Case Study
Surface Engineering by SYLOCON®

Consistent Strengthening and Making Impermeable and Durable Buildings with AAC Blocks, Fly Ash Bricks and Concrete

SYLOCON® - The Nano composite additive for plastering is commonly used to get rid of the cracks on plastered surface and waterproofing AAC blocks, Fly ash bricks and other masonry components.

But a recent study has shown that it has another unique property which couldn't be identified earlier. The most interesting property of this Nano composite is gradually strengthening and making the entire surface impermeable. This property makes all masonry components much more durable and maintenance free.

From the moment that any material is released from the point of production, it is in theory subjected to some form of materials degradation although such degradation may not be readily observed or measured. Material degradation imposes a cost penalty on all civil engineering. This can be defined in terms of loss of performance of an engineering system. Loss of performance can relate to many parameters. Some loss of performance is inevitable unless right control measures are implemented.

In view of Surface Engineering, the present day's pollution and effect of Green House Gases has a major impact on buildings. pH of the storm water is decreased than before, the composition of any masonry unit which are based on cement are being deteriorated because, cement-based materials after hydration are deteriorated due to decomposition. As pH of storm water decreases to values lower than stability limits of cement hydrates, cement hydrate loses calcium and decomposes. It becomes an amorphous hydrogel.

Surface engineering is pertinent to know the surface condition of any substance and provides right solution that protects the outer surface of the substance. As because of any deterioration of any substance under weather action is due to the consistent deterioration of the outer surface.

SYLOCON® - the Nano composite plaster additive is closely related with Surface engineering. This is a time-honored solution to protect masonry and concrete from aggressive weather action consistently. This strengthens the masonry units and concrete as well as serves to shield the structure against weather actions. From the point of Surface engineering, now there is a range of techniques available to get rid of material degradation. But, in some cases it's noticed that shielding material itself degrades due to Biological and Biochemical modes of materials degradation. Different type of modes is found in this field. I would like to add few relevant points for better understanding of this claim of self-degradation of shielding materials by the Biological and Biochemical effects. If we talk about few polymers those are widely used in shielding purposes like PVC, Polyurethane, Nylon, Different Acrylics, POLY (Styrene Butadiene Styrene} – SBS, Styrene Butadiene Copolymer, etc. we find the mode of degradation of different types of shielding material those are based on these kinds of protective polymers. I am just discussing on few of those.

- POLY (Styrene Butadiene Styrene) – SBS, Styrene Butadiene Copolymer - The Biocompatibility of ESBS Membrane was evaluated with the cell culture of fibroblasts on the membrane. It revealed that the cells not only remained viable but also proliferated on the surface of the various ESBS membranes and the population doubling time for fibroblast culture decreased.
- PVC - This popular item itself is degraded by microorganisms like Fungi (e.g. Aureobasidium Pullulans) and bacteria (e.g. Pseudomonas Aeruginosa). The main mode of action is increased loss of plasticizers due to microbial degradation.

> ***"The most interesting property of this Nano composite is gradually strengthening and making the entire surface impermeable."***

- Polyurethane – This is widely used base material for shielding. But, that too is degraded by Fungi (e.g. Chaetomium Globosum) and bacteria (e.g. Bacillus Subtilis). The enzymatic activity of Fungi and bacteria causes a major failure of the shielding products based on this.
- Nylon - This is strange degradation of this shielding compound by wood – degrading fungi (e.g. Bjerkandera Adusta) and bacteria (e.g. Bacillus Pallidus). The degradation is physical disruption and enzymatic degradation.

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Technology Coordination Technology

PART-XII

Lime terracing was a popular method of roof treatment for ancient structures. Roofs of many buildings are witness of that technology. I remember a summer about 45 years back. That was a pleasant activity to me, which I have still kept in the jewel of my mind. Bankura district in West Bengal is very hot in summer. I grew up there in a single storey Govt. quarter of irrigation project. The staff quarter was newly built and had no top covering on brick bat, cement concrete roof. It was so hot to stay under the particular roof that the children used to suffer from fever. I too could not escape from this problem. One fine morning, I heard that SAONTAL TRIBAL women are coming to do something on the roof and our small house will turn to cold. That surprised me. I enjoyed the entire activities which I remember. The tribal women used to come every morning and sitting on opposite rows, started compacting red coloured mortar on roof in a fantastic rhythm with their tribal song. After few days, an engineer came to see the finished work. I climbed up on that nice red coloured finished surface. Someone was applying mastered oil on the finished surface. The engineer wearing a SOLA hat (Sola wood comes from a tapioca plant), took a betelnut and a hammer. One man placed the betelnut (SUPARI) on the finished surface and hammered on it to break repeatedly. After he broke it, the engineer looked on the surface where the betelnut was placed to break. He was happy to see that there was no impression left on the surface after hammering the betelnut repeatedly.

We stayed comfortably under that excellent insulated and waterproof roof till the date we left that quarter after my father's retirement, when I left for USSR.

Now I can explain that technology in view of participation of microbes.

The main ingredients of that lime surki mix was small brick bats, surki (coarse part of broken clay bricks after screening), dense jaggery with adhesive property, METHI and water.

The first step of the methodology was fermentation of jaggery by bacteria.







Lactobacillus plantarum, Bacillus sp and Arthrobacter sp are the species of bacteria, which meet most of fermentation. It reduces the pH value; hence jaggery is converted to an acidic end product. When available sugar for microbial growth depleted, acid production decreased. The pH first decreased and then started to increase. The rise in pH in later stages was mainly due to the depletion of sugar for lactic acid production. The buffering capacity of the calcium from the shell solubilised into the media and nitrogenous compounds released by the proteolytic activity of the endogenous and microbial enzymes were also responsible for the increase in pH values of the protein liquor. The abovementioned bacteria are identified today for calcification and hardening of lime. Today those bacteria are used to prevent decay of marble stone monuments.

So, the use of microbes is not a new technology. Earlier people had no idea about microbes. But, they were aware of the function of microbes in fermentation. Today, these type of bacteria are sprayed to protect marble monuments from natural degradation.

In this section of Technology Coordination Technology Part-12, I would like to emphasis on the old traditional technology of roof insulation and waterproofing using modified methodology. Because of that, old technology has proved its durability, excellent thermal

insulation and waterproofing property. Today, advanced polymer technology are not able to perform equally in terms of durability and cost-effectiveness. The materials which were used for the purpose were not friendly with parent concrete by nature. As a result, layers of polymer coating after placing insulation board could not perform in terms of durability.

But, red brick surki is not available today.

So, is it possible to recall that old technology to enjoy that comfort, durability with low cost? Researchers will certainly think on this subject today.

Before we start any research on this subject, we should try to choose natural ingredients. Our aim is to achieve the insulation property with waterproofing at low cost by calcification and hardening of lime. Accordingly, the ingredients should be selected carefully. We know how to incubate the colony of bacteria in modern technology. Still, we can choose the old method of fermentation. That takes 24-36 hours fermentation time. If we look back to the old roofs covered by lime terracing, we observe an effect of self-healing concrete. Many concrete roof cracks were sealed due to calcification of lime by bacteria. We will get that benefit in the modified technology based on that old methodology.

Intensive research work is available on microbes used for calcification and hardening of lime to prepare self-healing concrete. This is not at all a complicated subject if you look back to our old traditional technology. Most of my engineer friends are excited to know more about the microbial utilization for self-healing concrete. Many of them are worried about its cost. Because of the modern technology based on microbial culture and utilization in structure, it seems to be costly. Yes, it is. But, in our old traditional technology, those were not costly. The reason behind this is the advanced technological approach which includes lots of experiment, trials, study and research that were already done by our late technologists. Only we have to finish it using our available natural resources.

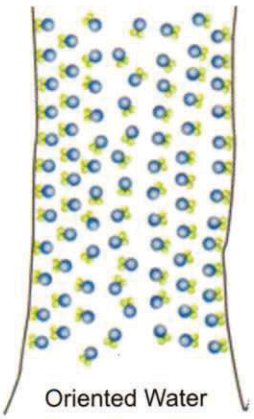
This work will help us establish a new modified method of low cost long term durable, waterproof with excellent insulation property. I hope the researchers on the related subject will think on this matter and be interested to share their ideas in TECHNOLOGY COORDINATION TECHNOLOGY PART-13. I would like to invite all technical professionals to share their valuable views to establish a new concept in the building industry, which is useful in the case of cost, quality and durability.

To be continued in Part XIII... ■



SYLOCON® (Nanocomposite with copolymer nano filler)

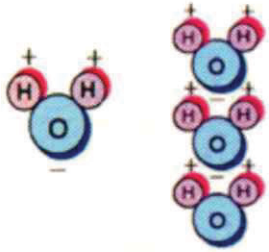
Key benefits
1) Waterproofing
2) Efflorescence prevention
3) Prevention of shrinkage crack
4) Minimizing rebound loss in case of plastering and shotcreting



Waterproofing

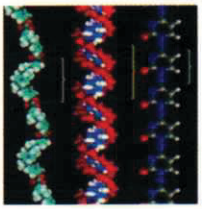
The durability of concrete has proven to be a formidable obstacle in the service life of new and existing structures. The durability of concrete and plaster is a function of permeability. Permeability is governed by the capillary pores in the cement paste. Pores that are too large will result in a high permeability, while pores that are small will result in a low permeability.

Permeability to define water proofing property of a concrete or mortar prepared with SYLOOCON is related with its pore structure, arrangement of co polymer nano particles in the pores and behavior of the nano particles in contact with water molecules.



The H-O-H molecule is covalent bonded. Due to differences in the charge centers of hydrogen and oxygen, the positively charged proton of the hydrogen ion belonging to a water molecule attracts the negatively charged electrons of the neighboring water molecules.

Nanocomposite in SYLOOCON with selected copolymer molecules repel water molecule to attract each other. Due to discontinuity of chain, water loses its energy to exert upward pressure. As a result, capillary action is failed to perform successfully. Some larger pores may allow water accumulation from external source. But, this cannot perform capillary action. Copolymer nano fillers are fixed rigidly between particles and bond strength is increased. The resulting concrete and mortar becomes durable and less permeable.



Copolymer blocks the path of capillary in concrete.

When SYLOCON is added into wet mortar, nano particles are dispersed uniformly and occupy the pores in the matrix.

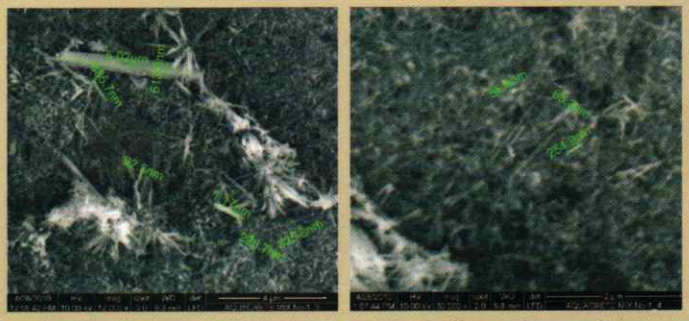
Scanning Electron Microscopic Views of the mortar with and without SYLOCON®



The scanning electron microscope photograph shows the capillaries and pores in a cement, sand mortar. The sample is prepared without any additive.



SYLOCON produces crystals in cement mortar.



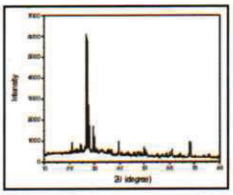
SYLOCON makes crystal hydration products of different shape and sizes. Those plug the pores and the capillaries.

Understanding property of SYLOCON by X-ray Diffraction Test

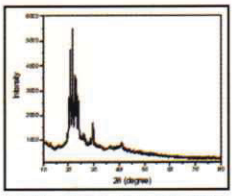
After the product is added to the cement mortar, a different pattern is observed. This indicates the growth of the new hydration products in the concrete.

The crystals developed fill up the capillaries. The following diffractograph shows the new properties developed after hydration.

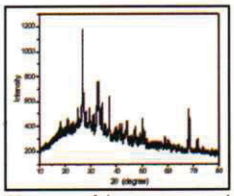
From experimental results, it appears that in the presence of **SYLOCON**, some nano particles are formed, which the products of hydration are. The extremely nano size particles have some favorable characteristics. Those fill up the pores and increase the strength of concrete. The microstructures of interface of cement and aggregate are greatly improved. This hinders the water percolation through the concrete.



