MODULE-5

READY MIX CONCRETE

RMC concrete - manufacture, transporting, placing, precautions, Methods of concreting- Pumping, under water concreting, shotcrete, High volume fly ash concrete concept, properties, typical mixSelf compacting concrete concept, materials, tests, properties, application and Typical mix

RMC industry is about 12 years old in India, while it was introduced in other countries much earlier

- PATENTED IN GERMANY

• 1913- FIRST DELIVERY OF RMC (BALTIMORE)
• 1926- BIRTH OF TRANSIT MIXER
• 1931- ERECTION OF FIRST COMMERCIAL PLANT IN LONDON
• 1950-1974 REMARKABLE GROWTH OF RMC – 31 MILLION CUBIC
METRE OF CONCRETE PER YEAR

<u>Factors Delaying Entry of RMC in India:</u>

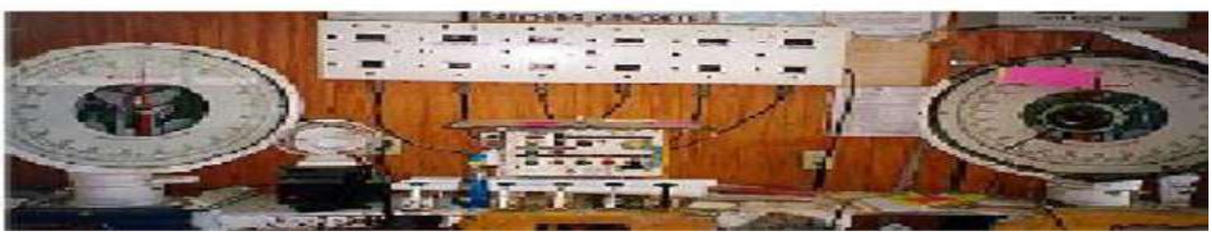
• RMC is highly mechanized activity and entails initial high cost. Especially dueto import of basic equipment and machinery.Smaller size of construction in unorganized sector highly competitive and cost conscious.Availability of abundant cheap labour for making and transporting concrete.Differential taxation between RMC and SMC. Especially before 1997 whenexcise duty @16% also existed.

Factors that Prompted Introduction of RMC

• Increasing stakes in the reliability and durability of construction of emerging users.

- Decreasing share of construction cost in overall cost of the facility.
- Increasing awareness on environmental factors and convenience.
- Globalization – adoption of best practices across the globe.
- Bigger size of projects and Time is recognised as a cost factor.

A TYPICAL 'RMC READYMIX' PLANT



RMC- MAJOR ADVANTAGES

• Assured And Uniform Quality Of Concrete
• Speedier Construction Through Mechanised Operations
• Need For Ordering And Storing Cement, Aggregates And Sand On Site Totally Eliminated
• Lower Labour And Supervisory Costs

• Minimisation of cement wastage through bulk handling and storage
• Cleaner working environment
• -Eco-friendly product

COMMON QUALITY PROBLEMS: Quality problems of various natures which

May get reported arelisted below:

• Delay in setting of concrete beyond 24 hours.

• Development of cracks when the concrete is still in fresh state.

• Development of cracks in hardened concrete.

• Non-compliance of concrete cube strength (cast at site) to specifications at 7-days.

• Non-compliance of concrete cube strength (cast at site) to specifications at 28-days.

• Concrete supplied to site either has more slump than specified or has becomestiff making it difficult to pump. Reasons for above problems to occur at construction site are many. It is necessary to understand the behaviour of each and every constituent of concrete and construction techniques adopted at site before arriving at any conclusion regarding quality problems of RMC.

In many cases, information regarding Concrete Mix Design adopted for the type of material available in the plant may not be available. Properties of the constituents may not be available due to lack of testing facilities at RMC plant 1. Delay in setting of concrete beyond 24 hours:

Delay in setting of concrete is mainly due to excess dosage of set retarding admixture used to retain pumpable slump for longer durations. These admixtures are used to prolong the plasticity of concrete. Useful to counter the effects of high temperature, eliminate cold joints, and reduce cracking associated with form deflections. Basically, retarding admixtures increase dormant stage in the C3S hydration process. Too large a dose of admixture than specified by the manufacturer will cause the hydration reaction never to proceed resulting in cement that will never set.

Remedies:

1. It is important to carryout extensive trials while using set retarding admixture to arrive at optimum dosage without delaying setting of concrete than required. This also establishes the compatibility between cement and admixture. It is important to note that when a particular brand of cement is found to be compatible with a particular admixture, results may not be reproducible when cement is from a factory at a different location even though brand of cement is same. It is necessary to have a good quality control practices as properties of constituent materials vary to a large extent.

2. Development of cracks when the concrete is still in fresh state:

Cracks which appear when the concrete is still in fresh state are called plastic shrinkage cracks. These are caused by rapidly evaporating surface moisture. While some evaporation occurs all the time, its rate is increased by high ambient air temperature, elevated fresh concrete temperature, low humidity and strong winds. All four factors are in full force on warm summer days. Evaporation may be so strong; it actually pulls moisture from the concrete. Cracks are also caused by plastic settlement. Horizontal reinforcing bars may put restraint to overall settlement of concrete. Due to this thin plastic settlement cracks can occur. Vertical cracks form along line of the bars, penetrating from surface to bars. Remedies: It is essential to keep the concrete surface moist always to prevent cracks being developed when the concrete is still in fresh state. Adoption of good curing techniques that stops moisture loss from surface as soon as after placing of concrete. Use of curing compounds can be a good solution wherever it is not possible to monitor effective curing of concrete.

3. Development of cracks in hardened concrete:

Early-age thermal cracking is caused by restraint to contraction on cooling from a temperature peak, which is associated with the release of the heat of hydration of the binders. Early-age thermal cracking occurs within few days in thin sections, but it may take several weeks to develop in massive sections. Because of fast track constructions taking place to meet demands of infrastructure development, the trend towards large continuous pours of concrete with the requirements of high early strength and shorter striking times and problems of heat of hydration are mainly responsible for early-age cracking in hardened concrete. This type of cracks occurs when the restrained thermal contraction strain exceeds tensile strain capacity of concrete. The concrete temperature rise depends on number factors such as cement and addition type and content, type of aggregate, as well as ambient temperature, formwork used and section thickness.

Restraint is a function of the construction sequence and the constraint of neighbouring elements. Non-compliance of concrete cube strength (cast at site) to specifications at 7-days: Concrete cubes are cast both at plant and at site to determine compressive strength of concrete at various ages viz. at 7-day and 28 day. Even though specifications do not exist for 7-day strength in IS 456-2000, concrete cubes are tested at 7-day to check progressive development of strength. Normally expected strength at 7-days is about 2/3 of the 28-day compressive strength for a particular grade of concrete. Getting 80%-90% of 28-day compressive strength can easily be achieved when 53- Grade OPC is used.

However with addition of fly ash as a partial replacement to cement, strength at 7-day may not reach a value of 2/3 of the compressive strength at 28-days. In such cases, concrete cubes are certain to reach the required value at 28-days provided mix design is in order and standard procedure of cube ,curing and testing are followed. Non-compliance of concrete cube strength (cast at site) to specifications at 28-days When concrete cubes cast at site do not comply with specifications of 28-day compressive strength, then it becomes necessary to resort to non-destructive testing methods.

Of all the non-destructive testing methods determination of in-situ strength of concrete using concrete core extraction is most relied upon method. Reasons for failure of concrete cubes at 28-day can be many. Concrete supplied to site either has more slump than specified or has become stiff making it difficult to pump: Doubts will always be raised if the concrete supplied at site has more slump than specified. Addition of water during transit can be suspected which is bound to affect the quality of concrete. On the other hand it could be due to defects in carrying out trial mixes to assess the slump retaining characteristics of concrete using a particular admixture. Concrete loosing workability making it difficult to pump is another area of concern. In such cases, water added to make concrete pumpable which again affects quality of concrete. Re-dosing of admixture, if adopted, has to be done under technical supervision following recommendation of manufacturer of admixture. Otherwise it may lead to delayed setting of concrete SAMPLING AND TESTING OF READY-MIXED CONCRETE (As per IS 4926-2003):

For the assessment of compliance of ready-mixed concrete, the point and the time of sampling shall be at the discharge from the producer‟s delivery vehicle or from the mixer to the site or when delivered into the purchaser‟s vehicle.

Time in Transport:

The general requirement is that concrete shall be discharged from the truck mixer within 2 hours of the time of loading. However, longer period may be permitted if retarding admixtures are used or in cool humid weather or when chilled concrete is produced.

Workability:

Workability is measured in terms of slump of concrete using the standard procedure laid down in IS 1199: 1959- Methods of sampling and analysis of concrete.

Acceptance criteria for workability:

The workability shall be within the following limit on the specified value as appropriate: Slump: ±25 mm or ±1/3 of the specified value whichever is less. Sampling of concrete for assessment of compliance to strength: Unless otherwise agreed between the parties involved, the minimum testing frequency to be applied by the producer in the absence of a recognized ready-mixed concrete industry method of production control, should be one sample for every 50 m3 production or every 50 batches, whichever is the greater frequency.

Three test specimens shall be made up for each sample for testing at 28 days. The purchaser shall inform the producer if his requirements for sampling and testing are higher than one sample every 50 m3 or 50 batches, whichever is the greater frequency Acceptance criteria as per IS 456-2000: The test results of the sample shall be average of the strength of the three specimens. The individual variation should not be more than ±15% of the average.

Module 4:

SELF COMPACTING CONCRETE

Normal Concrete

Traditionally Concrete is made by mixing:

• Cement
• Water
• Coarse and fine aggregates

The four main properties of concrete are:

• Workability
• Cohesiveness
• Strength
• Durability

Workability means how easy it is to:

• Place
• Handle
• Compact and
• Finish a concrete mix
• Never try to make a mixture more workable by just adding more water becausethis lowers the strength and durability of concrete. Compressive Strength is governed by Abram‟s law
• Proper compaction results in concrete with an increased density which is stronger and more durable.So,
• By adding more water
• In fresh state- leads to segregation & bleeding
• In hardened state- leads to durability problems

So, what is Normal Concrete?

• Cement: 300-450Kg /m3

• Max. W/C ratio: 0.55

• Grade of Concrete: M20 - M40

• Permits the use of : Mineral Admixtures (Fly Ash, Silica Fume, GGBS, Rice Husk Ash, Metakaoline)Chemical Admixtures

Problems persist……

• Lack of adequate compaction in normal concrete

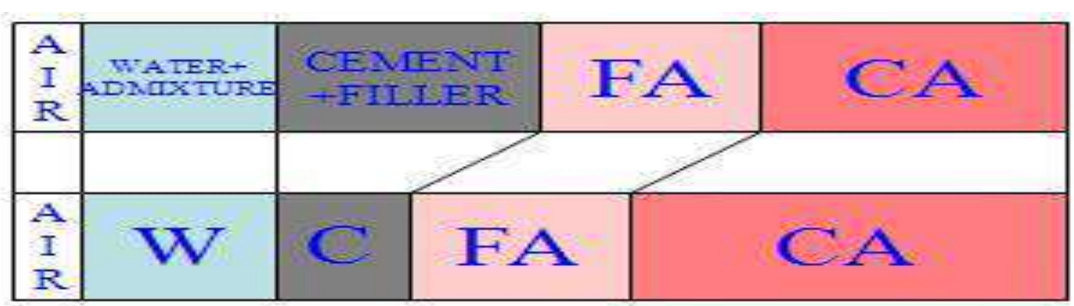
• Compaction requires the use of heavy, noisy, expensive, energy-consuming vibrators – sometimes not available

• More advanced complex RC design - high density of reinforcing bars, complex shapes - shortage of skilled labour for supervisionThere is a quest amongst concrete engineers for a still higher strength/ higher performance/ higher ductility concrete

• **Self-Compacting Concrete (SCC)**

Defined by researchers as: “concrete that is able to flow and consolidate under its own weight, completely fill the formwork of any shape, even in the presence of dense reinforcement, while maintaining homogeneity and without the need for any additional compaction.

