PROPERTIES OF SELF-COMPACTING CONCRETE INCORPORATING WASTE FOUNDRY SAND

A thesis submitted
in partial fulfillment of the requirements for
the award of the degree of

MASTERS OF ENGINEERING
IN
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DECLARATION

The author hereby declares that this thesis entitled **"Properties of Self-Compacting Concrete Incorporating Waste Foundary Sand"**, in whole or part, has not been used to obtain any degree in this, or any other, institute. Except where references have been given in text, it is entirely the authors own work.

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CERTIFICATE

This is to certify that the thesis entitled **"Properties of Self-Compacting Concrete Incorporating Waste Foundary Sand "** being submitted by **Ms. Ravinder Kaur Sandhu, Roll No 801122019** in partial fulfillment for the award of degree of **Masters of Engineering in Structural Engineering** at **Thapar University, Patiala** is a bonafide work carried out by her under my guidance and supervision and that no part of this thesis has been submitted for the award of any other degree.

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Sandhu

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ABSTRACT

Self-compacting concrete (SCC), a recent innovation in concrete technology, has numerous advantages over conventional concrete. Self-compacting concrete, as the name indicates, is a type of concrete that does not require external or internal compaction, because it becomes levelled and consolidated under its self-weight. SCC can spread and fill all corners of the formwork, purely by means of its self-weight, thus eliminating the need of vibration or any type of consolidating effort .

Foundry sand is a high quality silica sand used as a moulding material by ferrous and non-ferrous metal casting industries. It can be reused several times in foundries but, after a certain period, cannot be used further and becomes waste material, referred to as used or spent foundry sand (UFS or SFS). The majority of spent moulding sands are classified as nonhazardous waste (i.e. not corrosive, ignitable, reactive or toxic).

This report demonstrates the possibilities of using waste foundry sand as partial replacement of sand in concrete. This experimental investigation was performed to evaluate the strength and durability properties of concrete, in which natural sand was partial replaced with waste foundry sand (WFS). Natural sand was replaced with four percentage (0%, 10%, 15%, 20%) of WFS by weight. Fresh properties of self-compacting concrete were studied. Compression test and splitting tensile strength test were carried out to evaluate the strength properties of concrete at the age of 7, 28, and 56 days. In case of durability properties, sulphate resistance was evaluated at the age of 7, 28 and 56 days and Rapid Chloride Permeability test was conducted at age of 28 days.

Test results showed that there is increase in compressive strength, splitting tensile strength of self-compacting concrete by incorporating waste foundry sand (WFS) as partial replacement by sand up to 15%. Resistance of concrete against sulphate attack and rapid chloride permeability were also improved for concrete mixes. Test results indicated that there was better enhancement in strength and durability properties of concrete up to 15% replacement of fine aggregate with WFS.

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INTRODUCTION

1.1 GENERAL

Concrete is the man-made material which has the vastest utilization worldwide. This fact leads to important problems regarding its design and preparation to finally obtain an economic cost of the product on short and long time periods. The material has to be also “friendly with the environment” during its fabrication process and also its aesthetical appearance when it is used in the structures. Its success is when its raw materials that have a large spreading into the world, the prices of raw materials that are low and the properties and the performances of the concrete that confers it a large scale of application. Concrete’s performances have continuously rise in order to accomplish the society needs. Many studies have been made concerning the use of additives and super–plasticizers in the concrete by using minimum water content for a good workability of a concrete. As a result of this, high performance concretes developed having a superior durability.

Self-compacting concrete, as the name indicates, is a type of concrete that does not require external or internal vibration for placing and compaction but it gets compacted under its self-weight. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. At the same time it is cohesive enough to fill spaces of almost any size and shape without segregation or bleeding. This makes SCC particularly useful wherever placing is difficult, such as in heavily reinforced concrete members or in complicated formwork.

1.2 DEVELOPMENT OF SELF- COMPACTING CONCRETE

For several years beginning in 1983, the problem of the durability of concrete structures was a major topic of interest in Japan. To make durable concrete structures, sufficient compaction by skilled workers is required. However, the gradual reduction in the number of skilled workers in Japan's construction industry has led to a similar reduction in the quality of construction work. One solution for the achievement of durable concrete structures independent of the quality of construction work is the employment of self-compacting concrete, which can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibrating compaction. The necessity of this type of concrete was proposed by Professor Hajime Okamura in 1986. Studies to develop self-compacting concrete, including a fundamental study on the workability of concrete, were carried out by Ozawa and Maekawa at the University of Tokyo. SCC technology in Japan was based on using conventional superplasticizers to create highly fluid concrete, while also using viscosity-modifying agents (VMA) which increase plastic viscosity thus preventing segregation up to a level of fluidity that would normally cause segregation. The prototype of self-compacting concrete was first completed in 1988 using materials already on the market. The prototype performed satisfactorily with regard to drying and hardening shrinkage, heat of hydration, denseness after hardening, and other properties(Okamura and Ouchi , 2003). This concrete was named “High Performance Concrete.” and was defined as follows at the three stages of concrete:

(1) fresh: self-compactable
(2) early age: avoidance of initial defects
(3) hardened: protection against external factors

At almost the same time, “High Performance Concrete” was defined as a concrete with high durability due to low water-cement ratio by Professor Aitcin. Since then, the term high performance concrete has been used around the world to refer to high durability concrete. Therefore, Okamura has changed the term for the proposed concrete to “Self-Compacting High Performance Concrete.”

1.3 MECHANISM OF SELF-COMPACTING CONCRETE

Self-compactability can be largely affected by the characteristics of materials and the mixproportion. A rational mix-design method for self-compacting concrete is necessary. Okamura and Ozawa have proposed a simple mix-proportioning system assuming general supply from ready-mixed concrete plants . The coarse and fine aggregate contents are fixed so that self-compactability can be achieved easily by adjusting the water powder ratio and superplasticizer dosage only. SCC requires a higher level of quality control than conventional slump concrete. Okamura, Ozawa (2003) have employed the following methods to achieve self-compactability:

- Limited aggregate content
- Low water-powder ratio
- Use of super plasticizer

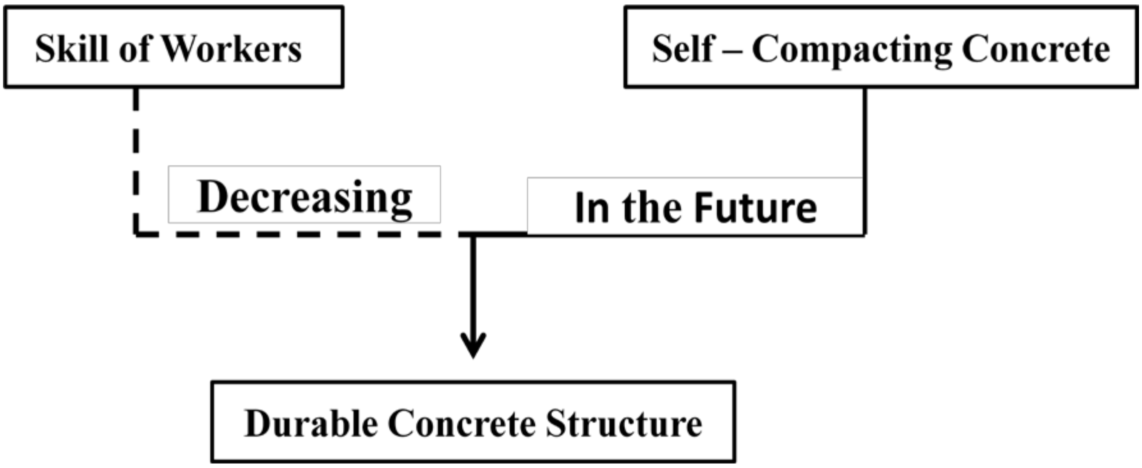

Fig. 1.1: Necessity of Self- Compacting Concrete (Ouchi and Hibino, 2000)

The method for achieving self-compactability involves not only high deformability of paste or mortar, but also resistance to segregation between coarse aggregate and mortar when the concrete flows through the confined zone reinforcing bars.

The frequency of collision and contact between aggregate particles can increase as the relative distance between the particles decreases and then internal stress can increase when concrete is deformed, particularly near obstacles. Research has found that the energy required for flowing is consumed by the increased internal stress, resulting in blockage of aggregate particles. Limiting the coarse aggregate content, whose energy consumption is particularly intense, to a level lower than normal is effective in avoiding this kind of blockage. Highly viscous paste is also required to avoid the blockage of coarse aggregate when the concrete flows through obstacles. When the concrete is deformed, paste with a high viscosity also prevents localized increases in internal stress due the approach of coarse aggregate particles. High deformability can be achieved only by the employment of a super-plasticizer, keeping the water-powder ratio to a very low value.

Additionally, the paste or mortar has to deform well too. Contact and collision between aggregates as well as the interparticle friction increase with the decreases in relative distance between aggregates particles in the concrete mix, resulting in the blockage of aggregate particles. Limiting coarse aggregate volume increases inter-particle separation and reduces the inter-particle friction and collisions resulting in minimization of the blockage leading to improvement in passing ability.

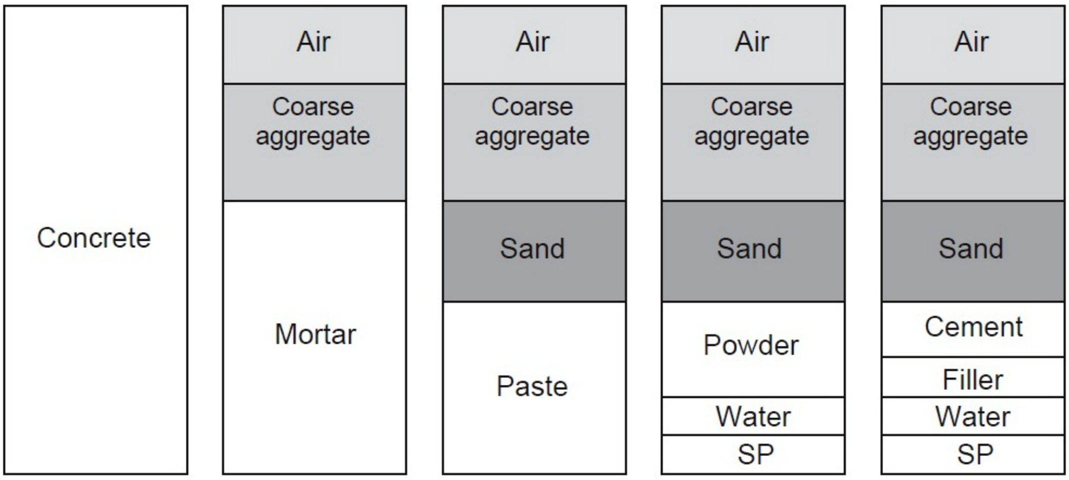

Fig. 1.2: The schematic composition of SCC (Brouwers and Radix, 2005)

The increase of paste volume with emphasis to low water powder ratio (w/p) in presence of compatible chemical admixtures further strengthens the fluidity and helps in attaining homogeneity. Adequate homogeneity improves viscosity of the mix, which in turn enhances the segregation resistance. An optimum balance between fluidity and viscosity is the key to achieve efficient self-compacting characteristics of the concrete mix at fresh state. In SCC, the powder contains binder component consisting of ordinary Portland cement (OPC), mineral admixtures like fly ash along with/ without filler material like limestone powder, dolomite etc. To achieve moderate plastic viscosity and low yield value, multiple chemical admixtures are required. Special chemical admixture like viscosity modifier admixture (VMA) is used for controlling the viscosity of the mix and super plasticizer for lowering the yield stress. In addition, the characteristics of fine and coarse aggregates play very important role on the yield stress of the mix.

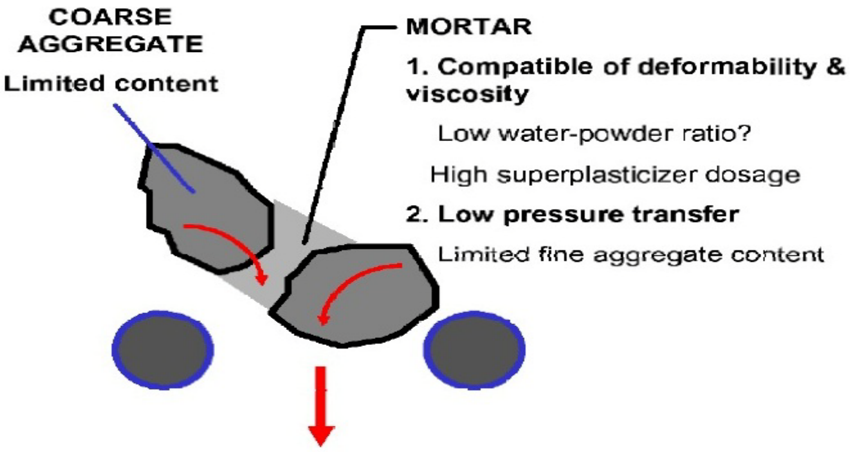

Fig. 1.3: Mechanism for achieving self-compactability. (Okamura and Ouchi, 2003)

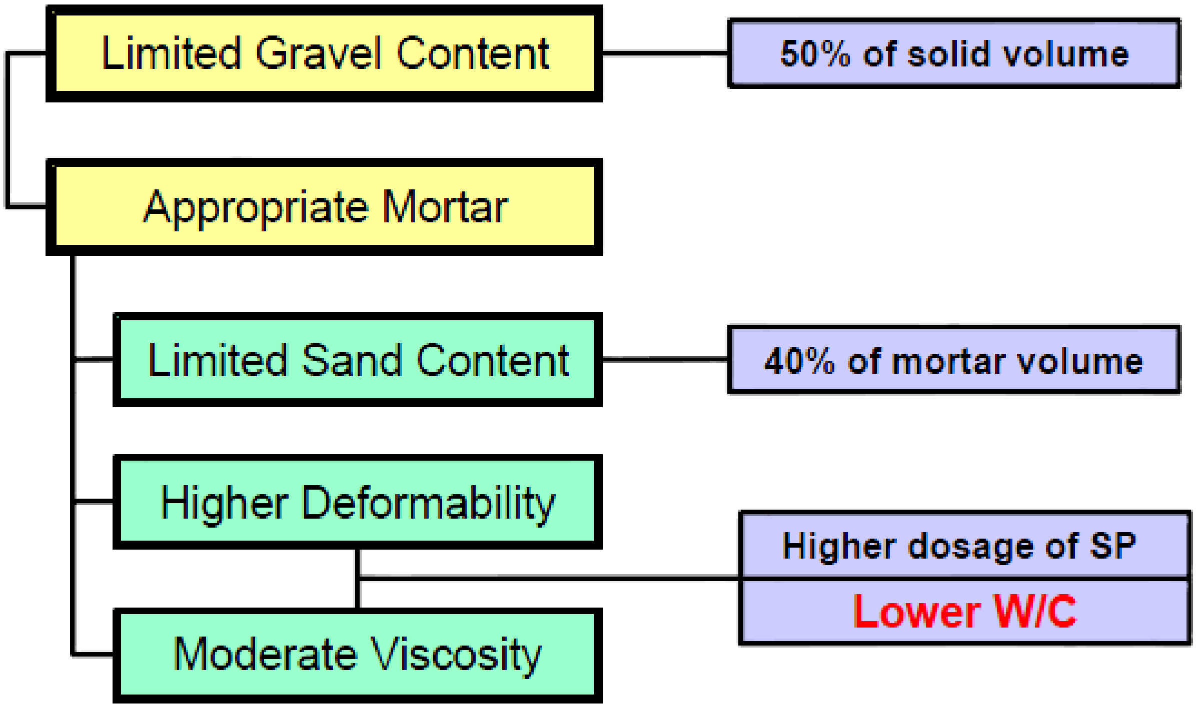

Fig. 1.4: Methods to achieve self-compactability of fresh concrete (Okamura and Ouchi, 2003)

1.4 PROPERTIES AND TESTS OF SELF-COMPACTING CONCRETE

1.4.1 PROPERTIES

Fresh SCC must possess at required levels the following key properties related to workability:

Filling ability: This is the ability of the SCC to flow, spread and fill into all spaces within the formwork under its own weight.

Passing ability: This is the ability of the SCC to flow through tight openings such as spaces between steel reinforcing bars, under its own weight without blocking them.

Resistance to segregation: The SCC must meet the required levels of properties and its composition remains uniform throughout the process of transport and placing that is keeps the sand and aggregate in suspension.

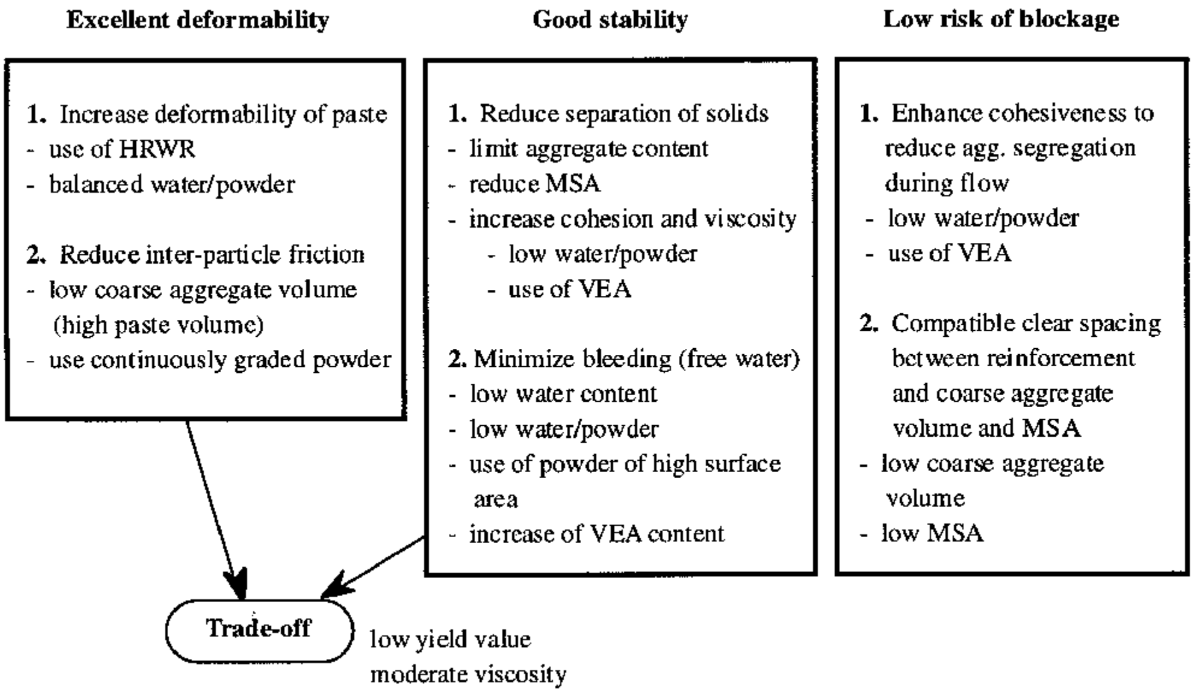

Fig.1.5: Basic workability requirements for successful casting of SCC (Khayat, 1999)

1.4.2 TESTS

Some of the important tests conducted on fresh SCC to evaluate its workability are briefly explained and summarized below in a table:

Table 1.1: Test methods to evaluate the workability properties of SCC (EFNARC, 2002).

Property	Test Methods	
	Laboratory (Mix Design)	Field (Quality Control)
Filling Ability	Slump Flow Test T_{50} Flow Test V-Funnel Test Orimet Test	Slump Flow Test T_{50} Flow Test V-Funnel Test Orimet Test
Passing Ability	L-Box Test U-Box Test Fill Box Test	J-Ring Test
Segregation Resistance	GTM Test V-Funnel At T_{5min}	GTM Test V-Funnel At T_{5mins}

U-type test: Of the many testing methods used for evaluating self-compact ability, the U-type test (Fig. 1.6) proposed by the Taisei group is the most appropriate, due to the small amount of concrete used, compared to others (Ferraris, 1999). This test is used to measure the filling ability of SCC. The apparatus consists of a vessel that is divided by a middle wall into two compartments. It provides a good direct assessment of passing ability.

For conducting the U-box test, one of the compartments of the apparatus is filled with the concrete sample and filled concrete is left to stand for 1 minute. Then the sliding gate is lifted to allow the concrete to flow out into the other compartment. After the concrete comes to rest, the height of the concrete in the compartment that has been filled is measured in two places and the mean height (H1) is calculated. Also the height in the other compartment (H2) is measured. The filling height is then calculated as H1- H2. The whole test has to be performed within 5 minutes. If the concrete flows as freely as water, at rest it will be horizontal, so H1- H2 = 0. Therefore, the nearer this test value, that is, the filling height', is zero, the better the flow and passing ability of SCC (EFNARC, 2002).

