EFFECT OF SIZE OF AGGREGATE ON SELF COMPACTING CONCRETE OF M70 GRADE

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ABSTRACT

Concrete is a versatile widely used construction material. Ever since concrete has been accepted as a material for construction, researchers have been trying to improve its quality and enhance its performance. Recent changes in the construction industry demand improved durability of structures. There is a methodological shift in the concrete design from a strength-based concept to a performance-based design. At present, there is a large emphasis on the performance aspect of concrete. One such thought has led to the development of Self-Compacting Concrete (SCC). It is considered as "the most revolutionary development in concrete construction". SCC is a new kind of High-Performance Concrete (HPC) with excellent deformability and segregation resistance. It can flow through and fill the gaps of reinforcement and corners of molds without any need for vibration and compaction during the placing process. The guiding principle behind self-compaction is that "the sedimentation velocity of a particle is inversely proportional to the viscosity of the floating medium in which the particle exists". The other features of mix proportion of SCC include low water to cementitious material ratio, high volume of powder, high paste to aggregate ratio, and less amount of coarse aggregate. One of the popularly employed techniques to produce Self-Compacting Concrete is to use fine materials like Fly Ash, GGBFS, etc., in concrete, besides cement, the idea being to increase powder content or fines in concrete. The original contribution in the field of SCC is attributed to the pioneering work of Nan Su et al.; who have developed a simple mix design methodology for Self-Compacting Concrete. In this method, the amount of aggregate required is determined first, based on Packing Factor (PF). This will ensure that the concrete obtained has good flowability, self-compacting ability, and other desired SCC properties. The European Federation of Producers and Applicators of Specialist Products for Structures (EFNARC) have also laid down certain guidelines for fresh properties of SCC. The present investigation is aimed at developing high-strength Self-Compacting Concrete of M70 Grade. The parameters of the study include the grade of concrete and the effect of the size of the aggregate. The existing Nan Su method of mix design was based on the packing factor for a particular grade of concrete, obtained on the basis of experimental investigation. SCC characteristics such as flowability, passing ability, and segregation resistance have been verified using slump flow, L box, and V funnel tests.

Keywords: *Self Compacting Concrete, High performance Concrete, Cementitious material, Workability, Segregation.*

I. INTRODUCTION

The versatility and application of concrete in the construction industry are undeniable. Research on normal and high-strength concrete has been ongoing for over two decades, following the guidelines of IS:456–2000 [Code of Practice for Plain and Reinforced Concrete]. Concrete with strengths ranging from 25 to 55 MPa is categorized as standard concrete, while those exceeding 55 MPa can be termed as high-strength concrete. Concrete surpassing 120/150 MPa is labeled as ultra-high-strength concrete. High-strength concrete finds extensive use globally, especially in tall buildings, long-span bridges, and structures in aggressive environments. However, building elements made of high-strength concrete often require dense reinforcement, leading to challenges during concreting due to congestion. Solutions to these densely reinforced concrete problems can be addressed by using easily placed and spreadable concrete between congested reinforcement elements. This approach ensures the creation of highly homogeneous, well-spread, and dense concrete, enhancing construction efficiency and quality.

Constituents of SCC:

- **Coarse aggregate:** The coarse aggregate chosen for Self Compacting Concrete should be well graded and smaller in terms of the maximum size than that used for conventionally vibrated concrete (NC).
- **Fine Aggregate:** All normal river sands are suitable for SCC. Both crushed and rounded

sands can be used. Siliceous and calcareous sands can be used for production of SCC.

- **Cement:** All types of cements conforming to Bureau of Indian standards are suitable as per Indian conditions. Selection of the type of the cement is made depending on the overall requirements of SCC such as strength, durability etc.
- **Water:** Potable water shall be used for the production of SCC. In case of conventional concretes (NC), the water is proportionate only with the cement content. It is called as the water-cement ratio.
- **Mineral admixtures:** Mineral admixtures are added to concrete as a part of the cementitious material. They may be used as an addition to or as a part replacement of Portland cement in concrete.
- **Fly ash**: a residue from the combustion of pulverized coal collected by mechanical separators, from the fuel gases of thermal plants. Particles below 10 microns provide the early strength in concrete, while particle between 10 and 45 microns react more slowly. Figure 1 shows the SEM micrograph of fly ash particles. The specific gravity of fly ash particles ranges between 2.0 to 2.4 depending on the source of coal. The fineness of fly ash is in the range of 250 - 600 m2/kg.

