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Mechanical properties analysis of reactive powder concrete with curing temperature variation

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Mechanical properties analysis of reactive powder concrete with curing temperature variation

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Abstract. A Reactive powder concrete is one of Ultra High Performance Concrete developed through microstructure repair. This research uses silica fume and steel fibre with w/c = 0.23. The curing temperature variations used in the study were 27°C, 60°C, 90°C, and 120°C. Testing methods slump flow, compressive strength, modulus of elasticity, tensile strength and flexural strength were performed based on ASTM and ACI. This research shows that the compressive strength, modulus of elasticity, tensile strength and flexural strength are directly proportional. The optimum temperature of the study was 90°C. The compressive strength and maximum modulus of elasticity this study were 111.43 MPa and 51,400 MPa at curing temperature of 90°C. Tensile strength and maximum flexural strength in this study were 6.19 MPa and 10.82 MPa at curing temperature of 90°C.

1. Introduction

Ultra High Performance Concrete is one of the most active concrete research fields, because it contributed to a longer life and structural efficiency. UHPC has superior mechanical properties in terms of compressive strength, flexural strength, ductility, high ability and durability (Halit, 2012). Reactive powder concrete is one type of UHPC that is developed through the improvement of microstructure techniques in materials (Masdar, 2015). Applications RPC in the civil field, such as the construction of military, petroleum and nuclear power project facilities (Wenzhong, et.al, 2013).

Improvement of RPC's mechanical properties was achieved by microstructure engineering approach, including eliminating coarse aggregate, decreasing ratio water cement, and reducing CaO-SiO₂ content. Based on the research Raja and Sujatha (2012), the low use of w/c on RPC can reduce the porosity to a minimum so that the compressive strength and flexural strength increase. Silica fume as the main variable of RPC has an important role in the strength of concrete (Yin and Shu, 2003). The content silica fume optimal in RPC is between 20% and 30%.

The low number of air cavities in high quality concrete can minimize resistance to fire (Yang et.al, 2015). Therefore, to increase the strength of reactive powder concrete, it is did curing. Steam curing more effective than ordinary care in improving mechanical properties (Davood et.al., 2016). Steam curing at different temperatures affected the strength and microstructure of RPC concrete (Liu and Song, 2010). High temperatures in high strength concrete cause the concrete to experience evaporation, but the water vapor cannot escape due to its solid material structure. As a result, there was spalling on the concrete surface. At a temperature of 170°C high strength concrete with heated fibre can easily melt which can create additional porosity and small channels in the concrete (Canbaz, 2014). The main disadvantage of RPC is the high cement content which usually varies between 800 and 1,000 kg /m³ (Richad et.al, 1995).



2. Mix Design and Sample Preparations

The research method used is an experimental method that explains the effect of curing temperature variation on the mechanical properties of concrete. Concrete maintenance temperature used was 27°C, 60°C, 90°C, and 120°C with RPC composition using silica fume and steel fibre. Concrete testing is compressive strength, tensile strength, flexural strength, and modulus of elasticity with cylinder 10 x 20 cm, cylinder 15 x 30 cm, and beam 10 x 10 x 35 cm. Material used in this research is most of the production from the factory, so that in this research is not required testing material. RPC materials are as follows:

1. Portland

Cement used in this research is Ordinary Portland Cement (OPC) type 1. Type 1 which is used in accordance with ASTM C 150-04a standard.

2. Quartz sand

Quartz sand in this study is a sand beach originating from Bangka, then produced by PT. Karunia Hosanna, Bekasi. Quartz sand produced by PT. Karunia Hosanna is 50 - 650 µm. Quartz sand used in this research is mesh 30.

3. Quartz flour

Quartz flour has a finer size than quartz sand is 0.3-25 µm. Quartz sand used production by PT. Karunia Hosanna is mesh 550. Quartz sand served to increase the effect of fillers in the RPC mixture (Khadiranaikar and Muranal, 2012)

4. Steel fibre

Steel fibre used in this research is the production of PT. Bekaert. Steel fibre used is dramix 3D that has a curve like a wave is inhibited. The use of steel fibre serves to increase the strength of concrete up to an additional 20 MPa (Baek et.al., 2016).

