The Development, Production and Application of CN2000®B Cementitious Capillary Crystalline Waterproofing (CCCW)

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The Development, Production and Application of CN2000®B Cementitious Capillary Crystalline Waterproofing (CCCW)

Summary: **CN2000®B** is one of our series of waterproof materials with an Eka-Molecular Sieve Structure developed by our Manufacturer. This Concrete Waterproofing and Coating material enhances the durability of concrete structures and infrastructure, and is effective in saving costs for future maintenance of Concrete Structures to a significant level.

CN2000®B and its related products are necessary to ensure the building of an efficient infrastructure in our Communities and to maintain sustainable development of infrastructure and concrete structures in our Communities.

This document will introduce the reader to **CN2000®B** its structure, characteristics, production technology, installation and application in various concrete projects.

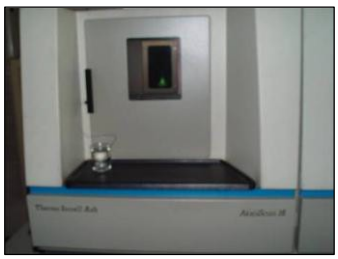
Key words: Cementitious Capillary Crystalline Waterproofing (CCCW) - Eka-Molecular Sieve – Waterproof – Anticorrosion - Full Automatic Powder Preparation System - Spray Coating Installation – Durability - Life Cycle Cost Analysis (LCCA).

Our Manufacturer is a High-Tech Corporation based in China utilizing the Technologies developed by the Chinese Institute of Physical and Chemical Engineering of The Nuclear Industry. The Manufacturer specializes in the development and production of waterproof materials, and it owns several patents and proprietary techniques for developing conditions and advanced equipment for experimental analysis that make its products unique and more efficient than similar products.

MTS Universal Material Testing Equipment

Electronic Tensile Testing Equipment

Metallurgical Microscope



ICP Atomic Emitting Spectrum

Infrared Spectrograph

Scan Electron Microscope

The **CN2000®** series of waterproof materials belong to the High-Tech and **Environmentally Friendly** product types

The products were appraised by the Science and Technology Commission of the National Defense Industry of China. The conclusion of the appraisal is that "the synthetic performance and technical index of the series of waterproof materials has reached internationally advanced level". This series of products has been listed as "Important National Products" by the Commission of Economy and Trade of China. As well, they were placed in "The Chinese Peaceful Purpose Export Products List with Military Technology."

The Manufacturer uses high-tech methods, such as a Digitally Controlled Automatic Powder Preparation System which has independent intellectual property rights (**seven patents in China**) and a Latex Preparation System for producing the waterproof material, and to ensure the high quality and purity of its products.

The Manufacturer currently has the ability to produce its product line on a large scale and can expand its production capabilities to meet market demand.

(Current production capacity is now at a level of ten thousand tons per annum).

The Manufacturer has passed **ISO 9001-2000, GB/ 19001-2000** Authentication System of Quality Control and Material Safety Data Sheets. **(MSDS)**

The Manufacturer has successfully developed a spray coating application/installation technology, solving the difficulty of installation of its products in difficult application areas.

Example of CN2000®B Spray Application utilizing CN2000® Spray Equipment

The Development and Characteristics of CN2000B® (CCCW)

1: General Description of the Waterproof Mechanism of CN2000B®

In the process of developing the **CN2000®B (CCCW),** the Manufacturer started with molecular physics and the research of intermolecular force and the movement rule of molecules, this introduced the concept of "eka-molecular sieve" and "capillary crystalline".

The main body of the waterproof material was made to have a structure of the eka-molecular sieve. Its waterproof layer has a high impervious strength and yet still has the ability to breath. With this technology, the effect of ventilation and waterproofing is jointly achieved.

In **CN2000®B (CCCW)** the manufacturer has specifically developed **"**the activating substance" (briefly called "**R**") which is developed from unsaturated polar molecules and is an ultra-fine (nm) powder. It enriches the surface of the concrete by the action of another important special auxiliary material ☐ a sort of eka-molecular sieve. The latter has many pores with a uniform size, and has very high specific surface. Its characteristics are:

(1) It can absorb certain molecules optionally according to the size and form of molecules.

(2) For polar and unsaturated molecules, the stronger the polarity and unsaturated degree are, the stronger its absorption opting ability is.

Cement and quartz sand in **CN2000®B (CCCW)** acts as a dispersing agent and it is distributed uniformly.

After the activating substance in molecular level is absorbed on the surface of the eka-molecular sieve and all its fine holes, it spontaneously separates into the atomic level state. During this time, the activating substance exists in the small cages of the eka- molecular sieve in a positive or negative ion or their "inclusion body" form, and then the activating substance is activated.

Diffusion

Enrichment and ionization of the activating substance with the help of the eka-molecular sieve creates the condition for its diffusing and migrating into the concrete substrate.
The diffusion of the activating substance through the interface of the cement due to the concentration gradient is a non-steady state diffusion. It conforms to the second **Fick** law.

As outlined in the pages below

That is

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2} \quad \cdots\cdots \text{i}$$

Where, **c** is the contents (%) of "**R**" at **x** (mm) from the surface of cement substrate, t is the time (week), **D** is the diffusion coefficient of "**R**" in the cement. The boundary condition is:

$$C(0,t) = C_0(t) \quad \cdots\cdots \text{ii}$$

$$C(\infty,t) = 0 \quad \cdots\cdots \text{iii}$$

Find the solution of the following equations:

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2} \quad \cdots\cdots \text{i}$$

$$C(0,t) = C_0(t) \quad \cdots\cdots \text{ii}$$

$$C(\infty,t) = 0 \quad \cdots\cdots \text{iii}$$

The standard solution of i 、 ii 、 iii :

Let

$$Z = \frac{x}{\sqrt{4Dt}} \quad \cdots\cdots \text{iv}$$

Thus

$$C(x,t) = C(z,t) = \frac{2Co(t)}{\sqrt{\pi}}\int_z^{\infty} \exp(-u^2)du \quad \cdots\cdots \text{v}$$

$$\operatorname{erfc}(z) = 1 - \operatorname{erf}(z) = \frac{2}{\sqrt{\pi}}\int_z^{\infty} \exp(-u^2)du \quad \cdots\cdots \text{vi}$$

vi is the remaining probability integral (or remaining probability function).

Suppose in the interface between **CCCW** and the substrate, the changing rate of the "**R**" concentration is proportional to the square of the concentration **Co(t),** then

$$\frac{dCo(t)}{dt} = -kCo(t)^2 \quad \cdots\cdots \text{vii}$$

The solution is:

$$Co(t) = \frac{Co}{Co \cdot k \cdot t + 1}$$

That is

$$\frac{1}{Co(t)} = k \cdot t + \frac{1}{Co} \quad \cdots\cdots \text{viii}$$

Where **Co** is the integral constant, which is the initial boundary concentration of "**R**" in the interface between **CCCW** and the substrate, at **t=0**.

The **k** and **Co** can be found with regression analysis to the equation ⍰ using the data of the **table I**;

With the least-square method it gives **D**=2.37 (mm^2/week). Then substitute **D** into equation vi and obtain **C(x, t)** (**x**=2, 4, 6, 8, 10; **t**=1, 2, 3, 4) finally make the curve of **C** against **t** (**table I, fig 1~4**).

From **table I, fig 1~4** shows the theoretic curve is near to the experimental data, this indicates: the basic hypothesis for the diffusion of "**R**" in the cement to conform to the **Fick** law.

Table I: The concentration (C_R%) distribution of "R" in the sample

Position/week \ Age/week		3d	1	2	3	4
.Substrate	1.5—2.5	0.185	0.215 (0.225)	0.302 (0. 324)	0.360 (0. 372)	0.370 (0. 402)
	3.5—4.5	0.010	0.052 (0. 041)	0.148 (0. 120)	0.170 (0. 181)	0.243 (0. 223)
	5.5—6.5	0.001	~0.005 (0.004)	0.020 (0. 031)	0.060 (0. 075)	0.085 (0. 105)
	7.5—8.5	~0	~0 (1 x 10^{-6})	0.005 (6.0 x 10^{-5})	0.033 (0. 021)	0.030 (0. 041)
	9.5—10.5	~0	~0 (~0)	~0 (8.2 x 10^{-6})	~0 (4.5 x 10^{-5})	0.010 (0. 015)

Note: the experimental data are statistical ones; the data in brackets are theoretic calculated data.