XRD-pattern of the normal mix of cement, sand mortar



XRD-pattern of the product SYLOCON



XRD pattern of the concrete sample with additive SYLOCON

Efflorescence Prevention

Efflorescence is the appearance of the deposited salt over the finished surface. The soluble salts are entrapped in the bricks or in the plaster matrix along with sand. The source of salt may be river bed or the soil. In contact with water the salt is turned into saline water and on drying and evaporated from the outer surface, leaving the salt patches. If the product is added to the mortar, hydrophobic crystals do not allow water to dissolve the salts. Entrapped moisture cannot transport the salt ions due to presence of the nano particles in the plaster matrix.

SYLOCON Prevents water seepage & efflorescence in brick work


Salt affects brick


Back of the plastered brick


Waterproof property of plaster


Water droplets on plastered surface


Bricks are well saturated and affected by saline water


Efflorescence is appeared on brick surface. But the plaster is not affceted

Prevention of Shrinkage Cracks

Properties:

With polypropylene as its raw material, this fiber was produced by special technology. The products appear net-like structure with many fiber monofilaments connected. When the fiber was put into the plaster, the horizontal structure in fiber monofilament can be destroyed in the course of stirring owing to friction and rubbing, and the fiber monofilament or net-like structure will fully stretch, thus the plaster is reinforced.


Polypropylene Fiber

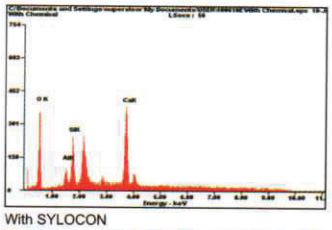

Plaster Crack

Brief specification of fiber :

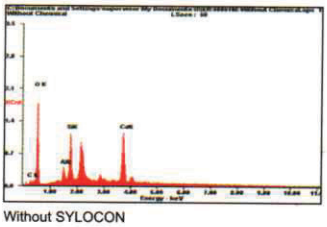
Density (g/cm3)-0.91+/-0.01
Elastic Modulas (MPa)-.3500
Length (mm)- 6, 12
Equivalent Diameter (um)- 100+/-50
Shape Beam-like Net
Acid & Alkali Resistance - Strong
Water absorbency - Nil
Tensile Strength (MPa)- 346-560
Melting Point (C. Deg)- 160 — 170
Tensile Ratio (%)- 5-10

Microanalysis study of the mortar with and without Sylocon

The microanalysis report of the mortar specimens show no development of any new product after hydration. A foreign carbon particle from any external source is present in the concrete without Sylocon. But, the Chemical composition of the concrete is unchanged after the reaction of cement and sylocon. So, the waterproofing properties developed in the treated mortar are due to the presence of the same nature of crystal formed in the capillaries and pores of the concrete. These crystals of different shapes and sizes plug the water ingression path without changing the basic properties of concrete and mortar. In the microanalysis report this is very clear, only the percentage of the elements are changed.


With SYLOCON

Element	Wt%	At%
O K	31.61	51.52
Al K	03.52	03.40
Si K	10.36	09.62
Ca K	54.51	35.46


Without SYLOCON

Element	Wt%	At%
C K	02.12	04.12
O K	39.66	57.88
Al K	03.28	02.84
Si K	12.65	10.51

Minimizing Rebounds Loss

Adhesion : The Sylocon modified plaster can be applied to ordinary bricks, concrete blocks, foamed cement concrete blocks, and to hacked RCC columns, beams and ceilings. It greatly reduces the rebound loss and increases the rate of application of the plaster. It greatly improves the strength of the mortar bond and the integrity of the walls.

Cohesion: The greatly increased cohesion of the modified plaster helps in reducing the rebound losses. The modified plaster is non-shrinking and therefore resists the formation of cracks after curing and drying.

Recommended dose of SYLOCON

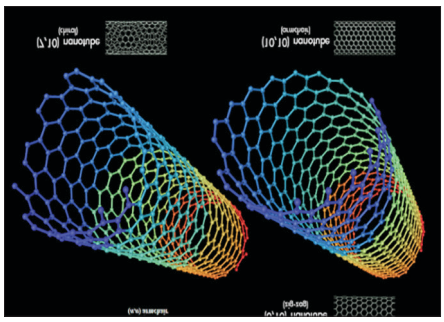
- Normal plastering requires 1 Litre. per bag of cement used in standard grade of cement, sand mortar.
- Efflorescence affected brick plastering and thin outer wall plastering requires 1 liter per bag of cement used in standard grade of cement, sand mortar.
- Waterproof concrete for R.C.C. water tank, basement retaining wall and floor and top R.C.C. roof requires 1 liter per bag of cement used in standard concrete mix.

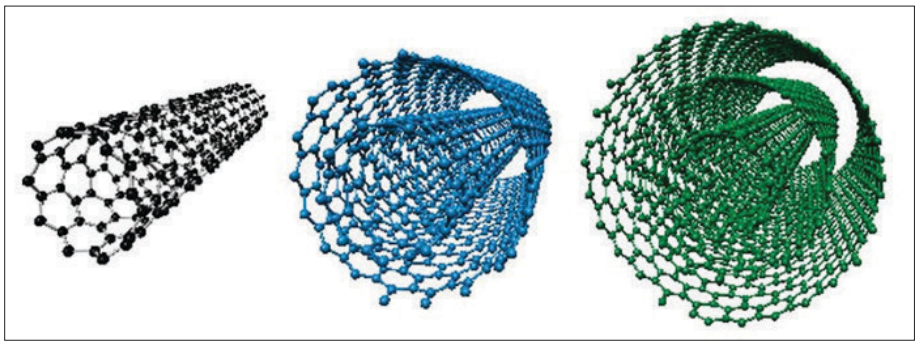
Plaster Cracks On AAC Blocks And Putty?

A Common Problem And Solution

Crack on plastered or putty finished surface on AAC Block is a common problem which spoils the look and change the aesthetical view of building. External and internal surface of the building are subjected to face different atmosphere. As the outer plaster/putty finished surface is subjected to adjust with external weather parameters like rain, sun heat, wind blowing and other stresses due to temperature and humidity variation, the internal plaster/putty finished surface is subjected to adjust other stresses like humidity, temperature variation and mostly the masonry surface.

AAC Block surface is the most common reason of crack development of plaster and putty finish on AAC Block masonry. Autoclaved aerated concrete (AAC) is manufactured using cement, fine aggregates and an aerating additive. The Aerating additive makes the mix lump into a dough. Mostly AAC Blocks contains a large amount of air. The prepared mix is put in mould and cut into desired dimensioned units. The major advantages of AAC Block is its light weight, insulation and easy installation with cost-effective benefit. Water ingression cannot take place through AAC Block. Water absorption property of AAC Blocks was investigated





by capillary suction method. It was found that the inflow height (i) of water in aerated concrete by capillary suction effect was a function of the elapsed time (t), i. e. $i=a+s\times t\ 1/2$. Based on the theory of Laplace and characteristics of aerated concrete, the physical implication of the parameter "a" and "s" in the formula and their influencing factors were discussed. The results showed that "a" was mainly depended on the pore radius of the surface layer of aerated concrete and "s" was determined by the total porosity, the quantity of connected pore and pore size distribution of aerated concrete. According to the observation of the profiles of macro pores in aerated concrete, the relationships between capillary absorptivity and connected pores, pore size distribution of aerated concrete were investigated, by which the theoretical analysis mentioned above was proved to be appropriate. The impermeable surface property of AAC Block has welcome the major disadvantage, which causes the crack development on plastered surface.

The reason is very simple. As the cement slurry is not absorbed by its surface, it can't function as a key to hold the plaster on it. This phenomenon is the root cause of debonding between AAC Block surfaces and plaster or putty on it. The lack of bond between cement particles causes surface bond failure of plaster. But the expansion–contraction property is not at all similar to the plaster on it. Considering the above two factors in study, it is established to state that plaster on AAC Blocks definitely will crack.

There is a practice to limit this problem is introduced by using polymer adhesive based system. But, that has a limitation of bonding due to its reduced durability under weather action. The kind of polymer used for the purpose is degraded under weather action, mainly the storm water affects its structure. Low pH of storm water slowly degrades the molecular structure of the bonding polymer in this case. As a result, the plaster on it or with the polymer is degraded and cracks are developed at random and surrounding the degraded polymer. This has raised a big question to the advantage of AAC Blocks.

A long study and use of a Nano composite has shown the way to get rid of this serious problem. The Nano tubes has played a great role to stop this crack development problem of plaster on AAC Block. Nano tubes in plaster mortar

helps to produce key between cement particles in calcium silicate hydrate gel. The resultant products after reaction between Nano composites and cement produces a Nano particle flow towards the surface of the AAC Block, which makes a key between the plaster and the AAC Blocks. This flow of Nano particles towards the horizontal axis is called horizontal suction. Similarly the vertical suction plays the same role in producing key between the cement particles. This inward flow creates millions of keys to hold the plaster mortar to the AAC Block surface. There are many such evidences which has proved its efficiency and also named as BOND FLOW. The BOND FLOW has a great impact to make the plaster durable on AAC Block. The advantage of the Nano Bond Flow is the faster plastering work and reduced rebound loss. As the Nano composite is an



inorganic in nature, it has no degradable property under weather action, after formation of calcium silicate hydrate hydrophobic gel the plaster is formed into a hydrophobic monolithic substrate with AAC Block. The monolithic cover behaves similar expansion contraction property with AAC Block. This exquisite property of the Nano composite is proven successful to stop any crack propagation in hydraulic material like cement and putty. The putty also behaves similarly with Nano composite on AAC Blocks and other non-porous surface. The study is conducted based on a Nano composite product, which is widely used in many constructions built by AAC Blocks. The product has proved its efficacy to prevent these types of cracks and in the field of waterproofing of structure too.

The study conducted on SYLOCON® is analyzed by Scanning Electron **Microscope and X-ray diffraction. Also** the product is tested on several projects all over India and it is established as an only tool to prevent cracks on plaster and putty on AAC Blocks and non-porous structure.





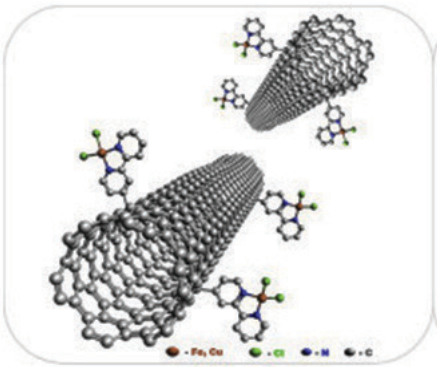
Performance Of Selected Nano Tubes In Cement Mortar In Presence Of Nano Particles After Hydration

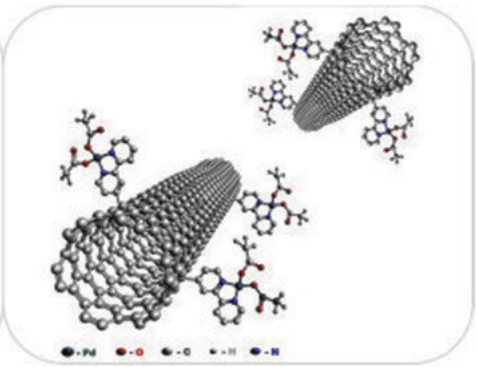
Cement pastes and mortars are normally prepared with cement and sand. Water is added to prepare a homogeneous mix that can make the mortar workable to adhere to any concrete or brick surface. Cement acts as a bonding material but in case of smooth surface like AAC Blocks, concrete, Fly ash bricks and similar surface, the bonding particles of cement slurry can't impregnate. Therefore, a lack of bond between cement mortar and smooth surface is noticed. This phenomenon is the root cause of bond failure resulting into crack propagation on smooth surface like AAC Blocks, etc. This is a very common problem as noticed in every such building project. Although there are several other factors which are responsible to develop cracks on AAC Blocks and similar masonry units. In this connection we can make a general study on AAC Blocks.

