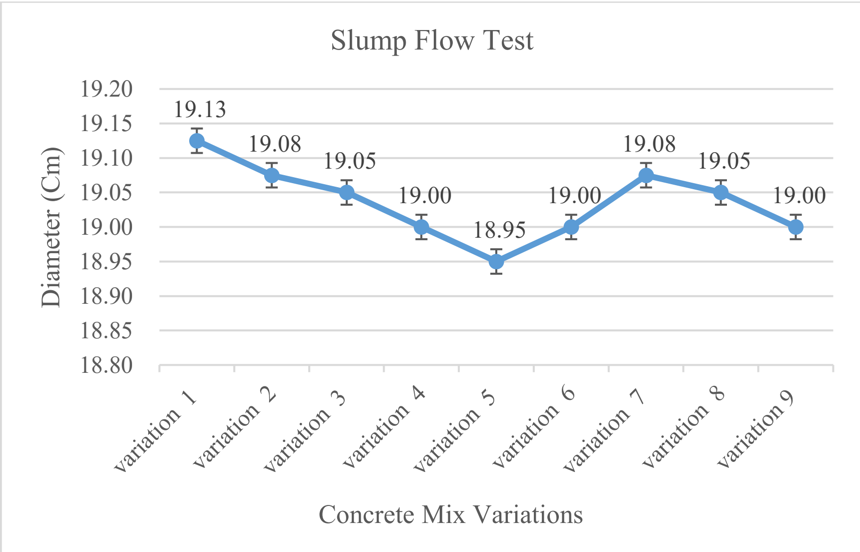

Figure 1. Slump Flow Test .

3.2 Concrete Compressive Strength

Concrete compressive strength testing was carried out at the age of 3 days, 7 days, 14 days, and 28 days using cube-shaped test specimens with a side size of 5 cm. The concrete compressive strength testing method used a Digital Concrete Compression Machine Test Electric [17]. The results of concrete compressive strength for variation A are presented in table 3.

Table 3. The result of variation A concrete compression strength test The compressive strength test for concrete variation B is presented in table 4.

No	Description	Concrete Age (day)	Area Of A Cube (cm)	Specimen Weight (gr)	*Compressive Strength* (Mpa)	*Compressive Strength* Average (Mpa)
1	Variation A	3	25	293	40,79	40,56

2	Variation A	3	25	291	40,29	
3	Variation A	3	25	293	40,96	
4	Variation A	3	25	291	40,29	
5	Variation A	3	25	291	40,46	
6	Variation A	7	25	291	54,67	
7	Variation A	7	25	292	54,84	
8	Variation A	7	25	289	54,34	54,61
9	Variation A	7	25	279	54,51	
10	Variation A	7	25	290	54,67	
11	Variation A	14	25	279	66,02	
12	Variation A	14	25	291	66,35	
13	Variation A	14	25	289	66,19	66,15
14	Variation A	14	25	287	66,02	
15	Variation A	14	25	295	66,19	
16	Variation A	28	25	293	72,79	
17	Variation A	28	25	291	72,96	
18	Variation A	28	25	293	72,79	72,85
19	Variation A	28	25	291	72,79	
20	Variation A	28	25	291	72,96	

Table 4. The results of variation B concrete compression strength test.

No	Description	Concrete Age (day)	Area of a Cube (cm)	Specimen Weight (gr)	*Compressive Strength* (Mpa)	*Compressive Strength* Average (Mpa)
1	Variation B	3	25	291	48,58	
2	Variation B	3	25	291	48,41	
3	Variation B	3	25	290	48,58	48,51
4	Variation B	3	25	291	48,41	
5	Variation B	3	25	292	48,58	
6	Variation B	7	25	287	61,95	
7	Variation B	7	25	295	61,78	
8	Variation B	7	25	293	61,95	61,89
9	Variation B	7	25	291	61,78	
10	Variation B	7	25	293	61,95	
11	Variation B	14	25	289	72,62	
12	Variation B	14	25	290	72,45	
13	Variation B	14	25	291	72,45	72,52
14	Variation B	14	25	291	72,62	
15	Variation B	14	25	290	72,45	
16	Variation B	28	25	289	78,88	
17	Variation B	28	25	291	79,05	
18	Variation B	28	25	291	78,88	78,95
19	Variation B	28	25	287	79,05	
20	Variation B	28	25	292	78,88	

The compressive strength test for concrete variation C is presented in Table 5.

Table 5. The results of variation C concrete compressive strength test.