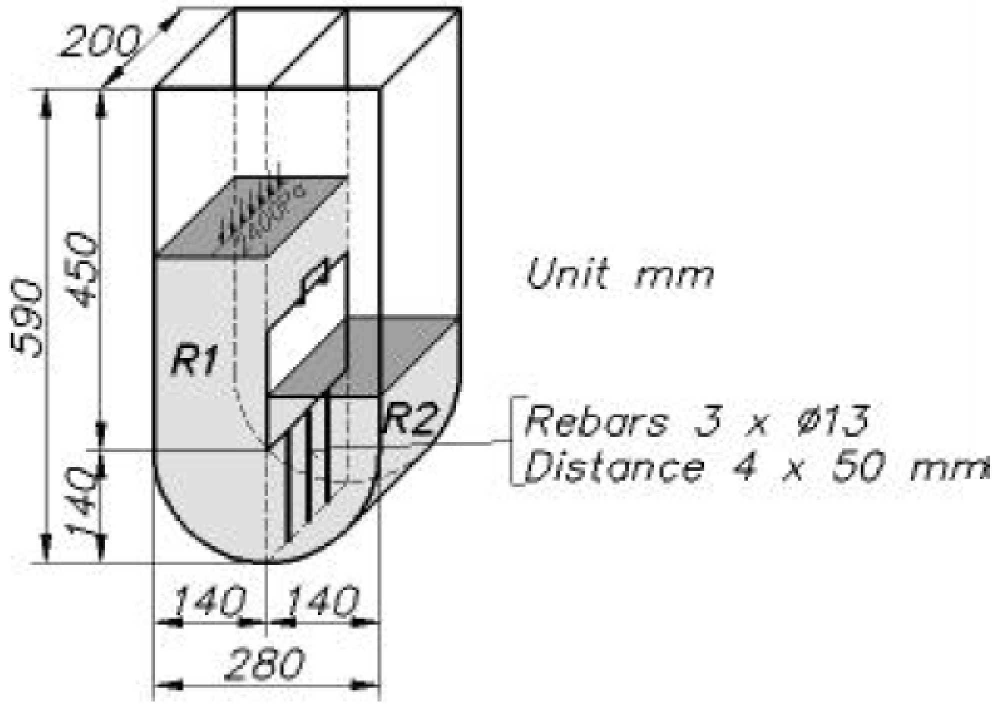

Fig. 1.6: U-type test (EFNARC, 2002)

Slump Flow test: The slump flow test is used to assess the horizontal free flow of SCC in the absence of obstructions. The basic equipment used is the same as for the conventional Slump test. The test method differs from the conventional one by the fact that the concrete sample placed into the mould is not rodded and when the slump cone is removed the sample collapses (Ferraris, 1999). The diameter of the spread of the sample is measured, that is a horizontal distance is determined as opposed to the vertical distance in the conventional Slump test. The Slump Flow test can give an indication as to the consistency, filling ability and workability of SCC. The SCC is assumed of having a good filling ability and consistency if the diameter of the spread reaches values between 650mm to 800mm (EFNARC, 2002).

Fig. 1.7: Slump flow test (Zhimin *et al.*, 2008)

Orimet test: The test is based on the principle of an orifice rheometer applied to fresh concrete (Bartos, 2000). The test involves recording of time that it takes for a concrete sample to flow out from a vertical casting pipe through an interchangeable orifice attached at its lower end. The shorter the Flow-Time, the higher is the filling ability of the fresh mix. The Orimet test also shows potential as a means of assessment of resistance to segregation on a site.

L-Box test: This method uses a test apparatus comprising of a vertical section and a horizontal trough into which the concrete is allowed to flow on the release of a trap door from the vertical section passing through reinforcing bars placed at the intersection of the two areas of the apparatus (Dietz *et al.*, 2000). The time that it takes the concrete to flow a distance of 200mm and 400mm into the horizontal section is measured, as is the height of the concrete at both ends of the apparatus (H1 & H2). The L-Box test can give an indication as to the filling ability and passing ability.

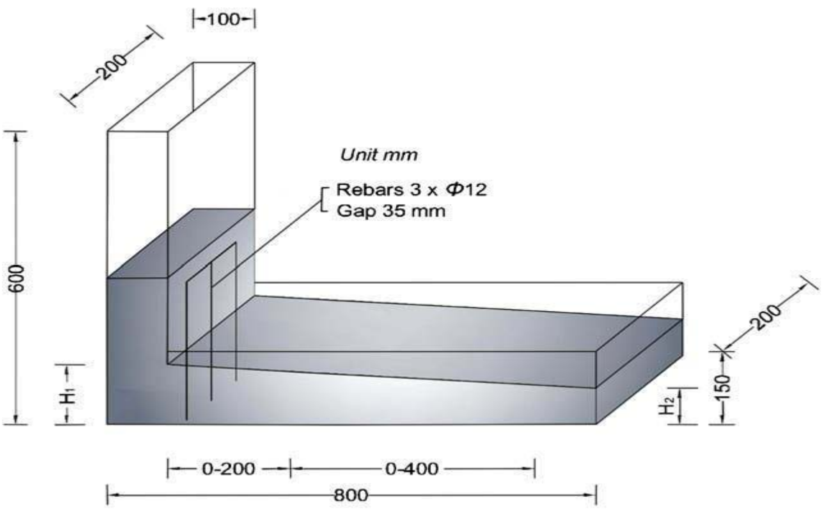

Fig. 1.8: Schematic of L-box (Grdic *et al.*, 2010).

Orimet/J-Ring combination test: This recently developed test involves the J-Ring being placed centrally below the orifice of the Orimet apparatus, allowing the discharged mix to fall into it and flow outwards (Bartos, 2000). The Orimet time is recorded as in the conventional Orimet test, along with the diameter of the concrete spread and the height of the concrete within the J-Ring. The more dynamic flow of concrete in this test simulates better the behaviour of a SCC mix when placed in practice compared with the Slump-Flow variation. The Orimet/J-Ring combination test will be used in the future as a method of assessing filling ability, passing ability and resistance to segregation (Bartos, 2000).

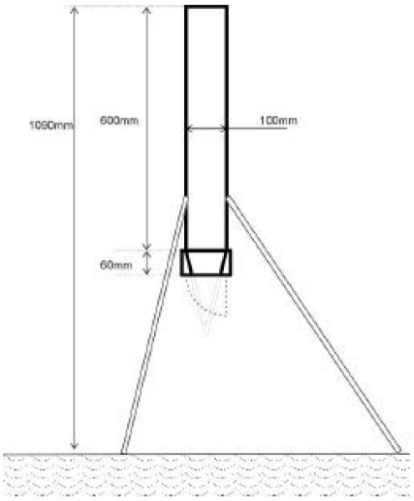

Fig: 1.9 Orimet test (EFNARC, 2002)

V-funnel test: Viscosity of the self-compacting concrete is obtained by using a V-funnel apparatus, which has certain dimensions (Fig. 1.10), in order for a given amount of concrete to pass through an orifice (Dietz et al., 2000).

The amount of concrete needed is 12 litres and the maximum aggregate diameter is 20 mm. The time for the amount of concrete to flow through the orifice is being measured. If the concrete starts moving through the orifice, it means that the stress is higher than the yield stress; therefore, this test measures a value that is related to the viscosity. If the concrete does not move, it shows that the yield stress is greater than the weight of the volume used.

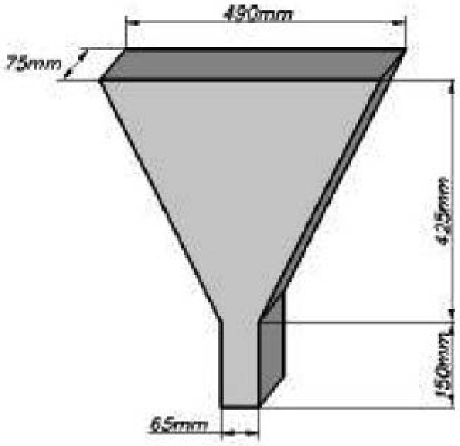

Fig 1.10: V-funnel (Dietz et al., 2000)

GTM Segregation test: This is a very recent test measuring the separation of aggregate in a sample after a period of time and wet sieving. The test has a potential for detection of tendency to segregate (Dehn et al., 2000). It completes the tests (Slump-Flow, L-Box, etc.) carried out to estimate the filling ability in free or shut-in environment (that is with some "wall-effect") by specifying the segregation resistance. This test can be used in laboratory when developing a concrete mix, as well as on site, when carrying out suitability tests on the delivered concrete.

Slump Flow/J-Ring combination test: This test (Fig. 1.11) involves the slump cone being placed inside a 300mm diameter steel ring attached to vertical reinforcing bars at appropriate spacing (the J-Ring itself) (Kosmatka et al., 2002). The number of bars has to be adjusted depending on the maximum size aggregate in the SCC mix. Like in the Slump Flow test, the diameter of the spread and the T-50 time are recorded for the evaluation of SCC viscosity. The Slump Flow/J-Ring combination test is an improvement upon the Slump Flow test on its own as it aims to assess also the passing ability of the fresh mix. In this respect, the SCC has to pass through the reinforcing bars without separation of paste and coarse aggregate.

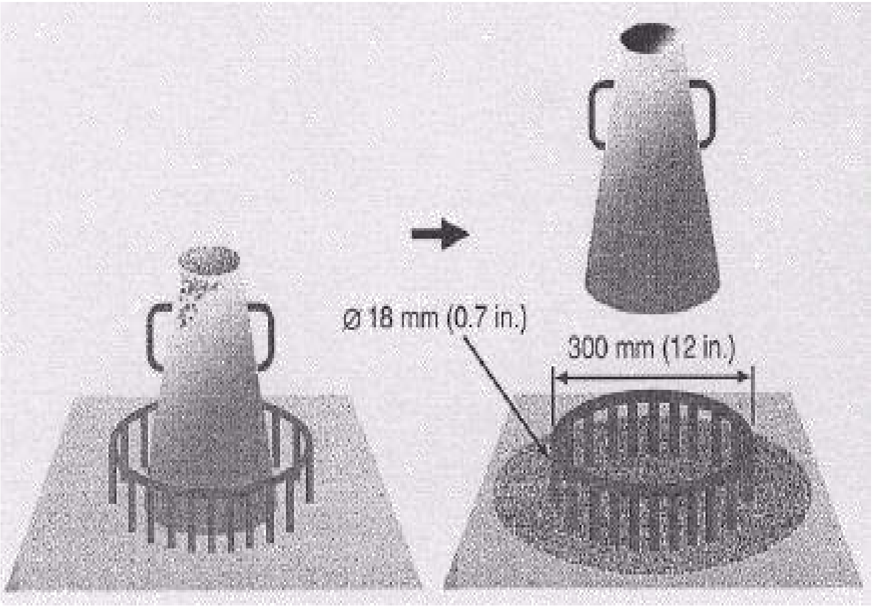

Fig. 1.11 : Slump Flow/J-Ring combination test (Kosmatka et al., 2002)

Typical acceptance criteria for SCC with a maximum aggregate size of up to 20 mm are presented in Table 1.2.

Table 1.2 : Acceptance criteria for Self-compacting Concrete (EFNARC, 2002)

Method	Unit	Minimum Value	Maximum Value
Slump flow	mm	650	800
J –Ring	mm	0	10
V- Funnel	sec	6	12
L-Box	(H2/H1)	0,8	1,0
U- Box	(H2-H1)mm	0	30
Orimet	sec	0	5
Fill Box	%	90	100

1.5 ADVANTAGES AND DISADVANTAGES OF SELF-COMPACTING CONCRETE

1.5.1 ADVANTAGES

- No vibration of fresh concrete is necessary during placement into forms.

- Placement of concrete is easier.
- Faster and more efficient placement of fresh concrete is achieved. Total concreting time is reduced.
- Energy consumption is reduced.
- Required number of workers on construction site is reduced.
- Safer and healthier working environment is obtained.
- High quality of placed concrete is achieved, regardless the skill of the workers.
- Good bond between concrete and reinforcement is obtained, even in congested reinforcement.
- High quality of concrete surface finish is obtained with no need for subsequent repair.
- Improved form surface finish and reduced need to repair defects such as bug holes and honeycombing.
- Improved ability of concrete to flow into intricate spaces and between congested reinforcement.
- Reduced construction costs due to reduced labour costs and reduced equipment purchase and maintenance costs.
- Increased construction speed due to fewer construction tasks.
- Faster unloading of ready mixed concrete trucks.
- Improved working conditions with fewer accidents due to elimination of vibrators.
- Improved durability and strength of the hardened concrete in some cases.
- Reduced noise generated by vibrators.

1.5.2 DISADVANTAGES

- Increased material costs, especially for admixtures and cementitious materials.
- Increased formwork costs due to possibly higher formwork pressures and to prevent leakage.
- Increased technical expertise required to develop and control mixtures.
- Increased variability in properties, especially workability.
- Increased quality control requirements.
- Reduced quality of hardened properties in some cases possibly including modulus of
- Elasticity and dimensional stability—due to factors such as high paste volumes or finer combined aggregate grading.
- Delayed setting time in some cases due to the use of admixtures.

- Requires more trial batches at laboratory as well as at plants.
- Increased risk and uncertainty associated with the use of a new product.

1.6 APPLICATIONS OF SELF-COMPACTING CONCRETE

SCC technology originated in Japan in the early 1980s, arising out of durability concerns due to poor compaction on the job site. Use of SCC quickly became widespread in Japan, especially since the government implemented a plan to use SCC for 50% of all concrete jobs by 2003(FrancesYang,2004). It then spread to Europe in the 1990's after invention of polycarboxylate super plasticizers. In the UK, The Concrete Society has issued official measures to expand the use of SCC as a means of replacing vibratory compaction. In the US and Canada, SCC technology is available mostly in the form of proprietary concrete mixes from ready-mix producer subsidiaries of cement manufacturers such as Lafarge and Lehigh. It is also available as specialized admixtures combining super plasticizer and viscosity modifiers. Given how important maintaining mix quality of SCC is for its successful performance, using SCC demands increased attention and skill. In particular, superplasticizer dramatically increases the sensitivity of the mix to water. This allows little room for error in mix proportioning, which can become problematic in-field when weather and timing cannot always be controlled by the contractor. In light of this, most applications of SCC in the US have been limited to precast construction due to tighter quality control ensured in-plant compared to in-field. However, the industry has shown eagerness to expand its use. Whereas in 2000, only about 10% of the precast industry had tried SCC, by 2003, the number jumped to almost 90%, of which 40% used it on a regular basis.

Some notable projects have utilized SCC in Canada. One is the Toronto International Airport, where concrete had to be pumped upwards from the ground to form 101-foot tall columns. Another project in Vancouver, B.C used SCC so little patching would be required for highly visible, outrigger columns. In Asia, SCC was used for a monolithic foundation mat in Singapore where the concrete needed to reach massive dimensions in a short amount of time. In the US, a high-strength SCC was imperative for constructing tightly reinforced elements poured in below-freezing weather for the 68-story Trump Tower in New York City.SCC has also shown successful application for residential projects, such as homes for Habitat for Humanity in the Houston area. Some of the structures built with self compacting concrete are Burj Dubai , Arlanda airport control tower Stockholm, Sweden, National Museum of 21st Century in Rome , Italy.

(Ouchi et al., 2003) A typical application example of Self-compacting concrete is the two anchorages of Akashi-Kaikyo (Straits) Bridge opened in April 1998, a suspension bridge with the longest span in the world (1,991 meters) . The volume of the cast concrete in the two ahchorages amounted to 290,000 m^3. A new construction system, which makes full use of the performance of self -compacting concrete, was introduced for this. The concrete was mixed at the batcher plant beside the site, and was the pumped out of the plant. It was transported 200 meters through pipes to the casting site, where the pipes were arranged in rows 3 to 5 meters apart. The concrete was cast from gate valves located at 5 meter intervals along the pipes. These valves were automatically controlled so that a surface level of the cast concrete could be maintained. In the final analysis, the use of self compacting concrete shortened the anchorage construction period by 20%, from 2.5 to 2 years. Self-compacting concrete was used for the wall of a large LNG tank belonging to the Osaka Gas Company, whose concrete casting was completed in June 1998 . The volume of the self-compacting concrete used in the tank amounted to 12,000 m^3.

The Ritto Bridge is a PC extra-dosed bridge with corrugated steel webs on the New Meishin Expressway in Japan . The highest pier is 65-meter high. High strength concrete and reinforcements, of which specified compressive strength and yield strength are 50 MPa and 685 MPa respectively, were applied to the construction of the pier to meet the earthquake resistance. Arrangement of reinforcement was very dense; therefore SCC was chosen to obtain good workability for the pier construction.

The Sodra Lanken Project (SL) is the largest infrastructure project in Sweden. The overall cost of the SL is estimated to around 800 million USD. The SL will provide a six kilometre four lane west - east link in the southern parts of Stockholm. The SL project includes seven major junctions, with bridges, earth retention walls, tunnel entrances and concrete box tunnels. The overall length of the rock tunnels are16.6 kilometres. They are partly lined with concrete. The concrete volume used in the project amounts 225,000 cubic meters. The duration of the SL project is estimated to last 6 years (1998 - 2004). The experiences with SCC are generally good. SCC has primarily been used in connection with constructions difficult to compact by normal vibration and high demands on aesthetics, for examples, in concrete rock lining, underground installation structures and rock tunnel entrances, retention walls with negative inclination and relief structures.

In India Delhi Metro Project have used SCC in large scale for dome construction, tunnel lining , column casting. Hindustan Construction Company have also carried out considerable studies on the use of High Volume Fly Ash self compacting concrete for domes walls in turbine building in Rajasthan Power Project ,and Concrete for piers in Bandra Worli Sea Link Projects.At Tarapur Atomic Power Project SCC was used for the construction of three walls of a pump house .The height of the wall was 14.4 m and it was done in 5 pours.At Kaiga Nuclear Power Project (Karnataka) SCC of characteristic strength 30 MPa was used in the two Mock up structures one being heavily reinforced column with two beams passing through it and the other being a thin wall (140mm thick).

1.7 LIMITATIONS OF SELF-COMPACTING CONCRETE

1.7.1 SCC PRODUCTION

- Production of SCC requires more experience and care than the conventional vibrated concrete. The plant personnel would need training and experience to successfully produce and handle SCC. In the beginning, it may be necessary to carry out more tests than usual to learn how to handle SCC and gain the experience.
- Before any SCC is produced at the plant and used at the job site, the mix must be properly designed and tested to assure compliance with the project specifications. The ingredients and the equipment used in developing the mix and testing should be the same ingredients and equipment to be used in the final mix for the project.
- Most common concrete mixers can be used for producing SCC. However, the mixing time may be longer than that for the conventional vibrated concrete. SCC is more sensitive to the total water content in the mix. It is necessary to take into account the moisture/water content in the aggregates and the admixtures before adding the remaining water in the mix. The mixer must be clean and moist, and contains no free water.
- Admixtures for the SCC may be added at the plant or at the site. There is cost benefit in adding the admixtures at the site. Conventional ready-mix concrete can be bought at a lower cost than the cost of SCC bought from a ready-mix supplier.

1.7.2 TRANSPORTATION

- The truck drivers should be given oral and written instructions for handling SCC. The truck drivers must check the concrete drum before filling with SCC to make sure that the drum is clean and moist, but with no free water. Extra care must be taken for long deliveries. In addition to the usual information, the delivery note should show the following information:

  - Slump flow - target value and acceptable range.
  - Production time - time when it was produced.
  - Instruction for adding admixtures at the site, if allowed.

- The truck drivers should not be allowed to add water and/or admixtures during transit.

1.7.3 FORM SYSTEM

- All commonly used form materials are suitable for SCC. For surface quality of SCC, wood is better than plywood, and plywood is better than steel. More pores seem to form on the surface when the form skin is colder than the SCC. During cold weather placement of SCC, it may be necessary to insulate the formwork to maintain temperature and normal setting time. SCC is more sensitive to temperature during the hardening process than the conventional vibrated concrete.
- Due to the cohesiveness of SCC, the formwork does not need to be tighter than that for conventional vibrated concrete.
- Higher form pressures than normal were not observed even at high rate of concrete placement. However, it is recommended that the formwork be designed for hydrostatic pressure, unless testing has shown otherwise.

1.7.4 CASTING ON SITE

- A pre-SCC placement meeting with all personnel involved in the SCC placement would be beneficial. The SCC placement plan, including QC/QA, and the roles and responsibilities of the field personnel should be explained and understood.
- In addition to the normal testing, the slump flow, T50 and L-box tests are useful to check SCC at the job site before placement.
- SCC can flow horizontally a distance of 15 to 20m without segregation. A well-designed SCC may have a free fall of as much as 8m without segregation. However, it is recommended that the distance of horizontal flow be limited to 10m and the vertical free fall distance be limited to 5m.
- For deck slab of a bridge, it would be difficult for the SCC to flow too far. This could be handled by designing an SCC with a lower slump flow. With a lower slump flow, a bridge deck with a slope of 2% could also be accomplished.

