Analysis Of Sulphate Resistance Reactive Powder Concrete With W/C Variations

Saloma, Hanafiah, Muhammad Prayogane

Abstract: Reactive powder concrete is a type of high-performance concrete with low porosity. RPC eliminates the use of coarse aggregates in the mixture to increase compactness, stability of the mixture components, and to minimize internal defects in materials such as void area. Reactive powder concrete is composed by materials such as Portland cement (OPC), quartz sand, quartz flour, silica fume, water, superplasticizer, and without coarse aggregate. The purpose of this research is to analyze the characteristics of reactive powder concrete in density, compressive strength and durability with variation of w/c. This mixture has three variations consisting of variations of w/c. Variations in w/c used were 0.20, 0.23 and 0.26 with sulfate immersion for 28 and 56 days. The ASTM standard is used as the basis for testing slump flow, setting time, and compressive strength. The result of the maximum compressive strength test is 71.15 N/mm^2 with w/c = 0.20 in the condition without immersion. The result of microstructure test which has the highest C-S-H and the lowest porosity is w/c = 0.20.

Index Terms: Reactive powder concrete, w/c, silica fume, sulfate, microstructure.

1 Introduction

Reactive powder concrete was first developed by a Buoygues company in France in the 1990s. RPC is a concrete innovation without the use of coarse concrete. Coarse aggregates that are not used in the RPC mixture cause the concrete to become very dense without any cracks in the concrete structure. This also makes RPC have a much better performance than conventional concrete. This concrete is also a special concrete in which its microstructure is optimized by precise gradation of all mixed particles to produce maximum density in the concrete [1], [2]. RPC belongs to the high quality concrete group. The main compositions in this concrete are fiber reinforcement, admixtures, silica fume and low water-cement ratio. In some studies, the RPC compressive strength can reach 150 MPa and with steel fiber reinforcement the flexural strength is 30-40 MPa [2], [3], [4]. Concrete as a major structural component in construction requires the development needed for concrete to have a good and environmentally friendly performance. Utilization of concrete as a protector of the building even more prevalent, began with the development of textile and chemical industry that almost the whole building is made of concrete. Especially in the pulp and paper industry that uses sulfuric acid in its production process, this industry has a high rate of accidents and building failures [5], [6]. Penetration of acid content of sulfuric acid can lead to reduced weight on concrete, destruction of mixed homogeneity, damage to microstructural balance and reduce compressive strength and durability of concrete. RPCs that have low porosity levels due to the removal of coarse aggregates in the mixture are expected to overcome the problem of durability in industrial buildings concrete against sulfate [7], [8], [9].

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The use of silica fume as a substitute for cement in RPC can improve the performance of the concrete, with concentrations of 10%, 15%, 20%, 25% and 30% in place of cement, silica fume has a chemical composition and physical requirements better than ordinary cement. In this research used silica fume as RPC admixtures. Utilization of silica fume that rich in silica content is expected to improve the properties of concrete, improving the performance and quality of the concrete. Variations w/c were investigated to compare the mechanical properties and RPC microstructure to sulfate infiltration. Microstructural testing and RPC mechanical properties of sulfate infiltration aim to control the characteristics of concrete.

2 Materials and Methodology

The research method used is an experimental method. The water and cement comparisons used were 0.20, 0.23, 0.26 and variations in immersion age. From these variations, obtained nine variations of the mixture of reactive powder concrete. The composition of the concrete mixture used in the study was silica fume, quartz sand, quartz flour, and Portland cement. Tests conducted are testing on fresh concrete and hard concrete. Fresh concrete test includes slump flow test and setting time to get workability value on concrete, while hard concrete test include compressive strength test and resistance to sulfate. The compressive strength tested using a cylindrical sample of size 10 x 20 cm and the resistance of concrete to sulfate was tested at 28 days and 56 days of concrete. The use of materials as test samples in the study include Portland cement type I, silica fume, superplasticizer, water, and quartz sand. Most of the materials used are goods from the factory that have the size and type listed, so that in this study there is no need for material testing. The cement used in the study was Ordinary Portland Cement Type 1. Silica fume used in this study has SiO_2 content of 90% with a maximum use of 10% of the weight of cement. The research used quartz sand measuring 50-650 μm with a mesh value of 30. The quartz flour used in this study was 0.3-25 μm with a mesh value of 550. The superplasticizer used was limited to a range of 0.8-2.0%. The water used in this study is that it meets hygiene standards, does not contain compounds that can damage concrete structures, and does not smell. This study uses distilled water, because distilled water does not contain substances or other compounds. Reference for RPC manufacture based on journal from previous research because there is no reference standard of RPC manufacture issued by ASTM, ACI, and SNI. The use of silica fume is 10% of the use of cement material. In the process of making concrete, the material is mixed manually. First, the mixing process is done on the whole dry material evenly and continued by inserting the water material containing half of the superplasticizer for 10-15 minutes. A portion of the water mixer is stored to melt the residue from half the superplasticizer. The composition of RPC used has three variations w/c with values of 0.20, 0.23, and 0.26. Three variations of RPC composition according to w/c values are described in Table 1.