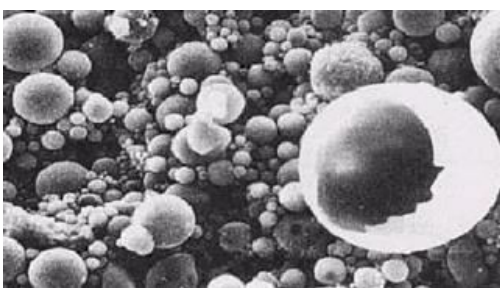

Figure 1 SEM Micrograph of fly ash particles

Chemical admixtures:

Chemical admixtures are used in Self Compacting Concrete as ingredients which can be added to the concrete mixture immediately before or during mixing. The use of chemical admixtures such as water reducers, retarders, high-range water reducers or Super Plasticizers (SP), and Viscosity Modifying Admixtures (VMA) is necessary in order to improve the fundamental characteristics of fresh and hardened concrete.

a. Super Plasticizer
b. Viscosity Modifying Agent

Development of Self-Compacting Concrete in India:

The development of Self Compacting Concrete (SCC) is considered as the most sought development in construction industry due to its numerous inherited benefits. In India, this technology is yet to realize its full potential. Central Road Research Institute (CRRI) [2005] New Delhi, has been working on SCC technology since the year 2000 and carried out significant research work on various aspects of SCC starting from selection of suitable ingredients including super plasticizer, viscosity modifying agent, mineral admixtures, mix proportion optimization, evaluation of the characteristic properties at fresh stage and hardened properties such as compressive strength, splitting tensile strength, flexural strength, Young's modulus of elasticity.

Mechanical properties of SCC:

Fresh SCC mixes must meet three key properties:

1. Ability to flow into and completely fill intricate and complex forms under its own weight
2. Ability to pass through and bond to congested reinforcement under its own weight.
3. High resistance to aggregate segregation.

II. LITERATURE REVIEW

[1] ARABIN.S.ALQADI et al: The objective of this research is to determine the effect of adding the JORPHOS (Jordanian phosphate) as filler on fresh and hardened properties of SCC. Construction companies that use SCC having trouble with importing fly ash to Jordan because it is environmental impact and prohibited from entering Jordan. The research gave good results by addition of different percentages of JORPHOS (4%, 8%, 12%, and 16%). It concluded that 8% of JORPHOS by volume gave the optimum value**.**

[2] BURCU AKCAY et al: Partial replacement of cement by metakaolin (MK) increases the strength of concrete, but since the properties of MK are important parameters, it is not entirely clear whether MK is more effective than silica fume (SF) in enhancing the properties of concrete. In this study, in high-performance self-compacting concretes (SCC) with two different water/binder (w/b) ratios (0.28 and 0.35), cement was replaced by MK or SF at the weight fraction of 10%. In order to provide a meaningful comparison, the pozzolans with similar particle sizes were used.

[3] STRATIOS G. BADOGIANNIS et al: The aim of this study is to evaluate the durability of Self-Compacting Concrete (SCC) incorporating metakaolin (mk). For the mixture preparation, cement or limestone powder were replaced by mk at different levels. The incorporation of mk improved durability, but not the near surface water permeability of the concrete.

[4] F.A MUSTAPHA et al: The paper focused on the feasibility of substituting the ordinary Portland cement with waste supplementary cementing materials (SCMs) that is, fly ash (FA) and silica fume (SF). The aim is to improve the compressive strength of self-compacting high-performance concrete (SCHPC) and to find environmentally friendly and economical application of the abundant FA generated from the four coal-powered electricity generating plants in Malaysia. The study used SCHPC with partial replacement of Portland cement with ASTM C618 class F FA and SF in exploring the fresh properties and compressive strength of six different SCHPC mixes. The mixes contained 0%, 25%, 40%, 50%, 65%, and 75% cement replacement by FA, SF was maintained at 10% constant replacement.