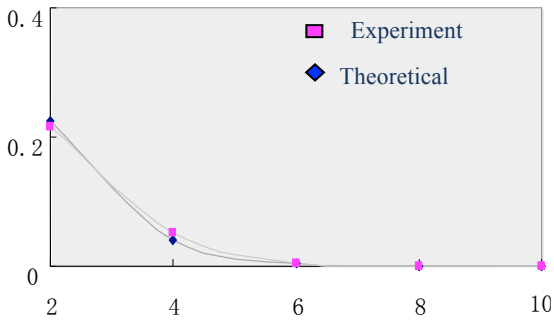


Fig 1 t=1, C～X

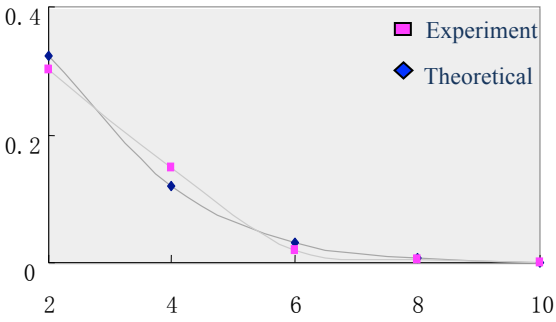


Fig 2 t=2, C～X

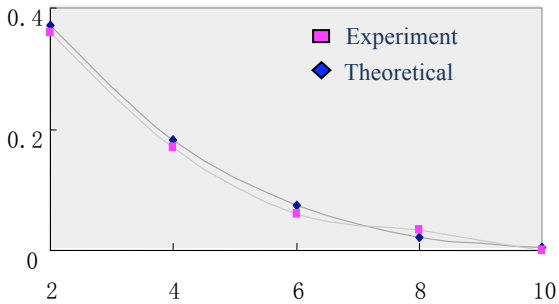


Fig 3 t=3, C～X

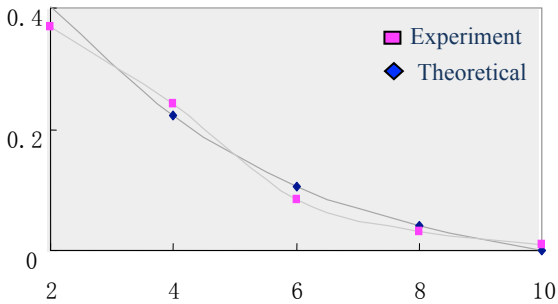


Fig 4 t=4, C～X

• The action mechanism of the activating substance "R" in the cement stone surface

Table Ⅱ content of crystalline water / C (%)

Sample \ Age/week	3d	1	2	3	4
Sample without coating	5.10	9.92	12.93	14.68	16.37
Sample with coating	10.75	14.34	15.94	16.79	17.21
△C*	5.65	4.42	3.10	2.11	1.16

*△C : The value of sample with coating – the value of the sample without coating

Table Ⅲ Ca(OH)$_2$ content /C (%)

Age/week / sample	3d	1	2	3	4
Sample without coating	**6.1**	**7.92**	**8.80**	**9.25**	**9.50**
Sample with coating	**3.23**	**4.7**	**5.32**	**5.31**	**5.22**
△C*	**2.87**	**3.22**	**3.52**	**3.94**	**4.28**

*△C : The value of sample with coating – the value of the sample without coating

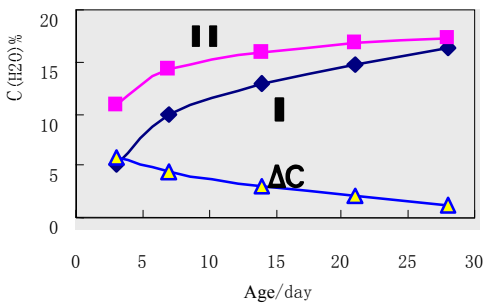


Fig 5 crystalline water ~ day

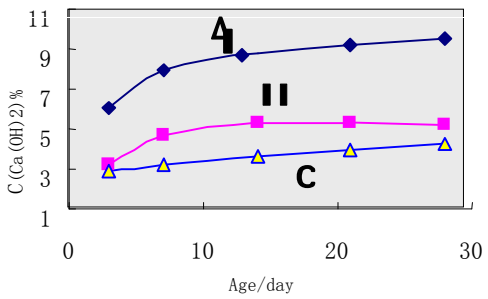


Fig 6 Ca(OH)$_2$ content ~ day

From table II and Fig. 5 – shows the sample without coating

(Curve Ⅰ) water crystalline content appears to increase along with storage time; the sample with coating (curve Ⅱ) the water crystalline content also increases and levels, but is higher than the sample without coating at all times, the difference shows a decreasing trend along with storage time.

From table Ⅲ and Fig. 6 -- the Ca(OH)2 content of the sample without coating increases with the storage time, the values of the sample with coating are lower than the value of sample without coating

The changing trend of crystalline water and **Ca(OH)$_2$** contents in the blank samples shows that along with the storage time the hydration of the cement progresses slowly, from its surface to inner layer.

As the following reactions (1) ~ (4) show, along with the production of hydrated calcium silicate and hydrated calcium aluminate increases, free-water is consumed continuously and changes into chemical crystalline water; at the same time, the separated quantity of the **Ca(OH)$_2$,** which is one of the products, is also increased.

The difference of analyzed values between the coating sample and the blank sample is made by the coating **CCCW**, and is related directly with the penetration of the activating substance "**R**". With the special activating action, "**R**" activates **SiO$_2$**, **Al$_2$O$_3$**, water and the hydrated product **Ca(OH)$_2$**, and makes more reactions, producing **C-S-H** gel again, thus the chemical crystalline water is increased but the content of **Ca(OH)$_2$** is decreased.

The activating substance "**R**" interfaces with the cement through absorption and diffusion with its special characteristics and structure. This promotes the migration and exchange of ions leading and catalyzing the hydration reaction further. As a result, the surface layer of the cement substrate, the **C-S-H** gel is again formed, filling in, and blocking up the larger pores, diminishing the pore size in the cement; the void factor being reduced, the structure becomes denser, and the compressive and impervious strength increases dramatically. When and if small cracks in the concrete substrate occurs or should ever occur from inner stress or outside forces, the presence of water with the activating substance results in chemical activity and catalyses to produce a gel reaction, making the **C-S-H** crystals to form along the cracks, and as a result, this blocks the small cracks, achieving the "self healing" function and renews the cements impervious strength. Thus the waterproofing and impervious purpose is effectively achieved through the cement structure and will activate even years down the road to seal further cracks up to 0.4 mm.

The reaction process can be expressed as following reaction formulas.

$$xCa(OH)_2+SiO_2+mH_2O \rightarrow xCaO\cdot SiO_2\cdot nH_2O \quad \ldots\ldots (1)$$

$$xCa(OH)_2+Al_2O_3+mH_2O \rightarrow xCaO\cdot Al_2O_3\cdot nH_2O \quad \ldots\ldots (2)$$

$$3Ca(OH)_2+Al_2O_3+2SiO_2+mH_2O \rightarrow 3CaO\cdot Al_2O_3\cdot 2SiO_2\cdot nH_2O \quad \ldots\ldots (3)$$

A part of hydrous calcium aluminates react with plaster in the cement to produce the hydrous calcium -aluminate-sulfate crystals:

$$Al_2O_3+Ca(OH)_2+CaSO_4+H_2O \rightarrow CaO\cdot Al_2O_3\cdot CaSO_4\cdot H_2O \quad \ldots\ldots (4)$$

As stated above, the existence of water, silicate and hydrated product of cement stone, **Ca (OH)$_2$** is the basic condition to produce new **C-S-H** gel (crystalline), and the activating substance play the role of catalysis which cannot be short for producing the new **C-S-H** gel.

It needs to be pointed out, that the content of the activating substance in the coating layer is higher than that penetrating into the cement substrate, so the hydration and the second-hydration in coating itself is stronger than in the latter, and plays a key role in the waterproofing effect; that the coating layer compacts with the cement substrate together and has some strength complementing actions to it, which is the important difference between this waterproof material and other ones (such as roll materials).

The research and testing for our waterproof product **CN2000®B (CCCW)** by the **ZHONGNAN** University shows that the active substances in the coating layer have obvious penetration and that the penetration increases with age. The results improve the impervious performance and high waterproofing dynamics of the **CN2000®B (CCCW)** (see fig 1~6).