5. Silica fume

Silica fume used is the production of PT. Sika Indonesia. The content is present in SiO₂ in silica fume this reaches 90%. The addition of Silica fume to RPC is needed to modify the ratio of CaO/SiO₂ as a binding (Sarika and Elson, 2015)

6. Superplasticizer

Superplasticizer used is obtained from PT. Waskita Beton Precast, Palembang. The use of superplasticizer is limited to a range of 0.8-2.0% by weight of cement.

Standard mix design of RPC concrete is based on international journals, this is because there is no standard defining RPC concrete composition. The determination of the composition RPC plan is done by trial mix design. The RPC composition used is described in Table 1.

Table 1. Proportion of material mix in the experiment

Composition of RPC	
Material	Amount (kg /m ³)
	RPC
Cement	672.00
Silica Fume	67.20
Quartz flour	301.16
Quartz sand	913.36
Superplasticizer	25.42
Steel fibre	48.00
Water	170.00
w/c	0.23

3. Discussion

3.1. Slump Flow

The slump flow testing process is carried out using a slump cone that is coated with plywood measuring 60 x 60 cm. The composition of RPC concrete mixture with $w/c = 0.23$ was obtained by value slump flow from four directions that is 60 cm, 59 cm, 60 cm, and 61 cm. Then, the value of the slump flow is averaged 60 cm.

3.2. Setting Time

The initial setting result obtained in this study with $w/c = 0.23$ is 154 minutes and the final setting is 233 minutes. Testing the setting time in this study uses a cube measuring 15 x 15 x 15 cm. Cube formwork is then filled with fresh concrete and pressed with a penetrometer to reach a depth of 1 cm.

3.3. Density

Density test result at age 7 days is present at 120 °C curing temperature is 2,272 kg/m³ and 28 days is 2,293 kg/m³. The results of the average type of weight testing on the 28 days old concrete with 90°C curing temperature is 2,332 kg/m³ while at 28 days age is 2,370 kg/m³. The results of the RPC type weight testing are seen in Figure 1.

3.4. Compressive Strength

The results of the compressive strength test can be seen in Figure 2. Based on the results of testing the compressive strength of 28 days old RPC obtained is 111.44 MPa at 90°C curing temperature. The high compressive strength at the curing temperature of 90°C was influenced by the large C-S-H bond and the dense pore so that the mechanical properties such as compressive strength increased. The minimum compressive strength for 28 days of age occurs at a curing temperature of 120°C where the compressive strength is 93.08 MPa. This is because at a temperature of 120°C there are many pores and the formation of many C-H so that it does not give an impact on the matrix bond and the compressive strength is low.

3.5. Stress and Strain

Based on the results of the largest RPC stress and strain test of 40% RPC compressive strength is present at a temperature of 120°C that is 0.00129. The smallest strain is present at a temperature of 90°C that is 0.000189. The test results of the RPC stress and strain can be seen in Figure 3. The results of this study indicate that strain and stress are inversely proportional to the higher strain, the smaller the voltage and vice versa.

3.6. Modulus of Elasticity

Modulus of elasticity test result used in this research is age 28 days. Based on the result of RPC compressive strength test is obtained that is 51.40 MPa at curing temperature 90°C. This is because, at a temperature of 90°C, a more compact concrete composition is produced so that the modulus of elasticity achieved is high. Modulus of elasticity test result can be seen in Figure 4. The minimum modulus elasticity occurs at the maintenance temperature of 120°C is 28,764 MPa. This is because, the temperature is too high can cause the hydration process is not perfect and cause crack in the concrete. Based on Figure 4 we can conclude the optimum temperature at the modulus elasticity test is 90°C.