MATERIALS SELF-COMPACTING CONCRETE

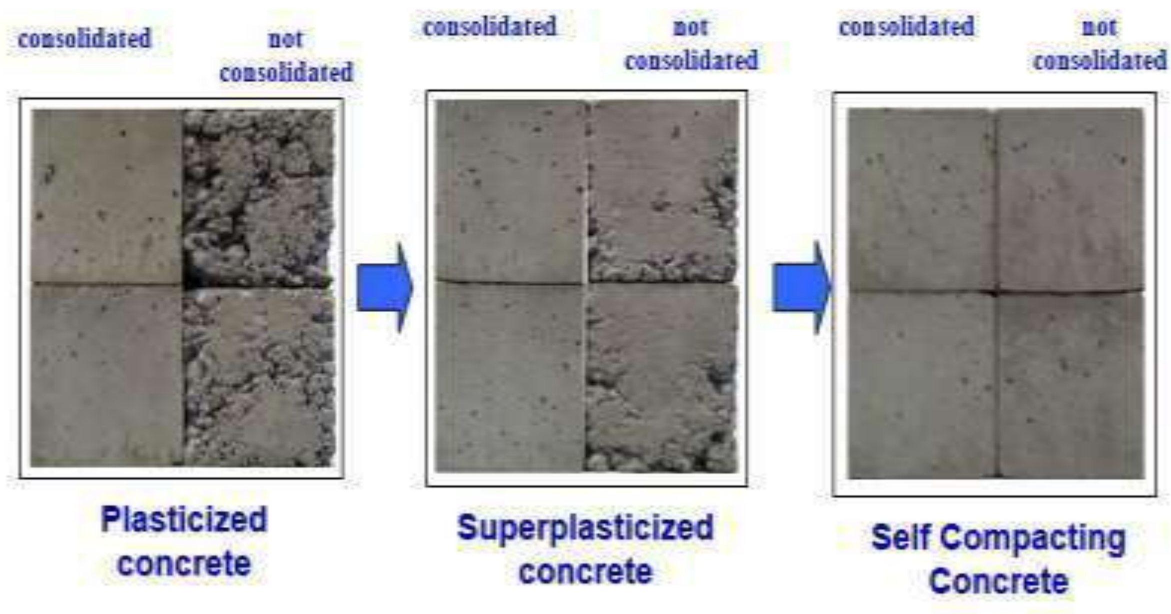


• SCC has more powder content and less coarse aggregate

• Fillers used can be flyash, ground granulated blast furnace slag, condensed silicafume, rice husk ash, lime powder, chalk powder & quarry dust.

• SCC incorporates high range water reducers (HRWR, Superplasticizers) & frequently, viscosity modifying agent in small amount.

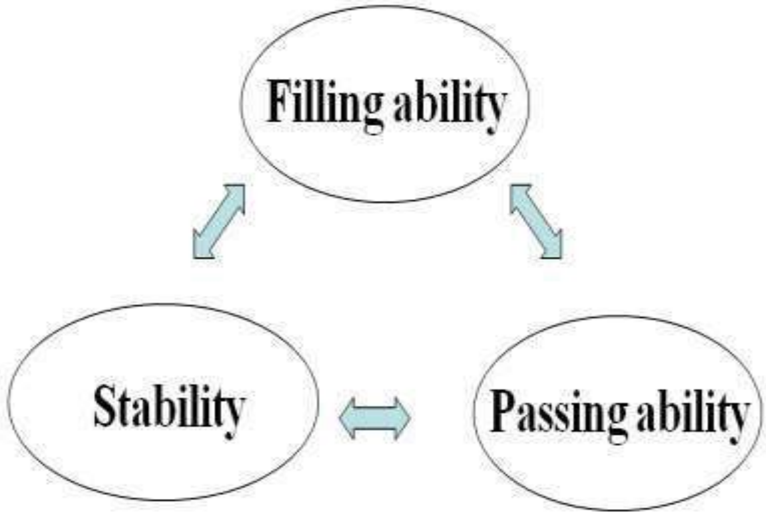
From traditional concrete to SCC



Potential Benefits of SCCContractor:

• Reduced labor requirement & cost
• Reduced plant requirement
• Reduced remedial work
• Reduced noise, improved site health & safety
• No vibrating equipment required, Reduces placing costsDesigner / client
• Use in more complex design & heavy reinforcement
• Improved aesthetics & durability
• Quicker construction time
• Less variation in the production of concrete & more homogeneous concrete
• Better surface finish

FRESH SCC REQUIREMENTS



Fresh SCC Property:

The ability of SCC to flow into and fill completely all spaces within the formwork, under its ownweight.”

Passing ability

“The ability of SCC to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking.”

Fresh SCC Properties

• Segregation resistance

“The ability of SCC to remain homogeneous in composition during transport andplacing.”

CHARACTERSTICS OF SCC

• If SCC should not segregate- it must have mortar rich in fines & is also able to transport the coarse aggregate & keep them in viscous suspension

• Cement cannot be the only finer/filler material

• Mineral admixtures are used to enhance the deformability & stability of concrete

• Chemical admixtures are a must for achieving excellent flow at low water

content. VMA reduces bleeding & improves the stability of the concrete mixture

Compared to Conventional Concrete,.

SCC has

• Higher powder content in the order of 450-600 Kg/m3

• Lower water/cement ratio. Typical range of water is 160 to 185 kg/ m3 &water/binder ratio, by volume in the range of 0.7 to 1.25. Volume of paste 0.36 to 0.43

• Lower coarse/fine aggregate ratio

• Use of superplasticizers& VMA compatible with cement in small percentages.

TEST METHODS FOR DETERMINIG FRESH SCC PROPERTIES

_ FILLING ABILITY

• Slump flow & T50CM slump flow
• V- Funnel

_ PASSING ABILITY

• L-Box
• U-box
• J-ring
• Fill Box

_ SEGREGATION RESISTANCE

• V-Funnel at T5 Minutes
• GTM Screen stability test

Slump flow (spread)

• Most popular method

• Assess the horizontal free flow of concrete in the absence of obstruction

• Measures the filling ability

• Normal range of flow recommended

o 650 mm to 800 mm

TEST METHODS

Slump flow (spread)

• Secondary measurement of T50 cm can be made

• Represents time taken in seconds to reach horizontal diameter of 500 mm

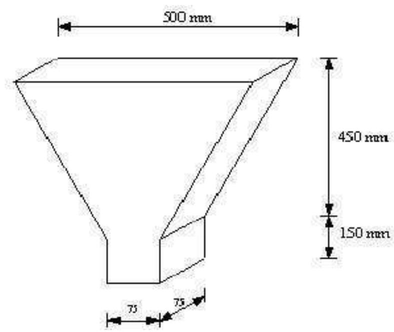
• Recommended limits are-2sec to 5sec

V-Funnel Test

• To assess the flowability of fresh concrete

• The time taken for concrete to flow through the narrow end is measured

• Measures viscosity of concrete



V-Funnel Test

• Recommended value for V-funnel flow

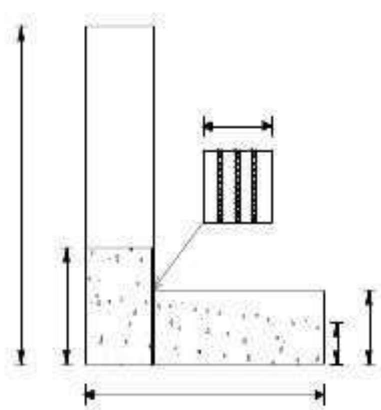
• < 12sec

TEST METHODS

L-Box Test

• Passing ability of fresh concrete.

• T 20 cm and T 40 cm marks of horizontal section of L – box are the indications of ease of flow of concrete.



L-Box Test

• Height of the concrete at the end of the horizontal section is expressed as a proportion of that of remaining in the vertical section (H2/H1).

• Recommended value for blocking ratio:o Blocking ratio H2/H1 ≥ 0.80.

U-Box Test

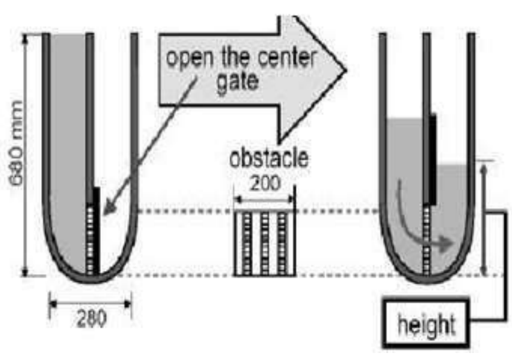
• Also called as „Box-shaped‟

• Measures the filling ability of concrete.

• The difference in height of two sections is measured.

• Recommended value:

o difference in the height of the limbs < 30 mm



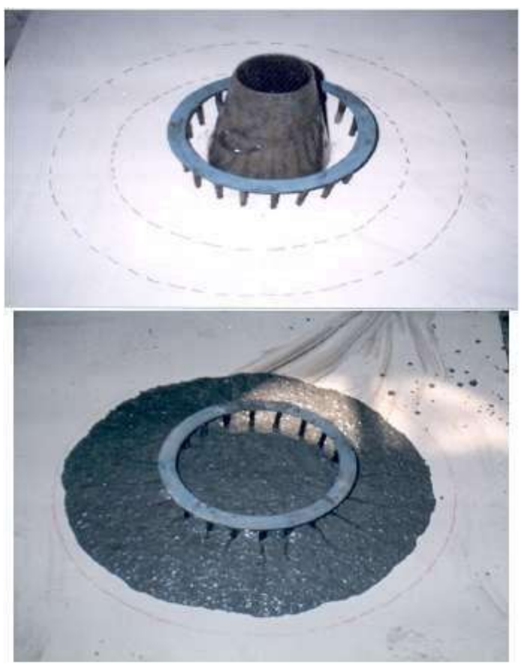
J-Ring Test

• Measures passing ability of concrete

• Can be used in conjunction with Slump flow test, combination can test filling ability& passing ability

• The difference in height, in between the concrete inside and that just outside the J-ring is measured

• Difference in height of maximum of 10 mm is considered appropriate



• Bars can be of different diameters and also varied spacing: Preferably three times the maximum aggregate size

• Used in conjunction with slump flow test V5min flow time

• This is secondary parameter of the V-funnel test

• Measures time of flow of concrete after time gap of 5min

• Indicates the tendency for segregation

• Recommended value is:

o< +3 sec of time at zero hours

MODULE 1:

Fiber reinforced concrete - Fibers types and properties, Behavior of FRC in compression, tension including pre-cracking stage and post-cracking stages, behavior in flexure and shear, Ferro cement - materials, techniques of manufacture, properties and application

Introduction

The weak matrix in concrete, when reinforced with steel fibers, uniformly distributed across its entire mass, gets strengthened enormously, thereby rendering the matrix to behave as a composite material with properties significantly different from conventional concrete. Because of the vast improvements achieved by the addition of fibers to concrete, there are several applications where Fibers Reinforced Concrete (FRC) can be intelligently and beneficially used. These fibers have already been used in many large projects involving the construction of industrial floors, pavements, highway-overlays, etc. in India. The principal fibers in common commercial use for Civil Engineering applications include steel (SFRC/SFRS), glass, carbon and aramid. These fibers are also used in the production of continuous fibers and are used as a replacement to reinforcing steel. High percentages of steel fibers are used extensively in pavements and in tunneling. This invention uses Slurry Infiltrated Fiber Concrete (SIFCON).

