The influence of cement substitution with rice husk ash on high-strength concrete

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Abstract. High-strength concrete is a crucial construction material in modern infrastructure development. It involves replacing some conventional raw materials with environmentally friendly alternatives to enhance concrete quality. Rice husk ash (RHA) is an agricultural waste that contains natural pozzolanic materials capable of improving the mechanical properties and strength of concrete. The use of rice husk ash (RHA) in high-strength concrete mixtures has the potential to reduce cement consumption and enhance crack resistance. The aim of this study is to investigate the impact of substituting cement with rice husk ash (RHA) and adding superplasticizer on the compressive strength of concrete. The targeted concrete strength is 45 MPa with variations of rice husk ash substitution at 5%, 10%, and 15% by weight of cement. This research obtained the compressive strength of concrete at 7 days with variations of 5% at 30.59 MPa, 10% at 25.20 MPa, and 15% at 20.77 MPa. Subsequently, at 14 days, the compressive strength increased with variations of 5% at 37.48 MPa, 10% at 27.56 MPa, and 15% at 22.23 MPa. The compressive strength continued to rise at 28 days, with variations of 5% at 44.26 MPa, 10% at 29.36 MPa, and 15% at 29.19 MPa.

1 Introduction

The increase in vehicle traffic and heavy loads on roads has driven the demand for stronger road pavement. With advancements in science and technology in the field of construction, humans are expected to be more creative and innovative, especially in concrete technology. Considering its function, concrete is a widely used structural material today. Concrete is a mixture of Portland cement or other hydraulic cement, fine aggregate, coarse aggregate, and water, with or without additional materials forming a solid mass [1].

Concrete is a building material that supports efforts for sustainable and environmentally friendly development when we can utilize materials from other industrial waste on a large scale [2]. Materials such as fly ash, silica fumes, and rice husk ash are industrial waste materials that can enhance the performance of concrete, increase its strength, and reduce the cement content in concrete, aligning with the concept of sustainable development [3].

The magnitude of rice consumption as a staple food and the increasing national rice production can provide a macro estimate of the quantity of such materials from year to year. Based on data from the Central Statistics Agency [4], rice production in West Sumatra in 2022 reached 1.3 million tons, meaning there is a significant amount of residual material from rice production.

Utilizing waste is essentially the most effective way to reduce the increasing waste levels. One of the uses of rice husk ash waste is as a partial replacement for cement. Rice husk ash contains 90% amorphous silica (SiO2), 5% carbon, and 2% K2O, making it suitable as a pozzolan in the construction industry [5].

Rice husk ash contains silica that can react with the by-products of cement and water reactions, namely calcium hydroxide, which will transform into calcium silicate hydrate. This can make concrete denser, thereby increasing its compressive strength. The results of compressive strength development indicate that rice husk ash has the potential to be used as a partial replacement for cement because it can accelerate the development of concrete compressive strength and save on cement usage. Additionally, the use of rice husk ash can reduce water absorption by concrete by up to 50% compared to regular concrete, potentially leading to better durability [3].

In this research, the author will attempt to use rice husk ash in high-quality concrete mixtures with varying percentages of 5%, 10%, and 15%, to determine the effective percentage of rice husk ash usage in high-quality concrete mixes in order to enhance compressive strength values in concrete. It is hoped that the use of rice husk ash waste will not only provide a solution for its disposal but also improve the quality of concrete in terms of compressive strength values.

2 Materials and method

2.1 Material used

Materials used in concrete mix design include water, cement, fine aggregate (sand), coarse aggregate (gravel),

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along with rice husk ash and superplasticizer. Material testing is intended to assess the characteristicsof the raw materials used in concrete production to determine whether they meet the requirements or not. Subsequently, this data is used in the calculation of concrete mix design based on ACI 211.4R-93 [6], with variations in the replacement of cement with rice husk ash at 5%, 10%, and 15% of the cement weight.

2.1.1 Fine aggregate

In the testing of fine aggregate, several parameters are examined, including specific gravity and absorption, aggregate bulk density, moisture content, and clay content. Careful attention and precision are required when conducting these tests because fine aggregate has a finer and smaller gradation compared to coarse aggregate, which increases the possibility of material wastage. These tests are conducted following the American Standard Testing Material (ASTM).

Table 1. Fine aggregate properties.

Test Type	Test Result	Standard Value
Apparent specific gravity	2.78	≥ 2.48
SSD specific gravity	2.66	≥ 2.48
Dry specific gravity	2.60	≥ 2.48
Absorption (%)	2.57	≥ 1.0
Loose bulk weight (kg/lt)	1.33	≥ 1.20
Solid weight(kg/lt)	1.56	≥ 1.20
Water content (%)	1.74	≤ 2.50
Sludge level (%)	2.26	≤ 3.00

2.1.2 Coarse aggregate

In the testing of coarse aggregate, several parameters are examined, including specific gravity and absorption, aggregate bulk density, moisture content, clay content, and aggregate abrasion. In the testing of coarse aggregate, the specific gravity of the aggregate affects the pore content, which is directly related to the water and cement requirements in concrete mixtures. Testing the properties of coarse aggregate is carried out following the American Standard Testing Material (ASTM).

Table 2. Coarse aggregate properties.

