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THE COMPARISON OF PREPLACED AGGREGATE CONCRETE COMPRESSIVE STRENGTH BASED ON THE VARIATION OF AGGREGATE AND PREDICTIONS

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ABSTRACT

Preplaced Aggregate Concrete (PAC) is a concrete produce by placing its aggregates in the mold first then injectedit with grout. One of the variable to a good result of PAC is the quality of grout.This paper was investigate about the effect of coarse aggregate variation to PAC compressive strength. Coarse aggregate used were rounded stone with diameter of 20 mm and 30 mm, and crushed stone with diameter of 30 mm. The researches about PAC had conducted by Abdelgader (1999) and Ganaw (2012) which gave equations to estimated PAC compressive strength. Compressive strength result from this study would compared to the predictions using equation from previous research.The results showed that PAC that uses smaller aggregates had a smaller average of compressive strength. This was shown with the result of the compressive strength of PAC with coarse aggregate of 20 mm diameter of rounded stone was 11.11% smaller than diameter of 30 mm.PAC that used crushed stone as aggregate has a higher average compressive strength than rounded stone aggregate one. It shown from the result of the compressive strength of PAC with crushed stone coarse aggregate had an average compressive strength of 6.79% that was greater than concrete with rounded stone coarse aggregate.The results of compressive strength prediction by using formulas from the previous studies indicated that Ganaw’s formula has the closest result to the test result performed in this study.

***Keywords**: Preplaced Aggregate Concrete, Compressive Strenght, Coarse Aggregate.*

I. INTRODUCTION

Concrete is a construction material which made from a mixture of coarse aggregate, fine aggregate, cement and water with particular proportions. Concrete is widely used in construction due to the easy forming material. Conventional concrete is produced by mixing all the constituent material and pour into a formwork. However, implementation conventional concrete in construction site is difficult to apply such as for concreting on port foundation, closely spaced reinforcement, and under water construction. Hence, Preplaced Aggregate Concrete (PAC) technology is an alternative solution this problem.

Preplaced aggregate concrete was discovered by Louis S. Wertz and Lee Turzillo in 1937. Initially the common use of PAC was for repairing beam, column dams, bridges, and foundations [3, 10].Application of PAC develop over the time. PAC is used when the conventional concrete is difficult to apply [15].

Preplaced aggregate concrete (PAC) is produced by placing the coarse aggregates into the formwork then injecting grout to fill the voids between the aggregates [1, 5, 8, 12]. Grouted-aggregate, injected-aggregate, prepakt, colcrete, naturbeton, and arbeton are other names of PACthat are used in America and international code[9].

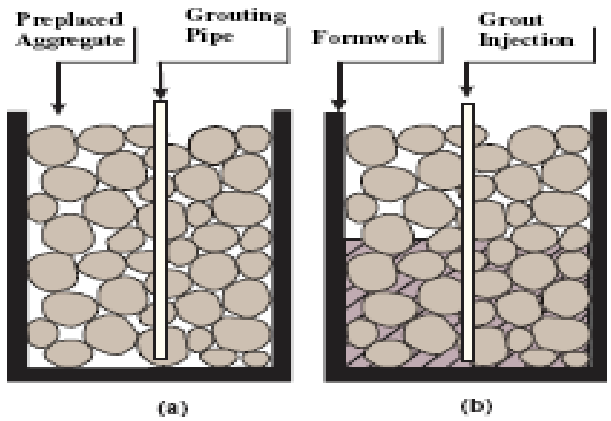

Figure 1. Preplaced Aggregate Concrete(Abdelgader, 2018)

Compacted process in PAC is not required because the coarse aggregate had been installed in advance and grouting is intended to fill the empty voids between the aggregate[6, 15]. The compressive strength of a PAC is different from the conventional concrete, because of the manufacturing process is indeed different and contains a higher proportion of coarse aggregate. Several studies of PAC have been carried out and developed formulations of PAC.