- If an SCC placement is interrupted and the concrete has started to harden, it would be necessary to .wake up. the placed concrete by striking a stick or board into the concrete several times before starting the placement again.
- SCC takes some time before the hardening starts, especially during cold weather conditions. When it starts to harden, the process is very rapid, which can cause problems in levelling and treating large surface areas.

1.7.5 SURFACE FINISHING AND CURING

- Finishing and curing of SCC can follow the good practices of super plasticized high performance concrete. Surface of SCC should be roughly levelled to the specified dimensions, and the final finishing applied as necessary before the concrete hardens.
- SCC tends to dry faster than conventional vibrated concrete, because there is little or no bleeding water at the surface. SCC should be cured as soon as practicable after placement to prevent surface shrinkage cracking.

1.7.6 COLD JOINT

- When placing a new layer of SCC on old SCC, the bond between the old and new SCC is equal to or better than in the case of conventional vibrated concrete. Normal vibration will not destroy the concrete, such as in the case of placing conventional vibrated concrete on fresh SCC. This may be necessary when the surface slope is greater than practicable for SCC (Ouchi et al., 2003).

1.8 WORLD-WIDE CURRENT SITUATION OF SELF-COMPACTING CONCRETE

Self-compacting concrete has already been used in several countries. In Japan, major construction projects included the use of SCC in the late ’90s. Today, in Japan, efforts are being made to free SCC of the “special concrete” label and integrate it into day-to-day concrete industry production. Currently, the percentage of self-compacting concrete in annual product of ready-mixed concrete (RMC), as well as precast concrete (PC), in Japan is around 1.2% and 0.5% of concrete products. In the United States, the precast industry is also leading SCC technology implementation through the Precast/Pre-stressed Concrete Institute (PCI) which has done some research on the use of SCC in precast/pre-stressed concretes starting with 1999. It is estimated that the daily production of SCC in the precast/pre-stressed industry in the United States will be 8000 m^3 in the first quarter of 2003 (around 1% of the annual ready-mix concrete). Furthermore, several state departments of transportation in the United States (23 according to a recent survey).

Bartos, (2000) are already involved in the study of SCC. With such a high level of interest from the construction industry, as well as manufacturers of this new concrete, the use of SCC should grow at a tremendous rate in the next few years in the United States. However, even if it is made from the same constituents the industry has used for years, the whole process, from mix design to placing practices, including quality control procedures, needs to be reviewed and adapted in order for this new technology to be applied properly. Research regarding the self-compacting concrete was also carried out in Canada, few years after the concept was introduced in Japan. Institute for Research in Construction, Canadian Precast/Pre-stressed Concrete Institute, CONMET-ICON, and ISIS are some of the bodies which studied various aspects of the new technology. The introduction of the SCC in Europe is largely connected with the activities of the international association RILEM, France, particularly of its Technical Committee TC145-WSM on “Workability of Fresh Special Concrete Mixes” (Dhir and Dyer, 1999). The TC145-WSM was founded in 1992 and immediately attracted expert memberships from all over the world. The aim was to look at the production stage of a number of “special” concretes and identify workability parameters and other characteristics of the mixes in their fresh state that governed the reliable and economical achievement of the “special” or “high-performance” parameters the concretes offered. As the importance of the SCC became widely recognized, other European countries, Germany, Sweden, UK, Denmark, Netherlands, Norway, Finland, etc., have decided to keep up with the developments in this area. For example, in Sweden, the SCC market share was at five percent in RMC and PC in 2002, and was expected to double in 2003. Housing and tunnelling, as well as bridge construction for the Swedish National Road Administration were the main areas of use for SCC. In the Netherlands and Germany, the precast industry is mainly driving the development of SCC, with an expected eight percent of market share in 2003 in Netherlands. Today, self-compacting concrete is being studied worldwide, with as per presented at almost every concrete-related conference, but until now - year 2003 - there is no universally adopted standardized test method for evaluation of self-compatibility of this concrete.

In India ,during the last few years ,attempts were made in the laboratories and in the field to develop and use SCC. Some pioneering efforts have been made in Delhi Metro projects in association with L&T and MBT .Nuclear Power Corporation , Gammon India, Hindustan Construction Company have made large scale laboratory trials .Laboratory studies conducted at SERC(Structural engineering research centre) Chennai, Indian Institute of Technology at Madras, Roorkee and other places have given enough inputs and confidence to adopt SCC in India. Of all the places Delhi Metro project have used SCC in large scale for dome construction, tunnel lining, column casting.(Sood et al. 2009)In India, the development of concrete possessing self compacting properties is still very much in its infancy.During the last couple of years, few attempts were made using European Guidelines for testing SCC in the laboratories and in the field. SCC was used by Nuclear Power Corporation of India Ltd. at Tarapur, Kaiga and Rajasthan Atomic Power Project (RAPP). Some pioneering efforts have been made in Delhi Metro Project. In all the above investigations European standards were followed for determining rheological properties of Self compacting concrete.

Today, self-compacting concrete is being studied worldwide, with papers presented at almost every concrete-related conference, but until now there is no universally adopted standardized test method for evaluation of self-compact ability of this concrete. Currently, the use of self-compacting concrete is being rapidly adopted in many countries. The use of self-compacting concrete should overcome concrete placement problems associated with the concrete construction industry. However, there still is a need for conducting more research and development work for the measurement and standardization of the methods for the evaluation of the self-compacting characteristics of SCC.

1.9 NEED FOR THIS RESEARCH

There are many situations in today’s construction market that make SCC an interesting alternative to conventional slump concrete. In general, cost savings and/or performance enhancement tend to be the driving forces behind the added value of SCC. Contractors, producers and owners are under great pressure to produce better quality construction at lower costs of labour, materials and equipment. They are also faced with tougher environmental and safety regulations, and increased insurance costs. The economic benefits of a less intensive construction environment results in labour savings, time savings from higher productivity, and greater flexibility of design. SCC offers some help in all of the following areas. The main barrier to the increased use of SCC seems to be the lack of experience of the process, and the lack of published guidance, codes and specifications. This situation will improve, however, as experience and knowledge increases and each country begins to produce its own guidance and specifications for the production of SCC with local marginal aggregates and the harsh environmental conditions prevailing in the region. Therefore, there is a need to conduct studies on SCC.

1.10 FOUNDRY SAND

A foundry produces metal castings by pouring molten metal into a preformed mould to yield the resulting hardened cast. The metal casts include iron and steel from the ferrous family and aluminium, copper, brass and bronze from non-ferrous family (Siddique, 2008). Foundry sand is high quality silica sand used as a moulding material by ferrous and non-ferrous metal casting industries. It can be reused several times in foundries but, after a certain period, cannot be used further and becomes waste material, referred to as used or spent foundry sand (UFS or SFS). The majority of spent moulding sands are classified as nonhazardous waste (that is not corrosive, ignitable, reactive or toxic) (Siddique and Noumowe, 2008).Foundries use high quality size-specific silica sands for use in their moulding and casting operations. The raw sand is normally of a higher quality than the typical bank run or natural sands used in fill construction sites. In the casting process, moulding sands are recycled and reused multiple times. Eventually, however, the recycled sand degrades to the point that it can no longer be reused in the casting process. When it is not possible to further reuse sand in the foundry, it is removed from the foundry and is termed as spent foundry sand. The physical and chemical characteristics of foundry sand will depend in great part on the type of casting process and the industry sector from which it originates. In a recent study, (Siddique et al. 2009) reported that in the United States alone, up to 10 million tons of foundry sand are discarded annually and are available for recycling. Foundries purchase new, virgin sand to make casting moulds and the sand is reused numerous times within the foundry. However, heat and mechanical abrasion eventually render the sand unsuitable for use in casting moulds, and a portion of the sand is continuously removed and replaced with virgin sand. The spent foundry sand, that is, the sand that is removed, is either recycled in a non-foundry application or land filled.

1.11 PRODUCTION OF FOUNDRY INDUSTRY IN INDIA AND WORLD

There are about 35,000 foundries in the world with annual production of 90 million tonnes. In terms of number of foundries China has the highest score (9374), followed by

India (6000). The share of Iron foundries is the maximum that is almost 56%, followed by steel with 14% and then the non-ferrous ones with 30%. The growing environmental concerns and globalization of economies have led to a closure of some 8000 foundries in Europe. These countries have been contemplating to shift their business to the low labour cost centres that is, the developing countries.

The impetus for foundry sector in India was given by the Jute industry in Bengal and the cotton industry in Mumbai in late 19th century. The establishment of TISCO, Bengal Iron Company and the IISCO led to some remarkable new uses of castings, in domestic as well as industrial areas. India ranks second in the world based on the number of foundry units present (4550 units) - after China – and fourth in terms of total production (7.8 million tonnes) (42nd Census of World Casting Production – 2007). Apart from the registered 4550 units there are several unregistered units, which according to various sources range approximately from 1500 to 5000 units. As per the IREDA- CII Report 2004, there are around 10,000 foundry units present in India including registered and unregistered units. Considering that 4550 units are registered, the total number of units unregistered is around 5450 units. As per estimation of experts of the foundry sector, there are around 1500 unregistered foundry units that are scattered across the country. This discrepancy in unregistered units is mainly due to the fact that the 5450 units included all kinds of micro and small units engaged in castings. Whereas the 1500 units data incorporates only those foundry units that are engaged in grey iron casting and use conventional cupola and excludes those units that are too micro in nature and use crucible for melting of metals. Also several foundry units had closed due to non compliance with the pollution standard set by the government for example Howrah, Agra and nearby areas. The foundry produces a wide variety of castings such as manhole covers, pipe and pipe fittings, sanitary items, tube well body, metric weights, automobile components, railway parts, electric motor, fan body etc. 90% of the castings produced are from the SSI sector. Most of these units are situated in clusters, with cluster size ranging from 30- 500 units. (Bhimani et al. 2013)

1.12 TYPES OF FOUNDRY SAND

Classification of foundry sands depends upon the type of binder systems used in metal casting. Generally two types of binder systems are used and based on that foundry sands are classified as: clay-bonded systems (green sand) and chemically bonded systems. Both types of sands are suitable for beneficial use but they have different physical and environmental characteristics.(Siddique and Singh , 2011)

1.12.1 GREEN SAND

Clay-bonded (Green) sand is composed of naturally occurring materials which are blended together; high quality silica sand (85–95%), bentonite clay (4–10%) as a binder, a carbonaceous additive (2–10%) to improve the casting surface finish and water (2–5%). It is black in colour due to carbon content. Green sand is the most commonly used moulding media by foundries. The silica sand is the bulk medium that resists high temperatures while the coating of clay binds the sand together. The water adds plasticity. The carbonaceous additives prevent the “burn-on” or fusing of sand onto the casting surface. Green sands also contain trace chemicals such as MgO, K_2O, and TiO_2. The green sand used in the process constitutes upwards of 90% of the moulding materials used.

1.12.2 CHEMICALLY BONDED SANDS

Chemically bonded sands are used both in core making where high strengths are necessary to withstand the heat of molten metal, and in mould making. Chemically bonded sand consists of 93–99% silica and 1–3% chemical binder. Silica sand is thoroughly mixed with the chemicals; a catalyst initiates the reaction that cures and hardens the mass. There are various types of chemical binder systems used in the foundry industry. The most common chemical binder systems used are phenolic-urethanes, epoxy-resins, furfyl alcohol, and sodium silicates. Chemically bonded sands are generally light in colour and in texture than clay bonded sands. Waste foundry sand (WFS) is also referred as spent foundry sand (SFS) or used foundry sand (UFS).

1.13 PROPERTIES OF WASTE FOUNDRY SAND

1.13.1 PHYSICAL PROPERTIES

Generally, waste foundry sand (WFS) is sub-angular to round in shape. Green sands are black or grey, whereas chemically bonded sands are of medium tan or off-white color. Grain size distribution of waste foundry sand is uniform with 85-95% of the material in between 0.6 mm to 0.15 mm and approximately 5 to 20% of foundry sand can be smaller than 0.075 mm. Dayton et al. (2010) mentioned that sand (0.05 to 2 mm) was the dominant size fraction in the 39 spent foundry sands ranging from 76.6% to 100% with a median of 90.3%.The specific gravity of foundry sand varies between 2.39 and 2.79. Waste foundry sand has low absorption capacity and is non-plastic. Physical properties of waste foundry as reported by Javed and Lovell (1994), Naik et al. (2001), Guney et al. (2010) and Siddique et al. (2011), are given in Table 1.3

Table 1.3: Typical Physical Properties of Waste Foundry Sand (Siddique and Singh , 2011)

Property	**Javed and Lovell**	**Naik et al.**	**Guney et al.**	**Siddique et al.**
	(1994)	(2001)	(2010)	(2011)
Specific gravity	2.39-2.55	2.79	2.45	2.61
Fineness modulus	-	2.32	-	1.78
Unit Weight (kg/m^3)	-	1784	-	1638
Absorption (%)	0.45	5	-	1.3
Moisture content (%)	0.1-10.1	-	3.25	-
Clay lumps and friable particles	1-44	0.4	-	0.9
Materials finer than 75µm (%)	-	1.08	24	18

1.13.2 CHEMICAL PROPERTIES

Chemical composition of the waste foundry sand depends on the type of metal, type of binder and combustible used. The chemical composition of the foundry sand may influence its performance. Waste foundry sand is rich in silica content. It is coated with a thin film of burnt carbon, residual binder (bentonite, sea coal, resins/chemicals) and dust. Silica sand is hydrophilic and consequently attracts water to its surface. Chemical composition of WFS as reported by American Foundryman’s Society (1991), Guney et al. (2010), Etxeberria et al. (2010) and Siddique et al. (2011) is given in Table 1.4

It has been reported that some waste foundry sands can be corrosive to metals (MNR, 1992). Due to the presence of phenols in foundry sand, it raises concerns that precipitation percolating through stockpiles could mobilize leachable fractions, resulting in phenol discharges into surface or ground water supplies.

Table 1.4: Chemical Composition of Foundry Sand (Siddique and Singh, 2011)

Constituent	**Value (%)**			
	American Foundryman's Society (1991)	Guney et al. (2010)	Etxeberria et al. (2010)	Siddique et al. (2011)
SiO_2	87.91	98	95.1	78.81
Al_2O_3	4.7	0.8	1.47	6.32
Fe_2O_3	0.94	0.25	0.49	4.83
CaO	0.14	0.035	0.19	1.88
MgO	0.3	0.023	0.19	1.95
SO_3	0.09	0.01	0.03	0.05
Na_2O	0.19	0.04	0.26	0.1
K_2O	0.25	0.04	0.68	-
TiO_2	0.15	-	0.04	-
Mn_2O_3	0.02	-		-
SrO	0.03	-		-
LOI	5.15	-	1.32	2.15

1.13.3 MECHANICAL PROPERTIES

Waste foundry sand has good durability properties as measured by low Micro-Deval abrasion (Ontario Ministry of Transportation, Canada 1996). Javed and Lovell (1994) have revealed relatively high soundness loss, which may be due to the samples of bound sand loss and not a breakdown of individual sand particles. The angle of shearing resistance (also known as friction angle) of waste foundry sand varies between 33 and 40 degrees, which is comparable to that of conventional sands. Typical mechanical properties of waste foundry sand are given in Table 1.5

Table 1.5: Typical Mechanical Properties of Spent Foundry Sand

(Siddique and Singh ,2011)

Property	Results
Micro-deval abrasion loss (%) (MNR–1992)	< 2
Magnesium sulfate soundness loss (%)(MNR–1992)	5 – 15 6 – 47
Friction angle (deg)	33 – 40
California bearing ratio (%) (Javed and Lovell 1994)	4 – 20

1.14 APPLICATIONS OF WASTE FOUNDRY SAND

Indian foundries produce approximately 1.71 million tons of waste foundry sand each year (Metal World, 2006). In United States of America, metal casting foundries dispose of approximately 9 million metric tons of waste foundry sand (WFS) in landfills in 2000 (Winkler and Bol’shakov, 2000). United States’s average land-filling tipping fee of foundry by products is US $15-75 per ton inclusive of storage, transportation and labour costs (Winkler et al. 1999). The annual cost of WFS disposal was around US $ 135- 675 million. The considerable disposal expense has made the current practice of WFS disposal in landfills less favourable. Besides the financial burden to the foundries, land-filling WFS also makes them liable for future environmental costs, remediation problems and regulation restrict ions. This issue is increasingly addressed by alternate options of reusing WFS beneficially. Waste foundry sand is made up of mostly natural sand material. Its properties are similar to the properties of natural or manufactured sand. Thus it can normally be used as a replacement of sand.

Beneficial reuses of WFS span a variety of applications related to infrastructure engineering rehabilitation works. Some of the researchers have reported the possible use of waste foundry sand in different civil engineering applications, which are given in Table1.6. These alternate applications offer cost savings for both foundries and user industries and an environmental benefits at the local and national level.

Table 1.6: Uses of WFS in Various Applications

Author's Name	Application
Javed and Lovell(1994), Traeger(1987), Kleven et al.(2000), MOEE(1993), Abichou et al.(1998), Mast and Fox(1998), Kirk(1998) and Gunney et al.(2006)	Highway
Nail et al. (2003; 2004), Tikalsky et al. (1998) and Siddique et al.(2008)	Controlled low strength materials
Dungan et al. (2006), Deng and Tikalsky (2008)	Geotechnical Field
Braham A. (2002)	Hot Mix Asphalt
Ham RK and Boyle (1981), Fero et al. (1986), Engroff et al. (1989), Siddique et al. (2010) and Dungan et al. (2009)	Leachate Characteristic
Seung-Whee and Woo-Keun(2006), Naga and El-Maghraby(2003), Pereiraa et al. (2006) and Quaranta et al. (2004)	Ceramic material
El Haggar and El Hatow(2009)	Manhole cover
Periraa et al. (2004)	Refractory Mortars
Colombo et al. (2003), Ferraris et al. (2001), Geo and Drummond (1999)	Interization and Reuse of Waste Materials by Vitrification
Santurde et al. (2011)	Clay Brick

Environment Protection Agency (2007) EPA has found that spent foundry sands produced by iron, steel, and aluminium foundries are rarely hazardous. EPA supports the use of spent foundry sands from these foundry types in the following applications:

- As partial replacement for fine aggregate in asphalt mixtures.
- As partial replacement for fine aggregate in Portland cement concrete.
- As source material for the manufacture of Portland cement and
- As a sand used in masonry mortar mixes

In addition, use of foundry sand from iron, steel and aluminum foundries in flowable fill, road embankments, road base, manufactured soil, agricultural amendments, and similar uses may be appropriate depending on the site and the sand composition.

1.15 ORIENTATION OF THESIS REPORT

This thesis is presented in five chapters as detailed below:

Chapter-1	Gives the introduction about Self-Compacting Concrete and Foundry Sand
Chapter-2	Literature review presents the work done by various researchers in the field of Self-Compacting Concrete.
Chapter-3	Details the scheme of experimentation, materials used with their properties, and variables involved, Concrete mixes, mix design, casting of specimens for studying various properties and methodology adopted for testing of different properties.
Chapter-4	Gives results and their analysis for the fresh properties, strength properties such as compressive strength, splitting tensile strength and durability properties like sulphate resistance and rapid chloride penetration resistance of the mixes with waste foundry sand and are compared with control concrete.
Chapter-5	Gives the major conclusions made in the study.
References	

CHAPTER: 2
LITERATURE REVIEW

2.1 GENERAL

Self-compacting concrete (SCC), a recent innovation in concrete technology, has numerous advantages over conventional concrete. Self-compacting concrete, as the name indicates, is a type of concrete that does not require external or internal compaction, because it becomes levelled and consolidated under its self-weight. SCC can spread and fill all corners of the formwork, purely by means of its self-weight, thus eliminating the need of vibration or any type of consolidating effort. The notion behind developing SCC were the concerns regarding the homogeneity and consolidation of conventional cast-in-place concrete within intricate (that is, heavily-reinforced) structures and to improve the overall strength, durability, and quality of concrete. The SCC concrete is highly flowable and cohesive enough to be handled without segregation. It is also referred to as self-compacting concrete, super-workable concrete, highly flowable concrete, non-vibrating concrete, and other similar names.

