

Chapter 2

Important Raw Material—Coarse Aggregate

Aggregate is a very crucial raw material for preparing concrete, especially coarse aggregate, which greatly affects the concrete performance. Concrete performances, such as frost resistance, permeability resistance, drying shrinkage, and durability, are closely related with aggregate. This chapter focuses on a summary and research on this question by utilizing different kinds of rock distributed in most parts of China.

Rock, employed in concrete as coarse aggregate, is a kind of material which distributes widely. Rock can be divided into three types—sedimentary rock, igneous rock, and metamorphic rock. Different kinds of rocks have different impacts on concrete.

2.1 Aggregate Varieties and Causes Overview

Different aggregates have different formation mechanism. In order to make it clear about the question, we ought to explain from engineering geology.

Figure 2.1 has described briefly the formation process of sedimentary rock, igneous rock, metamorphic rock, various rock names commonly used in concrete engineering, and probable formation zone.

Figure 2.1 is simplified from the engineering geology textbooks according to practical demands of concrete project by the author. Some parts may not be very consistent with the principles of geology, mainly for the purpose of making concrete workers to understand the formation and evolution process of rock concisely and clearly. This is of great meaning for us to finish qualified concrete works.

1. Sedimentary rock

Among sedimentary rocks, the commonly used rock in concrete engineering is limestone, which is one of the most typical kinds of sedimentary rocks. Compared to the other rocks, limestone has a wider distribution and larger reserves and was formatted by died animal skeleton that was sedimented in ancient sea or lake. As the animal skeleton is rich in calcium ion, the main composition of limestone

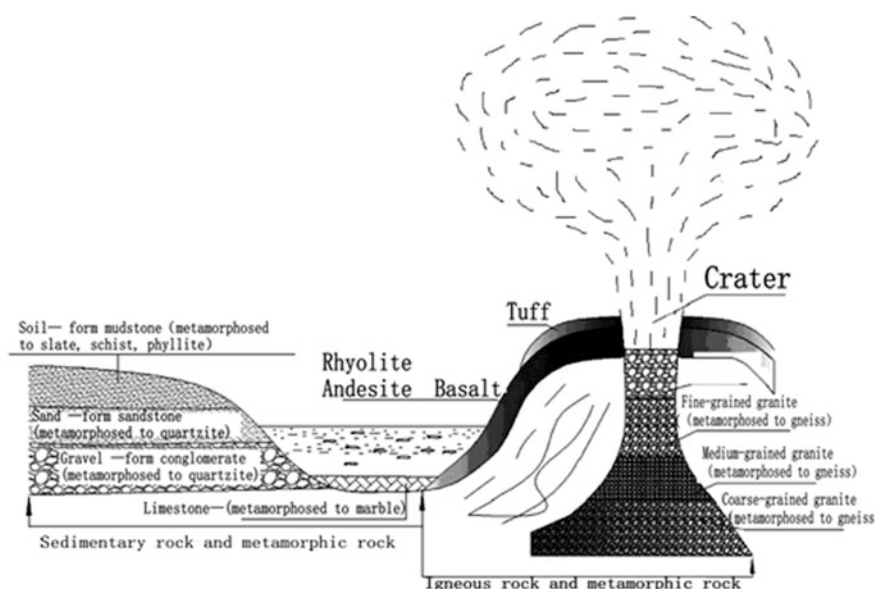


Fig. 2.1 Schematic diagram of formation process of sedimentary rock, igneous rock, and metamorphic rock

is CaCO_3 . Sometimes, limestone is called calcareous limestone, magnesia limestone, and siliceous (argillaceous) limestone.

Sandstone is another typical sedimentary rock, including lake sedimentation and sea sedimentation. Owing to different formation causes, the color and density of sandstone remarkably vary from each other. As sedimentary and diagenetic time is short, most sandstone in China possesses poor mechanical property and therefore cannot be utilized for concrete aggregate. For example, sandstone, distributed in Shaoguan in Guangdong Province, Enshi in Hubei Province, northern Shanxi, is unable to be utilized as coarse aggregate for compressive strength is too low. The author has never adopted sandstone as coarse aggregate and only found few usage of sandstone in China as aggregate on some data. Sandstone and limestone are shown in Figs. 2.2 and 2.3.