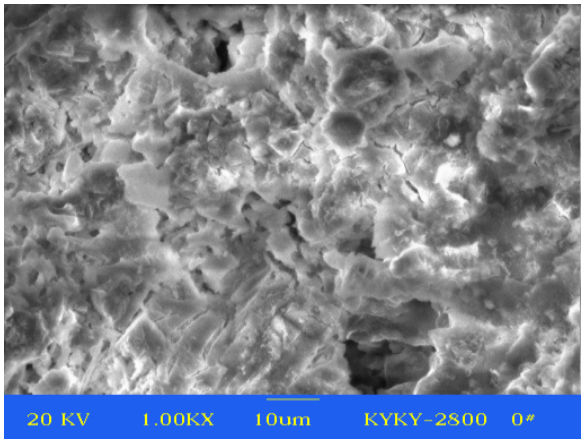


Fig 1 **SEM** picture of **CN2000®B** crystalline product at the age of 28 days

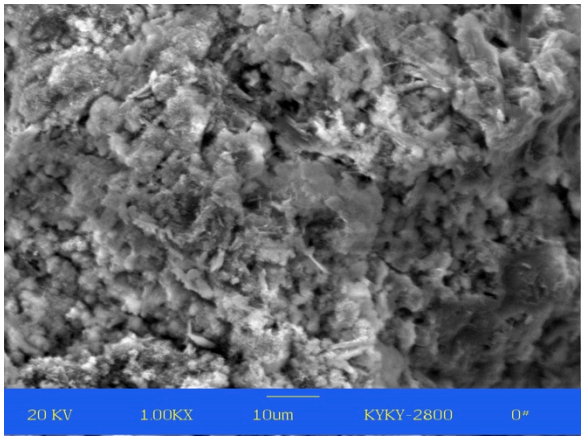


Fig 2 **SEM** picture of mortar crystalline product at the age of 28 days

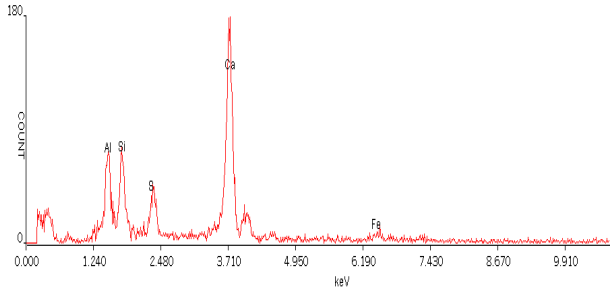


Fig 3: The **EDAX** curve of **CN2000®B** crystalline product

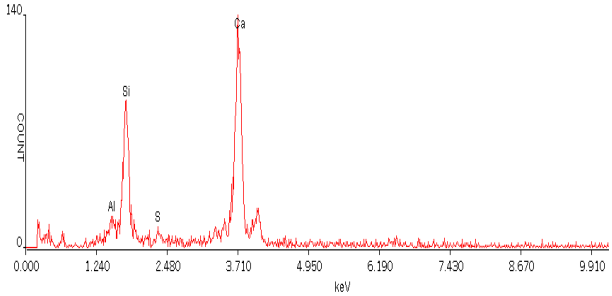


Fig 4: The **EDAX** curve of mortar crystalline product

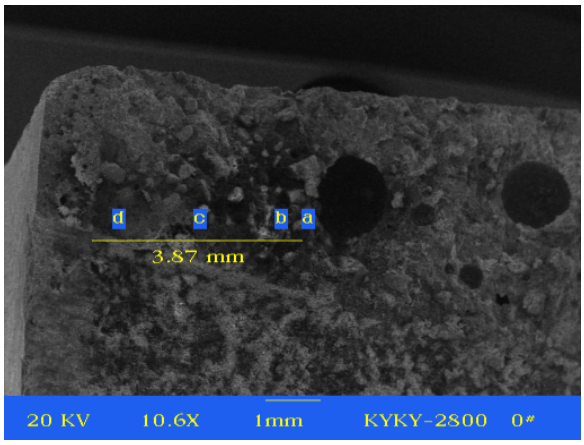


Fig 5: **SEM** picture of sample coated with **CN2000®B** at the age of 7 days

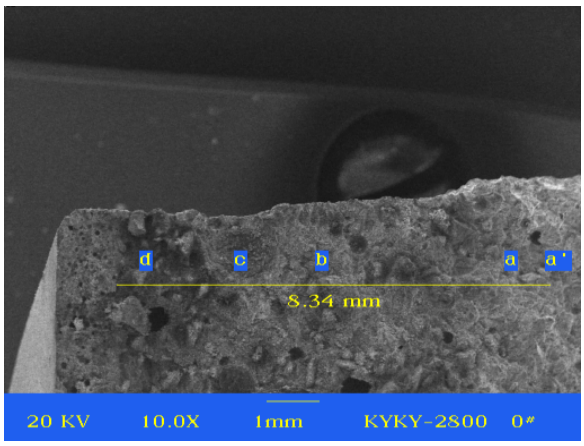


Fig 6: **SEM** picture of sample coated with **CN2000®B** at the age of 14 days

1.2: The Characteristics of CN2000®B (CCCW)

a.) **Waterproofing and impervious** performance is outstanding due to the Capillary Crystalline characteristics of the material; the waterproofing effect becomes more effective over time as the active materials of the product are absorbed through the concrete structure.

b.) **Anti-Corrosion Properties.** The material resists high or low temperature, dry – damp cycles, freeze – thaw cycles, and resists the alkali aggregate reaction, resists aging, carbonization and corrosion due to acid gases and acid water, chloride, sulfate and so forth. Further to this, when properly applied, the product ensures that the internal structure (rebar structure) becomes corrosion resistant as a result of the application of **CN2000®B (CCCW).**

c.) **High strength.** Due to the action of the capillary crystalline, the coating layer becomes an integral component of the concrete. Thus a high pressure water head can be effectively resisted.

d.) **High stability.** As a crystalline structure is produced in the coating layer the interface doesn't decompose, it resists aging from ultraviolet radiation (Sunlight).

e.) **Long life-span.** A concrete structure coated with **CN2000®B (CCCW)** has an increased life span due to **CN2000®B's** properties and protection. The durability of the CCCW coating layer has the same life-span as the concrete substrate.

f.) **Normal ventilation.** The crystalline products of CCCW will not affect the breathing ability of the concrete and the concrete will continue to breathe normally to allow for normal setting, curing and drying.

g.) **Self-healing ability.** Fine cracks less than 0.4 mm will self-heal when exposed to water. This in itself proves its effectiveness and waterproofing properties.

h.) **Environmentally Friendly Product**. The material is nontoxic, odorless, and will not become a secondary pollutant upon demolition. This product can be safely used in projects such as drinking water/potable water engineering, food processing, swimming pools, spas, and bathrooms. The examination show that the contents of formaldehyde, Volatile Organic Compounds (VOC), heavy metal and other harmful substances are far less than the detectable, or for that matter, allowable limits.

i.) **Convenient Application / Installation**. **CN2000®B** can be applied in normal temperature ranges and on damp concrete substrate; it can be applied by brush, trowel coating or by an approved spray application, which is the simplest method. The product is quick setting and saves valuable time on large projects. In underground projects there is no need for any specialized ventilation conditions for proper curing. The product is suitable for various substrate conditions (new, old and/or complicated substrates).

j.) **Economy.** The ratio of performance to price is very reasonable. The installation and curing times are economical and timely. The costing of materials and installation are much less than similar products of other companies. Costs of the product are soon recovered due to the extended life span and durability of the coated concrete structures, specifically in the maintenance and replacement of concrete structures

and /or infrastructures.

2: The Development of the Production Equipment for CN2000®B (CCCW)

The Cementitious Capillary Crystalline Waterproofing Materials are uniform powder mixtures which are comprised of, cement as the main material, the proprietary activating substance and other additives in the concentrate and/or auxiliary material. Although the amounts of these additives are minimal, comparatively, they act decisively in the performance of the product. The precise batching and uniform mixing is a very important precondition for ensuring the complicated physical and chemical reactions required, and to ensure the quality and performance of the **CN2000®B (CCCW)** product line.

2.1: General Description of Traditional Powder Material Batching and Mixing.

2.1.1: Batching:

At present, in China, and in other countries, the traditional intermittent batch mixing is utilized in the powder industry. With this method it is difficult to avoid large random errors in mixtures and this process doesn't have the ability to automatically change the amounts of auxiliary material being fed into the mixture, to allow for changes in the main material flow rate, causing unstable mixing proportions of the materials. This batching technology is not appropriate for High-tech mixing, and affects product quality, and the continuous production of these High tech materials and products.

