DURABLE, HIGH PERFORMANCE AND SUSTAINABLE CONCRETE

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ABSTRACT. Concrete is a widely used construction material. There has been phenomenal growth in research and development activities to develop durable, high performance and sustainable concrete. Concrete is a composite material with each component having different thermal characteristics. However, high standards of durability are not being achieved in practice. We have witnessed a large number of existing structures which after a few years of construction have started showing signs of distress. This remains a big challenge for engineers and technicians to ensure proper quality control of the raw materials. This paper suggests a few measures to make the concrete durable, thereby, to insure improvement of the service life of reinforced concrete structures. This paper also gives an over view of the factors to be considered for making concrete durable, high performance and sustainable from the selection of the suitable materials, mix design process, mixing, transporting, placing, compaction and efficient curing. Emphasis needs to be given during the process of concreting to obtain desired fresh and hardened properties of concrete by way of conducting proper checks and trials.

Keywords: Sustainability, Durability, Degradation, Carbon dioxide emissions, Concrete

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INTRODUCTION

The world's yearly cement production of over 2 Billion tons accounts for about 7% of the global loading of the Carbon Dioxide into the atmosphere. Portland cement, the principal hydraulic cement in use today, is not only one of the most energy intensive materials of construction but also produces a large amount of greenhouse gases.

Ordinary cement concrete typically contains about 12% cement and 80 % aggregates; this means that " globally " for making it, we are consuming sand, water and rock at the rate of 10 to 11 billion tons every year. The concrete industry also uses large amount of fresh water, the mixing water requirement alone is approximately 1 billion tons every year. In addition to this we need fresh water for making ready mixed concrete and for curing concrete. In addition to cement, fine and coarse aggregates, water, mineral admixture and chemical admixtures are incorporated into concrete mixtures. They too represent huge inputs of energy and materials into the final product. Batching, mixing, transport, placement, consolidation and finishing of concrete are energy intensive. Fossil fuels are the primary source of energy today, and the public is seriously debating the environment costs associated with the use of fossil fuel.

Admixtures shall comply with IS 9103. Such materials should be considered in relation to the likely standards of supervision and workmanship to the work being specified. Admixtures should not impair durability of concrete nor combine with the constituent to form harmful compounds nor increase the risk of corrosion of reinforcement. The chloride content of admixtures shall be independently tested for each batch before acceptance. If two or more admixtures are used simultaneously in the same concrete mix, they should be obtained to assess their interaction and to ensure their compatibility.

DURABLITY OF CONCRETE

A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure condition during service. The materials and mix proportions specified and used should be such as to maintain its integrity and should be applicable to protect embedded rebar from corrosion. By making concrete durable, thereby increasing the service life of products, is solution for providing the earth's natural resources. Engineered concrete requires selection of good quality ingredients, right mixture proportioning and continuous monitoring, adequate compaction, proper curing, deployment of trained and skilled manpower and rigorous supervision. The desired properties like workability, compressive strength and slump loss of concrete with and without use of the admixtures shall be established during the trial mixes before use of admixtures.

Durability depends on pore connectivity. Dimension stability depends on efficient packing of granular materials and water content. Desired specifications, characteristics and processing is required making the desired strength and durability. The durability of concrete depends on the cover provided to the embedded reinforcement, the type, the quality and proportion of the constituent material of cement, specially the cement content, and water - binder ratio, the workmanship, particularly compaction of concrete, the type, shape and size of the member. The constituent materials of concrete have to be free from injurious elements. The grade of the concrete has to be of required strength. Water/Cement ratio has to be minimum possible. Compaction of concrete and curing has to be of utmost necessity. Factors related to the design of the section such as detailing of reinforcement, ductile and confinement reinforcement at the junction of column and beam are to be taken into consideration.

IS 456-2000 code lists the definitions of different environmental exposures that may be witnessed. The most influencing factor for durability is environment. The major environmental parameters that influence the different deterioration mechanism in reinforced concrete are temperature, rainfall, concentration of chloride and carbon dioxide. There is a risk of corrosion of reinforcement due to ingress of chloride from aggressive environment. Higher grade of concrete with low permeability and higher reinforcement cover are needed to sustain durability. With ever increasing accumulation of knowledge and concrete technology, durability of concrete, besides strength is found essential for the sustainable period and the intended service life.

HIGH-PERFORMANCE CONCRETE

For upcoming infrastructure, conventional concrete is not sufficient. High Performance Concrete (HPC) meets special performance requirements that cannot be always achieved routinely by using only conventional materials and normal mixing, placing and curing practices. Advent of super plasticizers and silica fumes are among the foremost developments in concrete technology in the last few decades, which led to high strength and high-performance concrete. Super plasticizers allowed the workability of concrete to increase greatly or to lower the water /cement ratio, resulting in lower capillary porosity and high compressive strength. Addition of silica fumes aided high strength by pozzolanic reaction and denser packing of solid particles by fine powder effect. This resulted in higher compressive strength and enhanced durability. Where strength is the basic consideration, e.g. in tall buildings, high strength concrete IRC from grade M65 to M100 are used. High performance concrete is used when durability is added consideration, e.g. in bridges, IRC concrete bridge code IRC: 112-2011 defines "High performance concrete" from grade M30 to M90. The requirements may involve enhancement of strength, durability, longer service life in severe environments, ductility, toughness, volume stability etc. Another requirement could be very high workability without segregation; this is the main characteristic of Self-Compacting Concrete (SCC). However, HPC is normally used for high strength in structure like tall buildings while for bridges we don't need strength greater than 40MPa, except for long span bridges.