Due to ever increasing quantities of waste materials and industrial by-products, solid waste management is the prime concern in the world. Scarcity of land-filling space, because of its ever increasing cost, recycling and utilization of industrial by-products and waste materials has become an attractive proposition to disposal. There are several types of industrial by-products and waste materials. The utilization of such materials in concrete not only makes it economical but also helps in reducing disposal concerns. Natural sand is getting depleted due to large scale construction. So it is important to find out an alternative of natural sand, which can be used as partial replacement of natural sand (fine aggregate). There are several types of waste material by products, which have been explored for possible use in concrete as a partial replacement of fine aggregate. Such types of materials are coal bottom ash, recycled fine aggregate, sewage sludge ash, stone dust and glass cullet, and waste foundry sand, etc.

In this chapter we discuss the literature related to the use of waste foundry sand in self-compacting concrete and other industrial by products as partial replacement of fine aggregates in self-compacting concrete.

2.2 FRESH CONCRETE PROPERTIES

Pathak and Siddique (2012) investigated the influence of fly ash as partial replacement of cement, and spent foundry sand as partial replacement of sand on the properties of SCC. In this mixes were prepared with three percentages of fly ash ranging from 30% to 50% and one controlled mixture without fly ash was also prepared for comparison. Fine aggregate was replaced with 10% of spent foundry sand. Slump flow test and U-box tests were performed for determining the self-compatibility properties. The slump flow test judges the capability of concrete to deform under its own weight against the friction of the surface with no restraint present. The results of various fresh properties tested are given in Table 2.1

Table 2.1 Fresh concrete properties(Pathak and Siddique ,2012)

Mix	Slump(mm)	U-Box(mm)
SCC1	627(mm)	13
SCC2	640(mm)	12
SCC3	659(mm)	10
SCC4	678(mm)	08

Siddique et al., (2012) conducted test for determining the self-compactibility properties (slump flow, T50cm time, V-funnel flow times, L-box blocking ratio, U-box difference in height). SCC was made with coal bottom ash as replacement of fine aggregates in varying percentages of 0%, 10%, 20% and 30% and fly ash as replacement of cement in varying percentages of 15–35%. A slump flow value ranging from 500 to 700 mm for a concrete to be self-compacting was suggested. At slump flow >700 mm, the concrete might segregate, and at <500 mm, the concrete might have insufficient flow to pass through highly congested reinforcement. All the mixes in the study conform to the above range, the slump flow of SCC mixes is in the range of 590–675 mm. The slump flow time of the concrete, to reach diameter (500 mm) for all mixes was less than 6 s. As per EFNARC (2002) time ranging from 6 to 12 s is considered adequate for a SCC. The V-funnel flow times were in the range of 4– 10 s. Test results indicate that all SCC mixes meet the requirements of allowable flow time. The L-box ratio (H2/H1) for the mixes was above 0.6. U-box difference in height of concrete in two compartments was in the range of 10–65 mm. All the mixes satisfied the workability criteria for SCC mix.

Sahmaran et al., (2011) studied the fresh properties such as flow ability, passing ability, segregation resistance of self-compacting concrete using spent foundry sand and fly ash. Sixteen SCC mixtures were prepared with the proportions. The Portland cement in the mixtures was replaced with Fly ash at 0, 30, 50 and 70% by mass. For each FA replacement level, about 0, 25, 50 and 100% of sand by volume was replaced with SFS. For all mixtures, the total amount of binder (PC + FA) and the water to binder ratio (w/b) were kept constant at 450 kg/m3 and 0.40, respectively. Super plasticizer was added by an amount to secure the concrete be SCC considering the specifications of The European Guidelines for Self Compacting Concrete. The results for slump flow diameter, slump flow time, V-funnel flow time, and rheological parameters (yield stress and relative viscosity) of the SCC mixtures satisfy the The European Guidelines for Self Compacting Concrete. Moreover, no visible segregation or bleeding was observed in the fresh mixtures. Spread of 50FA-50SFS mixture which was a typical example of the uniform spread of SCC mixtures. Generally, for a given FA content, the super plasticizer requirement increases with SFS content for fresh properties like slump flow diameter .The conclusion, therefore, is that SCC with proper fresh properties can successfully be produced with SFS and FA.

Naik et al., (2009) performed the various tests on the use of foundry silica dust in self compacting concrete. A control mixture was made in which ASTM C 618 Class C fly ash constituted 40% mass of the total cementitious materials. Three more SCC mixtures was made using silica dust obtained from an iron industry. Silica dust was used to replace 10%,20% and 30% of fly ash at a 1:2 (fly ash and foundry dust) ratio by mass. The extra amount of foundry dust was treated as very fine sand. Use of foundry dust in SCC resulted in very high air content values. At 30% replacement of fly ash with foundry silica dust, the super plasticizer demand for SCC increased considerably. The VMA demand decreased as more fly ash was replaced with silica dust. This could be due to the increase in the amount of fines in SCC at higher replacements level. The slump flow of SCC containing the foundry silica dust was in range of 710-725mm,and H2/H1 in the U-flow test was 99%.SCC containing foundry silica dust did not show noticeably higher bleeding than the reference mixture.

2.3 HARDENED CONCRETE PROPERTIES

2.3.1 COMPRESSIVE STRENGTH

Safi et al., (2013) studied the possibility of recycling waste plastic (polyethylene terephthalate (PET) used for the bags manufacture) as a fine aggregate instead of sand in the manufacturing of the self-compacting mortars. For this, an experimental study was carried out to evaluate physical and mechanical properties of the self-compacting mortars (SCMs) with plastic wastes. The sand is substituted with the plastic waste at dosages (0%, 10%, 20%, 30% and 50% by weight of the sand). The compressive strength of self-compacting mortars decreased with increase in plastic waste content at all curing times. At 30% and 50% of substitution of waste, the percentage reduction of compressive strength was 15% and 33% respectively. The reduction in the compressive strength of SCMs might be due to either a poor bond between the cement paste and the plastic wastes or to the low strength of this plastic wastes.

Suaiam and Makul (2013) examined use of recycled alumina as fine aggregate replacement in self-compacting concrete. The fine aggregate was replaced with up to 100% alumina waste AW by weight. The cement content was held constant at 450 or 550 kg/m3. The water content was adjusted to achieve a w/c ratio of 0.38 or 0.45. Mass measurements were preferred to volume measurements due to the significant difference in specific gravity between AW and sand.AW was used to replace natural sand in amounts of 0%, 25%, 50%, 75, or 100% by weight. The compressive strength continued to increase over the 91-day curing period. The 28-day compressive strength ranged from 22.9 to 59.9 MPa , while the 91-day compressive strength ranged from 28.6 to 66.6 MPa. The greatest compressive strength at 28 and 91 days was achieved in the high-cement, low w/c ratio mixture containing 75% AW. Conversely, the lowest compressive strength at all ages occurred in samples containing 0% AW. The increase in strength was ascribed to the filling ability and pozzolanic activity of AW . The added alumina may be amorphous or glassy and reacts with calcium hydroxide produced from the hydration of calcium aluminates. The rate of the pozzolanic reaction is proportional to the amount of surface area available for reaction . The mechanical interlocking capacity between the fine aggregate particles and the matrix phase, which improves the mechanical performance of the transition zone, is related to the compressive strength. Both of these properties improve the microstructure in the bulk paste matrix and transition zone . The compressive strength of concrete increases with curing time.

Moreover, the binding mechanisms of radionuclides to cement eventually enter calcium–silicate–hydrate (C–S–H) . On the other hand, mixtures containing 100% AW possessed lower compressive strengths due to the lack of interlocking between the AW particles indicated by longer V-funnel flow times.

Ali and Al-Tersawy (2013) studied the compressive strength of self-compacting concrete using recycled glass as a partial replacement for fine aggregate. A total of 18 concrete mixes were produced with different cement contents (350, 400 and 450 kg/m3) at W/C ratio of 0.4. Recycled glass was used to replace fine aggregate in proportions of 0%, 10%, 20%, 30%, 40%, and 50%.The reduction in 28 days compressive strength of recycled glass SCC mixes were [6%, 10.4%, 12.7%, 17.5%, 23.2%], [4.5%, 14.4%, 17.2%, 22.2%, 23.6%] and [3.7%, 10.5%, 13.5%, 17.5%, 21%] at cement contents of 350, 400, and 450 kg/m3, respectively. Where the high smoothness of recycled glass waste leading to cracks was determined to lead to incomplete adhesion between the recycled glass waste and cement paste inter-phase. Due to the poor geometry of waste glass a homogeneous distribution of aggregates could not be achieved, accordingly an increase in the amount of glass waste used in 4% in compressive strength, compared with its control mixtures. As the cement content increase from 350 to 450 kg/m3, the rate of loss in compressive strength is lowered compared with the control mixes.

Yung et al., (2013) examined properties of waste tire rubber applied to self-compacting concrete. This study used waste tire rubber as a recycled material and replaced part of the fine aggregate by waste tire rubber powder filtered through #30 and #50 sieves to produce self-compacting rubber concrete (SCRC). Part of the fine aggregate was replaced with waste tire rubber powder that had been passed through sieves at volume ratios of 5%, 10%, 15% and 20%, respectively. The results showed that when 5% waste tire rubber powder that had been passed through a #50 sieve was added, the 91 day compressive strength was higher than the control group by 10%. However, when 5% of the #50 sieved waste tire rubbers were added, the compressive strength was 96% of the control group. The compressive strength of other addition levels was low than that of the control group (32.07 MPa), and the compressive strength declined when the addition level was increased. This result proved that the compressive strength declined as the rubber addition increased. The addition level was only 5% of the total granular material. The strength of the concrete with waste tire rubber powder is generated after hydrate formation. When these hydrates are formed, the compressive strength of the concrete is increased. The compressive strength was higher than the control group by 10% after 91 days. The compressive strength of SCRC was the best when 5% of the waste tire rubber powder that had been passed through a #50 sieve was added (increased by 1–10%), which meant that adding waste tire rubber powder can meet the safety performance requirements of SCRC. This may attributed to the effect of pozzolanic reactions which evolve as the cement content increases with the addition of silica fume and the high percentage of fines produced as the percentage of recycled glass waste increases.The compressive strength of recycled glass SCC mixes decrease with the increase of recycled glass content compared with the control mixtures.

Pathak and Siddique (2012) studied compressive strength of self-compacting concrete containing fly ash and spent foundry sand at elevated temperatures. The influence of fly ash as partial replacement of cement, and spent foundry sand as partial replacement of sand on the properties of SCC is investigated. In this research, mixes were prepared with three percentages of fly ash ranging from 30% to 50% and one controlled mixture without fly ash was also prepared for comparison. Fine aggregate was replaced with 10% of spent foundry sand. The specimens of each concrete mixture were heated up to different temperatures (27 ^{0}C, 100 ^{0}C, 200 ^{0}C, and 300 ^{0}C). In order to ensure a uniform temperature throughout the specimens, the temperature was held constant at the maximum value for 1 h before cooling. Using Ordinary Portland cement, an increase of about 24–25% in compressive strength, was observed at 28 days when fly ash content was decreased from 50% to 30%. Four concrete mixes were made, which had total powder content of 500 kg/m3. Coarse aggregate content was maintained at 51% by volume of concrete and fine aggregate content at 49% by volume of mortar in concrete, the w/p ratio was varied from 0.38 to 0.42 by weight with air content being assumed to be 2%. The compressive strength of concretes elevated temperature was much less than that reported by previous researchers, and this is because of incorporation of fly ash and spent foundry sand. The results of this research clearly showed that the evolution of residual compressive strength between 200 ^{0}C and 300 ^{0}C was due to the hydration of anhydrous cement which leads to the formation of hydrates having better bonding properties. The increase in strength was also due to an increase in the bonding properties of hydrates (a larger compressive strength was obtained for a larger porosity of the material).

Siddique et al.,(2012) investigated the effect of coal fly ash and bottom ash in self-compacting concrete. SCC was made with coal bottom ash as replacement of fine aggregates in varying percentages of 0%, 10%, 20% and 30% and fly ash as replacement of cement in varying percentages of 15–35%. Strength properties tests were carried out at the ages of 28, 90 and 365 days for the various mixes. The results show that difference of compressive strength of various mixes depend on the bottom ash content in the mix. The SCCs without bottom ash developed compressive strengths ranging from 30 to 35, 40 to 60, 43 to 65 MPa at 28, 90 and 365 days, respectively which is the compressive strength commonly used for normal construction applications. It was observed that the strength gain at 90 days and 365 days was within the limits corresponding to the amount of cement content used in the SCC mixes. At 10% replacement of fine aggregates with bottom ash, strengths were observed to be in the range of 25–35 MPa, 33– 47 MPa, and 40–49 MPa at 28, 90, and 365 days, respectively. A gain of strength of about 37% at 28 days and 21% at 365 days (as compared to 18% and 40% for 0% bottom ash) was observed with the decrease in fly ash contents from 35% (M105) to 15% (M101). The gain of strength for 15% and 20% fly ash contents was higher as compared to other mixes in regards to 0% bottom ash mixes. The strength was found to increase with age for all mixes and also with percentages of fly ash varying from 35% to 15% at a particular age. At 20% replacement with bottom ash, strengths were observed to be in the range of 23–29 MPa, 32–40 MPa, and 38–45 MPa at 28, 90, and 365 days respectively. A gain of strength of about 23% at 28 days and 18% at 365 days was observed with the decrease in fly ash contents from 35% (M205) to 15% (M201). For 30% replacement with bottom ash the strength of M301 was observed to be 25.77 MPa at the age of 28 days. In normal concrete also, reduction in strength was observed up to 30% replacement of fine aggregate with bottom ash. 28-day compressive strength for percentages of fly ash (15–35%) and mixes at 10% bottom ash showed 0.3–14% strength decrease, 18–20% strength decrease with 20% bottom ash and 26– 38% decrease with 30% bottom ash in comparison to corresponding mixes with 0% bottom ash. Similarly, 90-day compressive strength for mixes with 10% bottom ash showed 15–21% strength decrease, 18–33% strength decrease with 20% bottom ash and 22–38% decrease with 30% bottom ash in comparison to corresponding mixes with 0% bottom ash. Also, 365-day compressive strength for mixes with 10% bottom ash showed the 7–20% strength decrease, 11–26% strength decrease with 20% bottom ash and 16–32% decrease with 30% bottom ash, in comparison to corresponding mixes with 0% bottom ash. All mixes showed strength gain beyond 28 days and the mixes with 15% and 35% fly ash mixes gained strength of the order of 60 MPa and 40 MPa, respectively at 90 days. However, it was possible to produce SCC with a compressive strength of 40–50 MPa with 15–35% fly ash replacement. The bottom ash could be used up to 20% keeping in view the decrease of strength of about 15–20% (if fly ash percentages with 15% and 20% are not taken into consideration), as they show higher decrease of strength. Thus, the optimum fly ash percentage was 25–35% and bottom ash percentage was up to 20% in the present study. Thus it was concluded that the compressive strength increased with a decrease in the percentage of the fly ash and the water-to-cementitious materials ratio. Increase in bottom ash content resulted in decrease in compressive strength with reference to mix with 0% bottom ash for a specific age for particular fly ash content. Compressive strength of SCC mixes was found to increase with age for all mixes with varying percentages of fly ash and bottom ash.

Nanthagopalan and Santhanam (2011) studied the use of manufactured sand (Msand) in self- compacting concrete. In recent years, manufactured sand (Msand) produced by crushing rock deposits is being identified as a suitable alternative source for river sand in concrete. In this process, an attempt was made to understand the influence of paste volume and w/p ratio (water to powder ratio) on the properties of self-compacting concrete (SCC) using Msand. The powder and aggregate combinations were optimised by using the particle packing approach, which involves the selection of combinations having maximum packing density. The chemical admixtures (super plasticisers, viscosity modifying agent) were optimised based on simple empirical tests. Msand, as compared to river sand low and medium strength (25–60 MPa) SCCs were achieved by using Msand based on the approach adopted in the study. Results showed that it is possible to successfully utilise manufactured sand in producing SCC. For SCC, achieving high strengths is not difficult, due to the presence of high powder content. However, achieving low and medium strength SCC is a difficult task. Therefore, in this investigation, the emphasis was given to achieve low and medium strength SCC. Studies were conducted to investigate the influence of w/p ratio on the compressive strength of SCC. Concrete cubes of dimension 150 mm x 150 mm x 150 mm was cast and moist cured for 28 days. The compression test of concrete cube was performed as per IS 516 . The compressive strengths for the different mixtures varied from 25 MPa to 60 MPa.

Sahmaran et al., (2011) determined the effect of used foundry sand and fly ash as partial replacement of aggregate and cement in self- compacting concrete. Sixteen SCC mixtures were prepared with the proportions . The Portland Cement in the mixtures was replaced with Fly ash at 0, 30, 50 and 70% by mass. For each FA replacement level, about 0, 25, 50 and 100% of sand by volume was replaced with SFS. For all mixtures, the total amount of binder (PC + FA) and the water to binder ratio (w/b) were kept constant at 450 kg/m3 and 0.40, respectively. In all curing ages, the compressive strength of the control mixtures with 0% SFS was higher than the one containing SFS. However, when the strengths at7 and 90 days were compared, it was observed that for a given FA content (except 70%), the SFS-related decrease in strength was lower at 90 days than at 7 days. In 30% FA concretes, the strengths of 0 and 100% SFS at 7 days were 32.0 and 24.1 MPa, respectively, a decrease of 25%. At 90 days, the strength had decreased by only 11%, from 49.4 to 44.0 MPa. Therefore, the beneficial effects of FA observed at later ages partially compensated for the negative impact of SFS on strength. (For 70% FA content, strength loss due to SFS replacement were comparable at 7 and 90 days.) For a given SFS content, the use of FA reduced strengths, especially at 7 days. However, the difference between the concretes with FA and without FA was smaller at 90 days. In fact, 0% FA and 30% FA concretes showed almost the same strengths at all SFS contents , which can be explained by the slow, ongoing pozzolanic reactions of FA during specimen curing. 70% replacement of PC with FA, however, reduced strengths significantly at both ages. Although both SFS and FA were found to reduce strengths, producing SCC with compressive strengths around 40 MPa at 28 days and 50 MPa at 90 days was still possible by using a combination of SFS and FA. With the exception of 70% FA concretes, almost all specimens had strengths higher than 40 MPa. This holds true even at 100% SFS replacement level. Although SFS and FA reduce the strengths, it is still possible to produce SCC with compressive strengths around 40 MPa at 28 days and 50 MPa at 90 days by using both SFS and FA. Strengths over 40 MPa can be reached even at 100% SFS replacement.

Gesoglu and Guneyisi (2011) carried out research to investigate the permeability characteristics of self-compacting rubberized concretes with and without fly ash. At a water–cementitious material (w/cm) ratio of 0.35, the self-compacting concretes (SCCs) were produced by replacing the fine aggregate with four designated crump rubber contents of 0%, 5%, 15%, and 25% by fine aggregate volume. Moreover, the SCCs with fly ash were produced by partial substitution of cement with fly ash at varying amounts of 20% to 60%.. The tests were conducted at 28 and 90 days after casting. The overall compressive strength ranged from 16.2 to 71.3 MPa and from 20.8 to 86.7 MPa at 28 and 90 days, respectively. It was evident that there was a marked reduction in the compressive strength of concretes with increasing rubber content, irrespective of the testing age.

Wang and Huang (2010) investigated the properties of self-compacting glass concrete (SCGC), where liquid crystal glass sand (0%, 10%, 20%, and 30%) is used in place of aggregates. The unit cementing material can be obtained by W/B and the mixing water content. The amount of cementing material in this study was 661 kg/m3, with the cement partially replaced by fly ash and slag. The mixing water content was adjusted to 185 kg/m3, according to the test results. Because the waste LCD glass is hydrophobic with a smooth surface, a large amount of adhesive paste is required to promote the waste LCD glass sand. The SCGC compressive strengths of each group increased with time. Compressive strength increased similarly at 7 days and 28 days. At 90 days, with a glass replacement of 30%, the compressive strength reached 98.4% of the control group’s compressive strength; the smooth surface of the glass sand allowed more cement paste to participate in adhering the glass to the cement mortar, thereby enhancing the concrete strength. The compressive strength of the concretes containing waste LCD glass aggregates decreased with an increase in LCD glass content. The concrete containing 20% waste glass aggregates resulted in the highest strength properties.

Naik et al., (2009) examined the effect of foundry silica dust in self compacting concrete.A control mixture was made in which ASTM C 618 Class C fly ash constituted 40% mass of the total cementitious materials. Three more SCC mixtures was made using silica dust obtained from an iron industry. Silica dust was used to replace 10%,20% and 30% of fly ash at a 1:2 (fly ash and foundry dust) ratio by mass. The extra amount of foundry dust was treated as very fine sand. Compared with reference mixture, some reduction in the 3-day strength and considerable reductions in the 7-day and 28-day strengths were observed when 10–30% of fly ash was replaced with foundry silica-dust. This was attributed to the higher air content and lower density and increased water to- cementitious material ratio, of the SCC mixtures containing foundry silica-dust and the reduction in fly ash content. Further, perhaps organic contaminants in the foundry dust might have also contributed to strength reductions due to interference with cement hydration reactions.

