Contents

Chapter 1

Structural Material — Concrete

Section A

Concrete is a mixture of **cement**, **aggregates** and water, with any other admixtures which may be added to modify the **placing** and **curing** processes or the ultimate physical properties. Initially when mixed, concrete is a plastic material, which takes the shape of the **mould** or **formwork**. When hardened, it may be a dense load-bearing material or a lightweight thermally insulating material, depending largely on the aggregates used. It may be reinforced or prestressed by the incorporation of steel.

Most concrete is crushed and recycled at the end of its useful life, frequently as hard core for new construction work. However, a growth in the use of recycled aggregates for new concrete can be anticipated, as this will have a significant environmental gain in reducing the demand on new aggregate extraction.

Concrete Composition

Cement

Portland cement may be manufactured from any of a number of raw materials, providing they are combined to yield the necessary amounts of lime, iron, silica, and alumina.[1] Lime is commonly furnished by limestone, **marble**, marl, or seashells. Iron, silica, and alumina may be obtained in the form of clay or shale. The exact **ingredients** used depend on what is readily available, and the recipe varies widely from one **geographic** region to another, often including slag or flue dust from iron furnaces, chalk, sand, ore washings, bauxite, and other minerals. The selected constituents are crushed, ground, proportioned and **blended**, then conducted through a rotating kiln at temperatures of 2600 to 3000 degrees Fahrenheit (1400 to 1650℃) to produce clinker. After cooling, the clinker is pulverized (along with a small amount of gypsum to retard the curing process) to a powder finer than flour. This powder, **Portland cement**, is either packaged in bags or shipped **in bulk**.

Aggregates and Water

Because aggregates make up roughly three-quarters of the **volume** of concrete, the structural strength of a concrete is heavily dependent on the quality of its aggregates. Aggregates for concrete must be strong, clean, resistant to freeze-thaw deterioration, chemically stable, and properly graded for size. An aggregate that is dusty or muddy will contaminate the cement paste with inert particles that weaken it, and an aggregate containing any of a number of chemicals from sea salt to organic compounds can cause problems ranging from **corrosion** of reinforcing steel to retardation of the curing process and ultimate weakening of the concrete. A number of standard **ASTM** laboratory tests are used to assess the various qualities of aggregates.

Mixing water for concrete must be free of harmful substances, especially organic material, clay, and salts such as chlorides and sulfates. Water suitable for drinking is generally suitable for concrete.

Admixtures

Ingredients other than cement, aggregates, and water are often added to concrete to alter its properties in various ways.

Air-Entraining Admixtures. Air-entraining admixtures may be put in the mix, if they are not already in the cement, to increase workability of the wet concrete, reduce freeze-thaw damage, or in larger amounts, to create very light weight nonstructural concretes with thermal insulating properties.

Water-Reducing Admixtures. Water-reducing admixtures allow a reduction in the amount of mixing water while retaining the same workability, while results in a higher strength concrete.

Accelerating Admixtures. Accelerating admixtures cause the concrete to cure more rapidly, and retarding admixtures slow its curing to allow more time for working with the wet concrete.

Fly Ash. Fly ash, affine powder that is a waste product from coal-fired power plants, increases concrete strength, decreases **permeability**, increases sulfate resistance, reduces temperature rise, reduces mixing water, and improves pump ability and workability of concrete.

Silica Fume. Silica fume, also known as micro-silica, is a kind of powder that is approximately 100 times finer than Portland cement, consisting mostly of silicon dioxide. When added to a mix, it can be used to produce extremely high-strength concrete that also has a very low permeability.

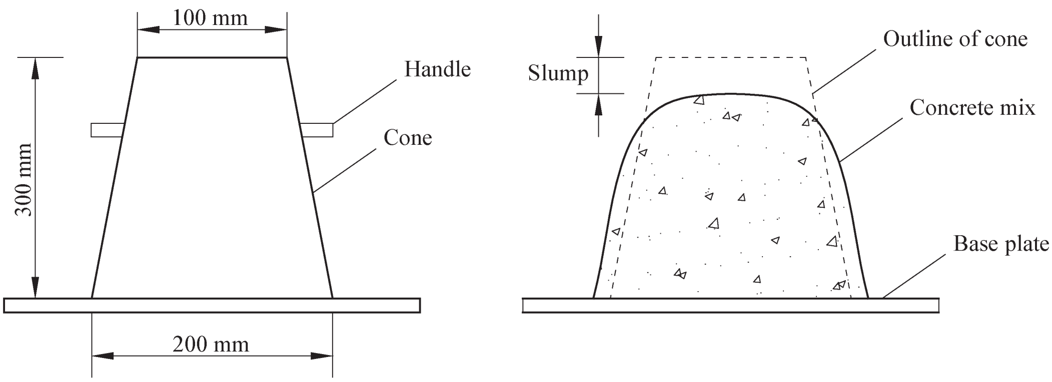
Blast Furnace Slag. Blast furnace slag is a by-product of iron manufacture that can improve concrete workability, increase strength, reduce permeability, reduce temperature rise, and improve sulfate resistance.