Fibers in the form of mat are also being used in the development of high performance structural composite. Continuous fiber-mat high performance fiber reinforced concrete (HPFRCs) called Slurry Infiltrated Mat Concrete (SIMCON) is used in the production of High performance concrete. Use of basalt fibers are picking up in western countries. Steel fibers are also used in the production new generation concretes such as Reactive Powder Concrete (RPC), Ductal and Compact Reinforcing Concrete (CRC). Properties and applications of SFRC and some of these new generation fiber concrete materials are discussed.

Types of Fibre:

1. Steel Fibre Reinforced Concrete (SFRC)

Concrete is the most widely used structural material in the world with an annual production of over seven billion tons. For a variety of reasons, much of this concrete is cracked. The reason for concrete to suffer cracking may be attributed to structural, environmental or economic factors, but most of the cracks are formed due to the inherent weakness of the material to resist tensile forces. Again, concrete shrinks and will again crack, when it is restrained. It is now well established that steel fibre reinforcement offers a solution to the problem of cracking by making concrete tougher and more ductile. It has also been proved by extensive research and field trials carried out over the past three decades, that addition of steel fibres to conventional plain or reinforced and prestressed concrete members at the time of mixing/production imparts improvements to several properties of concrete, particularly those related to strength, performance and durability.

The weak matrix in concrete, when reinforced with steel fibres, uniformly distributed across its entire mass, gets strengthened enormously, thereby rendering the matrix to behave as a composite material with properties significantly different from conventional concrete.

The randomly-oriented steel fibres assist in controlling the propagation of micro-cracks present in the matrix, first by improving the overall cracking resistance of matrix itself, and later by bridging across even smaller cracks formed after the application of load on the member, thereby preventing their widening into major cracks (Fig. 1).

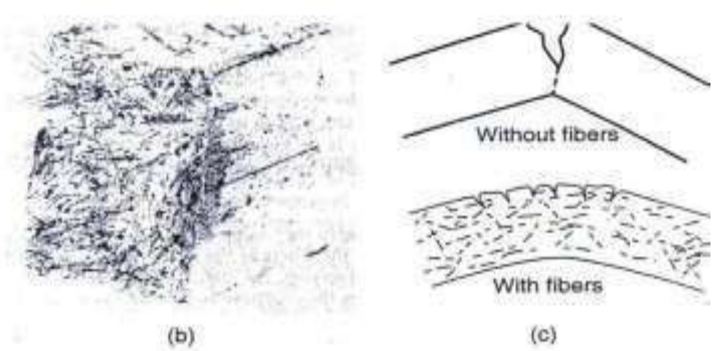
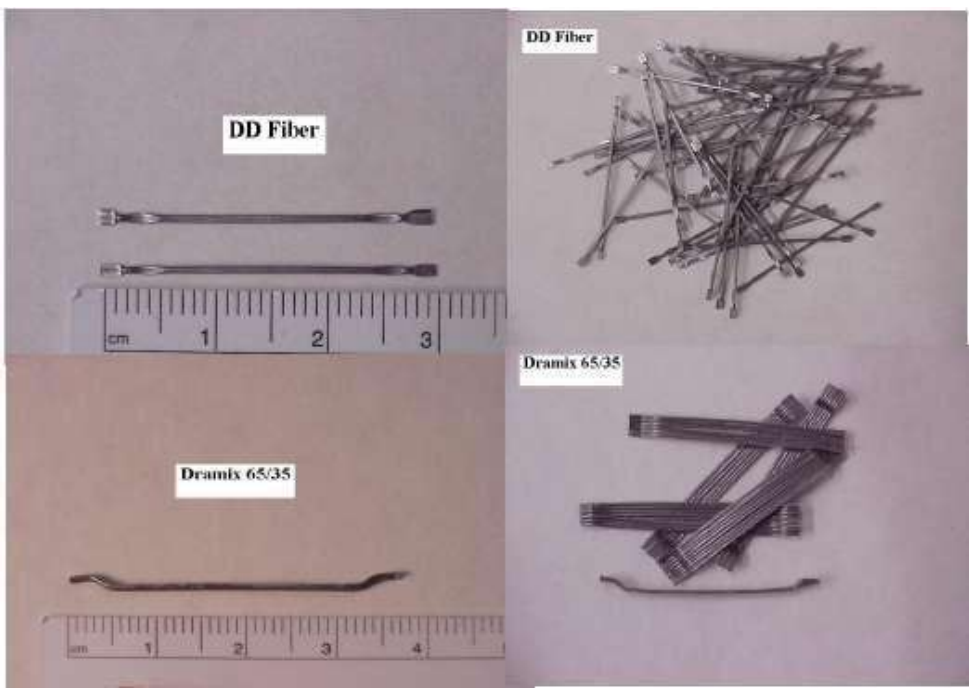


Fig. 1 Failure mechanism and the effect of fibers

The idea that concrete can be strengthened by fibre inclusion was first put forward by Porter in 1910, but little progress was made in its development till 1963, when Roumaldi and Batson carried out extensive laboratory investigations and published their classical paper on the subject. Since then, there has been a great wave of interest in and applications of SFRC in many parts of the world. While steel fibres improve the compressive strength of concrete only marginally by about 10 to 30%, significant improvement is achieved in several other properties of concrete as listed in Table. Somepopular shapes of fibres are given in Fig.2.



In general, SFRC is very ductile and particularly well suited for structures which are equired to exhibit:

• Resistance to impact, blast and shock loads and high fatigue

• Shrinkage control of concrete (fissuration)

• Very high flexural, shear and tensile strength

• Resistance to splitting/spalling, erosion and abrasion

• High thermal/ temperature resistance

• Resistance to seismic hazards.

The degree of improvement gained in any specific property exhibited by SFRC is dependent on a number of factors that include:

• Concrete mix and its age

• Steel fiber content

• Fibre shape, its aspect ratio (length to diameter ratio) and bond characteristics. The efficiency of steel fibres as concrete macro-reinforcement is in proportion to increasing fibre content, fibre strength, aspect ratio and bonding efficiency of the fibres in the concrete matrix. The efficiency is further improved by deforming the fibres and by resorting to advanced production techniques. Any improvement in the mechanical bond ensures that the failure of a SFRC specimen is due mainly to fibres reaching their ultimate strength, and not due to their pull-out.

1.1 Mix Design for SFRC

Just as different types of fibres have different characteristics, concrete made with steel fibres will also have different properties. When developing an SFRC mix design, the fibre type and the application of the concrete must be considered. There must be sufficient quantity of mortar fraction in the concrete to adhere to the fibres and allow them to flow without tangling together, a phenomenon called balling of fibres". Cement content is, therefore, usually higher for SFRC than conventional mixes Aggregate shape and content is critical. Coarse aggregates of sizes ranging from 10 mm to 20 mm are commonly used with SFRC. Larger aggregate sizes usually require less volume of fibres per cubic meter. SFRC with10 mm maximum size aggregates typically uses 50 to 75 kg of fibres per cubic meter, while the one with 20 mm size uses 40 to 60 kg. It has been demonstrated that the coarse aggregate shape has a significant effect on workability and material properties. Crushed coarse aggregates result in higher strength and tensile strain capacity. Fine aggregates in SFRC mixes typically constitute about 45 to 55 percent of the total aggregate content. Typical mix proportions for SFRC will be: cement 325 to 560 kg; water-cement ratio 0.4- 0.6; ratio of fine aggregate to total aggregate 0.5-1.0; maximum aggregate size 10mm; air content 6-9%; fibre content 0.5-2.5% by volume of concrete. An appropriate pozzolan may be used as a replacement for a portion of the Portland cement to improve workability further, and reduce heat of hydration and production cost.

The use of steel fibres in concrete generally reduces the slump by about 50 mm. To overcome this and to improve workability, it is highly recommended that a super plasticizer be included in the mix. This is especially true for SFRC used for high performance applications. Generally, the ACI Committee Report No. ACI 554 Guide for Specifying, Mixing, Placing and Finishing Steel Fibre Reinforced Concrete" is followed for the design of SFRC mixes appropriate to specific applications.

1.2 Factors Controlling SFRC

- Aspect ratio, l/d
- Volume fraction, vf
- Fiber reinforcing index, RI=l/d x vf
- Critical length, lmin
- Balling of fibers
- Good mix design: more matrix, small aggregate, workable
- Type of fibers-size, shape, strength, modulus

Workability

- We know that it is usually wrong to add water to concrete for workability.

- The main problem with workability of steel fiber reinforced concrete is in getting proper distribution of the fibers so that they don't ball up.
- This difficulty is usually overcome by slow, continuous and uniform feeding of the fibers into the wet or dry mix by means of vibratory feeders.
- Sometimes the fibers are passed through screens as they are introduced. Proper feeding can virtually eliminate the problem of balling. On the other hand, addition of

water to improve workability can reduce the flexural strength significantly, a critical matter when one considers that one of the main reasons for using steel fibers is to improve the flexural strength.

• In such cases use of suitable admixture probably would improve the workability

to certain extent and may not to the extent that you require

Test for workability

• Slump test- subsidence in mm

• Inverted slump test-time in seconds

• Compacting factor test-degree of compaction

• VB test-time in seconds. The relationship among the different workability parameters are shown in Fig. 3. The effect of volume fraction and aspect ratio on VB time is shown in Fig.

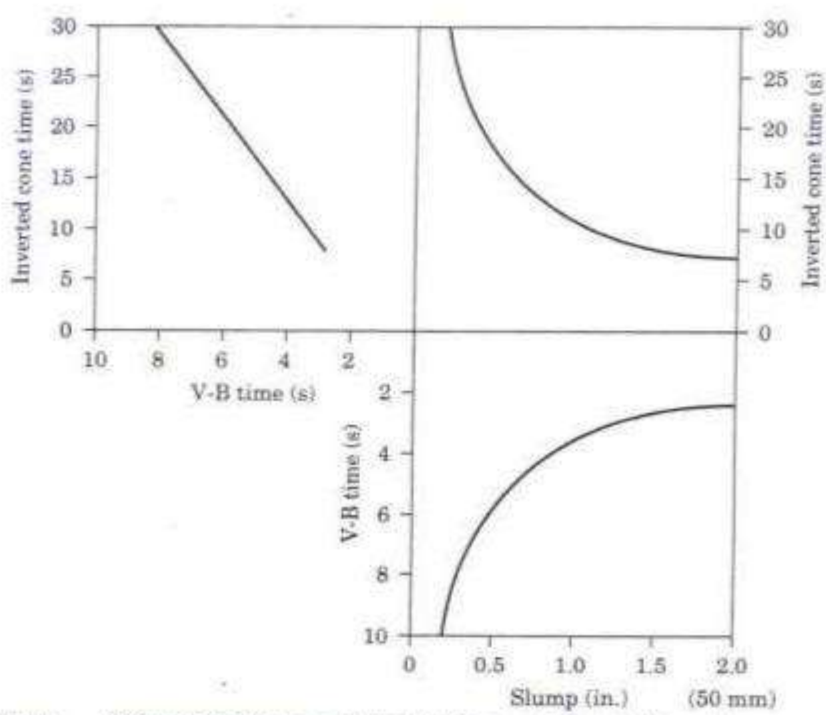
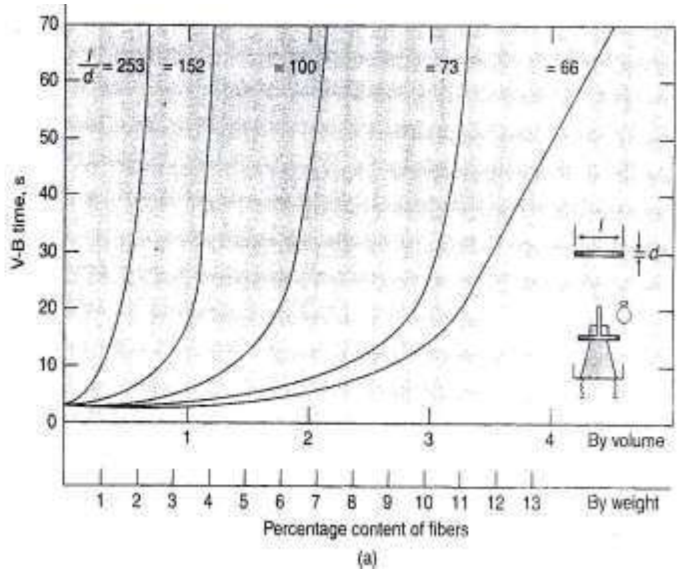