Table 1. *Mix proportion*

RPC proportion			
Material	Amount (kg/m^3)		
	RPC1	RPC2	RPC3
Cement	773.00	672.00	594.00
Silica fume	77.30	67.20	59.40
Quartz flour	301.16	301.16	301.16
Quartz sand	913.36	913.36	913.36
Superplasticizer	25.42	25.42	25.42
Water	170.00	170.00	170.00
w/(c+sf)	0.20	0.23	0.26

3 Results and Discussion

3.1 Slump Flow

Slump flow test results can be seen in Fig. 1. This test is measured using a meter on all four sides, namely the vertical, horizontal and two diagonal sides.

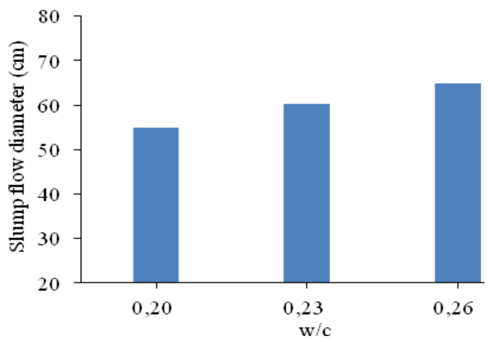


Fig. 1. *Effect of w/c on slump flow*

The mean of slump flow test with w/c = 0.20 is 55 cm, w/c = 0.23 is 60 cm, and w/c = 0.26 is 65 cm. The magnitude of the slump flow diameter is influenced by the value w/c, the higher the w/c value the greater the slump flow diameter produced and the higher the workability of the concrete. The results of testing the slump flow shows that at w/c 0.26 has the largest slump flow. The value of w/c 0.2 has the smallest slump flow because it contains a few water in the mixture.

3.2 Setting Time

The setting time test results are seen in Fig. 2. The reading of the setting time tool is recorded every 15 minutes, starting from zero minutes to a maximum of 270 minutes. The data generated in this setting time test is the initial and final setting time. The initial and final setting times at w/c = 0.20 are 129 and 208 seconds, w/c = 0.23 are 154 and 179 seconds, and w/c = 0.26 are 233 and 258 seconds. The results of the setting time test shows that at w/c 0.26 has the largest setting value. The value of w/c = 0.20 has the smallest setting value because it contains a little water in the mixture. The setting time is influenced by water content of the mixture, so the greater the w/c value used, the setting time on fresh concrete will be slower.

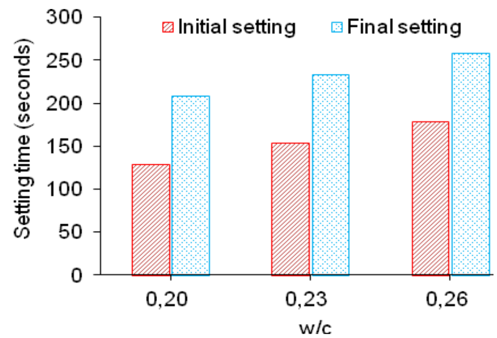


Fig. 2. *Effect of w/c on setting time*

3.3 Density

Density with w/c variations can be seen in Fig. 3. In this study the maximum density at 28 days before immersion was 2,395 kg/m^3 for the w/c = 0.20. While the lowest density was obtained at 2,185 kg/m^3 for the w/c = 0.26 when it was submerged in 56 days of sulfate.

