Environmental Ecology and Technology of Concrete

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Edited by

Nai-Qian Feng and Gai-Fei Peng

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Phone: +41 (44) 922 10 22
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The Characteristic of the Concrete Technology in the Construction of Western China

Zhi-Feng Zhang, Hong Ding[a], Jun Wang, Zhan-Min Zhang

Xinjiang West Construction Co., Ltd., Urumchi, XinJiang, China

[a]dihong988@163.com

Keywords: Concrete technology; ecological environment; durability

Abstract. The characteristics of the ecological environment and concrete materials in the constructions of western china were summarized, and the main durability problems of the concrete structures were investigated. Efficient measures for energy and resource conservation, as well as for durability improvement of concrete structures were proposed based on a series of experimental investigations by the Xinjiang West Construction Co., Ltd.

Introduction

The ecological environment of Xinjiang is of great variety and complication, the arid climate makes the ecological environment very weak, and the environmental change affects the safety of people and the oasis ecosystem directly.

Xinjiang is far from the sea. It is located in the center of the Eurasian continent. The high elevation, low temperature and extreme water shortage in the middle of the basin constitutes the characteristics that the main economy activities of the Xinjiang people were distributed around the edge of the basin. Since the water resource is unevenly distributed in different time and places, the oasis inlaying the Gobi Desert emerges in Xinjiang.

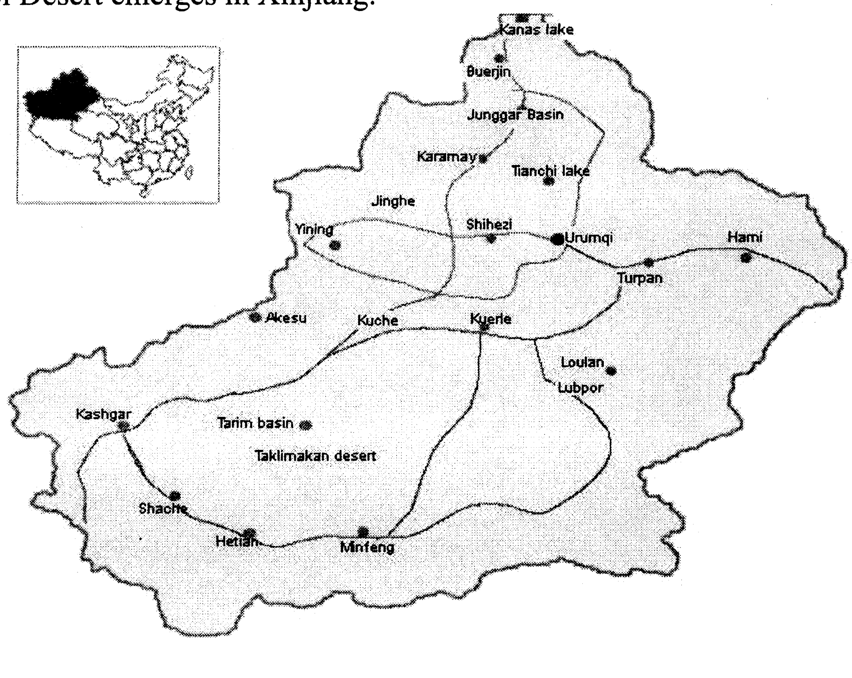

Fig. 1 The map of Xinjiang Uygur Autonomous Region

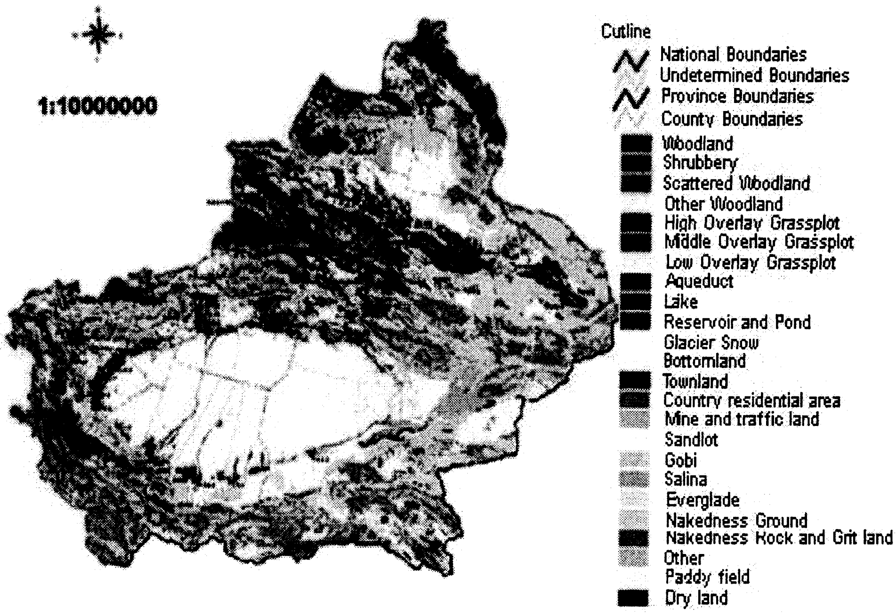

Fig. 2 The environmental map of Xinjiang

The area of Xinjiang is 1.66 million square kilometers, which makes up for 1/6 of the total area of China. The 40 % of the land is barren, and the forest cover rate is only 1/10~1/8 of the average of china. There are vast sands and strong wind force. Deserts are distributed in over 53 counties out of 87, which makes up for 63 % of the total desert area of china. For Xinjiang is geographically in the windy zone in Alashankou Pass, 188 days of every year are windy.

Xinjiang geographically belongs to the centripetal hydrographic system. Great amount of evaporation brings out the land salinity and the polluter accumulation increase. About 95 % of the people lives in the oasis area that makes up only for 4.2 % of the total of the region, the oasis scatters in the edge of the basin and inlays the Gobi Desert. This distribution makes up its ecological environment not only affected easily by the nature outside but also limited by the change of the mountainous ecological environment. The oasis' shrinkage and enlargement is influenced by human activities and desert changing as well.

In the production process of concrete, ecology environment problems were also taken into consideration in Xinjiang West Construction Co., Ltd. In the process of pre-mixed concrete production, it makes full use of limestone tail mine as coarse aggregate, applying lots of industry waste residue such as superfine fly ash to conserve energy source and improve environment condition, in an effort to maintain our oasis where the 95 % people in our region inhabit. According to different requirements of environment, different measures were taken to increase concrete density and strength, reduce its chlorine ion permeability, enhance its resistance to wind and sulphate erosion, and increase the resistance of the oasis environment to external natural impact for the improvement of desert ecosystem.

The overall techno-level of concrete in Xinjiang gets behind of developed provinces in our country. With the requirement of capital construction and the development of science and technology in eighties of the 20th century, important progresses were made in the quantity and techno-level of concrete, especially in the middle of nineties, concrete industry was lead into the track of industrialization with development and application of ready mixed concrete, by which application technique and the range and quantities of concrete were continuously improved and enlarged, as the country's wholesale exploitation policy in the west brings opportunities to concrete's development and application. The mechanical properties of concrete develop very fast in architecture work field, compressive strength increased from C30～C40 to C50~C60, while utmost considerations were paid to the durability of concrete in hydraulic engineering, from improving the resistance to freeze and thaw damage to controlling AAR expansion. The improvement and application of chemical admixtures and mineral mixture promotes the techno-level's development and improvement of concrete. According to incomplete statistic, there are thirty-eight pre-mixed concrete companies located separately in fifteen counties and states in Xinjiang, with annual output of about 4.6 million m^3. There are eight companies in Urumchi, with actual output of more than 1.6 million m^3 per year. The pre-mixed concrete of Xinjiang West Construction Co., Ltd. is 1.2 million m^3 per year, sharing 70 % of the market in Urumchi.

Concrete is the important material basis of architecture, hydraulic engineering, bridge and railway engineering, improving concrete durability is important to improve ecological environment, advance economical construct in Xinjiang and west region, and to maintain stable development; it is also important for architecture advancement, improving people's living standard, strengthening technique communication and trade with around countries, as well as actualization of cross-century's developmental object in west china and in Xinjiang region.

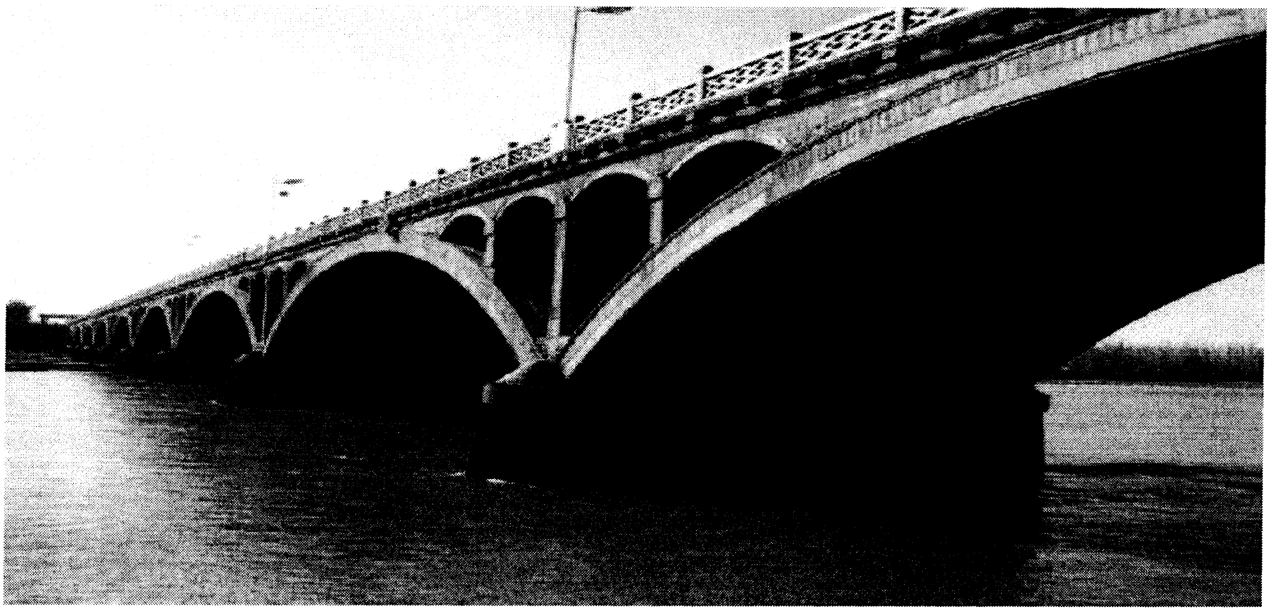

Fig. 3 The Yiliriver great Bridge

The Environmental Characteristics in West Construction

Arid in Climate, Rich in Heat and Light, and Scarce in Precipitation. Xinjiang is far from the seas and circled with high mountains, accompanied with arid environment. Xinjiang is divided into two large parts-- the north and the south region by Tianshan Mountain, which becomes boundary of the climate. The average precipitation is 145 mm per year in the whole region of Xinjiang, which is only 23 % of the average precipitation of China (630 mm), Xinjiang is almost the least precipitation region among the global regions of the same latitude. Generally speaking, precipitation in the north region is more than in south region, the west is more than in the east, the mountainous region more than in the plains, while basin edge more than in basin center and the wind facing slope more than leeward slope. The precipitation of the north region is 400-600 mm, with some places about 1000 mm; the annual precipitation in south slope of Tianshan Mountain and north slope of Kunlun Mountain is 20-40 mm and 150-250 mm respectively, while the precipitation is 100-150 mm in center and east of Junggar basin, 50-70 mm in west and north rim of Tarim basin, 20-50 mm in east and south rim of Tarim basin, less than 20 mm in center of Tarim basin, and only 4 mm in TuoKeXun county of Turpan Basin.