[5] HA THANH LET al: This paper is an effort towards presenting a new mix design method for self-compact high-performance concrete (SCHPC) containing various mineral admixtures 9 (MA). In the proposed method, the constituent materials were calculated by using the absolute volume method. The packing theory of Funk and Dinger with the exponent q=0.25 was adopted to determine the grading of aggregate. The primary paste volume for filling capacity was computed from the void content of compacted aggregate.

[6] HAJIME OKAMURA et al: Self-compacting concrete was first developed in 1988 to achieve durable concrete structures. Investigations for establishing a rational mix-design method and self-compatibility testing methods have been carried out from the viewpoint of making self-compacting concrete a standard concrete.

[7] I.M. NIKBIN et al: The popularity of self-compacting concrete (SCC), as an innovative construction material in concrete industry, has increased all over the world in recent decades. SCC offers a safer construction process and durable concrete structure due to its typical fresh concrete behavior which is achieved by SCC's significantly different mixture composition. This modification of mix composition may have significant effect on the hardened mechanical properties of SCC as compared to normal vibrated concrete (NVC).

[8] IOANNIS P. SFIKAS et al: Metakaolin is a supplementary cementing material (SCM), which has been recently used in Self-Compacting Concrete (SCC). This study investigates the effect of replacement of cement or limestone powder by metakaolin, on the rheology and the mechanical characteristics of the concrete mixtures.

[9] JYOTHSNA SEELAPUREDDY et al: SCC is one of the special concretes with excellent strength and durability properties. However, the mix proportioning and testing methods for SCC characteristics are different than the ordinary concrete. SCC has high binder content and a super plasticizer for enabling flow while keeping coarse aggregate in a viscous suspension.

[10] KAMAL HENRI KHAYAT et al: This paper presents a mix design method for ultra-high performance concrete (UHPC) prepared with high-volume supplementary cementations materials and conventional concrete sand. The method involves the optimization of binder combinations to enhance packing density, compressive strength, and rheological properties. The water-to-cementitious materials ratio is then determined for pastes prepared with the selected binders.

III. OBJECTIVES AND SCOPE OF THE WORK

Despite its advantages and versatile nature, SCC has not gained much popularity in India, though it has been widely promoted in the Middle East for the last two decades. Awareness of SCC has spread across the world, prompted by concerns with poor consolidation and durability in case of conventionally vibrated normal concrete. All the researchers have developed SCC taking the CA/FA ratio and also considered the limited content of coarse aggregate and more content of fines. But, there are very limited investigations reported considering the size effect of coarse aggregate content in the development of SCC.

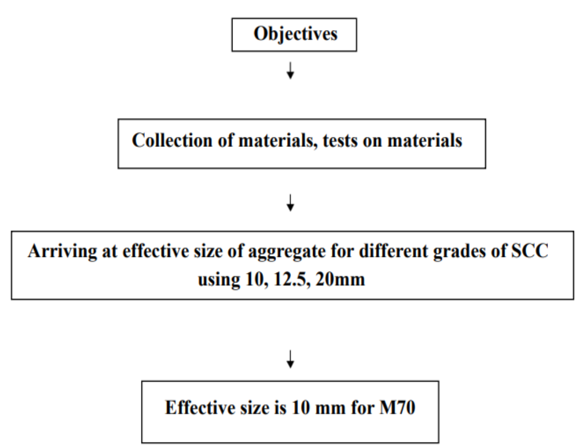

Figure 2 Schematic representation of the flow of work

Keeping this in view, the present experimental investigation is taken up to study the effect of size of coarse aggregate in the development of M70 grade of Self Compacting Concrete. Powder content is the main aspect of a SCC mix design. In the present work, flyash is maximized in the SCC mixes as a filler material. Keeping in view the idea explained above, a detailed and a systematic experimental program is laid down as explained in the next paragraphs. The main objective of the present investigation is: To study of effect of the size of aggregate on the strength and flow of M70 grade of Self compacting concrete by using Nansu mix design procedure. With the above objectives in mind the experimental program is categorized as detailed below. Casting of 27 standard cubes, 27 standard cylinders and 27 standard prisms, covering M70 grade of concrete, three aggregate sizes, three periods of curing and three specimens of each type. In this study, high strength (M70) of SCC with three different maximum size of aggregate (20, 12.5, 10 mm) were designed based on Nan Su method, to determine the effective maximum size of aggregate. The grade of concrete and age of curing were the parameters in the study.

