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Analysis of the effect of the combination of fly ash, plastic waste, and natural stone waste as a substitute additive for making environmentally friendly concrete on the compressive strength of concrete

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ABSTRACT

The ongoing development of infrastructure technology, particularly in constructing buildings, plays a vital role in national progress. Concrete, a widely used construction material, is crucial for civil works and overall development.In this study using an innovation in concrete mixes by utilizing waste that can damage the environment, such as fly ash as a cement additive, plastic waste as a coarse aggregate additive, natural stone waste as a fine aggregate additive. The primary objectives of this study are to assess the impact of waste addition on concrete production, establish optimal and minimal waste variations affecting concrete compressive strength, and evaluate the performance of waste mixtures in comparison to normal concrete. Various waste percentages were integrated into the concrete mix: fly ash (5%, 10%, 15%, 20%, 25%, 30%), plastic waste (2%), and natural stone waste (40%). Test specimens were cube-shaped, measuring 15x15x15 cm. Concrete curing took place over 7, 14, 21, and 28 days, with subsequent compressive strength testing. . From the analysis results show a significant correlation between the proportion of added ingredients in the concrete mixture tends to increase the compressive strength of concrete at a certain limit, obtained the optimum value at 20% variation with a compressive strength of 328.0036 kg/cm2 and the minimum value at 30% variation with a compressive strength of 276.3318 kg/cm2 at the age of 28 days, the use of waste in concrete mixes is very good and can be an alternative in making concrete with environmentally friendly properties.

INTRODUCTION

The development of infrastructure technology such as buildings, bridges, and so on which continues to grow from year to year plays an important role in national development. One of the widely used construction materials is concrete, concrete is one of the construction materials of civil works that plays a very important role in development. The specialty of concrete is that it is easily formed in accordance with the wishes, has a high compressive strength value, has long-term durability with simple maintenance and is relatively cheap because it uses basic ingredients from local materials (Hassan et al., 2023; Patnaikuni & Palli, 2021; Scrivener et al., 2022; Uddin et al., 2021; Vafaeva & Zegait, 2024). Another thing that underlies the selection and use of concrete as a construction material is its effectiveness and efficiency level. In general, concrete fillers are made from materials that are easy to obtain, easy to process (workability), and have durability and strength that are needed in the construction of a construction.

In this study, using coal combustion ash in the form of Fly Ash as a cement additive, Plastic Waste derived from household plastic waste as a coarse aggregate additive, and Natural Stone Waste derived from solid powder from cutting natural stone as an aggregate additive to produce more environmentally friendly concrete. Green concrete is concrete composed of materials that do not damage the environment (Al-Hamrani et al., 2021; Chen et al., 2022; Louzi et al., 2022; Mohamed et al., 2023; Shehata et al., 2022). One of them is the replacement of concrete constituent aggregates with materials that do not damage the environment.

Coal fly ash is a material that has a fine grayish grain size and is obtained from the combustion of coal (Grabias-Blicharz & Franus, 2023; Hitesh et al., 2021; Kelechi et al., 2022; Mathapati et al., 2021; Strzałkowska, 2021). In burning coal in a PLTU, there is solid waste, namely fly ash and bottom ash. The ash particles carried by the flue gas are called fly ash, while the ash left behind and removed from the bottom of the furnace is called bottom ash. In Indonesia, the production of bottom ash and fly ash waste from year to year increases in proportion to the consumption of coal use as raw material in the PLTU industry (Budiarto et al., 2024; Febriyani & Hartiwiningsih, 2022; Pandiangan & Audah, 2022; Prayoga & Afla, 2023; Putri et al., 2023). Concrete using 10% fly ash has a higher compressive strength of 4.6% against normal concrete at the age of 28 days and is also included in the K225 concrete category (Roesdiana, 2015)

Plastic waste is something that endangers the environment because it cannot be decomposed if it is dumped on the ground. In addition to polluting the environment will be able to cause flooding if disposed of in the river. Because plastic is not from biological compounds, it has properties difficult to degrade (non-biodegradable). The utilization of Waste Plastic formed to resemble coarse aggregate in concrete is one interesting approach in an effort to improve the sustainability of construction and reduce the environmental impact of Waste Plastic.