The climate of Xinjiang belongs to the continental climate of temperate zone with the wide discrepancy between cold and hot temperature, arid climate and rare precipitation, shorter spring and autumn and longer winter and summer. It is just because of the arid climate, rare precipitation and relatively low humidity that make the concrete structural crack of drying shrinkage serious.

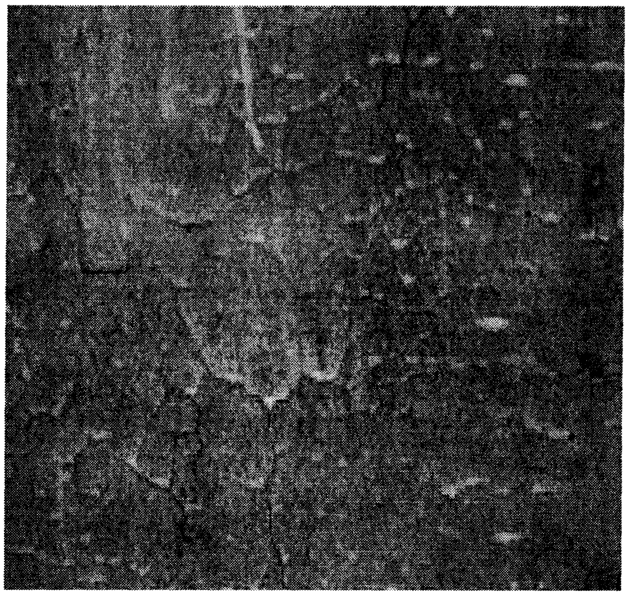

Fig. 4 The Concrete Surface Crack of Drying Shrinkage in Western Region

Fig. 5 The Structure Crack on Pole Concrete in Western Region

The Construction Periods in Low and Negative Temperature are Relatively Longer, Freezing and Thawing Is More Frequent. The north region of Xinjiang belongs to the middle temperate zone with annual average temperature less than 10 ℃, and south region of Xinjiang belongs to the warm temperate zone with average temperature 10-13 ℃. The highest temperature of the Turpan basin reached 48.9 ℃, while the lowest temperature in Keketuohai of Fuwen county reached –51.5 ℃. The frost – free period of South region of Xinjiang is 200-220 days, but north plain region doesn't go to 150 days. In area of Aletai of the north region, the winter temperature reaches –40 ℃, therefore, concrete structure is more seriously damaged by freezing and thawing.

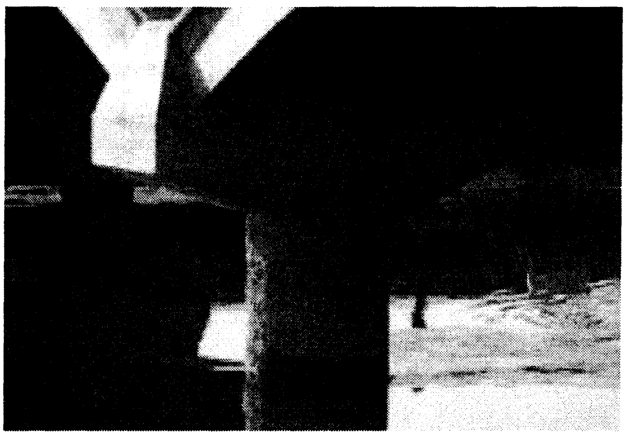

Fig. 6 The Instance of Concrete Pier Peeled off by Freezing and Melting

Fig. 7 The Instance of Concrete Pier Peeled off by Freezing and Melting

The Salinization of Soil, the Sands and the Wind is Serious. The saline-alkali soil is distributed widely in the area of Xinjiang with high salt content, and the type of salt and alkali is various. The salt soil is more than 110 million Mu and the alkaline soil is more than 20 million Mu, The alkaline saline soil of the south region accounts for more than 90 % of the whole area. The saline and alkaline composition includes chloride salt, soda, nitrate salt and so on, the main harmful composition is sulphate and chlorine, there is magnesium corrosion when it is serious, the content of the sulphate ion is about 3700～6100 mg/L, the content of the chlorine ion is about 2750～3700 mg/L.

Xinjiang belongs to the absence monsoon climate area, where the wind-force resources are very abundant, especially in the area of Daban city. The wind quality is very good. Tianshan Mountain plays a protective screen function against the cold air coming form the North, forming two climate areas in the south and north of Xinjiang. South of Xinjiang is relatively warm, it is arid and short of rain, much sand weather; North of Xinjiang is frigid, with much strong wind.

The biggest wind speed once appeared is 55 m/s in Bole and Alashankou Pass, historically the areas with maximum wind speed no less than 40 m/s include the Turpan region, Karamay, Bole, and Tacheng, etc.. After the invasion of cold air, there is often strong wind towards east, lasting for some days. The strong wind in South of Xinjiang disappears basically.

The concrete structure of Xinjiang and the west region is often corroded by salt and the sand wearing, which cause the anti abrasion layer of concrete to peel off.

Therefore both construction and application of concrete structure are subjected to an inferior environment in the west and Xinjiang region.

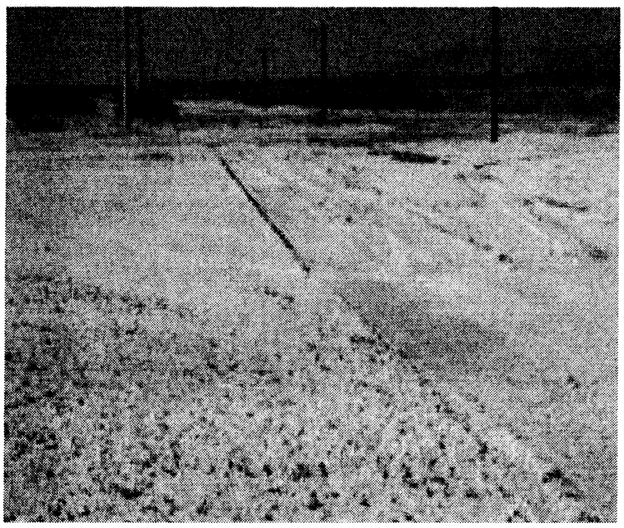

Fig. 8 The Saline-alkali Soil in Xinjiang

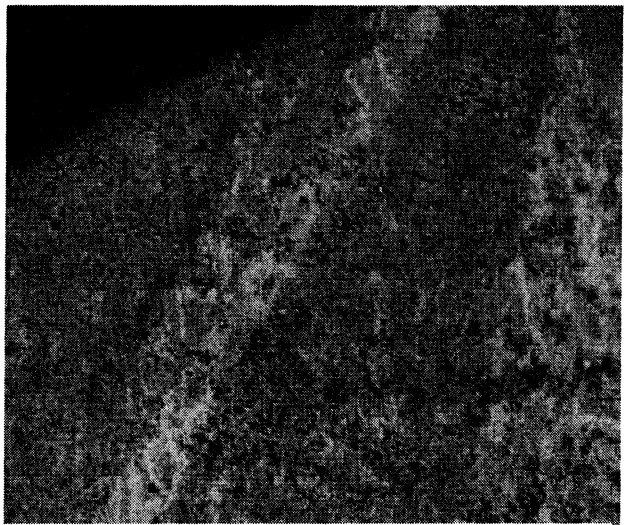

Fig. 9 Sand Blown on Concrete in Xinjiang

Fig.10 Sulphate Corrod on Concrete Structure

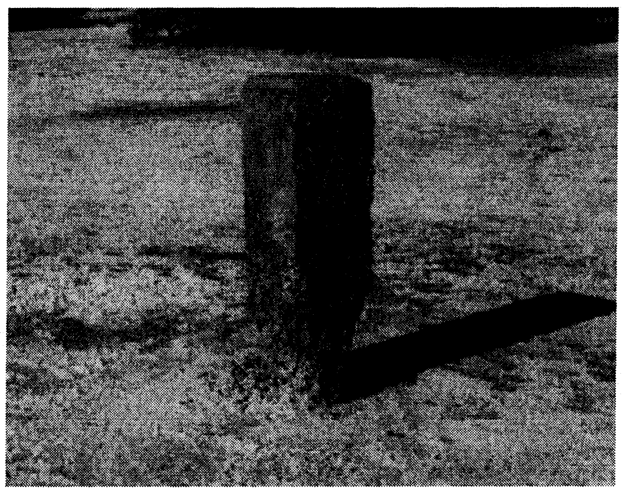

Fig. 11 Sulphate Attack on Concrete

Fig.12 Sulfate Attack on Concrete Telegraph

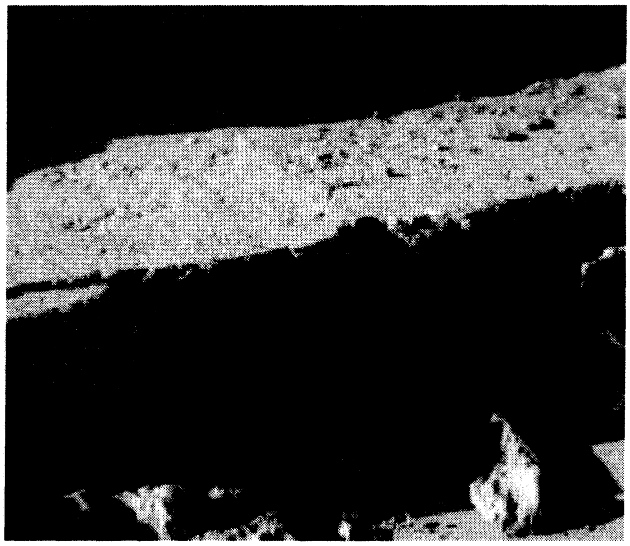

Fig. 13 Chlorine Corrod on Dam Stairs

The Characteristics of the Concrete in the West Region of China

The High Alkalinity of Cement. In 2003, there are 90 cement manufacturers in Xinjiang with an annual output of 14.7 million tons. 70 % of the cement or about 11 million tons is produced by the rotating kiln, of which 15 % is made by precalciner kiln. The cement market in Xinjiang is controlled by two large companies: Tianshan corporation in the north and Qingsong corporation limited in the south. The cement made by these two companies occupies 90 % of the total cement production in Xinjiang. But the cement usually gets a high level of alkalinity (around 0.6-0.8 %) and high C_3A content (around 6-8 %) due to the raw materials used.

For the industry and residence construction, the types of cement used include ordinary Portland cement, slag Portland cement, blended Portland cement, masonry cement, and medium or high sulfate-resistant cement.

River Sand and Gravel Are the Main Resource of Aggregate, Some of Which Is Alkali-Reactive. Xinjiang is abundant with natural river sand and gravel. The quarry spreads throughout the Xinjiang area, most of which process the natural materials. The statistics shows that Xinjiang owns as much as a billion tons of natural fine-quality aggregate, laying a solid foundation for the development of the ready-mixed concrete.

The fine aggregate include coarse, medium, and fine sand. The main types of fine aggregate are coarse and medium sand in Urumchi, and fine sand in most of the south area. The coarse aggregate consists of natural gravel and crushed stone with the dimensions of 5-20 mm and 20-40 mm. the coarse aggregate in some areas have a high apparent density, high absorbability, and low crushability. In north part of Xinjiang, the problems with the coarse aggregate are the low water absorbability, the crushability more than that required by national standards, for example, the high sulfate content in the city of Kelamayi, and the alkali-aggregate reactivity found in some areas of Wu'erhe.

