Research progress of tunnel air-tight concrete

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Abstract. With the quick development of transportation network construction, the tunnel construction has been an important part. During the tunnel construction process, especially in the gas zone, gas leaking has been a common problem. For avoiding gas leakage, it is necessary to enhance the air-tightness of the tunnel concrete, air-tight concrete is a kind of concrete with excellent air tightness performance. In this paper, we introduced the research progress of tunnel air-tight concrete, including the effect of mix ratio, composition on the air-tight performance of tunnel concrete and corresponding characterization methods.

1 Background

In recent years, the rapid development of economic construction and the western region of large construction further implement in China make traffic infrastructure construction develop rapidly, especially in the construction of roads and railways. Concrete as one of the most important materials in engineering, the usage amount of concrete is extremely huge. However, due to the difference of the regional geological terrain and environment, the demanding of concrete, such as strength, durability and other requirements are increasing, especially in its durability.

Due to the rapid development of construction in the west of China, tunnel under construction and crossing the gas zone have become an inevitable problem. If the gas in the rock is leaking through the tunnel lining, and accumulates to a certain concentration, it may induce to a serious gas explosion. The main component of gas is methane, when the volume concentration of methane in the air reaches 5%~6%, the methane will cause the explosion. Therefore, various protective measurements should be taken to prevent the gas leakage in tunnels. Like the corrosion resistance of concrete in various erosion environments are proposed, the air tightness of concrete is also one of the important indicators to investigate the durability of concrete, especially for tunnel concrete.

2 The influencing factors of tunnel concrete's airtightness

For improving the air tightness of concrete, it is necessary to consider the type of cement, the clay content, maximum particle size of aggregate, water to cement ratio, curing age and so on.

Impact of water cement ratio on concrete confidentiality. The water binder ratio is an important index in evaluating the air tightness of concrete. In order to reduce the porosity of concrete, the concrete with low water binder ratio should be considered first to reduce the capillary pore of concrete. In addition, the water binder ratio can also affect the workability of concrete, thereby affecting the air tightness of concrete. Excessive water binder ratio will cause the concrete slump to drop, while too small water binder ratio will affect the workability of concrete. With the increase of water binder ratio, the air permeability coefficient of concrete will increase significantly, especially when the water binder ratio reaches 0.45, so the effect of admixture is more obvious when the water binder ratio is small. Liu [1] has studied the effect of water/cement ratio and mineral admixture' dosage on the air tightness of tunnel concrete. They found that when the water/cement ratio was higher than 0.42, the air permeability of concrete increased obviously, which would result in a poor air tightness of concrete. Moreover, the mineral admixture also influenced the air tightness of concrete, when the dosage of mineral admixture was over 25%, the air permeability would decrease markedly.

Kou [2] has studied the effect of air-tight agent on the permeability of tunnel concrete, it can be found that for C30 air-tight tunnel concrete, with the dosage of air-tight agent dosage increasing, the air-tightness performance of concrete would increase significantly. Moreover, the sand ratio of tunnel concrete should be lower than 45.7%.

Wang [3] studied the dosage of air-tight agent dosage on the air permeability of tunnel concrete, he found that when the dosage of air-tight agent was 6.05%, the concrete had the lowest air permeability, and the dosage of air-tight agent did not influence the concrete's air content and workability.

Porosity is an important component of concrete, which has an important impact on the performance of concrete. The air tightness of concrete is directly related to its porosity. However, there are few studies on the relationship between pore structure and concrete permeability. From some research results, the air tightness

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of concrete is related to porosity, but it is not a simple function

The air tightness of concrete depends on the connectivity of the internal porosity. Based on this, the pore structure of concrete can be densificated to improve the air tightness of concrete. Adding water reducing agent to concrete can improve the structure of cement mortar to a certain extent, and the use of cement with silica fume can also significantly improve the air tightness of concrete.

According to the influence of admixture on the confidentiality of concrete, the air permeability coefficient of concrete will increase with the addition of fly ash, which is mainly due to the contact between fly ash and aggregate. Although the fly ash will increase the volume of the hole, the low early strength of the fly ash causes the air tightness of the concrete.