Andesite Waste Natural Stone is one of the black volcanic igneous rocks, containing 52-63% silica (SiO_2), with a fairly high level of hardness. Sand that has a high silica (SiO_2) content tends to provide better performance in concrete, as silica contributes to the binding of concrete ingredients and increases concrete strength. Andesite has more in common with granite than with limestone or marble, as it has a higher silica (SiO_2) and alumina (Al_2O_3) content compared to calcium oxide (CaO).

This research is focused on testing the concrete substitution of Fly Ash as a cement additive, Plastic Waste as a coarse aggregate additive, Natural Stone Waste as a fine aggregate additive to the compressive strength of concrete which refers to SNI 03-1974 -1990 (Badan Standardisasi Nasional, n.d.) How to test the compressive strength of concrete cubes. (Nasional, n.d.). Based on the problem formulation above, the objectives of this research are as follows are as follows:

1. To determine the effect of the addition of Fly Ash, Plastic Waste, and Natural Stone Waste as additives to the manufacture of concrete.
2. To determine the optimum level of variation between Fly Ash, Plastic Waste, and Natural Stone Waste mixtures.
3. To determine whether or not the mixture of Fly Ash, Plastic Waste, and Natural Stone Waste is better than normal concrete.

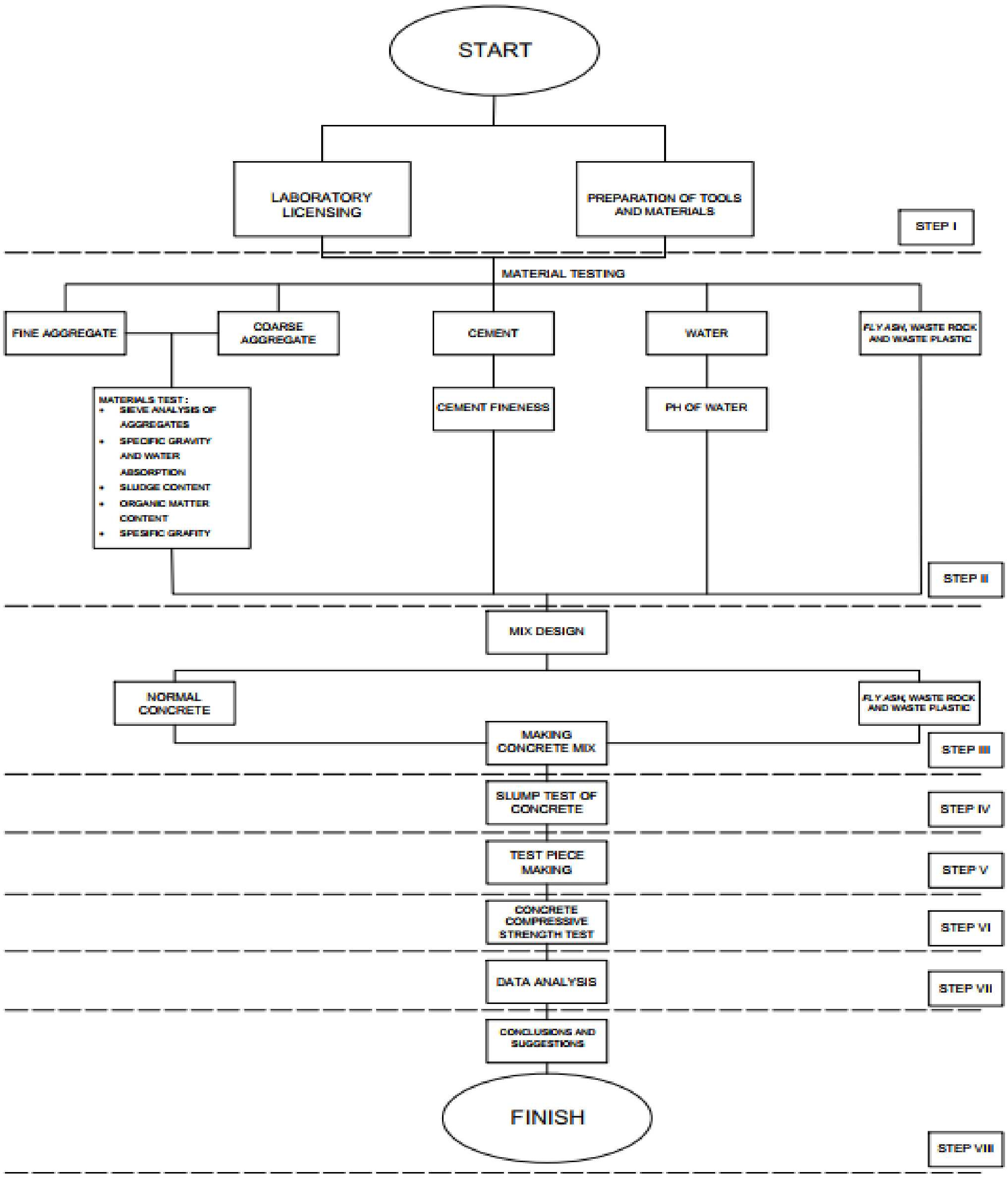
METHOD

Research Location

The research was conducted at the Civil Engineering Laboratory of Swadaya Gunung Jati University, West Java Province.

Figure 1. Research location

The following is the flow of making environmentally friendly concrete. Along with a flow chart of normal concrete making.



Type of Research

The types of research conducted are:

1) Experimental: The type of research in this study is experimental. Where experimentation itself is a method where we look for influences or differences when we regulate a variable.(Arifin, Z., Al-Hikmah, S., Agung, B., & Kanan, 2020).
