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Experimental Test of Compressive Strength of Eco-Friendly Concrete Using 0%, 10%, 20% Aren Tree Powder Waste as a Substitute for Fine Aggregate

Guntur Nugroho[1,*]

[1]*Program Studi Teknik Sipil, Universitas Muhammadiyah Yogyakarta*
Jl. Brawijaya, Bantul, Yogyakarta, Indonesia

*guntur.nugroho@umy.ac.id

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Abstrak

Pembangunan pada bidang konstruksi di Indonesia mengalami kemajuan yang pesat sehingga beberapa macam inovasi dilakukan dalam campuran beton menggunakan limbah organik. Limbah pati onggok merupakan limbah dari industri tapioka berbentuk padatan yang diperoleh dari proses ektstrasi. Salah satu cara agar limbah tersebut dapat dimanfaatkan menjadi campuran beton dengan mensubstitusikan pada agregat halus, sehingga limbah tersebut dapat mengurangi limbah yang mencemari lingkungan. Tujuan penelitian adalah untuk mengetahui nilai kuat tekan beton dengan campuran Limbah Serbuk Aren (LSA) sebagai subtitusi agregat halus sebesar 0%,10%,20%. Metode penelitian yang digunakan adalah pengujian eksperimen dengan benda uji silinder beton yang berukuran diametar15cm dan tinggi 30cm. Jumlah sampel pada setiap variasi campuran adalah 3 benda uji. Pengujian kuat tekan dilakukan pada benda uji silinder beton yang telah berumur 28 hari. Hasil pengujian menunjukkan nilai kuat tekan rerata 24,01MPa, 23,97MPa, 22,91MPa, pada variasi 0%,10%,20%. Nilai kuat tekan beton menurun sebesar 0,16 %, 4,52%, untuk variasi 10%,20% terhadap beton normal. Kesimpulan dari penelitian menunjukkan bahwa beton dengan variasi 10%,20% termasuk beton mutu sedang yang dapat digunakan untuk struktur beton bertulang.

Kata Kunci: Kuat Tekan Beton, Limbah Serbuk Aren.

Abstract

Construction development in Indonesia is experiencing rapid progress, leading to various innovations in concrete mixtures using organic waste. Aren Tree Powder (ATP) waste is a solid waste from the tapioca industry obtained from the extraction process. One way to utilize this waste is by incorporating it into concrete mixtures as a substitute for fine aggregate, thereby reducing waste that pollutes the environment. The purpose of the research is to determine the compressive strength of concrete with a mixture of Aren Tree Powder (ATP) as a substitute for fine aggregate at 0%, 10%, and 20%. The research method used is experimental testing with concrete cylinder test specimens measuring 15cm in diameter and 30cm in height. The number of samples for each mix variation is 3 test specimens. The compressive strength test was conducted on concrete cylinder specimens that had cured for 28 days. The test results show average compressive strength values of 24.01MPa, 23.97MPa, 22.91MPa, at variations of 0%, 10%, 20%. The compressive strength of the concrete decreased by 0.16%, 4.52% for the 10%, 20% variations compared to normal concrete. The conclusion of the research shows that

concrete with 10% and 20% variations falls into the medium-strength category, which can be used for reinforced concrete structures.
***Keywords**: Concrete Compressive Strength, Aren Tree Powder (ATP)*

A. Introduction

Construction development in Indonesia is experiencing rapid progress, taking place in various construction projects, such as buildings, bridges, dams, and so on. There are several construction materials used such as concrete, steel, wood, and glass. Concrete is a construction material that is frequently used in the construction field in Indonesia. Concrete is highly sought after because it has many advantages compared to other materials, including relatively lower prices, ease of shaping according to construction needs, readily available constituent materials, resistance to high temperatures, and low maintenance costs. Concrete innovation at this time is required to meet the very high demand for concrete, with the produced concrete expected to have high quality, including strength and durability, without neglecting economic value. Various studies in the field of concrete have been conducted as an effort to improve the quality of concrete. Research efforts conducted by mixing organic and inorganic waste.

1. Literature Review

The development of environmentally friendly concrete is very important for several reasons: The production of conventional cement, which is the main component of concrete, causes significant greenhouse gas emissions. Almost 10% of global carbon dioxide (CO2) emissions come from cement production (Amran et al., 2021).Therefore, the development of more environmentally friendly alternatives is urgently needed to reduce the environmental impact of the construction industry. Eco-friendly concrete can support the achievement of several Sustainable Development Goals (SDGs) through carbon footprint reduction and more efficient resource use. This aligns with the global commitment to achieving carbon neutrality and promoting sustainable construction practices (Kolya & Kang, 2024). The use of alternative materials such as Ground Granulated Blast Furnace Slag (GGBFS), Recycled Coarse Aggregate (RCA), and fly ash in eco-friendly concrete can significantly reduce the carbon footprint. For example, concrete with 90% GGBFS and 10% ordinary Portland cement can produce emissions of only 125 kg/m3, much lower than conventional concrete (Elchalakani et al., 2017). In addition to environmental benefits, eco-friendly concrete can also provide economic advantages. (Agrawal et al., 2024; Al-Taai et al., 2023) use of recycled materials and industrial waste not only reduces waste but can also lower production costs. This supports the transition towards a circular economy in the construction industry (Khair et al., 2024).