The Rich Source of the Mineral Admixtures. The admixtures rich in Xinjiang include fly ash, blast-furnace flag, lithium residue and natural zeolite. As thermal power plant is the major electricity generator in Xinjiang, there is a large amount of fly ash for further usage. For example, Hongyanchi I & II power plants discharge 300-400 thousand tons of fly ash, Xinjiang Steel Group drains off approximately the same amount of slag, and 60 thousand tons of lithium residue are produced from the Xinjiang lithium salt plant annually (accumulated storage reaches 400-500 thousand tons). There is also 40 million tons of natural zeolite deposit in the Fuyun County.

It's a common practice to add the mineral admixtures into the commercial concrete in the Urumchi areas. Xinjiang West Construction Limited Corporation has introduced into the pre-cast concrete products the different kinds of mineral admixtures and into high strength pre-cast concrete products the blended mineral admixtures. In the concrete manufacture, this company consumes 30 thousand tons of fly ash, 80 thousand tons of KM superfine fly ash, and 11 thousand tons of superfine flag. The application of the admixtures results in the remarkable improvement of the consistency, mechanical properties and durability of concrete.

The Application of Chemical Admixtures. Of the total concrete consumed nationwide, 30 % has used admixtures. However, the popularity of the admixtures in Xinjiang is lower than this national average level. In the great development of western china, the central government put a lot of investments in infrastructure constructions in Xinjiang autonomous region, such as express highway, railway, hydraulic, and civil constructions. Therefore, Xinjiang is a big potential market for the concrete admixture.

Basically all kinds of admixtures have been used in the concrete in Xinjiang, including the early strengthening agent, freezing resistant agent, expansion agent, and water reducer ranging from the high efficiency polycarboxylic super plasticizer to common naphthalene water reducers.

In conclusion, all the raw materials can meet the requirements for the ordinary concrete production, the cement, aggregates and chemical admixtures however, show insufficient properties for producing high performance concrete.

Conservation of Resources and Energy and the Approach to Improving the Durability of the Concrete

The Development and Application of Superfine Powder.

The Manufacture and Application of the Superfine Fly Ash. With the rich resources of fly ash and slag, Xinjiang West Construction Limited Corporation built a KM superfine fly ash producing line with 200 thousand tons of annual output, with the purpose of improving the performance of concrete, protecting the ecological environments and recycling the resources, while decreasing the cost of concrete manufacture. The fly ash, with a specific area as high as 650 m^2/kg, provides such benefits as follows:

a) The fly ash is easy to distribute uniformly in the concrete mixture. With 25 % - 40 % of substitution of cement by fly ash, the consistency of the fresh concrete can be improved remarkably.
b) The resistances of concrete to permeability and deterioration can be enhanced.
c) It helps to decrease the shrinkage of concrete and hydration heat at early stage in the mass concrete.
d) It contributes to protecting the environment and conserving the energy by recycling the resources.

KM superfine fly ash has been applied into 2.9 million m^3 of concrete widely used in the construction projects in such areas as Urumchi, Ku'er'le and Kuitwen with good performance.

The Development and Application of Blast-furnace Slag, Lithium Residue and Natural Zeolite. The main source of blast-furnace slag is the steel plant of the Xinjiang Steel Group. The annual discharge reaches 300-400 thousand tons, and is expected to give rise to 600 thousand tons after the expansion of the plant. There are 5-6 plants producing the superfine slag. The specific area of the slag is around 430 m^2/kg (S75). The amount of superfine slag, produced by Xinjiang Steel Group reaches 50 thousand tons. The slag production has been used in the different concrete projects like residential and hydraulic constructions. The superfine slag powder produced by Xinjiang West Construction Limited Corporation, has been applied to approximate 20 thousand tons of concrete. Due to the high specific area (no less than 600 m^2/kg), the concrete strength at early stage has been increased dramatically.

Lithium residue is a special industry waste limited to Xinjiang region. The only lithium salt plant discharges lithium residue of 60 thousand tons annually, and the accumulating storage has reached 400-500 thousand tons. The residue has been applied to such industries as engineering ceramics and gypsum decoration. By the end of 1990s, the lithium silica powder has been introduced to the concrete production as admixture.

Located between Asia and Europe, Xinjiang is well-known for the rich natural sources, particularly the nonmetallic minerals. As many as 21 types of nonmetallic minerals have been exploited and utilized. The natural zeolite in Fuyun County has 40 million tons of deposit. Xinjiang West Construction Limited Corporation has initiated the research work on the application of superfine zeolite powder to the ready-mixed concrete. The achievements of this research have set the foundation to the utilization of the natural zeolite resource.

Recycling and Application of the Resource. West Construction Limited Corporation recycles the concrete leftover from the construction sites with the special instrumentation for the separating and recycling. The volume of recycled aggregate reach 10 m^3/day (360 m^3/year), achieving the purpose of saving natural resources.

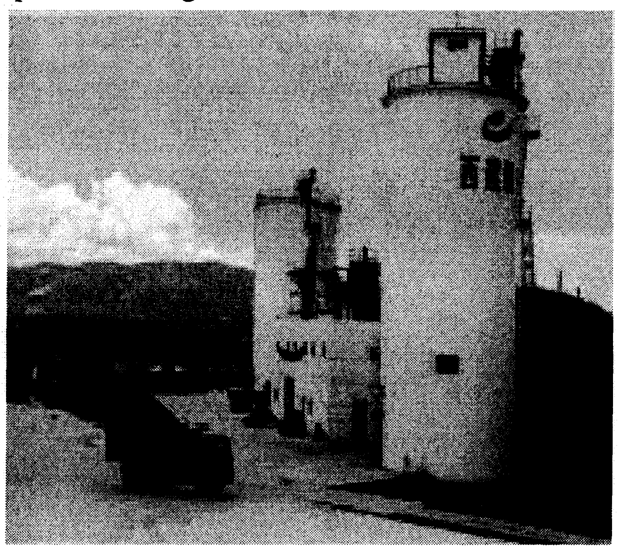

Fig.14 The Production Workshop of the KM ultra-fine fly ash

Fig.15 The Reclaim and Separating Equipment of the Concrete leftover

Experience and Approach in Improving the Durability of Concrete.

Adjust the Mix Proportion to Meet the Requirement of Durability. The durability of concrete should be one of the control factors in the concrete proportion design, along with the features of the concrete structure, the workability, and the strength of concrete. The general conditions that must be considered in the design of concrete durability include the temperature, humidity, radiation, and concrete neutralization, etc. under some special circumstances, the damages caused by the salt, frost, and other aggressive substances have to be considered.

To guarantee the resistance of concrete to carbonation and freeze-thaw deterioration, W/B ratio should be strictly controlled. When concrete with W/B ratio of over 0.3 was subjected to freeze-thaw deterioration, air entraining agent should be introduced to increase the air content to 4~5 %; for low permeable or Cl^- penetration resistant concrete, the W/B ratio should be adjusted according to charge passed experiment; when the concrete is subjected to sulfate aggression, cement type and mineral admixtures should be selected, and the C_3A content should be controlled; mineral admixtures should be incorporated as well to inhibit alkali-aggregate reaction as alkali reactive aggregate is used.

Different Approaches to Improve Durability of Concrete under Different Circumstances. West Construction Limited Corporation substitutes 25 %-40 % of cement with the superfine fly ash in making concrete to improve the properties of concrete and decrease the penetration of chloride ions. In order to improve the workability and the freezing resistance of concrete in the cold weather, anti-freezing agents of different levels and air-entraining admixtures are added to concrete in the winter construction. The resistance to wind wearing and sulfate attack can be enhanced by decreasing the w/c ratio, choosing the low-alkali cement, adding the fly ash, and reducing the C_3A content. Finally, the cracking in the concrete should be repaired before it is too late; in the severe environment (high alkali and saline) that the concrete is placed, the surface of the concrete structure should be coated with the bitumen, in order to prevent concrete from damaging by the penetrated chloride and sulfate ions.

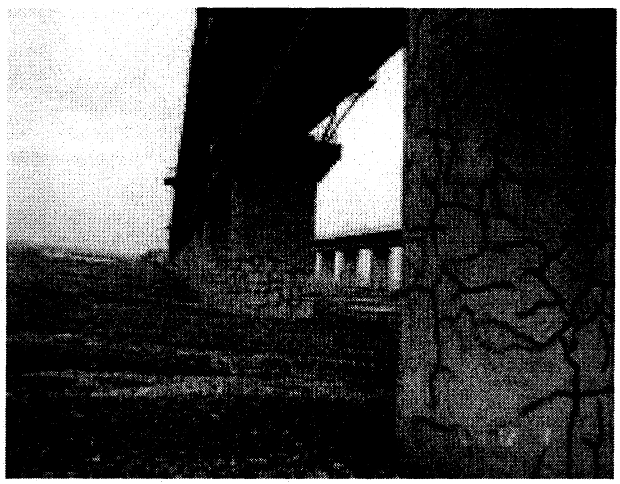

Fig.16 Repairing of the Railway Bridge Pier in Daheyan

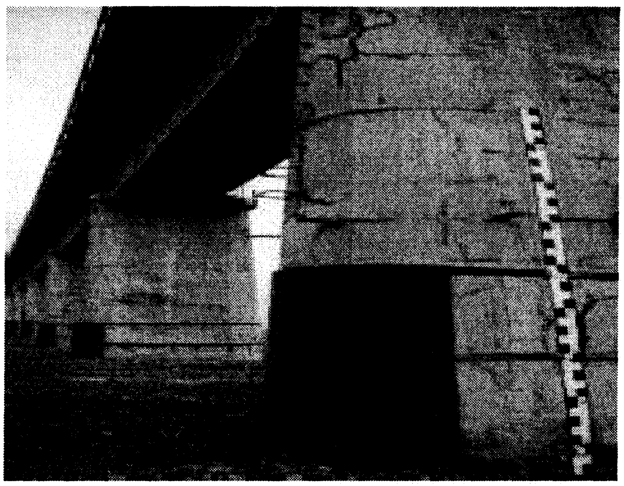

Fig.17 Protection of the Railway Bridge Pier in Daheyan

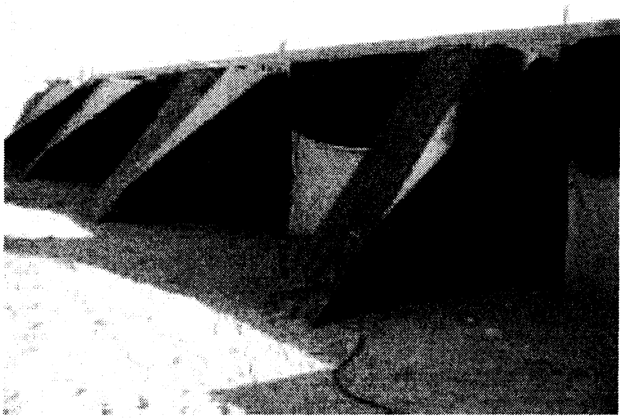

Fig.18 Protection of Bitumen Cost in the East Pump Station of BoHu

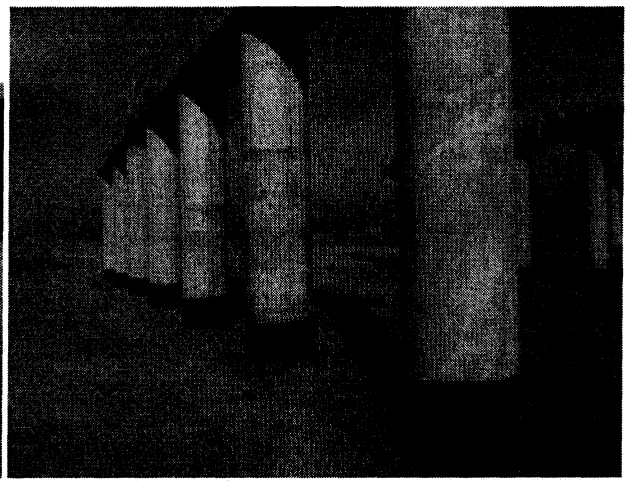

Fig.19 Protection of Bitumen Cost in the Base of Concrete Post

Following the National Standards and the Local Standards. West Construction Limited Corporation follows all the national standards and local regulations in manufacturing the ready mixed concrete. Every process gets closely monitored, from raw materials, mixing, and transport, to pump casting. No unqualified raw materials are allowed to come in, and no unqualified concrete to come out. At the same time, professional technical person is delivered to construction site for supervising. With the projects of high significance or/and difficulty, the plan for quality control and the guidance for the construction will be composed accordingly. The evaluation of the raw materials is carried out strictly following the national standards. The slump is monitored more frequently than that required by the national standard. Besides at 28 day, the strength at 3 days and 7 days is tested. In addition, the open test and the verification of the concrete strength are made based on the local regulations.