Figure Relationship between slump, V-B time, and inverted cone time

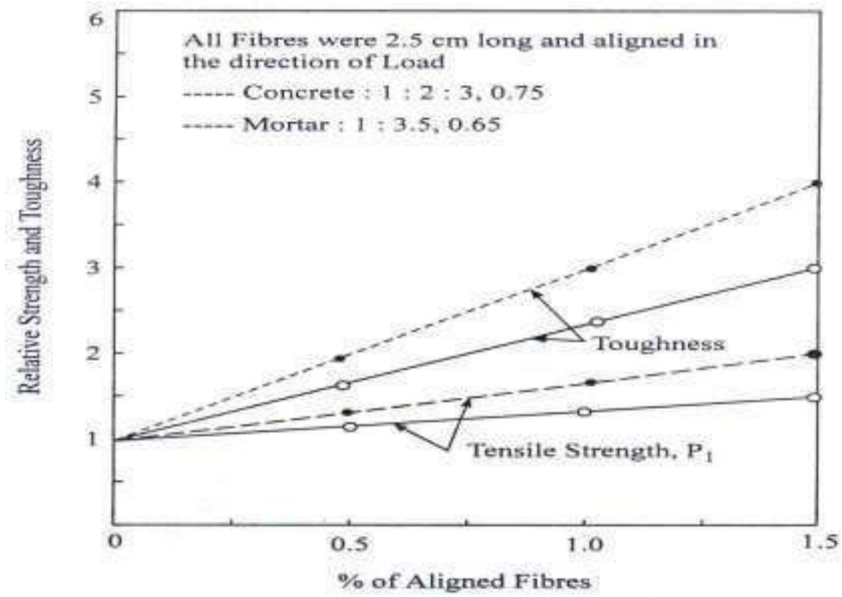
Fig.4. VB time vs percentage of fibers



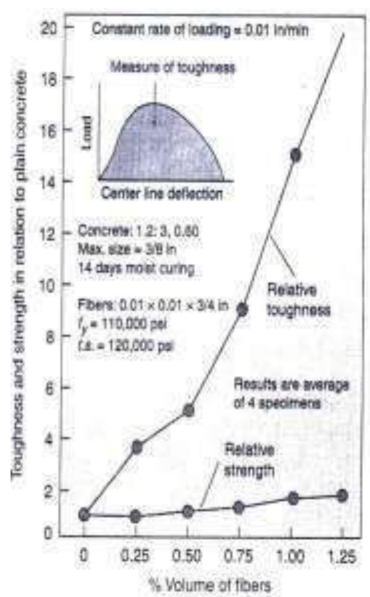
VB time v/s percentage of fibers

Mechanical properties and strength of SFRC

The various properties of SFRC and other FRCs can be seen in the following figures.Relative strength and toughness of the fiber reinforced mortar and concrete can be seen in Fig. As the percentage of fibers increases, the strength and toughness of fiber concrete increases. The increase in toughness and the effect of aspect ratio can be seen in Fig. . The effect of different types of fibers on the uniaxial tensile strength is presented in Fig. . The variation of compressive strength and the strain is shown in Fig. 8. The strain of SFRC corresponding to peak compressive strength increases as the volume fraction of fibers increases. As aspect ratio increases, the compressive strength of SFRC also increases marginally. The load vs deflection of SFRC beam subjected to bending is presented in Figs 9 and 10. As the load increases, the deflection also increases. However the area under the load – deflection curve also increases substantially depending the type and amount of fibers added.



Relative strength v/s percentage of aligned fibers

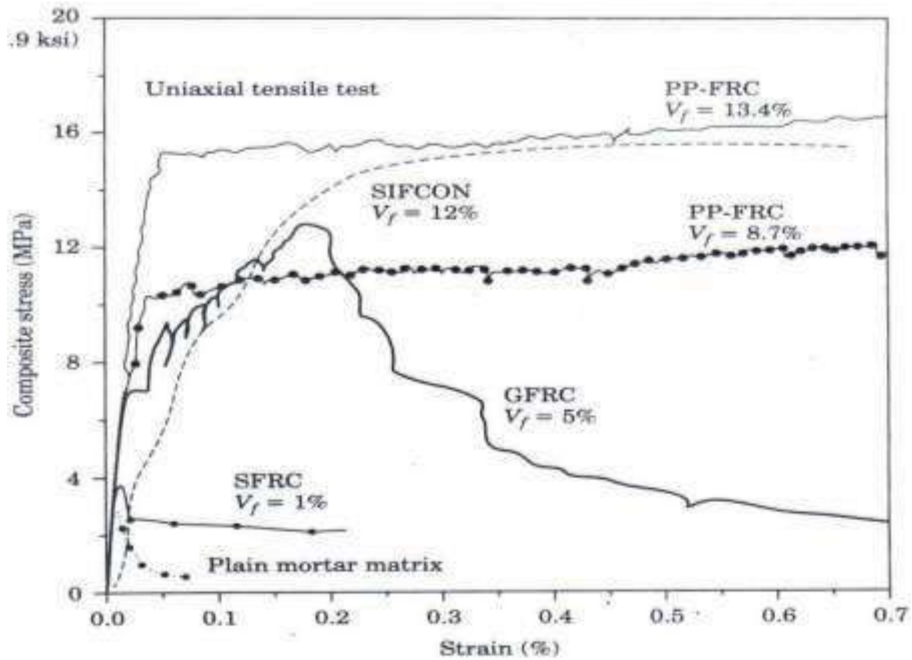


(a)

Effect of aspect ratio			
Type reinforcement	Aspect ratio L/d	Relative strength	Relative toughness
Plain concrete	0	1.00	1.0
	25	1.50	2.0
Random fiber	50	1.60	8.0
	75	1.70	10.5
	100	1.50	8.5
Effect of type reinforcement			
Conventional tensile bar	—	3.15	—
Random fibers	75	1.00	—

(b)

Toughness and strength in relation to plain concrete



Uniaxial tensile strength v/s strain for different FRCs

FibreShotcreting

“Shotcreting” using steel fibres is being successfully employed in the construction of domes, ground level storage tanks, tunnel linings, rock slope stabilization and repair and retrofitting of deteriorated surfaces and concrete. Steel fibre reinforced shotcrete is substantially superior in toughness index and impact strength compared to plain concrete or mesh reinforced shotcrete. In Scandinavian countries, shotcreting is done by the wet process and as much as 60% of ground support structures (tanks and domes) in Norway are constructed using steel fibres. In many countries including India, steel fibreshotcrete has been successfully used in the construction of several railway and penstock tunnels.

1.4 Applications of SFRC

The applications of SFRC depend on the ingenuity of the designer and builder in taking advantage of its much enhanced and superior static and dynamic tensile strength, ductility, energy-absorbing characteristics, abrasion resistance and fatigue strength. Growing experience and confidence by engineers, designers and contractors has led to many new areas of use particularly in precast, cast in-situ, and shotcrete applications. Traditional application where SFRC was initially used as pavements, has now gained wide acceptance in the construction of a number of airport runways, heavy-duty and container yard floors in several parts of the world due to savings in cost and superior performance during service.

The advantages of SFRC have now been recognised and utilised in precast application where designers are looking for thinner sections and more complex shapes. Applications include building panels, sea-defence walls and blocks, piles, blast-resistant storage cabins, coffins, pipes, highway kerbs, prefabricated storage tanks, composite panels and ducts. Precast fibre reinforced concrete manhole covers and frames are being widely used in India, Europe and USA. Cast in-situ application includes bank vaults, bridges, nosing joints and water slides. “Sprayed-in” ground swimming pools is a new and growing area of shotcrete application.
in Australia.

SFRC has become a standard building material in Scandinavia. Applications of SFRC to bio-logical shielding in atomic reactors and also to waterfront marine structures which have to resist deterioration at the air-water interface and impact loadings have also been successfully made. The latter category includes jetty armor, floating pontoons, and caissons. Easiness with which fibre concrete can be moulded to compound curves makes it attractive for ship hull construction either alone or in conjunction with ferrocement.

SFRC shotcrete has recently been used for sealing the recesses at the anchorages of post stressing cables in oil platform concrete structures. Recent developments in fibre types and their geometry and also in concrete technology and equipment for mixing, placing and compaction of SFRC and mechanized methods for shotcreting have placed

Scandinavian and German consultants and contractors in a front position in fibreshotcreting operations world wide.

Laboratory investigations have indicated that steel fibres can be used in lieu of stirrups in RCC frames, beams, and flat slabs and also as supplementary shear reinforcement in precast, thin-webbed beams. Steel fibre reinforcement can also be added to critical end zones of precast pre stressed concrete beams and columns and in cast-in-place concrete to eliminate much of the secondary reinforcement. SFRC may also be an improved means of providing ductility to blast-resistant and seismic-resistant structures especially at their joints, owing to the ability of the fibres to resist deformation and undergo large rotations by permitting the development of plastic hinges under over-load conditions.

General Application of Steel Fibres

General Applications and Advantages steel fiber concrete

Steel Fiber Reinforced Concrete or Shotcrete (SFRC/SFRS) have been used in various applications throughout the world. In India their use is picking up slowly. The principal advantages of SFRC versus plain or mesh/bar reinforced concretes are:

• Cost savings of 10% - 30% over conventional concrete flooring systems.

• Reinforcement throughout the section in all directions versus one plane of

reinforcement (sometimes in the sub-grade) in only two directions.

• Increased ultimate flexural strength of the concrete composite and thus thinnersections.

• Increased flexural fatigue endurance and again thinner slabs.

• Increased flexural toughness, or the ability to absorb energy.

• Increased impact resistance and thus reduced chipping and joint spalling.

• Increased shear strength and thus the ability to transfer loads across joints in thin sections.

• Increased tensile strength and tensile strain capacity thus allowing increased contraction/construction joint spacing The six major areas in which Steel Fibers can be used to achieve hi-strength, durable and economical concrete are:

a) Overlays

Roads, Airfields, Runways, Container, Movement and Storage Yards, Industrial Floors and Bridges.

Advantages of using SFRC

• Fatigue and impact resistance increased

• Wear and tear resistance increased

• Joint spacing increased

• Thinner pavements possible due to higher flexural strength of SFRC

• Long service life with little or no maintenance

b) Pre-cast Concrete Products

Manhole covers and Frames, Pipes, Break-Water Units, Building Floor and Walling Components, Acoustic Barriers, Krebs, Impact Barriers, Blast Resistant Panels, Vaults, Coffins etc.

Advantages of using SFRC

• Fatigue and impact resistance increased

• Thinner sections possible with SFRC reducing handling and transportation costs.

• Reduced consumption and savings in cost of materials makes pre-cast products competitive in price with cast iron or reinforced concrete products.

• Products possess increased ductility and resistance to chipping and cracking.

SFRC products suffer less damage and loss during handling and erection

• Overall improvement in all structural properties

• Many different sizes and shapes of pre-cast units possible with SFRC.

c) Hydraulic and Marine Structures

Dams, Spillways, Aprons, Boats and Barges, Sea Protection Works.

Advantages of using SFRC

• Outperforms conventional materials by exhibiting superior resistance to cavitations and impact damage due to wave action, hydraulic heads and swirling water currents.

• Ideally suitable for repair of hydraulic and marine structures

d) Defence and Military Structures

Aircrafts Hangers, Missile and Weaponry Storage Structures, Blast Resistant Structure, Ammunition Production and Storage Depots, Underground Shelters etc.

Advantages of using SFRC

• Exhibits high ductile and toughness resulting in superior resistance to blast, impact and falling loads and missiles.