Other benefits of HPC include blast resistance properties and very good resistance to carbonation due to low permeability properties; it has high resistance to both scaling and physical breakup due to freezing and thawing, resistance to chemical attack and low w-C material ratio. HPC particularly that formulated with silica fume has high resistivity which would suppress the development of corrosion.

Basic Considerations

The basic considerations of high performance are the relationships, linking water-cement ratio to strength and durability of concrete. Optimum particle packing is necessary for dense microstructures. Fiber reinforcements impart ductility and toughness while low water / cement ratio ensures low permeability. The requirements of high strength and low permeability (high durability) are achieved by

- Low water-cement ratio for high strength.
- Low water-cement ratio and pore blocking by fine powder for low permeability.
- Part replacement of cement by silica fumes, fly ash or slag to reduce cement content.
- Increased fine powder and low water content requiring use of super plasticizers.

Use of fiber reinforcement, to improve ductility, crack resistance and roughness becomes necessary.

Covered concrete provides long term protection to steel and results in the longer intended design life of the structure.

Strength of aggregate itself and the bond between aggregate and paste becomes an important factor often overlooked. Crushed stone aggregates induce high strength in concrete than gravel aggregate using same sized aggregates and same cementing material. Coarse aggregates used should be clean, free from detrimental coating of dust and clay. In high rise buildings and bridges, for example, the stiffness of structure is of interest to the structural engineer; therefore optimum elastic modulus in concrete can be achieved by properties of aggregates and also by the mixture proportions. It should also meet workability and cohesive requirements. Fine aggregates (sand) from zone 2 with fineness modulus of about 3 is found to be satisfactory for producing good workability and high strength. It should be noted that both coarse and fine aggregates should be well graded.

Curing of HPC is another important stage where adequate moisture and favorable temperatures need to be provided. Normally, fog curing followed by 7 days of wet curing has proven to be very effective. HPC to show that the

Ingredients of High-Performance Concrete

For HPC, engineered materials are required for specifically designed concrete that should meet a combination of performance requirements including high strength, high modulus of elasticity, high abrasive resistance, high durability, low permeability, low diffusion coefficient, resistance to chemical attack, high resistance to frost and de-icing scaling damage, toughness and impact resistance, volume stability, ease of placement, compaction without segregation, etc. For this we need to carefully select high quality ingredients and optimize mixture design, which are batched, mixed, placed, compacted and cured to the highest industrial standards.

Cement, fine aggregates, coarse aggregates, water, mineral admixtures, silica fume, fly ash, granulated slag, chemical admixtures, super plasticizers, viscosity modifying agents for very high workability of concrete (self-compacting concrete) are used accordingly to achieve desired qualities. Fiber reinforcement for ductility, toughness and abrasion resistance is used.

Some Application of High-Performance Concrete Structures

Figure 1 J.J.Flyover (Mumbai)

Figure 2. Bandra–Worli Sea link (Mumbai)

SELF-COMPACTING CONCRETE (SCC)

A concrete that is able to flow and fill every part and corner of formwork, even in the presence of dense reinforcement, purely by means of its own weight and without the need of any vibration or other type of compaction. There should be no segregation during pouring of the concrete and its flow.

Where is SCC Required?

- Where reinforcement is very congested,
- Where access to allow vibration is not available, complicated geometry of the form work,
- Where pouring is possible only from a single point,
- Where speedy placement is required.
- Other advantages are- no noise, no finish required.

The Basic Approach

- Limit the maximum size and amount of coarse aggregate so that the flow is not restricted,
- High powder content acts as 'lubricant to coarse aggregate,
- Adequate paste volume to provide fluidity and cohesion to concrete,
- Water/binder ratio for strength requirement, sand to make up the balance of the total volume, and special additives for flow ability and cohesiveness are required.
- Broad Guidelines (EFNARC 2005)

Coarse aggregate content 750-1000 per cub meter of concrete, total powder content 380 to 600 kg per cub meter of concrete, water/ powder ratio by solid volume 0.85 to 1.1, water content 150to 210 liters, paste volume 300 to 380 liters per cub meter, water/cement ratio selected for strength and durability requirements 0.30, sand content required to balance the remaining volume, is usually 48 to 55 % of total aggregate by weight.