No	Description	Concrete Age (day)	Area of a Cube (cm)	Specimen Weight (gr)	*Compressive Strength* (MPa)	*Compressive Strength* Average (MPa)
1	Variation C	3	25	291	46,04	
2	Variation C	3	25	292	45,87	
3	Variation C	3	25	289	46,04	45,94
4	Variation C	3	25	279	45,87	
5	Variation C	3	25	290	45,87	
6	Variation C	7	25	279	59,25	
7	Variation C	7	25	291	59,08	
8	Variation C	7	25	289	59,25	59,18
9	Variation C	7	25	287	59,08	
10	Variation C	7	25	295	59,25	
11	Variation C	14	25	293	70,08	
12	Variation C	14	25	291	70,25	
13	Variation C	14	25	293	70,25	70,25
14	Variation C	14	25	293	70,42	
15	Variation C	14	25	291	70,25	
16	Variation C	28	25	293	76,85	
17	Variation C	28	25	291	77,02	
18	Variation C	28	25	291	76,85	76,92
19	Variation C	28	25	278	77,02	
20	Variation C	28	25	291	76,85	

The compressive strength test for concrete variation D is presented in table 6.

Table 6. The results of variation D concrete compressive strength test.

No	Description	Concrete Age (day)	Area of a Cube (cm)	Specimen Weight (gr)	*Compressive Strength* (MPa)	*Compressive Strength* Average (MPa)
1	Variation D	3	25	291	41,64	
2	Variation D	3	25	291	41,30	
3	Variation D	3	25	292	41,47	41,47
4	Variation D	3	25	289	41,47	
5	Variation D	3	25	279	41,47	
6	Variation D	7	25	290	55,86	
7	Variation D	7	25	279	55,69	
8	Variation D	7	25	291	55,69	55,79
9	Variation D	7	25	289	55,86	
10	Variation D	7	25	291	55,86	
11	Variation D	14	25	293	68,39	
12	Variation D	14	25	291	68,39	
13	Variation D	14	25	293	68,22	68,39
14	Variation D	14	25	291	68,39	
15	Variation D	14	25	291	68,56	
16	Variation D	28	25	278	75,33	
17	Variation D	28	25	290	75,50	
18	Variation D	28	25	291	75,50	75,43
19	Variation D	28	25	291	75,33	
20	Variation D	28	25	290	75,50	

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The compressive strength test for concrete variation E is presented in table 7.

Table 7. Concrete compressive strength test results for variation E.

No	Description	Concrete Age (day)	Area of a Cube (cm)	Specimen Weight (gr)	*Compressive Strength* (MPa)	*Compressive Strength* Average (MPa)
1	Variation E	3	25	291	49,77	
2	Variation E	3	25	292	49,60	
3	Variation E	3	25	289	49,77	49,77
4	Variation E	3	25	279	49,94	
5	Variation E	3	25	290	49,77	
6	Variation E	7	25	279	63,14	
7	Variation E	7	25	291	63,31	
8	Variation E	7	25	289	63,14	63,17
9	Variation E	7	25	292	63,14	
10	Variation E	7	25	289	63,14	
11	Variation E	14	25	279	75,16	
12	Variation E	14	25	290	75,33	
13	Variation E	14	25	279	75,16	75,22
14	Variation E	14	25	289	75,33	
15	Variation E	14	25	279	75,16	
16	Variation E	28	25	290	81,59	
17	Variation E	28	25	279	81,76	
18	Variation E	28	25	291	81,76	81,76
19	Variation E	28	25	290	81,76	
20	Variation E	28	25	290	81,93	

The compressive strength test for concrete variation F is presented in Table 8.

Table 8. concrete compressive strength test variations F.

No	Description	Concrete Age (day)	Area of a Cube (cm)	Specimen Weight (gr)	*Compressive Strength* (MPa)	*Compressive Strength* Average (MPa)
1	Variation F	3	25	292	46,38	
2	Variation F	3	25	289	46,72	
3	Variation F	3	25	279	46,89	46,75
4	Variation F	3	25	290	46,89	
5	Variation F	3	25	279	46,89	
6	Variation F	7	25	290	60,26	
7	Variation F	7	25	279	60,09	
8	Variation F	7	25	291	60,26	60,23
9	Variation F	7	25	289	60,26	
10	Variation F	7	25	278	60,26	
11	Variation F	14	25	292	72,96	
12	Variation F	14	25	290	73,13	
13	Variation F	14	25	291	72,96	73,09
14	Variation F	14	25	291	73,29	
15	Variation F	14	25	292	73,13	
16	Variation F	28	25	290	79,39	
17	Variation F	28	25	291	79,22	79,29
18	Variation F	28	25	291	79,22	

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19	Variation F	28	25	290	79,22	
20	Variation F	28	25	289	79,39	

The compressive strength test for concrete variation G is presented in Table 9.