3.7. Tensile Strength

Based on the results of the 28 days RPC tensile strength test obtained is 6.19 MPa at a curing temperature of 90°C while the minimum tensile strength is at 120°C of 3.39 MPa. The result of tensile strength test can be seen in Figure 5. This is because at a temperature of 90°C the pore diameter is so small that steel fibre and silica fume are acting as an RPC peg can increase the density and tensile strength of the concrete. The use of steel fibre in this study serves to prevent crack.

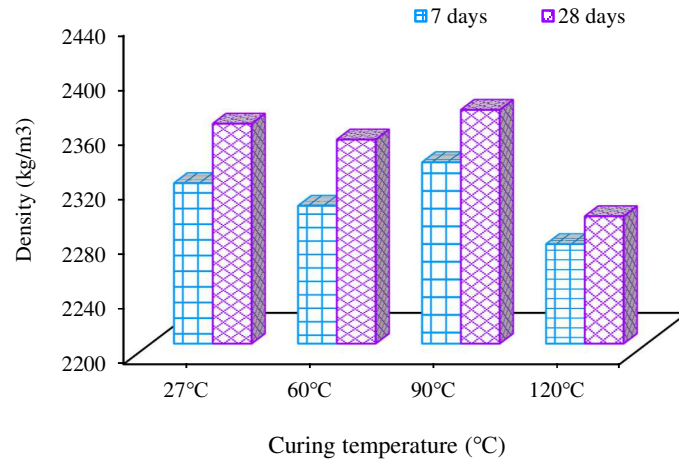


Figure 1. Density

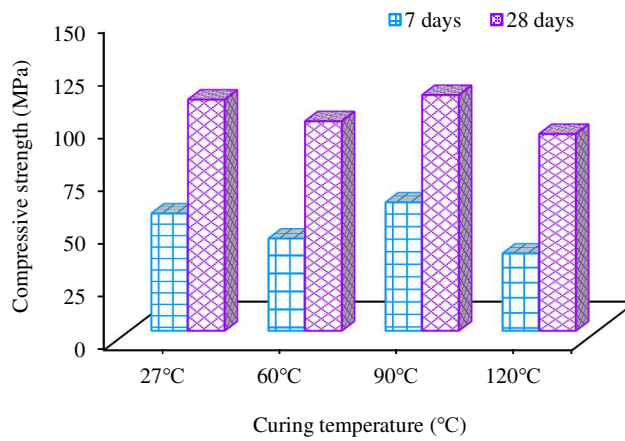


Figure 2. Compressive strength

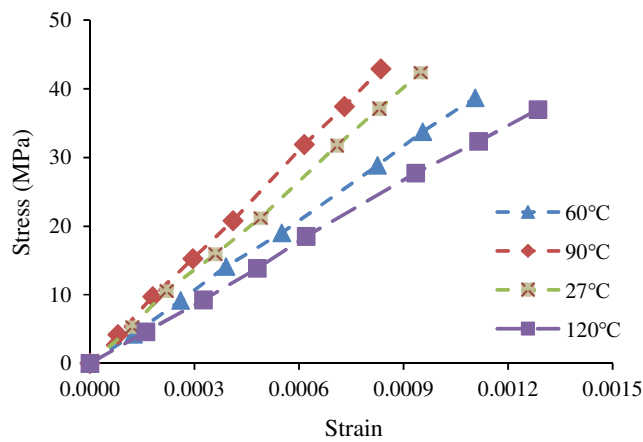


Figure 3. Stress and strain test result

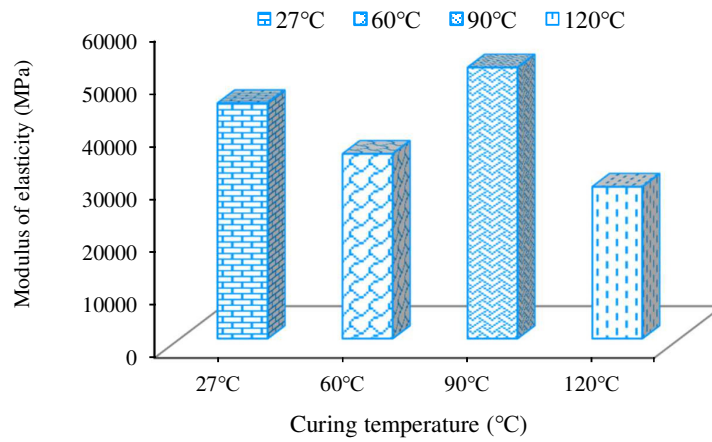


Figure 4. Modulus of elasticity

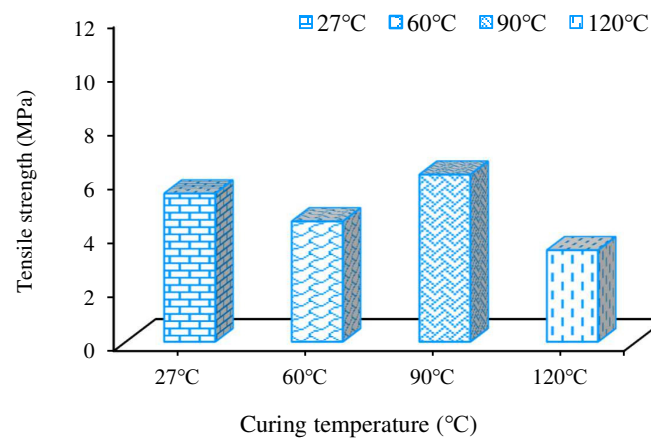


Figure 5. Tensile strength

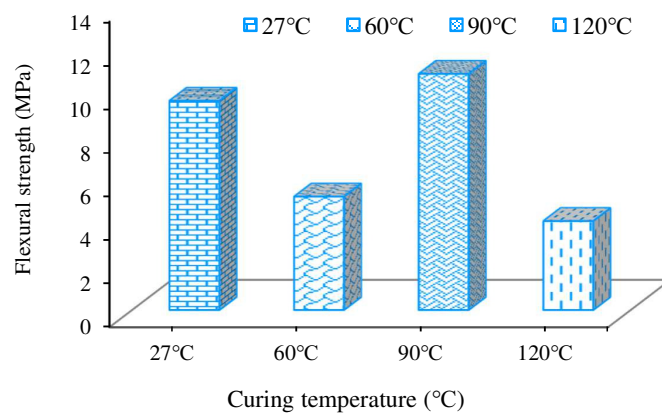


Figure 6. Flexural strength

3.8. Flexural Strength

Based on the results of the minimum tensile strength test is at a temperature of 120°C of 4.08 MPa. Test results can be seen in Figure 6. Maximum tensile strength at 90°C is 10.82 MPa. This temperature of 90 has a high tensile strength because it has less pore than at 27°C so that the concrete is very solid and slightly cracked like microcrack in the concrete. In addition to the temperature factor, the use of steel fibre in this study also serves to improve the flexural strength of RPC concrete.

3.9. Regression Analysis Compressive Strength and Tensile Strength

Regression analysis can be seen in Figure 7. The ACI-318 equation is the reference standard for regression analysis of tensile strength and compressive strength as follows:

$$f_{sp} = 0.56(f_c')^{0.5} \quad (1)$$

where:

f_c' = compressive strength (MPa)

f_{sp} = tensile strength (MPa)

Figure 7 describes the relationship between the compressive strength and tensile strength which obtained the coefficient of determination (R^2) of 0.912. The regression analysis between the research data and the ACI equation corresponds to the y-line that is worth 5,6 and the line x between 100 and 110. After interpolation ACI equations intersect at a value of 105 MPa. The regression equation of compressive strength and tensile strength is obtained as follows:

$$f_{sp} = 0.251e^{0.0295 f_c'} \quad (2)$$

where:

f_c' = compressive strength (MPa)

f_{sp} = tensile strength (MPa)