2) Quantitative: The data collected are numbers that can be measured quantitatively, such as the measurement of concrete compressive strength.

Material Testing Methods

In this test consists of testing fine aggregates referring to SNI 03-6820-2002 and SK SNI S-04-1989-F (Badan Standardisasi Nasional, 2002), testing coarse aggregates referring to SNI 03-6820-2002 and SK SNI S-04-1989-F (Badan Standardisasi Nasional, 1989), testing the fineness of cement and fly ash referring to SNI 03-2530-1991 (Nasional, 1991), water testing refers to (ASTM, 2002), testing the manufacture and treatment of concrete refers to SNI 2493: 2011 (Nasional, 2011), concrete slump test refers to SNI 1972: 2008 (Nasional, 2008), concrete content weight test, concrete compressive strength test refers to SNI 03-1974-1990 (Nasional, n.d.).

Mix Design Calculation Method

The concrete mix design is carried out to determine the proportion of each mixture of concrete constituent materials. there is this research made test objects as many as 7 variations of the mixture where the mixture refers to the normal concrete mix design.

The proportion of concrete mixture in this study uses K-300 concrete quality with a cement water factor of 0.52% . (Badan Standardisasi Nasional, 2008) This value becomes a constant value because it wants to know the changes in concrete characteristics only from the influence of cement substitution, fine aggregate (sand), coarse aggregate (split).

RESULTS AND DISCUSSION

Fine Aggregate Testing

Fine aggregate testing is carried out in accordance to the requirements of SNI 03-6820-2002 and SK SNI S-04-1989-F (Badan Standardisasi Nasional, 2002) (Badan Standardisasi Nasional, 1989), the results obtained from testing fine aggregate for river sand and natural stone waste can be seen in table 1.