AAC Block

The composition is changed in different manufacturing unit.

1. Autoclaved Aerated Concrete is a lightweight, great insulating, durable building product, which is manufactured in different sizes. This is also known as Autoclaved Lightweight Concrete (ALC).
2. This is the eco – friendly and green building materials.
3. AAC is a made of cement, fly ash, sand, water and aluminium powder or aerating additives. Aluminium powder reacts with calcium hydroxide and water to form H2. The hydrogen gas increases volume of the raw mix by gas bubbles. After steaming and hardening process and reacting with calcium hydroxide calcium silicate hydrate is produced, which gives AAC its strength and lightweight properties.
   a. Cement Binder - It hardens and binds all material together.
   b. Fly Ash - A by-product of burning pulverised coal. It provides thermal insulation, fire resistance and sound absorption
   c. Sand – An aggregate material, sand with silica content more than 80% is generally used in AAC bricks.
   d. Limestone - A sedimentary rock composed largely of the mineral calcite (calcium carbonate: CaCO3) and it can be directly purchased as limestone powder.
   e. Aluminium Powder - Aluminium is an aerating agent, air bubbles (hydrogen gas) is produced after reaction with calcium hydroxide.
   f. Gypsum - Gypsum is used for fast setting.





Preparation Of Mix

1. 53-grade Ordinary Portland Cement (OPC).
2. Fly ash and sand are mixed with water to prepare slurry. The slurry is mixed with other lime powder, cement, gypsum and aluminium powder.
3. Lime powder is another ingredient.

Processing (Dosing, Mixing)

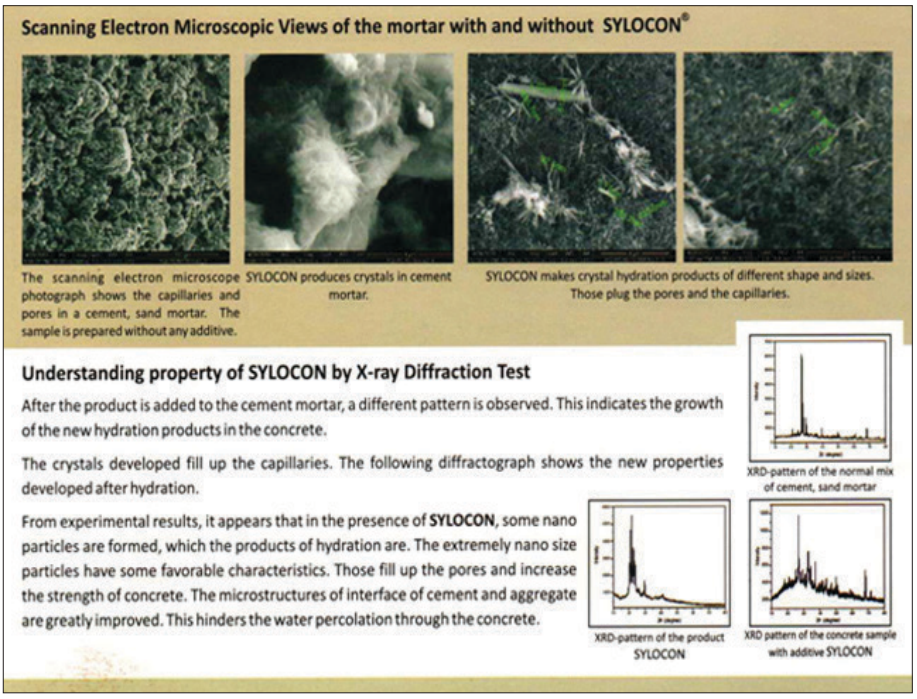
Dosing and mixing is an important operation for AAC blocks manufacturing process. Process of dosing and mixing means the quality of final products. Maintaining the ratio as Fly ash or Sand: Lime: Cement: Gypsum = 69:20:8:3.

Aluminium @0.08% and water used in a ratio of 0.60 to 0.65. At this step the ingredients are mixed homogeneously and finely to produce the appropriate product ready for manufacturing AAC blocks. The control system accumulates all the components in a mixing vessel. A small pot is used for Aluminium powder to add into the vessel.

Churning of the mixture is begun for a standard time and the mix is poured into moulds. Dosing and mixing process is continued because if there is a break between charging and discharging of elements, the left mixture might start hardening and choke up the entire unit.

But, AAC Blocks shows few problems which are important to notice.
One important reason is crack development which is due to volumetric changes. These changes appear in the product due to drying/wetting, temperature change or carbonation. Drying shrinkage presents the most important volumetric change during the lifetime of any AAC construction. First, the rate of drying shrinkage depends on the composition of AAC. It is reported in that drying shrinkage of AAC with only cement as a binder is significantly higher than that produced with lime or lime and cement. Knowledge of the proper composition of AAC is not enough, as long as there is still the common practice of designing AAC constructions that involves empirical processes. These processes usually either underestimate the risk of possible failures due to drying shrinkage, or are not powerful enough to reveal potential weakness. Even the national standard in the Czech Republic CSN EN 680-733 1356:2006 underestimates the risks of possible damage by defining the conventional drying range of moisture content for estimation of drying shrinkage from 30% to 6% by mass. These thresholds represent the moisture content change from freshly produced AAC to the equilibrium moisture content in the AAC. It has been concluded in recent research that drying shrinkage of different types of AAC is increasing with decreasing moisture content in the AAC pore system and this increase is fastest in the range of very low moisture, much lower than 6%.

This feature of the AAC drying process is commonly not considered by designers and may be responsible for surface cracking. On the other hand, in some research papers there already exist more sophisticated approaches for designing AAC constructions, so far dealing with heat and moisture transport only. In this paper, we present a hygro-thermo-mechanical model, which is used for the description of hygric expansion/shrinkage of AAC. This model is verified by approximation of a laboratory experiment for determination of drying shrinkage. Finally, the usage of verified model settings is demonstrated in the long-term simulation of hygric expansion/ shrinkage of an AAC wall exposed to real weather data. The initial moisture content of the material is set differently, ranging from 30% to 6% by mass and thus describing the state of the material in different time intervals between its journey from the factory and construction on site.



The best performance of AAC was achieved with the lowest initial moisture content of the block. To avoid mechanical damage caused by drying shrinkage, it is strongly recommended to use as much dry AAC as possible.

Introduction Of Nano Tubes And Nano Particles In Cement Matrix Of Plaster

The microstructural investigation of the Nano composites reveals that Nano tubes helps in filling upmicro/nano pores between the calcium silicate hydrate (CSH) and ettringite during the process of hydration, after placing mortar on AAC Blocks or similar surface the Nano tubes acts as an anchoring element which helps mortar to fix with the smooth surface.

The following SEM IMAGES X-ray Diffraction pattern shows the performance, The Nano tubes are along with Nano particles produce the composite which enhance the durability of the structure. Cracks are not developed on the plastered or putty surface.

For further information,
visit: www.aquacrete.co.in



Effective And Durable Concrete Lining In Tunnels And Silos With SYLOCON®

More Than 15 Years Of Successful Result In Producing Durable Concrete Lining

History Of Sprayed Concrete

Dr Akeley wanted to make an equipment which can spray mortar mixture on concrete surface to make parent concrete durable. He made a special chamber working as a pressure vessel which can spray the mortar mixture on the R.C.C. wall surface. The seed concept of today's sprayed concrete was born more than one hundred years and was known as "CEMENT GUN". This unique method became popular within a short period that was patented in 1911, which was owned by Cement Gun Company.

Based on this concept different technical modification enriched the system and worked better than the past.

In this case study we will focus on an innovative idea of sprayed concrete in Graphite Storage Silo, which could prove its outstanding durability for a longer period. The technical analysis will be presented accordingly.

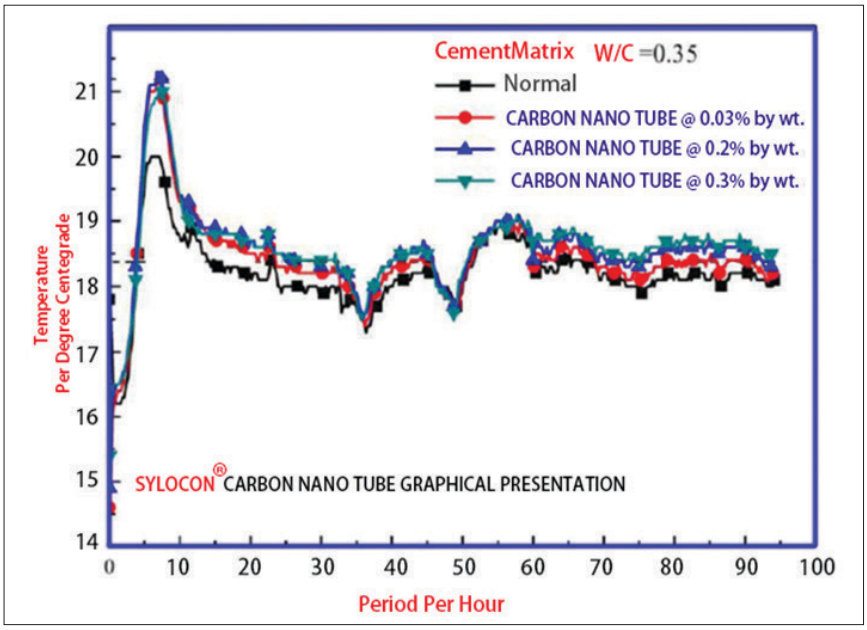
How SYLOCON worked to enhance durability of the lining?

In ancient time it was believed that a complex material containing clay with nanopores into which indigo dye was combined chemically to create an environmentally stable pigment. Based on this concept a corrosion resistant azure pigment was produced, known as Maya Blue in AD 800. It was discovered in the pre-Columbian Mayan city of Chichen Itza.

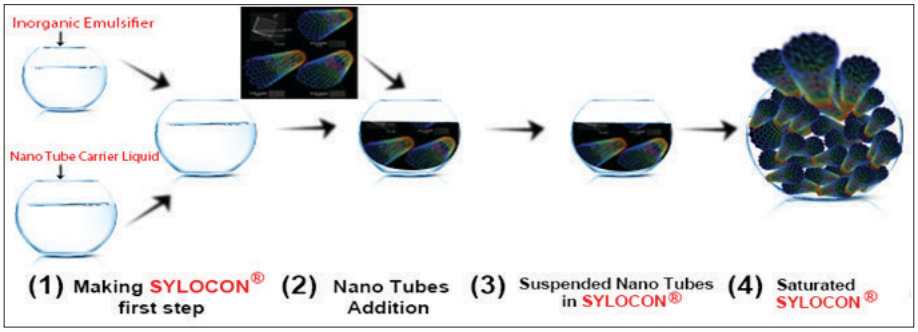
Today's Nano technology can meet several requirements in different industry. Nano tubes in SYLOCON® has opened a new window to solve the major problems of debonding between sprayed mortar and parent R.C.C. structure in tunnel lining. SYLOCON® is a complex of different Nano tubes. The bonding of Carbon nanotubes are due to the carbon atoms linked in hexagonal shapes, with each carbon atom covalently bonded to three other carbon atoms. The tensile strength of carbon nanotubes is approximately 100 times greater than that of steel of the same diameter. There are two things that account for this strength. The first is the strength

provided by the interlocking carbon-to-carbon covalent bonds. After mixing of SYLOCON in concrete the Nanotubes are widely distributed in the cement mortar.Moreover Carbon Nanotubes have capacity to hold maximum weight. It has a low density for a solid of 1.3 to 1.4 g/cm^3, its specific strength of up to 48,000 kN·m·kg^{-1} is the best of known materials, compared to high-carbon steel›s 154 kN·m·kg^{-1}.Its reaction with cement is more intense than that of the larger fibers. Nanotubes in SYLOCON possess a high modulus of elasticity, tensile strength, and yield strain. Those characteristics make SYLOCON an effective reinforcing material for cement mortar that makes concrete durable. The basic technology of SYLOCON is presented here to understand the dispersion and bond linkage of Nano tubes in SYLOCON.