2.3.2 SPLITTING TENSILE STRENGTH

Pathak and Siddique (2012) studied the splitting tensile strength of self- compacting concrete incorporating fly ash as partial replacement of cement and spent foundry sand as partial replacement of sand at elevated temperature. In this research, mixes were prepared with three percentages of fly ash ranging from 30% to 50% and one controlled mixture without fly ash was also prepared for comparison. Fine aggregate was replaced with 10% of spent foundry sand. The specimens of each concrete mixture were heated up to different temperatures (27 ^{0}C, 100 ^{0}C, 200 ^{0}C, and 300 ^{0}C). In order to ensure a uniform temperature throughout the specimens, the temperature was held constant at the maximum value for 1 h before cooling. Using Ordinary Portland cement, an increase of 18–22% in splitting tensile strength was observed at 28 days when fly ash content was decreased from 50% to 30%. Splitting tensile strength increased with the decrease in percentage of fly ash content and the water-to-cementitious materials ratio and decreased with increase in temperature, at all ages and also there is more reduction in splitting tensile strength with increase in temperature from 200 ^{0}C to 300 ^{0}C as compared strength loss of SCC mixes in the temperature range of 27 ^{0}C to 100 ^{0}C.

Siddique et al., (2012) investigated the strength properties of self-compacting concrete containing coal fly ash and bottom ash.SCC was made with coal bottom ash as replacement of fine aggregates in varying percentages of 0%, 10%, 20% and 30% and fly ash as replacement of cement in varying percentages of 15–35%. Strength properties tests were carried out at the ages of 28, 90 and 365 days for the various mixes. The split tensile strength increased with a decrease in the percentage of the fly ash and the water-to-cementitious materials ratio. Increase in bottom ash content resulted in decrease in split tensile strength with reference to mix with 0% bottom ash for a specific age for particular fly ash content. Split tensile strength of SCC mixes was found to increase with age for all mixes with varying percentages of fly ash and bottom ash. Increase in bottom ash decreased the split tensile strength with reference to mix with 0% bottom ash for a specific age for particular fly ash content.

Parra et al.,(2011) conducted experimental work on the splitting tensile strength for self-compacting concretes of different ages. Eight different concretes were used, four self- compacting and four normally-vibrated, with different water/cement ratios and different types of cement. The results obtained show that in self-compacting concretes made with limestone filler the splitting tensile strength is on average 15% less than that of normally-vibrated concretes. This is due to factors that affect aggregate–paste bond, which thus have a greater influence on tensile than compressive strength and can be caused, for example, by using different super plasticizers or higher fines content in the SCCs. If the tensile strength is analysed at different ages, it can be seen that the strength does not evolve in the same way in the two types of concrete. At 7 days the differences between SCC and NVC are small, on average 3.5% . During the early days of hydration the limestone fines rise the rate of hydration of some clinker compounds, especially C_3S, since the fines act as nucleation sites of the hydrates formed in the hydration reactions . In SCCs made with limestone filler, the splitting tensile strength is lower than that of NVCs. At 7 days, the difference between the two concretes is small, and even has a tendency to disappear when the fines content used in the SCCs is high. At higher ages, 28 and 90 days, the differences increase, the average being 15.5%.

2.4 DURABILITY PROPERTIES

2.4.1 RESISTANCE TO SULPHATE ATTACK

Solution of sulphate can attack the hardened cement paste in the concrete causing deterioration. The precise chemical reaction will depend on the nature of the sulphate present and the type of cement. In some clay soils the ground water is solution of magnesium and calcium sulphates. These salts reacts with the $Ca(OH)_2$ and the calcium aluminate hydrate in the concrete to produce gypsum and calcium sulphoaluminate. These products have considerably have greater volume than the compounds they replace, leading to expansion and disruption of the concrete. Sea water and de-icing salt also contain appreciable concentrations of sulphates. The rate and extent of sulphate attack depend upon the ease with which sulphate ions are able to penetrate the concrete and upon the chemical resistance of cement paste.

There have been numerous field studies on the distress caused to concrete structures generated by sulphate attack . In particular, volume of cementitious paste (34–40%) and the larger powder content (400–600 kg/m3) of SCC can make it particularly vulnerable to chemical attack, for example by sulphate solutions. Since the last decade, SCC has been widely used in areas vulnerable to sulphate attack such as substructures, infrastructure and industrial floors. Sulphate attack has often been discussed in terms of the reaction between the hydrates in cement pastes and dissolved compounds, such as sodium sulphate or magnesium sulphate, in the attacking solution (Taylor 1997).

The classical form of sulphate attack involves alkali sulphates such as sodium sulphate which reacts with calcium hydroxide and calcium aluminate hydrate to form gypsum and ettringite. The gypsum and ettringite formed as a result of sulphate attack is significantly more voluminous (1.2–2.2 times) than the initial reactants, which can cause expansion, cracking, and deterioration of concrete by the reaction of SO_2_4 ions (Bonen, 1993). A magnesium sulphate solution may cause the deterioration of concrete due to the formation of Mg-containing hydrates (e.g. M–S–H gel), as well as gypsum and thaumasite. Some researchers have reported on the sulphate resistance imparted by mineral admixtures, which is generally incorporated in concrete to improve its engineering properties and durability.

Uysal and Sumer (2011) reported the effect of different mineral admixtures on self-compacting concrete. Portland cement (PC) was replaced with fly ash (FA), granulated blast furnace slag (GBFS), limestone powder (LP), basalt powder (BP) and marble powder (MP) in various proportioning rates. Sulphate resistance tests involved immersion in 10% magnesium sulphateand 10% sodium sulphate solutions for a period of 400 days. The degree of sulphate attack was evaluated using visual examination and reduction in compressive strength. A thorough visual inspection was carried out after 400 days to evaluate the visible signs of softening, cracking and spalling in the SCC specimens exposed to sulphate attack. Although it was observed that a small amount of spalling at edges and corners of the GBFS40 specimen which showed the best performance exposed to 10% magnesium sulphate solution for 400 days. Different results of visual examination were observed on the control specimen. In addition white substance was deposited on the face of the control specimen it was affected the worst in this solution exhibited relatively severe spalling at edges and corners. The visual examination of SCC specimens stored in the magnesium and sodium sulphate solutions for 400 days, indicated that the intensity of the damage by magnesium sulphate attack was greater than sodium sulphate attack. Compressive strength loss discussed in terms of strength loss in order to highlight the damage caused to SCC mixtures by exposure to sulphate attack. After 400 days exposure in the MgSO4 solution, the amounts of strength loss have been measured in the range of 4.55–13.09% for SCC mixtures. The strength loss decreased as the replacement of mineral admixtures increased; For example, the strength loss of FA35, was about 6.91%, compared to strength loss of 10.34% for the FA15 specimen. It is clear that the mixtures containing GBFS exhibited a much better resistance to magnesium sulphate attack than the mixtures containing other mineral admixtures. Moreover, these results indicate that the incorporation of mineral admixtures leads to reduced strength loss compared with those having only PC (control). The best resistance to sodium sulphate attack was obtained with

GBFS series. However, FA series performed very well resistance to sodium sulphate attack and showed lower strength loss than other series.

2.4.2 RAPID CHLORIDE PERMEABILITY TEST

Pathak and Siddique (2012) studied chloride penetration resistance of self-compacting concrete containing fly ash as partial replacement of cement and spent foundry sand as partial replacement of fine aggregates at elevated temperatures. In this research, mixes were prepared with three percentages of fly ash ranging from 30% to 50% and one controlled mixture without fly ash was also prepared for comparison. Fine aggregate was replaced with 10% of spent foundry sand. The specimens of each concrete mixture were heated up to different temperatures (27 ^{0}C, 100 ^{0}C, 200 ^{0}C, and 300 ^{0}C). In order to ensure a uniform temperature throughout the specimens, the temperature was held constant at the maximum value for 1 h before cooling. It is evident from the results that SCC mixes (SCC2, SCC3, SCC4) made with fly ash and foundry sand reduced the rapid chloride ion penetrability to low range (1000–2000 Coulomb) at the age of 28 days, between low range to very low range (<1000 Coulomb) at the age of 91 and 365 days, as compared with the control mix (SCC1). The incorporation of fly ash and foundry sand resulted in a reduction in coulomb charges. Lower rapid chloride permeability of fly ash concretes can be attributed to the more compact structure of the paste, which is a result of finer fly ash particles than Portland cement. One of the most important factor affecting the permeability of concrete was the internal pore structure, which in turn was dependent on the extent of hydration of the cementitious materials. From the test results it is observed that most concretes become significantly less permeable with increase in curing time. The curing conditions and the age of concrete thus largely determine the ease with which chloride ions can move into the concrete. The high volume fly ash SCC mixes showed significantly lower chloride ion permeability than SCC mixes without fly ash and spent foundry sand. Most of the SCC mixes were assessed as ‘‘very low’’ chloride permeability concretes as per ASTM C 1202-94 assessment criteria, with less than 1000 coulombs of total charge passing. From the test results of this research, it was concluded that most concretes become significantly less permeable with increase in time.

Sahmaran et al., (2011) investigated the permeability of self compacting concrete with fly ash and spent foundry sand. Sixteen SCC mixtures were prepared with the proportions. The Portland Cement in the mixtures was replaced with Fly ash at 0, 30, 50 and

70% by mass. For each FA replacement level, about 0, 25, 50 and 100% of sand by volume was replaced with SFS. For all mixtures, the total amount of binder (PC + FA) and the water to binder ratio (w/b) were kept constant at 450 kg/m3 and 0.40, respectively. The results of RCP tests performed at 28 and 90 days. the use of FA significantly reduced the chloride permeability of the hardened SCC mixtures when compared to the control concretes with 0% FA. For any given SFS content, the reduction was generally greater than 80% for FA replacement levels of 50 and 70% at both 28 and 90 days. The lower RCP of FA concretes can be attributed to the more compact structure of the paste, which is a result of finer FA particles than PC (filler effect) and pozzolanic reactions of FA. Permeability was lower at 90 days than at 28 days, as expected due to the hydration of PC and pozzolanic reactions of FA. The reduction ranged between 15% (for 70% FA and 0% SFS concrete) and 63% (for 30% FA and 100% SFS concrete).The results also showed that the rapid chloride permeability of most concretes containing FA and SFS was below 750 coulomb at 90 days, which indicate relatively high-quality SCC mixtures from rapid chloride permeability standpoint (ASTM C 1202 classifies the chloride ion penetrability of a concrete as ‘‘very low’’ as long as the charge passed is between 100 and 1,000 coulomb). When FA with low lime and low alkali contents, is used to partially replace PC, the concentration of alkali ions and associated hydroxyl ions in the pore solution generally decreases significantly, and the extent of this reduction depends also on FA replacement level . Because of the expected differences in electrical resistance between SCC mixtures, however, the electrical conductivity values may also be different. As a result, the RCPT values may reflect this difference and therefore should be interpreted with care. Although SFS has a detrimental effect on chloride permeability, this effect is very minor (especially when the SFS amount is 50% or less) provided that the mixtures contain FA. In such mixtures, total charge passed below 900 coulombs at 90 days.

CHAPTER: 3

EXPERIMENTAL PROGRAMME

3.1 GENERAL

The chapter describes the details of experimental programs for the measurements of fresh properties, strength properties (compressive strength, splitting tensile strength) and durability properties such as sulphate attack and rapid chloride permeability of self-compacting concrete mixes made with varying percentages of waste foundry sand as partial replacement of fine aggregates. The basic tests carried out on concrete samples are discussed in this chapter, followed by a brief description about mix deign and curing procedure adopted. At the end, the various tests conducted on the specimens are discussed.

3.2 MATERIALS USED

3.2.1 CEMENT

Ordinary Portland Cement (OPC) Grade 43 JK cement was used for casting cubes and cylinders for all concrete mixes.

Table 3.1: Physical Properties of Ordinary Portland Cement

Physical Properties	**BIS- 8112:1989**	**Test Results**
Standard Consistency (%)		29.5
Setting time (min)		
Initial	30 Min.	92
Final	600 Max	248
Compressive Strength (MPa)		
3 day	23	24.5
7 day	37.5	39.1
28 day	43	47.8
Specific gravity	_	3.12

The cement was of uniform colour i.e. grey with a light greenish shade and was free from any hard lumps. It was tested as per Indian standard specification (BIS-8112:1989). Test results are given in Table 3.1 as above.

3.2.2 FINE AGGREGATES

The sand used for the experimental programme was locally procured and conformed to Indian Standard Specifications BIS: 383-1970. The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm.The aggregates were sieved through a set of sieves to obtain sieve analysis.Aggregates used were in dry state and correction for water absorption was made. The fine aggregated belonged to grading zone II. Its physical properties and sieve analysis are given in Tables 3.2 and Table 3.3 respectively.

Table 3.2: Physical Properties of Fine Aggregate

Characteristics	**Value**
Specific gravity	2.57
Bulk density	1.3
Fineness modulus	2.65
Water absorption	1.2
Grading Zone (Based on percentage passing 0.60 mm)	Zone II

Table 3.3: Sieve Analysis of Fine Aggregates

Weight of the sample taken = 1.0 kg

I.S. Sieve Size	Weight retained in Grams	Percentage weight retained in grams	Cumulative percentage of Weight Retained	Percentage Passing	BIS: 383-1970 Requirement for Zone II
10.0mm	00	00	00	100	100
4.75mm	17	1.7	1.7	98.3	90-100
2.36mm	73	7.3	9	91	75-100
1.18mm	241.5	24.15	33.15	66.85	55-90
600µm	166.5	16.65	49.5	50.20	35-59
300µm	256.5	25.65	75.45	24.55	8-30
150µm	216	21.6	97.05	2.95	0-10
Pan	29.5	2.95	100	0	--

Fineness modulus of fine aggregate = 2.65

The sand conforms to grading zone II as per BIS: 383-1970

3.2.3 COARSE AGGREGATES

The material which is retained on IS sieve no. 4.75 is termed as a coarse aggregate. The crushed stone is generally used as a coarse aggregate.. Locally available coarse aggregate having the maximum size of 10 mm was used.The aggregates used were dry condition and correction of absorption was taken. The aggregates were tested as per IS: 383-1970.Physical properties and sieve analysis results are given in Tables 3.4 and Table 3.5 respectively.

Table 3.4: Physical Properties of Coarse Aggregates (10mm)

Properties	Observed values
Colour	Grey
Maximum size (mm)	10
Specific Gravity	2.65
Total Water Absorption (%)	0.70
Moisture content (%)	Nil

Table 3.5: Sieve Analysis of Coarse Aggregates

Weight of the sample taken = 3.0 kg.

I.S. Sieve Size	Weight Retained in grams	Percentage Weight Retained in grams	Cumulative percentage of weight retained	Percentage Passing	BIS: 383-1970 Requirement
80mm	00	00	00	100	----
40mm	00	00	00	100	----
20mm	00	00	00	100	----
10mm	1815	60.5	60.5	39.5	40-85
4.75mm	1103.5	36.78	97.28	2.72	0-10
2.36mm	78.5	2.62	99.90	0.1	0-2
Pan	3	0.1	100	0	----

Fineness modulus of coarse aggregate = 7.57

Coarse aggregates conformed to BIS: 383- 1970.

3.2.4 WATER

Generally, water that is suitable for drinking is satisfactory for use in concrete. Water from lakes and streams that contain marine life also usually is suitable. When water is obtained from sources mentioned above, no sampling is necessary. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent tap water is used for casting.

3.2.5 USED FOUNDRY SAND

Foundry sand obtained from Insaf foundry, Model Town, Mandi Gobindgarh, Punjab was used. The physical properties and sieve analysis of foundry sand are given in the Tables 3.6 and 3.7 respectively.

Fig: 3.1 Used Foundry Sand

Table.3.6: Physical Properties of Foundry Sand

Properties	**Observed values**
Colour	Grey(Blackish)
Fineness Modulus	1.23
Specific Gravity	2.43
Water Absorption (%)	1.21

Table.3.7: Sieve Analysis of Waste Foundry Sand

Weight of the sample taken = 1.0 kg

I.S. Sieve Size	**Weight retained in Grams**	**Percentage weight retained in grams**	**Cumulative percentage of weight Retained**	**Percentage Passing**
4.75mm	00	00	00	100
2.36mm	11	1.1	1.1	98.9
1.18mm	7.0	0.7	1.8	98.2
600µm	11	1.1	2.9	97.1
300µm	222.5	22.25	25.15	74.85
150µm	674.5	67.45	92.6	7.4
Pan	74	7.4	100	00

Fineness modulus of waste foundry sand 1.23

3.2.6 ADMIXTURE

Auramix 400 of FOSROC brand is a high performance superplasticizer intended for applications where high water reduction and long workability retention are required, and it has been developed for use in Self Compacting concrete , Pumped concrete , Concrete requiring long workability retention ,High performance concrete. It is based on a polycarboxylic ether polymer with long lateral chains. This greatly improves cement dispersion. At the start of the mixing process an electrostatic dispersion occurs but the cement particle's capacity to separate and disperse. Its specific gravity is 1.11. This mechanism considerably reduces the water demand in flowable concrete. It combines the properties of water reduction and workability retention. It allows the production of high performance concrete and/or concrete with high workability. Specifications of super plasticizer are given in Table 3.8

Table 3.8: Specifications of Superplasticizer

Basis	Aqueous solution of modified polycarboxylate
Appearance	Light yellow coloured liquid
Volumetric mass	1.105 ± 0.02 kg/litre @ 20^0C
pH	Minimum 6
Chloride content	Nil to IS:456
Alkali content	Typically less than 1.5 g Na_2O equivalent / litre of admixture.

3.2.7 MAGNESIUM SULPHATE

Powder form of magnesium sulphate was obtained from Scientific Junction, Patiala. It was white in colour. Its solution of strength 5% by adding it to water was made and used for sulphate resistance test.

3.3 CASTING AND CURING

Before casting, the entire test specimen were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage of slurry. Careful procedure was adopted in the batching, mixing and casting operations. The coarse aggregates and fine aggregates were weighed first with an accuracy of 0.5 grams. The concrete mixture was prepared in pan mixer . Initially, the coarse and fine aggregates were mixed thoroughly by dry mixing in pan mixer. To this mixture, the cement was added. These were mixed to uniform colour. Then water was added carefully so that no water was lost during mixing and admixture was added along with it.After proper mixing concrete is checked for fresh properties, if concrete mix fulfil the workability requirements then only it can be classified as Self-compacting Concrete and the specimens are casted. For each mix 30 samples were prepared, which consists of 9 cubes (150x150x150) for 7 , 28 and 56 days compressive strength , 9 (300x150) cylinders for split tensile strength at 7 , 28 and 56 days and 3 cylinders (200x100) for RCPT and 9 cubes(150x150x150) for 7 ,28 and 56 days for sulphate resistance test.