Table 1. Recapitulation of Fine Aggregate Testing

No	Description	Test Results			Information	
		Sand	Natural Stone Waste	Testing Standards	Sand	Natural Stone Waste
1	Grading Zone	I	I	-	-	-
2	Finnes Modulus	2,94	2,97	SNI 03-6825-2002.	Qualify	Qualify
3	Bulk Spesific Gravity	2,479	2,411		Qualify	Qualify
4	Bulk Spesific Gravity SSD	2,546	2,53	SNI 1969:2008	Qualify	Qualify
5	Absorption	0,027	0,052			
6	Mud and Mud Rate	2,50%	4,53%	SNI 03-4142-1996	Qualify	Qualify
7	Organic Substances Rate	No 1	No 1	SNI 03-2816-1992	Qualify	Qualify

From the results of the fine aggregate tests that have been carried out, which consist of testing Grading Zone, Finnes Modulus, Bulk Specific, Absorption, Mud and Clay Content, and Organic Material Content have met the Testing Standards.

Coarse Aggregate Testing

Testing of coarse aggregate includes testing of sieve analysis, specific gravity, and water absorption Testing of coarse aggregate is carried out in accordance to the requirements of SNI 03-6820-2002 and SK SNI S-04-1989-F (Badan Standardisasi Nasional, 2002) (Badan Standardisasi Nasional, 1989), , the results obtained from testing coarse aggregate for split and plastic waste can be seen in table 2

Table 2. Recapitulation of Coarse Aggregate Testing

No	Description	Test Results			Information	
		Split	Plastic Waste	Testing Standards	Split	Plastic Waste
1	Grading Zone	III	III	-	-	
2	Finnes Modulus	6,04	4,18	SNI 03-1968-1990	Qualify	Not Qualify
3	Bulk Spesific Gravity	2,725	2,662		Qualify	Qualify
4	Bulk Spesific Gravity SSD	2,699	2,575	SNI 1969:2008	Qualify	Qualify
5	Absorption	0,025	0,039		-	-

From the results of the coarse aggregate testing that has been carried out consisting of testing Grading Zone, Finnes Modulus, Bulk Specific, Absorption, Sludge and Clay Content, and Organic Material Content have met the Test Standards.

Fineness Testing of Cement and Fly Ash

Fineness testing of cement and fly ash referring to ASTM C184-66 can be declared to meet the fineness requirements if held in filter No.100 at a maximum of 0% and held in filter No.200 at a maximum of 22% can be seen in table 3 (ASTM INTERNASIONAL, 2002).

Table 3. Cement and Fly Ash Fineness Testing

No.	Description	Test Results		Requirement	
		Value	Standar Pengujian	Value	Standar Pengujian
1.	Specific Gravity (%)	3,15	-	3,15	-
2.	Fineness of Cement:		ASTM C184-66		ASTM C184-66
	F1	0%		0	
	F2	21%		22	
2.	Subtleties of Fly Ash:		ASTM C184-66		ASTM C184-66
	F3	0%		0	
	F4	19%		22	

From the results of the analysis of the fineness testing of cement and fly ash, it passed the No.100 and No.200 filters and has met ASTM C184 – 66 standards.

Water Ph Testing

Based on the results of the examination of water used for concrete mixtures, it meets the requirements as described in Table 4.

Table 4. Water Testing Recapitulation

No.	Description	Test Results		Information
		Value	Testing Standards	
1.	Water state	Clear	SNI 7974:2013	Qualify
2.	Water taste	Neutral		Qualify
3.	Construction Water	No odor		Qualify
4.	Water PH	8,000	SNI 7974:2013	Qualify

The water pH test is carried out by manual method using litmus paper. After the test was carried out and the color was matched with litmus paper, the pH value of water was obtained at 8 which means that the water is normal or alkaline.

