Development of Free Flow Concrete with Different Admixtures

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***Abstract*: Free flow concrete is a concrete that can be compacted in to every corner of a formwork purely by means of own weight, without using any vibrators. Free flow concrete is a fluid mixture suitable for placing in structures with congested reinforcement without vibration. Normal concrete was designed by using IS method and free flow concrete was designed by a simple mix design proposed by Nan Su. FFC was developed in the year of 1988's by Prof. Hagime Okamura in Japan. FFC was one of the special concrete in across the world. The construction and placing becomes faster and then easy, it eliminates need for vibration & to reducing the noise pollution**

In this study the strength and flow of concrete when compared to normal concrete. The chemical admixtures used for FFC is Silica fume with 1, 2, &3%.

However, the durability of such FFC needs to be proved,

- **Development of a suitable mix for FFC that would satisfy the requirements of the plastic state**
- **Casting of concrete samples and testing them for compressive strength, shrinkage & water absorption. The local aggregates, cement, admixtures and additives produced by the local suppliers were used in this design. The test results for acceptance characteristics of free flow concrete such as Slump flow, J-ring, V-funnel & L-box are presented. For the compressive strength at the ages of 7, 14&28 days was also determined and results are included here. The significance of this work lies in its attempt to provide some performance data of FFC so as to draw attention to the possible use of FFC**.*(Abstract)*

IndexTerms*— Free Flow Concrete, Aggregates, Cement, Mix Design, Compressive Strength, Silica Fume.*(keywords)

I. INTRODUCTION

Concrete: Concrete is the most basic element for any kind of construction work. No matter what type of building structure it is, the concrete used should be sturdy and well compacted. The main reasons for compacting any type of concrete are:

- To ensure attaining maximum density by removal of any entrapped air.
- To ensure that the concrete used is in full contact with both the steel reinforcement and the form work.

Free flow concrete: Unlike the conventional concrete, free flow concrete doesn't require compacting using external force from mechanical equipment such as an immersion vibrator; instead FFC is designed in such as way that it gets compacted using its own weight and characteristics.

How is FFC made?

Free flow concrete is a type of concrete, which is not a product of mixing substances having different properties but a combination of several mixes having the same flow characteristics.

- High amount of water reducing substance or super plasticizers is added for obtaining high flowing characteristics.
- A type of aggregates mixture is added to gain the desired compactness and Note that the aggregate content is of round shape and proportional in size in order to increase the locking tendency of the concrete.
- Alteration of fluid properties is done to ensure the cohesive mix which will keep the aggregate and paste together.

Two Main Methods of Making FFC: ***There are two known and main methods for making FFC. They are as follows***

Powder method:

In this method super plasticisers are mixed with cementitious materials such as micro silica fly ash, slag, etc. to form a paste. The paste increases the flow of the concrete and holds all the constituents together.

Admixture method:

In this method instead of the conventional super plasticisers, new types of super plasticisers known as polycarboxylate super plasticisers are used. This not only increases the flow capability of the concrete but also improves the viscosity and the constituent's retention property.

Usage of Self-Compacting Cements has increased tremendously in the past few years. FFC not only ensures a structure with robust characteristics but also helps in timely completion of building structures.

Free flow concrete composition:

Free flow concrete is a fluid mixture, which is suitable for placing in difficult conditions and in structures with congested reinforcement without vibration. In principle, a Free flow or Free consolidation concrete must have: Fluidity, Homogeneous, Flow easily through reinforcement

The technology of FFC is based on adding or partially replacing Portland cement with amounts of fine material such as **silica fume** without modifying the water content. This process changes the rheological behaviour of the concrete.

What are the reasons for the sudden popularity of FFC:

There are many situations in today's construction market that make FFC 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 FFC. Contractors, producers and owners are under great pressure to produce better quality construction at lower costs of labor, 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 labor savings, time savings from higher productivity, and greater flexibility of design. FFC offers some help in all of the following areas.

Reduced in-place cost:

Productivity Improvements – FFC can increase the speed of construction, improve formed surface finish and thus reduce repair and patching costs, reduce maintenance costs on equipment, and provide faster form and truck turn-around time.

Improved work environment and safety:

FFC eliminates the use of vibrators for concrete placement, thus minimizing vibration and noise exposures. It eliminates trip hazards caused by cords. It reduces fall hazards, as workers do not have to stand on forms to consolidate concrete.

Improved aesthetics:

FFC provides unequalled formed surfaces.

Application:

Caution should be taken when using FFC in flatwork as it has limited bleeding characteristics and may be subject to plastic shrinkage cracking if not properly protected and cured. Higher powder contents bleed less than conventional concrete and can also lead to plastic shrinkage cracking if not properly cured.