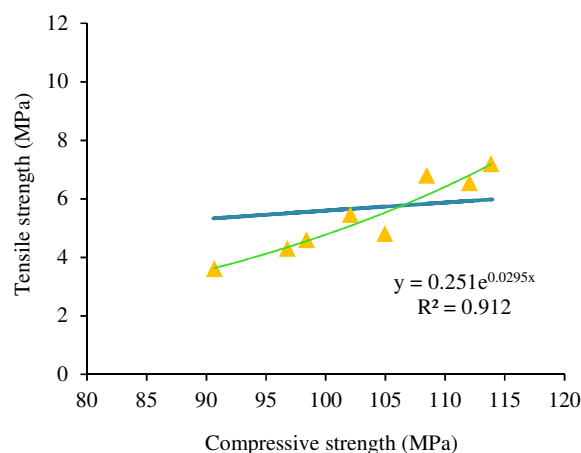


Figure 7. Regression analysis compressive strength and tensile strength

Table 2. Relation of compressive strength and tensile strength

Temperature	Research (MPa)	Compressive strength (MPa)	ACI (MPa)	Equation 2	Difference (%)
27°C	5.49	109.28	5.85	6.31	7.16
60°C	4.46	99.08	5.57	4.68	19.43
90°C	6.19	111.43	5.91	6.71	12.01
120°C	3.38	93.07	5.40	3.91	38.21

3.10 Regression Analysis Compressive Strength and Flexural Strength

Regression analysis of compressive strength with flexural strength can be seen in Figure 8. Coefficient of determination (R^2) obtained in the regression analysis that is equal to 0.9085. Logistic regression equation compressive strength and flexural strength at 28 days with temperature variation is obtained:

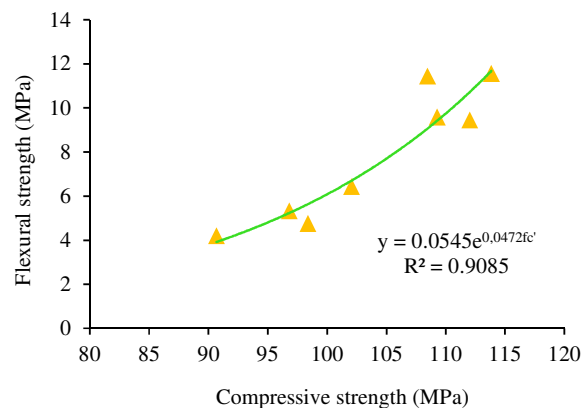
$$f_L = 0.0545e^{0.0472fc'} \quad (3)$$

where:

f_L = flexural strength (MPa)

fc' = compressive strength (MPa)

Based on research data, can it was concluded that the compressive strength and flexural strength were directly proportional. Increased compressive strength in RPC concrete is followed by a strong flexural strength increase and vice versa.

**Figure 8.** Regression analysis compressive strength and flexural strength

3.11. Regression Analysis Flexural Strength and Tensile Strength

Regression Analysis of compressive strength regression analysis with tensile strength can be seen in Figure 9. Coefficient of determination (R^2) obtained in the regression analysis that is equal to 0.8501. The regression equation of compressive strength and flexural strength at 28 days with temperature variation 27°C, 60°C, 90°C, and 120°C obtained:

$$f_{sp} = 2.6766e^{0.0668fL} \quad (4)$$

where:

f_l = flexural strength (MPa)

f_{sp} = tensile strength (MPa)

It can be concluded that the tensile strength and flexural strength are directly proportional. The compressive strengthening of these RPC is accompanied by strong flexural strength and vice versa.

