Effect of Packing Density of aggregate on characteristics of Self Compacting Concrete

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Abstract - The Experimental investigations are carried out for determining the effect of packing density (PD) of aggregate on characteristics of Self-compacting concrete (SCC).For this purpose several mix designs of SCC for the proportion of C.A:F.A (45:55) was carried out. The SCC was prepared as per the said mix proportion of CA: FA and test were carried out on L box, J-ring test, V funnel and slump cone to find fresh property, cubes and cylinders were casted for testing the hardened properties of SCC. The obtained results of fresh and hardened properties of SCC for proportions of CA: FA was compared with the standard values as per EFNARC guidelines, ASTM.

Key Words: SCC, PD, flowability, passing ability, fly ash, and superplasticizer.

1. INTRODUCTION

The growing use of concrete in special architectural configurations and closely spaced reinforcing bars have made it very important to produce concrete that ensures proper filling ability, good structural performance and adequate durability. In recent years, a lot of research was carried out throughout the world to improve the performance of concrete in terms of its most important properties, i.e. Strength and durability [5]. Till 1980 the research study was focused only to flow ability of concrete, so as to enhance the strength however durability did not draw lot of attention of the concrete technologists. This type of study has resulted in the development of SCC, a much needed revolution in concrete industry. SCC is highly engineered concrete with much higher fluidity without segregation and is capable of filling every corner of form work under its self-weight only. Thus SCC eliminates the needs of vibration either external or internal for the compaction of the concrete without compromising its engineering properties. SCC is basically a concrete which is capable of flowing in to the formwork, without segregation, to fill uniformly and completely every corner of it by its own weight without any application of vibration or other energy during placing [1,3,4]. There is no standard SCC. Therefore, each SCC has to be designed for the particular structure to be constructed. However, working on the parameters which affect the basic properties of SCC such as plastic viscosity, deformability, flowability and resistance to segregation, SCC may be proportioned for almost any type of concrete structure. The SCC concept can be stated as the concrete that meets special performance and uniformity requirements that cannot always be obtained by using conventional ingredients, normal mixing procedure and curing practices. The SCC is an engineered material consisting of cement, aggregates, water and admixtures with several new constituents like colloidal silica, pozzolanic materials, and chemical admixtures to take care of specific requirements, such as, high-flowability, compressive strength, high workability, enhanced resistances to chemical or mechanical stresses, lower permeability, durability, resistance against segregation, and possibility under dense reinforcement conditions [6].

In this research work PD of aggregate is given a due consideration while designing the mix proportion of SCC and then various tests are performed on fresh properties such as L-Box test, V-funnel test, J-ring test and slump flow test and on hardened properties such as compression test and split tensile strength test are carried out as per EFNARC [9] guidelines and IS: 516-1959 [10].

2. MATERIALS AND METHODOLOGY

2.1 Methodology Adopted

[1]. Review of literature related to Research.
[2]. To develop design mix analytically for M40 and M60 grade of concrete using PD method.
[3]. To perform above mix design experimentally.
[4]. To find out effect of PD on hardened and fresh properties of M40, M60 grade by experimentation.
[5]. To compare the experimental result as per EFNARC [9] guidelines and ASTM [12].

2.3 Material Specifications

Following are the materials used for the experimental work.

2.3.1 Cement

The cement used in this experimental work is 53 grades Ordinary Portland Cement. All properties of cement are tested by referring IS 12269 - 1987 Specification for 53 Grade Ordinary Portland cement. The specific gravity of the cement is 3.15. The initial and final setting times were found as 108 minutes and 222 minutes respectively. Standard consistency and strength of cement was 32% and 53.7 N/mm^2.

2.3.2 Water

Potable water used for the experimentation.

2.3.3 Fine aggregate

Locally available sand passed through 4.75mm IS sieve is used. The specific gravity of 2.85 and fineness modulus of 3.87 are used as fine aggregate. The water absorption is of 1.60%.

2.3.4 Coarse Aggregate

Crushed aggregate available from local sources has been used. The coarse aggregates with a maximum size of 20mm having the specific gravity value of 2.90 and fineness modulus of 7.136 are used as coarse aggregate. The water absorption is of 0.97%.

