Study on the influence of the shape and size of coarse aggregate on the strength of concrete

Ya Guo*, Jianfeng Wu, Caihua Wang, Fang Zhang

Department of Architecture and Engineering, Qinhuangdao College, Northeast Petroleum University, Qinhuangdao, Hebei, 066004, China

*Corresponding author’s e-mail: guoya2019@163.com

Abstract: Concrete is the largest building material at present, and coarse aggregate as one of the important materials of concrete, its performance will have an important impact on the performance of concrete. Firstly, the effect of coarse aggregate on the length of concrete is analyzed, then the influence of morphology, particle size and content of coarse aggregate on the performance of concrete is analyzed, and the existing problems are pointed out. All these work provide a basis for improving the performance of concrete and lays a foundation for optimizing the mix design.

1. Introduction

Concrete is the largest building material at present. It is a kind of multiphase composite material. Its strength depends on the interface strength between cement paste, coarse aggregate and cement paste. Coarse aggregate is the skeleton of concrete. According to statistics, coarse aggregate can account for 50%-70% of the volume of concrete. It will affect the theological properties of fresh concrete and the mechanical properties and durability of hardened concrete. In recent years, due to the shortage of natural sand resources, people have strengthened the research on fine aggregates, making the production and use of machine-made sand develop rapidly, but still not enough attention has been paid to coarse aggregates [1].

Nowadays, with the super-high-rise and large-scale of concrete engineering, the use of high-strength concrete is more and more widely. In high-strength concrete, coarse aggregate is relatively the weak link. The characteristics of coarse aggregate itself, such as type, particle shape and size, surface characteristics and gradation, have an important impact on the performance of both fresh concrete and hardened concrete. Therefore, it is necessary to thoroughly explore the influence of physical and chemical properties of coarse aggregate on the performance of concrete.

2. The role of coarse aggregate in concrete

Coarse aggregate is an important component of concrete. It was originally thought that coarse aggregate is an inert material. It is composed of concrete through the bonding effect of cement slurry and cement mortar. In fact, coarse aggregate is not inactive. its physical and chemical properties will have an impact on the performance of concrete. A well-known American concrete expert, once pointed out that the use of coarse aggregate as an inert filling material should be a question mark. It can summarize the research results of domestic and foreign scholars on the role of coarse aggregate in concrete as follows.
2.1. Rigid skeleton action of coarse aggregate
In the mix design of ordinary concrete, it is generally considered that the compressive strength of coarse aggregate should be about 2 times of the design strength of concrete, not less than 1.5 times of the design strength. The strength and modulus of elasticity of coarse aggregate are usually higher than that of cement paste. Its durability and volume stability are also the best among the components of concrete, and the volume of coarse aggregate is more than half of the volume of concrete, so it is coarse. Aggregate plays a role of rigid skeleton in concrete. When concrete is subjected to compressive load, its internal stress is transferred by coarse aggregate. When concrete is damaged under external load, cracks can hardly penetrate through coarse aggregate, but appear around coarse aggregate. Under certain conditions, concrete may absorb higher energy when it is damaged, thus improving the strength of concrete. This effect of coarse aggregate can not only improve the strength of concrete, but also increase the elastic modulus of concrete, reduce the deformation under load, improve the deformability of concrete, and make the volume stability and durability of concrete better than cement mortar [2].

2.2. Initiation and blocking effect of coarse aggregate on concrete cracks
The research shows that the essence of concrete compression failure is the result of the continuous expansion of existing structural defects in concrete under load. It can be seen from this that the coarse aggregate is used to initiate cracks in concrete. The unreasonable content of coarse aggregate in concrete mix proportion, the limitation of concrete construction technology and the shrinkage and creep of concrete will cause microcracks, bubbles and water bags under coarse aggregate in concrete before bearing load. These defects will damage concrete before reaching its strength. Coarse aggregate can limit the shrinkage of concrete and make its shrinkage value much smaller than that of cement mortar, which will lead to internal stress in concrete and micro-cracks. The magnitude and distribution of internal stress are related to the elastic modulus of concrete and coarse aggregate, and also to the size of coarse aggregate [3,4]. When the micro-cracks extend to coarse aggregate, it is difficult to pass through the coarse aggregate which is denser than the concrete matrix. Therefore, cracks usually need to bypass the coarse aggregate, so the crack propagation process may absorb more energy, which is the blocking effect of coarse aggregate on cracks.