Abdelgader (1999) developed the equations to estimate the compressive strength of grout and the PAC. For grout compressive strength formulation can be seen in Equation 1.

$$f_g = \alpha_0 + \alpha_1 \left(\frac{w}{c}\right) + \alpha_2 \left(\frac{c}{s}\right) + \alpha_3 . \text{time} \qquad (1)$$

Formulation for the PAC compressive strength that depend on the strength of the grout can be seen in Equation 2.

$$f'_c = \beta_0 + \beta_1 . {f_g}^{\beta_2} \qquad (2)$$

Whereas the estimated PAC compressive strength based on the type of coarse aggregate can be seen in Equation 3.

$$\mathbf{f'_c = \gamma_0 + \gamma_1 \left(\frac{w}{c}\right) + \gamma_2 \left(\frac{c}{s}\right) + \gamma_3 . time} \qquad (3)$$

where:

f_g : grout compressive strength (MPa)
f'_c : compressive strength of PAC (MPa)
w/c : water cement ratio
c/s : cement to sand ratio
time : mixing time with a ultrahigh speedmixer (m/s)
$\alpha_0, \alpha_1, \alpha_2, \alpha_3$: the regression constants that can be seen in Table 1
$\beta_0, \beta_1, \beta_2$: the regression constants that can be seen in Table 2
$\gamma_0, \gamma_1, \gamma_2, \gamma_3$:the regression constants that can be seen in Table 3

γ3.time in equation 3 can be ignored because the effect of mixing time contribute a small difference to the compressive strength.

Table 1. Regression Constants α

Regression Coefficient	α_0	α_1	α_2	α_3
Value	90.88	-117.97	3.56	0.61

(source: How To Design Concrete Produced By A Two-Stage Concreting Method, 1999)

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Table 2. Regression Constants β

Kind of Stone Aggregate	β_0	β_1	β_2
Rounded	9.56	0.14	1.32
Crushed	6.70	0.42	1.07
Mixed	7.37	0.32	1.14

(source: How To Design Concrete Produced By A Two-Stage Concreting Method, 1999)

Table 3 Regression Constants γ

Kind of Stone Aggregate	Void ratio (%)	γ_0	γ_1	γ_2	γ_3
Rounded	39	63.43	-75.25	-0.06	0.21
Crushed	47	61.24	-71.00	0.52	0.21
Mixed	43	64.26	-75.33	0.26	0.13

(source: How To Design Concrete Produced By A Two-Stage Concreting Method, 1999)

Ganaw (2012) developed relationship between the compressive strength of grout and PAC that can be seen inEquation 4.

$$\mathbf{f_{cu} = 0.55\, f_g + 2.09} \qquad (4)$$

where,f_{cu} is compressive strength of PAC(MPa) and f_g is compressive strength of grout (MPa).

II. MATERIAL

2.1. Materials

Rounded coarse aggregate from Martadah and crushed coarse aggregatefrom Katunun, and fine aggregate from Baritowere used in this research. Portland Composite Cement (PCC)and superplasticizer from Sika Viscocrete-1003 with high flow ability and self-compaction ability were used.

2.2. Grout

The composition of the grout that was used in this research based on the results of the Chairunnisa(2018). which the optimum composition of PAC was found in the cement to sand ratio of 1: 2; water to cement ratio of 0.6; percentage of viscocrete to cement weight 0.7 and got 27.40 MPa for the grout compressive strength. Grout made from that composition with the material used in this study will be examined for the flow time based on ASTM C939. The results from test obtained was 33.34 seconds. This shows that the mixture used meets the standard flow time requirements for grout mixtures (8-35 seconds).

III. METHOD

The materials used for the mixing volume per cubic meter with a predetermined grout composition were calculated with the formula found bySatyarno (2015)based on aggregate's cavity volume. The calculation results can be seen in Table 4.

The researchers made 3 pieces of 5x5x5 cm cubic grout specimens and 2 pieces of 15x30 cm cylindrical concrete specimens of aggregate for each type, so that the total cylindrical specimens was 6. The test objects were then treated for 28 days. After reaching the desired time, the tested materials were tested with reference to ASTM C39/C39M-18.

Table 4. Material Requirements

Materials	Requirements
Sand	494.605 kg
Water	148.382 lt
Concrete	247.303 kg
Viscocrete	1.731 lt
Coarse Aggregate	1 m^3

IV. RESULT & DISCUSSION

4.1. The Grout Compressive Test Result

The results of grout compressive strength test can be seen in Table 5.