2.3.5 Fly ash

Fly ash is a by- product obtained during the combustion of coal in thermal power plants, Typical physical properties: - Colour: grey, Specific gravity: 2.1.The advantage of Fly ash when used with Portland cement ensures higher durability of concrete avoids thermal cracking and improves workability. Slag has a pozzolanic reaction which allows the increase of concrete strength.

2.3.6 Super plasticizer

The super plasticizer used in concrete mix makes it highly workable for more time with much lesser water quantity. It is observe that with the use of large quantities of finer material, the concrete is much stiff and requires more water for required workability. Hence in the present investigation samples of superplasticizer are used for better results. Also to check the compatibility of superplasticizer with concrete Master Glenium sky 8276 is used.
The BASF's Master Glenium sky 8276 superplasticizer having specific gravity of 1.12 is used.

3. DESIGN OF CONCRETE BY PD METHOD

3.1 Determination of aggregate fractions

PD, i.e. the ratio of the volume of solids to the bulk volume of the solid Particles, is playing more important role in modern concrete mix design because of the increasing awareness that maximization of PD by adjusting the grading of the whole range of solid particles, including coarse aggregate, fine aggregate and the cementations materials, can improve the overall performance of the concrete mix. The aim of obtaining PD is to combine different aggregate particles to maximize the PD of aggregates and indirectly minimize the porosity which allows use of least possible amount of binder.

Three size groups of coarse aggregate i.e. (20-16mm, 16-10mm, 10-4.75mm) and two size groups of fine aggregates i.e.(4.75-2.36mm, 2.36-1.18mm) were selected for this study.

The values of PD of coarse aggregates were determined separately for different size groups mentioned above for different proportion by mass such as (60:30:10, 50:35:15, 45:40:15, 40:45:15, 35:45:20)

Similarly PD of fine aggregates were determined separately for different size groups mentioned above for different proportion by mass such as (30:70, 35:65, 40:60, 45:55, 50:50)

Out of each i.e. PD. of Coarse aggregate and PD. of fine aggregates which having maximum 3 PD. values were selected and further it is mixed for 45:55 (C.A:F.A) to find maximum PD of combined aggregates.

3.2 Determination of PD

The PD of aggregates is determined from the following relation.

Packing Density (D_p) =

$$\frac{\textit{Weight of aggregates}}{\textit{Speific gravity of aggregares} * \textit{Volume occupied by aggregates}}$$

$$D_P = \frac{W}{G * V}$$

Where:

D_P = Packing density of aggregate.

W= mass of aggregate in overall volume "V".

G= specific Gravity of aggregate

The value of Specific gravity should be taken as average in the case of mixed PD of aggregates.

4. MIX DESIGN FOR M40 AND M60 GRADE CONCRETE (PD METHOD)

4.1 For M40 grade and PD of 0.728

For PD of 0.728 gm/cm^3

Minimum paste content is sum of the void content in combined aggregate and excess paste over and above it to coat the aggregate particle. Meaning of minimum paste content can be explained as; a concrete mix containing minimum paste content should be cohesive, free from segregation and bleeding.

Voids content = 1 – 0.728 = 0.272

Assuming paste content as 10% in excess of void content, detailed calculations to obtain all the ingredients of concrete such as coarse aggregate, fine aggregate, cement and water content is given below.

Paste content 10% in excess of void content

Paste content = 0.272 + 0.1x 0.272

= 0.2992

Volume of aggregates = 1 – 0.2992 = 0.7008 cc

Total solid volume of aggregates $= \frac{\text{Weight fraction of coarse aggregate}}{\text{Specific gravity of coarse aggregate}} + \frac{\text{Weight fraction of fine aggregate}}{\text{Specific gravity of fine aggregate}}$

$$= \frac{0.45}{2.9} + \frac{0.55}{2.85}$$

= 0.348

Weight of Coarse aggregates $= \frac{\text{Volume of aggregate}}{\text{Total solid volume of aggregate.}}$ X CA Proportion X 1000

$$= \frac{0.7008}{0.348} \text{ X } 0.45 \text{ X } 1000$$

= 906.20 KG/Cum

Weight of Fine aggregates $= \frac{\text{Volume of aggregate}}{\text{Total solid volume of aggregate.}}$ X FA Proportion X 1000

$$= \frac{0.7008}{0.348} \text{ X } 0.55 \text{ X } 1000$$

= 1107.86 KG/Cum

For M40 grade concrete keeping in mind the target mean strength suitable water-cement ratio is fixed as per trial mixes.