Similarly the ductility, flexural strength and permeability of concrete is of great importance in view of durability. The change in volume of concrete has also a great impact on durability and other utilities of concrete. This is termed as autogenous shrinkage. Different cracks are observed in concrete leads to rejection in quality due to the autogenous shrinkage. SYLOCON contains the nano particles to overcome this problem. The following graphical presentation shows the result by SYLOCON'S control mechanism to reduce this adverse effect of concrete.



Different quantity of nano tubes are used to examine the autogenous shrinkage behaviour of concrete. Temperature of concrete due to heat of hydration is recorded with time. This tool helps to design most effective formulation of SYLOCON. SYLOCON containsCarbon nanotubes which are seamless, carbon cylinders which have unique mechanical and electronic properties. The length is varied with single wall or more than one wall. Young's modulus of those are five times and eight times (theoretically 100 times) the strength of steel, with 1/6th the density. The major advantages are mechanical durability as well as prevention of cracks in concrete. This is well established 15 years back that SYLOCON can produce an impermeable, crack free and durable concrete. Use of SYLOCON in Graphite India Limited storage silo is one of the authentic examples to know its effect. So, this is clearly understood that SYLOCON is the perfect additive for sprayed concrete in tunnel lining.



Detailed morphology of SYLOCON and cement compound strand was studied using TEM. it was verified from this test that there was a physical bonding between cement matrix and CNT. The diameter of the cement compound strand was almost the same as that of CNT.

Water and soluble contaminants penetrate through the pores of the structure and causes gradual degradation of the concrete.

The degradation appears in the form of efflorescence, laitance, spalling concrete and cracks. These facilitate active ingression of water with various ion contaminants transported from higher concentration to lower concentration within the inner pores of the concrete. This ingression can be avoided blocking the pores of concrete. SYLOCON® produces the crystal on hydration reacting with

un-hydrated free calcium oxide present in the cement, which blocks the pores and makes concrete stronger, impermeable and durable.

Reaction And Its Result

Four phase cement reaction-

1). Cement before hydration.

2). Surface products like C-S-H grows outward with connected gel pores.

3). Pore products as calcium hydroxide is polycrystalline and fully dense with no connected pores.

4). Capillary pores- the water filled space between the solid phases.

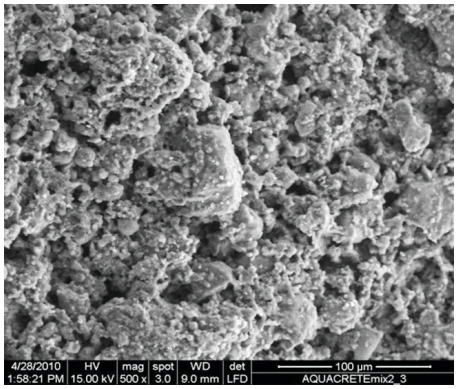
As soon as water is added to cement, rapid heat evolution takes place. Within few minutes, this is decreased and remains constant in plastic stage up to 3-5 hours until the concentration of the ions in the solutions before starting the precipitation of products of hydration.

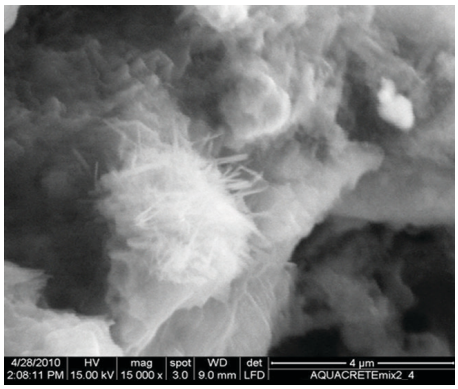
When the maximum heat is evolved, CH crystallizes from the solution and a slow coating process of C-S-H product is started, which covers unreacted C_3S grains. As the hydration goes on, this coating becomes thicker and does not allow water to contact the un- hydrated core particles.

Nano particles of SYLOCON® contacts all the particles of cementing material and produce the crystal products under controlled hydration, which fill up pores and capillary pores The capillary pores are known to be responsible for the impermeability of concrete. The size and number of pores are greatly reduced. As a result, the strength of concrete is also increased.

Scanning electron microscope shows the pores in concrete, development of different sizes of crystal in cement mortar after hydration. Nano particles are observed in the scanned photograph.

Scanning Electron Microscopic Views Of The Mortar With And Without SYLOCON®

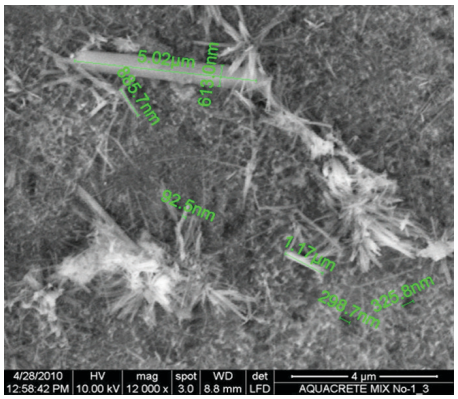


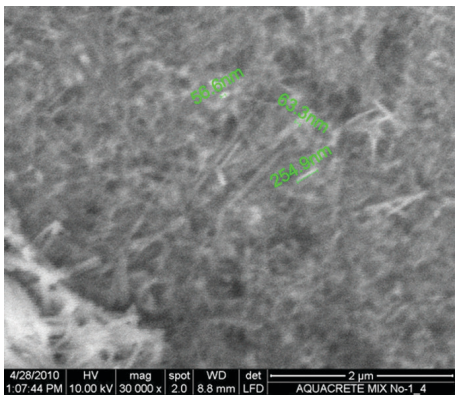


The Scanning Electron Microscope Photograph Shows the Capillaries and Pores in a Cement, Sand Mortar.

SYLOCON® Produces Crystals in Cement Mortar.

The sample is prepared without any additive.



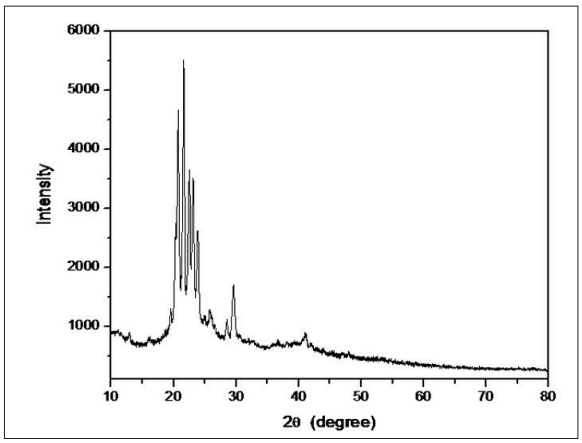


SYLOCON® Makes Crystal Hydration Products of Different Shape and Sizes.
Those Plug the Pores and the Capillaries.

X-ray Diffraction Test Of SYLOCON

After the product is added to the cement mortar, a different pattern is observed. This indicates the growth of the new hydration products in the concrete.

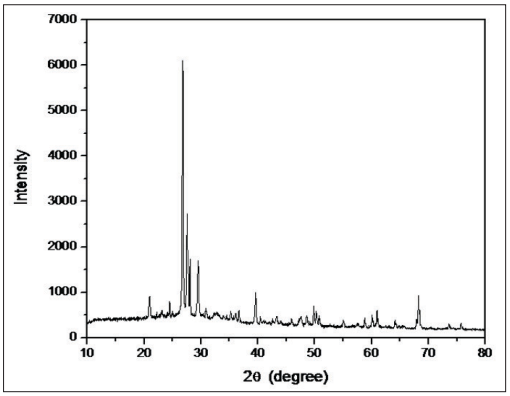
The crystals developed as hydration products fill up the capillaries. The following diffractograph shows the new properties developed after hydration.



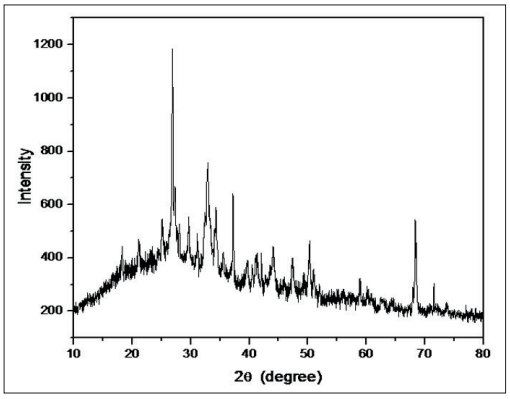
XRD-Pattern of the Product SYLOCON®

Microanalysis Study On The Products Of Hydration With And Without SYLOCON®

The microanalysis report of the mortar specimens show no development of any new product after hydration. A foreign carbon particle

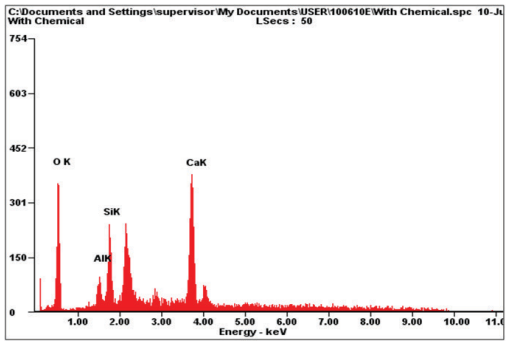


XRD-Pattern of the Normal Mix of Cement, Sand Mortar



XRD Pattern of the Concrete Aample with Additive SYLOCON®

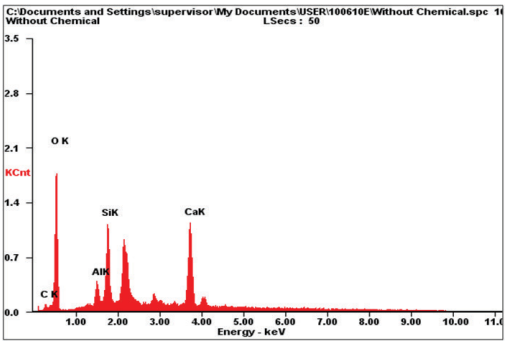
from any external source is present in the concrete without SYLOCON®. But, the chemical composition of the concrete is unchanged after the reaction of cement and SYLOCON®. So, the waterproofing properties developed in the treated mortar are due to the presence of the same nature of crystal formed in the capillaries and the pores of the concrete. These crystals of different shapes and sizes plug the water ingression path without changing the basic properties of concrete. In the microanalysis report this is very clear, only the percentage of the elements are changed.



kV: 10.01 Tilt: 0.00 Take-off: 35.10 AmpT: 102.4 Detector Type: SUTW-Sapphire Resolution: 131.17

Element	Wt %	At %
O K	31.61	51.52
AlK	03.52	03.40
SiK	10.36	09.62
CaK	54.51	35.46

Edax ZAF Quantification Standardless Sec Table: Default



kV: 10.01 Tilt: 0.00 Take-off: 33.75 AmpT: 102.4 Detector Type: SUTW-Sapphire Resolution:131.17

(WITH SYLOCON®)

Element	Wt %	At %
C K	02.12	04.12
O K	39.66	57.88
AlK	03.28	02.84
SiK	12.65	10.51
CaK	42.29	24.64

Edax ZAF Quantification Standardless Sec Table: Default

(WITHOUT SYLOCON®)

Heat evolution during hydration

Heat evolution during hydration is plotted here.

The rate of heat evolution curve in the presence of SYLOCON® is slightly lower than the curve of a normal mix. Total heat evolved during the hydration is plotted here. This indicates the retardation of hydration.

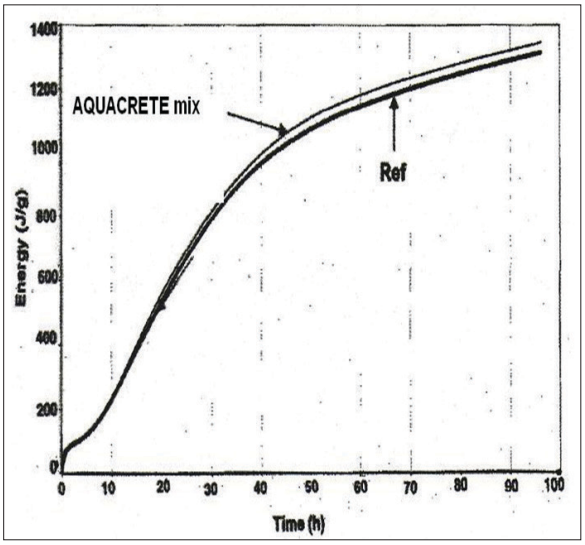
From experimental results, it appears that in the presence of, mix some nano particles are formed, which the products of hydration are. The extremely nano size particles have some favourable characteristics. Those fill up the pores and increase the strength of concrete.