After that we started our analysis on the basis of the plan made and it can be done manually or through software but we are doing it with the help of Staad Pro V8i. After this Designing will be started. Bending moment, shear force, slabs, beams and others factors will be taken into account while designing the residential building. At last estimation of the building will be done by taking all the material used while Construction of the residential building and it will also include the labor charge on it. we used AutoCAD for creating 2D, and Staad pro for analysis of the residential building. Revit was also used to create the 3D view of the residential building.

IV. EXPERIMENTAL PROGRAM

Wide spread applications of SCC have been restricted due to lack of standard mix design procedure and testing methods. It is pertinent to mention that only features of SCC have been included in Indian Standard Code of practice for plain and reinforced concrete (fourth revision), [2000]. Slump flow test, L-box test, V-funnel test, U-box test, Orimet test & GTM Screen test are recommended by EFNARC [European Federation of Producers and Applicators of Specialist Products for Structures, for determining the properties of SCC in fresh state.

Materials

The materials used in the experimental investigation are locally available cement, sand, coarse aggregate, mineral and chemical admixtures. The chemicals used in the present investigation are of commercial grade.

- Cement
- Fine Aggregates
- Coarse Aggregate
- Water
- Fly Ash
- Super Plasticizer
- Viscosity Modifying Agent

Size of Graded Aggregate (mm)	Mix Proportion	w/b	Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	S.P	VMA
20	1: 1.42: 4.49: 3.76: 0.043	0.455	210	300	944	791	9.12	1.75
12.5	1:0.425:1.250:1.181 :0.024	0.257	680	289.28	850.30	803.17	16.82	1.75
10	1:0.450:1.250:1.170: 0.023	0.269	680	305.50	850.30	795.65	15.85	1.75

Table 1 Mix Proportion and Quantities of M70 grade of SCC

V. REQUIREMENTS OF SELF COMPACTING CONCRETE

SCC mixes must meet three key properties: Ability to flow into and completely fill intricate and complex forms under its own weight 1. Ability to pass through the congested reinforcement under its own weight. 2. High resistance to aggregate segregation. By definition of SCC, it is clear that the fresh concrete has to fulfill various properties. The SCC must be adequately free flowing so that the coarse aggregate particles can float in mortar but the air can still rise and escape adequately.

S.NO	Method	Property
1	Slump flow test	Filling ability
2	T_{50}cm Slump flow	Filling ability
3	V-funnel test	Filling ability
4	V-Funnel at T_5 minutes	Segregation resistance
5	L-Box test	Passing ability
6	U – Box test	Passing ability
7	Fill box apparatus test	Passing ability
8	J-Ring	Passing ability
9	Orimet test	Filling ability
10	GTM screen stability test	Segregation resistance

Table 2 List of test methods for workability properties of SCC

Workability criteria for the fresh SCC:

Filling ability, passing ability and segregation resistance are the requirements for judging the workability criteria of fresh SCC. These requirements are to be fulfilled at the time of placing of concrete. Typical acceptance criteria for Self-compacting Concrete with a maximum aggregate size up to 20 mm

S No	Method	Unit	Typical range of values	
			Minimum	Maximum
1.	Slump flow test	mm	650	800
2.	T_{50} cm Slump flow	sec	2	5
3.	J – Ring	mm	0	10
4.	V – Funnel	sec	6	12
5.	V – Funnel at T_5 minutes	sec	6	15
6.	L – Box	h2/h1	0.8	1.0
7.	U – Box	(h_2-h_1) mm	0	30
8.	Fill Box	%	90	100
9.	GTM Screen stability test	%	0	15
10.	Orimet test	sec	0	5