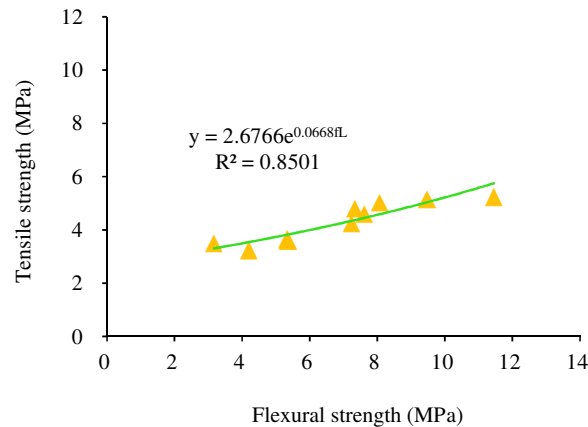


Figure 9. Regression analysis compressive strength and tensile strength

3.12. Regression Analysis Compressive Strength and Modulus of Elasticity

Relationship between modulus of elasticity and compressive strength is calculated using regression analysis. Regression analysis for compressive strength and modulus of elasticity of concrete refer to ACI-363 and CEB/FEB standard equation as follows:

$$\text{ACI equation 363 R: } E_c = 3320 (f_{c28})^{0.5} + 6900 \quad (5)$$

$$\text{Equation CEB / FEB: } E_c = 2.15 \times 10^4 (f_c' / 10)^{1/3} \quad (6)$$

Figure 10 describes the regression analysis between research data and ACI equations tangent to the x line between 100 and 110 and on the y line of 40,000 MPa. After, an interpolation of the equation x is tangent to a value of 105 MPa. The coefficient of determination (R^2) to the curing temperature variation is 0.9454 with the following equation:

$$E_c = 0.0438 (f_c')^{2.9528} \quad (7)$$

where:

f_c' = compressive strength (MPa)

E_c = modulus of elasticity (MPa)

Table 3 and 4 describes the average difference between research data and ACI and CEB equations. The biggest difference is at temperature 120 °C in ACI and CEB equation that is 36.55% and 58.63%.

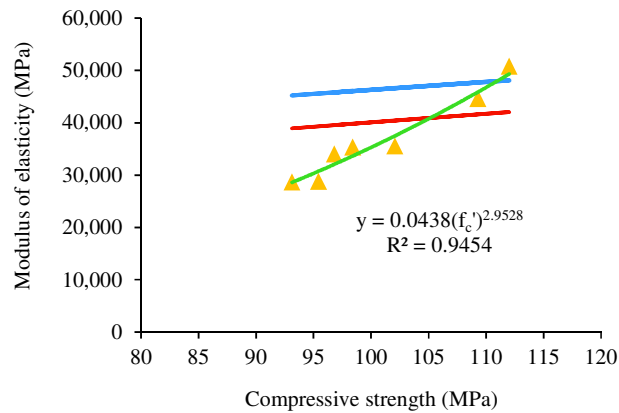


Figure 10. Regression analysis compressive strength and modulus of elasticity

Table 3. The compressive strength and modulus of elasticity in equation ACI

Temperature	Research (MPa)	Compressive strength (MPa)	ACI (MPa)	Equation 5	Difference (%)
27°C	44.631	109.28	41.606	45.801	9.16
60°C	35.004	99.08	39.946	34.294	16.48
90°C	51.400	111.43	41.946	48.513	13.53
120°C	28.764	93.07	38.928	28.508	36.55

Table 4. Relation of compressive strength and modulus of elasticity in equation CEB

Temperature	Research (MPa)	Compressive strength (MPa)	ACI (MPa)	Equation 6	Difference (%)
27°C	44.631	109.28	47.711	45.801	9.16
60°C	35.004	99.08	46.177	34.294	16.48
90°C	51.400	111.43	48.021	48.513	13.53
120°C	28.764	93.07	45.224	28.508	36.55

3.13. Regression Analysis Compressive Strength and Flexural Strength

Regression analysis and modulus of elasticity at 28 days are described in Figure 11. Figure 11 is a regression analysis of the modulus of elasticity and flexural strength obtained by the coefficient of determination (R^2) is 0.9729. The flexural regression equation is flexural strength and the modulus of elasticity is as follows:

$$E_c = 219741e^{0.0729 f_L} \quad (8)$$

where:

E_c' = modulus of elasticity (MPa)

f_L = flexural strength (MPa)