New developments in computer and transducer technologies and especially in the continuous detecting techniques of flow rates of dispersed solid materials are becoming more mature with each passing year. Although the development of the continuous burden method has made tremendous progress in the world of mixing technologies, "the servo control" of the flow rate is still an unresolved problem for the continuous burden process.
"The auxiliary material servo system" developed by our manufacturer of **CN2000®B** has resolved this difficult problem successfully (see following "brief introduction of full automatic powder preparation system".

2.1.2: Mixing

In the traditional mixing process, the mechanical stirring, rotating, vibration, centrifuging, or air streaming is utilized to physically move the materials to produce countercurrents, diffusion, and shearing, (that is displacement, movement, and sliding of the target materials) and other physical behavior, to reach a level of uniformity. In the mixing process, mixing and segregating alter each other, and the mixed quality will reach the highest value firstly, and then comes to an equilibrium state, which is a dynamic balancing course. This equilibrium is built under a certain conditions and cannot obviously reach the optimum quality mixture. It is very difficult to search and determine for this condition for an ordinal (level of measure) mixing machine.

This "system of mixing in many fine streams" developed by our Manufacturer has successfully resolved this difficult problem. (See the introduction of the full automatic powder preparation system).

2.2: Introduction of the Fully Automatic Powder Preparation System (Patent Number: 539822)

The main body of this production system includes a servo affixation system of auxiliary material and a system of mixing in many fine streams. It can complete the near perfect integration of many and varied sorts of powder, and can maintain continuous mixing and automatic production. Using this methodology, the annual output of **CN2000®B (CCCW)** of our manufacturer has increased production from a hundred ton level per production line to a ten thousand ton level per production line.

2.2.1: Servo Affixation System of Auxiliary Materials

By means of a highly accurate force transducer and a reliable force transmission mechanism, this system precisely measures the immediate flow of the specific materials.

According to the ratio set by computer, the actuator comprised of the servo motor and precise screw driver can adjust the added quantities of auxiliary materials accurately within 1 ms, insuring the burden ratio of various auxiliary materials to be accurate, stable and uniform.

2.2.2: System of High-Tech Mixing in Many Fine Streams

`The material stream is ensured by dividing the materials into many beams, with the diameter of each of them as small as 10 times the diameter of a grain. The force of continuously changing direction is continuously applied to all the material, and each grain of material is then stricken. The timing of the changing of force can be adjusted to a time less than that it takes for a grain to fall a distance equal to the grain size.

The development of the servo affixation system and system of mixing in many fine streams makes the burden ratio of various materials with different sizes and specific gravities to ensure precise and uniform mixing is achieved. In this process, the material does not allow the destruction, overheating, disintegration or delaminating phenomena that occur in other processes. This allows the burden ratio of various powder materials to comply with exacting requirements in each and every cubic centimeter (1 cm3) of the product. The indexes of the burden ratio are accurate and uniform and exceed the corresponding index of other existing mixing and blending equipment (see table 1).

Using proprietary designed and developed software; the system can effectively be controlled remotely to realize precise measurements, quality control and security through-out the production process, via a linked computer. No other manufacturer reports this type of technique or technology according to science and technology reports worldwide or through patent searches.

The full automatic powder preparation system structure sketch can be seen in fig 7. The photo of the actual system can be seen in fig 8.

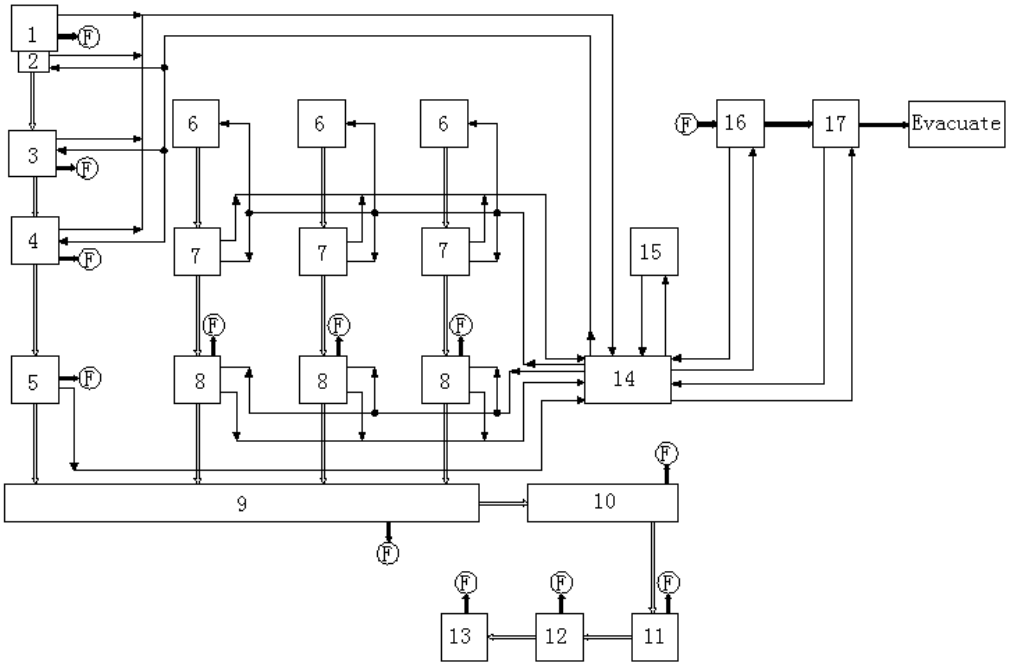
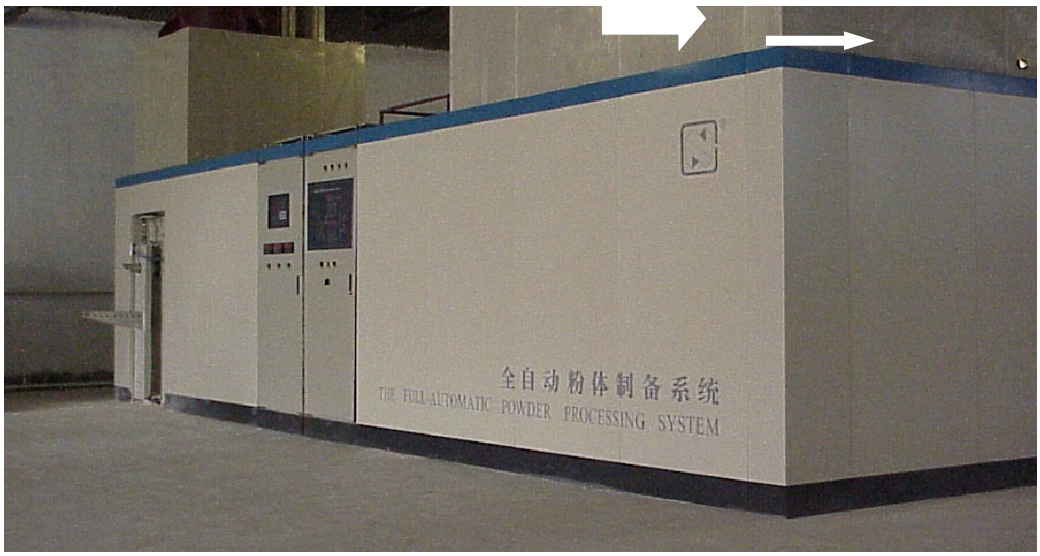


Fig 7. The Fully Automatic Powder Preparation System structure sketch

1— Bunker of bulk material 2— Feeding machine 3— Sieving equipment 4— Conveying machine of bulk material 5— Impulse-type flow meter 6— Bunker of auxiliary material 7— Weighing machine in terms of decrease 8— Affixing machine of auxiliary material 9— burden machine 10— Mixing machine 11— Product bunker 12— Packing machine 13—Storage room for product 14— Central controller 15— Remote computer 16— Negative pressure source 17— Tail gas treatment device

Electric signal line Material flow line Air flow line



The Manufacturers Fully Automatic Powder Preparation System

Table Ⅳ Comparison of the main technical index between the Fully Automatic Powder Preparation System and other mixing equipment.

Item	Ordinary mixing equipments	The full automatic powder preparation system
Operating method	Intermittent	Continuously
Mixing method	Manual	Automatic
Ratio deviation of mixture	—	< 2%
Mixture uniformity (coefficient variation)	< 1.5%	< 1%
Respond time of auxiliary material adding	No requirement	Electrical portion：< 1ms Mechanical portion：0.5～3ms
Energy consumption of the mixing portion	2kwh/t	< 0.5kwh / t
Dead area	Exist	No
Unloading ratio	< 100%	100%
Occupied area and space	large	small

Environmental Conservation Indexes:

The manufacturing of **CN2000®B** poses no threat to the **environment** through air or noise pollution and meets or exceeds relevant National Standards worldwide.