Table 9. Concrete compressive strength test variations G.

No	Description	Concrete Age (day)	Area of a Cube (cm)	Specimen Weight (gr)	*Compressive Strength* (MPa)	*Compressive Strength* Average (MPa)
1	Variation G	3	25	278	41,64	
2	Variation G	3	25	291	41,98	
3	Variation G	3	25	292	41,64	41,84
4	Variation G	3	25	289	41,98	
5	Variation G	3	25	279	41,98	
6	Variation G	7	25	290	56,71	
7	Variation G	7	25	279	56,37	
8	Variation G	7	25	290	56,54	56,54
9	Variation G	7	25	279	56,54	
10	Variation G	7	25	291	56,54	
11	Variation G	14	25	289	70,92	
12	Variation G	14	25	278	70,92	
13	Variation G	14	25	291	70,92	70,92
14	Variation G	14	25	290	70,92	
15	Variation G	14	25	293	70,92	
16	Variation G	28	25	291	78,20	
17	Variation G	28	25	290	78,20	
18	Variation G	28	25	278	77,53	77,87
19	Variation G	28	25	290	77,53	
20	Variation G	28	25	286	77,87	

The compressive strength test for concrete variation H is presented in Table 10.

Table 10 concrete compressive strength test variations H.

No	Description	Concrete Age (day)	Area of a Cube (cm)	Specimen Weight (gr)	*Compressive Strength* (MPa)	*Compressive Strength* Average (MPa)
1	Variation H	3	25	291	50,78	
2	Variation H	3	25	291	50,61	
3	Variation H	3	25	292	50,44	50,58
4	Variation H	3	25	289	50,44	
5	Variation H	3	25	279	50,61	
6	Variation H	7	25	290	64,15	
7	Variation H	7	25	279	64,15	
8	Variation H	7	25	291	64,15	64,15
9	Variation H	7	25	289	64,15	
10	Variation H	7	25	291	64,15	
11	Variation H	14	25	293	77,36	
12	Variation H	14	25	291	77,19	
13	Variation H	14	25	279	77,19	77,29
14	Variation H	14	25	291	77,36	
15	Variation H	14	25	289	77,36	

16	Variation H	28	25	278	84,81	
17	Variation H	28	25	291	84,64	
18	Variation H	28	25	291	84,64	84,67
19	Variation H	28	25	290	84,64	
20	Variation H	28	25	278	84,64	

The compressive strength test for concrete variation I is presented in Table 11.

Table 11. Concrete compressive strength test results for variation I.

No	Description	Concrete Age (day)	Area Of A Cube (cm)	Specimen Weight (gr)	*Compressive Strength* (MPa)	*Compressive Strength* Average (MPa)
1	Variation I	3	25	279	47,90	
2	Variation I	3	25	291	47,90	
3	Variation I	3	25	289	47,90	47,84
4	Variation I	3	25	278	47,73	
5	Variation I	3	25	291	47,73	
6	Variation I	7	25	289	61,61	
7	Variation I	7	25	279	61,61	
8	Variation I	7	25	290	61,61	61,65
9	Variation I	7	25	279	61,61	
10	Variation I	7	25	291	61,78	
11	Variation I	14	25	289	74,99	
12	Variation I	14	25	279	74,99	
13	Variation I	14	25	291	74,99	74,95
14	Variation I	14	25	293	74,99	
15	Variation I	14	25	291	74,82	
16	Variation I	28	25	293	82,27	
17	Variation I	28	25	291	82,27	
18	Variation I	28	25	291	82,27	82,33
19	Variation I	28	25	278	82,44	
20	Variation I	28	25	279	82,44	

3.3 Effect of Fly Ash and Bagasse Ash on Compressive Strength

The results show that the incorporation of fly ash from the Labuhan Angin Power Plant and bagasse ash from the Kwala Madu Sugar Factory significantly influenced the compressive strength development of high-performance concrete at all curing ages. The compressive strength increased gradually with curing time due to the ongoing hydration reaction of cement and the pozzolanic reaction contributed by supplementary cementitious materials (SCMs).