• Fragmentation effect very less compared to other material due to confinement effect of fibers on concrete.

• Far superior resistance to fire and corrosion

• High resistance to penetration by drills hammers etc, almost impenetrable.

• A highly versatile material with longer service life.

e) Shotcreting Applications

Tunnel Linings, Domes, Mine Linings, Rock-Slope Stabilization, Repaint and Restoration Distresses Concrete Structures etc.

Advantages of using SFRC

• Highly efficient, convenient and economical compared to mesh and bar reinforcement used in conventional shot crating.

• One stage operation for irregular profiles.

• High resistance to abrasion and impact loads.

• Reduction in 'shadow' effects resulting in compact and dense layer.

• Improvement in ductility

• Only high performing technique suitable for tunnel and drainage lining, rock stabilization jobs and also for repair of bridges, dams, storage tanks etc.

• Construction of energy-efficient domes and shell structures possible.

f) Special Structures

Machine Foundations, Currency Vaults and Strong Rooms, Impact and Fiber-Protective Shells and Lost Forms, Column-Beam Joints in Seismic-Resistant Structures, End Zones of Prestressed Concrete Elements, High Volume Steel Fiber Reinforce Concrete structures made out of SIFCON and CRC (Slurry Infiltrated Fiber Concrete and Compact Reinforced Concrete)

Advantages of using SFRC

• Improved performances under action of any kind of loading

• High seismic-resistance in buildings due to ductile behaviours of joints and Connections

Some applications in India

Fiber reinforced concrete is in use since many years in India, but the structural applications are very much limited. However, its application is picking up in the recent days. Following are some of the major projects where large quantities of steel fibers are used.

1.More than 400 tones ofShaktiman Steel Fibers have been used recently in the construction of a road overlay for a project at Mathura (UP).

2.They have also been successfully used at the end anchorage zones of prestressed concrete girders for resisting bursting and spalling forces in bridge projects in Bangalore and Ahmedabad executed by one of the reputed construction companies.

3.The fibers have also been used for heavy-duty industrial floors.

4.Other projects include Samsonity Factory-Nasik, BIPL Plant-Pune, KRCLMSRDC tunnels, NathaJakri Hydro Electric Plant, Kol HEP, Baglihar HEP, Chamera HEP, Sala HEP, Ranganadi HEP, Sirsisilam project, Tehri Dam project, Uri Dam Project, etc.

5.Used in many tunnelling projects and for slope stabilisation in India.

2. High-Performance Composite Infrastructural Systems Utilizing Advanced

Cementitious Composites

This system is a partially cast-in-place high-performance composite frame system (HPCFS) developed by selectively using high-performance materials, including (continuous fiber-mat high performance fiber reinforced concrete (HPFRCs) called slurry infiltrated mat concrete (SIMCON), (2) discontinuous fiber HPFRCs called slurry infiltrated fiber concrete (SIFCON), and (3) high-strength, lightweight aggregate fiber reinforced concrete (HS-LWA FRC). These advanced composites exhibit superior strength, energy-absorption capacity, and/or decreased weight, and are thus ideally suited for an innovative seismic-resistant design. No conventional concrete materials are used.

Technical Approach

Partially cast-in-place HPCFSs are built using stay-in-place formwork elements made by encasing light steel sections and tubes into advanced cementitious composites including (1) continuous HPFRCs and (2) discontinuous fiber HPFRCs. The "core" of the beam and column members is cast-in-place HS-LWS FRC. The stay-in-place formwork also serves as surface reinforcement, thus replacing conventional steel reinforcement and simplifying casting of the member core by eliminating reinforcement congestion. Furthermore, by encasing steel elements into HPFRC, their fire resistance and durability is improved. The construction procedure consists of first welding or bolting together of the stay-in-place formwork, followed by casting in place of HS-LWA FRC in both(1) the member core and (2) the beam-column joint region.

Since the subsequent floor can be erected as soon as the steel elements are bolted together, it is anticipated that the speed of construction per story can be comparable to that of conventional, prefabricated steel frames. If successful, the proposed concept will result in advanced concrete frame systems exhibiting high strength and seismic resistance, while being faster and more cost effective to construct than conventional cast-in-place systems.

2.3 Slurry Infiltrated Fibrous Concrete (SIFCON)

SIFCON is a high-strength, high-performance material containing a relatively high volume percentage of steel fibres as compared to SFRC. It is also sometimes termed as high-volume fibrous concrete‟. The origin of SIFCON dates to 1979, when Prof. Lankard carried out extensive experiments in his laboratory in Columbus, Ohio, USA and proved that, if the percentage of steel fibres in a cement matrix could be increased substantially, then a material of very high strength could be obtained, which he christened as SIFCON.
While in conventional SFRC, the steel fibre content usually varies from 1 to 3 percent by volume, it varies from 4 to 20 percent in SIFCON depending on the geometry of the fibres and the type of application. The process of making SIFCON is also different, because of its high steel fibre content. While in SFRC, the steel fibres are mixed intimately with the wet or dry mix of concrete, prior to the mix being poured into the forms, SIFCON is made by infiltrating a low-viscosity cement slurry into a bed of steel fibres „pre-packed‟ in forms/moulds The matrix in SIFCON has no coarse aggregates,

but a high cementitious content. However, it may contain fine or coarse sand and additives such as fly ash, micro silica and latex emulsions.

The matrix fineness must be designed so as to properly penetrate (infiltrate) the fibre network placed in the moulds, since otherwise, large pores may form leading to a substantial reduction in properties. A controlled quantity of high-range water-reducing admixture (super plasticizer) may be used for improving the flowing characteristics of SIFCON. All types of steel fibres, namely, straight, hooked, or crimped can be used.

Proportions of cement and sand generally used for making SIFCON are 1: 1, 1:1.5, or 1:2. Cement slurry alone can also be used for some applications. Generally, fly ash or silica fume equal to 10 to 15% by weight of cement is used in the mix. The water-cement ratio varies between 0.3 and 0.4, while the percentage of the super plasticizer varies from 2 to 5% by weight of cement. The percentage of fibres by volume can be any where from 4 to 20%, even though the current practical range ranges only from 4 to 12%.

Slurry Infiltrated Mat Concrete (SIMCON)

SIMCON can also be considered a pre-placed fibre concrete, similar to SIFCON.

However, in the making of SIMCON, the fibres are placed in a "mat form" rather than as discrete fibres. The advantage of using steel fibre mats over a large volume of discrete fibres is that the mat configuration provides inherent strength and utilizes the fibres contained in it with very much higher aspect ratios.

The fibre volume can, hence, be substantially less than that required for making of SIFCON, still achieving identical flexural strength and energy absorbing toughness. SIMCON is made using a non-woven "steel fibre mats" that are infiltrated with a concrete slurry. Steel fibres produced directly from molten metal using a chilled wheel concept are interwoven into a 0.5 to 2 inches thick mat. This mat is then rolled and coiled into weights and sizes convenient to a customer‟s application (normally up to 120 cm wide and weighing around 200 kg).

As in conventional SFRC, factors such as aspect ratio and fibre volume have a direct influence on the performance of SIMCON. Higher aspect ratios are desirable to obtain increased flexural strength. Generally, because of the use of mats, SIMCON the aspect ratios of fibres contained in it could well exceed 500. Since the mat is already in a preformed shape, handling problems are significantly minimised resulting in savings in labour cost. Besides this, “balling” of fibres does not become a factor at all in the production of SIMCON.

Indian Scenerio

In India, SIFCON, CRC, SIMCON and RPC are yet to be used in any major construction projects. For that matter, even the well-proven SFRC has not found many applications yet, in spite of the fact that its vast potentials for civil engineering uses are quite well known. The reason for these materials not findingfavour with designers as well as user agencies in the country could be attributed to the non-availability of steel fibres on a commercial scale till a few years ago. The situation has now changed. Plain round or flat and corrugated steel fibres are presently available in the country in different lengths and diameters. It is, therefore, possible now to use new-age construction materials like SIFCON and CRC in our country in the construction of several structures that demand high standards of strength coupled with superior performance and durability.

Carbon Fiber Based Linear Reinforcing Elements

Due to their light weight (about one fifth that of steel), high tensile strength (higher than steel) and good overall environmental durability, carbon fiber based tendons and cables are increasingly being used for reinforcement of concrete structures in Japan. The reduction in weight facilitates better handling and easier field installation compared to steel. These elements also cause significantly less sag under their own weight, which increases load capacity while enabling the construction of longer bridge spans.

Leadline Rods/Tendons

Leadline reinforcing elements are circular rods that are pultrudedusing unidirectional carbon fibers at 65% fiber volume fraction with an epoxy resin. The rods have a specific gravity of 1.6, a relaxation ratio of 2-4% at 20°C, and a coefficient of thermal expansion of 0.68 x 10-6 /°C in the longitudinal direction. The rods have a tensile modulus of 147 GPa and 1.5 to 1.7% elongations at break. Rods are available in a number of diameters with four major surface types.

	Round Rods							Indented Rods			
Designation	R1	R3	R5	R8	R10	R12	R17	D5	D8	D10	D12
Diameter (mm)	1	3	5	8	10	12	17	5	8	10	12
Tension (kN)	1.8	16	44	111	170	255	512	40	104	162	245
C/S Area (mm^2)	0.8	7.1	19.6	49.0	75.4	113.1	227	17.8	46.1	71.8	108.6
Weight (g/m)	1.2	11	32	78	119	178	360	30	77	118	177

Table: Characteristics of Leadline Rods

High-Performance Fiber-Reinforced Concrete (HPFRC)

Introduction

High-Performance Fiber-Reinforced Concrete (HPFRC), a series of new generation concrete, results from the addition of either short discrete fibers or continuous longfibers to the cement based matrix. Due to the superior performance characteristics of this category of SFRC or HPC, its use by the construction industry has significantly increased in the last 5 years. A very good guide to various Portland cement-based composites as well as their constituent materials is available in a recently published book.

For highway pavement applications, concretes with early strength are attractive for potential use in repair and rehabilitation with a view towards early opening of traffic. In this direction lot of work has been done on high early strength fiber reinforced concrete (HESFRC) and is being used in practice. Technical papers and reports provide an extensive database and a summary of comprehensive experimental investigation on the fresh and mechanical properties of HESFRC. The control high early strength (HES) concrete (used with the fiber addition) were defined as achieving a target minimum compressive strength of 35 MPa in 24 hours, as measured from 100 x 200 mm cylinders.

Continuous Fiber-Reinforced Concrete

In the last 5 years, there has been significant interest and development in the use of continuous fiber reinforcement for improving the behavior of cementitious composites and/or concrete. Fiber Reinforced Polymers (FRP) or sometime also referred to Fiber Reinforced Plastic are increasingly being accepted as an alternative for uncoated and epoxy-coated steel reinforcement for prestressed and non-prestressed concrete applications.

In 1990, the American Concrete Institute formed the ACI Committee 440 on Non-Metallic Reinforcement. The Committee has just developed a state-of-the-art report on Fiber Reinforced Plastic (FRP) for Concrete Structures [ACI Committee 440 1996].

4.2.1 Reinforcing Fibers

The principal fibers in common commercial use for civil engineering applications include glass, carbon and aramid. The most common form of fiber-reinforced composites used in structural applications is called a laminate. Laminates are made by stacking a number of thin layers (laminae) or fibers and matrix and consolidating them into the desired thickness. Fiber orientation in each layer as well as the stacking sequence of the various layers can be controlled to generate a wide range of physical and mechanical properties for the composite laminate. A composite can be any combination of two or more materials as long as the material properties are different and there is a recognizable region for each material.The materials are intermingled. There is an interface between the materials, and often an inter phase region such as the surface treatment used on fibers to improve matrix adhesion and other performance parameters via the coupling agent.Glass has been the predominant fiber for many civil engineering applications because of an economical balance of cost and specific strength properties. Glass fibers are commercially available in "E-Glass" formulation (for "Electrical" grade), the most widely used general-purpose form of composite reinforcement, high strength S-2 glass and ECR Glass, a modified E-Glass which offers greater alkali resistance. Although considerably more expensive than glass, other fibers including carbon and aramid are used for their strength or modulus properties or in special situations as hybrids with glass.