Properties of Concrete

Workability

The term workability is used to describe the ease or difficulty with which the concrete is handled, transported and placed between the forms with minimum loss of homogeneity. However, this gives a very loose description of this vital property of concrete which also depends on the means of compaction available. For instance, the workability suitable for mass concrete is not necessarily sufficient for thin, inaccessible or heavily reinforced sections. The compaction is achieved either by ramming or vibrating. The workability, as a physical property of concrete alone irrespective of a particular type of construction, can be defined as the amount of useful internal work necessary to produce full compaction.[2]

In the workability of concrete mixture, various tests are developed. Tests such as flow test and **compaction** test are used mostly in laboratory. The **slump test**, which is commonly used in the field, is briefly described below. It should, however, be remembered that numerous attempts have been made to correlate workability with some easily determinable physical measurement. Although they may provide useful information within a range of variation in workability but none of these tests is fully satisfactory. At the same time, the slump test does not measure the workability of concrete. It is simply useful in detecting variations in the uniformity of a mix of given nominal **proportions**.



(a) The cone filled with concrete paste

(b) The settled paste after the cone is removed

Fig. 1–1 Slump Test

Compressive Strength

It may be defined as the maximum compressive load that can be taken by concrete per unit area. It has been shown that with special care and control, concrete can be made to bear loads as high as 80 N/mm^2 or even more. In practice, however, concrete with compressive strength between 10—50 N/mm^2 can be easily made on the site for common type of construction.

The compressive strength also called the crushing strength of concrete is determined by loading axially cube shaped (or cylindrical shaped) specimens made out of the concrete. The tests are carried out 3 days, 7 days and 28 days after the casting of the samples. It is the 28 days compressive strength which is taken as a standard value for concrete of a particular batch.

Tensile Strength

Plain concrete (without **steel reinforcement**) is quite weak in tensile strength which may vary from 1/8 to 1/20 of the ultimate compressive strength. It is primarily for this reason that steel bars (reinforcement) are introduced into the concrete at the laying stage so as to get a concrete which is very strong in compression as well as in tension.[3] In plain concrete, tensile strength depends to a great extent on the same factors as the compressive strength does.

Tensile strength of concrete becomes an important property when it is to be used in road making and runways. It is determined by using indirect methods.

Durability of Concrete

It refers to that concrete can resist the influence of exterior corrosive substance and maintain good usability and complete appearance so that it can maintain the safety and usability of the structure.[4] That is to say, concrete can maintain stable quality after being used for a long time.

Anti-Permeability. It refers to the ability to resist the permeability from compressive water. It is one of the most important symbols of durability. It influences the anti-freezing and anti-corrosion of the concrete directly.

It is necessary for any of the various **voids** in concrete to become filled with water before any of the deteriorating mechanisms of freezing and thawing operate. **Gel pores** are too small to significantly contribute to permeability, and the air voids are not connected. It is the capillary voids that become filled with water and permit the ingress of **moisture** into concrete. They tend to rise and collect under particles of aggregate, thus providing channels for water to **penetrate**. The **capillary porosity** can be reduced by reducing the amount of uncombined water in the Portland cement paste. Low water-cement ratios and low mixing-water content will reduce permeability. Although normal amounts of entrained-air voids increase the porosity of concrete, they do not tend to increase permeability. Being larger, spherical disconnected voids, they tend to stop capillary flow through concrete.

Freezing Resistance. It refers to that concrete can resist circles of freezing and thawing after saturation with water. Concrete in cold region should have strong anti-freezing ability after contacting with water or suffering from freezing. The density, pore's quantity and structure and water filling are all the important factors regarding to anti-freezing.

Carbonation / Neutralization. When calcium hydroxide, $Ca(OH)_2$, is exposed to the air, it will react with CO_2 and form $CaCO_3$. Calcium hydroxide is one of the hydration products of Portland cement and is available to react with CO_2 in the atmosphere. This process occurs slowly and is not usually important in hardened concrete with the possible exception of dimensional instability of lightweight masonry units.