Enhance Testing, and Improve the Capability of Development and Research. West Construction Limited Corporation established Xinjiang Xijian research and testing limited Company, who has obtained the license for measurements and testing. The company is qualified to testing the physical and mechanical properties of concrete materials, and particle characterization, both microscopic and macroscopic, of the admixtures. The company has the advanced equipments and instrumentations of the concrete industry in china. West Construction Limited Corporation also set up the department focusing on the research and development. This department has made a deep investigation not only on the reduction of the cost and the increase of the concrete strength, but also on the durability of the concrete in terms of the resistances to freezing, ion penetration and carbonation, corrosion, shrinkage, and so on. Ever year there is a self-funded research project related with concrete. By addressing simultaneously the production, the accumulation, and the exploitation, the company is stepping onto the path leading to the healthy growing process.

In order to ensure good quality of concrete, some special properties related with durability, as well as the strength, are tested in some projects with special requirements, including charge passed of concrete, cracking in the slab, or dynamic modulus, and particle gradation, and so on.

Conclusions

The current situations and problems in Xinjiang and other west regions include:

- Dry climate, and severe environment,
- Weak ecological environment for the human being;
- Relatively insufficient amount, and non-decent quality, of the building materials,
- The damaging mechanisms that threaten the durability of concrete include freezing and thawing, salt deterioration, wind wearing, and shrinkage cracking.

Therefore, special attentions should be paid to the ecological environment and the application of new concrete technologies. West Construction Limited Corporation has taken the first step, aiming at resource-saving, energy-conserving, and durability-improving in the concrete industry. The effective approaches has been formed to improving durability of concrete and protecting of the ecological environment, including applying and developing the mineral admixtures, recycling the aggregates, and designing the durability orientated proportion.

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Ecological Environment and Concrete Technology in China

Nai-Qian Feng[1,a], Jian-Hua Yan[2,b] and Gai-Fei Peng[3,c]

[1]Department of Civil Engineering, Tsinghua University, Beijing, China
[2]Material Institute, Beijing University of Technology, Beijing, China
[3]Faculty of Civil Engineering and Architecture, Beijing Jiaotong University, Beijing, China
[a]fengnq@mail.tsinghua.edu.cn, [b]yanjianhua@bjut.edu.cn, [c]gfpeng@center.njtu.edu.cn

Keywords: Ecological environment; resource saving; durability of concrete; recycled aggregate; ecological cement

Abstract. From review of the background of concrete construction in China, technical suggestions are given. It is the new requirements for concrete materials and technology to be ecological in 21st century, including resource saving and environment friendly. Utilization of substituting fuel and lowered firing temperature are both energy saving and environment friendly. The reliability and safety of concrete materials and technology is closely related with the ecological environment. From a viewpoint of the ecological environment, it is important to produce concrete on an approach both energy saving and environment friendly, for example by use of solid wastes and waste water. It is also imperative to design strength of concrete for structures with both enough strength and strength reserve, to provide them with superior resistance to environmental degradation factors.

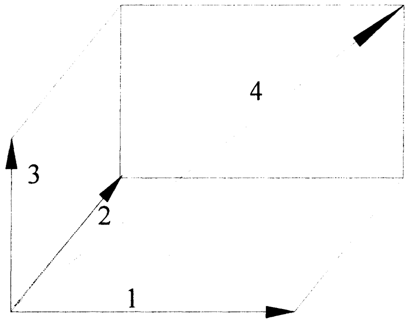
Introduction

At the beginning of the 21st century, the world is facing three fundamental issues, namely, population explosion, resource shortage and environmental deterioration. In China, the situation is worse as resources per capita are less than half of the world average. For instance, per capita owning amount of fresh water resources, arable land, and mineral resources are approximately only 18 %, 32 %, and 50 % of the world level respectively. It is estimated that, by 2010, the water shortage in China will amount to 700 billion m^3. According to the national survey results of 1998 in China, the annual wastewater discharge was 4,397 billion tons, exceeding 82 % of the environmental capacity. Furthermore, China is exposed to severe air pollutions, with emission of SO_2 and CO_2 being on the top of the world level, emission of CO_2 exceeding the environment self-cleaning capacity and nearly 1/3 of the land being polluted by acid rain. In 1995, the mean value of air-borne suspension particles was as high as 432 mg/m^3 and discharge of particles will increase by 39 % by 2010 than the amount in 1995.

China is a large country in resource consumption and environmental pollutions, with annual output of cement and concrete being 700 million tons and 1.3 billion m^3 respectively. It is reported that limestone available in China for cement production is approximately 500 billion tons. In other words, it is only enough for cement production for 50 years at a scale of the present cement production. Moreover, a large amount of SO_2 and CO_2 was discharged during cement production. Concrete production causes a consumption of 1.3 billion tons of aggregate, 600 to 700 million tons of fine aggregate and a large amount of water resources annually, and discharges a large amount of wastewater. Many newly constructed steel-reinforced concrete suffer from damage or even failure too early because of shortcomings in both structural design and concrete durability. Many reinforced-concrete highway bridges in costal regions, for example, were considerably damaged after only 20-years of service, some of which have to be demolished and rebuilt. It is a huge waste of manpower, material resources and financial expense, moreover, it deteriorates the ecological environment.

We are also facing ecological problems rising from solid wastes, such as rubbish of daily life and industrial solid wastes. Various kinds of solid wastes are discharged every year. For example, the annual discharges of fly ash and gangue reach 200 million tons and 400 million tons respectively. Through accumulating over a long period, the solid wastes are becoming a severe threat to the ecological environment, by producing dust or dissolving hazardous substance. It is urgent for us to study new methods to cope with the solid wastes.

Ecological concrete technology is a good way to solve problems occurred in concrete development and those caused by solid wastes. Modern concrete should be developed in three directions, i.e. technical properties, practical performance and ecological environmental friendliness, as schematically shown in Fig. 1.



1— Technical properties
2— Using function
3— Environment compatibility
4— Developing direction of concrete materials and technology

Fig. 1 Developing direction of concrete material and technology

Ecological Cement Technology

Research and Development of High Performance Cement.

High performance cement consists of two constituents, one of which is Portland cement with a specific surface area of 3000-3200 cm^2/g prepared by grinding the mixture of 90 % clinkers and 10 % gypsum, another of which is the mixture with a specific surface area greater than 6000 cm^2/g prepared by grinding metakaolinite, slag or fly ash, and small amount of chemical products together. The two constituents are mixed at a ratio of 45-50 to 55-50 to get high performance cement with strength greater than 32.5 MPa. This type of cement has a low hydration heat, high resistance to sulphate attack and low permeation of Cl^-. The cement is capable of inhibiting ASR and ACR and also has a positive effect on frost resistance of concrete. High performance concrete can be made by use of this type of cement. Besides, the cement is also energy saving concrete by saving more than 50 of clinker. It is also a resource saving cement by use of fly ash or slag at a dosage of 25 % to 30 %. This type of cement was developed jointly by Tsinghua University and Shandong Weifang Transportation Supervision Center.

Ecological Cement.

The clinker of ecological cement is produced in a rotation kiln using solid residue left after burning of urban rubbish and sludge after waste water treatment as raw materials and pressed plastic as fuel. Ecological cement is produced by mixing the clinker with cement set admixtures. The manufacturing process of ecological cement [1] is shown in Fig. 2.

Ecological cement has been produced on a large scale in Japan since 2001. An ecological cement plant, located in the countryside of Tokyo, produces nearly 3 million tons of ecological cement every year. The production and application of ecological cement in Japan has been proved to be both resource saving and environmental friendly [2]. Thus Japan has obtained a successful experience in the production of ecological cement in the world. In China, however, we have much to do to develop ecological cement, because solid residue left after burning of urban rubbish has not been fully harnessed or even caused secondary pollution. In Tsinghua University, we conducted trial preparation of light-weight aggregate with waste glass and solid residue left after burning of urban rubbish, and initial success has been obtained.

Recycled cement.

Recycled cement is produced by mixing the paste obtained after washing a concrete mixer in a ready-mix concrete plant, with fly ash and lime powder added. After drying, the mixture can be used as a part of raw materials for cement production. Recycled concrete can also be used in a similar manner as a part of raw materials for cement production.

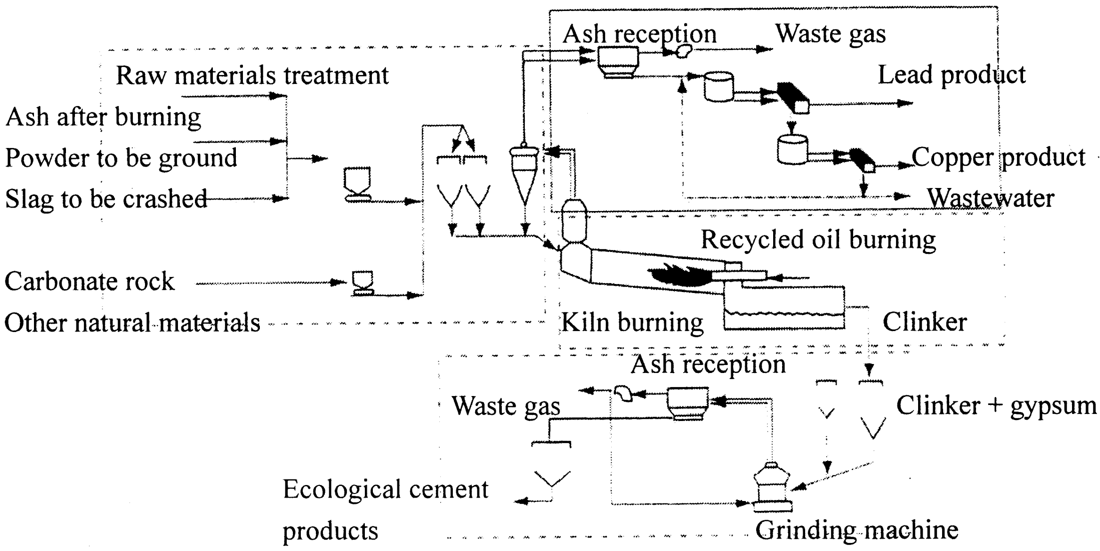


Fig. 2 Schematic illustration of manufacturing process of ecological cement [1]

Ecological Aggregate Technology

Development and Application of Fly Ash-Glass Ceramsite.

Fly ash ceramsite were developed and applied in concrete as early as in the 1950s in China. The ceramsite produced is usually fired to have an apparent density of 750-800 kg/m^2 and water absorption as high as 20 % within 24 hr. Light-weight concretes of C30 and C20 have been produced by using ceramsite with a density of 1850-1900 kg/m^3. Fly ash ceramsite was a good solution to the disposal problem of fly ash at that time.