2. Igneous rock

Igneous rock can be divided into rapid cooling (magma ejected to ground, such as basalt), slow cooling, and temporarily uncooled (magma buried deep in the earth's surface which are not ejected out, such as medium-grained or coarse-grained granite) according to the differences in magma chemical composition, ejection time, and cooling degree. As a result, performance gap between different igneous rocks can be very remarkable, just as shown in Fig. 2.4. Fine-grained granite in Taishan Mountain of China is a typical igneous rock, of which the density and strength are very high.



Fig. 2.2 Sandstone (*left*) and limestone (*right*)

Fig. 2.3 Sandstone in Shaoguan, Guangdong Province



Granite is the most common igneous rock. It is not extrusive rock but a kind of acid rock. Granite is generated by long time cooling of magma from volcano bottom to crater during the process of volcanic eruption. According to the length of cooling time, different sizes of macroscopic crystalline particles sequentially formed from volcano bottom to crater are called fine, medium, coarse-grained granite, respectively.

The appearance of basalt is dark gray. Although it is also igneous rock and extrusive rock, it is formed by rapid cooling of magma ejected to ground during the process of volcanic eruption. Andesite and rhyolite are formed simultaneously for containing different amount of other minerals. They are collectively referred to as extrusive rock. These rocks are ejected from underground instantly with thousands of degrees Celsius, and the temperature drops sharply after they reach the ground, thus, the formed rocks have the characteristics of dense and solid. The most typical and standard basalt is six prism, such as basalt in Zhangzhou of Fujian Province and Jining of Inner Mongolia, as shown in Fig. 2.5. Partial parts of basalt in some places



Fig. 2.4 Basalt (*left*), coarse-grained granite (*middle*), and medium-grained granite (*right*)



Fig. 2.5 Basalt in Zhangzhou, Fujian Province

have visible pores, such as Haikou of Hainan Province. Basalt in most parts of China has the characteristics of high density and low water absorption.

Andesite is a kind of extrusive rock and has an appearance of dark gray. It distributes more in the surface layer of Northeast and Inner Mongolia in China, which is also one of the most commonly used aggregates in concrete.

Diabase belongs to igneous rock but is not extrusive rock. It is formed by the condensation of volcanic magma under deep geological formations. Due to relatively higher content of CuSO_4 , the appearance is suffused with green. It is also one of the most commonly used aggregates in concrete.

Tuff is a kind of rock which is generated by the landing decomposition of dust erupted into the air when volcano erupts. It exposes more in the vicinity of Shanghai and Zhejiang.

3. Metamorphic rock

When sedimentary rock and igneous rock had been formed, they would begin to metamorphose after a long-term geological effect and form metamorphic rock. We can consider that both rock and human beings can be seen as iterative process from birth to death. When the rocks had been formed, they would form metamorphic rock after a process of long-term evolution, such as limestone, and it would turn into marble after a long-term evolution, as shown in Fig. 2.6. The case is similar to granite. Granite is formed under the ground when volcano erupts, and it will turn

into gneiss after a long-term evolution, as shown in Fig. 2.7. Gneiss is more widely distributed in China. Foundation of the Three Gorges Dam is on gneiss. Any rocks exposed to air will turn into soil after long-term weathering and corroding. The soil will turn into sedimentary rocks back again after a long-term evolution. That is why soil in Northeast of China is entirely black, while it is all red in Southern China.

Based on engineering experiences obtained in more than 20 different provinces and cities, rocks exposed to the earth's surface are mostly granite, limestone, and basalt. Andesite and diabase distribute more widely in local areas. Rock in northeast area is mainly basalt and andesite; that in Xinjiang area is mainly basalt; that in Haikou in Hainan Island is mainly basalt; Sanya area is mainly granite; that in Shanghai, Zhejiang, Hangzhou, and Ningbo areas utilizes tuff more commonly; that in Shanxi, Shanxi, Henan, Hubei, and many southern areas is mainly limestone; and that in many parts in Inner Mongolia (especially in eastern areas) is mainly diabase.