Production and Quality Control:

FFC requires a higher level of quality control than conventional slump concrete. Combined aggregate grading, tightly controlled mix water, controlled cement source, and the use of advanced admixtures require a greater awareness on the part of all production personnel. Processes must be put in place to compensate for normal variation of materials.

Key items to monitor are:

- Coarse and fine aggregate grading
- Coarse aggregate void volume
- Aggregate moistures

Properties of FFC:

Compressive strength:

FFC with a characteristic compressive strength up to 60N/mm^2 can be easily produced. For a lower specified strength, the high fines content and low water/(cement fines) ratio required for the essential theological properties of FFC may make it difficult to keep the strength down.

Tensile strength:

When assessed using the cylinder splitting test, as specified in BS 1881: Part 117: 1983 Testing concrete: method for determination of tensile splitting strength, the tensile strength is comparable to the same grade of traditional concrete, as is the ratio of tensile to compressive strength.

Shrinkage:

Drying shrinkage has been shown to be similar or lower than that of traditional concrete of the same grade. This is contrary to that expected from the lower grade aggregate content, but is partially explained by the similar water content of FFC and traditional concrete. The high fines content and viscosity of FFC inhibit bleeding and, therefore, evaporation, so the total plastic settlement is reduced.

Structural performance:

The structural performance of FFC does not differ much from that of traditional concrete. Assessment by loading to failure of 3000 x 300 x300nmm reinforced columns and 4000 x 300 x200mm beams has shown that normal fracture patterns occur in all cases, with the actual failure load exceeding the calculated ultimate load.

II. LITERATURE REVIEW

Khayat et al:

The use of self-consolidating concrete can facilitate the placement of concrete in congested members and in restricted areas. Given the highly flow able nature of such concrete, care is required to ensure adequate stability. This is especially important in deep structural members and wall elements where concrete can segregate and exhibit bleeding and settlement, which can result in local structural defects that can reduce mechanical properties.

Ozawa et al. (1989):

Focused on the influence of mineral admixtures, like fly ash and blast furnace slag on the flowing ability and segregation resistance of self-compacting concrete. They found out that on partially replacement of OPC by fly ash and blast furnace slag the flowing ability of the concrete improved remarkably. He concluded that the best flowing ability and strength characteristics 10-20% of fly ash and 25- 45% of slag cement by mass

Domone and His-Wen (1997):

Performed a slump test for high workability concrete. A beneficial correlation between the slump values and flow was obtained from the laboratory test. It showed satisfying value of the slump flow.

Bui et al. (2002):

Discussed a speedy method in order to test the resistance to segregation of Self-compacting concrete. Extensive test programme of FFC with different water-binder ratios, paste volumes, combinations between coarse and fine aggregates and various types and contents of mineral admixtures was carried out. The test was helpful in concluding the method along with the apparatus used for examining the segregation resistance of FFC in both the directions (vertical and horizontal).

III. EXPERIMENTAL INVESTIGATION

(a). Experimental Programme

An experimental study is conducted to find out the 7 and 28 days Compressive, split-tensile, Flexure test were conducted on self-compacting concrete. In concrete micro silica and additives are added. The effect of addition of micro silica and additives on strength and workability of concrete over the conventional concrete are investigated.

Materials

Cement:

Ordinary Portland Cement of 53 Grade available in local market is used in the investigation. The cement used has been tested for various properties as per IS: 4031 – 1988 and found to be conforming to various specifications as per IS: 12269 – 1987.

Fine aggregate:

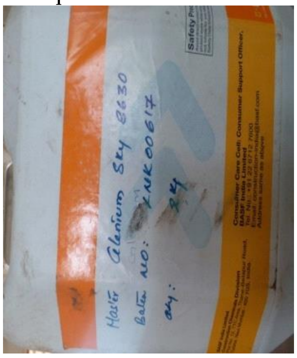
The locally available sand is used as fine aggregate. It should be free from clay, silt, organic impurities, etc., the sand is tested for various properties such as specific gravity, bulk density, etc., in accordance with IS: 2386 – 1963. The grading or particle size distribution of fine aggregate shows that, it is close to grading or particle size distribution of fine aggregate shows that, it is close to grading zone – II or IS: 383 – 1970.

Coarse aggregate:

Machine crushed angular granite metal of 20 mm size from the local source is used as coarse aggregate. It should free from impurities such as dust, clay particles, organic matter etc., the fine and coarse aggregate are tested for its various properties as shown in table – 4.2.The grading or particle size distribution of coarse aggregate shown close for single sized aggregate of nominal size 20 mm as per IS: 383 – 1970

Super plasticizer:

In the present work water-reducing admixture Glenium SKY 8630 conforming to ASTM C494 Types F, EN934-2 T3.1/3.2, IS 9103: 1999 is used. GLENIUM SKY 8630 is an admixture of a new generation based on modified polycarboxylic ether. The product has been primarily developed for applications in high performance concrete where the highest durability and performance is required.