Fig. 3 Fly ash-glass ceramsite samples

Nowadays, the amount of waste discharge increases sharply owing to the rapid economic development and the rise of urban population in China. Waste glass has become one of the main causes of pollutions. Consequently, fly ash–glass ceramsite was developed in Tsinghua University by using fly ash and waste glass as raw materials.

Fly ash-glass ceramsite is prepared as follows: pulverizing waste glass, mixing fly ash with glass powder, adding binder and fuel to the mixture, shaping and finally firing at 800 °C for 10-20 min. Samples of fly ash-glass ceramsite are shown in Fig. 3. This ceramsite is light-weighted, low water absorptive, of high strength, and suitable for preparation of ultra-light weight concrete (which can float on water) and C50 high strength concrete.

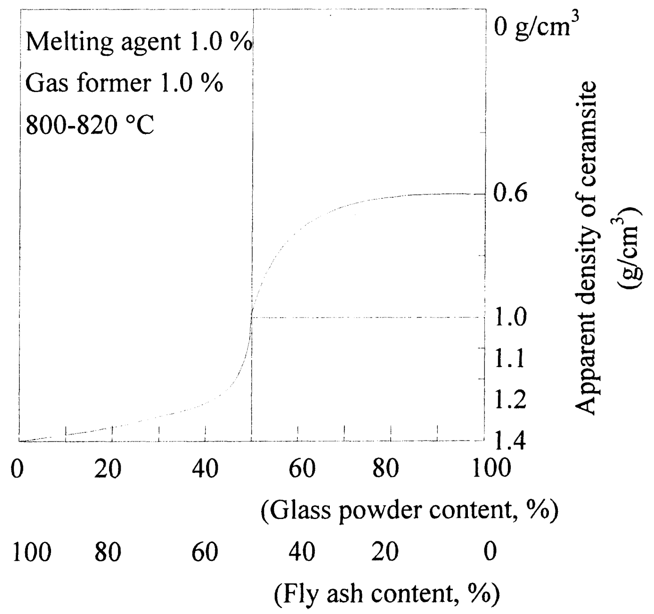


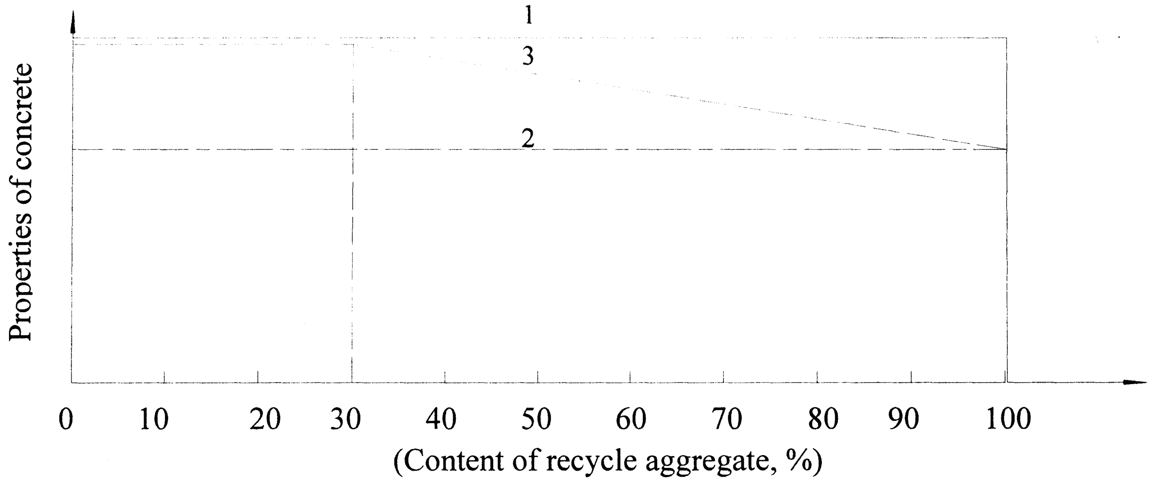
Fig. 4 Expansion curve of fly ash-glass ceramsite as aggregate

In the past, clay ceramsite and shale ceramsite were commonly used in concrete. These ceramsites were fired at 1100-1200 °C and the porous structure forms when gas was enwrapped by melting phase. Fly ash-glass ceramsite, however, is fired at 800 °C with glass melted to entrain gas, fly ash acting as filler to enhance strength of aggregate, and gas former producing CO_2 to form pores. The effect of the ratio of glass to fly ash on apparant density of aggregate is shown in Fig. 4.

Fly ash-glass ceramsite is an environmental friendly new material by using waste solid, i.e. fly ash and waste glass, as raw materials and firing at a relatively low temperature of 800 °C, which is only 2/3 of the firing temperature at which clay ceramsite and shale ceramsite are normally fired. Moreover, some theoretically valuable viewpoint has been put forward in the study of fly ash-glass ceramsite by Tsinghua University.

Aggregate Made from Recycled Concrete.

Aggregate made from recycled concrete is prepared by firstly striking the steel reinforced concrete to make steel apart from concrete and then crashing the concrete into coarse or fine aggregate [3]. It is verified that this recycled aggregate can be used by as much as 30 % with natural aggregate to form a type of mixed aggregate for concrete production. For concrete of strength grade below C40, mechanical properties of almost the same magnitude can be obtained either by using mixed aggregate, or by using natural aggregate. On the other hand, when the proportion of recycled aggregate exceeds 30 % in the mixed aggregate, mechanical and some other properties of concrete would be significantly influenced. In general, concrete using recycled aggregate lonely as aggregate results in a high water demand for mixing, significant bleeding, low strength, and bad durability. The effect of the content of recycled aggregate in mixed aggregate on performance of concrete is shown in Fig. 5. As recycled aggregate may cause degradation in performance of concrete, it is advisable to used mixed aggregate only in concrete below C30, but it is not suitable for important construction or concrete of high performance requirements. But anyway, recycled aggregate made from waste concrete is an effective approach for the objective of resource saving.



1—100 % raw aggregate 2—100 % recycle aggregate 3—variety of recycle aggregate

Fig. 4 Performance of concrete compounding with various aggregates

Ecological Concrete Technology

Development and Application of Ultra-Fine Mineral Powders.

Materials such as ultra-fine fly ash, ultra-fine zeolite, ultra-fine metakaolinite, ultra-fine lithium dregs, and ultra-fine phosphous slag can be used either lonely or in a mixed manner to replace 15-30 % of cement by mass in concrete, while mechanical properties of the concrete can be maintained or slightly improved, and its durability and workability are significantly improved. Several cases are described below.

Former Changsha Railway College (now called by Central Southern University) used fly ash ultra-fine powders to replace 30 % of cement for preparation of reinforced concrete beams of grade C60, which has survived 3 million cycles of fatigue tests. These 300-meter span prestress concrete beams have been used in railway construction practice.

If ultra-fine lithium slag, which is discharged at a great amount during industrial production in Xinjiang, is used to replace 15-25 % of cement, high performance concrete of C60 to C80 can be prepared.

Cast-in-situ concrete pole of C30, in which ultra-fine zeolite-fly ash compound powder was used to replace 25-30 % of cement, was prepared and applied by Tsinghua University and Dongying Yellow River Bridge Engineering Department. It was verified that replacement of 25-30 % of cement with ultra-fine zeolite-fly ash compound powder could not only solve segregation and bleeding problems, maintain high fluidity and self-consolidation performance of fresh concrete, but could also prevent chemical attack by sulphate and Cl^-, inhibit alkali-aggregate reaction (AAR), and reduce the release of alkali in concrete.

Ultra-fine phosphous slag powder, developed jointly by The China First Construction Bureau, The China Second Construction Bureau, and Tsinghua University, was proved to be more efficient in reducing water demand and improving fluidity as well as durability of concrete.

Production and application of mineral ultra-fine powders is an energy-saving approach only requiring a process of grinding for further concrete production, compared with large energy consumption cause by two processes of grinding and firing in the production of clinker. As usage of ultra-fine mineral powders is quite resource saving, for example, more than 30 % of energy consumption and more than 30 % of natural materials in cement production can be saved, if 30 % of cement is replaced with ultra-fine powders. Ultra-fine mineral powder technology has now been widely applied and promoted in China.

Recycling of Waste in Ready-Mix Concrete Station.

The annual output of commercial concrete is now 130 million to 150 million m^3. A large amount of waste water and solid wastes may be discharged when the mixer and mixer truck are washed after daily concrete production. The waste water produced every year amounts to nearly 100 million. The paste and sand in the wastewater can cause environmental pollution and a waste of resources, if the wastewater is discharged without any treatment.

A small quantity of ready-mix concrete plants in China has set up installations for separating water, sand, and aggregate in the wastewater, to make full use of water resource and recycled solid resources. Wastewater can be recycled from the upper part of paste after keeping the paste still for enough time. The sand and aggregate can be recycled for production of concrete. The paste can be recycled to mix with cement, sand and aggregate to produce new type of construction materials. Such an installation was, for example, set up in Shenyang Hefeng Concrete Company, Liaoning Province, and was proved to work well.

The Ecological Problems Encountered in the Service of Concrete Structure and Solutions

The following aspects should be considered to make concrete to serve safely and reliablly in the design service-life.

The structure should have both enough strength and strength reserve, to provide enough load-supporting capacity or even overload-supporting capacity in some cases. Concrete structures which are weak in some aspects such as strength, strength reserve, safety, or reliability should cause not only economical loss but also ecological pollution. Some reinforced concrete bridge in China, for example, collapsed shortly after being put into service, owing to unsatisfactory load-supporting capacity, causing both destruction of vehicles and loss of life. Some newly built bridges performed even worse and collapsed just before they were to put into service and open for transportation.

Scientific and proper measures should be taken for maintenance of concrete structures. The performance of concrete is declining constantly in service regardless of the type of a concrete structure. Concrete should be maintained and repaired periodically during service process, in order to keep it safe within whole design service-life. Accordingly, scientific maintenance is imperative for the concrete structure to serve normally in whole designed service life.

Concrete should be prepared to have resistance to degradation, damage, or failure of concrete caused by ecological environment. Performance of concrete will be degraded, damaged or even subjected to failure with time passing, which may be considerably affected by factors in the ecological environment. Consequently, the effect of environmental factors on degradation of concrete should be seriously considered at various stages such as design, materials selection, and construction of concrete, in order to provide the concrete with enough resistance to degradation caused by the environmental factors' effect.

Conclusions

It is the new requirements for concrete materials and technology to be ecological in 21st century, including resource saving and environment friendliness. Use of industrial solid wastes and municipal refuse in a large amount is not only resource saving but also environment friendly. Utilization of substituting fuel and decrease in firing temperature are both energy saving and environment friendly. The reliability and safety of concrete materials and technology are closely connected with ecological technology. From a viewpoint of ecological environment, it is important to produce concrete on an approach both energy saving and environment friendly, for example by use of solid wastes and waste water. It is also imperative to design strength of concrete for structures with both enough strength and enough strength reserve, to provide them with superior resistance to environmental degradation factors.

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Exploitation of Particle Migration Mechanism to Promote Economy and Ecology in Concrete Technology

P. Stroeven, J. Hu, M. Stroeven
Faculty of Civil Engineering and Geosciences,
Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands
P.Stroeven@citg.tudelft.nl; J.Hu@citg.tudelft.nl; M.Stroeven@citg.tudelft.nl

Keywords: computer simulation; concrete technology; diffusion capacity; gap grading

Abstract. The computer simulation study of Portland cement blending confirmed the major mechanism to be size segregation in the Interfacial Transition Zones around the aggregate particles. Fine particles tend to move through the skeleton of larger particles towards the surface of the aggregate grains, improving local density. But the most interesting feature is a disproportionately larger internal bond capacity (based on van der Waals forces between nearby particles). In this contribution, we have isolated the mechanism of internal *diffusion capacity* of particles, on which blending efficiency relies, for a simulation study on the migration of fine sand particles into the network of coarse aggregate grains. The influences of technical parameters (including gap in size between fine sand and coarse aggregate, as well as the workability conditions) have been investigated on the migration capacity of fine sand particles. This paper will report briefly the outcomes of this computer simulation study on aggregate mix systems.