Tabel 5. Grout Compressive Strength

Maximum Load (N)	Grout Compressive Strength (MPa)	Average Grout Compressive Strength (MPa)
66439	26.58	
60939	24.38	24.73
58093	23.24	

The comparison of the grout compressive strength obtained in this study, Chairunnisa (2018), and the one calculated by using Abdelgader equation can be seen in Table 6.

Table 6. The comparison of the grout compressive strength based on the result from this study, Chairunnisa(2018), dan Abdelgader Equation (1999)

Grout Compressive Strength (MPa)		
Result From This Study	Chairunnisa (2018)	Abdelgader Equation (1999)
24.73	27.40	21.88

From Table 6, it can be seen that the grout compressive strength in this study met the estimated compressive strength based on the formula made by Abdelgader (1999). This ini because the equation made by Abdelgader was obtained from the results of Abdelgader research analysis which showed different compositions and types of admixture from this study.

Furthermore, when compared with the compressive strength of the results of the previous study, this study had lower result. This is because the two studies used different fine aggregate, although the mixture and admixture composition were the same. The previous study used fine aggregate from Mount Merapi sand, while this study used the material from Barito sand. Therefore, the compressive strengths are different due to the materials used. According to Ganaw (2012), fine aggregate characteristics affect the nature of the grout where the texture of the sand will affect the PAC grout.

4.2. Preplaced Aggregated Concrete Compressive Test Result

Concrete compressive test result on this study can be seen on Table 7 and Figure 2. From Figure 2, it can be seen that PAC with smaller aggregate diameter has smaller average of compressive strength. This is shown from the results of the average compressive strength of BK20 that was 11.318 MPa or 11.11% smaller than BK30.PAC used crushed stone as coarse aggregate has a higher average compressive strength than rounded stone one. It can be seen from the results of the compressive test for PAC with crushed aggregate was 6.79% and greater than rounded stone one.

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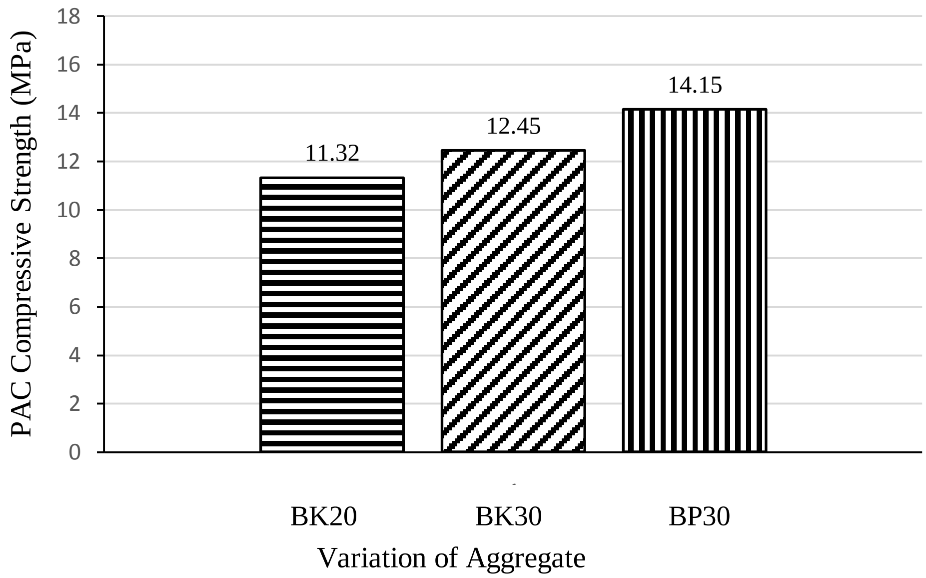
Tabel 7. PAC Compressive Strength

Variation of Aggregate (mm)	P Average (N)	A (mm^2)	$f_c$average (MPa)
Rounded Stone 20 mm (BK20)	200000	17671.459	11.318
Rounded Stone 30 mm (BK30)	220000	17671.459	12.449
Crushed Stone 30 mm (BP30)	250000	17671.459	14.147



Figures 2. PAC Compressive Strength

4.3. Preplaced Aggregate Concrete Compressive Strenght Predictions

PAC compressive strength results were not only obtained from the test results, they were also obtained from the prediction results based on the existing compressive strength of the grout, coarse aggregate type and the grout mixture composition. The compressive strength obtained in this study was compared to the results of predictive compressive strength based on the existing formulas. The results of the predictive compressive strength calculations can be seen in Table 8.

