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Compressive Strength Study on Reactive Powder Concrete with 30% Quartz Sand and Variations in Fly Ash Composition as Partial Substitution of Cement

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Abstract: The concrete industry is considered environmentally unfriendly and unsustainable due to the significant consumption of natural materials. Currently, the industry predominantly uses Portland cement as its main ingredient, leading to an increase in Portland cement production. However, the use of fly ash can help make the concrete industry more sustainable in the future. Fly ash can be used as a partial replacement for Portland cement in concrete production. This study aims to determine the effect of fly ash variations on the compressive strength of reactive powder concrete. The research method used is experimental. The concrete mix design includes 30% quartz sand and fly ash variations of 0%, 5%, 10%, 15%, 20%, and 25%. The compressive strength test specimens are cylindrical with a diameter of 7.5 cm and a height of 15 cm. The resulting test specimens have a compressive strength of more than 41.4 MPa, thus qualifying as high-strength concrete. The compressive strength test results for fly ash variations of 0%, 5%, 10%, 15%, 20%, and 25% are 62.62 MPa, 66.27 MPa, 75.59 MPa, 68.78 MPa, 66.21 MPa, and 63.70 MPa, respectively.

Keywords: Concrete, High-Strength Concrete, Fly Ash, Compressive Strength, Quartz Sand

Introduction

The rapid development of science and knowledge greatly affects all aspects of humanity. One aspect that has progressed is the construction field (Fedosov, 2024; Liu, 2024). Where we can feel this with the many developments that occur in Indonesia. This development aims to improve the economic level of the community, with the development of connectivity infrastructure as a link between regions and regions (Redondo-Pérez, 2024; Shen, 2024). Equality can occur due to the development of sustainable connectivity infrastructure as a driver of the community's economy.

The high demand for concrete in construction development in Indonesia encourages the development of concrete technology (X. Li, 2024; Ye, 2024). The goal is to improve the performance and durability of concrete in order to meet the need for concrete construction materials with high compressive strength (Geng, 2024; W. Li, 2024). Concrete technology innovations, such as Reactive Powder Concrete (RPC), are one of the efforts to meet these needs (Nie, 2024; Zhang, 2024). RPC is an ultra-strong concrete made by replacing ordinary aggregates from normal concrete with nanometer-sized particles such as cement, natural sand, quartz sand, water, superplasticizer and steel fibers (optional) so that unlike in the manufacture of ordinary concrete RPC not only has high strength but also has high ductility (Alabduljabbar, 2023; Fatriliani, 2024). The compressive strength of this concrete ranges from 200 Mpa to 800 Mpa.

The use of Reactive Powder Concrate (RPC) has been applied to major projects in Dubai, the United States, Taiwan, and countries in Europe (Arora, 2023; Bayrak, 2023). The use of RPC has benefits, such as reducing column dimensions and fire damage (Ge, 2023; Shantanu, 2023). However, the significant increase in the compressive strength of the concrete can cause brittleness in the concrete (Magureanu at al 2012). This brittleness needs to be avoided to maintain occupant safety in case of structural failure (Guan, 2023; Khunt, 2023). One approach to reduce the brittleness of structures is to use different types of fibers that have flexible characteristics and are able to indirectly increase the compressive strength of concrete, according to the type and properties of the fiber. In our research on RPC, we used steel fibers that help limit the spread of cracks and increase the strength of concrete. These fibers exhibit strain hardening or deflection properties in the presence of micro-cracks, and various relevant studies are actively being conducted for further development (Wille and Naaman, 2013).

The study conducted by Fitriana (2023) focused on Reactive Powder Concrate (RPC) using 15% silica fume and fly ash variations of 0%; 2.5%; 5%; 7.5%; 10%; and 12.5% of the total cement mass and using a quartz sand composition of 30% of the total aggregate mass. The results showed that concrete with 0% variation produced the maximum compressive strength value of concrete. This study noted that the maximum compressive strength of concrete achieved was 83.36 MPa, with a modulus of elasticity reaching 37409.48.90 MPa. While research (Mufti and Raudha, 2019) on the average compressive strength of normal mortar (0%) and fly ash mortar with variations in the addition of 10%, 20%, 30%, 40% and 50% are 24.91 MPa, 26.68 MPa, 29.61 MPa, 27.87 MPa, 23.97 MPa and 23.54 MPa respectively. The compressive strength of mortar after adding fly ash at 10% increased by 7.08%, the addition of 20% increased the compressive strength by 18.85%, the addition of 30% increased the compressive strength by 11.85%, then at the addition of 40% and 50% the compressive strength decreased by 3.77% and 5.51% respectively. The addition of quartz sand, and steel fiber and the use of fly ash variations with levels of 0%, 5%, 10%, 15%, 20%, and 25% as a substitute for cement materials are expected to increase the durability of concrete and quality of concrete.