Introduction

Portland cement (PC) is contributing worldwide by about 6 % to carbon dioxide production, thereby increasing the risks for global warming. Moreover, production requires large amounts of fossil and electrical energy, and precious raw materials. This violates energy conservation requirements and leads to excessive destruction of natural landscapes. PC blending with mineral admixtures has been experimentally demonstrated to offer promising solutions to economical and ecological aspects in concrete technology by significantly reducing PC demands and by making use of cheap mineral admixtures that can be obtained from waste. We have envisaged the use of the abundantly available agricultural waste, *i.e.*, rice husk ash (RHA), kaolin, diatomite, and mine tailings for high performance concrete (HPC), revealing quite favorable results [1,2].

Of special interest are outcomes of fine-ground RHA combined with PC ground to two different finenesses. Concrete with the finest PC, either plain or blended, yielded the highest strength levels, of course. However, the concrete based on the *gap-graded combination* of coarser type PC and fine-grained RHA turned out to be the most efficient one [1,3]. It should be noted that gap grading in the present context is referring to the gap between the size distributions (grading) of composing particle ranges. As a result, very significant portions of the PC could be replaced by RHA without strength reduction. These experiments were supplemented by a computer simulation study with the SPACE system. Realistic simulations of densely packed particle systems can be achieved by SPACE since it is based on a so-called concurrent algorithm [4,5]. The computer simulation results confirmed the major mechanism to be *size segregation* in the Interfacial Transition Zones (ITZs) around the aggregate particles. Fine binder particles tend to migrate through the skeleton of the larger ones towards the surface of the aggregate grains, improving local density. But the most interesting feature is a disproportionately larger bond capacity in the ITZ (based on van der Waals forces between nearby particles) [5,6]. This mechanism has been demonstrated by computer simulation to be effective only under favorable conditions, whereby the amount of the compaction energy and the duration of this process in combination with a sufficient level of workability are key factors [7].

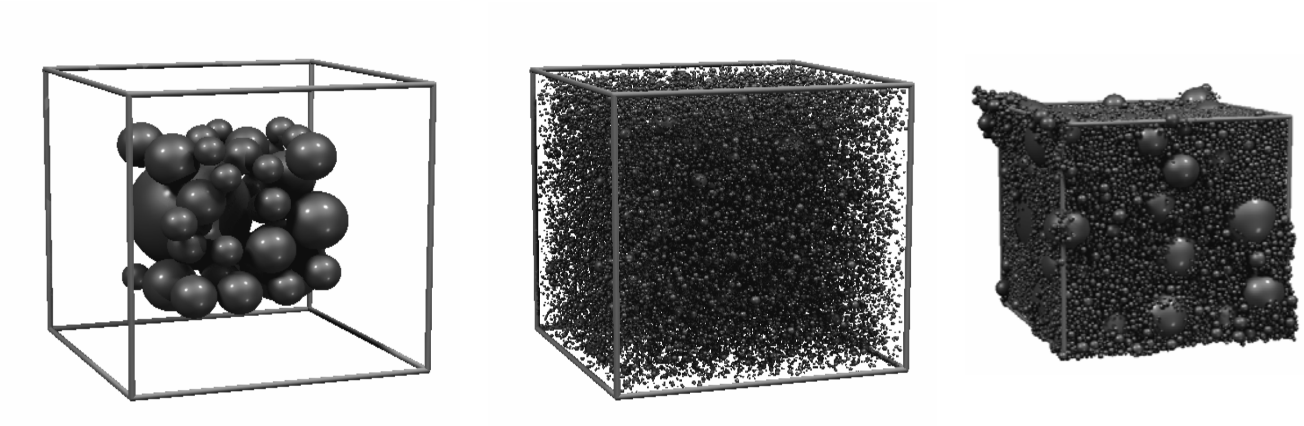
Research results obtained independently in the USA [8] and Israel [9] demonstrated *inert* mineral admixtures (carbon black in both cases) to yield significant contributions to strength, whereby the physical portion can exceed the chemical one. A preliminary conclusion that could be drawn is that *inert (chemically stable) waste* of which the particle size range is properly gap graded with respect to that of the PC could be an economic and ecologically favorable solution, particularly in the low water to cement ratio range (hence, for the production of HPC). Therefore, we are presently conducting a computer simulation study in which we focus on the internal *diffusion or migration* capacity of particles, particularly considering the effect of gap grading. This paper will report briefly the outcomes of this computer simulation study.

The SPACE approach is *size invariant*, so that investigations on bulk efficiency of mixing sand and coarse aggregate in the millimeter range will be analogous to that on cement blending in the micrometer range, the subject of prime interest in this paper. Of course, packing efficiency in the ITZ can be associated directly with the mixture characteristics of sand and aggregate near the container wall. Data on the effects of variations in the particle size distribution (PSD) on the compaction efficiency (and thus on strength) are more readily available on millimeter level, and can thus be employed for reference purposes. We have also investigated experimentally and by computer simulation the sand accumulation capacity in bulk of different coarse aggregate mixtures, indeed revealing the PSD to exert significant effects [10]. On meso- and micro-level alike, packing efficiency requires migration of smaller particles through the porous spatial network of the larger particles. The “pores” in this system are governed by the PSD of the coarse particle component and by the extent of gap grading. Therefore, in this paper, the capacity of fine sand to migrate through the network structure of coarse aggregate grains under different technical conditions is studied by means of computer simulation with the SPACE system. Three coarse aggregate mixtures of different particle size distributions (PSDs) are simulated. The migration capacity of fine sand is studied as a function of the *size gap* between PSDs of sand and coarse aggregate grains.

Materials and Modeling Approach

Sagoe-Crentsil *et al*. [11] studied the mechanical properties of PC-based concrete cylinders (continuously stored under moist conditions for up to 365 days) made with recycled coarse aggregate. Data on PSD for the coarse aggregate used in their experiments are approximated as much as possible and denoted as ‘recycled’ series in this simulation study (size range 4-16 mm). A coarse aggregate system of Fuller-type size distribution (indicated as ‘Fuller’ series) is designed in the same size range and simulated for comparison purposes. In addition, an aggregate mix of Fuller type size distribution (marked as Fuller-A) is simulated with a wider size range, *i.e*., between 4 and 19 mm. Size of the simulated sand particles is ranging from 0.15 mm to 3.25 mm, with a mean diameter and mode diameter of 0.99 and 0.70 mm, respectively. The mass ratio of fine sand to coarse aggregate is 0.5, yielding a sand/aggregate ratio, *s/a*, of 0.33. The simulated mixes of coarse aggregate and fine sand are referred to as ‘recycled+sand’ and ‘Fuller+sand’ series in what follows.

The simulation procedures start by generating aggregate grains in a cubic container with rigid boundary conditions, yielding a dilute system with a relatively low (10 %) initial density. Thereupon, the system of particles is subjected to a dynamic mixing algorithm that is implemented in SPACE. This is accompanied by a continuous decline in container size until the desired density is obtained, in the present case a volume fraction of 40 % aggregate grains. Next, the container size is enlarged with the compacted aggregate in the center (Fig. 1a). The second step is the random generation (within the container) of fine sand particles in the space around the densely packed coarse aggregate grains. Finally, the mixture of sand and coarse aggregate is subjected in the gravitation field during size reduction of the container to the aforementioned dynamic mixing algorithm until the ultimate volume fraction of total aggregate is 65 % for all the investigated mixtures. Fig. 1 provides a schematic description of the simulation procedures at the intermediate stage of generating sand particles (Fig. 1b) and at the final stage after dynamic mixing (Fig. 1c), respectively. On a macro-level, the model material can be considered as aggregate grains dispersed in a cement matrix. On meso-level, the SPACE system allows direct evaluation of volume density gradients in separate size fractions due to migration of the sand in the coarse aggregate skeleton.



(a) (b) (c)

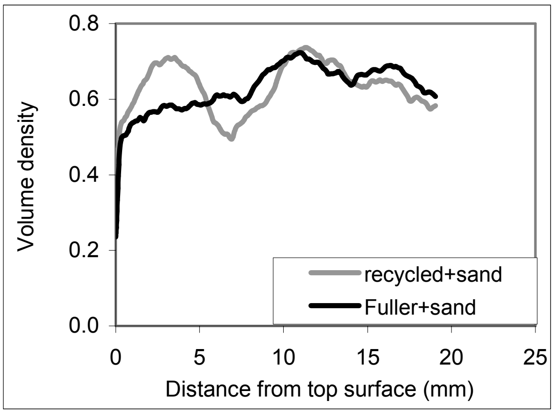
Fig. 1 Schematic description of the simulation procedures with the SPACE system.

Diffusion Capacity

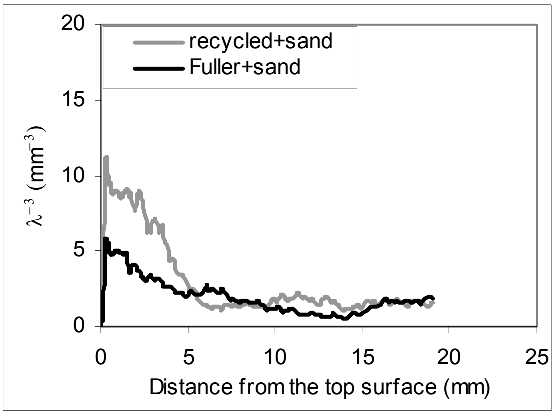
Mechanism of Gap Grading. Under good workability conditions, fine sand particles can easily migrate through the network of coarse aggregate particles, thereby promoting the development of uniform density in bulk (resulting in improved strength level). The finest particles compensate also for the deficit left by the larger particles near the surface of the container (the so called size segregation effect). Section patterns of model concrete made with sand that migrated in the gravity direction into the coarse aggregate structure are taken at different distances from the top surface of the sample, visualizing the gradient in dispersion characteristics of the composite particle structure. The PSD of coarse aggregate is expected to exert significant influences on the diffusion capacity of the fine sand particles. When the gap in size between sand and coarse aggregate is larger (*i.e.*, in cases of coarser aggregate, or finer sand), the aggregate mixture will lead to larger 'open spaces' between the grains, which are *more easily* accessible by the sand particles without increase in overall volume. In contrast, a finer aggregate system contains larger number of small grains, which subdivide the open space into smaller and less accessible spaces [12].

Effect of Gap Grading. The influence of the magnitude of the size gap between coarse aggregate and fine sand particles on the mechanical properties of model concretes will be discussed in what follows. Gap grading activates the mechanism of 'migration capacity' of fine sand particles into the network structure of coarse aggregate grains; or, analogously, of the fine particles of the mineral admixture into the network structure of the coarser grained Portland cement. The result is a denser particulate structure and an improved strength level. The inter-particle (van der Waals-based physical) bond strength is supposed governed by a stereological spacing parameter, the so-called *mean free distance* between particles (denoted as λ in standard stereological literature [13]). By λ the average of the uninterrupted surface-to-surface distances between all neighboring particles in space is defined. Global bond strength in this study is assumed proportional to λ^{-3}, in agreement with earlier research efforts [5,6], and reflecting its van der Waals' type background.