Tabel 7. The Predictions of PAC Compressive Strength Based On Equation From Previous Research

Variation of Aggregate	Diameter (mm)	PAC Compressive Strenght (MPa)		
		with f_g Abdelgader Equation (1999)	with f_g Chairunnisa (2018)	with f_g from this study
Gamma Abdelgader (1999)				
Rounded Stone	20	18.25	18.25	18.25
Rounded Stone	30	18.25	18.25	18.25
Crushed Stone	30	18.38	18.38	18.38
Betta Abdelgader (1999)				
Rounded Stone	20	17.78	20.63	19.20

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Rounded Stone	30	17.78	20.63	19.20
Crushed Stone	30	18.10	21.21	19.68
Ganaw (2012)				
Rounded Stone	20	14.12	17.16	15.67
Rounded Stone	30	14.12	17.16	15.67
Crushed Stone	30	14.12	17.16	15.67

4.3.1. PAC Compressive Strength Prediction Using The Abdelgader Equation (1999)

From Table 8, a graph of PAC compressive strength prediction was made by using the formula given by Abdelgader and the research conducted by Chairunnisa (2018) as in Figure 3.

Abdelgader (1999) provides two formulato predict PAC compressive strength, namely the formula that uses regression coefficients γ (gamma) and β (betta). The difference between the two formulas lies in the component analysis. In Abdelgader gamma, Abdelgader only uses coarse aggregate types in mixtures and mix compositions, namely water to cement ratio and cement to sand ratio to predict concrete compressive strength. Thus, in this study, the compressive strength for rounded stone and crushed stone aggregate were 18.25 MPa, and 18.38 MPa, respectively.

Moreover, beside for considering the type of coarse aggregate used, Abdelgader betta equation also used to consider the grout compressive strength value. The estimated compressive strength of Abdelgader Betta equation using the Abdelgader equation grout was 17.78 MPa for rounded stone and 18.10 MPa for crushed stone. The estimated PAC compressive strength using Chairunnisa grout compressive strength was 20.63 MPa for rounded stone and 21.21 MPa for crushed stone. In addition, the estimated compressive strength by using the result of compressive strength of grout in this study was 19.20 MPa for rounded stone and 19.68 MPa for crushed stone.

The difference of the results by using the Abdelgader Betta equation was due to one component of the equation, namely grout compressive strength, which has a different value. Abdelgader (1999) gave the equation of concrete compressive strength that is directly proportional to the grout compressive strength, which means the higher the compressive strength value of the grout the higher the predicted compressive strength of the concrete. The prediction value of concrete compressive strength by using Chairunnisa grout has the highest number due to the highest compressive strength of grout.

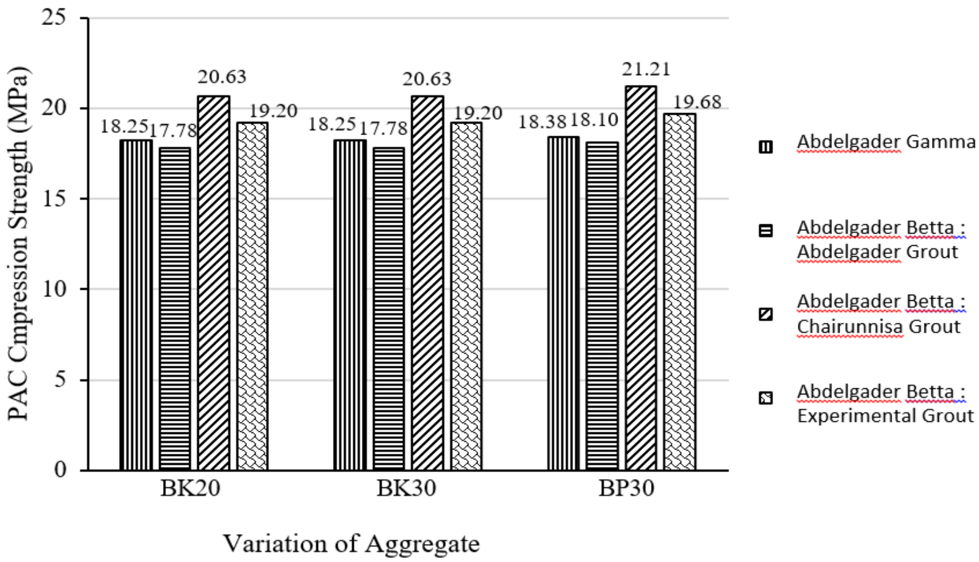


Figure 3. PAC Compressive Strength Prediction Using Abdelgader Equation (1999)