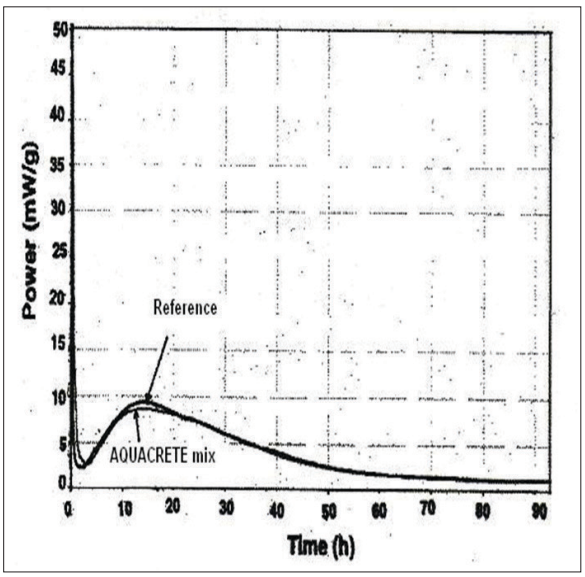


Mr. Debasish Bhattacharyya

Graphite India Ltd. was facing a serious problem in storage silo. The inside concrete lining of big silos was spalling, that became a part of regular maintenance of Graphite India Ltd. The matter was brought to the Senior Consulting Engineer of STUP CONSULTANT Mr.Debasish Bhattacharyya.

He thought to eliminate this problem using Nano composite in sprayed concrete mortar. SYLOCON was chosen as a Nano Composite to short out this problem. In fact it was the innovative introduction of Nano tubes to provide excellent bonding between R.C.C surface and sprayed concrete. After a period of 15 years I personally visited the industry and spoke to the related authority. The result was really wonderful. No rectification was done within this long period.







Cooling tower



Basement



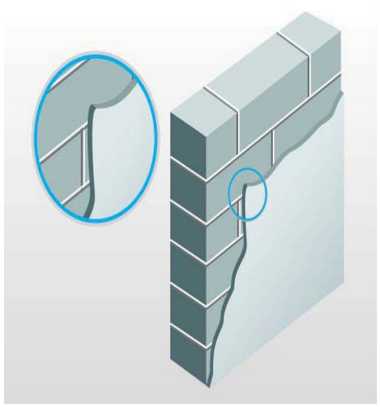
Tunnel



Underground Water Tank



Swimming Pool



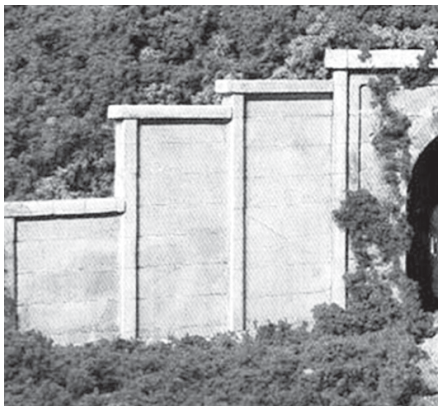
AAC Block Plastering

The microstructures of interface of cement and aggregate are greatly improved. This hinders the water percolation through the concrete.

Uses Of SYLOCON In Structure



Overhead Reservoir



Earth Retaining Wall

Conclusion

The practical examples and experiments has established that SYLOCON is the perfect combination for lining with cement mortar or concrete to enhance bond strength and durability of concrete tunnels and silos.

For more information, contact: email–aquacrete93@gmail.com / premankurbhattacharji@gmail.com / premankur@aquacrete.co.in

SYLOCON® Since 1993 - Value Of Future

SYLOCON® is the product to overcome the challenges of cracking, efflorescence, water seepage on plaster or putty finished AAC Blocks, Fly ash bricks, Red clay bricks, R.C.C. surface and Screed concrete on mother slab.

AAC falls under aerated concrete, high on suction, very high on shrinkage movement.

1) Should be dry to control shrinkage.
2) Cracks appear mostly at brick joints. Cracks are usually in straight lines or sometimes stepped / diagonal.

AAC blocks are designed to be with low density for economic design of building. Aeration reduces density, by-products being low strength, high water absorption and very high shrinkage. These blocks are produced using aerated cementitious composite, which is autoclaved. Immediately after production, AAC Blocks are usually with high moisture content.

Materials used in AAC blocks, autoclaving process affect shrinkage. For example, if graded aggregates are not up to mark, they will have high shrinkage. AAC blocks should be dried sufficiently before putting them into use. Additionally, no water shall be supplied to AAC blocks during construction. Now, it is common

> "At this point in time we are not facing any sort of abnormalities while using Sylocon, and we are very much satisfied with this new product from Ann World"
>
> Dilip Kumar Goyal
> Senior Manager (Production), Graphite India Limited



sense that effective water curing affects high cracking in AAC. In that case block fixing agent is used which strength is higher than AAC block, as a result cracks appears at other places. Normal cement sand weak mortar with self curing compound should be used for fixing blocks. Air increases porosity. When pores in the block receive water, they expand. When dried, these pores shrink.

So, AAC expands and contracts. Although very marginal on change in length, brick binding mortar cracks due to tensile stress. While storing at factory/site, blocks are stacked in piles. Blocks in the outer periphery dry out well but the blocks deep inside the pile do not dry enough. Curing is the most important source of expansion. Rain water is another source. Sun is important source of drying. Wind as well, depending on Relative Humidity. Diagonal cracks / cracks through bricks are due to handling of the bricks by labour. AAC blocks are poor in compressive strength; do not resist shocks when dumped from a height. They develop minor fissures internally. Crack propagation is always through the weakest zone. Brick binding mortar will be stronger than the cracked block, so crack goes through the

> "I have known Mr. Premankur Bhattacharya for quite some time now, with Sylocon, I am impressed with his ability to think of new ideas and his zeal to develop new products. The depth of his knowledge is praise worthy and all the trouble which he takes in developing his products is really commendable. The products manufactured, are very effective"
>
> Shyamal Kumar Mitra
> Geo Technical Consultant

brick. Therefore, we see diagonal cracks Otherwise, cracks in AAC blocks are always in straight lines. Steps may be observed, depending on weaker zones for crack propagation.

Why AAC Blocks Crack?

As the size of block increases, cracking reduces. 4" wide blocks crack higher than 9" wide blocks due to lesser self weight. Change in background is weak zone especially where mesh application is not possible. We see straight line cracks between junctions of columns / beams and walls with no mesh. One or two concrete beds are provided in the walls usually in AAC blocks. If such beds are provided, mesh shall be applied before plastering considering change in background.

If the wall is exposed to wind movement / heavy sun, chances to cracking is high. As the height increases, due to heavy wind cracks may develop. Workmanship For example, cutting the bricks for electrical conduits etc shall be done carefully, without subjecting the blocks to high loads.

> “Sylocon is a fantastic product; it has the potential to reduce cracks invariably. We have been using this product for about seven to eight years. And I have personally chosen to use this product in one of our reputed residential project where the result was exceptionally good. It is a combination of fibres, nano-components, etc which can be used in mortar, plastering purposes, and also in concreting, which in turn plays an important role in increasing the waterproofing capacity of your concrete”

Tapas Nandy
Deputy General Manager –
Project, Shapoorji Pallonji Real Estate

Shocks : Due to lack of sufficient self weight, the walls move heavily even with smallest shocks. If nails are used to fix meshes at background changes before plastering, the brick binding cracks.

Packing / filling materials in holes of electrical fittings etc. These also are weak zones, through which cracks appear.

Rain: Always store the blocks in a shade away from rain. Ensure they are dried well before use.

Materials Storage And Brick Binding

Factory Inspection is essential to observe storage conditions. Buy from reliable suppliers who store blocks away from rain. This should be sufficiently dried before supplying to site.

Mesh- Use glass fibre mesh in all junctions. Fibre mesh is flexible and can be easily applied at all junctions even if the column / beam does not flush into the wall. Also apply mesh at the concrete beds.

Use Self curing Mortar by using SYLOCON ® in mortar for both brick binding, putty finishing and plastering.

Precast lintels to avoid curing after application. Store AAC blocks on a dry platform and protected from rain. Make smaller stock piles with enough sun and air to pass through the blocks for drying. Ensure that bricks being used are dry. Moisten surface only to receive mortar.

Carefully select unbroken bricks for brick binding. Any bricks with cracks / defects shall be quarantined for disposal. Apply self curing mortar thoroughly on the full face of the block (not just only at the corners of each side). If the mortar is self curing, thickness does not matter much. However, excess thickness affects the last layer of blocks ending at the concrete slab/ beam etc. The opening left for the top most (last) layer could be so small that the mason will be forced to use broken bricks, which results in a weak zone. Due to this, most AAC manufacturers recommend thickness of 3-5 mm for brick binding mortar. Therefore, ensure full blocks are used always.

Best practice is to cast precast lintels and be installed in place. Allow at least 3 weeks of drying of the brick binding before application of plaster. At this stage, some cracks may appear at the joints yielding to shrinkage movement of blocks. Check for cracks to see if any blocks have completely dislodged and can be removed by hand. Remove such loose blocks and scrape the dead mortar in the hole and the block. Check if the block has no damage and can be reused. Apply fresh mortar thoroughly over the face and reinstall the brick using waterproof coating compound. Repeat the process of crack inspection. If due to any reason, half blocks have to be used in the top layers, neatly cut the blocks to required size before application into the wall. Do not use broken bricks.

Ensure water does not reach the blocks in the whole process. Due to uncontrollable reasons like rain etc, if the wall becomes damp, leave it for 2 months of drying. External plaster shall be done only after 2 months of cessation of rains.

Declare the wall is ready to receive plaster if there are no dislodging blocks. Pack all the gaps etc., in the electrical conduits with mortar prepared using SYLOCON ®. Use fibre Mesh of 8” width in all junctions. It is flexible and gets into all the junctions, even if the column / beam do not flush into the wall. Do not use nails to fix the mesh. Mortar may be applied on the mesh, which is self curing.

De-bonding between plaster and putty is another important reason behind appearing cracks on finished surface. This is very difficult to control all the above mentioned parameters at site. Ultimate user is mason and workers. System should be mason friendly and complication free.

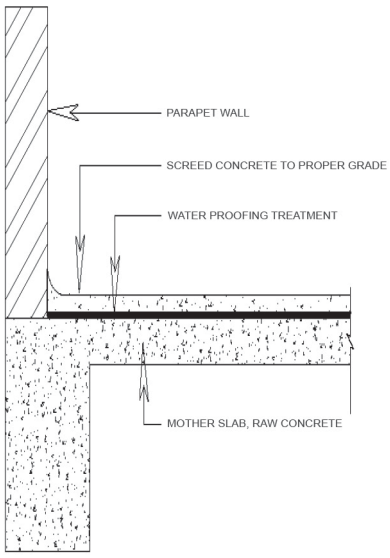
SYLOCON® has all the properties to get rid of this problem. Once plastering is done with SYLOCON®, AAC Blocks property is changed to non-absorbent. If SYLOCON® is added to the putty, even gypsum putty, the putty is non-absorbent and crack free in nature. No water ingression is found through the SYLOCON® added mortar or putty surface. So, once AAC Block is wrapped to avoid moisture and adequate bonding with waterproof plaster or putty is achieved, cracks can’t develop. Due to its non water absorbent and crack resistant property, water can’t dissolve salts in masonry due to impermeability of outer finished surface.

**For more information,
visit: www.aquacrete.co.in**

Value Of Future - SYLOCON®

www.aquacrete.co.in

Screed Concrete On R.C.C. Mother Slab



ROOF TREATMENT WORK

Screed concrete in slope on R.C.C. mother slab is a common method to drain out storm water from terrace. And we know there is a joint between old and new concrete. So, in every joint a bonding agent is required between old and new concrete. That too should have a property to adhere wet concrete to old concrete.