3: The Development of the High Viscosity Mortar Spray Coating Applicator Equipment and CN2000®B (CCCW) Spray Coating Technology

Trowel and brush coatings are common installation methods of **CN2000®B** however for the application to walls and overhead surfaces of a vehicular traffic tunnel, the vaulted ceiling (See figures below) required an efficient overhead application method to appropriately coat the substrate surface in large installation/application area. To this end our Manufacturer researched and developed a Spray Coating Installation/Application technology.

After years of research and development our Manufacturer has designed and now markets a full line of approved spray coating equipment and related accessories designed specifically for the application of the **CN2000®** line of products.

Examples of the equipment usage and the successful application in the entrance and exit archway of the Sanxia underground Power Station are shown below.

Prior to the application of **CN2000®B (CCCW)** serious water leakage was documented throughout the underground areas of the Power Station (See figures 10, 11, and 12 below.)

Sanxia Underground Power Station – Spray Application of CN2000®B

Fig 10. - Penetration of water in anchor eye

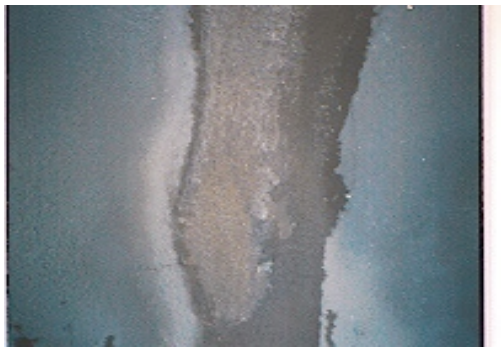


Fig 11. - Strip of water penetration

Fig 12. - Water penetration in vaulted ceiling cracks

Fig 13. –Application with approved spray equipment

After the spray coating treatment the experimental area with **CN2000®B (CCCW),** the water leakage has been eliminated; in the experimental area and around the test area, water flows normally from the blind channel by-pass pipe.

On each side of the experimental test area, new water-leakage points appear (see fig 15) showing the waterproof effect of the treated surface as contrasted with the untreated surfaces on each side. Water pouring testing shows that water is falling down in the sphere or column form and there is no water spreading and sinking in, nor is there the diffusion phenomenon on the surface. The coating is uniform, fast bonding and the treated surface relatively smooth.

The quality of engineering conforms to the Chinese National Standard **GB50208-20002**, the Underground Waterproof Quality Acceptance Specifications and the Waterpower Engineering Specifications. The product and application are also approved and identified by all the General Engineers and the Professional Construction Manager of the **Sanxia** Underground Hydropower Station. The work efficiency of the spray coating is higher than that of the manual coating and is noted as being 20 times more effective than other similar coatings.

The contrast of effects before and after spray coating can be seen from fig 14 and fig 15.

Fig 14 Strip water leakage before installation

Fig 15 the Strip after spray coating

4: The Applications of CN2000®B (CCCW)

4.1 The main functions and actions of CN2000®B (CCCW)

As the name implies the foremost function of the waterproof material is to prevent concrete structures and infrastructures from water leakage and penetration. Fast curing allows for the continued activity of workers in a timely manner during the construction period of any given project.

The completed structures and infrastructures coated with **CN2000®B (CCCW)** provide completely waterproof internal areas for the safe installation of electronics and electrical systems and further ensure dry and comfortable work areas for workers.

The **CN2000®B** ensures high impervious strength and self healing abilities, which can be utilized in many and varied waterproofing projects. Further to this, the coating material ensures an anti corrosive function of the internal concrete structure from environmental corrosion, and further ensures the increased longevity of the concrete structure.

Environmental contaminants are becoming more severe every year, and concrete structures and infrastructures are being severely degraded due to the affects of these contaminants. The affects of this environmental degradation on concrete structures result in instability in the structures requiring extensive maintenance and reduces the life span of the structure causing extensive costs for repair, maintenance and replacement of these structures and infrastructures. The loss of the structural lifespan results in further economic losses.

Further to this, we are seeing loss of life and severe injuries worldwide due to the structural failure of many infrastructures before their designed lifespan has been achieved.

4: The Present Situation of the Durability of Concrete Structures Worldwide:

Any concrete structure should fully comply with the requirements of security, applicability and durability. The requirement for concrete durability is that under normal maintenance conditions the structure should keep its use/function without major overhaul or repairs during the designed lifespan of the structure. Generally speaking, the lifespan should be 50 years for the ordinary buildings and structures, and 100 years for important infrastructures. It causes great concern to many, that the useful life spans of many concrete structures are far less than the original designed requirements.

For many decades, concrete has been thought of as a very durable and lasting material. It was not until the 1970's; that the developed countries worldwide gradually noticed that many infrastructures appeared structurally unsound prior to their designed lifespan in certain environments.

These countries began to invest a great deal of resources and scientific research to determine causation and remedies to resolve their deteriorating infrastructure problems.

Environmental Affects on Concrete Structure Durability:

• Acid rain

Coal bed gases (CH_4, CO, SO_2, and NxOy) discharged from the combustion of coal, SO_2 discharged from the industrial production, and SO_3 from the oxidation of SO_2 are all maleficent resources causing the air pollution and hot house gas effect. These acid gases and aerosols gathered continuously in the atmosphere, and after the nucleus condensation, absorption, collision, coacervation, and washing out and resolving by rain or snow, and at last form a acid rain region of a striking large area. The acid rain causes the concrete structure of bridges and buildings neutralized, brings further the corrosion of the steel bars, in the end causes the entire building structure destructed. The reactions are as follows:

$$SO_2 + H_2O + Ca(OH)_2 \rightleftharpoons CaSO_3 + 2H_2O$$

$$mCaO \cdot nSiO_2 \cdot aq + mH_2SO_3 + H_2O \rightarrow mCaSO_3 \cdot aq + nSi(OH)_2$$

$$SO_3 + H_2O + Ca(OH)_2 \rightleftharpoons Ca\,SO_4 + 2H_2O$$

$$mCaO \cdot nSiO_2 \cdot aq + mH_2SO_4 + H_2O \rightarrow mCaSO_4 \cdot aq + nSi(OH)_2$$

• Small sand

Sand storms happen to all parts of the world not only to developing countries like China. In the 1950's, in middle Asia, violent white salt (sand) storms occurred frequently to Kazakhstan. In the 1990's, sand storms occurred successively to the mid-south of the U.S. Colorado, Kansas, the west of Texas, and southeast New Mexico were severely affected by these storms. These sand storms not only lead to desertification but also cause corrosive destruction to all structures, concrete or otherwise.

These sand storms are a severe pollution resource, as they violently increase the particle pollutants in the atmosphere wherever the sand storms occur. The research shows the fine grains are the main means of transport for the acid sulfides. Therefore in the atmosphere, the dust corrosion to a building is actually due to the corrosion of the sulfate,

chloride, magnesium salts and so on. The means of the sulfate corrosion include: production of the **ettringite** (**AFt**) causing extensive destruction; production of a cohesion less **M-S-H,** causing the concrete lose its strength; production of **C-S-Si-Ca** stone type corrosion causing the cement stone structure lose cohesiveness and general anti-sulfate cement can not withstand such a corrosion.

The two most striking examples are: stone carvings of the **Yungang** rock-cave in **Datong**, **Sansi** province of China, and the stone-carving cultural relic of the **Maiji**-mountain in **Ganshu** province of China. Both have suffered serious weathering and destruction as a result of these atmospheric pollutants.

• Offshore and Ocean Side Structures

Ocean circumstances are far more inclement than what is endured inland. The corrosion of concrete structures is far more serious. The salt fog in the ocean's atmosphere, the temperature and humidity, sunlight, the temperature and flow velocity of seawater, the dissolved oxygen and salinity in seawater, the impact of salt water waves, the impact of floating debris, halobios, bacteria in the seabed soil, etc. All of the noted items conspire to create erosion and deterioration to Oceanside and offshore concrete structures to different degrees; in the wave splash zone and tidal areas, the erosion destruction is especially serious. Generally speaking, the lifespan of concrete construction in seaports is only one third to one-half of that noted in inland structures. The mechanism of destructive erosion is as follows:

The ions such as Cl^- can enormously increase the solubility of $Ca(OH)_2$, speeding the dissolving attack; reacting with calcium aluminate (C_3A) in concrete, producing aqueous calcium aluminate chloride ($3CaO{\bullet}Al_2O_3{\bullet}CaCl_2{\bullet}10H_2O$ and $3CaO{\bullet}Al_2O_3{\bullet}CaCl_2{\bullet}3H_2O$), and cause crystalline expansion; once concrete coming to "neutralization", these Cl^- will dissociate from the double salts and speeding the eroding destroy to the steel bar. The reactions are as follows:

$$Fe^{2+} + 2Cl^- + 4H_2O \rightarrow FeCl_2{\bullet}4H_2O$$

$$FeCl_2{\bullet}4H_2O \rightarrow Fe(OH)_2 + 2Cl^- + 2H^+ + 2H_2O$$

• Inland Salt Lake and Saline Soil

This environment is comparable to the offshore and ocean's environment. Concrete Structures suffer similar erosion and destruction by airborne sand. The inland saline soil, has considerable salt lamination containing ions of SO_4^{2-}, Cl^-, and Mg^{2+} at a very high level, this also causes extreme erosion and destruction of concrete structures.