Thus, the development of environmentally friendly concrete is an important step towards sustainable construction, reducing environmental impact, and supporting global efforts in climate change mitigation. A number of studies have been conducted to evaluate the use of various types of waste as alternative materials in the production of eco-friendly concrete. (Mayanti et al., 2024) studied the effect of adding wood powder on the compressive strength of concrete. The results show that substituting wood powder for fine aggregate up to 6% can increase the concrete strength, but adding more than 9% actually decreases the compressive strength of the concrete. (Sarmadika et al., 2022) used a mixture of bayur wood powder and coconut coir fibers as a partial substitute for sand in lightweight concrete, which can result in an increase in split tensile strength of up to 6%. (Putri & Romadhon, 2024) The use of a combination of wood powder and iron powder in K-175 concrete, which has proven to be stable and meets the compressive strength specifications according to Indonesian national standards.

Additionally, (Wibowo, 2015) conducted research on the effect of wood sawdust as a partial substitute for cement and the addition of the chemical Bestmittel, which showed fairly good concrete characteristics. (Putranto & Syaiful, 2019) also conducted experiments by adding Jatiwangi tile waste and Damdex material to the concrete mix to observe its effect on compressive strength. (Farhan et al., 2023) reinforced this finding by proving that rice husk ash can be used as a concrete additive without significantly reducing its strength. (Dewi & Renaldi, 2024) also demonstrated the potential of rice husk ash in utilizing waste that has not been maximized, with concrete compressive strength results that still meet the standards. Various other types of organic waste have also been tested as substitutes in concrete. (Saputra et al., 2022) studied the use of post-burn palm shells and found that heat treatment increases the compressive strength and splitting tensile strength of concrete. (Carolina et al., 2018) studied the addition of coconut coir, which can increase the compressive strength of concrete and provide a sound-dampening effect. (Fauzi, 2014) utilized wood dust waste as a substitute for sand, and showed that this material is effective when used in certain proportions.

(Hidayat, 2019) added that Kalimantan ulin wood powder is capable of improving the quality of concrete in terms of both strength and workability. In the context of inorganic waste, (Rulhendri et al., 2013) found that the addition of fibers to concrete not only increases compressive strength but also plays an important role in reducing cracking in concrete structures. Nugraha. MA, (2021) used corn cob ash in the production of lightweight concrete. This material can improve thermal insulation and reduce structural load. Research using Aren Tree Powder (ATP) waste as a substitute for fine aggregate with variations of 0%, 10%, 20%, has not been conducted. The objective of this research is to determine the effect of ATP material substitution on the compressive strength and workability of concrete. This research is also conducted as an effort to help utilize the waste of ATP available in Tulung

Klaten, Central Java. This research is expected to serve as an alternative to environmentally friendly concrete, possessing the required strength and quality for both structural and non-structural concrete, and to be used according to the existing situations and conditions.

2. The Theoretical Basis

Concrete compressive strength is the magnitude of the load per unit area that causes the test specimen to fail when subjected to a certain pressure produced by the concrete compression machine. The concrete compressive strength test aims to determine the compressive strength value of the test specimen. The concrete compressive strength test is conducted after the concrete to be tested has undergone the curing process. Concrete is tested at 28 days using a compression tester machine. From the compression tester machine, the maximum axial load value was obtained. The compressive strength calculation is determined using the Equation 1:

Concrete Compressive Strength (fc') = P_{max}/A (1)

with, fc' = Maximum Compressive Strength (MPa)

P_{Max} = Maximum load (N)

A = Cross-sectional Area (mm²)

B. Research Method

The method used in this research is an experimental method using 15 concrete cylinder test specimens. variation of ATP waste in the substitution of fine aggregate volume by 0%, 10% and 20%. The compressive strength test of the concrete was conducted when the test specimen was 28 days old. The examination of the materials composing the concrete mix is conducted as a standardization in the creation of the mix design. The material inspection conducted includes testing the gradation of fine aggregate particles, testing the specific gravity and absorption of fine and coarse aggregates, testing the silt content of fine aggregates, and testing the abrasion of coarse aggregates.