In practice we apply one or two coats of liquid copolymer on mother slab, this may be a mix of cement with copolymer or only acrylic copolymer coating on mother R.C.C. slab. The property of coating by nature is water impermeable.

Cement slurry in screed concrete is not absorbed by this treated surface. So, there is always a lack of bond between two layers. Upon drying up of the screed concrete layer, moisture is evaporated. During evaporation, upward pressure of moisture causes initial de-bonding between mother R.C.C. slab and layer of screed concrete. As well as, this drying up causes shrinkage cracks in screed concrete layer, which are ultimately turns into major cracks due to thermal expansion and contraction and de bonding with mother R.C.C. slab. Storm water is entrapped in layer of screed concrete through the propagated cracks and retains on the mother slab. As a result, the polymer on mother slab is damaged due to swelling property of copolymer in long time contact with water. Treated surface is damaged in course of time and crack appears, through which water takes place in mother slab after one or two seasons. Water leakage is a result of this practice.

In fact, this is a major issue in regular building roof. There is no doubt that de-bonding between two layers and shrinkage is major issue to develop cracks in screed concrete layer.

> “We have been using SYLOCON for the last seven to eight years at Shapoorji Pallonji. Mostly, we have used it in external plaster, sometimes in the roof. For external plaster surface, with added SYLOCON the surface ends up being very good and helps to keep the sheen of the external paint. Along with that, it also acts as a waterproofing agent and usual cracks which we see in any plaster are not present when SYLOCON is added.”
>
> Rana Gupta
> Vice President, Shapoorji Pallonji Real Estate

SYLOCON® is the right answer to overcome this challenge. SYLOCON® added concrete mix, which is laid in panels on mother slab with proper slope reduces heat of hydration of cement. Micro fibres, which are well dispersed in SYLOCON® produce a complete net bonding as additional reinforcement.

Bonding between mother R.C.C. slab and screed concrete layer is so good that de bonding is totally avoided. SYLOCON® added mortar is waterproof by nature after hydration is complete. There are no chances of appearing cracks in concrete during evaporation of moisture, due to less heat of hydration.

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Materials used in AAC blocks and autoclaving process affect shrinkage. For example, if graded and it turns out that the aggregates are not up to mark, it will have high shrinkage. AAC blocks should be dried sufficiently before putting them into use. Additionally, no water shall be supplied to AAC blocks during construction. Now, it is common sense that effective water curing affects high cracking in AAC. In that case block fixing agent is used whose strength is higher than AAC block, as a result cracks appears at other places. Normal cement sand weak mortar with self-curing compound should be used for fixing blocks. Air increases porosity; when pores in the block receive water, they expand; and when dried, these pores shrink.

So, AAC expands and contracts. Although very marginal on change in length, brick binding mortar cracks due to tensile stress. While storing at factory / site, blocks are stacked in piles. Blocks in the outer periphery dry out well but the blocks deep inside the pile do not dry enough. Curing is the most important source of expansion. Rainwater is another source. Sun is important source of drying.

> “We had a long discussion about – how to modify this product, where I wanted a product, which would place the fibres uniformly within the mortar as earlier; the fibres were getting into a lump. After much work on this product, Mr Bhattacharya came up with SYLOCON, which is an amazing product. It became a secondary reinforcement to the plaster and hence it reduced the shrinkage gag, I would recommend the engineers to use this product and notice the changes in the paster.”
>
> Subhas Chandra Basu
> General Manager – Engineering,
> Tata Housing Development Co. Ltd



Wind as well, depending on Relative Humidity. Diagonal cracks / cracks through bricks are due to handling of the bricks by labour. AAC blocks are poor in compressive strength; do not resist shocks when dumped from a height. They develop minor fissures internally. Crack propagation is always through the weakest zone. Brick binding mortar will be stronger than the cracked block, so crack goes through the brick. Therefore, we see diagonal cracks Otherwise, cracks in AAC blocks are always in straight lines. Steps may be observed, depending on weaker zones for crack propagation.

Size Of Block

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Workmanship: For example, cutting the bricks for electrical conduits etc shall be done carefully, without subjecting the blocks to high loads.

Shocks: Due to lack of enough self-weight, the walls move heavily even with smallest shocks. If nails are used to fix meshes at background changes before plastering, the brick binding cracks. Packing / filling materials in holes of electrical fittings etc. These also are weak zones, through which cracks appear.

Rain: Always store the blocks in a shade away from rain. Ensure they are dried well before use.

Methodology

Factory Inspection is essential to observe storage conditions. Buy from reliable suppliers who store blocks away from rain. This should be sufficiently dried before supplying to site.

Mesh: Use glass fibre meshes in all junctions. Fibre mesh is flexible and can be easily applied at all junctions even if the column / beam does not flush with the wall. Also apply mesh at the concrete beds.

Use Self Curing Mortar by using SYLOCON ® in mortar for both brick binding, putty finishing and plastering.

Precast Lintels: Precast lintels to avoid curing after application - store AAC blocks on a dry platform and protected from rain. Make smaller stockpiles with enough sun and air to pass through the blocks for drying. Ensure that bricks being used are dry. Moisten surface only to receive mortar.

Carefully select unbroken bricks for brick binding. Any bricks with cracks / defects shall be quarantined for disposal. Apply self-curing mortar thoroughly on the full face of the block (not just only at the

corners of each side). If the mortar is self-curing, thickness does not matter much. However, excess thickness affects the last layer of blocks ending at the concrete slab/ beam etc. The opening left for the topmost (last) layer could be so small that the mason will be forced to use broken bricks, which results in a weak zone.

Due to this, most AAC manufacturers recommend thickness of 3-5 mm for brick binding mortar. Therefore, ensure full blocks are used always.

Best practice is to cast precast lintels and be installed in place. Allow at least 3 weeks of drying of the brick binding before application of plaster. At this stage, some cracks may appear at the joints yielding to shrinkage movement of blocks. Check for cracks to see if any blocks have completely dislodged and can be removed by hand. Remove such loose blocks and scrape the dead mortar in the hole and the block.

Check if the block has no damage and can be reused. Apply fresh mortar thoroughly over the face and reinstall the brick using waterproof coating compound. Repeat the process of crack inspection. If due to any reason, half blocks must be used in the top layers, neatly cut the blocks to the required size before application into the wall. Do not use broken bricks. Ensure water does not reach the blocks in the whole process. Due to uncontrollable reasons like rain etc, if the wall becomes damp, leave it for 2 months of drying. External plaster shall be done only after 2 months of cessation of rains.

Declare the wall is ready to receive plaster if there are no dislodging blocks. Pack all the gaps etc, in the electrical conduits with mortar prepared using SYLOCON ®. Use fibre Mesh of 8" width in all junctions. It is flexible and gets into all the junctions, even if the column / beam does not flush into the wall. Do not use nails to fix the mesh. Mortar may be applied on the mesh, which is self-curing. De bonding between plaster and putty is another important reason behind appearing cracks on finished surface. This is very difficult to control all the above-mentioned parameters at site. Ultimate user is mason and workers. System should be mason friendly and complication free.

SYLOCON® has all the properties to get rid of this problem. Once plastering is done with SYLOCON®, AAC Blocks property is changed to non-absorbent. If SYLOCON® is added to the putty, even gypsum putty, the putty is non-absorbent and crack free in nature. No water ingression is found through the SYLOCON® added mortar or putty surface. So, once AAC Block is wrapped to avoid moisture and adequate bonding with waterproof plaster or putty is achieved, cracks can't develop. Due to its non-water absorbent and crack resistant property, water can't dissolve salts in masonry due to impermeability of outer finished surface.

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Technology Coordination Technology

PART-V

Corrosion Of Steel In Concrete

TCT endeavours to establish a close relationship between different technologies related to civil engineering, and the civil engineers know the basics.

I would like to emphasize only the basic concept of corrosion. Corrosion is a very common term, which indicates deterioration of any substance by the direct influence of some other conditions. Generally, we focus on the deterioration of steel, concrete and other metals; but, any condition is ionic. Therefore, our study and analysis are based on this concept.

Rusting is the aqueous or atmospheric corrosion of iron, zinc, copper, aluminium and other metals to either cover the metal component in a layer of corrosion products, or in more severe cases, cause the metal component to be damaged by extensive conversion of metal to corrosion products. In most cases, the corrosion products are oxides and hydroxides of the rusted metal, but other compounds such as carbonates, atmospheric oxygen, water and sulfates are also possible.

Atmospheric oxygen, water and atmospheric pollutants such as sulphur compounds and to a lesser extent atmospheric carbon dioxide activate rusting. The rate of rusting and the corrosion product formed is closely dependent on environmental factors, making accurate prediction of rusting very difficult. The temperature, frequency of rainfall and sunshine, orientation of the rusted surface relative to gravity, the concentration of sulphur dioxide, salt crystals and dust particles influence rusting rates. In general, iron and steel suffer the most severe rust damage of all the metals in common use. The basic reason for that is the product of rusting, i.e., iron hydroxide is impermeable and does not protect the underlying surface to the extent that aluminium oxide protects aluminium.

Under typically humid conditions, a film of water about one micron thick will cover any exposed metal surface. Further, proximity to the sea will expose metals to airborne salt crystals, which lower the minimum humidity for water accumulation on the metal surface. The salt crystals on the metal surface will dissolve in the water film to create a saline solution.

Exposure to polluted atmospheres adds sulphates and nitrates to the aqueous solution. Iron and steel surfaces, particularly those that lie horizontally, are therefore covered in a layer of a corrosive solution of electrolytes, unless the surface is continuously irradiated by the sun or some other source of heat. Light rain increases the amount of water available for corrosion, while heavy rain washes off the electrolytes and delays rusting. Corrosion often begins around a crystal of salt or some other hygroscopic material which is in the process of absorbing water. A minute electrochemical cell is then formed close to this deposit.

A basic characteristic of electrochemical corrosion is that the formation of an electrochemical cell is often a slow process. Once formed, the electrochemical cell usually grows in size and strength to cause an over-accelerating corrosion rate. After a period of initial corrosion, a layer of iron hydroxide covers a small pit in the metal, which is filled with an aqueous solution of sulphate ions, ferrous ions and hydronium ions. This aqueous solution can become highly concentrated, as compared to surface water away from the rust pit, and will generate an electrochemical potential that is large enough to permit rapid corrosion of iron. The adjoining metal becomes cathodic to complete the electrochemical cell. Further, the surface of the rusting iron or steel is covered with an inner layer of amorphous ferrous hydroxide (FeOOH) and magnetite (Fe_3O_4), which has sufficient electrical conduction to convey current to the surrounding metal.

Corrosion of reinforcement in RCC is one of the major causes of distress or failure in a structure and has contributed greatly to the less favourable perception of the material, which emerged in the 1980s. The perception of the problem is reflected in current attitude towards housing and all construction industries. However, the technology of steel protection is now well-established.

As per standard code, particular covers are mentioned for different concretes for different environments. It should be appreciated that the requirement of different cover thickness is important in worst cases. Also, difficulties of obtaining required cover in practice have directed an investigation into other ways of preventing steel corrosion. The high-risk situations may include:

1) Construction in difficult climates (such as in hot climate)

2) Inadequately skilled workmen
3) Chloride contamination

Corrosion-Resistant Or Corrosion Protected Steel

Galvanised steel is one of the best in the category; its main limitation lies probably in an aggressive environment containing localised concentrations of chloride ions which might cause a rapid loss of zinc. Galvanising is however, suitable as an added protection to steel in a normal environment and may permit a reduction in the size of precast goods by reducing cover required. Please note that:

1) Bending is best carried out before galvanising, since cracking or flaking may result in regions of tight bends.
2) Defects due to cutting or welding should be made good with a zinc/resin coating.
3) The chromatin of the finished surface may be advised if cement to be used has very low concentration. Non-chromated bars may react chemically with the cement, producing hydrogen, which reduces the surface bond.
4) Epoxy coated steels are new; they are produced by electrostatically coating method. It is vitally important that any imperfection in the coating, such as cut ends, must be made good to avoid corrosion spreading under the film, especially if chlorides are present. But it appears that bond strengths of epoxy-coated bars are slightly reduced. Most applications involved marine or water retaining structures but other applications might include situations in the vicinity of cathodically protected underground pipes. The electrically insulating coating would prevent corrosion due to stray currents in such instances.
5) Stainless steels are likely to give the greatest durability, especially in a more aggressive environment, though their cost is such that applications are likely to be limited to very sensitive types of work.