4.3.2. PAC Compressive Strength Prediction Using The Ganaw Equation (2012)

From Table 8, a graph about the compressive strength of PAC predictions using the formula given by Ganaw by using the compressive strength values of this study, Chairunnisa's (2018), and Abdelgader's (1999) was shown in Figure 4.

From Figure 4, it can be seen that the PAC compressive strength value in this study when predicted using the Ganaw's formula using experimental grout strength was greater than the predicted using Abdelgader grout compressive strength. However the result are lower than using Chairunnisa grout compressive strength. This conditions can occur because Chairunnisa grout compressive strength is greater than the grout compressive strength obtained in this study.

In addition, Abdelgader grout compressive strength is also lower than Chairunnisa's. Ganaw formula provides PAC compressive strength relationship that is directly proportional to the grout compressive strength. Hence, the greater the grout compressive strength the greater the concrete compressive strength.

4.3.2.1. The Comparison of PAC Compressive Strength from Test Results and The Predictions By Using Experimental Grout Compressive Strength

From the grout compressive strength obtained in experimental comparisons, the compressive strength can be made with a predictive compressive strength by using the existing formula. The comparison of predicted PAC compressive strength using experimental grout compressive strength and concrete compressive strength test results can be seen in Figure 5.

From Figure 5, it can be seen that the PAC compressive strength by using coarse aggregate in the form of rounded stone with a diameter of 20 mm (BK20) was 11.32 MPa. This value is smaller with the one predicted with concrete compressive strength using Abdelgader's gamma formula (18.25 MPa) and betta formula (19.20 MPa). The compressive strength of concrete with coarse aggregate of rounded stone with diameter of 30 mm (BK30) and crushed stone with diameter of 30 mm (BP30) also showed the same results.

The compressive strength prediction for rounded stone aggregate concrete with diameter of 30 mm was 18.25 MPa based on Abdelgader's gamma formula and 19.20 MPa based on Abdelgader's betta formula. Furthermore, the PAC compressive strength obtained from the test results was 12.45 MPa, so the value is smaller than the one predicted by using Abdelgader's formulas. The concrete compressive strength of crushed stone with diameter of 30 mm was 14.15 MPa which is also smaller than the one predicted by using Abdelgader's gamma formula (18.38 MPa) and Abdelgader's betta formula (19.68 MPa).

The differences were because Abdelgader's gamma and betta formula are actually obtained from the compressive strength analysis of Abdelgader grout which had a range of 29.38-51.10 MPa, while the grout compressive strength of the results of this study was 24.69 MPa which means this value is outside the range given by Abdelgader.

Compared to the result by using Abdelgader's formula, the prediction of compressive strength by using Ganaw's formula showed the closest results to the test results in this study. Although they are still higher for all variations of the aggregates used.

For rounded stone concrete aggregate with diameter of 20 mm, the prediction result with the Ganaw's formula was 15.67 MPa and the experimental compressive strength test result was 11.32 MPa. For rounded stone concrete aggregate with diameter of 30 mm, the compressive strength was 12.45 MPa, while the predicted result calculated by using Ganaw's formula was 15.67 MPa. For crushed stone concrete aggregate with diameter of 30 mm, the aggregate concrete compressive strength was 15.67 MPa and the research result was 14.15 MPa. The differences in the range of compressive strength values of the test results and the one calculated by using Ganaw's formula were due to the differences in the types of fine aggregates, coarse aggregates, cement, admixture, additives and the composition of the grout mixture used in the study. Therefore, the factors certainly greatly affected the results of the tests conducted.