Carbonation can be a serious problem when freshly placed concrete floors are exposed to excessive concentrations of CO_2. This problem occurs frequently when open-flame space heaters, used to prevent freezing, exhaust the oxygen in the air and leave excessive concentrations of CO_2. This produces a soft inferior layer on the surface of the concrete.

$$Ca(OH)_2+CO_2+H_2O=CaCO_3+2H_2O$$

Alkali-Aggregate Reaction. The volume of sodium silicate hydrate gel is over 3 times than that of the admixture, leading to expending crack. Reaction conditions: (1) cement with high alkali content; (2) active aggregate; (3) water.

$$Na_2O+SiO_2+nH_2O \rightarrow Na_2O \cdot SiO_2 \cdot nH_2O$$

The Varieties of Concrete

High Density Concrete

The concrete whose unit weight ranges from about 3360 — 3840 kg/m^3 and which is about 50 percent higher than the unit weight of normal concrete is known as high density concrete.

The high density concrete is mainly used in the construction of radioactive shields. High density concrete is made by using such a heavy weight aggregate whose specific gravity is more than 3.5. The aggregates used in this type of concrete should be clean, strong, inert and relatively free from deleterious material. Normally barite, magnetite, limonite are used to make high density concrete. To produce high density and high strength concrete, it is necessary to control the water-cement ratio, correct admixture and **vibrators** for good compaction.

Light Weight Concrete

Natural stone aggregate concretes typically have densities within the range 2,200 to 2,500 kg/m^3, but where densities below 2,000 kg/m^3 are required, then an appropriate light weight concrete must be used. The three general categories of light weight concrete are: light weight aggregate concrete, aerated concrete, and no-fines concrete.

Light Weight Aggregate Concrete. By replacing the usual mineral aggregate by cellular porous or light weight aggregate, light weight aggregate concrete can be produced. Light weight aggregate can be classified into two categories namely natural and artificial light weight aggregate.

Aerated Concrete. By introducing gas or air bubbles in **mortar**, aerated concrete can be produced. This concrete is a mixture of water, cement and finely crushed sand with air or gas introducing agents.

There are several ways in which aerated concrete can be manufactured. One important way is using finely powdered metal (usually aluminum powder) to form air bubbles. Chemical reaction takes place in the concrete and finally large quantity of **hydrogen** gas is liberated which gives the cellular structure.

No-Fines Concrete. No-fines concrete is manufactured from single sized aggregate (usually between 10 and 20 mm) and cement paste. Either dense or light weight aggregates may be used, but care has to be taken in placing the mix to ensure that the aggregate remains coated with the cement paste. The material should not be vibrated. Drying shrinkage is low, as essentially the aggregate is stacked up within the formwork, leaving void spaces; these increase the thermal-insulation properties of the material in comparison with the equivalent dense concrete. The rough surface of the cured concrete forms an excellent key for rendering or sound penetration. Dense aggregate no-fines concrete may be used for load-bearing applications.

Polymer Concrete

The incorporation of pre-polymers into concrete mixes, the pre-polymers then polymerizing as the concrete sets and hardens, can reduce the penetration of water and carbon dioxide into cured concrete. Typical polymers include styrene-butadiene rubber. Epoxy resin and acrylic-latex modified mortars are used for repairing damaged and spalled concrete because of their enhanced adhesive properties. Similarly, polymer-modified mortars are used for the cosmetic filling of blowholes and blemishes in visual concrete.

Fiber Reinforced Concrete

Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking.[5] Due to its poor tensile strength, internal micro cracks are present in concrete which leads to **brittle fracture**. To improve the tensile strength of concrete one of the method used is that of the conventional reinforced steel bars, and the other way is introducing fibers in the concrete and thereby increasing the inherent tensile strength of concrete. In order to reduce the micro cracks addition of small, closely spaced and uniformly dispersed fibers are used. These fibers act as crack arrester and substantially improve its static and dynamic properties. This type of concrete is known as Fiber Reinforced Concrete (FRC). Some of the fibers used are steel fibers, **polypropylene**, **nylons**, asbestos, coir, glass and carbon. The property of concrete may vary depending upon the type, diameter, length and volume of fibers.

Steel fiber is one of the most commonly used fibers. In many cases, round fibers are used. The diameter of such fibers may vary from 0.25—0.75 mm. The use of steel fibers may improve the flexural, impact and fatigue strength of concrete.