The concrete with fly ash shows better air tightness can be attributed to the introduced fly ash reduces the bleeding of concrete, which can be evenly distributed inside macrostructure of the concrete and improve the structural composition of concrete holes. Silica fume also has positive effect on the improvement of the air tightness and impermeability of cement concrete. When the water binder ratio is unchanged, adding silica fume can improve the compactness at the interface of concrete aggregate, reduce the gap in the mixture, and improve the air tightness of concrete.

The sand ratio also make effects on the air tightness of concrete. The sand ratio has a direct impact on the fluidity of concrete. Increasing the sand ratio can improve the workability of concrete in the pumping process. However, the increase of sand ratio will directly affect the drying shrinkage of concrete. With the increase of sand ratio in concrete, the air tightness of cement concrete will be increased. When the total sand ratio of concrete reaches a certain value, the air tightness of concrete will be significantly increased. Generally, the sand ratio of air tight concrete is about 38%~42%.

The influence of admixture on the air tightness of cement concrete. Water reducing agent is an additive commonly used in cement concrete, which can reduce the water binder ratio of concrete on the premise of ensuring the compactness of concrete. Thus, the gas permeability of concrete is reduced. Concrete surfactant can also increase the bonding property between concrete aggregate and binder, thus reducing the air permeability of concrete.

Effect of air permeability pressure on air permeability coefficient of concrete. Through relevant indoor tests, it can be found that when the air tight pressure value of concrete is increased from 0.3 MPa to 0.6 MPa, the air permeability coefficient of concrete will decrease, which indicates that the air permeability coefficient of concrete measured with large seepage pressure is smaller at the same time. Therefore, in the process of studying the air tight concrete of gas tunnel, appropriate test pressure should be selected in combination with the gas concentration, pressure and other conditions at the construction site.

Water binder ratio is the main factor to control the compactness of concrete. The research results of the original gas tight concrete of Dongjiashan Gas Tunnel show that when the water binder ratio is reduced from 0.55 to 0.49, the compressive strength of concrete is increased from 33.1 MPa to 37.4 MPa, and the air permeability coefficient of concrete is increased from 0.88×10^{-11} cm/s.

Gradually reduce to 0.60×10^{-11} cm/s. TB 10424-2010 stipulates that the water binder ratio of concrete should not exceed 0.45, otherwise the air permeability coefficient of concrete cannot meet the design requirements.

The amount of air sealing agent has a great influence on the air permeability of concrete. When the content of air sealing agent increases from 4% to 8%, the air permeability coefficient of concrete changes from 1.12×10^{-11} cm/s gradually decreases to 0.50×10^{-11} cm /s. The optimum dosage shall be determined through multiple tests.

The sand ratio has a great influence on the properties of concrete mixture and hardened concrete. In a certain range, the air permeability coefficient of concrete decreases gradually with the increase of sand ratio. The sand ratio of air tight concrete shall not be less than 36%. The sand ratio shall be as large as possible under the condition of meeting other performance indexes of concrete to improve the air tightness of concrete.

3 Testing methods

At the same time the airtightness measurements have also became an important part of modern building evaluation process. The measurement can help to evaluate the quality of the air tightness of concrete, which helps to reduce the energy consumption of the building. A few studies have reported the test method of permeability of concrete and rocks in labs [4–6] as well as in situ [7–9], and they reported that concrete permeability could change, depending on the details of the test conditions, such as water–cement ratio [10, 11], moisture content [12, 13], temperature [14], cement preparation methods [15], measuring scale [16] and so on. Thus, the concrete permeability, which is the most critical parameter for air tightness assessment. The air tightness of concrete can be measured through indoor tests. The measuring devices include air compressor, air tank, impermeability meter and measuring instrument. The measuring principle uses the relevant contents of Darcy's seepage law. Place the test piece in the sealed mold, apply 0.3 MPa and 0.6 MPa air pressure to the concrete, keep the pressure stable for 8 hours, and record the measured value.