Table 3Acceptance criteria for Self-compacting Concrete

Size of test specimen used:

The Self Compacting Concrete mixes, after having checked for the satisfaction of the fresh properties of self compacting specifications as per EFNARC [2002] was cast into cube moulds of size 150 mm x 150 mm, beam moulds of size 100mm x 100mm x 500 mm and cylindrical moulds of 300 mm height x 150mm diameter.. Moulds were provided with base plates, having smooth surface to support. The mould is filled without leakage. Care was taken to ensure that there were no leakages.

Curing of test specimens:

After 24 hours of casting, the specimens were removed from the moulds and immediately dipped in clean fresh water. The specimens were cured for 3 days, 7 days and 28 days respectively depending on the requirement of age of curing. The fresh water tanks used for the curing of the specimens were emptied and cleaned once in every fifteen days and were filled once again. All the specimens under immersion were always kept well under water and it was seen that at least about 15 cm of water.

Figure 3 Specimen casting and L – Box test apparatus

VI. TESTS ON HARDENED CONCRETE

Testing of hardened concrete plays an important role in controlling and confirming the quality of self compacting concrete.

Compressive Strength:

The value of uniaxial compressive stress reached when the material fails completely. In this investigation, the cube specimens of size 150 mm x 150 mm x 150 mm are tested in accordance with IS: 516 – 1969 [Method of test for strength of concrete]. The testing was done on a compression testing machine of 300 tons capacity. The machine has the facility to control the rate of loading with a control valve. The machine has been calibrated to the required standards. The plates are cleaned; oil level was checked and kept ready in all respects for testing.

Size of Aggregate	3 Days	7 Days	28 Days
20 mm	31.80	46.30	74.00
12.5 mm	36.20	49.00	77.10
10 mm	38.33	49.66	79.30

Table 4 Compressive strength of M 70 grade SCC

Flexural Strength:

Standard beam test (Modulus of rupture) was carried out on the beams of size 100 mm x 100 mm x 500 mm as per IS: 516 [Method of test for strength of concrete], by considering that material is homogeneous. To get these loads, a central point load has applied on a beam supported on steel rollers placed at third point as shown in Fig.4.8. The rate of loading is 1.8 kN/minute for 100 mm specimens and the load was increased until the beam failed. Depending on the type of failure, appearance of fracture and fracture load, the flexural tensile strength of the sample was estimated.

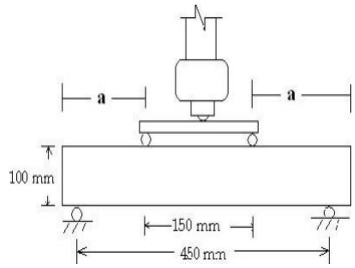

Figure 4 Schematic diagrams for flexure test setup

Size of Aggregate	3 Days	7 Days	28 Days
20 mm	4.03	6.75	8.50
12.5 mm	4.60	7.47	9.13
10 mm	5.35	7.65	9.35

Table 5 Flexural strength of M 70 grade SCC

Figure 5 compressive and Flexural strength tests

Split tensile strength:

This is also sometimes referred as “Brazilian Test” as this test was developed in Brazil in 1943. The cylinder was subjected to compression near the loaded region and the length of cylinder is subjected to uniform tensile stress.

Horizontal tensile stress=2P/Π D L

Where P= Compressive load on the cylinder.

L= Length of cylinder.

D= Diameter of cylinder**.**

Figure 6 split tensile strength test

Size of Aggregate	3 Days	7 Days	28 Days
20 mm	2.40	6.04	9.15
12.5 mm	2.80	5.90	9.62
10 mm	2.85	6.36	9.95

Table 6 Split tensile strength of M 70 grade SCC

VII. INTERPRETATION AND DISCUSSION OF TEST RESULTS

The parameters involved in the study are the size of aggregate (10, 12.5, 20 mm), age of curing (3, 7 and 28 days), grade of concrete (M70) and type of concrete (SCC).