Ultra High Performance Concrete

Ultra high performance concrete (UHPC) has six to eight times the compressive strength of traditional concrete. It is produced from a mixture of Portland cement, crushed quartz, sand, silica fume, super plasticizer, fibers and water with no aggregates larger than a few millimeters. Wollastonite (calcium silicate) filler may also be included in the mix. The fibers most frequently used are either high strength steel for maximum strength or polyvinyl acetate (PVA) of approximately 12 mm in length for lower load applications. The concrete can be cast into traditional moulds by gravity or pumped or even injection cast under pressure. When cast into traditional moulds, the material is self-leveling, so only slight external vibration of the formwork may be required to ensure complete filling.[6] The material is designed for use without steel reinforcement bars.

The enhanced compressive and **flexural** strengths of ductile fiber-reinforced ultra high performance concrete enable lighter and thinner sections to be used for structural components such as shell roofs and bridges, creating an enhanced sleek aesthetic. A high quality durable surface is produced from appropriate moulds coated with proprietary release agent.

Notes

[1] Portland cement may be manufactured from any of a number of raw materials, providing they are combined to yield the necessary amounts of lime, iron, silica, and alumina. 只要能组合产生足量的石灰、氧化铁、二氧化硅和氧化铝，任何数量的原材料都可以制造出硅酸盐水泥。

[2] The workability, as a physical property of concrete alone irrespective of a particular type of construction, can be defined as the amount of useful internal work necessary to produce full compaction. 和易性，可定义为充分压实所需的有用的内部工作的总量，它仅仅作为混凝土的一个物理性质，和特定结构类型无关。

[3] It is primarily for this reason that steel bars (reinforcement) are introduced into the concrete at the laying stage so as to get a concrete which is very strong in compression as well as in tension. 主要是因为混凝土在铺设阶段加入钢筋，可以使得混凝土同时具有较强的抗压和抗拉性能。

[4] It refers to that concrete can resist the influence of exterior corrosive substance and maintain good usability and complete appearance so that it can maintain the safety and usability of the structure. 这是指混凝土抵抗环境介质作用，并保持良好的使用性能和外观完整性，从而维持混凝土结构安全、正常使用的能力。

[5] Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. 普通（素）混凝土具有非常低的抗拉强度，塑性和抗裂性较差。

[6] The concrete can be cast into traditional moulds by gravity or pumped or even injection

cast under pressure. When cast into traditional moulds, the material is self-leveling, so only slight external vibration of the formwork may be required to ensure complete filling. 混凝土可以通过重力或泵甚至是在压力下喷射而浇筑到传统模板中。当浇筑到传统模板，材料是自流平，因此模板只需要轻微的外部振动就可能确保完全填充。

New Words

concrete /kɒŋ'kriːt/ *n.* 混凝土

cement /sɪ'ment/ *n.* 水泥；接合剂

aggregate /'æɡrɪɡeɪt/ *n.* 集料；骨料

placing /'pleɪsɪŋ/ *v.* 浇筑；铺设

curing /'kjʊərɪŋ/ *n.* 养护

mould /məʊld/ *n.* 模具

formwork /'fɔːmwɜːk/ *n.* 模板

marble /'mɑːbl/ *n.* 大理石；大理石制品

ingredient /ɪn'ɡriːdɪənt/ *n.* 材料；（混合物的）组成部分

geographic /dʒɪə'ɡræfɪk/ *adj.* 地理的；地理学的

blend /blend/ *v.* 混合

portland cement 硅酸盐水泥；波特兰水泥

in bulk 散装；整批；大批；大量

volume /'vɒljuːm/ *n.* 量；体积

corrosion /kə'rəʊʒən/ *n.* 腐蚀；腐蚀产生的物质

ASTM: 美国材料试验学会(American Society for Testing Materials)；美国材料试验标准 (American Standard for Testing Materials)