Figs. 4 and 5 present the volume density gradients of aggregate, as well as the global bond strength of model concretes made with different aggregate mixtures. Fig. 2 reveals clearly the effects of the PSD of coarse aggregate grains on the migration capacity of the fine sand particles. Compared with the model concrete of Fuller type size distribution ('Fuller+sand' in Fig. 2), the concrete made with 'recycled' aggregate yields a denser inter-phase layer adjacent the container wall (Fig. 2a). Even more pronounced, however, is the improvement in bond strength (represented by λ^{-3}) in this layer (Fig. 2b). This can be attributed to the larger size gap between coarse aggregate and fine sand in the case of 'recycled+sand' aggregate. Analogously, the disproportional strength improvement due to migration of fine (mineral admixture) particles into the ITZ is depicted.

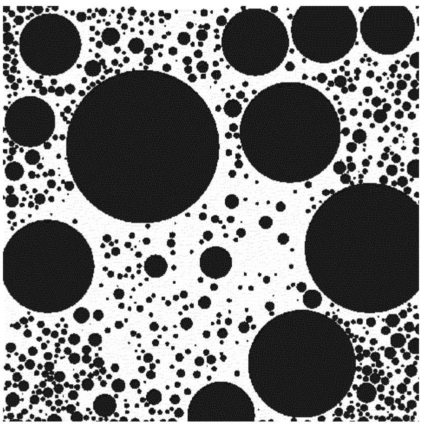


(a) Volume density of total aggregate

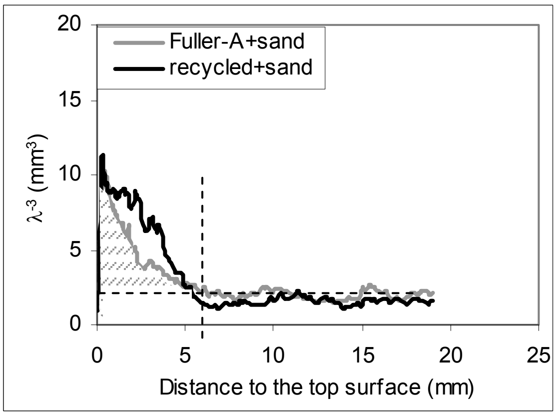


(b) Parameter corresponding to global bond capacity

Fig. 2 Influence of particle size distribution of coarse aggregate grains on the migration capacity of fine sand particles.



(a) 7.54 mm from top surface



(b) Definition of migration capacity

Fig. 3 (a) Section pattern of model concrete made with 'Fuller-A' mixture, taken at the specified distance from the top surface of the sample; (b) Comparison of global bond capacity between the model concrete made with 'Fuller-A' aggregate (size range between 4-19 mm) and that made with 'recycled' aggregate. The gray zone is defined as the migration capacity of fine sand particles for the 'Fuller-A+sand' aggregate mix.

A comparison in global bond strength is made in Fig. 3 between concretes made with 'Fuller-A' (size range between 4-19 mm) aggregate and with 'recycled' aggregate. Obviously, a wider size range in the Fuller-type coarse aggregate (yielding a bigger gap in the median size values with the sand) helps to counteract to some extent the deficiencies associated with Fuller type size distribution (comparing Fig. 2b and Fig. 3b). Hence, the bond strength in the inter-phase layer of concrete made with 'Fuller-A' aggregate is by this mechanism increased to almost similar level as in the concrete made with 'recycled+sand' aggregate (see Fig. 3), despite migration capacity of the fine sand still being inferior (Table 1). The thickness of the inter-phase layers near the container wall with *significantly improved* bond strength (attributed to the migration of fine sand particles) is in all cases about 6 to 8 mm. In earlier simulation studies [5], we had found the ITZ thickness for bond strength improvement to increase at reduced water to cement ratios in the HPC range, despite reduced migration speed due to enhanced particle density. Sufficient *time* is therefore required for full exploitation of the size segregation phenomenon. Fig. 4b and 5 suggest incomplete exploitation of size segregation capabilities.

The present and earlier simulation results on millimeter and micrometer level reveal that the migration capacity of fine sand is an increasing function of the size gap between sand and coarse aggregate. The migration capacity can be associated quantitatively with the enhancement in the thickness of an inter-phase layer in which bond strength is increased compared that in bulk material due to size segregation (Figs. 4b and 5). This is particularly so in the HPC range. An example is elaborated for the case indicated in Fig. 3 ('Fuller-A+sand' aggregate mix). The obtained migration parameter given in Table 1 (expressed in mm^{-2}) incorporates the absolute value of λ^{-3} as well as the migration depth of fine sand particles into the network of coarse aggregate grains.

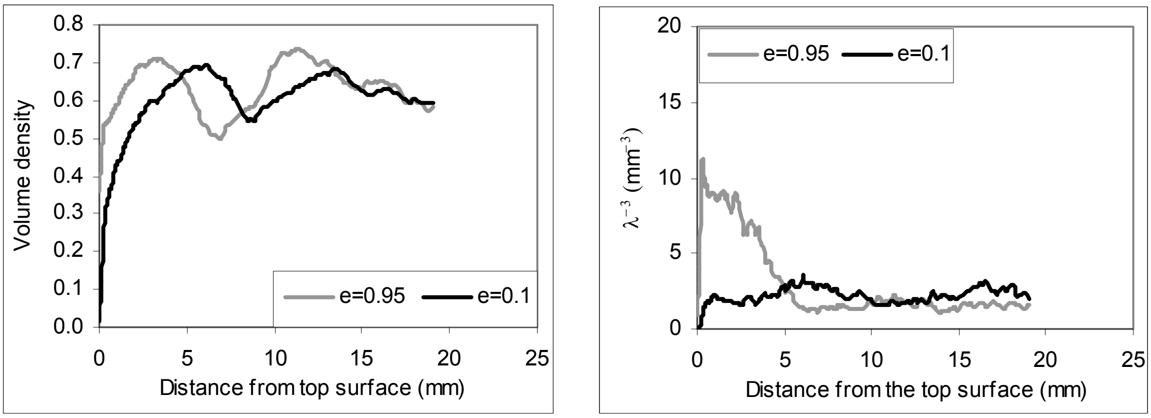
Evaluation

Table 1 summarizes properties of the model concretes, and gives the PSD parameters of the different coarse aggregate systems. The size gap with sand is for 'recycled' aggregate mix 11 % larger than for the 'Fuller' system, leading to a value of the migration capacity 65 % higher than in the latter case.

Table 1 Properties of concretes made with different types of coarse aggregates

Coarse aggregate	Recycled	Fuller	Fuller-A
Size range (mm)	4-14	4-14	4-19
Mean diameter (mm)	9.28	8.46	11.67
Median diameter (mm)	8.88	8.05	9.24
Mode diameter (mm)	11.15	10.65	15.47
Gap in size with sand (mm)	8.29	7.47	10.68
Global bond strength (λ^{-3}) in the surface layer (mm^{-3})	10.89	5.52	9.95
Global bond strength (λ^{-3}) in the bulk (interior part of the sample) (mm^{-3})	1.85	0.81	1.77
Migration capacity of sand particles (mm^{-2})	437.94	165.13	213.00

This confirms that the PSD of coarse aggregate and the gap in size with sand are the most important technical parameters affecting the migration capacity of fine sand particles (providing conditions to activate the mechanism of size segregation are optimized: intensity and duration of compaction, workability). The Fuller-type size distribution is relatively uniform (with similar volume fractions of particles in each class of the size range), yielding smaller values of mean and mode diameters than the 'recycled' aggregate system. It should be noted that computing time restrictions impose significant limitations to the number as well as the size range of coarse aggregate grains in the simulation study (due to the significantly larger number of fine sand particles that have to be generated in proportion to the mass of coarse aggregate). Hence, the positive effects of the gap grading mechanism can be expected much more pronounced in practical situations of concrete production.



(a) Volume density of total aggregate (b) Parameter corresponding to globe bond capacity

Fig. 4 Comparison between the admixtures made with 'recycled' aggregate in the case of different workability conditions.

For mixtures with similar volumetric mixture proportions and workability, no significant differences in the 28-day compressive strengths of concrete made with commercial recycled aggregate and normal weight natural basalt aggregate concrete were reported [11]. Workability of concrete is associated with the dosage of superplasticizer. It was demonstrated by the present authors in the earlier mentioned study on RHA-blending in concrete that the fine RHA particles cannot migrate through the network of large cement particles under poor workability conditions. As a result, the gap-grading mechanism is not exploited for improving the microstructure in the interfacial transition zone (ITZ) [7]. Concrete workability can be simulated in the SPACE system by specifying a so-called coefficient of restitution (denoted as *e*). This defines the energy dissipation during the dynamic generation stage of particle packing. Fig. 4 presents a comparison between the admixtures made with 'recycled' aggregate (volume fraction of total aggregates is 65 %) in the case of good (*e*=0.95) and poor (*e*=0.1) workability conditions. It is clear that the global bond strength (represented by λ^{-3}) remains relatively low throughout the sample in the case of insufficient migration of the sand particles. In contrast, dense inter-phase layers can be achieved (Fig. 4a) when the internal migration mechanism of sand particles can be optimized (under circumstances of suitable amount of compaction energy and length of the compaction process, and proper dosage of superplasticizer), leading to favorable strength and durability effects. Moreover, disproportionately larger internal bond capacity (based on van der Waals forces between nearby particles) is revealed in the surface layer (Fig. 4b).

Conclusions

This paper presents the outcomes of a computer simulation study with the SPACE system on the migration capacity of fine sand particles into the network of coarse aggregate grains in concrete production. Due to scale invariance, the results can be equally applied to cement blending case. The gap in size between fine sand and coarse aggregate has been found to exert significant influences on the migration capacity of fine sand. A larger size gap promotes the easier access of fine sand particles, which improves the density of material structure and, in particular, yields disproportionately enhanced bond strength in the inter-phase layer of model concrete. This is associated with the mechanical and durability properties of cementitious materials. The gap grading mechanism underlying the positive effects of the gap graded aggregate mixture should be fully exploited in concrete production practices. On the one hand, this has been demonstrated by computer simulation to be effective only when the internal diffusion mechanism of particles will operate. This depends in the first place on the compaction energy and the duration of this process, in combination with the proper workability level. Hence, workability and production conditions must ensure in practice the full exploitation of the migration mechanism.

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A Development of the Research on High Performance Concrete Incorporated with High Volume Fly Ash

Xing Feng[1,a], Xiang-yong Guo[2,3,b],
Fa-guang Leng[3,c], Ren-yu Zhang[3,d]
[1]Shenzhen University, Shenzhen Guangdong, 518000, PRC
[2]College of Water Resources and Hydropower, Wuhan University, Wuhan Hubei, 430072, PRC
[3]China Academy of Building Research, Beijing, 100013, PRC
[a]xingf@szu.edu.cn, [b]guoxy892@126.com
[c]cabrlengfg@126.com,[d]zhangrenyu@126.com

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Abstract. In this paper, the main characteristic of definition, property, requirement of raw material, mix proportion design and performance improvement of high volume fly ash concrete (for short HVFAC) are summarized. The applications of HVFAC in dam, highway, building and port are introduced. The research results have shown that HVFAC have outstanding properties of physical mechanics, but some problems need to be further studied. It is believed that an operable strict corresponding technical criterion would be set down as soon as possible for engineering practice.

Introduction

Recently, high volume fly ash concrete (for short HVFAC) [1] increasingly mature, and is extensively applied step by step in bridge engineering, highway construction, water conservancy project, building construction and port construction.

The history of HVFAC is short, HVFAC was studied and used by Britain's Dunstan etc. from 1979, the study of HVFAC is further advanced by Canada's Malhotra etc. from 1985.