The environmental impact to the durability of concrete structures has become a worldwide problem causing great concerns to both Governments and Engineers involved in major infrastructure projects.

• Aqueduct and Reservoir Dams

Generally in these places there are the eroding effects of soft water corrosion and of the carbonic water corrosion.

As an example the main trunk canal of headwater from the **Datong** river to **Qingwangchan** in **Ganshu** province of China**,** the great dam of the first and second period engineering of the water pumping and energy storing power station of **Huizhou City** in **Guangzhou** province of China, the reservoirs on the **Xinanjiang** river, at the **Foziling** ridge, and at **Meishan** mountain etc, all have shown signs of erosion causing many safety issues in the structure of the power station.

• Bridges

Salt causes extreme erosion to bridges. In winter, in order to dissolve snow and ice on the bridge decks, it is the normal practice to scatter salt on the decks of reinforced concrete highway bridges of the **Northern United States** and **Canada**. This method of ice and snow control result in destructive corrosion and erosion to the bridge deck and reinforced structure wherever the resulting calcified slush and water flows or is splashed. Even with short periods of exposure to the salted effluent, there is irreparable destruction to the external and internal structure of the bridge.

According to recent statistics, there are more than 526,000 interstate high-way bridges in the **United States**. At this time over 200,000 of these bridges have extensive damage. Of these, 90,000 bridges are reported to be in critical condition and need to be immediately replaced. On average, several thousand bridges are reported as severely damaged and several hundred are demolished and replaced. The lifespan of many of these structures are reported as being less than 20 years.

In the 1990's, the maintenance and replacement costs for these bridges reached an incredible 258 billion dollars, or as much a 4 times the cost of the initial investment.

In **England** the 11 viaducts on the medium annulus line had unanticipated severe corrosion and the resulting damage after only 12 years required maintenance costs of 120 million Pounds, or 6 times the initial investment.

There is no doubt that our changing environment is drastically affecting the durability of concrete structures around the world without exception. The result of this is that Government and Engineering interests worldwide require materials such as **CN2000®B ® (CCCW**) to ensure durable and sustainable concrete structures and infrastructure.

4.1.3 Cause and Mechanism of Concrete Degradation

The major factor in the degradation of concrete structures is due to the natural existence of pores and cracks within the concrete itself. Pores and cracks provide the paths for water and other harmful medium. The external factor is the physical environment and the resulting chemical actions to the concrete.

The research shows that whether it is the resulting physical actions (temperature, freeze and thaw, drying and damp, and so on) or the chemical action (dissolving attack, alkali-aggregate reaction, carbonization, acid gas corrosion or acid water corrosion, as well as the eroding of the chlorate or sulfate, and so on), they all are responsible for the degradation to the concrete layer primarily. Secondary actions result in the steel rebar in

the concrete to lose its protection and the corrosion of the rebar eventually causes the concrete structure lose its structural integrity, requiring costly maintenance and/or replacement.

Research shows that all the above physical and chemical corrosion are due to the presence of water, which is the carrier of the corrosive chemicals which is the destructive element to the external and internal structure of all concrete unless the total concrete structure is protected from these effects.

Countermeasures, Prevention and Cure

As above mentioned, the waterproofing is the primary barrier to corrosion. Waterproofing and anti-corrosion are complimentary. Under ordinary corrosive environment, if the water penetration can be prevented, the degradation to the concrete structure and erosion damage will be effectively prevented.
This opinion a common understanding and is supported by the Academics and Engineering Specialists after several decades of research. As the world-famous concrete specialist **Metha** pointed out: "In the long range the penetration and permeability of concrete is the only relevant character to durability. A great deal of information prove that if the concrete cannot be penetrated or permeated with water, then all the corrosion damage including steel rebar corrosion, alkali-aggregate reaction and freeze-thaw damage cannot occur at all."

"Five Time Law" and Full Lifespan Economic Analysis

In the past the durability of concrete structures and infrastructure was not regarded as a priority due to its low cost, availability and cost effective installation. The primary emphasis was only on reduction of the initial construction and engineering costs.

Due to the erroneous expected lifespan of these structures, very little thought was put into provisions for maintenance of the structures and infrastructure projects. In the end many countries paid out and continue to pay out enormous sums for the replacement and maintenance of these structures due to a lack of foresight in these areas.

Engineering scholars now describe the importance of the durability design of concrete structures utilizing "the five-time law", that is, if one dollar is saved from the cost which should be applied for the protection of reinforced concrete in design, then it means: when steel bars are found to be corroded, the adopted repair measure needs the added cost of $5.00, and when the surface of the concrete shows cracks along the bar, the required repair measure needs $25.00, after serious decay and damage to structures are discovered, the required repair or replacement measure needs $125.00.

In the recent years the "full life-time economic analysis" (or "total life cycle cost analysis" (LCCA)) concept recommended by American Engineering Scholars gives the investors and engineers designing these projects a new train of thought.

In regard to corrosion damage, and to put the LCCA in practice means "the protection as the main measure" is taken as a primary strategic guideline and requires the establishment of the economic analysis on "the total life cycle" from the very beginning of the design process. In order to assure the designed engineering life-time, a reliable technique, reasonable in cost and economy, an optimum plan must be developed, so as to reduce the future expense and enhance the quality and useful lifespan of the project, and finally to maximize the long term benefit.

Now let's take the salt harm to the bridge as an example doing LCCA. The results can be seen in fig 16 and table 2.

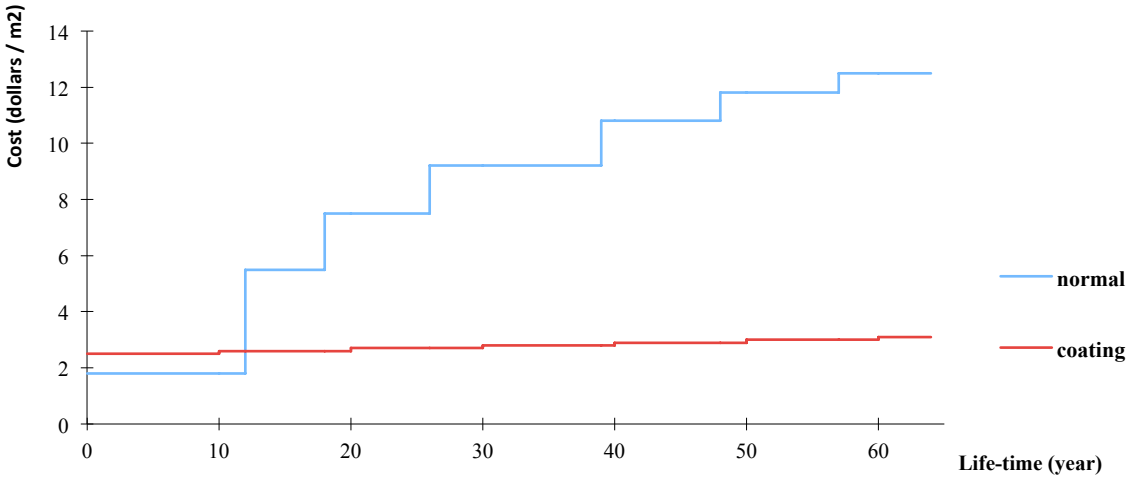


Fig.16 LLLC result after coating with ZHONGHE 2000

Fig. 16 LLLC Result after coating with CN2000®B

Table V LCCA results of the concrete-steel structure bridge before and after the coating

Life-time (year) / Cost (dallar/m^2) / Measure	0	10	12	18	20	26	30	39	40	48	50	57	60
Non	1.8	—	5.5	7.5	—	9.2	—	10.8	—	11.8	—	12.5	—
Coating with CN2000BB	2.5	2.6	—	—	2.7	—	2.8	—	2.9	—	3.0	—	3.1