admixture /əd'mɪkstʃə/ *n.* 外加剂；掺合料

air-entraining admixtures 引气剂

water-reducing admixtures 减水剂

accelerating admixtures 速凝剂

fly ash 火山灰

permeability /ˌpɜːmɪə'bɪlətɪ/ *n.* 渗透性

silica fume 硅粉

blast furnace slag 高炉矿渣

workability /ˌwɜːkə'bɪlətɪ/ *n.* 和易性

compaction /kəm'pækʃən/ *n.* 密实度；压紧；密封

slump test 坍落度试验；流动性试验

proportion /prə'pɔːʃn/ *n.* 比例；均衡

compressive strength 抗压强度
tensile strength 抗拉强度
steel reinforcement 钢筋
durability /ˌdjʊərə'bɪlətɪ/ *n.* 耐久性；耐用年限
anti-permeability 抗渗性
voids /vɔɪdz/ *n.* 孔洞；空隙率
gel pore 凝胶孔
moisture /'mɔɪstʃə/ *n.* 水分；湿度；潮湿
penetrate /'penɪtreɪt/ *v.* 渗透
capillary porosity 毛细孔隙
freezing resistance 抗冻性
carbonation /kɑːbə'neɪʃən/ *n.* 碳化作用；碳酸盐化
alkali-aggregate reaction 碱骨料反应
high density concrete 重混凝土
vibrator /vaɪ'breɪtə/ *n.* 振动器
light weight concrete 轻混凝土
aerated concrete 加气混凝土
mortar /'mɔːtə/ *n.* 砂浆
hydrogen /'haɪdrədʒən/ *n.* 氢
no-fines concrete 无砂混凝土
polymer concrete 聚合物混凝土
fiber reinforced concrete 纤维强化混凝土
brittle fracture 脆性破坏
polypropylene /ˌpɒlɪ'prəʊpəˌliːn/ *n.* 聚丙烯
nylon /'naɪlɒn/ *n.* 尼龙；聚酰胺
ultra high performance concrete 超高性能混凝土
flexural /'flekʃərəl/ *adj.* 弯曲的；曲折的

Exercises

▶ I. Translate the following expressions into English, or vice versa.

1. 承重材料
2. 化学稳定性
3. 缓凝剂
4. 坍落度
5. 素混凝土
6. 碱骨料反应
7. 干缩
8. 化学反应
9. 微裂缝
10. 结构构件
11. concrete composition
12. concrete mixture

13. maximum compressive load
14. axial load
15. reinforced concrete
16. anti-freezing
17. lightweight masonry units
18. high density concrete
19. polymer-modified mortars
20. water-cement ratio

▶ II. Translate the following sentences into Chinese.

1. Concrete is the universal material of construction. The raw materials for its manufacture are readily available in every part of globe, and concrete can be made into buildings with tools ranging from a primitive shovel to a computerized precasting plant.

2. Size of aggregate is important because a range of sizes must be included in each concrete mix to achieve close packing of the aggregate particles.

3. The quality of cured concrete is measured by any of several criteria, depending on the end use of the concrete.

4. Concrete has no useful tensile strength and was limited in its structural use until the concept of steel reinforcing was developed.

5. As a further check on quality, a slump test may be performed at the time of pouring to determine if the desired degree of workability has been achieved without making the concrete too wet.

▶ III. Answer the following questions according to the passage.

1. Describe the composition of concrete.

2. What is high density concrete and where is it mainly used?

3. What is compressive strength of concrete?

4. Briefly explain the different types of light weight concrete and list its advantages.

5. Explain how to measure the workability of the concrete mixture.

Section B

Why Concrete?

The use of concrete and cement based building products in low-rise construction has risen sharply in the past 20 years. Concrete walls have long dominated foundations, but above-grade they have grown from an estimated 3 percent of single-family homes in 1994 to 16 percent in 2004. They have jumped in commercial construction as well. A few years behind the growth in walls has witnessed a similar growth in concrete floors and roofs.

Stucco remains one of the most popular of all exterior wall finishes. Fiber-cement siding has grown from nothing to about 10 percent of all lapped siding in North America over the past 25 years. Concrete roof tile has grown from nearly zero to several percent of the coverings for pitched roofs in the same period.

Among landscape products retaining walls were nonexistent in 1980. Now they make up about half of the retaining walls surrounding new low-rise buildings. Concrete flatwork came seriously into use on the lots of small buildings after World War, and now it is estimated to make up over 50 percent of the drives and walkways were under 1 percent of the paving, and now they are believed to be over 10 percent.

The growth in these materials is projected to continue.

Why has this happened? The answer is that there have been important changes in both supply and demand. On the supply side, there have been dramatic improvements in concrete, concrete products and the systems that use them. These have made the concrete options more economical, easier to use, higher performing, and more aesthetic. On the demand side, buyers have rising incomes, and they are using some of that money to buy better buildings, to comfort, energy efficient, durable, low maintenance, and distinctive looking. All of these are inherent properties of concrete. So the market is shifting to the sort of product that concrete has been all along.