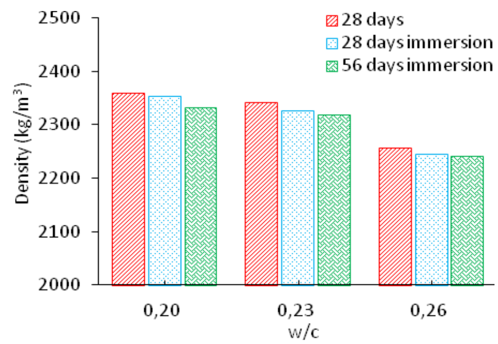


Fig. 3. *Effect of w/c on density*

The results of density testing shows that at w/c = 0.20 has a larger density where optimum value is obtained at age 28 days before immersion with sulfate. The value of w/c = 0.26 has the smallest density.

3.4 Compressive Strength

Fig. 4 shows the variation of w/c to the compressive strength of RPC, at w/c = 0.2 compressive strength has increased, but at w/c = 0.23 and 0.26 compressive strength has decreased. The result of compressive strength test at 28 days before immersion with value w/c = 0,2 reaching maximum compressive strength equal to 71.15 MPa. The minimum compressive strength of RPC occurs at the age of 56 days after immersion with a w/c = 0.26 of only 33.63 MPa.

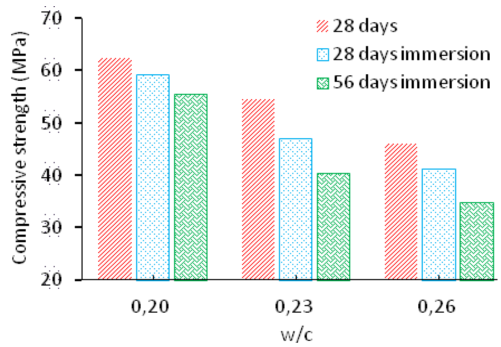


Fig. 4. *Effect of w/c on compressive strength*

3.5.1 Without Sulfate Immersion

In RPC test of 28 days concrete age without sulfate immersion, the minimum compressive strength of 41.40 MPa has a density of 2,242 kg/m^3 and the maximum compressive strength of 71.15 MPa has a density of 2,395 kg/m^3.

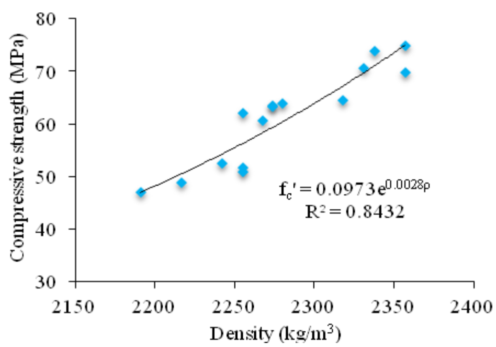


Fig. 5. *Compressive strength vs density without sulfate immersion*

The test results concluded that the compressive strength and density of the RPC were directly proportional. The regression graph of the relationship between compressive strength and RPC density at 28 days without soaking is described in Fig. 5. The results of the regression graph the relationship of compressive strength and density of 28 days, obtained the exponential equation as follows:

$$f_c' = 0.0973e^{0.0028\gamma} \quad (1)$$

where:
f_c' = compressive strength (MPa)
γ = density (kg/m^3)

The coefficient of determination of 0.8432 approaches one indicates that density affects compressive strength. The compressive strength and density are directly proportional.

3.5.2 With Sulfate Immersion (28 days)

RPC test of 28 days concrete with sulfate immersion, the minimum compressive strength of 37.27 MPa has a density of 2,229 kg/m^3 and the maximum compressive strength of 64.81 MPa has a density of 2,389 kg/m^3. The regression chart of the relationship between compressive strength and RPC density of 28 days with sulfate immersion is described in Fig. 6. The result of the regression graph of the compressive strength relationship and the RPC density of 28 days of sulfate immersion, the following exponential equations are obtained:

$$f_c' = 0.0506e^{0.003\gamma} \quad (2)$$

where:
f_c' = compressive strength (MPa)
γ = density (kg/m^3)

The coefficient of determination of 0.8342 approaches one indicating that density affects compressive strength. The compressive strength and density are directly proportional.