ADVANTAGES OF CONCRETE TERNARY CEMENT BLENDS

Cement is a blended mix; mineral and chemical mixtures are additionally added. Engineered concrete consists of cement, fine aggregates, coarse aggregates, water, mineral admixtures and chemical admixtures. Now pozzolanic cement is already available containing fly ash content. These pozzolanic materials are cementious, provide durability and higher strength by reducing water-cement ratio. Some other commonly used admixtures are hydration control admixtures, corrosion inhibitors, shrinkage reducers, alkali-silica reaction inhibitors, and more.

- Ternary blends of Ordinary Portland Cement (OPC), silica fume, fly ash or slag comprise efficient binder system.
- Reduction in content of OPC, thereby reducing heat of hydration.
- Adequate early age strength.
- Improvement in tensile strength as proportion of compressive strength, reducing cracking.
- Improved impermeability.
- Significant improvement in durability.

Ternary blends of OPC, silica fume and fly ash (or slag) comprise efficient binder system, reduction in content of OPC, thereby reducing heat hydration, adequate early-age strength, strengthening of aggregate-matrix inter-facial zone, improvement in tensile strength as proportion of compressive strength, reducing cracking, improved impermeability (lower Rapid Chloride Permeability Test (RCPT) value) & significant improvement in durability.

SUSTAINABLE CONCRETE

To meet performance requirements of the owner, designer, contractor & producers and minimize energy and carbon dioxide footprint, minimize portable water use, minimize construction waste. Environmental impact is reduced through resource productivity by considering materials and energy for concrete making and by improving the durability and strength of concrete products. Cement conservation (Minimize use of O.P.C).Use of blended cement containing cementations or pozzolanic by product, such as ground granulated blast furnace slag and fly ash. Adequate use of pozzolanic and cementations by-products that can be used as cement substitute will eliminate the need for production of more Portland cement clinker.

Aggregate Conservation

Recycle and reuse of construction and demolition waste, thereby improving the resource productivity by using coarse aggregate derived from construction and demolition waste. Dredged sand and mining waste could be processed for use as fine aggregate.

Water Conservation

Fresh clean water is getting more and scarcer every day. Due to increase in population and increase in demand of water, there is deep concern for water shortage in the country. Due to growing agricultural, urban and industrial needs, water table is depleting. Therefore, treating drainage water, rain harvesting and recycling and re use of water should be made mandatory in making concrete.

Process of Change

Reducing, reusing and recycle of construction material, reengineering the materials should be used and make use of recycled aggregates, other cementations materials rather than OPC alone (pozzolanic, fly ash, silica fume etc). Concrete can be durable and environmentally friendly by using construction and demolition waste and control the degree of damage by conserving the consumption of natural resources. Also, by improved long term durability there will be reduced potential for cracking and reduced cement clinker usage. Also use of recycled by product would minimize use of new materials used for production of concrete and will provide durability hereby long service life span of structure, lower carbon emission reducing green house gasses, low embodied energy use. Thus, sustainable concrete can be made by use of recycled aggregates, cement replaced with cementations materials, recycle of steel reinforcement use of natural fiber in concrete to improve the durability criteria and to improve the service life.

Mineral and Mixtures

- Fly ash shall conform to Grade I of IS 3812 used as part replacement of OPC provides uniform blending with cement.
- Silica fume shall conform to a standard approved by the deciding authority shall be used as part replacement of cement (Silica fume is a byproduct of the manufacture of silicon, ferrosilicon)
- Granulated blast furnace slag (GGBS) improves the proportions of concrete, thereby long strength development, the resistance to chemical attack, and increased durability.

The impact of supplementary cementations materials shall improve the long-term durability, reduce the cracks and reduce the use of cement clinker. The greatest challenge faced by the concrete industry, world over is to achieve durable and sustainable concrete construction; designed structures for better service life would also maximize the use of natural resources. Third party quality control for ready mix concrete is evolved and this would go a long way in improving the quality of concrete portion in the country. Cement consumption through mechanization and use of mineral and chemical admixture by use of base material like fly ash, GGBS, silica fume etc. and use of mineral and chemical admixtures.

Comprehensive quality control is required for pre-casted and on-site preparation to guarantee consistent production and placement. Proper supervision of all ingredients from the very start by pouring of aggregates till curing has to be done. Proper production control for projects is necessary, mandatory testing, routine sampling with supervision in all aspects of quality control and quality testing is necessary. Proper cover and protection of rebar should also be ensured.

CONCLUSIONS

Long term durability tailored to its performance, shall become a basic element in the development of making durable concrete by use of high-volume fly ash concrete system and making concrete mixtures that will shrink less, crack less and would be far more durable and resource efficient than conventional ordinary Portland cement concrete. By making the concrete durable we shall have the ability to design and build long and tall structures for more service life. Thereby, concrete industries shall become resource productive by many folds. By substituting the recycled material for natural material and conserving the use of water, it would be possible to make the concrete durable and sustainable.

Preserving natural resources by reducing, reusing and recycling the construction waste, will not only result in improved service life of the structures but also reduce the embedded carbon imprint and contribute towards sustainable development and environment protection.

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