1. Fine Aggregate

The fine aggregate used in this study comes from Kulon Progo. It has been used as a concrete mix and will be tested for particle size gradation analysis based on the ASTM C136-2012, specific gravity based on the SNI 1969:2008, water absorption based on the SNI 1970:2008, and mud content based on the SNI ASTM C123:2012. Details of the material was shown in Figure 1.

Figure 1. Fine Aggregate

2. Coarse Aggregate

Coarse aggregate serves as the main material that contributes the most strength to the concrete mix. The material used in this study comes from Kulon Progo. It has been used as a concrete mix and tested for specific gravity based on the SNI 1969:2008, water absorption based on the SNI 1970:2008, and abrasion SNI: 2417-2008. Details of the material was shown in Figure 2.

Figure 2. Coarse Aggregate

3. Cement

Cement is used as a binding material that is used together with fine aggregates, coarse aggregates, and water. The cement used is type 1 cement. The details of the cement material was shown in Figure 3.

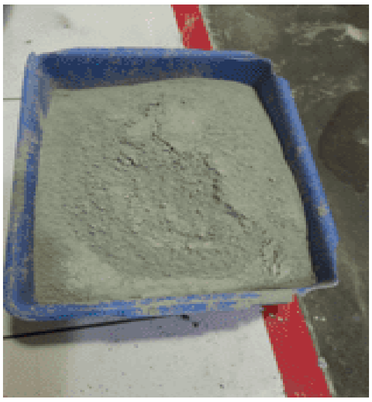

Figure 3. Cement

4. Aren Tree Powder (ATP)

Aren tree powder waste was used as a substitute material for some fine aggregates that function as a filler in the concrete mix. Details of the waste material was shown in Figure 4.

Figure 4. Material of Aren Tree Powder (ATP)

5. Mix Design of Concrete

Mix Design method according to SNI 7656-2012.The mixing calculation uses a target compressive strength of 30 MPa. From the mix design calculations, the results for the material requirements are obtained in Table 1.

Table 1. Mix design concrete per cylinder test specimen

Percent ATP	Cement (kg)	Water l	Course Aggregate (kg)	Fine Aggregate (kg)	ATP (kg)
0%	3,985	1,33	7,854	2,485	-
10%	3,985	1,33	7,854	2,237	0,109
20%	3,985	1,33	7,854	1,988	0,219

6. Slump Test

The slump test is conducted to obtain the workability value of fresh concrete that based on the SNI 1972: 2008. The slump value affects the workability and compressive strength of the concrete. If the slump value is high, the concrete becomes more fluid and easier to work with, but it has a lower compressive strength. If the slump value is small, the concrete becomes denser and more difficult to work with, but its compressive strength will be higher. The planned slump value in the mix design is 75 mm – 100 mm. Details of the slump test was shown in Figure 5.

Figure 5. Concrete slump test

C. Result and Discussion

1. Results of Fine Aggregate Testing

The results of the fine aggregate tests conducted in this study include the examination of particle gradation, specific gravity and water absorption, and the examination of silt content. The results of the fine aggregate examination was shown in Table 2.

Table 2 Results of fine aggregate testing

No	Test	Unit	Value
1	Grading FAM	-	Area 3
2	Mud content	%	1.5
3	Specific gravity (SSD)	-	2.481
4	Water absorption	%	1

Based on the test results in Table 2, the Fine Aggregate Modulus (FAM) of the fine aggregate is in zone 3, indicating that the aggregate gradation is suitable for use in structural concrete mixtures. This aggregate is expected to support the achievement of concrete quality and workability according to technical requirements. The mud content test on sand aims to check whether the sand is clean or dirty. The average mud content obtained was 2.67%. The maximum allowable mud content in sand is 5% (SNI: 04-1989-F), thus it can be concluded that the type of sand used meets the requirements of SNI: 04-1989-F. The specific gravity value (SSD) of fine aggregate is obtained at 2.48, which falls within the normal range for natural fine aggregate according to SNI 1970:2008. The specific gravity value of fine aggregate for concrete mixtures is in the range of 2.4–2.7. Based on the test results, the specific gravity of the fine aggregate is 2.48, which meets the quality standards for use in structural concrete mixtures and fulfills the requirements in technical planning. The ideal specific gravity range for both coarse and fine aggregates is between 2.4–2.7. This range reflects aggregates that have a sufficiently high density and specific gravity to support the overall structural strength of concrete.

2. Results of Course Aggregate Testing

The coarse aggregate testing conducted in this study includes specific gravity and water absorption tests, Los Angeles abrasion test, and unit weight test. The results of the fine aggregate examination was shown in Table 3.