3.4 MIX PROPORTION OF SELF-COMPACTING CONCRETE

Table 3.9: Test data for materials

<table>
<tr><td colspan="2">Type of Cement</td><td colspan="2">OPC</td></tr>
<tr><td colspan="2">Specific gravity of cement</td><td colspan="2">3.12</td></tr>
<tr><td colspan="2">Specific gravity of Coarse Aggregate</td><td colspan="2">2.65</td></tr>
<tr><td colspan="2">Specific gravity of Fine Aggregate</td><td colspan="2">2.75</td></tr>
<tr><td colspan="2">Specific gravity of Admixture</td><td colspan="2">1.11</td></tr>
<tr><th>Material</th><th>Water Absorption</th><th>Free Moisture</th><th>Total Correction</th></tr>
<tr><td>Coarse aggregate</td><td></td><td></td><td></td></tr>
<tr><td>10mm</td><td>0.70%</td><td>0.00%</td><td>0.00%</td></tr>
<tr><td>Fine Aggregate</td><td></td><td></td><td></td></tr>
<tr><td>River Sand</td><td>1.20%</td><td>0.00%</td><td>1.20%</td></tr>
</table>

Table 3.10 : All in Grading

IS SIEVE	Cumlative perctange passing		Combined Aggregate			Specified Limits NC		Specified Limits SCC	
	10mm	Sand	10mm	Sand	Cumulative	Lower	Upper	Lower	Upper
			40%	60%					
40	100	100	40	60	100	100	100	100	100
20	100	100	40	60	100	95	100	95	100
10	39.50	100	15.80	60	75.80	40	70	72	94
4.75	2.71	98.30	1.08	58.98	60.06	30	50	46	77
2.36	0.10	91	0.04	54.60	54.64	22	40	29	63
1.18	0.00	66.85	0.00	40.11	40.11	15	36	18	45
0.6	0.00	50.20	0.00	30.12	30.12	10	35	13	37
0.3	0.00	24.55	0.00	14.73	14.73	3	12	9	23
0.15	0.00	2.95	0.00	1.77	1.77	0	6	4	10
0.075	0.00	0.00	0.00	0.00	0.00	0	0	0	0

Coarse Aggregate		Fine Aggregate	
40.00%		60.00%	
20 mm	10 mm	C.Sand	R.Sand
0.00%	100%	0.00%	100%

Target Mean Strength of concrete	33.25
Water/Cementetious ratio	0.43
Water/Cement ratio	0.43

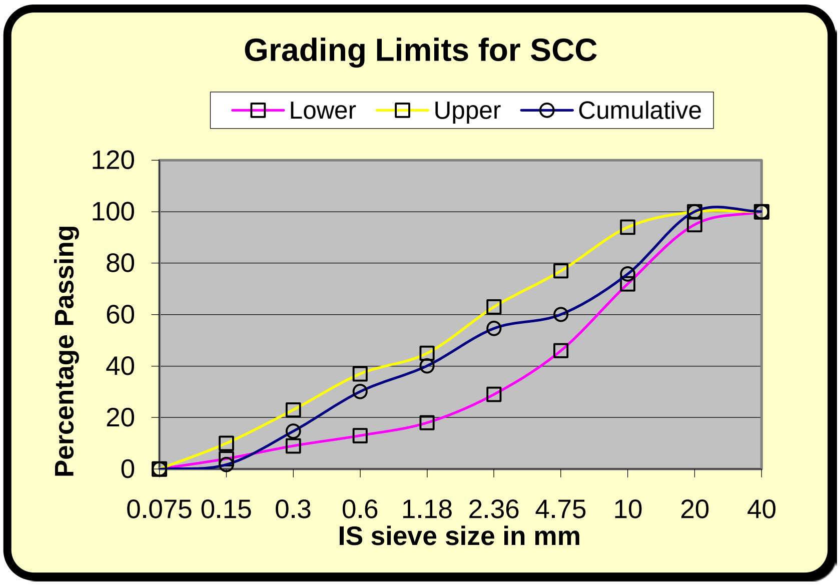

Fig.3.2 Grading limits for SCC

Table 3.11:Mix Proportion without water correction

Cement			450.00
Total Cementetious			450.00
Free Water content			193.50
Fine Aggregate	60%		
R. Sand	100%		1021.22
Coarse Aggregate	40%		
10mm	100%		702.01
Admixture			
auromix400		0.80%	3.60
TOTAL		0.80%	2370.33

Table 3.12: Correction

Material	Total Correction
Coarse aggregate	
10mm	4.914037692
Fine Aggregate	
River Sand	12.25462985
Total	**17.16866754**

Table 3.13: Ingredients in SSD condition Qty./m^3

Cement	450.00
Total Cementetious	450.00
Total Water content	210.67
Fine Aggregate	1008.96
Coarse Aggregate(10mm)	697.09
Admixture	3.6
Total	2370.32

w/c 0.47

The mix proportions of SCC are given below in Table 3.14.

Table 3.14 : Mix proportions

Mixture ID	**Cement kg/m^3**	**WFS Kg/m^3**	**Sand kg/m^3**	**C.A kg/m^3**	**Water (kg/m^3)**	**w/p**	**SP (kg/m^3)**	**SP (%)**
CM	450	0	1008	697	210.67	0.47	3.6	0.8
10%WFS	450	100.8	907.2	697	210.76	0.47	3.6	0.8
15%WFS	450	151.2	856.8	697	210.67	0.47	3.6	0.8
20%WFS	450	201.6	806.4	697	210.67	0.47	3.6	0.8

Where,

WFS: Waste Foundry Sand,

CA : Coarse Aggregates,

CM : Control Mix,

SP : Auramix 400

3.5 TESTING PROCEDURE

After required period of curing, the specimens were taken out of the curing tank and their surfaces were wiped off. Besides measuring the fresh properties(U- Box,L-Box,V-Funnel,Slump flow test), following tests were performed on hardened concrete.

3.5.1 STRENGTH PROPERTIES

Compressive strength	(BIS: 516 – 1959)
Splitting tensile strength	(BIS: 5816 – 1999)

These properties were determined at the age of 7, 28 and 56 days.

3.5.2 DURABILITY PROPERTIES

Sulphate resistance	(ASTM C 1012)
Rapid chloride permeability test	(ASTM C 1202)

The specimen properties were determined at the age of 7,28 and 56 days for compressive strength,splitting tensile strength and sulphate resistance test.For Rapid chloride permeability test specimens were tested at age of 28 days.

3.6 TESTS CONDUCTED

3.6.1 FRESH CONCRETE TESTS

A concrete mix can only be classified as Self-compacting Concrete if the requirements for all three characteristics are fulfilled :

- Filling Ability: Ability of to fill a formwork completely under its own weight.
- Passing Ability: Ability to overcome obstacles under its own weight without hindrance. Obstacles are e.g. reinforcement and small openings etc.
- Segregation Resistance: Homogeneous composition of concrete during and after the process of transport and placing.

It is important to appreciate that none of the test methods for SCC has yet been standardised, and the tests described are not yet perfected or definitive.

3.6.1.1 U- BOX TEST METHOD

Introduction:

The test was developed by the Technology Research Centre of the Taisei Corporation in Japan. Sometimes the apparatus is called a “box-shaped” test. The test is used to measure the filling ability of self-compacting concrete. The apparatus consists of a vessel that is divided by a middle wall into two compartments, shown by R1 and R2 in Figure 3.3.

An opening with a sliding gate is fitted between the two sections. Reinforcing bars with nominal diameters of 13 mm are installed at the gate with centre-to-centre spacing of 50 mm. This creates a clear spacing of 35 mm between the bars. The left hand section is filled with about 20 litre of concrete then the gate lifted and concrete flows *upwards* into the other section. The height of the concrete in both sections is measured.

Assessment of test

This is a simple test to conduct, but the equipment may be difficult to construct. It provides a good direct assessment of filling ability – this is literally what the concrete has to do – modified by an unmeasured requirement for passing ability. The 35mm gap between the sections of reinforcement may be considered too close. The question remains open of what filling height less than 30 cm. is still acceptable.

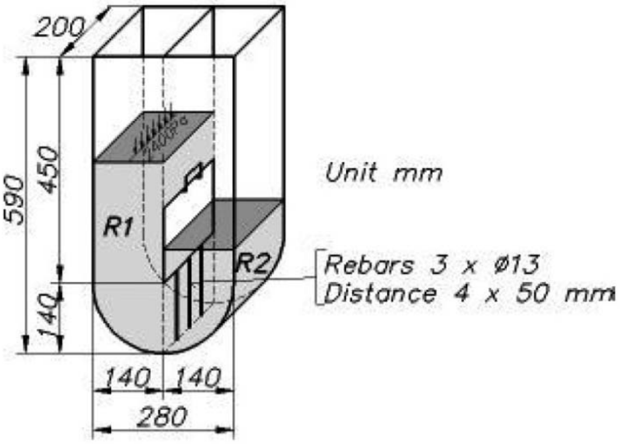

Figure 3.3: U box. (EFNARC, 2002).

Equipment

- U box of a stiff non absorbing material see figure 3.3.
- trowel
- scoop
- stopwatch

Procedure

About 20 litre of concrete is needed to perform the test, sampled normally. Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it. Moisten the inside surfaces of the apparatus, remove any surplus water. Fill the one compartment of the apparatus with the concrete sample. Leave it to stand for 1 minute. Lift the sliding gate and allow the concrete to flow out into the other compartment.

After the concrete has come to rest, measure the height of the concrete in the compartment that has been filled, in two places and calculate the mean (H1). Measure also the height in the other compartment (H2)

Calculate H1 - H2, the filling height.

The whole test has to be performed within 5 minutes.

Interpretation of result

If the concrete flows as freely as water, at rest it will be horizontal, so H1 - H2 = 0. Therefore the nearer this test value, the ‘filling height’, is to zero, the better the flow and passing ability of the concrete.

3.6.1.2 L- BOX TEST METHOD

Introduction

This test is based on a Japanese design for underwater concrete. The test assesses the flow of the concrete, and also the extent to which it is subject to blocking by reinforcement. The apparatus is shown in Figure 3.4.

The apparatus consists of a rectangular-section box in the shape of an ‘L’, with a vertical and horizontal section, separated by a moveable gate, in front of which vertical lengths of reinforcement bar are fitted. The vertical section is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. When the flow has stopped, the height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H2/H1in the diagram). It indicates the slope of the concrete when at rest. This is an indication passing ability, or the degree to which the passage of concrete through the bars is restricted. The horizontal section of the box can be marked at 200mm and 400mm from the gate and the times taken to reach these points measured. These are known as the T20 and T40 times and are an indication for the filling ability.The sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, 3x the maximum aggregate size might be appropriate.

The bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete.

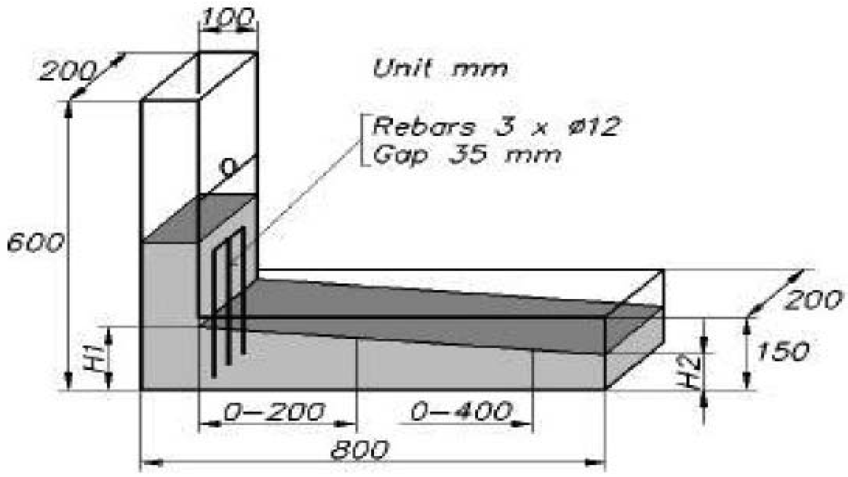

Figure 3.4: L box. (EFNARC, 2002).

Assessment of test

This is a widely used test, suitable for laboratory, and perhaps site use. It assesses filling and passing ability of SCC, and serious lack of stability (segregation) can be detected visually. Segregation may also be detected by subsequently sawing and inspecting sections of the concrete in the horizontal section. Unfortunately there is no agreement on materials, dimensions, or reinforcing bar arrangement, so it is difficult to compare test results. There is no evidence of what effect the wall of the apparatus and the consequent ‘wall effect’ might have on the concrete flow, but this arrangement does, to some extent, replicate what happens to concrete on site when it is confined within formwork.Two operators are required if times are measured, and a degree of operator error is inevitable.

Equipment

- L box of a stiff non absorbing material see Figure 3.4.
- Trowel
- scoop
- stopwatch

Procedure

About 14 litre of concrete is needed to perform the test, sampled normally.

Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it. Moisten the inside surfaces of the apparatus, remove any surplus water. Fill the vertical section of the apparatus with the concrete sample. Leave it to stand for 1 minute. Lift the sliding gate and allow the concrete to flow out into the horizontal section. Simultaneously, start the stopwatch and record the times taken for the concrete to reach the 200 and 400 mm marks. When the concrete stops flowing, the distances “H1” and “H2” are measured. Calculate H2/H1, the blocking ratio. The whole test has to be performed within 5 minutes.

Interpretation of result

If the concrete flows as freely as water, at rest it will be horizontal, so H2/H1 = 1. Therefore the nearer this test value, the ‘blocking ratio’, is to unity, the better the flow of the concrete. The EU research team suggested a minimum acceptable value of 0.8. T20 and T40 times can give some indication of ease of flow, but no suitable values have been generally agreed. Obvious blocking of coarse aggregate behind the reinforcing bars can be detected visually.

3.6.1.3 V-FUNNEL TEST METHOD

Introduction

The test was developed in Japan and used by Ozawa. The equipment consists of a V-shaped funnel, shown in Figure 3.5. An alternative type of V-funnel, the O funnel, with a circular section is also used in Japan. The described V-funnel test is used to determine the filling ability (flow ability) of the concrete with a maximum aggregate size of 20mm. The funnel is filled with about 12 litres of concrete and the time taken for it to flow through the apparatus measured. After this the funnel can be refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly.

Assessment of test

Though the test is designed to measure flow ability, the result is affected by concrete properties other than flow. The inverted cone shape will cause any liability of the concrete to block to be reflected in the result – if, for example there is too much coarse aggregate. High flow time can also be associated with low deformability due to a high paste viscosity, and with high inter-particle friction. While the apparatus is simple, the effect of the angle of the funnel and the wall effect on the flow of concrete are not clear.

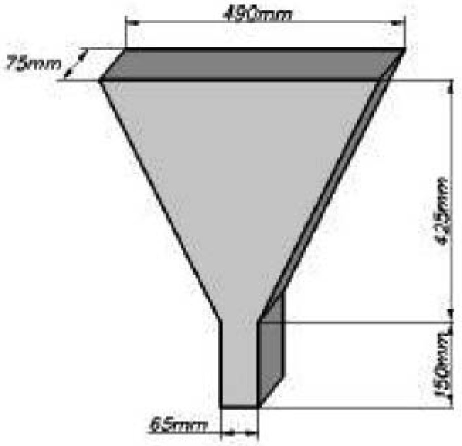

Figure 3.5: V- Funnel equipment. (EFNARC, 2002).

Equipments

- V-funnel
- bucket (±12 litre)
- trowel
- scoop
- stopwatch

Procedure flow time

About 12 litre of concrete is needed to perform the test, sampled normally. Set the V-funnel on firm ground. Moisten the inside surfaces of the funnel. Keep the trap door open to allow any surplus water to drain. Close the trap door and place a bucket underneath. Fill the apparatus completely with concrete without compacting or tamping, simply strike off the concrete level with the top with the trowel. Open within 10 sec after filling the trap door and allow the concrete to flow out under gravity. Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (the flow time). This is taken to be when light is seen from above through the funnel. The whole test has to be performed within 5 minutes.

Interpretation of result

This test measures the ease of flow of the concrete; shorter flow times indicate greater flow ability. For SCC a flow time of 10 seconds is considered appropriate. The inverted cone shape restricts flow, and prolonged flow times may give some indication of the susceptibility of the mix to blocking. After 5 minutes of settling, segregation of concrete will show a less continuous flow with an increase in flow time.

3.6.1.4 SLUMP FLOW TEST

Introduction

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan for use in assessment of underwater concrete. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for the filling ability of the concrete.

Assessment of test

This is a simple, rapid test procedure, though two people are needed if the T_{50} time is to be measured. It can be used on site, though the size of the base plate is somewhat unwieldy and level ground is essential. It is the most commonly used test, and gives a good assessment of filling ability. It gives no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation. It can be argued that the completely free flow, unrestrained by any boundaries, is not representative of what happens in practice in concrete construction, but the test can be profitably be used to assess the consistency of supply of ready-mixed concrete to a site from load to load.

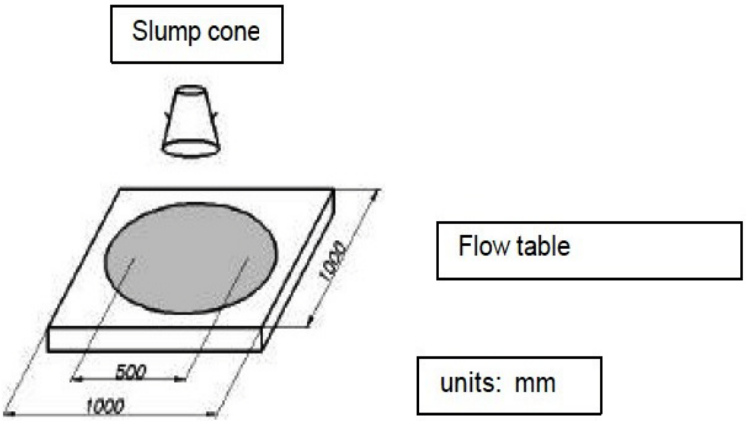

Figure 3.6: Slump flow test equipment. (EFNARC, 2002).

Equipment

The apparatus is shown in Figure 3.6

- Mould in the shape of a truncated cone with the internal dimensions 200 mm diameter at the base, 100 mm diameter at the top and a height of 300 mm, conforming to EN 12350-2
- Base plate of a stiff non absorbing material, at least 700mm square, marked with a circle marking the central location for the slump cone, and a further concentric circle of 500mm diameter
- trowel
- scoop
- ruler
- stopwatch (optional)

Procedure

About 6 litre of concrete is needed to perform the test, sampled normally. Moisten the base plate and inside of slump cone, Place base plate on level stable ground and the slump cone centrally on the base plate and hold down firmly. Fill the cone with the scoop. Do not tamp, simply strike off the concrete level with the top of the cone with the trowel. Remove any surplus concrete from around the base of the cone. Raise the cone vertically and allow the concrete to flow out freely. Simultaneously, start the stopwatch and record the time taken for the concrete to reach the 500mm spread circle. (This is the T50 time). Measure the final diameter of the concrete in two perpendicular directions. Calculate the average of the two measured diameters. (This is the slump flow in mm). Note any border of mortar or cement paste without coarse aggregate at the edge of the pool of concrete.

Interpretation of result

The higher the slump flow (SF) value, the greater its ability to fill formwork under its own weight. A value of at least 650mm is required for SCC. There is no generally accepted advice on what are reasonable tolerances about a specified value, though ± 50mm, as with the related flow table test, might be appropriate. The T50 time is a secondary indication of flow. A lower time indicates greater flow-ability. The Brite EuRam research suggested that a time of 3-7 seconds is acceptable for civil engineering applications, and 2-5 seconds for housing applications. In case of severe segregation most coarse aggregate will remain in the centre of the pool of concrete and mortar and cement paste at the concrete periphery. In case of minor segregation a border of mortar without coarse aggregate can occur at the edge of the pool of concrete. If none of these phenomena appear it is no assurance that segregation will not occur since this is a time related aspect that can occur after a longer period.

3.6.2 HARDENED CONCRETE TEST

3.6.2.1 COMPRESSIVE STRENGTH TEST (BIS: 516 – 1959)

Apparatus

Testing Machine - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified. The permissible error shall be not greater than ± 2 percent of the maximum load. The testing machine shall be equipped with two steel bearing platens with hardened faces. One of the platens (preferably the one that normally will bear on the upper surface of the specimen) shall be fitted with a ball seating in the form of a portion of a sphere, the centre of which coincides with the central point of the face of the platen. The other compression platen shall be plain rigid bearing block. The bearing faces of both platens shall be at least as large as, and preferably larger than the nominal size of the specimen to which the load is applied. The bearing surface of the platens, when new, shall not depart from a plane by more than 0.01 mm at any point, and they shall be maintained with a permissible variation limit of 0.02 mm. The movable portion of the spherically seated compression platen shall be held on the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction.

Age at Test

Tests shall be made at recognized ages of the test specimens, the most usual being 7 and 28 days. The ages shall be calculated from the time of the addition of water to the dry ingredients.

Number of Specimens

At least three specimens, preferably from different batches, shall be made for testing at each selected age.

Procedure

Cube specimens of size 150mm were cast for compressive strength as per Indian standard specifications BIS: 516-1959. After casting, all tests specimens were finished with steel trowel. Immediately after finishing, the specimens were covered with sheets to minimize the moisture loss from them. Specimens were demoulded after 24-hours and then cured in water at approximately room temperature till testing. Compressive strength tests for cubes were carried out at 7, 28 and 56 days. All the specimens were tested in an automated CTM shown in Fig.3.7

The compressive strength was then calculated according to the formula:

$$\sigma = P / A$$

Where σ = Compressive Strength (N/mm^2)

P = Maximum load (N)

A = Cross section area of cube (mm^2)

Fig. 3.7 Compressive Strength Test

3.6.2.2 SPLITTING TENSILE STRENGTH TEST (BIS 5816 : 1999)

Apparatus

Compression Testing Machine

Any compression machine of reliable type, of sufficient capacity for the tests and capable of applying the load. The load shall be applied without shock and increased continuously at a nominal rate within the range 1.2 N/(mm^2/min) to 2.4 N/ (mm^2 /min). shall be used. It shall comply with the requirements given in BIS 516 as far as applicable except that the bearing faces of both platens shall provide a minimum loading area of 12 mm x the length of the cylinder or cube, as the case may be so that the load is applied over the entire length of the specimen. If necessary, a supplementary bearing bar or plate of machined steel may be used.

Materials

6” x 12” Moist cured concrete cylinders

Number of specimens

At least three specimens shall be tested for each age of tests.