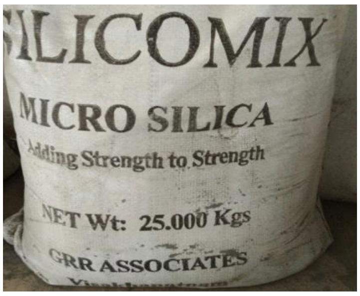


Microsilica:

Micro silica is an artificial pozzolanic admixture obtained from reduction of high purity quartz with coal in an electric furnace in the manufacture of silicon or ferrosilicon alloy. Elkom Micro silica was used in this work. Micro silica is the most reactive of several supplementary cementing materials for modifying the cement matrix to provide improved binders

This provides a homogeneous, fine grained, almost ceramic matrix linked with the very low water cement ratio governs the characteristic cube strength of 100Mpa concrete.

- Results in a more homogenous fine-grained cement structure.
- Fine spherical nature of Micro silica provides micro packing density and eliminates micro voids.
- Produces stronger C-S-H matrix.
- Marked changes in transition zone (between cement and aggregate),indicating non-micro cracked dense matrix as a result of removal of bleed water.



Water:

Water used for mixing and curing shall be clean and free from injurious amounts of oils, acid, alkalis, salts, organic materials or other substances they may be deleterious to concrete portable water is used for mixing as well as curing of concrete as prescribed in IS: 456 – 2000.

(b). Tests on free flow concrete

Tests on FFC:

1. Slump flow & T_{50} test
2. L-box test
3. V-funnel test & V-funnel at $T_{5minuts}$

List of test methods for workability properties of FFC:

S. No	Method	Property
1	Slump Flow Test	Filling Ability
2	T_{50cm} Slump Flow	Filling Ability
3	V-Funnel Test	Filling Ability
4	V-Funnel at $T_{5minuts}$	Segregation Resistance
5	L-Box Test	Passing Ability

Slump Flow & T_{50} test:

Slump Flow is definitely one of the most commonly used FFC tests at the current time. This test involves the use of the slump cone used with conventional concretes as described in ASTM C143 (2002). The main difference between the Slump Flow test and ASTM C143 is that the Slump Flow test measures the "spread" or "flow" of the concrete sample once the cone is lifted rather than the traditional "slump" (drop in height) of the concrete sample. The T_{50} test is determined during the Slump Flow test; it is simply the amount of time that the concrete takes to flow to a diameter of 50 centimeters. Typically, Slump Flow values of approximately 24 to 30 inches are within the acceptable range; acceptable T_{50} times range from 2 to 5 sec.

L-box test:

The L-box value is a ratio of the levels of concrete at each end of the box after the test is complete. The L-box consists of a "chimney" section and a "trough" section after the test is complete, the level of concrete in the chimney is recorded as H1; the level of concrete in the trough is recorded as H2. The L-box value (also referred to as the "L-box ratio", "blocking value", or "blocking ratio") is simply H2/H1. Typical acceptable values for the L-box value are in the range of 0.8 to 1.0. If the concrete was perfectly level after the test is complete, the L-box value would be equal to 1.0; conversely, if the concrete was too stiff to flow to the end of the trough the L-box value would be equal to zero.

V-funnel test and V-funnel test at $T_{5minutes}$:

V-funnel test is used to determine the filling ability (flowability) of the concrete with a maximum aggregate size of 20mm. The funnel is filled with about 12 liters 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.

Acceptance criteria for FFC:

S. No	Method	Unit	Typical Range of Values	
			Minimum	Maximum
1	Slump Flow Test	Mm	0	300
2	T_{50}cm Slump Flow	Sec	2	5
3	V-Funnel Test	Sec	6	12
4	V-Funnel at T_5minuts	Sec	6	15
5	L-Box Test	h_2/h_1	0.8	1.0

(c). Mix Design

Design Parameters for M_{60} grade of concrete

Grade of concrete	:M60
Size of aggregate	:20mm
Degree of workability	:0.90 (compaction factor)
Degree of quality control	:Good
Type of exposure	: Moderate
Grade of cement	:53 grade ordinary Portland cement

Test Data for Materials:

Specific gravity of cement: 3.15

Specific gravity of fine aggregate: 2.67

Specific gravity of coarse aggregate: 2.97

Mix Proportion of M60 Grade Concrete

Cement	Fine Aggregate	Coarse Aggregate	Water/Cement Ratio
636.36kg	653.09kg	864.8kg	
1	1.02	1.35	0.35

IV. EXPRIMENTAL RESULTS

PHYSICAL PROPERTIES OF ORDINARY PORTLAND CEMENT 53 GRADE

S. No	Property	Test Results
1	Normal consistency	31 %
2	Specific gravity	3.15
3	Setting time: Initial setting time,Final setting time	35 min, 230 min
4	Fineness of cement (IS sieve no.9)	4.0 %
5	Compressive strength 1:3 sand mortar cubes At 7 days At 28 days	 27.5 Mpa 55 Mpa