Field Applications

Composite materials have been used in a variety of civil engineering applications with both reinforced and prestressed concrete. They are manufactured as reinforcing elements, as prestressing and post-tensioning tendons and rods, and as strengthening materials for rehabilitation of existing structures. Several new structures utilizing FRP reinforcement are currently underway in USA and Japan.

applications of high performance SFRCPavements

During the past decade, there has been an increasing interest in using high performance concrete for highway pavements. The main reason for this heightened interest is the potential economic benefit that can be derived from the early strength gain of high performance concrete, its improved freeze-thaw durability, reduced permeability, and increased wear and impact resistance.

*Pavement Repairs for Early Opening to Traffic***"Fast Track" Concrete**

"Fast track" concrete is designed to give high strength at a very early age without using special materials or techniques, and it is durable. The early strength is controlled by the water-cement ratio, cement content and characteristics. Typically, a rich, low-watercontent mix containing 1 to 2 percent calcium chloride will produce adequate strength and abrasion resistance for opening to traffic in 4-5 hours at temperatures above 10 C.

Fast track concrete paving (FTCP) was developed originally by the concrete paving industry in Iowa. It was pointed out that the benefits of applying FTCP technology in such applications are (1) a reduced contract period, thus reducing the contract overhead cost, (2) early opening of the pavement to traffic, (3) minimizing the use of expensive concrete paving plant and traffic management systems, and (4) reduced traffic delay costs.

High Strength Concrete Pavement and Bridges

The benefits of using high strength concrete for bridges are well known to bridge engineers. Over the past several years, there have been a series of design studies published in the literature, all leading to the same conclusion that the use of high strength concrete would enable the standard prestressed concrete girders to span longer distances or to carry heavier loads.

Recent activities of organized programs on HPCReactive powder ConcreteThe need

The upper limit of compressive strength for materials that can be used in commercial applications continues to be pushed higher and higher. Within the past three years Portland cement based materials have been developed which have compressive strengths greater than 200 MPa (2 to 4 times greater than High Performance Concrete). These materials allow remarkable flexural strength and extremely high ductility, more than 250 times greater than that of conventional concrete.

The Technology Reactive Powder Concrete is an ultra high-strength and high ductility composite material with advanced mechanical properties. Developed in the 1990s by

Bouygues' laboratory in France, it consists of a special concrete where its microstructure is optimized by precise gradation of all particles in the mix to yield maximum density. It uses extensively the pozzolanic properties of highly refined silica fume and optimization of the Portland cement chemistry to produce the highest strength hydrates. RPC represents a new class of Portland cement-based material with compressive strengths in excess of 200 MPa range. By introducing fine steel fibers, RPC can achieve remarkable flexural strength up to 50 MPa. The material exhibits high ductility with typical values for energy absorption approaching those reserved for metals.

The benefits

• RPC is a better alternative to High Performance Concrete and has the potential to structurally compete with steel.Its superior strength combined with higher shear capacity results in significant dead load reduction and limitless structural member shape.With its ductile tension failure mechanism, RPC can be used to resist all butdirect primary tensile stresses. This eliminates the need for supplemental shear and other auxiliary reinforcing steel.RPC provides improve seismic performance by reducing inertia loads with lighter members, allowing larger deflections with reduced cross sections, and providing higher energy absorption.

• Its low and non-interconnected porosity diminishes mass transfer makingpenetration of liquid/gas or radioactive elements nearly non-existent. Cesium diffusion is non-existent and Tritium diffusion is 45 times lower than conventional containment materials.

Compact Reinforced Concrete

CRC is a new type of composite material. In its cement-based version, CRC is built up of a very strong and brittle cementitious matrix, toughened with a high concentration of fine steel fibres and an equally large concentration of conventional steel reinforcing bars continuously and uniformly placed across the entire cross section. CRC was initially developed and tested by Prof.Bache at the laboratories of Aalborg Portland cement factory in Denmark. The pioneering experiments carried out at this laboratory established the vast potential of CRC for applications that warrant high strength, ductility and durability.

CRC has structural similarities with reinforced concrete in the sense that it also incorporates main steel bars, but the main bars in CRC are large in number and are uniformly reinforced. Owing to this and also because of the large percentage of fibres used in its making, it exhibits mechanical behavior more like that of structural steel, having almost the same strength and extremely high ductility.CRC specimens are produced using 10-20% volume of main reinforcement (in the form of steel bars of diameter from about 5 mm to perhaps 40 or 50 mm) evenly distributed across the cross section) and 5-10% by volume of fine steel fibres. The water-cement ratio is generally very low, about 0.18% and the particle size of sand in the cement slurry is between 2 and 4mm.The flow characteristics while mixing and pouring is aided by the use of micro silica and a dispersant. High-frequency vibration is often resorted to for getting a the mix compacted and to obtain homogeneity. Prolonged processing time for mixing, about 15-20 minutes, ensures effective particle wetting and high degree of micro homogeneity.Such highly fibre-reinforced concrete typically has compressive strengths ranging from 150 to 270 MPa, and fracture energy from 5,000 to as much as 30,000 N/m. CRC beams exhibit load capacities almost equivalent to those of structural steel and remain substantially uncracked right up to the yield limit of the main reinforcement (about 3 mm/m), where as conventional reinforced concrete typically cracks at about 0.1- 0.2 mm/m. It is very strong concrete or composite. It consists of very strong cementitious matrix, high fraction of steel fiber and high percentage of continuous steel bars. Main reinforcement is in the form of long bars of 5mm to 40 mm diameter, 10 to 20 percent are used. Very fine steel fibers are also used to an extent of 5-=10%. Some of the properties are tabulated below.

Applications

• Large plates and shells designed for very large local loads from shocks and explosives, large pressure tanks

• High strength to density ratio-used where weight and inertia are important as in ships and vehicles

• To support large machinery parts

• Used in Hybrid structures-High performance structural joints in steel-concrete structures

• Used as an alternative to steel where corrosion and fire are the main criterion.

Properties	**CRC**	**RCC**
Load capacity up to	2mm to 3mm per m	0.1 to 0.2 mm per m
Ultimate flexural strength, MPa	140-260	5-25
Ultimate shear strength, MPa	100-150 with shear steel 15-20 without shear steel	3-20 0.25 to 3
Ultimate tensile strength, MPa	100-200	2-12
Ultimate compressive strength, MPa	150-400	20-80
Young‟s Modulus, GPa	30-100	20-40
Density Kg/m^3	3000-4000	2400-2500
Toughness	Several times	
Fatigue-At 65% Max. load	5 million compressive stress cycles	Few hundreds of Cycles
Fracture energy, N/m	5000- 30,000	100-1000

MODULE 2

LIGHT WEIGHT CONCRETE: Light weight concrete-materials properties and types. Typical light weight concrete mix High density concrete and high performance concrete-materials, properties and applications, typical mix**.**

Introduction

Lightweight concrete can be defined as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as nailibility and lessened the dead weight. It is lighter than the conventional concrete with a dry density of 300 kg/m3 up to 1840 kg/m3 87 to 23% lighter.The main specialties of lightweight concrete are its low density and thermal conductivity. Its advantages are that there is a reduction of dead load, faster building rates in construction and lower haulage and handling costs

TYPES OF LIGHTWEIGHT CONCRETE

Lightweight concrete can be prepared either by injecting air in its composition or it can be achieved by omitting the finer sizes of the aggregate or even replacing them by a hollow, cellular or porous aggregate.

Particularly, lightweight concrete can be categorized into three groups:

i) No-fines concrete

ii) Lightweight aggregate concrete

iii) Aerated/Foamed concrete

1. NO-FINES CONCRETE:

No-fines concrete can be defined as a lightweight concrete composed of cement and fine aggregate. Uniformly distributed voids are formed throughout its mass. The main characteristics of this type of lightweight concrete is it maintains its large voids and not forming laitance layers or cement film when placed on the wall. Figure 2 shows one example of No-fines concrete.No-fines concrete usually used for both load bearing and non-load bearing for external walls and partitions. The strength of no-fines concrete increases as the cement content is increased. However, it is sensitive to the water composition. Insufficient water can cause lack of cohesion between the particles and therefore, subsequent loss in strength of the concrete. Likewise too much water can cause cement film to run off the aggregate to form laitance layers, leaving the bulk of the concrete deficient in cement and thus weakens the strength.

2. LIGHTWEIGHT AGGREGATE CONCRETE

Porous lightweight aggregate of low specific gravity is used in this lightweight concrete instead of ordinary concrete. The lightweight aggregate can be natural aggregate such as pumice, scoria and all of those of volcanic origin and the artificial aggregate such as expanded blast-furnace slag, vermiculite and clinker aggregate. The main characteristic of this lightweight aggregate is its high porosity which results in a low specific gravity. Structurally lightweight aggregate concrete is fully compacted similar to that of the normal reinforced concrete of dense aggregate. It can be used with steel reinforcement as to have a good bond between the steel and the concrete. The concrete should provide adequate protection against the corrosion of the steel. The shape and the texture of the aggregate particles and the coarse nature of the fine aggregate tend to produce harsh concrete mixes. Only the denser varieties of lightweight aggregate are 6 suitable for use in structural concrete.

3. AERATED CONCRETE

Aerated concrete does not contain coarse aggregate, and can be regarded as an aerated mortar. Typically, aerated concrete is made by introducing air or other gas into a cement slurry and fine sand. In commercial practice, the sand is replaced by pulverized fuel ash or other siliceous material, and lime maybe used instead of cement. There are two methods to prepare the aerated concrete. The first method is to inject the gas into the mixing during its plastic condition by means of a chemical reaction. The second method, air is introduced either by mixing-in stable foam or by whipping-in air, using an air-entraining agent. The first method is usually used in precast concrete factories where the precast units are subsequently autoclaved in order to produce concrete with a reasonable high strength and low drying shrinkage. The second method is mainly used for in-situ concrete, suitable for insulation roof screeds or pipe lagging.

PROPERTIES OF LIGHT WEIGHT CONCRETE

- **Color:** Lightweight aggregates are typically dark gray, brown, reddish brown, rust-colored or even orange.
- **Polishing:** Because they have a large amount of internal voids, the aggregate does not polish well. Lightweight aggregate polished with a 3000 grit diamond pad will still remain dull because of the open nature of the aggregate. Air does not polish.
- **Strength:** The compressive strength, elastic modulus, splitting tensile strengths and other properties lightweight concrete are significantly affected by the structural and physical properties of the lightweight aggregate used. The aggregate itself must possess desirable properties such as adequate compressive strength, porosity, appearance, abrasion resistance and good bonding with the cement paste. For this reason, non-structural lightweight aggregate such as perlite, vermiculite, Styrofoam and air are not considered appropriate for structural concrete, but rather find uses in concrete meant for insulation or as a lightweight filler
- Reduction in dead loads making savings in foundations and reinforcement.
- Improved thermal properties.
- Improved fire resistance.
- Savings in transporting and handling precast units on site.
- Reduction in formwork and propping.

Mixing Procedure of Lightweight Aggregate Concrete

Mixing procedure for light-weight concretes may vary with different types of aggregates.

1. The general practice for structural light-weight concrete is to mix the aggregate and about 2/3 of the mixing water for a period up to one minute prior to the addition of cement and the balance mixing water.

2. Mixing is done continuously as required for homogeneity.

3. Usually 2 or more minutes are required to get uniform mixing. In case of some insulating concrete, the aggregate is added at the end of mixing to minimize degradation.