Age at test

Tests shall be made at the recognized ages of the test specimens, the most usual being 7 and 28 days. The splitting tensile strength is well known indirect test used for determining the tensile strength of concrete. Tensile strength is one of the most important fundamental properties of concrete. An accurate prediction of tensile strength of concrete will help in mitigating cracking problems, improve shear strength prediction and minimize the failure of concrete in tension due to inadequate methods of tensile strength prediction. The splitting tensile strength was determined at the age of 7, 28 and 56 days on cylinders 150 mm x 300 mm as per Indian standard specifications BIS: 516-1959. The test consists of applying compressive line loads along the opposite generators of a concrete cylinder placed with its axis horizontal between the plates. Due to the applied line loading a fairly uniform tensile stress is introduced over nearly two third of the loaded diameter as obtained from an elastic analysis.

Procedure

Central lines shall be drawn on the two opposite faces of the cube using any suitable procedure and device that will ensure that they are in the same axial plane. The mass and dimensions of the specimen shall be noted before testing. The sides of the specimen, lying in the plane of the pre-marked lines, shall be measured near the ends and the middle of the specimen and the average taken to the nearest 0.2 mm. The length of the specimen shall be taken to the nearest 0.2 mm by averaging the two lengths measured in the plane containing the pre-marked lines. Before placing of the Specimen in the testing machine the bearing surfaces of the testing machine and of the loading strips shall be wiped clean.The test specimen shall be placed in the centring jig with packing strip and/or loading pieces carefully positioning along the top and bottom of the plane of loading of the specimen. The jig shall then be placed in the machine so that the specimen is located centrally. In the case ofcubic specimens, the load shall be applied on the moulded faces in such a way that the fracture plane will cross the trowelled surface. For cylindrical specimen it shall be ensured that the upper platen is parallel with the lower platen. The load shall be applied without shock and increased continuously at a nominal rate within the range 1.2 N/(mm^2 /min) to 2.4 N/ (mm^2 $^{/}$min).The load ‘P’ is applied (as line load) on the cylinder specimen in compression testing machine.At failure load P the specimen fails by splitting along the loaded diameter as shown in Fig. 3.8.

The magnitude of this tensile stress (acting in a direction perpendicular to the line of action of applied compression) is given by

$$\Sigma = 2P/\pi Dl$$

Where Σ = Tensile Stress (N/mm^2)
P = Applied load at failure (N)
D = Diameter of cylinder (mm)
L = Length of cylinder (mm)

Fig. 3.8 Splitting Tensile Strength

3.6.3 DURABILITY TEST

3.6.3.1 SULPHATE RESISTANCE TEST (ASTM C 1012)

Tests performed for sulphate resistance in this work are compressive strength test after immersing the cube specimen in 5% magnesium sulphate solution for 7, 28 and 56 days. Before immersing them in sulphate solution, specimens are cured for 28 days in water under normal temperature. Compressive strength test is then conducted on the specimens.

3.6.3.2 RAPID CHLORIDE PERMEABILITY TEST (ASTM C 1202)

The rapid chloride permeability test was originally developed for the Federal Highway Administration (FHWA) by the Portland Cement Association (Whiting,1981) to provide a rapid test method that correlated well with ponding tests, such as AASHTO T 259. Ponding tests are considered to be the best method of determining the chloride permeability of concrete, but they take 90 days or more to complete, making them impractical for project quality assurance testing.Two very similar standards (AASHTO T 277 and ASTM C 1202) describe the rapid chloride permeability test. The tests are performed using 2 in. (51 mm) long, 3.75 in. (95 mm) diameter cylindrical specimens cut from cores obtained with a diamond-dressed coring bit (alternatively, tests are performed using 4 in. (100 mm) diameter cast cylinders, and the test values are normalized using the ratio of the standard to the actual cross-sectional areas).After the curved surface of a test specimen is coated with epoxy, the specimen is vacuum saturated with water Rapid Chloride Permeability Tests and then soaked for 18 hours. As shown in Fig. 3.9. and Fig. 3.10. The specimen is then placed in the testing apparatus where one end of the specimen is exposed to a solution containing sodium chloride (NaCl) and the other end is exposed to a solution containing sodium hydroxide (NaOH). To increase the rate of chloride penetration into the specimen, thus speeding up the test, a constant 60 V potential is applied across the specimen. The current across the specimen is measured at least every 30 minutes during the 6-hour test. In theory, as the chlorides penetrate deeper into the concrete, the pore solution becomes more conductive and the current readings

increase. In concretes with high conductivity values, however, these effects are small relative to changes in conductivity due to temperature rise. To reduce the effects of heating and resultant changes in conductivity over the 6-hour period of the test, it’s been suggested that earlier values be adjusted to obtain an equivalent 6-hour coulomb value. For example, data taken at 30 minutes would be multiplied by 12 to obtain an equivalent 6-hour value. Because the test results are highly variable (as with most, if not all, penetration resistance tests), two or three specimens are usually tested for each concrete sample. The total charge passing through the specimen (in coulombs) is found by calculating the total area under the plot of time versus current. Therefore, higher coulomb values at the completion of the test indicate higher permeability. The original researchers found good correlation between the coulomb values and the results of ponding tests performed on specimens from the same mixture for a wide variety of concretes.

Fig.3.9: Rapid chloride permeability test set up (ASTM C 1202).

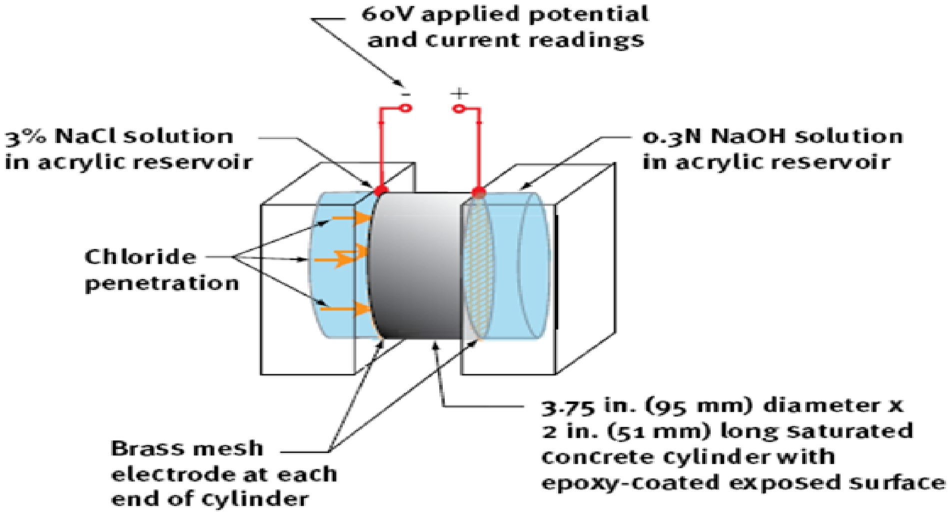

Fig.3.10: Schematic of rapid chloride permeability test setup(www.google.com)

The rapid chloride permeability test does not, however, directly measure the depth or rate of chloride penetration. This makes it difficult to directly correlate results from the test with a desired service life and has led to a significant amount of debate about the proper use and applicability of the test. It should also be noted that, in quality control and acceptance testing applications, ASTM C 1202 recommends the use of the qualitative terms shown in the right-hand column of Table 3.15, rather than the numerical results of the test.

Table 3.15: Chloride Ion Penetrability Based on Charge Passed (ASTM C1202)

Charge passed (Coulomb)	**Chloride Ion Penetrability**
> 4000	High
2000 – 4000	Moderate
1000- 2000	Low
100 – 1000	Very Low
< 100	Negligible

CHAPTER: 4

RESULTS AND DISCUSSION

4.1 GENERAL

In this chapter, the findings of experimental investigations are presented. In which, various tests were conducted to evaluate the effect of waste foundry sand on compressive strength, splitting tensile strength, rapid chloride penetration resistance and sulphate resistance of concrete.Waste foundry sand was used as a partial replacement of fine aggregate at the percentage of 0, 10, 15 and 20%. Design of different concrete mix and procedure of various tests are described in chapter 3.

4.2 EFFECT OF WASTE FOUNDRY SAND ON SCC

4.2.1 FRESH CONCRETE PROPERTIES

In order to study the effect on fresh concrete properties when waste foundry sand is used as a partial replacement of fine aggregate into the concrete ,SCC containing different proportion of waste foundry sand were tested for Slump flow, V-funnel, U-Box, L-box. The results of fresh properties of all Self-compacting concretes with waste foundry sand are included in Table 4.1. The table shows the properties such as slump flow, V-funnel flow times, L-box, U- box. In terms of slump flow, all SCCs exhibited satisfactory slump flows in the range of 550–800 mm, which is an indication of a good deformability.

Table: 4.1: Fresh concrete properties

Mixture ID	Slump (mm)	V-funnel (seconds)	L-Box (H2/H1)	U-box(H1-H2)
SCC1(0% WFS)	605	7	1	5
SCC2(10% WFS)	625	6.60	0.9	11
SCC3(15% WFS)	625	6.28	1	17
SCC4(20% WFS)	590	9.37	0.8	23

As per EFNARC, time ranging from 6 to 12 seconds is considered adequate for a SCC. The V-funnel flow times were in the range of 6–10 seconds. Test results of this investigation indicated that all SCC mixes meet the requirements of allowable flow time. The L-box ratio H2/H1 for the mixes was above 0.8 which is as per EFNARC standards. U-box difference in height of concrete in two compartments was in the range of 5–40 mm. All the fresh properties of concrete values were in good agreement to that of the values given by European guidelines.

Fig. 4.1 Slump flow test conducted for self-compacting concrete

Fig.4.2 Slump flow test

Fig.4.3 U-Box test

Fig.4.4: L-Box test

Fig.4.5: L-Box test in progress

4.2.2 COMPRESSIVE STRENGTH

4.4.2.1 EFFECT OF WFS ON COMPRESSIVE STRENGTH

Effect of WFS on compressive strength of M30 Grade concrete mixes SCC-1(0% WFS), SCC-2 (10% WFS), SCC-3(15% WFS) and SCC-4 (20% WFS) at the age of 7, 28 and 56days are shown in Fig. 4.6.

Mix proportion of control concrete mix SCC-1 (0% WFS) was 450 kg cement, 1021 kg fine aggregate and 702 kg coarse aggregate per cubic meter of concrete with water-cement ratio 0.43. Compressive strength of control concrete mix was 35.06 MPa at the age of 28 days. It was found that, at the age of 7 days, compressive strength of mix SCC-1 (0% WFS) was 27.69 MPa and mixes SCC-2 (10% WFS), SCC-3 (15%WFS) and SCC-4 (20% WFS) were 29.13, 37.42 and 31.10 MPa, respectively. Maximum compressive strength (37.42 MPa) was observed for SCC-3 (15% WFS) concrete mix; it was 35.14 % more than the control mix SCC-1(0% WFS). At the age of 28 days, percentage increase in compressive strength was 14.80, 22.73 and 14.26% for mixes SCC-2, SCC-3 and SCC-4 than control mix SCC-1(35.06 MPa). At 56 days, concrete mixes SCC-2, SCC-3 and SCC-4 exhibited increase in compressive strength12.60, 24.94 and 12.88 % respectively than SCC-1 (39.53 MPa). In investigation, it was observed that compressive strength of concrete increased with the increase in WFS content up to 15% as partial replacement of sand.

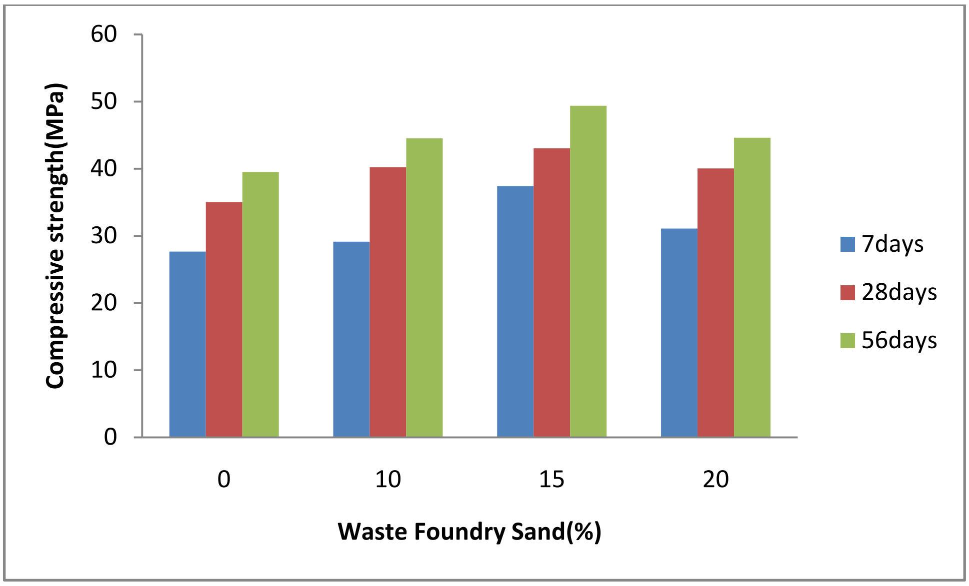

Fig. 4.6: Compressive strength of waste foundry sand concrete

Table 4.2 : Compressive strength of SCC Mixes of specimen size 150x150x150 with Waste Foundry Sand

Mix	**Compressive Strength (N/mm^2)**			**Average Compressive Strength (N/mm^2)**		
	7 days	28 days	56 days	7 days	28 days	56 days
CM	27.36	34.70	39.87	27.69	35.06	39.53
	28.01	35.30	39.93			
	27.7	35.17	38.78			
10%	31.16	38.74	44.71	29.13	40.25	44.51
	27.12	41.76	42.71			
	29.11	40.25	46.13			
15%	38.53	39.94	46.40	37.42	43.03	49.39
	36.32	45.82	48.67			
	37.41	43.34	53.11			
20%	31.44	41.09	45.82	31.10	40.06	44.62
	29	40.01	44.76			
	32.87	39.08	43.33			

Figure 4.7 shows the variation of percentage increase in compressive strength with replacement percentage of waste foundry sand. The results also indicate that early age strength gain i.e. at 7 and 28 days, is higher when compared to the control mix if 15% of fine aggregate is replaced by waste foundry sand.

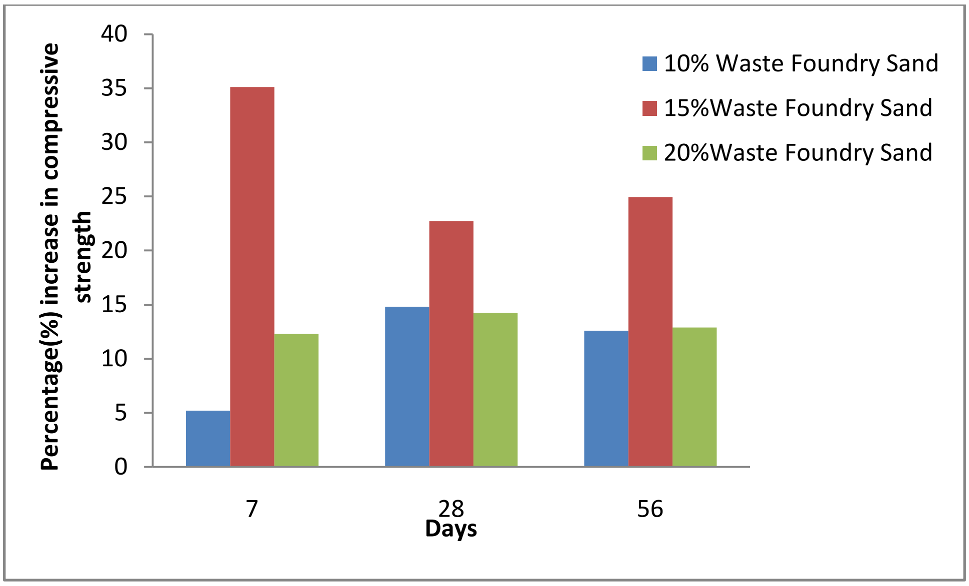

Fig. 4.7: Percentage (%) increase in compressive strength of waste foundry sand concrete

4.4.2.2 EFFECT OF AGE ON COMPRESSIVE STRENGTH

Effect of age on compressive strength of M30 Grade (35.06 MPa) concrete mixes are shown in Fig. 4.8. Compressive strength of all concrete mixes increased with age. Concrete mix SCC-1 (0% WFS) achieved an increase of 26.62 and 42.76 % at the age of 28 and 56 days respectively, when compared with 7 days compressive strength (27.69 MPa). For mix SCC-2 (29.13 MPa), compressive strength was increased by 38.17 and 52.80% at the age of 28 and 56 days respectively, whereas an increase of 15% was observed at 28 days and 31.99% at 56 days for SCC-3 (15% WFS). When SCC-4 (20% WFS) was compared with 7 days compressive strength (31.10 MPa), it was found that it increased by 28.81 and 43.47%.

Comparative study of compressive strength between 7 to 28 days indicate that % increase in compressive strength was observed as 26.62,38,17.15 and 28.81% for mix SCC-1, SCC-2, SCC-3 and SCC-4 respectively. Concrete mix SCC-1, SCC-2, SCC-3 and SCC-4 exhibited increase in compressive strength by 12.75, 10.58, 14.78 and 11.38% when comparative study was done between 28 and 56 day.

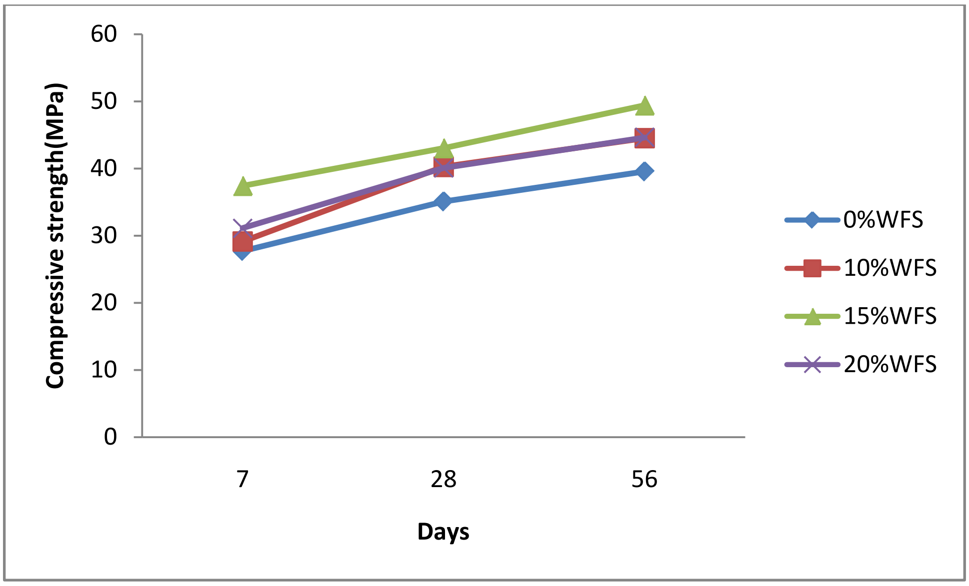

Fig 4.8: Compressive strength of Waste Foundry Sand Concrete verses age

4.2.3 SPLITTING TENSILE STRENGTH

4.2.3.1 EFFECT OF WFS ON SPLITTING TENSILE STRENGTH

Split tensile strength studies were carried out at the age of 7, 28 and 56 days. Test results are given below in Table 4.3.

The variations in splitting tensile strength with waste foundry sand content were similar to that observed in case of compressive strength. Splitting tensile strength of concrete mixes increased with the increase in WFS content. Splitting tensile strength of control mix SCC-1(0% WFS) was 2.28 MPa at 7 days. It increased by 6.14%, 11.84% and 11.40% for SCC-2 (10% WFS), SCC-3 (15% WFS) and SCC-4 (20% WFS) respectively. Higher value of splitting tensile strength was observed at 15% WFS. At the age of 28 days, increase was 15.14%,23.94 and 16.55% for SCC-2, SCC-3, and SCC-4 concrete mixes respectively than mix SCC-1 (2.84MPa). At 56 days, splitting tensile strength of mix SCC-1(0% WFS) was 2.92 MPa. Concrete mix SCC-2, SCC-3 and SCC-4 achieved an increase of 12.33, 23.29 and 21.23%.. It was observed that up to 15% replacement of natural sand with WFS, concrete mixture SCC-3 (15% WFS) showed higher value of splitting tensile strength among all mixes.