From the development of HVFAC, application technology of HVFAC is largely advanced by two main factors which one is the building dam technology of RCC and other is increasingly popularized about water-reducers, especially superplasticizer in 1970s.

From the meaning of developing HVFAC, the notion of HPC, HVFAC and environmental-acceptable lower cement concrete is methodically combined, and for developing three nations implication, going to a new type building material and green building material way, has guidance meaning.

From the benefit of founding HVFAC, there are outstandingly effect in some aspects such as the raise of fly ash application technology, the heightening of comprehensive utilization benefit, the increasing of both supply and demand benefit, the enhancement of environmental protection power. It is therefore of the triple benefits.

The development of HVFAC, hence, is a road of sustainable development and the embodiment of technical route of a new type environmental-acceptable concrete of green building material. To economize energy, improve environmental protection and control pollution, efficient eliminated industrial waste residue, have walked out of a good new road.

Definition

HVFAC has been not a unified definition yet now. Reference [2] deems that the implication of HVFAC is according to replacing cement ratio about 15 % with fly ash to decide in our country. i.e. replacing cement ratio above 30 % (including 30 %) mixing concrete is defined as HVFAC. But 40 percent fly ash is defined as upper limit in many state standards or regulations, the quantity of fly ash in concrete do not exceed 40 percent stipulated in many cases. Therefore, Reference [3] deem that above 40 percent fly ash in concrete defined as HVFAC is suitable. Some researchers suggested that the concrete may be defined as HVFAC while the quantity of fly ash exceed of cement in cementitious material, i.e. the quantity of fly ash is more than 50 percent. Reference [4] suggested that the quantity of fly ash in HVFAC must be 50 %～70 %, namely the volume of fly ash is larger than cement in concrete.

Reference [5] defined HVFAC is a new type material. It is deferent from ordinary concrete, which is even through a large quantity of fly ash. It is including follow as properties: 1) According to construction demand to mix concrete, which does not regard as reference from a uncontant fly ash mixing ratio on concrete, using same quantity of fly ash instead cement; 2) Due to fly ash to cementitious-water ratio is more sensitive that cement to, it demands to use chemical admixture or/and mechanical (e.g. vibrating and rolling) ways making cementitious-water ratio as decreasing as possible, the function of fly ash produced strength development is appeared in advance, therefore, the demand of the design may be satisfied by mixing 28-day or other designed age in concrete; 3) This result is that the quantity of fly ash is seriously increased than ordinary concrete, and the effectiveness of fly ash is not fully elaborated, it is therefore obvious in economic profits.

Present Conditions of the Research

Raw Material Demand

There are no special demand in HVFAC for cement and aggregate, which one generally similar with ordinary concrete. HVFAC need to mix superplasticizer in order to mix the concrete of the good property. With mixing superplasticizer the air-entraining agent is mixed in order that mixture in concrete has suitable air content and improve the properties of concrete.

Reference [6] believe that HVFAC is most different from ordinary concrete in raw material is that large volume fly ash is mixed. Britain's Dunstan deems that not the quality of fly ash and the variationality of its quality is important. Low quality fly ash may mix the concrete of the good property so long as the variationality of its quality no marked. Canada's Malhotra used eight kinds American fly ash does study of HPC, their 45 μｍ residue on sieve is 17 %～32 %, and only attained China's standard of Ⅱ or Ⅲ fly ash.

Reference [7] results have shown that low quality fly ash concrete may develop same mechanical property with ordinary concrete in reinforcement bending structure, and the common workability of concrete and steel reinforce bar is not affected by low quality fly ash. Meanwhile, Reference [8] results have shown that high volume low quality fly ash in concrete may largely improve chemical resistance. And Reference [9] deems that the flow and strength in concrete are affected remarkably by the fineness of fly ash in HVFAC, which the flow and strength in concrete are raised while fly ash is finer.

Research of Mechanism

The degree of alkalescence for HVFAC will remarkably cut down because of fly ash using up $Ca(OH)_2$. If the degree of alkalescence in concrete dropped to below 11.5, $Fe(OH)_2$ is dissolved, and cause steel bars passive film decrease to drop the character to protect reinforcing steel bar against corrosion. Besides, low degree of alkalescence inconcrete may drop the chlorine ion diffusion resistance. What's more, as will be seriously inadequate for $Ca(OH)_2$ which is depleted in the process of natural carbonation in concrete. So carbonation resistance of HVFAC may cut down. Though carbonation resistance is related to many factors, it is one of important factor for carbonation using up $Ca(OH)_2$. It is therefore profound to properly raise the degree of alkalescence of HVFAC in liquid phase. Reference [10]'s results have shown that the degree of alkalescence in HVFAC for porosity liquid phase compare with ordinary, obviously dropping after 7 days, 200 days approaching 11.5

about critical value, the degree of alkalescence is obviously raised by mixing lime powder and Na_2SO_4 in the same strength even increasing.

Table 1's results have shown that after mixing lime powder or Na_2SO_4, 100 days and 200 days the degree of alkalescence is differently raised in fly ash concrete, but after lime powder and Na_2SO_4 mixing together, the degree of alkalescence approach that of ordinary concrete.

Table 1 The effect of mixing lime powder and Na_2SO_4 on the degree of alkalescence in fly ash concrete for liquid phase

Cementitious materials (cement+ fly ash + lime) /%	Na_2SO_4 /%	Mixing ratio (CM:W:S:G)*	pH value	
			3d	28d
100+0+0	0	1：0.38：0.9：0.26 (mixing 1%FDNsuperplasticizer, usings super-fine sand)	12.12	12.10
50+50+0	0		11.65	11.60
50+40+10	0		11.95	11.90
50+50+0	1.5		11.75	11.70
50+40+0	1.5		12.10	12.00

* CM—cementitious materials; W—water; S—sand; G—gravel

Reference [11], in addition, thinks that the content of alkali is continuously increased in current cement, using fly ash largely saved cement clinker, and restrained alkali-aggregate reaction; for less content of C_3A and the heat of hydration in cement, the danger of surface opening crack which is caused by large temperature difference on concrete structures is reduced; the large quantity $Ca(OH)_2$ is depleted by fly ash hydration reaction and inferior quantity composition in concrete is reduced, so chemical resistance is more stronger than OPC(ordinary performance concrete). Meanwhile, the density and the impermeability are increased by the Three Effects of fly ash, and exists dose relation between the penetrability and the durability in concrete, the impermeability increased to a great is the key for improving durability in concrete.

Reference [12] deems that due to mass vitreous body spherical grain exist to fly ash, internal structure compacted, almost no cracks, so internal specific surface area is smaller than OPC in concrete, and the ability of absorbing water is lower than OPC. Therefore, the HVFAC has less shrinkage, high cracking resistance and obviously improve the brittleness.

Early age Properties

(1)Consistency

Reference [13] have shown that the volume of the paste increasing, which the specific gravity of fly ash is about 2/3 of the cement, cause cohesiveness to obviously increase, and the workability of the blender decreases and instead. At this time, a little dosage of superplasticizer or water requirement needs to increase. HVFAC has a good cohesiveness and moisture retention. HVFAC's consistency is influenced such as the quality of fly ash, the kind and dosage of admixture, etc.. In a word, if only the mix rate of HVFAC is suitable and the mixing time is ample, its consistency may satisfy the requirement of different kind projects.

(2)Entrapped air

When designing HVFAC needs to entrain air, the ignition loss of the influence of fly ash (the content of carbon) on air entraining efect is very oblivious. For fly ash with high content carbon, retraining high dosage air is very difficult.even through HVFAC of which using low carbonaceous fly ash meets is inferior to air entraining capability after entraining air. Therefore, for air entraining HVFAC, the entrapped air is ensured to satisfy designing demand by suitable the technical processes of conctruction ater HVFAC used into storehouse.

(3) set time

If the affect of admixture is not considered, the set time of HVFAC is as which with dosage increasing set time tend to delay as low dosage fly ash, which the degree o extension is in relation to the kind of cement and the quality of fly ash. At the same time, superplasticizer on air entraining agent is often mixed in HVFAC and the dosage is higher. so set time is influenced by the dosage of superplasticizer or air entraining agent. when their dosage is very high, HVFAC's specimens can't set and harden at day even 2 days.but active excitation agent may obviously accelerate set time, as is essentially equal with one of OPC. Besides, compared with OPC and low content fly ash concrete, the affect of temperature on set time and early age strength of HVFAC is more obvious.

(4) properties of heat

Due to AHVFAC containing high fly ash, the autogenous temperature rise of HVFAC is much lower than Portland cement concrete. Portland cement concrete is of obvious temperature peak and temperature decrease is quicker relative after arriving temperature peak, and temperature decrease of HVFAC is not obvious, the temperature can't rapidly decrease after arriving temperature maximum.

Harden Properties

(1) strength

When fly ash mixed in concrete, with the increasing of dosage its early age strength may generally decrease, the quality of each ingredient in HVFAC is of bigger flexibility and high early age strength for HVFAC may be mixed. Many testing studies have shown that the cube compressive strength of HVFFAC still increase notably for after 28days not only in lab but also on site.

(2) properties of deformation

The elastic modulus for HVFAC resembles the Portland cement concrete of which 28-day cube compressive strength of HVFAC is approach, the higher compressive strength is, the bigger elastic modulus is. The creep and drying shrinkage comparing to Portland cement concrete is low. For the brittleness of HVFAC, reference [14]'s research have shown that 28-day age flexure to compressive ratio (i.e. ratio of flexure strength and compressive strength) for HVFAC is 0.12, is greater than 0.11 of reference.

(3) durability

The distribution of porosity diameter in HVFAC differs from Portland cement concrete, which the quality of big porosity is less and the permeable coefficient is low and is generally $1.6\times10^{-14}\sim5.7\times10^{-13}$ m/s, and is of strong ion diffusion resistance. With age development the higher compressive strength is, the lower chloride ion diffusion resistance is. Reference [15]'s testing results have shown that the water-tightness of 28-day samples for HVFAC is lower than Portland cement concrete. but the water-tightness of 91-day samples is better than portland cement concrete, especially the water-tightness of 56 % fly ash concrete attain best grade.

HVFAC is of good freezing and thawing cycles resistance. Reference [16]'s testing results have shown that the coefficient of durability is higher than compared concrete. But it is founded by experiment that the sample surface for HVFAC peel off slightly after about 50 freezing and thawing cycles. Reference [17] compares the freezing and thawing resistance of HVFAC (c=150 KG/M3, FA=190 KG/M3) and ordering performance concrete(c=290 kg/m3~340 kg/m3), all mix rates entrained 5 %~7 % air content. Results have shown that the anti-freezing of HVFAC is obviously better than ordinary concrete.

Reference [18]'s studies have shown that the depth of carbonation is greater than ordinary performance concrete which has same age and the time of carbonation (it's quality of cement is equal with total amount of cementitious material in HVFAC).with increasing age the depth of carbonation decreases slightly. The depth of carbonation is affected obliviously by the amount of fly ash and cement. when total amount of cementitious material is 222 kg/m3, the depth of carbonation mixing 55 % fly ash in HVFAC increases mildly, but that of 70 % increases rapidly; when total amount of cementitious material is 333 kg/m3, the depth o carbonation mixing 55 % fly ash in HVFAC decreases obliviously and increasing tendency is mildl, as that of 70 %, with extended the time of carbonation, the process of carbonation is accelerate gradually.

HVFAC has the property of sulfate attack very well. HVFAC steapping at the solution of 10 % Na_2SO4 by japan effectively restrain alkali-aggregate expansion, even through at same severe environment conditions to do so. Studies by MALHOTRA have shown that the dosage of fly ash is 58 % in HVFAC greatly decreases swelling in concrete.