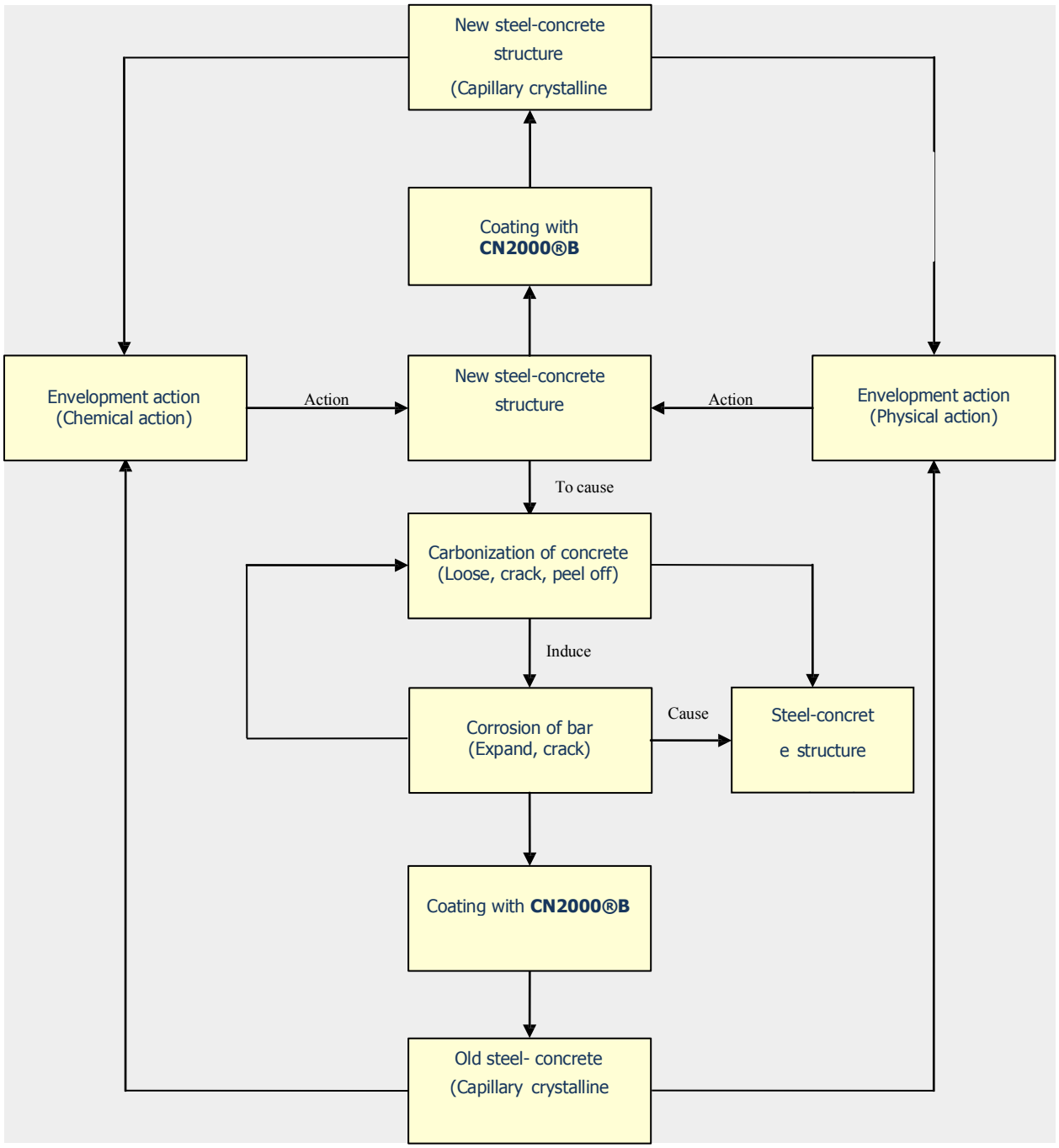
Note: ①formula: The present value = the initial value $(1+\eta)^n$, η —rehab ratio, n —rehab times.
②Suppose the useful life-time of **CN2000®B** is 10 years, one repair per 10 years, repair ratio area is 5%.

Figure 16 and table 2 show that under salt prevalent environmental conditions, should the surface of the concrete structure not have any protective measure applied, necessary repairs will be required in less than 12 years.

Although the initial repair costs are minimal, over a period of 60 years this structure will have been repaired 6 times and the total accumulated costs will have totaled over 6 times the original costs that were invested to build the structure. (Statistical figures for American bridges is 4 times)

When a structure is coated with **CN2000®B (CCCW)** as a protective shield, even if the structure requires repairs every ten years, the total accumulated costs will only equal one quarter of the original investment for a structure without a waterproofing installation. This results in saving of overall costs of more than 70%. This does not take into consideration the added longevity that can be achieved with the application and proper maintenance of **CN2000®B (CCCW)**. Undoubtedly, utilizing the **CCCA** into infrastructures has a great significance for building a resource efficient society and maintains its sustainable development.

The block diagram of the degradation to durability of the concrete structures and their prevention and cure are as shown the following Fig. 17



4.2: Project References: Application Engineering Case Studies with CN2000®B (CCCW)

The waterproof material **CN2000®B (CCCW)** has been applied in hundreds of projects including National water conservation, energy resources, roadways and bridges, **environmental protection**, military facilities and in industrial and construction civil engineering projects.

Excellent results have been obtained, in the grouting, leakage blocking and waterproof spray coating engineering in the:

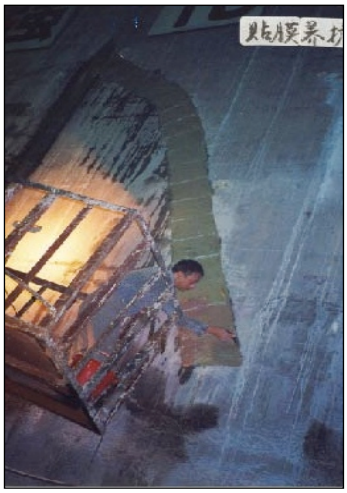
- Underground hydropower station on the right bank of Chinese Changjiang River Sanxia project.
- Leakage blocking and impervious project of the underground workshop of the Shuibuya Hydropower Station.
- Water proof and impervious engineering of the underground corridor of the Xiaolongdi hydropower station on the Huanghe River.
- Water proof and impervious engineering of underground railway in Tianjin
- Waterproof and impervious engineering of the Jiangbei Airport Station of the No.3 light railway line in Chongqing.
- Shinan bridge (cable-braced steel bridge) waterproof engineering of Wuhuan Road of Beijing
- Waterproof engineering of the Yongding River Spanning Bridge on the city-rounding highway of main line of the national road in Beijing
- Water regenerating engineering of the Jizhuangzi Sewage Treatment Plant in Tianjin (the national demonstrating engineering in 2000)
- Waterproof and impervious engineering of the weapons cave of Neimenggu Military Area of the PLA.
- Waterproof and impervious engineering of the underground base of the building of the Tianjin Frontier Inspection Bureau of the Ministry of Public Security.
- Waterproof and impervious engineering of the No.1 and No.3 air harbor command center of the Capital Airport.
- Waterproof engineering of National Swimming Center (the water cube) for the 2008 Olympic Games.
- Waterproof and impervious engineering of the Shanxi Xiangyuan Grain Depot directly under the Central Grain Depot.
- Waterproof of “Bird Nest Olympic Stadium” Bypass Tunnel in Beijing

Project: Waterproofing, grouting, leak repair, spray coating of the underground hydropower station on the right bank of the Sanxia River

Installation: Zhonghe Waterproof Material Co., Ltd.

Developer: Construction Department of the General Development Company of the Chinese Changjiang Sanxia Project.

Time: Jan, 2006



Project: Waterproofing, Leak Repair and impervious engineering of the underground workshop of the **Shuibuya** hydropower station.

Installation: Zhonghe Waterproof Material Co., Ltd.