Manufacture and Treatment of Test Objects

Based on the test results, the manufacture and treatment of concrete must be correct and meet the standards of SNI 2493: 2011. Concrete mixing must be done well to avoid air bubbles that can weaken the concrete structure. and in this practicum we use the concrete curing treatment method, namely soaking concrete in water for 7 days, 14 days, 21 days and 28 days until the concrete compressive strength test is carried out.

Concrete Slump Test

Slump test refers to SNI 1972: 2008, there are 7 slump tests consisting of variations of 0%, 5%, 10%, 15%, 20%, 25%, and 30%, It can be seen in table 5.

Table 5. Recapitulation of Concrete Slump Test Results

No	Description	Test Results		Requirement	Information
		Value (mm)	Testing Standards	Value	
1	*Slump Test* Concrete Normal	75	SNI 1972:2008 (How to Test Slump Concrete).	Medium Workability	Qualify
2	*Slump Test* Concrete Variations 5%	110		High workability	Qualify
3	*Slump Test* Concrete Variations 10%	120		High workability	Qualify
4	*Slump Test* Concrete Variations 15%	74		Medium Workability	Qualify
5	*Slump Test* Concrete Variations 20%	85		Medium Workability	Qualify
6	*Slump Test* Concrete Variations 25%	110		High workability	Qualify
7	*Slump Test* Concrete Variations 30%	72		Medium Workability	Qualify

Based on the test results, the slump value on normal concrete is 7.5 cm or 75, on the 5% variation concrete slump of 11 cm or 110 mm, on the 10% variation concrete slump of 12 cm or 120 mm, on the 15% variation concrete slump of 7.4 cm or 74 mm, on the 20% variation concrete slump of 8.5 cm or 85 mm, In a 25% variation concrete slump of 11 cm or 110 mm, in a 30% variation concrete slump of 7.2 cm or 72 mm, the condition of the concrete at the time of the slump test is true where the shape of the slump produced is correct and ideal. (National, 2008)

Concrete Content Weight Test

Testing the weight of concrete contents was carried out at the age of 7, 14, 21, 28 days in each variation, for more details can be seen in table 6

Table 6. Recapitulation of Concrete Fill Weight Testing

No	Mixed Variations	Contents weight (Kg)			
		7 Day	14 Day	21 Day	28 Day
1	Normal Concrete	7,8	7,6	8	8
2	Variations Concrete 5 %	7,3	7,5	7,4	7,5
3	Variations Concrete 10 %	7,2	7,5	7,5	7,2
4	Variations Concrete 15 %	7,5	7,3	7,4	7,5
5	Variations Concrete 20 %	7,3	7,4	7,3	7,7
6	Variations Concrete 25 %	7,1	7,5	7,4	7,4
7	Variations Concrete 30 %	7,1	7,3	7,4	7,5

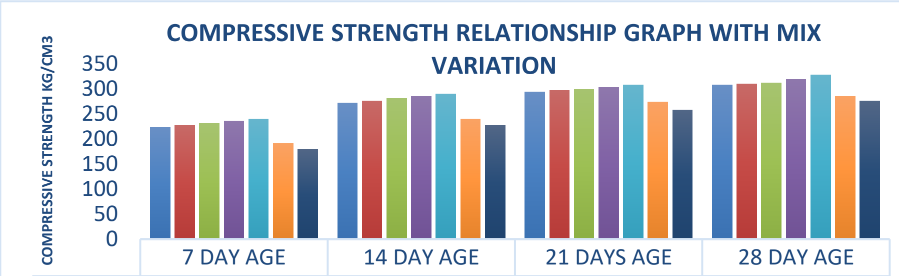
The average fill weight value in normal concrete was 7.8 kg/cm3 at the age of 7 days; 7.6 kg/cm3 at 14 days of age; 8 kg/cm3 at 21 days of age; and 8 kg/cm3 at the age of 28 days, and in concrete the average variation of 5% - 30% was obtained a value of 7.3 kg/cm3 at the age of 7 days; 7.4 kg/cm3 at 14 days of age; 7.4 kg/cm3 at 21 days of age; 7.5 kg/cm3 at the age of 28 days, this value is an initial reference for comparing the weight of the content between normal concrete and average variation concrete.