Table 3. Coarse Aggregate Testing

No	Test	Unit	Value
1	Wear inspection	%	28.93
2	weight	kg/m^3	1.5
3	Specific gravity (SSD)	-	2.64

Based on the test results in Table 2, the coarse aggregate wear value of 28.95% indicates that the aggregate has a fairly good abrasion resistance. Based on SNI 2417:2008, coarse aggregate used for highway construction should have a maximum wear value of 40%, depending on the type of work and technical specifications used. With a value of 28.95%, this aggregate meets the requirements for use in concrete work and asphalt pavement, which generally stipulate a maximum wear of 30%. This value indicates that the aggregate has resistance to abrasion and mechanical impact during its service life. The results of the coarse aggregate testing show a specific gravity of 2.64, a value that falls within the ideal range for good construction materials as follow SNI 1969: 2016, which have a specific gravity between 2.5 and 2.7. Based on the SNI 1969: 2016, this aggregate meets the requirements for use in concrete mixtures as well as other construction applications that require high-quality aggregates. The ideal specific gravity range for both coarse and fine aggregates is between 2.5–2.7. This range reflects aggregates that have a sufficiently high density and specific gravity to support the overall structural strength of concrete. Aggregates with a specific gravity of 2.5–2.7 generally have good compatibility with binders such as Portland cement. This is important because a significant difference in specific gravity between the aggregate and cement paste can cause segregation, bleeding, or weak interphase bonding. Aggregates that are too light tend to float in the mix, while aggregates that are too heavy can cause material separation and reduce homogeneity.

3. Results of Specific Gravity of Aren Tree Powder (ATP)

The test result of a specific gravity was 0.9 g/cm^3, it is indicates that Aren Tree Powder (ATP) falls into the category of materials with medium to high density. This specific gravity is relatively higher compared to several types of softwood powders, which generally range from 0.4–0.7 g/cm^3. This high density indicates that ATP has good mechanical strength potential when used as a raw material for composite products, such as particle boards, biomass briquettes, or filler materials in construction. The high specific gravity also affects the dimensional stability and durability of the final product, especially in applications that require resistance to mechanical loads.

4. Results of Slump Test

The slump test was conducted once for each variation of sago starch waste in the concrete mix. The results of the slump test can be seen in Table 4, which show that the more ATP content in the concrete mix, the lower the slump value of the mix. This is caused by the property of ATP waste that easily absorbs water, making the concrete mixture more brittle and resulting in a lower workability or making it more difficult to work with.

Table 4. Slump Test Value

No	Persen ATP (%)	Slump (cm)
1	0%	10
2	10%	9,3
3	20%	8

Based on the test results in Table 4, the slump values obtained range from 8.0 cm to 10.0 cm. Based on th SNI 7656: 2012, the slump value indicates that the fresh concrete has a moderate level of workability. With moderate workability, this concrete is suitable for casting ordinary structural elements such as beams, columns, and floor slabs, where ease of pouring and compaction is required, while still maintaining good structural strength.

5. Results of Compressive Strength

Concrete compressive strength testing using a universal compression tester machine was conducted on concrete aged 28 days with test specimens in the form of cylinders measuring approximately 15 cm in diameter and 30 cm in height. The results of the 28-day concrete compressive strength test as shown in Table 5.

Table 5. Compressive Strength Concrete

Percent of ATP	Compressive Strength (MPa)	Average (MPa)
0% ATP-1	24,07	
0% ATP-1	25,76	24,01
0% ATP-1	22,02	
10%ATP-1	25,74	
10% ATP-2	26,38	23,97
10% ATP-3	19,81	
20% ATP-1	22,63	
20% ATP-2	24,89	22,91
20% ATP-3	21,21	

Based on the test results in Table 5, the test results show that the compressive strength of the concrete ranges from 22.91 MPa to 24.01 MPa, with an average compressive strength of 23.63 MPa. This value indicates that the concrete falls into the medium quality category, typically used for low to medium-rise building structures, such as columns, beams, and floor slabs. The concrete quality in this range is commonly specified in structural planning, referring to concrete quality f'c = 20–25 MPa. It can be concluded that the use of ATP material at 20% as a substitute for fine aggregate in concrete produces medium-quality concrete that can be used for structural buildings of multi-story buildings, simple buildings, and shallow foundations.

D. Conclusion

Based on the results of the material and compressive strength testing, it can be concluded that: 1) Fine aggregate and coarse aggregate used meet the material criteria that can be used to make concrete mixtures. 2) ATP waste as a substitute for fine aggregate in concrete material can reduce environmental pollution and serve as an alternative to eco-friendly concrete. 3) ATP waste in concrete mixtures reduces the slump value of fresh concrete, thereby decreasing the workability of the concrete. 4) ATP waste in the concrete mix reduces the compressive strength. For the 10% and 20% ATP waste mixtures, there was a decrease of 0.16% and 4.52% compared to normal concrete. The addition of 10% and 20% ATP waste can be used in structural elements of buildings that fall under medium-strength concrete.

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