2.3. Interaction between coarse aggregate and cement mortar
There is an interface transition zone between coarse aggregate and cement mortar matrix in concrete. Research shows that in many cases, the bond between the matrix and coarse aggregate is a weak link in concrete structure. Only when the surface of coarse aggregate is easy to bond with the mortar matrix, the strength of the interface transition zone may be high. Many properties of concrete are often related to the performance of interface transition zone. The change of void content of coarse aggregate mixture will change the volume filling rate of concrete, which will affect the number of interface transition zone, thus affecting the performance of concrete. Better surface structure of coarse aggregate also improves the strength and durability of concrete [5].

3. Influence of coarse aggregate on the performance of concrete

3.1. Effect of coarse aggregate types
The material, strength, modulus of elasticity, chemical composition and water absorption of aggregates may vary with different kinds of aggregates. It can consider the influence of aggregates on the performance of concrete from these aspects. The strength, deformability and water absorption of aggregates are closely related to the performance of concrete. The chemical composition of aggregates may react with cement mortar and have beneficial or adverse effects on concrete.

(1) Effect of strength and elastic modulus of coarse aggregate on properties of concrete
Coarse aggregate has a great influence on high strength concrete. In high strength concrete, the water cement ratio is usually less than 0.4. At this time, because the strength of mortar and the
interface between mortar and coarse aggregate is very high, it is the strength of coarse aggregate itself and its mineral characteristics that restrict the strength of concrete. In ordinary concrete, the water cement ratio is high, the strength of mortar and the interface strength between mortar and coarse aggregate are low. They are the weak areas of concrete, which restrict the strength of concrete, not coarse aggregate. The properties of coarse aggregate determine the compressive strength and elastic modulus of high strength concrete. If the strength of coarse aggregate is insufficient, which is equivalent to congenital defects, no matter what kind of remedy method is adopted, it is impossible to achieve better results. At present, there are few studies on the effect of elastic modulus of coarse aggregate on concrete strength. It is generally believed that the elastic modulus of coarse aggregate directly affects the strength and elastic modulus of concrete. Qian [6] et al. research that the effect of several coarse aggregates with different strength on the flexural strength of concrete with different mortar matrix strength was studied. The results show that the compatibility between the two has a significant effect on the flexural strength of concrete. When the strength and elastic modulus of coarse aggregate matches the matrix of cement mortar, the flexural strength of concrete can be improved. Therefore, the compatibility between matrix and aggregate should be taken into account when preparing concrete.

(2) Effect of water absorption of coarse aggregate on properties of concrete
Different kinds of coarse aggregates have different materials, different voids and different water absorption. The water absorption of coarse aggregate can affect the workability of fresh concrete. Chen et al. obtained the following conclusions by studying the influence of water absorption of coarse aggregate on concrete performance: water absorption of aggregate has a direct impact on the water consumption of concrete. When water absorption of gravel is more than 3%, the slump of concrete is obviously reduced and the loss is very fast. The water absorption of coarse aggregate also affects the properties of hardened concrete. The results show that the strength of calcareous limestone and dolomite is higher in ordinary concrete, because the porosity of these two aggregates is larger. They can absorb more water, reduce the water cement ratio around aggregate, improve the strength of interface transition zone, and then improve the strength of concrete. The aggregate with high water absorption is not easy to form a water bag under the aggregate, which improves the internal structure of concrete and thus improves the strength of concrete. In fact, water absorbed by aggregates with high water absorption can strengthen the later maintenance of concrete to a certain extent, when aggregates are equivalent to small water sources. The water absorption of coarse aggregate can also affect the durability of concrete, especially its freeze-thaw resistance.

(3) Effect of coarse aggregate chemical composition on concrete performance
The influence of chemical composition of coarse aggregate on concrete performance can be summed up in three aspects. On the one hand, for the active aggregate, it may react with the active material in the cement slurry at the interface to produce hydrated calcium carbonate, aluminate and other substances that can increase the interfacial strength. Li [7] et al. research shows that coarse aggregate is one of the most important factors affecting the high temperature performance of concrete, and the anti-explosion property of calcium aggregate concrete is better than that of silica aggregate concrete.