4. Mix design data have been prepared for several, proprietary light-weight aggregates available in the United Kingdom.

5. The parameters obtained from these charts cannot be taken as final answers. However, they may give information for first trial.

DESIGN PROBLEMS SOLVED IN CLASS ROOM

HIGH DENSITY CONCRETE:

INTRODUCTION;

Concrete is the most widely used construction material in India with annual consumption exceeding 100 million cubic metres. It is well known that conventional concrete designed on the basis of compressive strength does not meet many functional requirements such as impermeability, resistance to frost, thermal cracking adequately. Conventional

Portland cement concrete is found deficient in respect of:

- Durability in severe environs (Shorter service life and require maintenance)
- Time of construction (longer release time of forms and slower gain of strength)
- Energy absorption capacity (for earthquake-resistant structures)
- Repair and retrofitting jobs

High performance concrete (HPC) successfully meets the above requirement. HPC is an engineered concrete possessing the most desirable properties during fresh as well as hardened concrete stages. HPC is far superior to conventional cement concrete as the ingredients of HPC contribute most optimally and efficiently to the various properties.

High performance concrete (HPC) is a specialized series of concrete designed to provide several benefits in the construction of concrete structures that cannot always be achieved routinely using conventional ingredients, normal mixing and curing practices. In the other words a high performance concrete is a concrete in which certain characteristics are developed for a particular application and environment, so that it will give excellent performance in the structure in which it will be placed, in the environment to which it will beexposed, and with the loads to which it will be subjected during its design life. It includes concrete that provides either substantially improved resistance toenvironmental influences (durability in service) or substantially increased structural capacity while maintaining adequate durability. It may also include concrete, which significantly reduces construction time without compromising long-term serviceability. While high strength concrete, aims at enhancing strength and consequent advantages owing to improved strength, the term high-performance concrete (HPC) is used to refer to concrete of required performance for the majority of construction applications.

The American Concrete Committee on HPC includes the following six criteria for material selections, mixing, placing, and curing procedures for concrete.

(1) Ease of placement
(2) Long term mechanical properties
(3) Early-age strength
(4) Toughness
(5) Life in severe environments
(6) Volumetric stability

The above-mentioned performance requirements can be grouped under the following three general categories.

(a) Attributes that benefit the construction process
(b) Attributes that lead to enhanced mechanical properties
(c) Attributes that enhance durability and long-term performance

Definition of HPC

The performance requirements of concrete cannot be the same for different applications. Hence the specific definition of HPC required for each industrial application is likely to vary. The Strategic Highway Research Programme (SHRP) has defined HPC for highway application on the following strength, durability, and w/c ratio criteria.

(a) It should satisfy one of the following strength criteria:

4 hour strength _17.5 Mpa

24 hour strength _35.0 Mpa

28 days strength _ 70.0 Mpa

(b) It should have a durability factor greater than 80% after 300 cycles of freezing and thawing.

(c) It should have a water-cement ratio of 0.35 or less.

In general, a "High performance Concrete" can be defined as that concrete which has the highest durability for any given strength class, and comparison between the concretes of different strength classes are not appropriate. This means that, with the available knowledge, one can always strive to achieve a better (most durable) concrete required for a particular application.

HPC is a concrete, which meets special performance, and uniformity requirements that cannot be always achieved by using only the conventional materials and normal mixing, placing, and curing practices. The performance requirements may involve enhancement ofplacement and compaction without segregation and long term mechanical properties, early age strength, toughness, volume stability, service life.

A High Performance concrete element is that which is designed to give optimized performance characteristics for a given set of load, usage and exposure conditions, consistent with requirement of cost, service life and durability.

High Performance concrete has,

(a) Very low porosity through a tight and refined pore structure of the cement paste.

(b) Very low permeability of the concrete

(c) High resistance to chemical attack.

(d) Low heat of hydration

(e) High early strength and continued strength development

(f) High workability and control of slump

(g) Low water binder ratio

(h) Low bleeding and plastic shrinkage

2.4 Civil Engineering Research Foundation (CERP)

High performance construction materials and systems: An essential program for American and infrastructure. HPC is a concrete in which some or all of the following properties have been enhanced

(a) Ease of placement

(b) Long term mechanical properties

(c) Early age strength

(d) Toughness

(e) Volume stability

(f) Extended service life in severe environments

A more broad definition of HPC was adopted by the ACI. HPC was defined as concrete, which meets special performance and uniformity requirements that cannot be always be achieved routinely by using only conventional materials and normal mixing, placing and curing practices. The requirements may involve enhancement of placement and compaction without segregation, long term mechanical properties, early age strength, volume stability or service life in severe environments. Concretes possessing many of these characteristics often achieve higher strength. Therefore, HPC is often of high strength, but high strength concrete may not necessarily be of high performance.

Material Selection

The main ingredients of HPC are almost the same as that of conventional concrete. These are

1) Cement
2) Fine aggregate
3) Coarse aggregate
4) Water
5) Mineral admixtures (fine filler and/or pozzolonic supplementary cementitious materials)

6) Chemical admixtures (plasticizers, superplasticizers, retarders, air-entraining agents)

Cement

There are two important requirements for any cement: (a) strength development with time and (b) facilitating appropriate rheological characteristics when fresh. Studies made by Perenchio (1973) and Hanna et al. (1989) have led to the following observations.

1) High C3A content in cement generally leads to a rapid loss of flow in fresh concrete. Therefore, high C3A content should be avoided in cements used for HPC.

2) The total amount of soluble sulphate present in cement is a fundamental consideration for the suitability of cement for HPC.

3) The fineness of cement is the critical parameter. Increasing fineness increases early strength development, but may lead to rheological deficiency.

4) The superplasticizer used in HPC should have long molecular chain in which the sulphonate group occupies the beta position in the poly condensate of formaldehyde and melamine sulphonate or that of naphthalene sulphonate.

5) The compatibility of cement with retarders, if used, is an important requirement. Ronneburg and Sandrik (1990) suggested tailor-made cements with characteristics suitable for HPC (Table 2). Note that SP30 is ordinary Portland cement. SP30-4A and SP30- 4A (mod) are two varieties of tailor-made special cements. It is to be noted that the two special cements recommended to produce very high strength concrete have low C3A content, sulphate level, and heat of hydration apart from phase composition.

Particulars	**SP30**	**SP30-4A**	**SP30-4A(mod)**
C2S (%)	18	28	28
C3S (%)	55	50	50

C3A (%)	8	5.5	5.5
C4AF (%)	9	9	9
Mgo (%)	3	1.5-2.0	1.5-2.0
SO3 (%)	3.3	2-3	2-3
Na2O equivalent (%)	1.1	0.6	0.6
Blain fineness (m /kg)	300	310	400
Heat of hydration (kcal/kg)	71	56	70
Setting time critical (min)	120	140	120
Final	180	200	170

Mix Proportion

The main difference between mix designs of HPC and CC is the emphasis laid on performance aspect also (in fresh as well as hardened stages of concrete) besides strength, in case of HPC, whereas in design of CC mixes, strength of concrete is an important criterion. By imposing the limitations on maximum water–cement ratio, minimum cement content, workability (slum, flow table, compaction factor, Vee-Bee consistency), etc., it is sought to assure performance of CC; rarely any specific tests are conducted to measure the durability aspects of CC, during the mix design. In HPC, however, besides strength, durability considerations are given utmost importance. To achieve high durability of HPC, the mix design of HPC should be based on the following considerations:

i) The water-binder (w/b) ratio should be as less as possible, preferably 0.3 and

below.

ii) The workability of concrete mix should be enough to obtain good compaction(use suitable chemical admixtures such as superplasticizer (SP)).

iii) The transition zone between aggregate and cement paste should bestrengthened (add fine fillers such as silica fume (SF)).

iv) The microstructure of cement concrete should be made dense and impermeable(add pozzolanic materials such as fly ash (FA), ground granulated blast furnace slag powder (GGBFSP), SF, etc.)

v) Proper curing regime of concrete should be established (this is to overcome theproblems associated with usual adoption of very low water content and high cement content in HPC mixes)

Properties of High Performance Concrete

Properties of Fresh Concrete

High performance concrete is characterized by special performance both short-and long-term and uniformity in behavior. Such requirements cannot always be achieved by using only conventional materials or applying conventional practices. It is wrong to believe that the mechanical properties of high performance concrete are simply those of a stronger concrete. It is also as wrong to consider that the mechanical properties of high-performance concrete can be deduced by extrapolating those of usual concretes as it would be wrong to consider that none of them are related. It is also wrong to apply blindly the relationships linking the mechanical properties of a usual concrete to its compressive strength that were developed through the years for usual concretes found in codes and text books.

Workability

The workability of HPC is normally good, even at low slumps, and HPC typically pumps very well, due to the ample volume of cementing material and the presence of chemical admixtures, particularly HRWR. Due to reduced water-cementing material ratio no bleeding occurs. In the flowing concrete bleeding is prevented by providing adequate fines in the concrete mix. The cohesiveness of superplastisized concrete is much better as a result of better dispersion of cement particles. Cohesion is a function of rheology of concrete mix, which is consequentlyimproved. However, excessive dosages of superplastisizer can induce some segregation, but it has little effect on physical properties of hardened concrete.

Rheological Properties

Widening the particle-size distribution of a solid suspension while maintaining constant solid volume reduces the viscosity of the suspension, known as the Farris effect. Thus, the blended or composite cements with wider particle-size distributions can achieve better rheological properties. The OPC-FA-SF ternary-cement concrete requires less water and is less sticky than OPC-SF concrete; however, it requires more water and is stickier than OPC-FA or OPC-GGBFS based concrete. In ternary cements FA seems to compensate for the rheological problems associated with the use of high SF contents. In binary cements containing relatively coarser GGBFS for example, addition of fine pozzolanas, such as SF or rice husk ash, inhibits bleeding problems.

Curing

The compressive strength of HPC is less sensitive to temperature and relative humidity than the normal strength concrete. However, tensile strength of HSC has been found to be more sensitive. The concrete containing very large quantities of ground granulated blastfurnace slag requires longer moist curing times to develop adequate strength and is more sensitive to drying than plain Portland cement concretes. The higher internal temperatures frequently found with high early strength HPC can lead to a rapid strength gain in concrete accompanied by a consequent gain in elastic modulus. The larger differential temperatures occurring within a stiffer concrete will create higher stresses and can cause more pronounced cracking than with normal concrete. These cracks will occur, regardless of the method of curing, due to stress caused by differential temperatures.

Properties of Hardened concrete

The behavior of hardened concrete can be characterized in terms of its short-term (essential instantaneous) and long-term properties. Short-term properties include strength in compression, tension and bond, and modulus of elasticity. The long-term properties include creep, shrinkage, behavior under fatigue, and durability characteristics such as porosity, permeability, freezing-thawing resistance, and abrasion resistance.

Stress-strain Behavior

Axial stress versus strain curves for HPC. The shape of the ascending part of the stress-strain curve is more linear and steeper for high-strength concrete, and the strain at the maximum stress is slightly higher for HPC. The slope of the descending part becomes steeper for high-performance concrete. To obtain the descending part of the stressstrain curve, it is generally necessary to avoid the specimen-testing system interaction. High performance concrete exhibits less internal microcracking than lower-strength concrete for a given imposed axial strain. As a result, the relative increase in lateral stain is less for HPC. The lower relative lateral expansion during the inelastic range may mean that the effects of triaxial stresses will be proportionally different for HPC. For example the influence of hoop reinforcement is observed to be different for HPC.

Strengths

Compressive, tensile and flexural strengths and modulus of elasticity of high performance concrete are much higher than those of the normal concrete of the same consistency. The enhancement in the mechanical properties is generally commensurate with reduction in water content when HRWR is used. In water reduced concrete the strength parameters can be generally increased by more than 20 percent. Strength of the order of normal concrete is achieved by superplastisized concrete with reduced cement content. The strength of the concrete depends on a number of factors including the properties and proportions of the constituent materials, degree of hydration, rate of loading, and methodof testing and specimen geometry. The properties of the constituent materials which affect the strength are: the quality of fine and coarse aggregates, the cement paste and the paste aggregate bond characteristics, i.e. properties of the interfacial transition zone. These, in turn, depend on the macro- and microscopic structural features including total porosity, pore size and shape, pore Distribution and morphology of the hydration products, plus the bond between individual components.