W/C ratio = 0.37; W = 0.37C

Total Paste = C + W $= \frac{C}{3.15} + \frac{0.37C}{1} = 0.6874C$

Cement content $= \frac{0.2992}{0.6874}$ X 1000 = 435.26 KG/Cum.

Water content = 0.37 x 435.26

= 161.04 Kg/cum

Water absorption of

C.A (0.97 %) = 8.79 Kg

Fine aggregate = (1.6%) = 17.72 Kg

Total water =187.55 lit.

- Cement = 390 kg.
- Fly ash = 156 kg.
- CA = 906 kg.
- FA = 1107 kg.
- Water = 187.5 lit.
- SP dosage = 1.750 lit.

4.2 For M60 grade and PD of 0.744

For PD of 0.744 gm./cm^3

Voids content = 1 – 0.744 = 0.256

Assuming paste content as 10% in excess of void content, detailed calculations to obtain all the ingredients of concrete such as coarse aggregate, fine aggregate, cement and water content is given below.

Paste content 10% in excess of void content.

Paste content = 0.256 + 0.1x 0.256

= 0.2816

Volume of aggregates = 1 – 0.2816 = 0.7184 cc

Total solid volume of aggregates $= \frac{\text{Weight fraction of coarse aggregate}}{\text{Specific gravity of coarse aggregate}} + \frac{\text{Weight fraction of fine aggregate}}{\text{Specific gravity of fine aggregate}}$

$$= \frac{0.45}{2.9} + \frac{0.55}{2.85}$$

= 0.348

Weight of Coarse aggregates $= \frac{\text{Volume of aggregate}}{\text{Total solid volume of aggregate.}}$ X CA Proportion X 1000

$$= \frac{0.7184}{0.348} \text{ X } 0.45 \text{ X } 1000$$

= 928.96 KG/Cum

Weight of Fine aggregates $= \frac{\text{Volume of aggregate}}{\text{Total solid volume of aggregate.}}$ X FA Proportion X 1000

$$= \frac{0.7184}{0.348} X\ 0.55\ X\ 1000$$

= 1135.40 KG/Cum

For M60 grade concrete keeping in mind the target mean strength suitable water-cement ratio is fixed as per trial mixes.

W/C ratio = 0.33; W = 0.33C

Total Paste = C + W= $\frac{C}{3.15} + \frac{0.33C}{1}$ = 0.6474C

Cement content = $\frac{0.2816}{0.6474}$ X 1000 = 434.97 KG/Cum

Water content = 0.33 x 434.97
= 143.54 Kg/cum

Water absorption of

C.A (0.97 %) = 9.01 Kg.

F.A (1.6%) = 18.16 Kg.

Total water = 170.71 lit.

- Cement = 420 kg.
- Fly ash = 120 kg.
- CA = 919.95 kg.
- FA = 1117.24 kg.
- Water = 170.71 lit.
- SP dosage = 1.520 lit.

4.3 Batching, Mixing and Casting

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 by Drum mixer. The cement, coarse and fine aggregates were mixed thoroughly. These were mixed to uniform colour. Then water was added carefully so that no water was lost during mixing. The moulds were filled with SCC (SCC). No vibration was given to the cube as it compacted under its own weight. The top surface of the specimen was leveled and finished. After 24 hours the specimens were demoulded and were transferred to curing tank wherein they were allowed to cure for 7, 28days.

4.4 L Box test:

This test is based on a Japanese design for under water concrete. The test assesses the flow of the concrete and also the extent to which it is subjected to blocking by reinforcement.

V Funnel Test:

The test was developed in Japan. The equipment consists of V-shaped funnel section. The described V-funnel test is used to determine the filling ability (flow ability) of the concrete with a maximum aggregate size of 20mm.

4.5 Slump Flow Test:

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

4.6 J-Ring Test:

The test is used to determine the passing ability of the concrete. The J Ring can be used in conjunction with the slump flow, the V-funnel. These combinations test the flowing ability and the passing ability of the concrete.

4.7 Compressive Strength Test:

The compressive strength of concrete is one of the most important properties of concrete in most structural applications. For compressive strength test, cube specimens of dimensions 150 x 150 x 150 mm were casted for M40 and M60 grade of concrete. After curing, these cubes were tested on Compression Testing machine as per I.S. 516-1959.In each category three cubes were tested and their average value is reported.