Test Type	Test Result	Standard Value
Apparent specific gravity	2.68	≥ 2.1
SSD specific gravity	2.61	≥ 2.1
Dry specific gravity	2.57	≥ 2.1
Absorption (%)	1.62	≤ 4.0
Loose bulk weight (kg/lt)	1.49	≥ 1.2
Solid weight(kg/lt)	1.65	≥ 1.2
Water content (%)	1.37	≤ 1.43
Sludge level (%)	0.93	≤ 1.0
Agregat wear (%)	34.4	≤ 50%

2.1.3 Rice Husk Ash (RHA)

Rice husk ash is prepared as a pozzolan through a specialized process to ensure that the final product meets technical requirements in terms of physical and chemical properties. It contains amorphous silica with a small amount of unburned carbon. The results indicate that this pozzolan can be produced with various levels of pozzolanic activity depending on the degree of grinding and the burning temperature [7].

Table 3. Chemical properties of RHA [8].

Chemical	%
Silicon Dioxide (SiO_3)	86.90 – 97.30
Pottasium Oxide (K_2O)	0.58 – 2.50
Sodium Oxide (Na_2O)	0.00 – 1.75
Calcium Oxide (CaO)	0.20 – 2.84
Magnesium Oxide (MgO)	0.12 – 1.96
Iron Oxide (Fe_2O_3)	0.00 – 0.54
Phosphorus Pentoxide (P_2O_5)	0.20 – 2.84
Sulphates (SO_3)	0.10 – 1.13
Chloros (Cl)	0.0 – 0.42

2.1.4 Concrete mix design

The concrete mix design is carried out based on the standard guidelines specified by ACI 211.4R-93. The quantity of material requirements per 1 m3 can be seen in Table 4.

Table 4. Mix proportions design.

Type of Materials	Unit	RHA 5%	RHA 10%	RHA 15%
Cement	Kg/m^3	411,93	390,25	368,57
Fine Aggregate	Kg/m^3	478,37	441,83	405,28
Coarse Aggregate (1-2)	Kg/m^3	1201,96	1201,96	1201,96
Water	Kg/m^3	180,74	179,86	178,99
Sika Viscocrete 1003	Kg/m^3	8,67	8,67	8,67
Rice Husk Ash	Kg/m^3	21,68	43,36	65,04

2.2 Experimental methods

The method applied in this research is an experimental method, which involves conducting direct tests in the materials Laboratory of the Civil Engineering Department, Polytechnic State University of Padang. The tests conducted in this research include testing the properties of materials and testing the compressive strength of concrete. After concrete specimens are cast in cylindrical steel molds with dimensions of 300 mm in height and 150 mm in diameter, they are released from the molds after 24 hours and immediately cured by immersion in fresh water for durations of 7 days, 14 days, and 28 days.

3 Research result

The results of compressive strength testing of concrete with rice husk ash substitution and the addition of superplasticizer can be seen in Table 5.

Table 5. Compressive strength of concrete at different age.

Term	fc' (MPa)					
	7 days		14 days		28 days	
RHA-5%	30,47	30,59	39,69	37,48	46,08	44,26
	30,95		36,82		46,05	
	30,37		35,93		40,64	
RHA-10%	29,93	25,20	22,61	27,56	33,15	29,36
	22,36		34,35		25,89	
	23,32		25,74		29,03	
RHA-15%	15,84	20,77	29,17	22,23	37,27	29,19
	16,09		17,68		25,29	
	30,36		19,85		25,02	

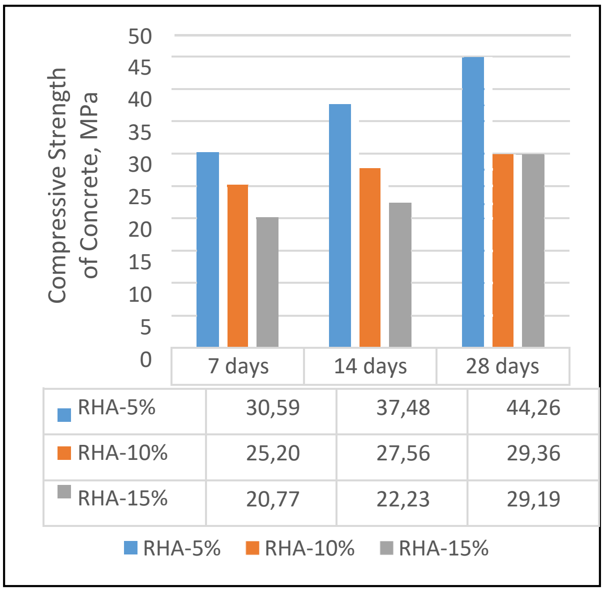

Fig. 1. Compressive strength of concrete.

From the graph, it can be observed that the optimum rice husk ash substitution level is 5%, with a compressive strength value of 44.26 MPa at 28 days of concrete age. However, at a rice husk ash substitution of 10%, there is a decrease in the compressive strength of concrete at 28 days, which is 29.36 MPa compared to the 5% substitution level. This is because increasing the substitution of rice husk ash leads to a reduction in the amount of cement used since rice husk ash has high water-absorbing properties, resulting in reduced performance of the mixture.

4 Conclusion

Based on the research activities conducted, the highest compressive strength value in concrete samples with a 5% variation of rice husk ash as a cement substitution is 44.26 MPa. The planned compressive strength (fc' = 45 MPa) was not achieved. This was due to factors such as a lack of precision or human error and other considerations, including inadequate supervision during material selection, weighing, and implementation. Always compare test results with applicable standards; if the concrete does not meet the established standards, consider necessary improvements or adjustments.

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