Compressive strength:

Grade of concrete, maximum size of aggregate and age of curing are the variables of investigation. The details of the compressive strengths of M70 grades are shown in Tables 6.3. From the results it was noted that, as the grade of concrete increased the effective maximum size of the aggregate has deceased. In the above cases, the cement content was 680 kg/m3 for M70 grades. The three effective sizes for the above three mixes have been arrived and the same was adopted in the further study.

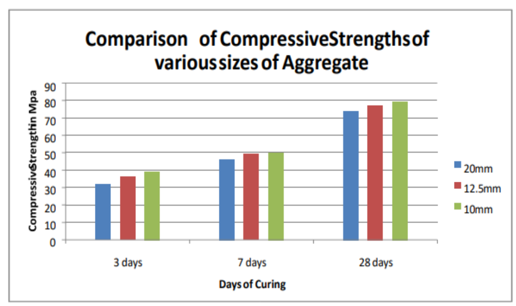

Figure 7 Bar Diagram of Compressive Strength with various sizes of Aggregates

Flexural strength:

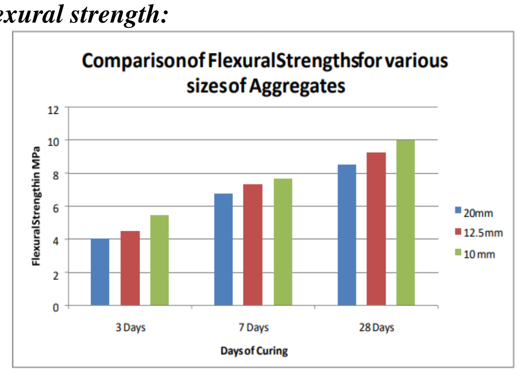

Figure 8 Bar Diagram of Flexural Strength with various sizes of Aggregates

The details of the flexural strength of the different sizes of aggregate and three grades of concrete. At 3, 7 and 28 days the effective size of aggregate was 10 mm for M 70 grades.

Split tensile strength

The details of the split tensile strength of M 70 grade of concrete for different sizes of aggregate. A similar trend as that of compressive strength was noted with regard to the size of aggregate. This was true at all the three different ages of curing.

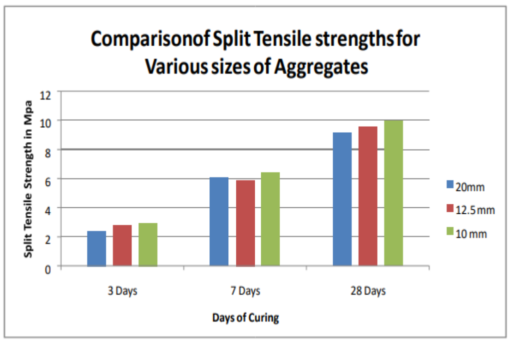

Figure 9 Bar Diagram of Split Tensile Strength with various sizes of Aggregates

From the results of the studies on mechanical properties for M70 grade of SCC mix, it is clear that the effective size of aggregate was 10 mm.

VIII. SCC – MIX DESIGN PROCEDURE

As per Nan Su's method of mix design of Self Compacting Concrete, the parameters that influence the mix proportions are packing factor, fine aggregate – total aggregate ratio and powder content.

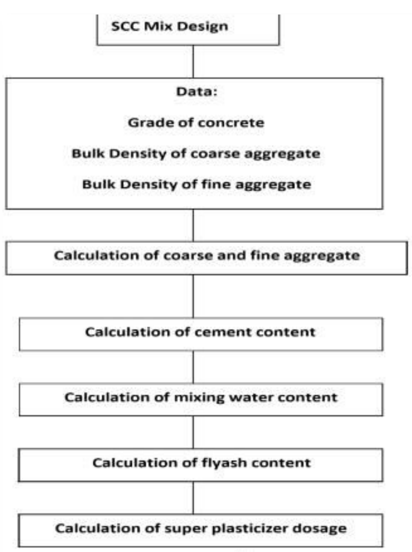

Figure 10 Flow chart of SCC mix design

However, as per Nan Su's method assumptions in lieu of packing factor, cement content, fly ash content and fine aggregate – total aggregate ratio were made. From the strength and workability studies conducted on SCC in the present investigation, it was noted that there is a significant change in the mix proportions with respect to packing factor, effective size of aggregate, fine aggregate – total aggregate ratio, fly ash content, cement content and water content. It was hence felt that these three parameters, which were otherwise assumed, are of reasonable importance. Hence, a rational mix design methodology modifying the existing Nan Su method has been proposed.