3.2. Effect of aggregate shape and surface state
The morphology of coarse aggregate has significant influence on the performance of fresh concrete and hardened concrete. The ideal particle shape of mixed concrete is close to sphere or regular polyhedron. Needle-flake aggregate will increase the void ratio and specific surface area of aggregate, which will easily increase the water absorption of aggregate surface, and then affect the fluidity of fresh concrete. At the same time, needle-flake aggregate is easy to be directionally arranged in the mixing and vibration process of concrete, which will lead to the strength of concrete. Generally speaking, the impact of the shape of the needle-like aggregate on the flexural strength of concrete is greater.
Yu [8] et al. studied the influence of coarse aggregate on the performance of concrete by grey correlation method. It was pointed out that the content of needle-like particles had the most obvious effect on the chloride ion penetration resistance of concrete. The results show that, in terms of strength alone, there is an optimum content of needle-like particles in concrete, and the optimum content of needle-like particles is 12%. The coarse aggregate of concrete can be divided into pebble and gravel.

The surface of gravel is rough and has high chemical activity, which is easy to bond with mortar. The surface of pebble is smooth, Ca(OH)$_2$ crystallization orientation is good, Ca(OH)$_2$ adhered to the surface is thicker, which deteriorates the structure of interface transition zone. Therefore, the strength of gravel concrete is higher than that of pebble concrete under the same water-cement ratio. At the same time, there are a certain number of needle-like particles in the gravel, and the surface of the gravel is not smooth, so in terms of workability, the workability of the pebble concrete is better than that of the gravel concrete when the water-cement ratio is the same, as shown in Figure 1.

![Figure 1. Strength reduction of concrete with excessive flaky particles in coarse aggregate](image)

3.3. **Effect of coarse aggregate size and particle gradation**

People have done a lot of research on the influence of the maximum size of coarse aggregate on the performance of concrete, but due to the complexity of the problem itself, no good conclusion has been achieved. For low-strength concrete, the effect of maximum aggregate size is not significant; for high-strength concrete, the effect of maximum aggregate size is greater. At this time, the use of small-size stones is conducive to improving the structure of interface transition zone. Increasing the content of coarse aggregate with a diameter of 20mm in concrete increases the slump of concrete and decreases its compressive strength. The compressive strength of concrete is increased with the improvement of the maximum diameter of coarse aggregate. When the maximum diameter of coarse aggregate is more than 20mm, the compressive strength is decreased slightly. Generally speaking, the impact of aggregate size on high strength concrete is significant. Through experimental study, it is found that there is particle size effect in concrete, which has a significant impact on medium and high strength concrete. Figure 2 shows the coarse aggregate of different sizes.

In another, particle gradation of aggregate is the key to concrete preparation. When aggregate particles are poorly graded concrete, slurry, bone and water must be separated and analyzed during construction. It is difficult to pour and form. Finally, it will lead to honeycomb, dog hole and hemp surface of finished concrete, which will reduce the strength of concrete and affect its durability. The coarse aggregate with good gradation has small porosity, large bulk density and good quality of concrete.
3.4. Effect of coarse aggregate dosage

The volume stability and strength of coarse aggregate are better than that of mortar, and the price of coarse aggregate is lower than that of cement. Therefore, increasing the amount of coarse aggregate appropriately can reduce the shrinkage and creep of concrete, improve the durability of concrete, and reduce the cost of concrete. However, the amount of coarse aggregate should not be too high. Otherwise, too little paste will affect the workability and interfacial bonding strength of concrete, and reduce the strength and durability of concrete. Therefore, the influence of the amount of coarse aggregate in concrete on the performance of concrete has attracted great attention of researchers. Xing et al. pointed out that the strength of concrete increases with the increase of the volume of coarse aggregate in a certain volume range. When the volume of coarse aggregate is 30%–40%, the performance of concrete is the worst. As shown in Figure 3, the coarse aggregate in concrete is not mixed evenly by fine aggregate and cement slurry, which will cause the segregation of concrete.

4. Conclusion

Coarse aggregate plays the role of skeleton and initiating and preventing cracks in concrete. Its type, surface state, maximum particle size, gradation and dosage will affect the performance of concrete. Generally speaking, coarse aggregate is the factor that restricts the strength of high-strength concrete. For ordinary concrete, simply increasing the strength of coarse aggregate can not improve the strength of concrete. The coarse aggregate with good gradation has small specific surface area, high compact density and small porosity. The concrete prepared under the same water cement ratio has good workability, durability and high strength, and can save cement consumption, which has good economic benefits.

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