Developer: General Development Company of the **Chinese Sanxia** Project

Date: Aug, 2006

Place: Hubei province



Project: Waterproofing, leak repair and impervious engineering of the Jiangbei Airport Station of No.3 light railway line in Chongqing
Installation: Chongqing Zonghe Waterproof Engineering Co., Ltd.
Date: 2005
Place: Jiangbei Airport Station - No.3 light railway line in Chongqing

Project: Waterproof engineering of the Yongding River Spanning Bridge on the city rounding highway of main line of the national road in Beijing
Installation: Beijing Wanhuading Waterproof Decorate Engineering Co Ltd.
Developer: Beijing Capital Road Development Co Ltd.
Time: Oct. 2004

Project: Shinan Bridge (cable-braced bridge) waterproof engineering on the Wuhuan Road of Beijing
Installation: Beijing Wanhuading Waterproof Decorate Engineering Co Ltd.
Developer: Beijing Capital road development Co., Ltd.
Date: Oct, 2004
Place: Beijing, Wuhuan road

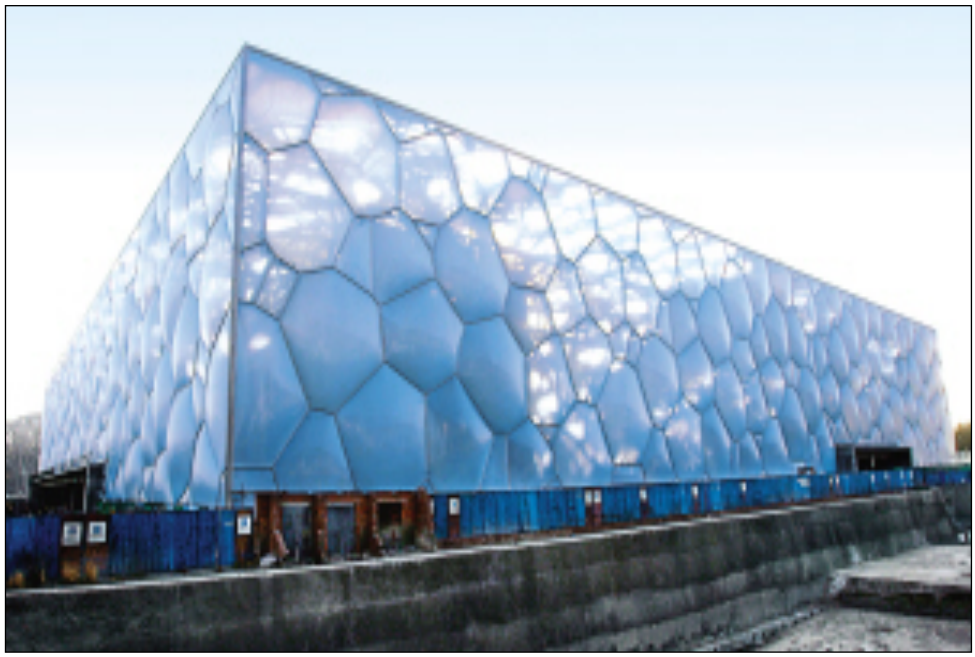
Project: Waterproofing and impervious engineering of the power station of Changjiang Xanxia (Three Gorges Hydro Electric Facilities)
Date: Jan, 2006 – May 2007

Project: Waterproofing and impervious engineering of the underground corridor of the Xiaolongdi hydropower station on the Huanghe River
Installation: Xiaolongdi Project Construction Company of the Water Conservancy department
Developer: Huanghe River Xiaolongdi Hydropower Station
Date: May, 2002
Place: Luoyang in Hunan province

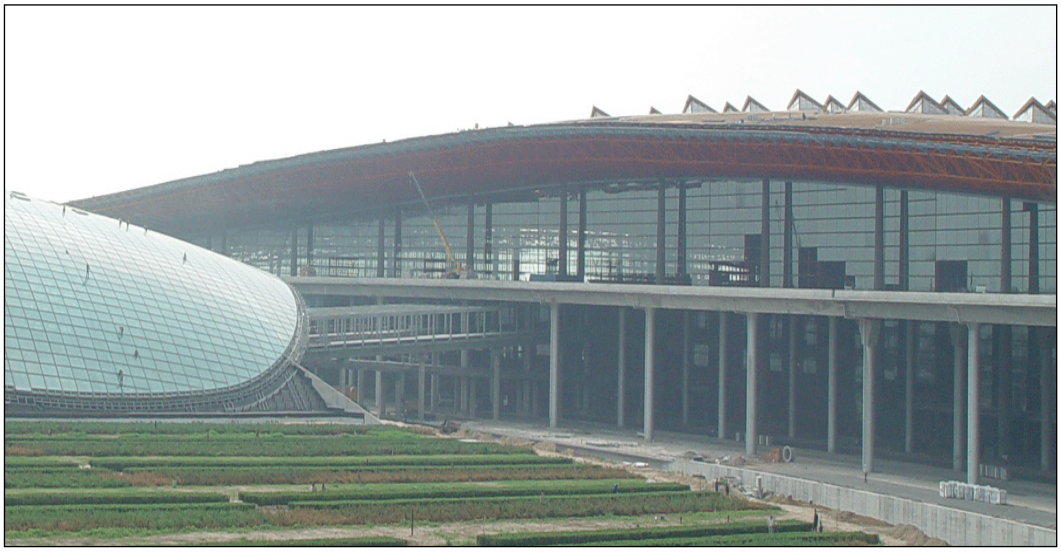
Project: Waterproofing and impervious engineering in the Tainjin Underground Railway
Installation: Henan Xinpu engineering Co., Ltd.
Developer: Division of the Tainjin First Civil Road Engineering Co., Ltd.
Date: July, 2004

Project: Waterproof and impervious engineering of the Weapons Cave of the Neimonggu Military Area of the PLA
Installation: Zhonghe Waterproof Material Co Ltd.
Developer: No 51292 Troop of the PLA
Date: Nov, 2002
Place: Neimonggu

Project: Water regenerating engineering of the Jizhuanzi Sewage Treatment Plant in Tianjin (National Demonstrating Engineering in 2000)
Installation: Jilin Zhonghe Waterproof Engineering Co., Ltd.
Developer:
Date: July, 2002



Project: Waterproof Engineering of the National Swimming Center (Water Cube) for the 2008 Olympics
Installation: No. 4 Company of the First Bureau of the Chinese Construction Department
Developer:
Time: Feb, 2004
Place: Beijing



Project: Waterproofing and impervious engineering of the No.3 Air Harbor Command Center of the Capital Airport
Installation:
Developer: No.16 Engineering Bureau of the Chinese Railway Department
Date: Feb, 2004
Place: Beijing

Project: Xianghuan grain depot / Central Grain Depot
Installation: Taiyuan Lidun Waterproof Technique Co., Ltd
Developer: Xianghuan National Grain Depot
Time: March, 2003
Place: Xianghuan, Shanxi

Project: Waterproof and Anticorrosion Engineering of the General Frontier Inspection Station of the Ministry of Public Security in Tainjin
Installation: Tainjin Hualu Waterproof Engineering Company
Developer: Frontier Inspection Station of the Ministry of Public Security in Tainjin
Date: March, 2003
Place: Tainjin Weiguodao

The repair of percolation, corrosion and damage to the chief trunk canal "leading water from the Datong River into Qingwangchan" in Ganshu province of China was successfully completed with **CN2000®B (CCCW).**

The constant exposure to water to the canal structure has caused the foundation to become non-uniform due to settling and has displaced the structural joints of the canal.

The surface of the canal suffers from extreme corrosive destruction

The surface of the canal is treated with brush coating of **CN2000®.**

After treatment the water flows in the now repaired and waterproofed canal

Closing Statement

As a result of our Manufacturers research and development in the field of **Cemetitious Capillary Crystalline Waterproofing (CCCW)** technologies, processes and installation methodology over the past decade, a review of the Manufacturer and their products was initiated by the Chinese Local and National authorities in 2006.

As a result of this review, the Tainjin Science Technology Commission and the National Science Technology Department approved our Manufacturer for research and development funding for the fully automatic production of the **Cemetitious Capillary Crystalline Waterproof** material with the **Eka- molecular Sieve Structure**" products of our Manufacturer

With this line of products **Kelso Coatings** and our Manufacturer, wish provide this technology worldwide to resolve the problems associated with the degradation of our structures and infrastructure due to environmental corrosives and contribute to durable structures and infrastructures that will achieve their designed lifespan to ensure our world's communities with sustainable development with our **Environmentally Friendly** products.

The **CN2000® Waterproof** line of products, unrivaled in the concrete waterproofing industry; play a vital role in the design of many world class projects.

In the years to come, the makeup of concrete will evolve to meet the demands of Designers' Engineers and Architects, and our Research and Development teams continue to find better ways to waterproof concrete structures, ensure quality control, enhance our production techniques and to meet the evolving needs of our clients in waterproofing.

When the clients of **RCS** want superior waterproofing solutions, they will be utilizing the same state of the art technologies that have been proven in world class projects.

CN2000® a Revolutionary Concrete Solution