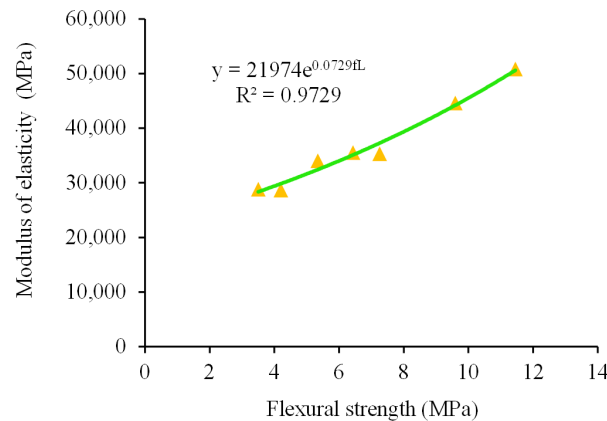


Figure 11. Regression analysis flexural strength and modulus of elasticity

4. Conclusion

The conclusions obtained from the results of research that has been done are as follows:

1. Effect of the use of temperature variations on curing the mechanical properties of RPC obtained include:
 - a. Composition of concrete mixtures with $w/c = 0.23$ obtained values slump flow from four directions, namely 60 cm, 59 cm, 60 cm, and 61 cm. The average value of slump flow with $w/c = 0.23$ which is 60 cm.
 - b. The test results time setting RPC show the results initial setting obtained in this study with $w/c = 0.23$ that is 154 minutes and the final setting is 233 minutes.
 - c. The results of the compressive strength testing showed that the compressive strength of maximum RPC age 7 days and 28 days at 90°C curing temperature was obtained at 60.06 MPa and 111.44 MPa. The test results of the minimum compressive strength of RPC aged 7 and 28 days at a curing temperature of 120°C were obtained at 43.74 MPa and 93.08 MPa. This is because at the maintenance temperature at a temperature of 90°C the CSH bond and the pore are denser compared to 27°C , 60°C and 120°C so that the compressive strength increases. In addition, the temperature that is too high 120°C makes the compressive strength low because there are many pores and the formation of many C-H so that it does not have an impact on the matrix bond. As for other factors that affect the compressive strength, the use of silica fume on RPC concrete makes the concrete more brittle because the porosity of the cement is smaller so that the compressive strength of the concrete increases.
 - d. The test results showed that the maximum modulus of elasticity of RPC at 28 days at 90°C curing temperature was 51,400 MPa. The results of the RPC minimum compressive strength of 28 days at a curing temperature of 120°C RPC were obtained at 28,764 MPa. So, the conclusion obtained based on the results of the study that the higher the temperature, the lower the modulus of elasticity. This is because, at a temperature of 90°C a more compact concrete composition is produced so that the modulus of elasticity achieved is high while too high a temperature can cause incomplete hydration processes and cause cracks in the concrete.
 - e. The test results showed that the maximum tensile strength of RPC at 28 days at a curing temperature of 90°C was 6.19 MPa. The test results of the minimum RPC compressive strength of 28 days at a curing temperature of 120°C RPC were obtained at 3.39 MPa. This is because at a temperature of 90°C the pore diameter is very small compared to 27°C , 60°C , 90°C and 120°C so that the steel fibre and silica fume are acting as an RPC can increase the density and tensile strength of concrete.

- f. The test results showed that the flexural strength of maximum RPC at 28 days at a curing temperature of 90°C was obtained at 10.82 MPa. The results of the RPC minimum flexural strength of 28 days at a curing temperature of 120°C RPC were obtained at 4.08 MPa. The temperature of 90°C has a slight pore compared to the 27°C so that the concrete is very dense and there are few cracks such as microcrack on concrete while at a temperature of 120°C large pore diameter and many C-H bonds so that the concrete is not compact and occurs spalling. In addition to temperature factors, the use of steel fibre in this study also serves to increase the flexural strength of RPC concrete.

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