Fig. 2.6 Marble



Fig. 2.7 Gneiss



2.2 Effects of Different Rock Aggregates on Performance of Concrete

2.2.1 Effects on Strength

In the previous concrete theory, aggregate, especially the strength of coarse aggregates is listed as one of the 3 factors governing concrete strength (the other two are W/C and bonding strength between cement paste and aggregate). But, in guiding modern concrete, the theory has a large deviation.

The results obtained by the author at Altay and Urumchi airport in Xinjiang before 2000 are listed in Table 2.1, namely, strengths of concrete when adopting three different kinds of crushed stone including limestone, granite, and basalt.

In recent years, experiments were carried out by using limestone and granite aggregates repeatedly under the same condition at airports all over the country, especially at the new Baiyun Airport in Guangzhou. The results had showed that the strengths of different concretes were close under the same condition. Since the twenty-first century, the author had found that various coarse aggregates that meet the requirements of specification had no significant effects on strength of concrete below C60. Some other scholars and experts in China had gained the same conclusion after experimental research. The book named *High Performance Concrete* written by Academician Wu Zhong-wei and Professor Lian Hui-zhen revealed that the strength of coarse aggregate is not very important for concrete ranging from C50 to C80. A university teaching book mainly edited by Professor Wen Xin-yun hold the view that aggregate strength has little influence on concrete strength of normal concrete.

Why do so many changes occur? The author believes that there are mainly three following factors.

- (1) The previous manufacture method for aggregate is jaw-crushing, and the contents of the elongated and flaky particles is excessive so that many aggregates are affected by bending and pulling factors when the coarse aggregate is under stress. Therefore, the flexural-tensile strength of the coarse aggregate has a great influence on concrete strength. The most typically coarse-grained granite, with a structure of phaneromer particle, will increase the compressive strength when the flexural-tensile strength is lower. But from the late twentieth century to the beginning of twenty-first century, Hammer and impact crushers were employed in important projects in China, which had reduced the contents of elongated and flaky particles greatly. Meanwhile, the particle of coarse aggregate trended to be finer, decreasing the effects (especially negative effects) of coarse aggregate on concrete strength.
- (2) Cement particles get finer and finer, improving the bonding status between cement paste and aggregate.
- (3) Before 1990s, W/C of concrete was basically above 0.5, and redundant water centralized mainly around the aggregate after cement hydration, generating weak interface around the coarse aggregates.

Table 2.1 Strengths of concrete which is prepared by three different kinds of crushed

Number	Rock name	Cement content/kg	W/C	Sand ratio/%	Experiment class number <i>n</i>	Freeze–thaw times <i>n</i>	Average compressive strength/MPa	Average flexural strength/MPa
1	Granite	320	0.45	31	9	78	56.09	5.97
2	Limestone	320	0.44	32	9	157	50.34	6.84
3	Basalt	320	0.44	32	9	251	51.01	7.72

Table 2.2 Classification chart of rock quality grade

Property Grade	Apparent specific gravity/ (g/cm ³)	Absorption/% (0.5–2 cm)	Rock quality grade	7-day soaking compressive/ MPa	Representative rock
First class	More than 2.80	Below 0.6	Excellent	More than 300	Basalt, etc.
Second class	More than 2.68	Below 1	Fine	More than 100	Limestone, diabase, fine-grained granite, etc.
Third class	More than 2.55	Below 1.2	Normal	More than 100	Coarse-grained granite, siliceous and carbonaceous rock with lower strength, etc.