Monitoring Of Corrosion Rate In Reinforced Concrete

The susceptibility of metal to corrosion depends on its effective electrode potential in a given environment and, therefore, will vary from place to place according to the chemical makeup of the surrounding medium. In buildings where some corrosion has been detected (normally by localized spalling), some means of assessing of further problems is a distinct advantage. For example, where tests suggest that the entire structure is at serious risk, the possibility of demolition might have to be considered, whereas if the problem is localised, surface treatment of the remaining parts may suffice.

There are several techniques by which the extent of potential corrosion problems can be estimated:

Half-Cell Potential

The electrode potential of steel relative to concrete cannot be measured directly since another electrode must be introduced to measure voltage. However, by use of a second half cell, the electrode potential of metal at any place can be inferred. Common arrangements are copper in a copper sulphate solution or silver in a silver chloride solution. Such half cells are described as the reversible; the current can flow either way in them. The reinforcement must be exposed in one position and the circuit is completed by means of a damp sponge. When the steel has a high corrosion risk (as in carbonated concrete or when salt is present), it will give rise to a higher negative potential, as for the reactive metals. A typical risk assessment would be:

i. if less than -200 mV, risk is low
ii. if between -200 and -300 mV, risk is medium and more negative, as compared to -350 mV, where risk is high

If readings at any position vary, then the concrete surface should be made wet by a 0.5% detergent solution to give readings steady to within ±20 mV, over a 5 minutes period. If this state cannot be achieved, the half-cell method is probably inappropriate.

Resistivity Measurement

Resistivity Measurement can give additional information to the half-cell technique because they measure the ability of the concrete to conduct ions between the anodes and cathodes of corrosion sites. The term resistivity applies to material and is defined such that:

$$\text{Electrical Resistance of a Given Current Path} = \text{Resistivity} \frac{\text{Path Length}}{\text{Area of Conducting Material}}$$

(Longer path lengths increase resistance, while larger conducting areas decrease resistance)

It will be from the above that the units of resistivity are resistance time's length. The method of measuring resistivity involves applying an alternating current between two points on the concrete surface, the voltage between two intermediate points being measured. Alternating currents must be used to avoid effects of polarisation that would occur with a direct voltage. The resistivity of the concrete will depend upon its moisture content; the presence of chlorides, oxygen levels and oxygen is a key part of the corrosion process. The corrosion rate corresponding to a given resistivity will depend upon the half-cell potential as obtained above though an approximate guide is that resistivity less than the risk of problems.

There are various methods suggested by many workers to prevent corrosion. But, in most of the cases, a few disadvantages also appeared due to faulty choice of material. Because all the parameters are not seriously considered, the perfect solution cannot be provided. So, choosing the right material and process is very important.

To be continued in Part VI...

Technology Coordination Technology (TCT)

Effect Of Global Warming On Infrastructure Is Alarming

Part-VI



Today, global warming caused by emission of green house gases is known to everyone. **Greenhouse gases** are relatively transparent to short-wave infrared radiation (such as heat from the sun), i.e., they allow sunlight to enter the atmosphere and heat earth's surfaces. These surfaces then re-radiate the heat as long-wave infrared radiation, which **greenhouse gases** tend to absorb rather than transmit. Consequently, the long-wave infrared radiation is 'trapped' and heat accumulates in the atmosphere, causing a warming process.

In modern technology, various kinds of building materials are introduced considering cost-effective construction and durability. But, emission of increasing rate of greenhouse gases has a very close chemical reaction with all components in infrastructure. Perhaps, we ignore this effect as we just look at the temperature rising in Antarctica, which has recently been recorded at 20°C for the first time: four glaciers are melting. As a result, bio diversity will be lost.

But, if we think of the effect of greenhouse gases in building and infrastructures, we will understand the result of chemical reaction between those increasing quantity of gases and all building components.

Buildings and Acid Rain: Acid rain, also known as acid deposition, is caused by emission of sulphur dioxide (SO_2) and nitrogen oxides (NOx) from power plants, cars and factories.

Man-Made Materials: Although sunlight, heat, cold, and wind contribute to the deterioration of man-made structures and objects, acid deposition speeds up this process. Metal structures and vehicles become corroded and concrete deteriorates faster when rain is acidic.

Protective polymer coatings like acrylic, among others used for external paint, cannot withstand the acid rain. Gradually, the effect increases. Further, external putty finish and paint are also affected. So, there is a need to introduce pertinent concept to establish new products.

The affect is alarming in the building industry. Acid rain deteriorates silicone-based sealant and silicone technology. Similarly, there are many other organic and inorganic materials used in building and infrastructure, which are severely affected by this reaction. So, advanced technology should consider the effect of green house gases.

Climate Factors

The buildings are designed, based on different climate conditions. There are different climate factors that must be considered in civil operations, building construction and building design. The most significant climate factors are as follows: weather temperature, soil temperature, angle and intensity of sunlight, relative humidity, direction and wind speed, rainfall and sunlight. These factors are not constant today due to global warming. Therefore, a great challenge is to design in the recent future, considering this effect. In fact, this has already shown impacts in many places; but, the root cause is not taken into consideration.

Further, climate factors cannot be reduced in these items. Rather, barometric pressure and such are also considered as climate factors, but they don't play a big part in designing and civil operations. Perhaps, weather temperature is the most important climate factor affecting climate designing.

The intended dimensions in designing various points of a building and also the material in use are determined by the maximum and the minimum temperature of the region. Therefore, the quantity and quality for constructing a building are different, depending on the type of the region: tropical, cold and moderate. Glacial region would require taking special decisions on the choice of materials. In order to prevent energy dissipation in tropical and cold regions in summer and winter time, body insulation of the buildings must be considered whereas this issue might not be of priority in moderate regions.

Buildings, Roads, Etc. Must Be Designed For Future Climatic Conditions

Wetter winters, and sudden and heavy downpours make it more important to direct rainwater and melt water away from houses, paved areas, roads, etc. A milder climate reduces the durability of building materials and affects the indoor climate of buildings. Warmer summers introduce a greater need for cooling. Further, higher groundwater levels, higher water levels in streams and watercourses, and greater risk of storm surges along the coastline, make it pertinent to safeguard buildings against seepage and flooding.

Buildings

Buildings can be vulnerable to climate change. While in the future, there may be an increase in the risk of collapse, declining health and significant loss of value, , and as a result of more storms, snow or subsidence damage, water encroachment, deteriorating indoor climate and

reduced building lifetime; in the short term, stronger storms are the greatest challenge.

Storms will constitute a safety risk in those parts of existing buildings that do not meet the building code's safety requirements. In the longer term, more and longer-lasting heat waves could have health-related consequences, especially for the elderly and weak, in nursing homes, for example.

Adapting Buildings To Climate Change

Adaptation in some places may be with regard to limiting snow-load and storm damage, as well as controlling indoor climate in particular. With respect to strengthening existing buildings, however, autonomous adaptation will be limited if owners are not familiar with weaknesses in the bearing elements of their buildings. Adaptation will only occur in new constructions, if standards are enhanced. As for counteracting consequences of heat waves, installation of air conditioning in existing buildings could be expected, along with a demand for buildings with more efficient indoor climate control.

It is the responsibility of individual building owners to see that applicable regulations are complied with, and it is also they who will seek solutions for satisfactory indoor climate. In the short term, there will be no changes in the laws pertaining to building safety under extreme weather conditions. For countering heat waves, the new regulations regarding the energy framework in the building code represent a step towards promoting solar screening and heat-deflecting windows, which will make it easier to regulate indoor climate.

For the time being, no measures are recommended for building extensions or renovation.

In the future, there may be a need to inform owners of existing buildings of the typical weaknesses in the bearing elements, with corresponding instructions on how to remedy them. Similarly, there may be a need for instructions on new building solutions to reduce indoor temperature extremes during heat waves, especially for vulnerable buildings. Finally, there may be a need to inform construction technicians of the recommended future-oriented design parameters, for example, concerning maximum snow load and wind speed, temperatures and durations of future heat waves and the maximum precipitation intensity a building should withstand.

The Roads Of The Future

New roads must be designed in accordance with future requirements. Investigations have therefore been launched to clarify on the method to update current guidelines for planning, constructing and managing roads.

Rain The Biggest Risk Factor

For the existing roads, the risk of more rain poses the greatest challenge. Surface water must be directed away from roads to ensure their durability, avoid aquaplaning and reduced pass ability for road users. Danish road authorities are therefore, currently looking at how road drainage systems may be adapted to future climate, both with regard to new construction and when managing existing infrastructure.

Ozone layer depletion causes increased Ultraviolet radiation at the earth's surface. The materials, which are claimed as UV resistant, need to be redesigned, following the climate change.

In current design codes, the climatic loads are considered as a static load; but, the growing trend in wind velocity is also noticed. However, in the actual design, this possible trend caused by climate change will be considered. Further, another load impact related to climate is temperature load. Temperature difference in the cross-section cause stresses in the structure. As a consequence, an unknown expansion and contraction will affect the structure.

So, this is a very clear understanding of global warming impact on civil structures. Also, it is known that many researchers will definitely come up with a revised design of technology, considering rapid global warming.

To be continued in Part VII...

Technical Comment



Avijit Dutta
Deputy General Manager (Construction), Shapoorji Pallonji And Co. Pvt.Ltd.

"Thank you for choosing such an interesting and authentic subject in regard to lifespan & performance of buildings and other civil engineering structures. Though you have covered most of the environmental factors and their remedies for sustainable development, yet some other relevant issues also need to be discussed which are as follows –

1. In today's world, most buildings and structures are constructed with high grade concrete during production of which heat is generated (which is called heat of hydration of cement). This process also dissipates heat to the atmosphere. To address this issue, low heat cement for concreting can be used which reduces heat of hydration significantly.
2. Water is a precious natural resource which is abundantly used in construction industry starting from steel & concrete production to curing of structures. But, we can reduce the use of water by using concrete made of low water cement mix & higher grade of chemical admixtures. Similarly, instead of using water, we can use curing compounds for curing of structures.
3. Another important aspect is how to reduce use of wooden materials in various stages of construction. Nowadays, instead of wooden formworks, lot of other alternative materials (viz. steel, aluminium & PVC etc.) are available which are environment-friendly and can have more number of uses. In case of doors & windows also, such substitute materials are being used in place of wooden products.
4. To avoid water and soil pollution, during pile foundation work, washing of bored piles can be done with soluble polymer compounds instead of bentonite which is not an environment-friendly product.
5. To reduce the adverse impact of heat on buildings, lot of heat reflective roof tiles & external paints are available in market which after application can reduce the internal temperature significantly. Thus it helps in reduction of power consumption and also enhances the life of the building.

Many such alternative and environment-friendly construction materials & methods are nowadays available which can contribute significantly in reduction of adverse effects of environmental factors on buildings & structures. But if they are not made affordable, then we shall remain deprived of the benefits."

Technology Coordination Technology

PART-XV

The force of static friction is responsible for keeping the feet in place. If a little force is applied to push an object horizontally, static friction is an equal and opposite force that keeps the object at rest. If a greater force is applied the static friction is increased to match the force. The object moves if the static friction force is maximum. The static friction coefficient (μ) between two solid surfaces is defined as the ratio of the tangential force (F) required to produce sliding divided by the normal force between the surfaces (N)μ = F /N For a horizontal surface the horizontal force (F) to move a solid resting on a flat surface F= μ x solid mass x g.

If a body rests on an incline plane the body is prevented from sliding down because of the frictional resistance. If the angle of the plane is increased there will be an angle at which the body begins to slide down the plane. This is the angle of repose and the tangent of this angle is the same as the coefficient of friction.

