Experiment and Analysis of Thermal Conductivity of Marine Concrete with Different Composition

Qingzhang Zhang 1,2*, Shuanzhu Tian 1, Kangzong Li 1 and Zhongyuan Li 1

1 College of Civil Engineering and Architecture, Henan University of Technology, Zhengzhou, Henan, 450001, China
2 Key Laboratory of Performance Evolution and Control for Engineering Structures (Tongji University), Ministry of Education, Shanghai, 200092, China

*Corresponding author’s e-mail: zqz313@163.com

Abstract. The thermal conductivity and porosity of marine concrete with different composition were measured by transient plane heat source method. The effects of aggregate volume fraction, sand ratio and water-cement ratio on thermal conductivity of marine concrete were investigated. Through the analysis of these factors and the comparison with other scholars, it is found that the thermal conductivity of marine concrete increases with the increase of aggregate volume fraction, decreases with the increase of sand ratio and water-cement ratio.

1. Introduction

The corrosion of steel bars in reinforced concrete, the corrosion of chloride ions in concrete in marine environment and the carbonation of concrete are all related to the temperature field in concrete, which is one of the key factors affecting the durability of concrete structures [1-3]. The thermal conductivity of concrete is an important parameter to characterize its thermal conductivity and determine its internal temperature field. At the same time, it is the key parameter of energy-saving design of thermal insulation concrete material and the important technical index of temperature control of mass concrete structure. The results show that the water-cement ratio of concrete, aggregate type and its volume fraction, sand ratio are the key factors affecting the thermal conductivity of concrete [4-7]. In this paper, the transient plane heat source method was used to determine the thermal conductivity of concrete with different aggregate volume fraction, different sand ratio and different water-cement ratio. The influence of aggregate volume fraction, sand ratio and water-cement ratio on the thermal conductivity of concrete was investigated.

2. Heat transfer test in concrete

2.1. Experimental Setup

Transient plane heat source method (TPS) is a new method for measuring thermal conductivity. The thermal resistive material is used to make a plane probe, which acts as a heat source and a temperature sensor. The relationship between the thermal resistance coefficient and the resistance is linear, it is that the loss of heat can be known by knowing the change of the resistance, which reflects the thermal conductivity of the sample.
2.2. Experimental Material
Xiujian 42.5 ordinary portland cement was used, which density is 3.06 g/cm$^3$. Density of mineral powder is 2.89 g/cm$^3$, and other parameters meet the specification requirements. Fine aggregate was made of medium sand with good gradation. Density of fine aggregate is 2.623 g/cm$^3$. Gravel was used as coarse aggregate to purchase in Zhengzhou Market and density is 2.71 g/cm$^3$.

2.3. Preparation and testing of specimens
The pouring size of the specimen is 150 mm × 150 mm × 150 mm. After molding, it was cured for 28 days in a standard curing room at temperature of 20°C and a humidity of 95% or more. After curing, each block was cut into three pieces of 150 mm × 150 mm × 50 mm, which are matched with the one shown in Table 1.

| Type        | Number | Water-binder ratio | Volume fraction (%) | Sand ratio (%) |
|-------------|--------|--------------------|---------------------|----------------|
| Aggregate   | C-1    | 0.45               | 0.203 0.147 0.232 0.418 0.650 | 35 |
|             | C-2    | 0.45               | 0.261 0.189 0.196 0.354 0.550 | 35 |
|             | C-3    | 0.45               | 0.319 0.231 0.16 0.290 0.450 | 35 |
|             | C-4    | 0.45               | 0.377 0.273 0.125 0.225 0.350 | 35 |
| Sand ratio  | S-1    | 0.45               | 0.261 0.189 0.196 0.354 0.55 | 35 |
|             | S-2    | 0.45               | 0.261 0.189 0.251 0.299 0.55 | 45 |
|             | S-3    | 0.45               | 0.261 0.189 0.307 0.243 0.55 | 55 |
|             | S-4    | 0.45               | 0.261 0.189 0.362 0.188 0.55 | 65 |
| Water-binder ratio | W-1 | 0.35               | 0.233 0.217 0.196 0.354 0.55 | 35 |
|             | W-2    | 0.45               | 0.261 0.189 0.196 0.354 0.55 | 35 |
|             | W-3    | 0.55               | 0.282 0.168 0.196 0.354 0.55 | 35 |
|             | W-4    | 0.65               | 0.299 0.151 0.196 0.354 0.55 | 35 |