2.2.2 Effects of Rock Mechanical Property on Other Performances of Concrete

According to researches conducted by domestic and overseas experts, mechanical properties of coarse aggregate (particularly aggregate density) have influences on drying shrinkage, creep, and temperature crack of concrete to different degrees. Previous studies confirmed that cracking possibility of concrete prepared by aggregate with low density is much bigger than that of concrete prepared by aggregate with high density. Some similar conclusions on the drying shrinkage are also drawn in foreign countries. Besides, it was indicated that elastic modulus of aggregate had important effect on concrete creep [1].

What is more, the expansion coefficient of coarse aggregate affects concrete temperature crack. Temperature crack possibility of concrete prepared by granite aggregate with a high expansion coefficient is much bigger than that prepared by limestone and basalt aggregate with a low expansion coefficient. Even in many data of durability in China, the application of aggregates with high expansion coefficients, such as granite, is required to avoid. The author disagrees with the viewpoint, since at least 20 percent of projects accomplished in China mainland adopt granite as aggregate, however, we have never found that the durability is poorer than that of concrete with other aggregates.

2.3 Two Different Opinions

2.3.1 Different Opinions About Rock Strength Requirement in Specification

Various specifications in China have proposed diverse requirements of rock strength according to different rock types [2], because people may cherish the

illusion that effect of rock with higher compressive strength is superior to that of rock with lower compressive strength. In fact, the question is rather complex. Particularly the compressive strength of granite may be higher than that of limestone under the same condition, while other effects of granite on concrete performance are worse than those of limestone. However, granite and limestone are aggregates with relatively larger demand in concrete engineering. Therefore, the author believes that it is inaccurate to classify the quality of rocks in this way. It is suggested to judge the quality of rocks according to their density and absorption, just as shown in Table 2.2. Despite of some demerits in judging elastic modulus of limestone, this method is accurate in other aspects.

2.3.2 Utilization of Gravel

No evidence can prove that durability of gravel is poorer than that of crushed stone though this viewpoint is prevalent in the academic field. Gravel was adopted as a coarse aggregate in projects finished before 1980s by the author, but no signals indicated that gravel concrete deteriorated faster than concrete prepared with crushed stone so far. Gravel was commonly used as a coarse aggregate in the projects of airport runways built before 1980s by the civil aviation. Some runways are still in use after 40 or 50 years, and are not found to be destroyed faster than concrete prepared with crushed stone.

Opinions that consider gravel is poorer than crushed stone may be due to the following illusion: destruction of gravel concrete is basically around the smooth surface of gravel when carrying out compressive experiment on concrete specimen.

The author comparatively and experimentally investigated the concrete below C60, and found that except the 7-day strength, there is no prominent difference in 28-day compressive strength between gravel concrete and crushed stone concrete. In fact, a number of advantages of gravel superior to those of crushed stone are neglected. Gravel with particle size ranging from 0.5 to 4 cm which is most commonly used in project possesses characteristic of lower void content compared with crushed stone. Gravel can exhibit greater superiority than crushed stone in some special engineerings, such as underwater cast-in-place pile and open caisson of bridge, etc [3].

In order to obtain the same strength, utilizing gravel as aggregate can greatly reduce W/C and cement consumption as well as improve the slump of concrete. In any engineering, slump and slump flow under the action of vibration of gravel concrete are much larger than those of crushed concrete at the same W/C.

It is unreasonable to compare gravel concrete with crushed concrete under the same condition and the same W/C. What we should do is to compare the concretes under the condition of same slump because the concrete with the same slump is generally prepared in the practical construction. According to the author's experiences, when preparing a same strength grade concrete at construction site, W/C and cement consumption can be decreased to some extent if employing gravel as aggregate.

In Gobi desert area like Xinjiang, gravel is a local material. Affected by the viewpoints of some experts that durability of gravel is not good enough, people have to accomplish some important projects by excavating the mountain and exploding the rock from dozens of kilometers away to produce aggregate, therefore, not only the project cost drastically rises, and project is delayed, but also the environment is destroyed. Nowadays, protecting environment is more and more focused on, so we should advocate adopting gravel as aggregate, especially in northwest Gobi desert region.

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