The above theory is closely related with our daily life ……

Our placed feet grip the floor and push backward, that causes the floor to push forward on your foot. This is termed «grippy» type of friction, where the surfaces are prevented from slipping across each other, a static frictional force.

This is the root cause of fatal accident that happens unfortunately on finished marble or granite floor. You've probably experienced having information that caused you observant to avoid accidents on marble floor that mostly happens in toilets. Slips generally take place either when the heel of the 'front' foot lands or as the sole of the 'rear' foot pushes off. Usually people fall almost exactly over the same location.

The accident happens on glossy, polished and shiny floor which is slippery. We use granite tiles in common places like public stairs, etc. Our reflex action makes us conscious while walking on this surface. You may feel even you amble in such places. That helps us in choosing the right flooring material.

Today's most popular flooring materials are marble, ceramic tiles, Porcelain tiles of different types of attractive finishes and wooden floors. etc. as floors are a significant design refresher, as well as an investment that can increase the value of house.

> "While choosing flooring material we should consider the frictional property of the product. We should avoid slippery flooring for toilets and common places. There are anti-skid tiles which should be preferred for those areas."

Wooden floors can develop scrapes, scratches and dents over time and incur moisture damage. However most of the expensive shining flooring material is low-absorbent and non-absorbent because of the less porosities. That is closely related with the foot fall effect. The floor surface which is none or less absorbent by property is slippery and we know that coefficient is a measurement of the relative ability of various surfaces to resist the sliding or slipping of the selected material. Occupational Safety & Health Administration (OSHA) currently recommends that the static coefficient of friction should be at least 0.5 for all walkway surfaces under both wet and dry conditions. ASTM C1028 gives, through the use of a force gauge (horizontal dynamometer) pull meter method, the static friction coefficient of the surface.

- Equal to or greater than .60 — excellent friction.
- Equal to or greater than .50 — adequate.
- Equal to or less than .40 — Caution necessary.

While choosing flooring material we should consider the frictional property of the product. There are various types of flooring materials are available in market. We should avoid slippery flooring for toilets and common places. There are anti-skid tiles which should be preferred for those areas. Manufacturers and sellers should suggest the right material for particular areas.

According to a report by World Health Organization falls are the second leading cause of accidental or unintentional injury deaths worldwide.

- Each year an estimated 646 000 individuals die from falls globally of which over 80% are in low- and middle-income countries.
- Adults older than 65 years of age suffer the greatest number of fatal falls.

- 37.3 million falls that are severe enough to require medical attention occur each year.

The above statistics shows the relevance of anti –skid floor.

Earlier we had no such technology to make a mirror finish floor. The marbles which was used in past, the walking surface was not polished. But, as the technology is advanced to meet the requirement of users, the surface technology is modified. But, today the advanced technology is focusing on the consciousness to choose the right material for safety.

The following flooring can be suggested for different locations in house.

1. Marble Flooring- This is good if not highly polished. Suitable for living room.



2. Vitrified Tiles- vitrified tiles are available in glossy, matte and anti-skid finishes.



3. Terrazzo Flooring- Good for home.



4. Quartz Flooring- Suitable for kitchen.



5. Laminate Flooring-Suitable for bedroom, inexpensive.



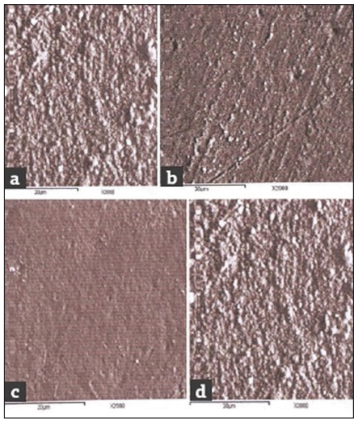
6. Vinyl Tiles- Suitable for toilets.



7. IPS flooring stands for Indian patent stone flooring, it is a basic type of flooring which provides good wearing properties. It is generally used for all types of floors and mix of concrete used for IPS flooring specification is 1:1.5:3 (cement, sand and stone aggregates). This is inexpensive and adequate anti-skid property is achieved with proper maintenance. This can be grey or colored.



8. IPS Flooring with Nano Composite SYLOCON® which contains millions of Nano tubes that makes the surface antiskid, crack free and receives any colour.



9. Wooden Flooring- Expensive. Good for interior and dry zone.



10. Vacuum Dewatered flooring- Good for industrial heavy duty flooring.



There are immense scope to research on this subject to make the floor safe, attractive, ease of maintenance and durable. Safety is first priority.

To be continued……..

For further information,
visit: www.aquacrete.co.in

Technology Coordination Technology (TCT)

PART-II

The interaction between every technical stream is comprehensible from the flow chart (Fig. 1). In the Part I of this article (published in October'19 Issue), we focussed on polymer science, where we mentioned names of different polymers, co-polymers, etc. To ensure a better understanding of the present article (Part II), we will refer Part I here.

Applied Polymer Chemistry Has A Major Role And Close Relation With Civil Engineering

The different polymers at a glance:

Cell of polymer chemistry–

1) Co-polymers
   - Styrene butadiene - Where the coating needs a covering of screed on top and expansion-contraction of structure is not an issue.
   - Styrene Acrylic - To some extent can resist weather action.
   - Acrylic - Can withstand weather action for maximum 2 to 3 years.
2) Polyurethane - Maximum 4-5 years in weather action. Best as sealant.
3) Silicone - Cannot withstand weather action due to acidity of rainwater.
4) Ceramic - Good as a basic material for additive in water proofing and concrete strengthening additive and effective in heat reflecting paint.
5) Bitumen emulsion - After a period oxidation degrades bitumen.
6) Mastic - Useful in water proofing under any cover.
7) Cyano acrylate - No evidence is found that this is failed to withstand water effect for long time. But good to achieve high bond strength between two substrates in presence of moisture even at room temperature.

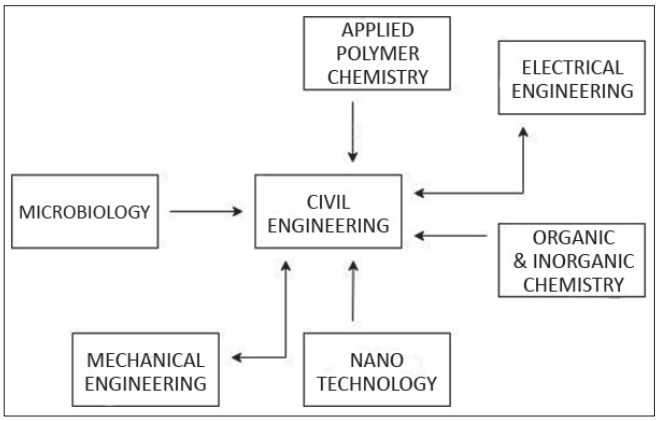


Fig. 1: General Interaction in a Technical Stream

8) Poly Methyl acrylate - Used as high strength film but not good to withstand weather action, used as an active ingredient to produce new generation tailor made plasticizer for concrete.
9) Poly methyl methacrylate - Same
10) Poly propylene - Good for fibre.
11) Poly vinyl alcohol - Not good for construction chemical.
12) Poly vinyl acetate - Specific uses.
13) Geotextiles
14) Epoxy system (How engineers can choose a right epoxy system for their actual requirement)
15) Polycarbonate
16) Concrete plasticizers
17) Concrete set retarders
18) Concrete water repellent
19) Concrete high strength achieving compound
20) Concrete quick setting compound
21) Stain removing agent
22) Stain protective coating
23) Construction adhesives
24) Nano composites - The best solution in construction if the composite is formulated in right way.
25) Heat resistant coating & Insulation technology
26) Floor cleaning agent
27) Timber protective coating to prevent decaying.

28) Efflorescence and shrinkage crack preventive plaster and concrete additives
29) Curing free plaster and concrete additives.
30) Fire resistance coating
31) Waterproofing membrane
32) Tiles adhesive
33) Ethylene propylene dyne monomer - The liquid or solid form of this polymer is the best to protect weather action and structural movement. The liquid can access all the tiny holes on the surface and creates a seamless membrane with good adhesion to any substrate.

Styrene Butadiene Copolymer (SBC)
Advantages- SBC is one of the cheaper synthetic rubbers. It offers excellent abrasion resistance, crack endurance and generally ages well, along with delivering good compression set resistance and water resistance.

Disadvantages- The major disadvantage of SBC includes its poor resistance to sunlight and ozone, ineffectiveness in outdoor applications, and inability to act in conditions containing steam and oil; due to this, it swells and becomes weakened over time.

Microbial Attack- A Noocardia species has been revealed to be capable of degrading Butadiene through stereo-specific epoxidization of the C=C bond and subsequent oxidation through pyruvate to acetate.

Poly Styrene Butadiene Styrene (SBS)
Advantages- SBS is a hard synthetic rubber used for durability.

Disadvantages- The inherent disadvantage of SBS is its flammability, which can be overcome by addition of supplementary fire retardants (such as aluminium hydroxide, magnesium hydroxide, colemanite, antimony oxide, etc.) to the polymer matrix. However, high loadings (>30 wt.%) of the two fillers are required to impair the flammability of the matrix to an enough level, which may deleteriously affect the elastic properties of matrix itself.

Microbial Effect- The biocompatibility of ESBS membrane was evaluated with the cell culture of fibroblasts on the membrane. It revealed that the cells not only remained viable but also proliferated on the surface of the various ESBS membranes, following which the population doubling time for fibroblast culture decreased.

The microorganisms degrading the synthetic polymers PVC, polyurethane, nylon, and acrylics and their mode of action, are mentioned in Table 1.

The reason of such a study is coordination between civil engineering, polymer chemistry and microbiology. The right material can be chosen for a specific purpose. Next we will study other polymers and material properties.

Table 1: Brief Summary of Synthetic Polymers

Synthetic Polymer(s)	Degrading Microorganisms	Main Mode of Action	Reference(s)
PVC	Fungi (e.g. Aureobasidiumpullulans) and bacteria (e.g. Pseudomonas aeruginosa)	Increased loss of plasticizers due to microbial degradation	Webb, J. S., Nixon, M., Eastwood, I. M., Greenhalgh, M., Robson, G. D., & Handley, P. S. (2000). Fungal colonization and biodeterioration of plasticized polyvinyl chloride. Appl. Environ. Microbiol., 66(8), 3194-3200.
Polyurethane[a]	Fungi (e.g. Chaetomiumglobosum) and bacteria (e.g. Bacillus subtilis)	Enzymatic activity	Russell, J. R., Huang, J., Anand, P., Kucera, K., Sandoval, A. G., Dantzler, K. W., ... & Marks, D. H. (2011). Biodegradation of polyester polyurethane by endophytic fungi. Appl. Environ. Microbiol., 77(17), 6076-6084. Kerr, N., & Batcheller, J. (1993). Degradation of polyurethanes in 20th-century museum textiles. Saving the Trentieth Century: The Conservation of Modern Materials.(ed Grattan, DW). Ottawa: Canadian Conservation Institute.
Nylon	Wood-degrading fungi (e.g. Bjerkanderaadusta) and bacteria (e.g. Bacillus pallidus)	Physical disruption and enzymatic degradation	Friedrich, J., Zalar, P., Mohorcic, M., Klun, U., & Kržan, A. (2007). Ability of fungi to degrade synthetic polymer nylon-6. Chemosphere, 67(10), 2089-2095. Szostak-Kotowa, J. (2004). Biodeterioration of textiles. Int. Biodeterior. Biodegrad, 53, 165-170.
Acrylics	Melanin-producing fungi	Likely physical disruption	Cappitelli, F., Principi, P., Pedrazzani, R., Toniolo, L., & Sorlini, C. (2007). Bacterial and fungal deterioration of the Milan Cathedral marble treated with protective synthetic resins. Science of the Total Environment, 385(1-3), 172-181. Kigawa, R. (2005). Evaluation of mould resistance of various synthetic resins used in conservation of historic sites [Title and text in Japanese]. Science for conservation= Hozon kagaku, (44), 149-156. Shirakawa, M. A., Gaylarde, C. C., Gaylarde, P. M., John, V., & Gambale, W. (2002). Fungal colonization and succession on newly painted buildings and the effect of biocide. FEMS microbiology ecology, 39(2), 165-173.

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