3. Experimental results and analysis
3.1. Experimental results
In the experiment, three blocks of the same sample were selected, the random four positions in the two random blocks were measured, and the average value of the four times of measurement results was taken. The results are shown in the following Table 2. The porosity results were obtained by mercury injection test. Due to the small porosity of coarse aggregate, only cement mortar was taken for sampling during mercury injection test, and the porosity of concrete itself is characterized by the porosity of mortar. In the design of mix ratio, only the difference of coarse aggregate volume exists in the concrete with different aggregate volume fraction, and the partial mix ratio of mortar is the same, so only a group of porosity measurements are taken. Different ratio of water to cement and sand Ratio represent different mix ratio of mortar, so the influence of microcosmic parameters on thermal conductivity was analyzed with the different porosity. The results of thermal conductivity measurement are shown in Table 2.
Table 2. Test results for thermal conductivity of concrete

| Block | Temperature | Result 1 | Result 2 | Result 3 | Result 4 | Average Value | Porosity |
|-------|-------------|----------|----------|----------|----------|---------------|----------|
| C-1   | 0.65        | 1.7359   | 1.6825   | 1.8326   | 2.1047   | 1.839         |          |
| C-2   | 0.55        | 2.0136   | 1.5108   | 1.5869   | 1.7761   | 1.722         | 0.1983   |
| C-3   | 0.45        | 1.5434   | 1.9724   | 1.6342   | 1.4784   | 1.657         |          |
| C-4   | 0.35        | 1.8066   | 1.6898   | 1.4624   | 1.3289   | 1.572         |          |
| S-1   | 0.35        | 1.6742   | 1.6205   | 1.8749   | 1.7014   | 1.718         | 0.1114   |
| S-2   | 0.45        | 1.7042   | 1.4707   | 1.5552   | 1.6319   | 1.591         | 0.1141   |
| S-3   | 0.55        | 1.4712   | 1.7977   | 1.4028   | 1.3546   | 1.507         | 0.1085   |
| S-4   | 0.65        | 1.2279   | 1.672    | 1.5511   | 1.3524   | 1.451         | 0.1065   |
| W-1   | 0.35        | 1.7431   | 2.3155   | 2.0155   | 1.8874   | 1.990         | 0.1018   |
| W-2   | 0.45        | 1.5288   | 1.7085   | 1.8112   | 2.0596   | 1.777         | 0.1148   |
| W-3   | 0.55        | 1.7001   | 2.0167   | 1.6018   | 1.5416   | 1.715         | 0.1303   |
| W-4   | 0.65        | 1.5356   | 2.0057   | 1.4761   | 1.3358   | 1.588         | 0.1503   |

3.2. Effect of aggregate volume fraction on thermal conductivity

The effect of volume fraction of aggregate on thermal conductivity is shown in figure 1 under the condition of 28°C and dry environment.

![Figure 1. Effect of aggregate volume fraction on thermal conductivity.](image_url)

It can be seen from figure 1 that the thermal conductivity of the specimen increases with the increase of the volume fraction of the aggregate, because the heat conductivity of the concrete depends on the multiphase transfer system composed of coarse aggregate, mortar, and gas in the pore. The thermal conductivity of coarse aggregate granite is about 2.5W/(m·K) -2.7W/(m·K), and that of cement mortar is about 1.0W/(m·K) -1.5W/(m·K). The thermal conductivity of water is about 0.5W/(m·K). Therefore, the thermal conductivity of coarse aggregate takes up the highest proportion in the overall thermal conductivity of concrete, and the content of coarse aggregate has the greatest influence on the overall thermal conductivity of concrete, so the concrete with high aggregate content has a high...
thermal conductivity.

3.3. Influence of sand volume fraction on thermal conductivity

It can be seen from figure 2 that the thermal conductivity of concrete tend to decrease gradually with the increase of sand ratio. Because the total aggregate volume and water-cement ratio remain unchanged. The more the amount of sand are added, then the amount of coarse aggregate is lower. The study of 3.1 shows that the thermal conductivity is the lower with reduced the volume of coarse aggregate. Although with the increase of the amount of sand, the mortar is wrapped the sand uniformly. As a whole, because of the cement content and the water-cement ratio keeping unchanged, the porosity of the concrete decrease with the increase of the amount of sand. But the thermal conductivities of water and air in pores and mortar are much lower than that of coarse aggregate. The reduction of coarse aggregate still plays a leading role in reducing the thermal conductivity of concrete. So the sand ratio is the larger, the overall thermal conductivity of concrete is the lower.

![Figure 2. Influence of sand volume fraction on thermal conductivity.](image)

![Figure 3. Comparison of different researchers [8-10].](image)

It can be seen from the data that although the porosity has increased and decreased, the overall fluctuation is between 10.65% and 11.41%, and the overall fluctuation is relatively small. The most important influence on the thermal conductivity test results is still due to the decrease of the amount of coarse aggregate. Of course, it can be clearly seen from the test data that when the sand ratio increases from 35% to 45%, the increase of porosity leads to speed up for the increase of thermal conductivity. When the sand ratio is greater than 45%, the porosity decreases and the thermal conductivity slows down.