Table 4.3: Splitting tensile strength of concrete mixes with Waste Foundry Sand

Mix	Splitting Tensile Strength (N/mm^2)			Average Splitting Tensile Strength (N/mm^2)		
	7 days	28 days	56 days	7 days	28 days	56 days
CM	2.44	2.68	3.12	2.28	2.84	2.92
	2.13	3.00	2.73			
	2.27	2.84	2.91			
10%	2.45	2.80	3.79	2.42	3.27	3.28
	2.38	3.75	2.77			
	2.42	3.26	3.28			
15%	2.23	3.57	3.19	2.55	3.52	3.60
	2.88	3.48	4.03			
	2.54	3.51	3.58			
20%	2.54	3.24	3.69	2.54	3.31	3.54
	2.54	3.39	4.03			
	2.54	3.30	2.9			

Figure shows the variation of split tensile strength with the percentage of waste foundry sand replaced. Figure 4.10 shows the variation of percentage increase in split tensile strength with replacement percentage of waste foundry sand. The strength gain at age of 7 ,28 and 56 days is highest for 15% waste foundry sand replacement.

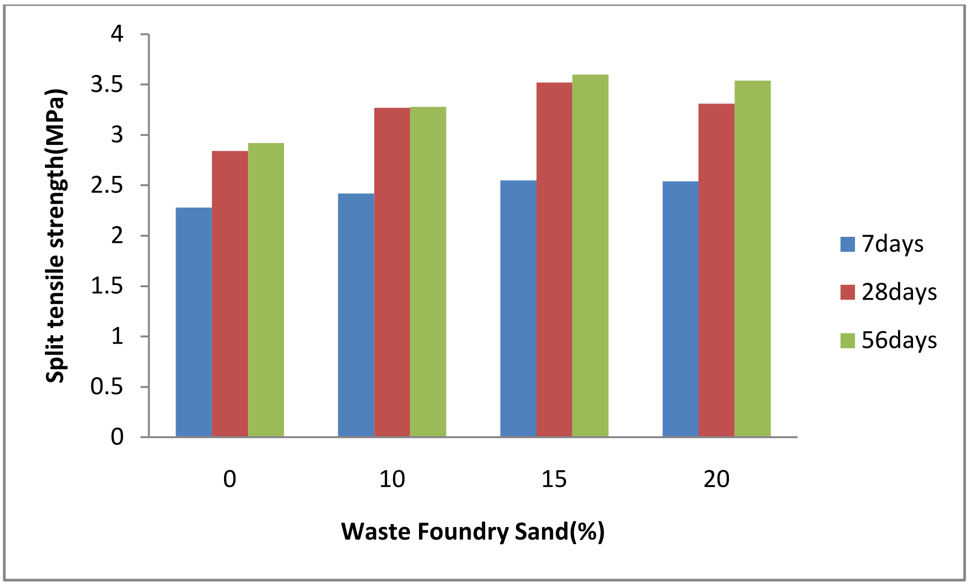

Fig 4.9: Splitting tensile strength of Waste Foundry Sand Concrete

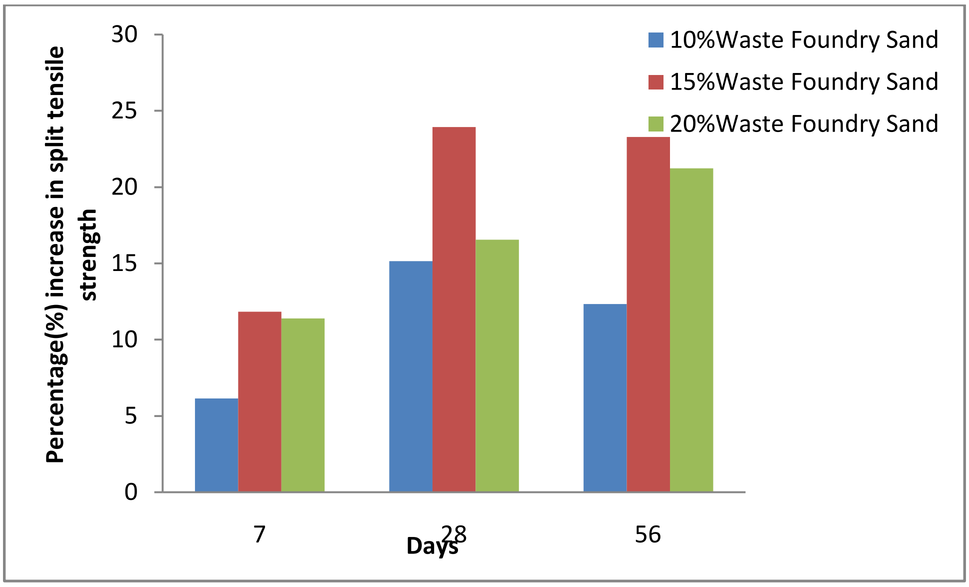

Fig. 4.10: percentage (%) increase in split tensile strength of waste foundry sand concrete

4.2.3.2 EFFECT OF AGE ON SPLITTING TENSILE STRENGTH

Effect of age on splitting tensile strength on concrete mixes are shown in Fig. 4.11. Splitting tensile strength of all concrete mixes increased with age. Concrete mix SCC-1 (0% WFS) achieved an increase of 24.56 and 28.04% at the age of 28 and 56 days respectively, when compared with 7 days splitting tensile strength (2.28 MPa). For mix SCC-2 (2.42 MPa), splitting tensile strength was increased by 35.12 and 35.54% at 28 and 56 days, respectively, whereas an increase of 38.04% was observed at 28 days and 41.18% at 56 days for SCC-3

(15% WFS). When SCC-4 (20% WFS) was compared with 7 days splitting tensile strength (2.54MPa), it was found that it increased by30.31 and 39.37%.

The concrete mixes SCC-1, SCC-2, SCC-3 and SCC-4 showed an increase in splitting tensile strength between 28 to 56 days, by 9.4, 7.6, 9.1, 8.1 and 10.8% respectively. Splitting tensile strength of all mixes are continue to increase with increase in age .

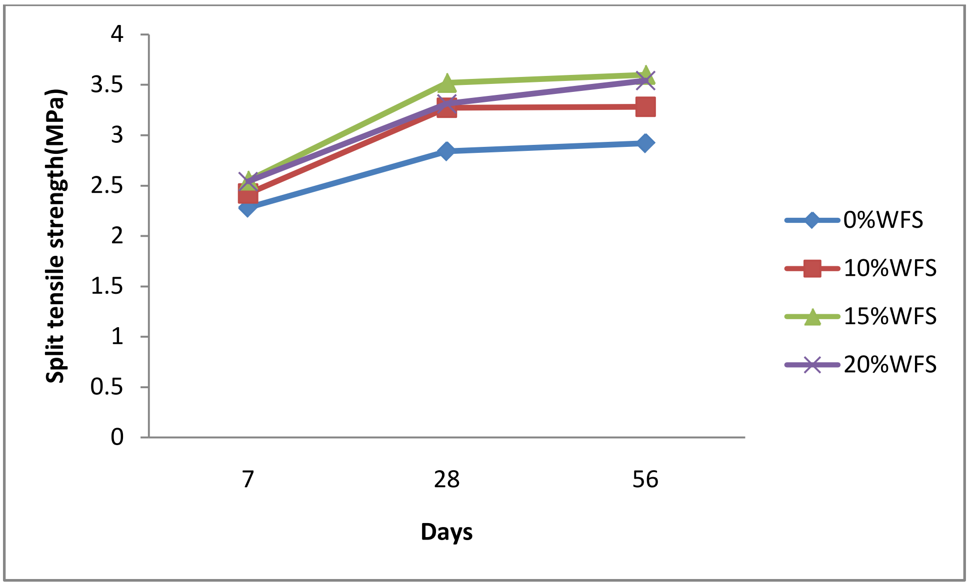

Fig 4.11 : Split tensile strength verses age

4.2.4 RESISTANCE TO SULPHATE ATTACK OF CONCRETE

This test was conducted on 150 x 150 x 150mm cube specimens. The cubes were casted and cured in water for 28 days. Magnesium sulphate solution of 50g/l is used to evaluate sulphate resistance of concrete. Cubes are immersed in solution after 28 days curing, and are tested for compressive strength after a further period of 7, 28 and 56 days. The cubes are tested for compressive strength and any reduction or change is noted. The compressive strength test results on immersed cube specimens are given in Table 4.4. Figure 4.12 shows the results.

This compressive strength is compared with the compressive strength of specimen cured in water at same ages. The Figure 4.13 shows the increased (+) or decreased (-) in percentage of compressive strength after immersion in $MgSo_4$ solution and compared with the compressive strength of specimen of same size 150 × 150 × 150 mm cured in normal water at same ages.

From the table and the concerned figure, it is observed that for the mix containing 10% waste foundary sand an increase in strength is observed at all ages as compared to the control mix even after immersing the cubes in magnesium sulphate solution. However, for both 15% and 20% replacement levels, a decrease in strength is observed when compared to the standard 28 days strength of the related concrete mix, at all ages after immersion in the sulphate solution. This indicates that, one, the strength loss will be much larger if the concrete is immersed in the solution for a larger period of time, the extent needs to be investigated and secondly, 10% waste foundry sand is optimum from the consideration of resistance to sulphate attack as observed from the experimental results.

Table 4.4: Compressive strength of concrete mixes after immersion in 50gm/litre of $MgSo_4$ solution

MIX	7 DAYS COMPRESSIVE STRENGTH (MPa)		28 DAYS COMPRESSIVE STRENGTH (MPa)		56 DAYS COMPRESSIVE STRENGTH (MPa)	
	CONTROL (28 days)	IMMERSED	CONTROL (28 days)	IMMERSED	CONTROL (28 days)	IMMERSED
10%	40.25	46.03	40.25	47.37	40.25	49.62
15%	43.03	39.04	43.03	40.18	43.03	42.44
20%	40.06	37.76	40.06	38.39	40.06	39.69

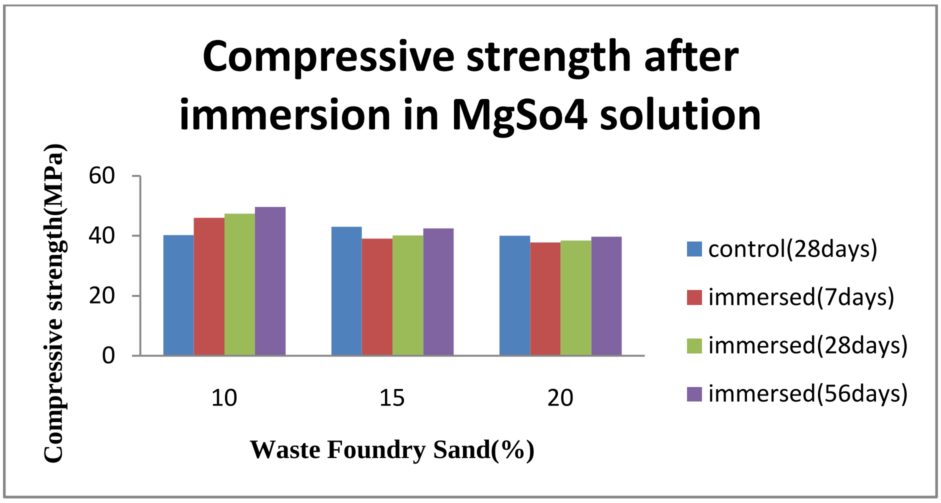

Fig4.12: Compressive strength after immersion in $MgSo_4$ solution (50g/l)

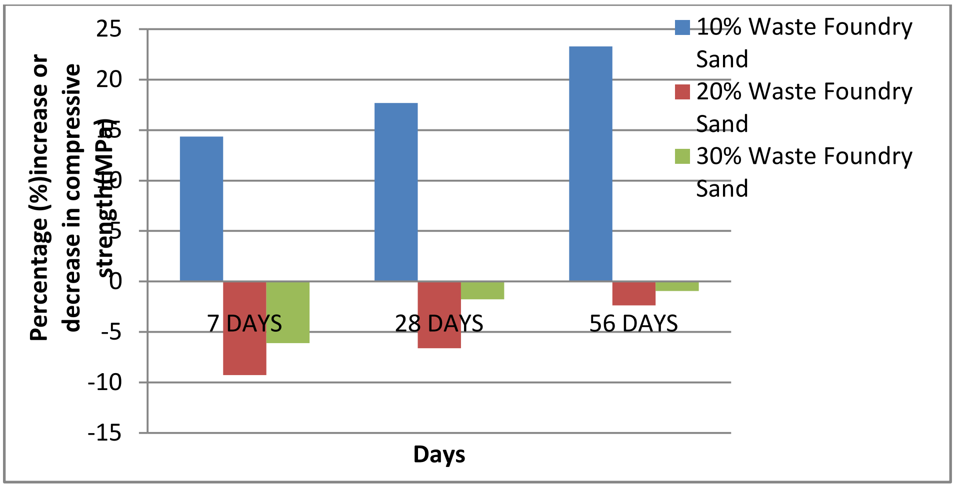

Fig4.13: Percentage(%) increased (+) or decreased (-) in compressive strength after immersion in $MgSo_4$ solution (50g/l) as compared with compressive strength of specimens cured in normal water at same ages.

4.2.5 RAPID CHLORIDE PERMEABILITY

The measurement concerns the chloride ions that come into concrete and also those flowing through the samples. It was reported that the use of Waste Foundry Sand decreased the rapid chloride penetration Coulomb value of concrete and the presence of Waste Foundry Sand could improve the permeability of concrete.

4.2.5.1 EFFECT OF WFS ON RAPID CHLORIDE PERMEABILITY

Influence of WFS on chloride-ion permeability of concrete mixes SCC-1(0%WFS), SCC-2(10%WFS), SCC-3(15%WFS) and SCC-4(20%WFS) are shown in Fig. 4.14.Chloride-ion permeability of concrete mixes decreased with the increase in WFS content. At 28 days, for mixes SCC-1 (0% WFS), SCC-2 (10% WFS), SCC-3 (15% WFS) and SCC-4 (20% WFS), charges passed were 1200, 910, 720, and 970 coulombs. Coulomb value decreased in mix SCC-3 with the increase in WFS content up to 15% WFS, which indicate that concrete became more dense. This aspect has also been reflected by the compressive strength results of concrete mix made with WFS up to 15% WFS. However, at 20% WFS (SCC-4), there is slight increase in coulomb value with references to 15% WFS. All concrete mixes have Low and very Low Permeability(coulombs between 100 and 2000) as per ASTM C1202. It can be seen that RCPT values decreased with the increase in WFS content (%). Maximum reduction in RCPT value was observed at 15% WFS. It can be concluded that at 15% WFS, concrete mix M-4 exhibited more resistance to chloride-ion penetrability than control mix SCC-1 (0% WFS). According to ASTM C 1202, all concrete mixes have low penetrability to chloride-ion.. The 15% replacement of WFS acts as filler material and yields a significant reduction in total charge passed.

These fine particles reduce the voids between ingredient of concrete and makes dense matrix. It also helps to decrease the electrical conductance of concrete.At 15% replacement of natural sand with WFS, WFS gives better effect to internal pore structure of concrete as a filler material.Finer particles of WFS act as a good filler material to make a stronger internal structure of concrete matrix. As per ASTM C1202, chloride ions penetrability based on charge passed given in Table 3.11

Table.4.5: Charge passed and rating for SCC mixes.

Mix	**28 days**	
	Charge passed in Coulombs (C)	Chloride ion penetrability
SCC1 (0%WFS)	1200	Low
SCC2(10%WFS)	910	Very Low
SCC3(15%WFS)	720	Very Low
SCC4(20%WFS)	970	Very Low

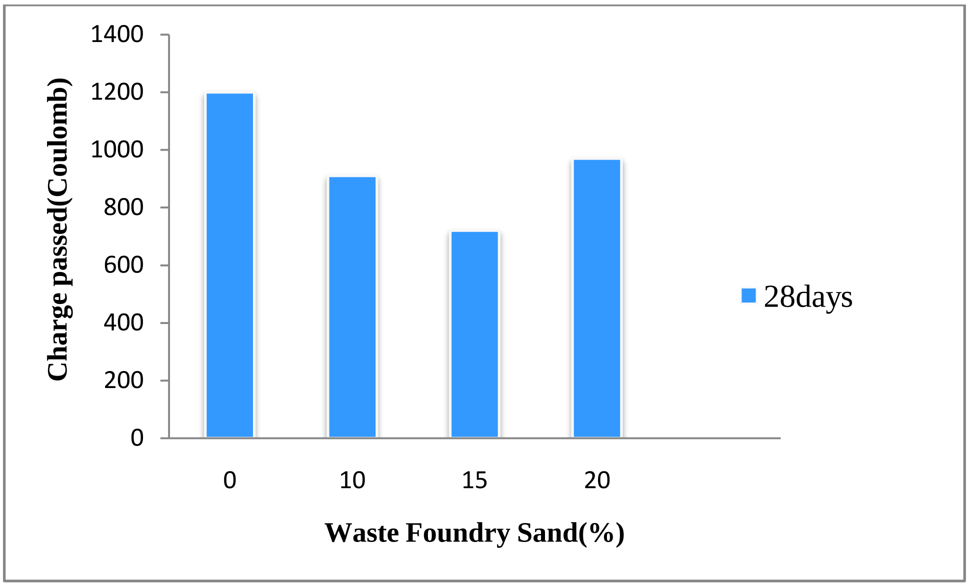

Fig.4.14: Chloride penetration for SCC mixes at various Waste Foundry Sand content

CHAPTER: 5

CONCLUSIONS

5.1 GENERAL

The present work investigated the influence of waste foundry sand as partial replacement of fine aggregate (sand) on the properties self-compacting concrete.On the basis of the results from the present study, following conclusions are drawn.

5.2 STRENGTH PROPERTIES

5.2.1 COMPRESSIVE STRENGTH

i. Compressive strength of concrete mixes increased due to replacement of fine aggregate with waste foundry sand. However, compressive strength observed was appropriate for structural uses.
ii. M30 (35.06MPa) grade concrete mix obtained increase in 28-day compressive strength from 35.06MPa to 43.03MPa on 15% replacement of fine aggregate with WFS. Maximum strength was achieved with 15% replacement of fine aggregate with WFS. Beyond 15% replacement it goes to decrease, but was still higher than control concretes
iii. Compressive strength also increased with increase in age of concrete. The rate of compressive development of waste foundry sand concrete mixes were higher compared to no waste foundry sand concrete mixes.

5.2.2 SPLIT TENSILE STRENGTH

i. Concrete mixes obtained linear increase in 28-day splitting tensile strength from 2.84 MPa to 3.31MPa for concrete mix on replacement of fine aggregate with waste foundry sand at various percentages of 0% to 20%.
ii. Splitting tensile strength of all concrete mixes was found to increase with increase in with varying percentage of waste foundry sand.
iii. Maximum increase in splitting tensile strength was observed at 15% replacement of fine aggregate with waste foundry sand at all age for concrete mixes .

5.3 DURABILITY PROPERTIES

5.3.1 SULPAHTE RESISTANCE

i. The compressive strength of 10% waste foundry sand specimens when immersed in 50g/l $MgSo_4$ solution gives more strength than standard mix value when immersed in water at 7, 28 and 56 days. But when the percentage of waste foundry sand increase to 15% and 20%, the compressive strength of the mix tends to decrease when compared with the compressive strength of specimen cured in water at same ages.

ii. The strength loss will be much larger if the concrete is immersed in the solution for a larger period of time, the extent needs to be investigated.

iii. 10% waste foundry sand is optimum from the consideration of resistance to sulphate attack as observed from the experimental results.

5.3.2 RAPID CHLORIDE PERMEABILITY RESISTANCE

i. Chloride permeability resistance of concrete mixes increased with the increase in waste foundry sand content.

ii. RCPT value (Coulombs) decreased with the increase in WFS content up to 15% WFS, which indicate that concrete has become denser. This aspect has also been reflected by the compressive strength result up to 15% WFS. However, at 20% WFS, there is slight increase in coulomb value with references to 15% WFS but it is less than control one.

iii. All concrete mixes with waste foundry sand come under “very low” permeability against chloride at all age as per ASTM standards. Only concrete mix SCC-1(0% WFS) comes under low permeability at 28 days of curing. SCC-3(15%WFS) has the lowest RCPT value among all the mixes.

5.4 SCOPE FOR FUTHER WORK

i. In the present study only up to 20 per cent replacement of sand by waste foundry sand has been considered. The other percentages i.e. 25 and 30 per cent need investigation.

ii. Sulphate resistance of concrete containing waste foundry sand needs to be investigated for larger exposure time.

iii. Rapid chloride permeability of concrete containing waste foundry sand needs to be evaluated at different ages .In present study rapid chloride permeability was evaluated after 28 days of curing.

iv. In the present study , natural sand is replaced by waste foundry sand by weight. Particle sizes, its water absorption ,specific gravity is not included in the design mix. If, included design mix will change for every replacement of waste foundry sand. It needs to be investigated.

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