Methodology

The method used in this research is the experiential method which utilizes two variables. The independent variable involves the variation of fly ash composition (0%; 5%; 10%; 15%; 20%; 25% by weight of se-men) while the dependent variable includes the value of compressive strength. The test specimens were in the form of cylinders with a height of 15 cm and a diameter of 7.5 cm as many as 18 pieces with 3 pieces each in each fly ash variation. After 24 hours, the test specimens that have been made are left before disassembling from the mold. The next stage is to aerate the specimens in a humid place for 24 hours. Then, curing or concrete treatment is carried out by soaking the specimens in water for 21 days.

RPC Mix Design

The mix design of 30% quartz sand Reactive Powder Concrete (RPC) with the addition of fly ash variation was made based on Richard & Cheyrezy (1995). The cement water factor (FAS) used was 0.19 and the superlasticizer was 1.90% of the binder weight. Recapitulation of RPC mix design of fly ash variation can be seen in Table 1.

Table 1. Recapitulation of RPC Mix Design

Fly Ash Content	Sementitius		Agregat				
	Fly Ash (Kg/m^2)	Semen (Kg/m^2)	Fine Sand (Kg/m^2)	Quartz Sand (Kg/m^2)	Steel Fiber (Kg/m^2)	Superplasticizer (lt/m^3)	Water (lt/m^3)
0%	0	1.59	1.97	0.88	0.02	0.01	0.30
5%	0.07	1.51	1.97	0.88	0.02	0.01	0.30
10%	0.15	1.43	1.97	0.88	0.02	0.01	0.30
15%	0.23	1.35	1.97	0.88	0.02	0.01	0.30
20%	0.31	1.27	1.97	0.88	0.02	0.01	0.30
25%	0.39	1.19	1.97	0.88	0.02	0.01	0.30

Testing of Concrete Ingredients

Testing of concrete constituent materials is done to determine the standard and quality of concrete constituent materials used. Testing of mud content, fineness modulus, organic matter, specific gravity, absorption for fine aggregates was carried out at the Civil Engineering Materials Laboratory of Sebelas Maret University.

Fresh Concrete Testing

Fresh concrete testing is done to determine the workability of reactive powder concrete. The test carried out is the slump flow test.

Compressive Strength Testing

Concrete compressive strength testing is carried out using a Compression Testing Machine (CTM) tool. Testing was carried out on 28-day-old concrete. The results of the CTM tool will determine the maximum value of concrete when receiving external forces. In testing the compressive strength of concrete, testing is carried out based on SNI 2847-2019. The formula used in calculating the compressive strength of concrete can be seen in Equation 1:

f^' c=P/A ....[1]

With:
f'c = compressive stress (MPa)
P = compression force (N)
A = cross-sectional area (〖mm〗^2)

Result and Discussion

Testing Results of Reactive Powder Concrete Ingredients

The results of the fine aggregate test consisting of specific gravity, silt content, organic matter content, and fineness modulus can be seen in Table 2.

Table 2. Testing Results of Natural Sand and Quartz Sand

Type of Testing	Fine Sand	Quartz Sand	Standard	Description
Absorbsion	3.92%	2.06%		
Apparent Spesific Grafity	2.85	2.69		
Bulk Spesific Gravity	2.56	2.55		
Bulk Spesific Gravity SSD	2.66	2.60	2.5 – 2.7 (ASTM C. 128-79)	Qualified

Type of Testing	Fine Sand	Quartz Sand	Standard	Description
Sludge Content	2.10%	1.30%	<5% (PBI 1971,ASTM C.117)	Qualified
Organic Matter Content	Dark Yellow	Light Yellow	Reddish Yellow (PBI 1971, ASTM C.40)	Qualified
Modulus of Fineness	2.53	3.42	1.5 < MH < 3.8 (SII 0052-80)	Qualified

Fresh Concrete Testing Results

The results of the slump flow test on fresh concrete in this study can be seen in Table 3.

Table 3. Slump Flow Test Results RPC

Fly Ash Content	D1(mm)	D2(mm)	Daverage (mm)	T average (detik)
0%	360.00	355.00	362.50	15.00
5%	355.00	350.00	352.50	14.80
10%	350.00	345.00	347.50	14.60
15%	345.00	340.00	342.50	14.30
20%	340.00	335.00	337.50	14.10
25%	335.00	330.00	332.50	13.80

Based on the data in Table 3, the graph of the relationship between the slump flow test results and the variation of fly ash content can be seen in Figure 1.

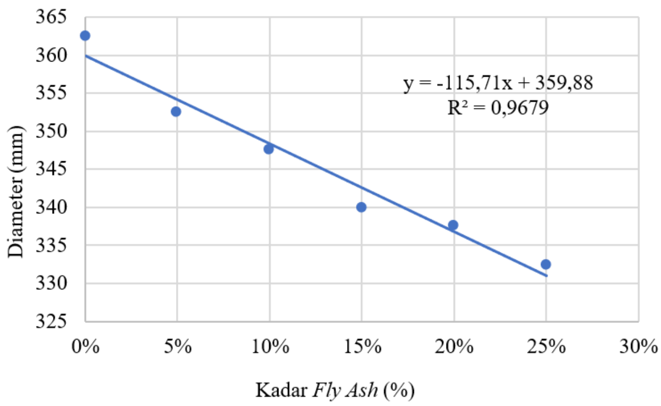

Figure 1. Graph of the relationship between the diameter of the slump flow test and the variation of fly ash content

Based on Figure 1, it can be seen that the additional use of fly ash content variations in the RPC concrete mixture causes the diameter and flow time of the slump flow test results to decrease in each additional fly ash content. This is because fly ash can absorb water better than cement, resulting in decreased workability.