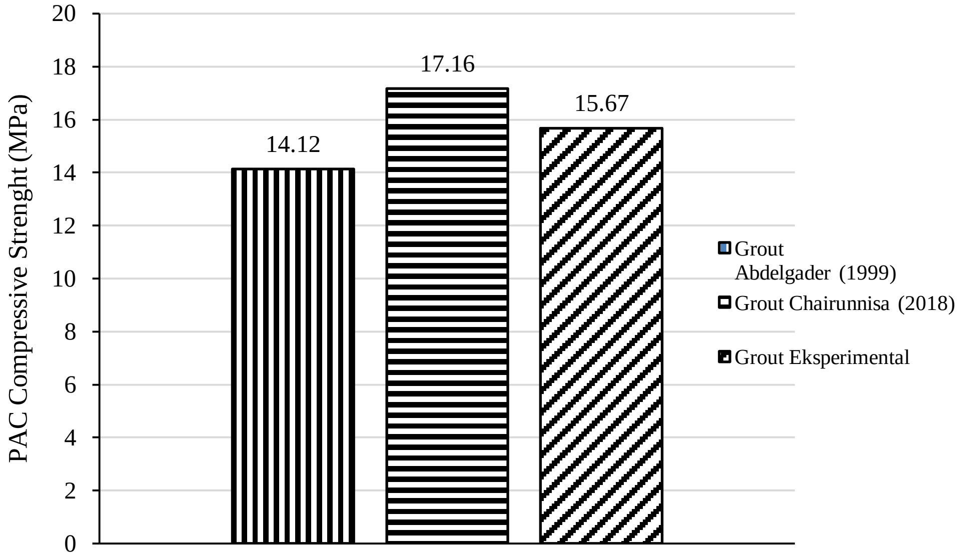
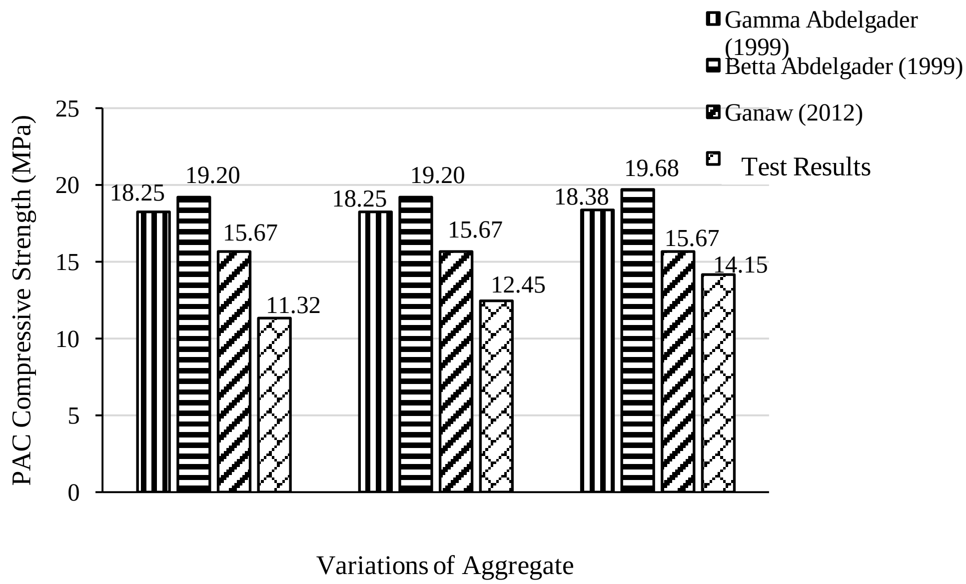


Figure 4. PAC Compressive Strength Prediction Using The Ganaw Equation (2012)



Figures 5. PAC Compressive Strenght Test Result and Compressive Strenght Prediction
Using Experimental Grout Compressive Strength

V. CONCLUSION

Based on the results of the study, PAC that uses smaller aggregates had a smaller average of compressive strength. This was shown with the result of the compressive strength of PAC with coarse aggregate of 20 mm diameter of rounded stone that was 11.11% smaller of the same stone type with diameter of 30 mm. PAC that used crushed stone as aggregate has a higher average compressive strength than rounded stone aggregate one. It shown from the result of the compressive strength of PAC with crushed stone coarse aggregate had an average compressive strength of 6.79% that was greater than concrete with rounded stone coarse aggregate. The results of compressive strength prediction by using formulas from the previous studies indicated that Ganaw's formula has the closest result to the test result performed in this study.

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