PROPERTIES OF FINE AGGREGATE:

S. No	Properties	Fine aggregates
1	Specific gravity	2.670
2	Loose bulk density	1450 kg/m^3
3	Rodded bulk density	1713 kg/m^3

PROPERTIES OF COARSE AGGREGATE:

S. No	Properties	Coarse aggregates
1	Specific gravity	2.74
2	Loose bulk density	1365 kg/m^3
3	Rodded bulk density	1610 kg/m^3

SIEVE ANALYSIS FOR FINE AGGREGATE:

S. No	I.S. sieve designation	Weight retained (grams)	Cumulative weight retained (grams)	Cumulative % of weight retained	Percentage passing By Weight	Remarks
1	40 mm	0	0	0	100	Fine Aggregate conforming to Grading Zone II of IS: 383 – 1970
2	20 mm	0	0	0	100	
3	10 mm	0	0	0	100	
4	4.75 mm	0	0	0	100	
5	2.36 mm	20	20	2	98	
6	1.18 mm	80	100	10.0	90	
7	600 microns	344	444	44.4	55.6	
8	300 microns	329	773	77.3	22.7	
9	150 microns	199	972	97.2	2.8	
10	< 150 microns	28	1000	100	0	
		Total = 1000 grams		330.90		

SIEVE ANALYSIS FOR COARSE AGGREGATE:

S.No	I.S. sieve designation	Weight retained (grams)	Cumulative weight retained (grams)	Cumulative % of weight retained	Percentage passing By weight	Remarks
1	40 mm	0	0	0	100	Coarse Aggregate conforming to Grading Zone II of IS: 383 – 1970
2	20 mm	0	0	0	100	
3	10 mm	9155	9155	91.55	8.45	
4	4.75 mm	750	9905	99.05	0.95	
5	2.36 mm	0	9975	99.05	0.95	
6	1.18 mm	0	9905	99.05	0.95	
7	600 microns	0	9905	99.05	0.95	
8	300 microns	0	9905	99.05	0.95	
9	150 microns	0	9905	99.05	0.95	
			Total = 9905 grams	685.85		

MIX PROPORTIONS FOR M60 GRADES OF CONCRETE: (Quantities of Materials per 1 Cubic Meter of Concrete)

Grade of Concrete	Cement (kg)	Fine Aggregate(kg)	Coarse Aggregate (kg)	Water (litres)	W/C Ratio
M60	636.36	615.82	805.3	1.12	0.4

Compressive Strength of FFC:

Grade of Concrete	Water – Binder ratio (Binder=Microsilica+cement)	Compressive Strength of Concrete Cubes (N/mm^2)		
		7 days	14days	28 days
M60	0.4	28	36	56

Compressive Strength of FFC:

Grade of Concrete	Water – Binder ratio (Binder=Microsilica+cement)	Compressive Strength of Concrete Cubes (N/mm^2)		
		7 days	14days	28 days
M60	0.4	35	41	65

V. ADVANTAGES AND DISADVANTAGES:

Advantages

- No mechanical vibration required.
- Easy of filling conjunction reinforcement and hard to reach areas.
- Shorter construction periods.
- Man power cost savings.
- The improved construction performance, combined with the health and safety benefits make.
- Improved and more uniform architectural surface finish.
- Resulting cost savings.
- Reduced equipment cost.

Disadvantages:

- More stringent requirements on the selection of materials.
- More precise measurement and monitoring of the constituent material.
- Requires more trial batches at laboratory as well as at ready mixed concrete plants.
- Costilier than the conventional concrete based on concrete material cost.
- Lack of globally accepted test standards and mix designs.

VI. CONCLUSIONS

- After conducting various trial tests, M_{60} grade of free flow concrete is finally obtained which satisfied all the FFC characteristics such as flow ability, passing ability and segregation resistance given by European standards. As there are no Indian standards for free flow concrete (FFC) comparison could not be made.
- From the observations it was found that nearly 2/3 of the compressive strength is gained in 7 days curing which satisfies code of Rein forced cement concrete IS: 456-2000.
- Finally we can conclude that the strength of Free Flow Concrete is higher than the normal concrete.
- Finally we reduce the man power and equipment cost.
- It has been verified, by using the slump flow, u-tube, test and other tests on fresh FFC that free flow concrete (FFC) achieved consistency and free compactibility under its own weight, without any external vibration or compaction.
- It can be concluded that method of curing has considerable effect on the mechanical properties including compressive, split tensile and shear strength of FFC.

- Hot water curing achieves satisfactory results for all the strengths. This method may be useful for precast/prefab industry for maintaining a control temperature is feasible.

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