For the thermal conductivity of concrete, a large number of scholars have done relevant research, as shown in figure 3. Different research methods have been used for different types of concrete, and the laws are roughly the same. As the sand ratio increases, the thermal conductivity of the concrete decreases. Liu's research shows that the concrete is compacted by reasonable mix ratio under the appropriate sand ratio, which leads to the heat conduction of concrete increase first and then drop. However, the mixture ratio is close for Liu choosing, so the overall fluctuation is not obvious. This is not in conflict with the results of the author's research results. In this paper, the results of different porosity to caused by different sand ratios are studied and compared, and the change of porosity to caused by reasonable sand ratio is obtained, which affects the variation of the decreasing rate of thermal conductivity. And then compared with Li, Xing and others, the test results are reasonable and reliable.
3.4. Influence of water-cement ratio on thermal conductivity

As can be seen from figure 4, with the increase of water-cement ratio, the thermal conductivity of concrete become lower. When other conditions remain unchanged, the thermal conductivity of water is lower than that of cement. When water-cement ratio is higher with the less the amount of cement, overall thermal conductivity is lower. In addition, with the increase of water-cement ratio, the internal porosity of concrete is the larger, the proportion of conductivity for water and air thermal to the overall thermal conductivity is the greater. Because the thermal conductivities of water and air are the lower, the overall thermal conductivity is the lower. The results of porosity measurement show that the porosity of concrete increases linearly with the increase of water-cement ratio. Therefore, when the volume of coarse aggregate remains constant, the content of cement has the greatest influence on the thermal conductivity. The higher the cement content, the higher the thermal conductivity, and with the increase of water-cement ratio, the concrete becomes porous and the large pores are mostly. This leads to the increase of water and air in the pore, so the greater the water-cement ratio, the lower the thermal conductivity.

![Figure 4. Influence of water-cement ratio on thermal conductivity.](image1)

![Figure 5. Comparison of different researchers [6,8-9,11].](image2)

Regarding the influence of water-cement ratio on the thermal conductivity of concrete, many scholars have studied different concrete types, as shown in figure 5. It can be seen that the influence of water-cement ratio on the thermal conductivity of concrete is consistent under different research conditions from the research results for different concrete types. The thermal conductivity decreases with the increase of water-cement ratio. Considering the type of concrete studied and the different testing methods (the author used the transient planar heat source method, and other researchers mostly used the thermal method of the protective plate, the water state of the tested parts is different when they are measured, and the effect on the results is different). There are differences in the values of specific test results, but the overall law is the same.

4. Conclusion

1. The volume fraction of aggregate has the greatest influence on the thermal conductivity of marine concrete. The thermal conductivity increases monotonously with the increase of aggregate volume fraction. The larger the volume fraction of marine concrete aggregate, the thermal conductivity of concrete is greater.

2. The sand content has a great influence on the thermal conductivity of marine concrete. When the other mixing ratios are the same, the thermal conductivity of marine concrete decreases monotonously with the increase of sand content. The higher the sand ratio, the lower the thermal conductivity of the marine concrete.
3. The water-cement ratio has great influence on the thermal conductivity of marine concrete. Under the same aggregate volume fraction and sand ratio, the thermal conductivity of marine concrete decreases monotonously with the increase of water-cement ratio. The larger the water-cement ratio, the higher the porosity and the smaller the thermal conductivity.

4. Compared with other scholars' studies on the influence of sand ratio and water-cement ratio on thermal conductivity, compared with other types of concrete, the effect of sand ratio and water-cement ratio on thermal conductivity is lesser different and the overall law is the same.

Acknowledgments
This study is financially supported by the National Natural Science Foundation of China (Grant No. 51509084), the Foundation of Key Laboratory of Performance Evolution and Control for Engineering Structures (Tongji University), Ministry of Education (Grant No. 2018KF-2), the Fundamental Research Funds for the Henan Provincial Colleges and Universities in Henan University of Technology (Grant No. 2017RCJH03).

References
[1] Chen, Z.Y. (2013) Safety, Durability and Crack Control of Concrete Structures. China Architecture & Building Press, Beijing.
[2] Jin, W.L., Zhao, Y.X. (2015) Durability of Concrete Structures. Science Press, Beijing.
[3] Xu, Q., Yu, H.Y., (2008) Study and Practice on Durability of Large Marine Concrete Structures. China Architecture & Building Press, Beijing.
[4] Kim, K.H., Jeon, S.E., Kim J.K., (2003) An experimental study on thermal conductivity of concrete. J. Cement and Concrete Research, 33(3): 363-371.
[5] Khan, M. I. (2002) Factors affecting the thermal properties of concrete and applicability of its prediction models. J. Building and Environment, 37(6): 607-614.
[6] Xiao, J.Z., Song, Z.W., Zhang, F. (2010) An Experimental Study on Thermal Conductivity of Concrete. J. Journal of Building Materials, 13(1): 17-21.
[7] Marie, I. (2017) Thermal conductivity of hybrid recycled aggregate-Rubberized concrete. J. Construction and Building Materials, 133(15): 516-524.
[8] Li, L., Liu, W.D., Li, Q.T. (2011) An experimental study on thermal conductivity of air-entraining concrete. J. Journal of Hebei University of Engineering (Natural Science Edition), 28(3): 17-20.
[9] Liu, W.D., Tian, B., Hou, Z.Y. (2012) Experimental study on thermal conductivity of concrete. J. Journal of China & Foreign Highway.
[10] Xing, Y.S. (2012) Study on thermal conductivity of concrete. D. Tongji University.
[11] Sun, H.P., Yuan, Y.S., Jiang, J.H. (2009) Experimental study on thermal conductivity of the surface layer concretes. J. Concrete,(5): 59-61.