There are some other common methods to determine the air-tight performance of concrete:

3.1 Constant pressure method

In this test method, the working pressure is unchanged, the air tightness index is the time needed for a certain amount of gas to flow through the specimen or the volume of gas to flow through the specimen in a certain time. This testing method is suitable for the common specimens.

3.2 Variable pressure method

In this test method, the pressure gradient is stable and the amount of air flowing through the specimen is monitored within a specified time interval. This method is suitable for box-shape specimen.

Previous researchers have studied the void ratio of ordinary concrete by constant pressure method. They found that the ordinary concrete's air tightness index K$\geqslant 10^{-3}$ (cm^3▪cm). Other researchers studied the effect of water/cement ratio on the air tightness of concrete and found that the air tightness index was increased with the water/cement ratio increasing (when the W/C is 0.4, the K=2×10^{-10}~7.5×10^{-11} cm/sec. However, when the W/C is 0.7, the K=5.8×10^{-3}~1.0×10^{-9} cm/sec). Li et. al found that the diffusion coefficient of methane in concrete is similar with the air. They showed the same magnitude, so it is reasonable to use the air tightness index of air to show the methane's air tightness index.

3.3 Research on construction technology of air tight concrete

Influence of mixing time on the performance of air tight concrete. The sufficient mixing process of concrete is the key link to ensure the air tightness of concrete. Through the research on the mixing time in the actual construction process, it can be found that when the concrete mixing time reaches about 3 minutes, the air tightness of the concrete is the best. If the mixing time is too long, the water in the concrete will evaporate, which will reduce the air tightness of the concrete.

Effect of standing time on the performance of air tight concrete. Pumping concrete is generally used in the construction of gas tunnels, which requires consideration of the influence of the static time of air tight concrete on its performance. Air tight concrete will produce certain segregation during transportation, and cement concrete will also start to try partial hydration heat. These concrete quality problems will have a certain impact on its air tightness. In general, the longer the standing time of concrete is, the lower the air tightness of concrete will be. Generally, the air tightness of concrete can be effectively guaranteed if the standing time of air tight concrete is kept within 45 minutes, so the concrete pouring shall be completed within 45 minutes as far as possible during the construction of air tight concrete.

Effect of vibration time on the performance of air tight concrete. Vibration is an important means to ensure the compactness of concrete during concrete construction. At present, the vibration methods for concrete are mainly for ordinary concrete, while ordinary vibration operations may not be suitable for air tight concrete. From the actual situation, the air permeability of air tight concrete is still relatively high after 10 s of vibration time, and the air tightness of concrete will be significantly improved when the vibration time reaches about 20~30 s. At the same time, it can also be predicted that the longer the vibration time of air tight concrete is, the better its air tightness will be. However, long-term vibration will cause the aggregate to sink and cause segregation. Therefore, in the actual construction process, the mixing time of air tight concrete should be determined comprehensively according to the actual situation.

Influence of concrete strength on the performance of air tight concrete. On the whole, there is a good linear relationship between the strength of concrete and the air tightness of concrete. This is mainly because the strength of concrete is directly affected by the internal porosity. With the occurrence of cement hydration heat, the internal porosity of concrete can be filled, which improves the strength of concrete and reduces the permeability of concrete. From the strength of concrete, there is a natural logarithmic curve between the strength curve and the permeability coefficient of concrete after 28 days of curing. However, the strength of air tight concrete will be improved when adding additives or admixtures, but the change of its air permeability coefficient may show different trends. Specific analysis should be made on the relationship between the strength and air tightness of air tight cement concrete with admixtures

4 Summary

Summary of previous researches, the type of cement, aggregate gradation and silt content, the maximum particle size of aggregate, water/cement ratio, curing age, admixture, etc., all of these factors have different influence degrees on the air tightness of concrete. However, in this research field, only a few scholars have done some research on the basic theory of concrete air tightness and the influencing factors of air tightness. In their researches, they proposed some detection methods. However, their results have not formed the standard, and the relating research data and results are limited.

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