Supply

Some developments in concrete chemistry give the material new properties. Others reduce concrete's cost without compromising its desirable properties. There are now exceptionally high-strength concretes, lightweight concretes filled with air bubbles, and concretes containing wood fibers for flexure and ease of cutting and nailing.

The possible aesthetics of concrete have grown dramatically. Pigments permit concrete to take any color of the rainbow. Concrete stains provide subtle gradations in color. Surface treatments, such as stamping, fracturing, sandblasting, retarding, tumbling, and grinding, create a wide range of finish textures that give concrete the look and feel of natural materials like stone or novel and high-tech looks nor available on any other construction material.

New accessory produced the cost and increased the variety of shapes and products that can be created out of concrete. Examples are formwork make of foam, steel forms optimized for above-grade walls, steel joists that bond with concrete flatwork to create with composite action, rubber molds that give concrete the exact shape and texture of natural stone, and machines designed to mold small objects like tiles, and paving stones efficiently.

Advances in concrete formulas have made it possible to use more recycled material. This helps reduce cost and makes concrete a more environmentally friendly material. Concrete suppliers have learned to incorporate waste products from other industrial processes. They include fly ash from the coal burned in power plants and slag from such processes as iron and steel production. Concrete masonry and precasting plants now regularly grind their waste material and put it back into the mix instead of discarding it.

During all this time the price of basic concrete has remained relatively stable. In contrast, some other materials have experienced both price increases and declines in availability. The stands of large trees that are easily harvested in North America are dwindling. As a result, the price of dimensional lumber over the last fifteen years has been volatile and has risen more rapidly than prices in general. To get every possible piece of material out of the available trees, suppliers are providing more pieces that are twisted, bowed, or shy of stated dimensions. An alternative from the forest products industry is engineered lumber. Engineered lumber consists of dimensional material that is created by gluing a set of smaller pieces together. The result is a quality product, but it can be as much as twice as expensive as conventional lumber.

Steel and asphalt have also experienced greater price volatility and steeper long-trice price trends than concrete and concrete products. Their future is difficult to predict, but the factors driving their price fluctuations in the past may continue.

Demand

As buyers' demand and incomes rise, increasingly people want the premium benefits of concrete.

Even before any of the improvements in concrete listed here the material had valuable properties that come "standard" with concrete. For one, any given volume of concrete is inexpensive to most other building materials. Concrete is also high in compressive strength, durable, and low in maintenance requirements. With proper steed reinforcing, it has proven to be one of the most resistant materials to such disasters as wind, earthquake, flood, fire, and impact.

Its durability stems from its high resistance to water, moisture, rot, rust, mold, mildew, heat, cold, fire, chemicals, and ultraviolet rays. This durability also leads to a low for maintenance. The normal forces of wear have little effect on concrete. Treatments to maintain it or repair it are necessary less often than with many other building materials. This is particularly true when the materials are exposed to the elements.

The properties have been valued by building owners. However, decades ago concrete was rarely chosen for many parts of the small building. In large buildings, it was often used because large structures require great strength, and their surfaces require durability to withstand heavy use. It was used in small buildings for foundations because strength and resistance to water are critical in exposed, below-grade applications. But in every other pan of the small building, it was used either never or much less often than alternative materials.

The primary reason for this situation was that the concrete products were often more expensive. Working on tight budgets, designers and owners would lean toward other materials to shave costs. They might want the benefits concrete had offer, but felt they could not afford them.

But budgets change. Incomes and expectations are slowly but surely rising for everyone consumers and governments. With more money, buyers gradually turn to spending more on all aspects of their lives. That includes their buildings. Eventually they begin to devote more money to get superior building materials.

It is therefore not surprising to see people request concrete products more and more often. They have always valued the sorts of properties that concrete possesses. Every year they have more means to pay them.

Other events have magnified this effect by heightening demand further. Perhaps the clearest of these was Hurricane Andrew in 1992 and the amazing string of four hurricanes that lashed the Southeast in 2004. In the news reports that followed people saw revealing photographs of the devastation. In many, a light frame building was little more than twisted wreckage, while alongside were reinforced concrete structures that were still largely intact. The resistance of reinforced concrete to wind was not lost on the public. These events served as a strong reminder of the general strength and durability properties of concrete. They led many buyers to consider it seriously foe upcoming projects. The Southwestern brush fires of the last ten years had a similar effect on public opinion.

For all of these reasons, people are requesting concrete in growing numbers.