At the age of 28 days, the highest compressive strength was obtained in Variation H, reaching 84.67 MPa, which indicates the characteristics of high-performance concrete. Compared to the control mixture (Variation A, 72.85 MPa), the compressive strength increased by approximately 16.22%, indicating the beneficial effect of combining fly ash and bagasse ash in the concrete mixture. Meanwhile, at early age (3 days), the highest compressive strength was recorded in Variation H, reaching 50.58 MPa, indicating good early strength development despite the use of supplementary materials.

Jurnal Mesil (Mesin Elektro Sipil) **E-ISSN : 2723-7052**
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https://doi.org/10.53695/jm.v7i1.1575

The improvement in compressive strength can be explained by the pozzolanic reaction mechanism. Fly ash and bagasse ash contain high silica (SiO_2) content, which reacts with calcium hydroxide $Ca(OH)_2$ released during cement hydration to form additional Calcium Silicate Hydrate (C–S–H) gel. The formation of additional C–S–H gel contributes to increased density of the cement matrix, reduced porosity, and improved interfacial transition zone (ITZ) between cement paste and aggregate.

In addition to pozzolanic activity, the filler effect also contributed to strength enhancement. The fine particle size of silica sand mesh 325, silica fume, fly ash, and bagasse ash filled microvoids within the concrete matrix, producing a denser microstructure. This resulted in reduced permeability and improved mechanical performance of the concrete.

3.4 Comparison with Previous Studies

The results obtained in this study are consistent with previous research findings regarding the use of fly ash and bagasse ash in concrete mixtures. Previous studies reported that the addition of fly ash can increase compressive strength by up to 20% compared to conventional concrete mixtures due to its pozzolanic properties and particle packing effects [6]. Similarly, research conducted on bagasse ash indicated that the addition of 5–10% bagasse ash could increase compressive strength by approximately 6–10% compared to normal concrete [8].

The compressive strength obtained in this study, particularly in Variation H (84.67 MPa at 28 days), is higher than several reported results in conventional high-strength concrete studies that typically range between 60–80 MPa, indicating that the combination of fly ash and bagasse ash with silica-based materials contributes to improved mechanical performance.

Furthermore, the use of multiple supplementary cementitious materials (SCMs), such as silica fume, fly ash, and bagasse ash, resulted in a synergistic effect. Silica fume provided rapid early reaction due to its high reactivity, while fly ash and bagasse ash contributed to long-term strength development through secondary hydration reactions. This combined effect enhanced the overall durability and strength of the concrete matrix.

3.5 Relationship Between Flowability and Strength

The slump flow results ranged from 18.95 cm to 19.13 cm, indicating that all mixtures exhibited good workability and flowability characteristics suitable for high-performance concrete. The relatively consistent slump flow values suggest that the use of superplasticizer Viscocrete® 8670 MN effectively maintained workability despite the low water-binder ratio (w/b = 0.19).

Adequate flowability ensured uniform distribution of particles and reduced the risk of segregation, which contributed to improved compressive strength. However, the presence of polypropylene fibers slightly reduced flowability due to the increased internal friction between particles, although this effect was controlled by the superplasticizer dosage.

4. CONCLUSION

Based on the experimental results obtained in this study, the following conclusions can be drawn:

1. Among the nine concrete mixture variations, Variation H produced the highest compressive strength of 84.67 MPa at 28 days, indicating the characteristics of high-performance concrete. This optimum mixture consisted of 7% fly ash, PCC cement, silica fume, silica sand mesh 35–60, silica sand mesh 325, water, Viscocrete® 8670 MN superplasticizer, and 0.1% polypropylene fiber.
2. The highest compressive strength for mixtures containing both fly ash and bagasse ash was achieved in Variation I, reaching 82.33 MPa at 28 days, with a composition of 3.5% fly ash and 3.5% bagasse ash, demonstrating the positive combined effect of industrial and agricultural waste materials.
3. The incorporation of fly ash and bagasse ash improved the compressive strength compared to the control mixture (72.85 MPa), with an increase of up to 16.22%, indicating the effectiveness of supplementary cementitious materials in enhancing the mechanical properties of high-performance concrete.
4. The utilization of fly ash from Labuhan Angin Power Plant and bagasse ash from Kwala Madu Sugar Factory demonstrates strong potential for sustainable concrete production by improving compressive strength while reducing environmental impact through industrial waste utilization.

Further studies are recommended to evaluate long-term durability properties such as permeability, shrinkage, and resistance to aggressive environments.

ACKNOWLEDGEMENT

The authors would like to thank the Civil Engineering Laboratory of the University of North Sumatra for providing facilities for this research.

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