Results of Concrete Compressive Strength Testing

Testing the compressive strength of concrete is carried out using a Compression Testing Machine (CTM) tool in the Materials Laboratory of the Faculty of Engineering UNS on 28-day-old concrete. The results of the concrete compressive strength test can be seen in Table 4.

Table 4. Results of Concrete Compressive Strength Testing

Fly Ash Content	Code	Pmax(kN)	Correlation Factor	F'c (MPa)	F'c average (Mpa)
0%	A	265	1.06	63.41	62.62
	B	260	1.06	62.05	
	C	260	1.06	62.38	
5%	A	275	1.06	65.98	66.27
	B	280	1.06	67.18	
	C	275	1.06	65.63	
10%	A	310	1.06	74.38	75.59
	B	315	1.06	75.78	
	C	315	1.06	76.60	
15%	A	285	1.06	68.75	68.78
	B	290	1.06	69.21	
	C	285	1.06	68.38	
20%	A	275	1.06	65.81	66.21
	B	280	1.06	67.18	
	C	275	1.06	65.63	
25%	A	270	1.06	64.78	63.70
	B	265	1.06	63.08	
	C	265	1.06	63.24	

The difference in compressive strength values is presented in graphical form in Figure 2. While the comparison of concrete with fly ash to concrete without fly ash can be seen in Table 5.

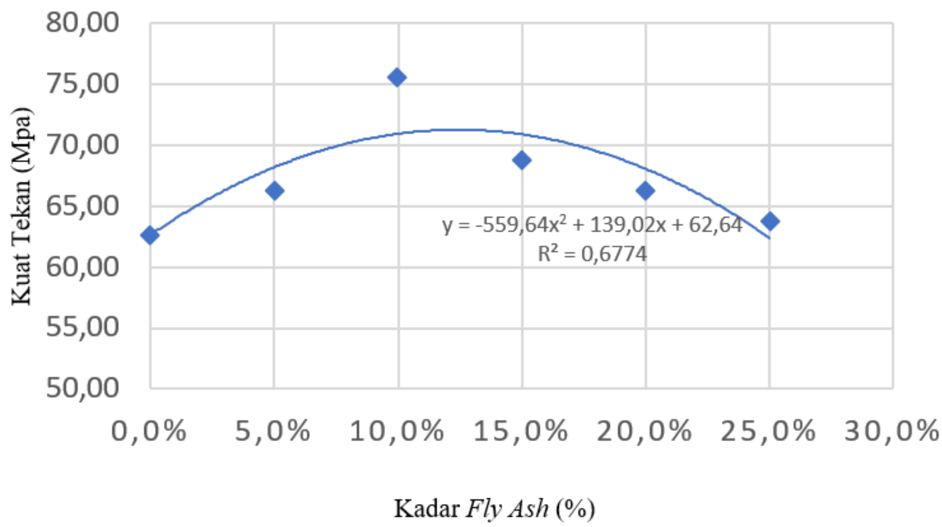

Figure 2. Graph of the Relationship between Compressive Strength and Fly Ash Content

Table 5. Effect of Fly Ash on the compressive strength value of RPC concrete

Fly Ash Content	F'c (MPa)	Percentage change of f'c against FA0% (%)
0%	62.62	0.00
5%	66.27	5.83
10%	75.59	20.71
15%	68.78	9.84
20%	66.21	5.73
25%	63.70	1.73

Based on the results of testing the compressive strength of all RPC concrete test specimens exceeds 41.4 MPa so that it meets the requirements as high quality concrete according to SNI 03-6468 (2000). The maximum 7.5 cm x 15 cm RPC concrete compressive strength value occurs in the 10% fly ash variation of 75.59 MPa. The compressive strength value of RPC concrete with 30% quartz sand, and variations in fly ash content as a partial substitution of cement increased up to 10% fly ash content and decreased at each addition of fly ash content above 10%. The increase in compressive strength of concrete is due to the pozzolanic properties of fly ash. The compressive strength value increases to the maximum at 10% fly ash variation level. This occurs due to the suitability of fly ash content with FAS. While the decrease occurs at fly ash variation levels above 10% due to the increasing amount of fly ash used. This results in the quality of concrete going down due to reduced adhesion.

Conclusion

The reactive powder concrete with 30% quartz sand, and variation of fly ash content in this study is qualified as RPC parameter i.e. compressive strength more than 41.4 MPa. The maximum increase in the compressive strength of concrete occurs at 10% fly ash content and then decreases up to 25% fly ash content. The concrete compressive strength values for cylindrical specimens of 7.5 cm diameter and 15 cm height with fly ash variations of 0%; 5%; 10%; 15%; 20%; and 25% are 62.62 MPa; 66.27 MPa; 75.59 MPa; 68.78 MPa; 66.21 MPa; and 63.70 MPa, respectively.

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