Modulus of elasticity

It is generally agreed that the elastic modulus of concrete increases with its compressive strength. The modulus is greatly affected by the properties of the coarse aggregate; the larger the amount of coarse aggregate with a high elastic modulus, the higher would be the modulus of elasticity of concrete. The concrete in wet condition has about 15 percent higher elastic modulus than that in the dry condition. This is attributed to the effect of drying of transition zone between the aggregate and the paste. The modulus of elasticity increases with the strain rate. It also increases as the concrete is subjected to very low temperatures. Addition of high volume of fly ash enhances elastic modulus significantly. The high elastic modulus of HVFA concrete is probably due to the fact that a considerable portion of the un reacted fly ash, consisting of glassy spherical particles, acts as a fine aggregate, and there is a strong interfacial bond between the paste and the aggregate.

Poisson's Ratio

Experimental data on values of Poisson‟s ratio for HPC are very limited. Pernchio and Klieger reported values for Poisson‟s ratio with a compressive strength ranging from 55 to 80 MPa between 0.2 and 0.28. They concluded that Poisson‟s ratio tends to decrease with increasing water-cement ratio. Kaplan found values for Poisson‟s ratio of concrete determined using dynamic measurements to be from 0.23 to 0.32 regardless of compressive strength, coarse aggregate, and test age for concretes having compressive strengths ranging from 17 to 79 Mpa. Based on the available information, Poisson‟s ratio of HPC in the elastic range seems comparable to the expected range of values for lower strength concretes.

Modulus of Rupture

For usual concrete modulus of rupture and splitting tensile strength are quite low and don't vary much, because they are very much influenced by the tensile strength of the hydrated cement paste. However, this is no longer the case for high performance concrete, for which the water binder ratio and the compressive strength can vary over a wide range. The relationships that have been suggested between compressive strength and modulus of rupture for usual concrete lose some of their predictive value when going from usual concrete to high-performance concrete.

Splitting Tensile Strength

Dewar studied the relationship between the indirect tensile strength and the compressive strength of concretes having compressive strengths upto 83 MPa at 28 days. He concluded that at low strengths, the indirect tensile strengths may be as high as 10 percent of the compressive strength but at higher strengths it may reduce to 5 percent. He observed that the tensile splitting strength was about 8 percent higher for crushed rock aggregate concrete than for gravel aggregate concrete. He also found that the indirect tensile strength was about 70 percent of the flexural strength at 28 days.

Shrinkage

Little information is available on the shrinkage behavior of High-Performance concrete. A relatively high initial rate of shrinkage has been reported, but after drying for 180 days there is little difference between the shrinkage of high-strength and lower strength concrete made with dolomite or limestone. Reducing the curing period from 28 to 7 days caused a slight increase in the shrinkage. Shrinkage was unaffected by w/c ratio but is approximately proportional to the percentage of water by volume in the concrete. Other laboratory and field studies have shown that shrinkage of high-performance concrete is similar to that of lower strength concrete. Nogataki and Yonekurus reported that the shrinkage of high performance concrete containing high-range water reducers was less than for lower-strength concrete.

Creep

Creep, the flow of the material under sustained load, is a very important factor in the long-term deformational performance of structures. It has been found that the specific creep and hence the creep coefficient value are less in high-performance concrete (HPC) than in normal-strength concrete (NSC).The creep coefficient decreases while the strength increases, that is to say while the w/c ratio decreases. For ordinary concretes, the value of the creep coefficient ¢ is generally taken equal to 2.0 when loading is applied at 28 days. It seems that this coefficient may be as low as 1.0 for some C60 concretes and 0.50 for some C 100 concretes. The creep of high-performance concrete made with high-range water reducers is reported to be decreased significantly. The maximum specific creep was less for high-strength concrete than for lower-strength concrete loaded at the same age.

Ductility

Compression tests show that the stronger the concrete the more brittle it is. This could be of concern since modern design methods take into account the plasticity of materials. Flexural tests run on the reinforced HPC beams show that their ductility is similar to that of beams with ordinary concrete. Care should nevertheless be exercised concerning HPC elements such as columns submitted to axial loads. Experiments are being carried out in France in order to set the rules concerning minimum longitudinal and transverse reinforcements in such pieces.

Fatigue strength

As the static strength of concrete increases, it becomes increasingly more brittle and its ultimate strain capacity does not increase proportionately with the increase in strength. Therefore high performance concrete would be vulnerable to fatigue loading. However in HPC the elastic modulus of the paste and that of aggregate are more similar, thereby reducing stress concentrations at the aggregate-paste interface is less susceptible to fatigue loading. Thus due to reduced microcracking in HPC, the fatigue life built-up damages are smaller when compared with those in normal strength concrete.

Alkali-Aggregate Reaction

Fly ash, blast furnace slag, and silica fume supplementary cementatiouspozzolanic additions to the concrete mixture (SCM) have shown to be effective ingredients in resisting alkali-aggregate reaction. The effect of the addition pozzolanic fly ash (PFA), blast furnace slag (BFS), and condensed silica fume (CSF) are effective in reducing the expansion in concrete, provided that they are used correctly and of the appropriate quality and amount. Coating the aggregates with acrylic or epoxy might be a solution, but effectiveness and cost does not match the other solution.

Abrasion Resistance

Abrasion resistance of concrete is of major importance in highway pavements and concrete bridge decks. Work available on the abrasion resistance of high-performance concretes has shown that increase in strength results in substantially increased service life, as documented by Gjorvet. al. In this work, an increase in concrete strength from 50 MPa to 100 MPa can reduce the abrasion deterioration by almost 50%. While the type of aggregate and its abrasion resistance affects the performance of the concrete, its effect becomes less significant at the highest compressive strength to abrasion. Service life of pavements ranged from 7 years in 40 MPa to 31 years in153 MPa ultrahigh strength concrete.

Carbonation

Carbonation is the chemical reaction caused by the diffusion of carbon dioxide (CO2) in the air into the permeable concrete and its reaction with Ca(OH)2 compound of the hydrated cement such that it carbonates to CaCo3. This decomposition of the calcium compounds in the hydrated matrix combined with alternating wetting and drying in air containing CO2 leads to an increase in the magnitude of irreversible shrinkage, contributing to crazing of the exposed surface and increase in the weight of the concretes, with progressive scaling of the concrete protective cover to the reinforcement. Use of pozzolanic cementations replacements in concrete such as silica fume or fly ash does not seem to have any significant effect on the carbonation development or rate. However, if scaling is prevented because of the higher tensile strength of the high-performance concrete, its dense composition and extremely low pore volume and permeability inhibit the oxidation process that causes corrosion of the reinforcement.

Porosity and Permeability

The exceptional properties of HPCs proceed essentially from their reduced porosity and not from their high compressive strength which is only one of their many facets; it is their reduced porosity which makes them new material with multiple advantages. It is generally agreed that mixing water is indirectly responsible for permeability of the hydrated cement paste because its content determines at the first instance the total space and subsequently the unfilled space after the water is consumed by either cement hydration reactions or evaporation

to the environment. In other words porosity of concrete resides principally in the cement paste.

APPLICATIONS OF HPC

1. Highway Pavements
2. High Rise Structures
3. Bridges

UNIT - 8

Test on Hardened concrete-Effect of end condition of specimen, capping, H/D ratio, rate of loading, moisture condition. Compression, tension and flexure tests. Tests on composition of hardened concrete-cement content, original w/c ratio. NDT tests concepts-Rebound hammer, pulse velocity methods.

TEST ON HARDENED CONCRETE

Why concrete strength is tested?

• During construction, an estimate of the in-place strength of concrete may be desired for determining the safe time to strip forms or to proceed with further work.
• The adequacy of mix proportions may need to be verified.
• Compressive strength data is necessary for quality control.

Testing of Concrete specimens • Hardened concrete is typically evaluated for acceptance using 6 in. (152 mm) by 12 in. (305 mm) cylinders. Cubes of 150 mm. • The measured results are dependent upon adhering strictly to standardized uniform procedures. • Most testing errors produce lower strength results.

Testing of cylinders

The consequences of falsely low results can be:
– Unnecessary delays
– Costly follow up testing
– Wasteful overdesign
– Possible rejection of good concrete

Variables that Influence Measured Concrete Compressive Strength

1. Sampling
2. Casting
3. Initial Curing
4. Transporting
5. Laboratory Curing
6. Capping

7. Testing
8. Reporting

Sampling

• Proper batch representation by sampling is often not achieved.
• ASTM C172 specifies that the sample should be taken from atleast two places in the middle portion of the load.
• Remixing of the sample is also specified to ensure uniformity of the sample.
• Maximum time interval between sampling and casting is also specified.
• Make sure that the concrete for a set of cylinders or cubes comes from a single truck.

Casting

• Consolidation
• Mold Material
• Specimen End Condition
• Cylinder Uniformity

Consolidation

• The proper number of layers, consolidation effort, rod type, and mold type are all important
• Insufficient consolidation can lead to a strength loss of as much as 61%

Mold Material

• The type of mold material is important in terms of rigidity, water absorption, and expansion.
• A more rigid mold will flex less during consolidation resulting in a more compact specimen.
• Mold types: – Cardboard molds with steel base plate – Steel – Plastic

Specimen End Condition

• The finished condition of the cylinder ends are important to concrete strength.
• A rough end can mean capping problems – Air pockets trapped underneath a sulfur cap can lead to a loss of strength up to 12%. – The rough interface between the concrete and capping material will present a nonstandard stress distribution during testing
• Upon casting, the specimens should be left on a level, smooth surface.

Cylinder Uniformity

• Unusual fracture types have been noted for cylinders when rod penetration has been insufficient, resulting in poor bond between layers.
• Cutting the cylinder end evenly may be a better procedure but it becomes very costly.

Initial Curing

• Temperature
• Humidity
• Specimen Disturbance during Initial Curing

Temperature

• Lower than standard curing temperatures for 3 to 7 days can cause as much as a 7% loss in strength.

• One day of freezing followed by standard curing can lead to a loss up to 56%.

• Higher than standard curing temperatures may increase early strength, but later strengths will suffer.

Humidity

• Insufficient humidity during initial curing can lower measured strength.

• Proper humidity can be approached by covering the cylinders. In general, the cylinders should be brought into the lab within 24 hours of casting.

Specimen Disturbance during Initial Curing

• Rough treatment of the cylinder while it is undergoing setting and initial hardening can damage the specimen.

• Disturbance can be in the form of gross disturbance or vibration.

• For traffic induced vibrations, wet mixes can lose as much as 5% strength through the segregation mechanism, while stiff mixes can gain 4% strength by virtue of improved consolidation.

Transporting

• Rolling and bumping in the back of a pickup truck and result in a 7% strength loss.

• Dropping cylinders from waist level can lower strength by at least 5%. Cylinders should be cushioned during transport and handled gently at all times.

<u>NDT TEST</u>

Rebound Hammer Test

- Non-destructive test performed on hardened concrete

  – A spring-loaded mass hits the concrete's surface

  – A scale measures how far the mass rebounds

– The higher the rebound, the harder the concrete's surface, and the greater the concrete's strength. Use a calibration chart graphs supplied to related the rebound to strength – 10 to 12 reading are performed per specimen.

The test is used to test the uniformity of the concrete

Ultrasonic Pulse Velocity Test (ASTM C597)

- Measures the velocity of an ultrasonic wave passing through the concrete
- The length between transducers/the travel time = average velocity of wave propagation
- It is used to detect discontinuities, cracks and internal deterioration in the structure of concrete