Calculation of coarse and fine aggregate content:

The size of aggregate plays an important role on the compressive strength of concrete and hence, on the design of concrete mix. In Nan Su method of mix design, there is no mention of the influence of the size of aggregate. In the present investigation, the effective maximum size of aggregate for M70 grade of concrete was obtained.

Grade of Concrete	Size aggregate (mm)	Packing Factor	28 days compressive strength (MPa)
M70	20	1.12	74.00
	12.5	1.12	77.10
	10	1.12	79.30

Table 7 Details of packing factor and strengths

In the Nan Su mix design procedure, (S/a) has been taken constant for all grades of concrete. The flow ability, filling capability and stability of fresh SCC are greatly influenced by ratio of volume between coarse aggregate and fine aggregate and there exists an optimum value to achieve the best workability of SCC. Hence, fine aggregate – total aggregate ratio (S/a) is an important parameter in the design of M70 grade of concrete. The ratio of fine aggregate to total aggregate for M70 grade of concrete, from the experimental results was shown below,

Grade of Concrete	M70
Fine to total aggregate ratio (S/a)	0.52

Table 8 Fine aggregate to total aggregate ratio

Calculation of cement content:

To get good flow ability and segregation resistance, the cement content should not be low. In the Nan Su mix design method, the cement content was calculated based on the assumption that 1 kg of cement gives 0.14 MPa strength of concrete. This is based on experimental results obtained from trials conducted in Taiwan.

Grade of Concrete	Cement Content (from Exp. results) kg/m³	Cement Content (from Nan Su) kg/m³
M70	680	500

Table 9 Cement content for M70 grade of concrete

Calculation of mixing water content:

From the experimental results, w/c ratio for M70 grade of concrete was given in the Table

*Grade of Concrete	M70
w/c ratio	0.38

Table 10 water-cement ratio for M70 grade of concrete

Calculation of Fly Ash content:

Large amounts of powder materials are required to achieve the self compatibility. However, if an excess amount of cement is added, the cost of materials and dry shrinkage will increase. To avoid the above two, a pozzolanic material like flyash (class - F) was taken into consideration in the present mix design procedure.

% fly ash in total powder (y) = 68.43 – 0.535 x grade of concrete (x) (7.6)

From the above equation, it is easy to find the percentage of fly ash content in total powder for any grade of concrete.

Calculation of Super Plasticizer dosage:

Adding an adequate dosage of Super Plasticizer (SP) can improve the flow ability, self compacting ability and segregation resistance of fresh SCC for meeting the design requirements. Water content of the SP can be regarded as part of the mixing water. In the present work, SNF condensate (SP 430) was used as a water reducing admixture (Super Plasticizer). The dosage of SP was obtained based on trial and error to suit the requirements of EFNARC. The dosage of SP used was ranging from 1.5 to 1.8% by weight of cement.

IX. CONCLUSION

Based on the systematic and detailed experimental study conducted on SCC mixes with an aim to develop performance mixes, the following are the conclusions arrived.

1. The mixes designed using the lower size of aggregate yielded better fresh properties than higher size of aggregates.
2. As the strength of concrete increases, the effective size of aggregate has decreased.

X. SCOPE OF THE FUTURE WORK:

The present investigation has brought out explicitly the effect of size of aggregate on the compressive strength and other mechanical properties of self compacting concrete.

1. The simplified mix design methodology was presented may be extended to the more number of concrete strength ranges.
2. The investigations may be conducted with different mineral admixtures like Rice Husk Ash and GGBS apart from fly ash.

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