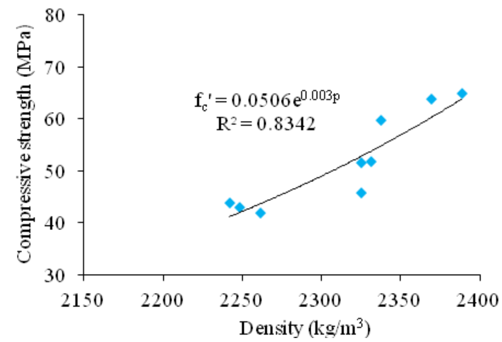


Fig. 6. *Compressive strength vs density with sulfate immersion (28 days)*

The RPC test, the concrete age of 56 days with sulfate immersion was found to be a minimum strength of 28.71 MPa having a density of 2,185 kg/m^3 and at a maximum compressive strength of 60.22 MPa having a density of 2,350 kg/m^3. The regression graph of the relationship between compressive strength and RPC density of 56 days with immersion is described in Fig. 7. The result of regression graph of relationship of compressive strength and RPC weight of 56 days of immersion, the exponential equation as follows:

$$f_c' = 0.0002e^{0.0054\gamma} \quad (3)$$

where:
f_c' = compressive strength (MPa)
γ = density (kg/m^3)

The coefficient of determination of 0.8495 approaches one indicates that density affects compressive strength. The compressive strength and density are directly proportional.

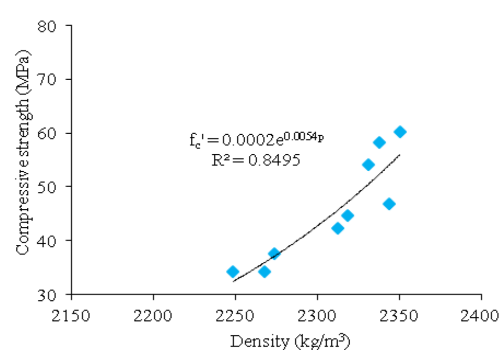
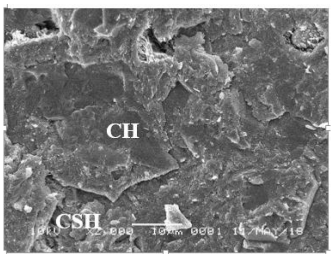


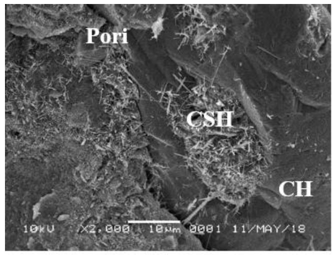
Fig. 7. *Compressive strength vs density with sulfate immersion (56 days)*

3.6 Microstructure

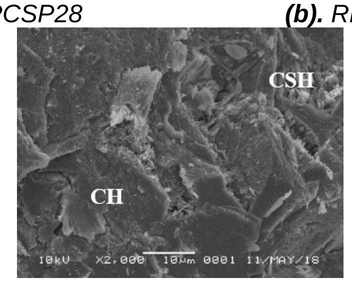
The RPC microstructure test is a reading with SEM 2000x magnification of three variations w/c = 0.20 is RPCSP28, RPCP28, and RPCP56. The w/c = 0.23, which is the code RPCSP28, RPCP28, and RPCP56. The w/c = 0.26 which is the code RPCSP28, RPCP28, and RPCP56.



*(**a**). RPCSP28*



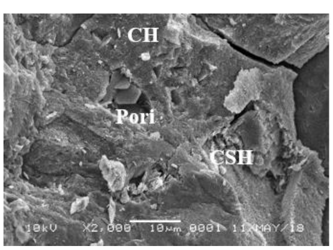
*(**b**). RPCP28*



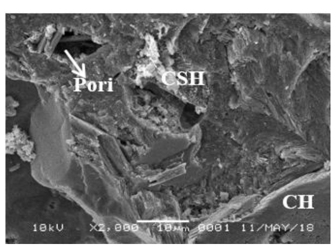
*(**c**). RPCSP56*

***Fig. 8.** SEM with w/c = 0.20*

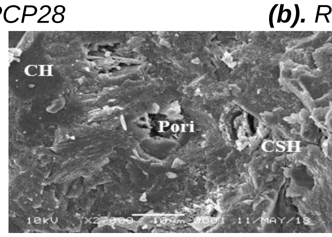
Fig. 8 describes SEM photos of 3 RPC samples with a w/c = 0.2. Fig. 8(a) is a SEM of RPCSP28, C-S-H is formed but there is little pore with a size of about 5 μm due to the low w/c value. Fig. 8(b) is a SEM RPCP28, seen in many pores of 1-3 μm in size but not tightly and microcrack with a width greater than 10 μm occurring near the C-H and C-S-H bonds. This shows a weak bond in the interface zone area. Fig. 8(c) is a SEM RPCAP56, a pore spread of less than 1 μm. This proves the compressive strength of the specimens after the soaked sulfate decreases. Fig. 9 describes SEM of RPC samples with a w/c = 0.23. RPC with a w/c = 0.20 is denser when compared to the w/c = 0.23. Increasing the value of w/c = 0.23 on the mixture led to the emergence of large pores and microcracks of varying sizes. Fig. 9 explains where the C-S-H is already visible but the pore size varies with wider spread, resulting in the ability of C-S-H in closing the pore to prevent sulfate penetration from falling.