Compressive Strength of Concrete

Table 7. Recapitulation Compressive Strength of Concrete

No	Age	Test Item Code	Concrete Compressive Strength Kg/Cm2	Increase %
1	7 Day	BN	222,4134	0
		BV 5%	226,9066	2,02
		BV10%	231,3998	4,04
		BV15%	235,893	6,06
		BV20%	240,3862	8,08
		BV25%	190,961	-14,14
		BV30%	179,728	-19,19
2	14 Day	BN	271,8386	0
		BV 5%	276,3318	1,65
		BV10%	280,825	3,31
		BV15%	285,3182	4,96
		BV20%	289,8114	6,61
		BV25%	240,3862	-11,57
		BV30%	226,9066	-16,53
3	21 Day	BN	294,3046	0
		BV 5%	296,5512	0,76
		BV10%	298,7978	1,53
		BV15%	303,291	3,05
		BV20%	307,7842	4,58
		BV25%	274,0852	-6,87
		BV30%	258,359	-12,21
4	28 Day	BN	307,7842	0
		BV 5%	310,0308	0,73
		BV10%	312,2774	1,46
		BV15%	319,0172	3,65

BV20%	328,0036	6,57
BV25%	285,3182	-7,30
BV30%	276,3318	-10,22



	7 DAY AGE	14 DAY AGE	21 DAYS AGE	28 DAY AGE
BN	222.4134	271.8386	294.3046	307.7842
BV 5%	226.9066	276.3318	296.5512	310.0308
BV 10%	231.3998	280.825	298.7978	312.2774
BV 15%	235.893	285.3182	303.291	319.0172
BV 20%	240.3862	289.8114	307.7842	328.0036
BV 25%	190.961	240.3862	274.0852	285.3182
BV 30%	179.728	226.9066	258.359	276.3318

Figure 2. Compressive Strength Relationship Graph With Mix Variation

Higher extent of Fly Fiery debris in concrete blend tends to extend the compressive quality of concrete inside a certain constrain. In any case, the expansion of Plastic Squander and Characteristic Stone Squander can decrease the compressive quality of concrete essentially.

The comes about appear that the utilize of a combination of Fly Cinder, Plastic Squander, and Characteristic Stone Squander in concrete can altogether increase the compressive quality of concrete at varieties of 5% to 20%, whereas at varieties of 25% to 30% there's a diminish within the compressive quality of concrete. Based on these tests, the most noteworthy concrete compressive quality occurred at the age of 28 days within the 20% variety with a concrete compressive quality of 328.0036 Kg/cm2, which expanded by 6.57% from typical concrete with a value of 307.7842 Kg/cm2, whereas the least compressive quality happened within the 30% variety with a concrete compressive quality of 276.3318 Kg/cm2, which diminished by -10.22% from typical concrete with a compressive quality esteem of 307.7842 Kg/cm2 at the age of 28 days.

CONCLUSION

This study examines the effect of a combination of Fly Ash as a cement additive, Plastic Waste as a coarse aggregate additive, and Natural Stone Waste as a fine aggregate additive on the compressive strength of concrete. Based on the results of experiments and analysis conducted, the main findings show that there is a significant correlation between the proportion of additives in the concrete mixture tends to increase the compressive strength of concrete at a certain limit, the optimum value is obtained at 20% variation with a compressive strength of 328.0036 kg/cm2 and the minimum value at 30% variation with a compressive strength of 276.3318 kg/cm2 at the age of 28 days, The use of waste in concrete mixes is very good and can be an alternative in making concrete with environmentally friendly properties. It is suggested that further research on the interaction between these additives and their long-term impact on the structural and environmental properties of concrete is recommended. And there is a need to experiment with other waste additives that can increase the compressive strength of concrete.

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