*(**a**). RPCP28*



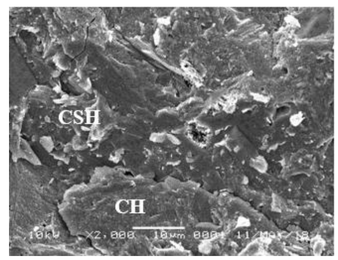
*(**b**). RPCSP28*



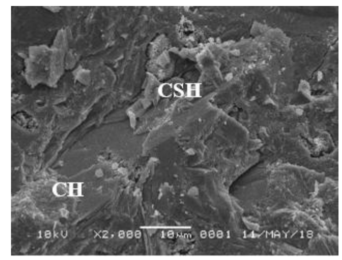
*(**c**). RPCSP56*

***Fig. 9.** SEM with w/c = 0.23*

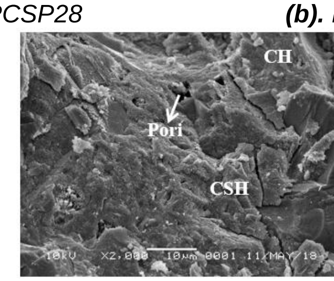
The less intact bonds between materials and increased pore content at w/c = 0.23 cause mechanical properties such as compressive strength of RPC to decrease. Fig. 10 describes a microstructure of RPC with a w/c = 0.26. RPC compressive strength at w/c value of 0.26 is lowest compared to w/c values of 0.2 and 0.23. Based on Fig. 10 the C-S-H compound formed is lower than the C-H. The C-H compound does not have an impact on the cement matrix bond which results in decreased compressive strength. Fig. 10(a) shows that C-S-H formed less dense due to increased water content in concrete, decreased compressive strength along with decreased number of C-S-H and increased pore levels. RPC with w/c = 0.20 have the most solid C-S-H bonds when compared with w/c = 0.23 and 0.26. This shows that the optimum RPC compressive strength occurs at w/c = 0.2 and concrete with w/c = 0.2 has the ability to prevent sulfate penetration better than w/c = 0.23 and 0.26.



*(**a**). RPCSP28*



*(**b**). RPCP28*



*(**c**). RPCP56*

***Fig. 10.** SEM with w/c = 0.26*

The RPC microstructure reading identified various types of reading specimens of the constituent material in micro sizes, namely anhydrous cement (C-S-H), calcium hydroxide (C-H), and silica fume. Solid C-S-H and low pore content showed high concrete compressive strength and ability of concrete to prevent sulfate penetration to increase, according to RPCSP28 concrete compressive strength data having the highest compressive strength, it is 71.15 MPa.

4 Conclusion

The conclusion that can be drawn from the research that has been done is as follows:

1. The effect of using silica fume on RPC sulfate resistance plays a role in the process of forming C-S-H on concrete which is useful to cover the pores formed due to variation of w/c variation. The results of microstructural testing prove that many C-S-H compounds are formed to close the pores and minimize the occurrence of microcrack in the concrete.
2. The effect of variations in w/c = 0.20, 0.23, and 0.26 on RPC sulfate resistance, among others, the compressive strength of RPC samples with a w/c = 0.26 having the lowest average value compared to the value w/c = 0.20

and 0.23 that is done when soaking 28 day equal to 41.05 MPa and 56 days equal to 34.69 MPa. This is because with the w/c value increasing, the more water content to create pores in the concrete microstructure and the C-S-H compound formed due to the use of silica fume does not work optimally in closing pores from sulfate penetration. The sulfate penetrated into the concrete will react with the C-H compound and flush on the decrease in the compressive strength of the concrete. The optimum w/c value of RPC is 0.20 which produces the highest compressive strength of 71.15 MPa and has the most solid C-S-H structure with the least porosity level when compared to other w/c variations.

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