4.8 Split Tensile Strength Test:

For split tensile strength test, cylinder specimens of dimension 150 mm diameter and 300 mm length were casted. The specimens were demoulded after 24 hours of casting and were transferred to curing tank wherein they were allowed to cure for 28 days. These specimens were tested under compression testing machine. In each category, three cylinders were tested and their average value is reported.

4.9 Checklist for Workability Test

AS Per EFNARC the checklist for workability test for different method like L box, V funnel, J-Ring and inverted slump cone test with their property and typical minimum and maximum range values are given in Table 5.1

Table -1: EFNARC typical minimum and maximum Range Values.

Sr.No.	**Test**	**Unit**	**Typical Range Of Values**		**Property**
			Minimum	**Maximum**	
1	L-Box Test	(H2/H1)	0.8	1.0	**Passing ability**
2	V-Funnel Test	Sec	8	12	**Filling Ability**
3	V-Funnel T5 min	Sec	11	15	**Filling Ability**
4	J-ring test	Mm	0	10	**Passing Ability**
5	Slump Flow	Mm	650	800	**Filling Ability**

5.EXPERIMENTAL RESULTS

Mix composition, fresh and hardened properties of SCC for proportions of CA: FA 45:55 shown in below and their results for tests like L box, V funnel, J- Ring, inverted slump flow test etc.

Table -2: PD and Fresh Properties of M40 grade concrete.

INGRADIETS	MIX 1	MIX 2	MIX 3	MIX 4
PD (gm/cm³)	0.744	0.744	0.744	0.728
Slump flow (mm)	536	567	700	689
J-Ring (mm)	-	-	< 10mm	<10 mm
V-Funnel (sec)	9	9	8	8
V-Funnel @T5 minutes (sec)	11	11	9	9
L-Box(H2/H1)	0.65	0.69	0.82	0.80
L-Box T20 (sec)	2.1	2.1	1.9	2
L-Box T40 (sec)	4	3.9	3.6	3.8

Table -3: Hardened properties of M40 Grade Concrete.

Mix Proportion	Compression St.		Tensile St.	
	7 days	28 days	7 days	28 days
MIX 1	37.74	51.17	3.90	5.20
MIX 2	37.09	49.12	3.74	5.13
MIX 3	35.91	48.38	3.52	4.78
MIX 4	36.68	48.92	3.61	4.98

Table -4 PD and Fresh Properties of M60 grade concrete.

INGRADIETS	MIX 5	MIX 6	MIX 7
PD (gm/cm³)	0.728	0.728	0.744
Slump flow (mm)	594	702	684
J-Ring (mm)	-	<10	<10
V-Funnel (sec)	8	10	11
V-Funnel @T5 minutes (sec)	9	11	13
L-Box(H2/H1)	0.72	0.87	0.84
L-Box T20 (sec)	1.9	2.0	2.2
L-Box T40 (sec)	4	3.8	4.0

Table -5 Hardened properties of M60 Grade Concrete.

Mix Proportion	Compression		Tensile	
	7 days	28 days	7 days	28 days
MIX 5	55.18	70.87	5.48	6.83
MIX 6	54.69	69.22	5.60	6.94
MIX 7	55.37	71.34	5.72	7.05

Table -6 PD of Coarse Aggregate.

MIX ID	Weight of Aggregate			PD.
	20-16	16-10	10-4.75	
CA1	60%	30%	10%	0.600
CA2	50%	35%	15%	0.606
CA3	45%	40%	15%	0.604
CA4	40%	45%	15%	0.603
CA5	35%	45%	20%	0.605

Table -7 PD of Fine Aggregate.

MIX ID	Weight Of Aggregate		PD.
	4.75-2.36	2.36-1.18	
FA1	30%	70%	0.641
FA2	35%	65%	0.648
FA3	40%	60%	0.656
FA4	45%	55%	0.659
FA5	50%	50%	0.667

Table -8 PD of Mixed Aggregate.

MIX ID	Weight of Aggregate					PD.
	20-16	16-10	10-4.75	4.75-2.36	2.36-1.18	
MIX 1	50%	35%	15%	50%	50%	0.741
MIX 2	35%	45%	20%	45%	55%	0.728
MIX 3	45%	40%	15%	40%	60%	0.719

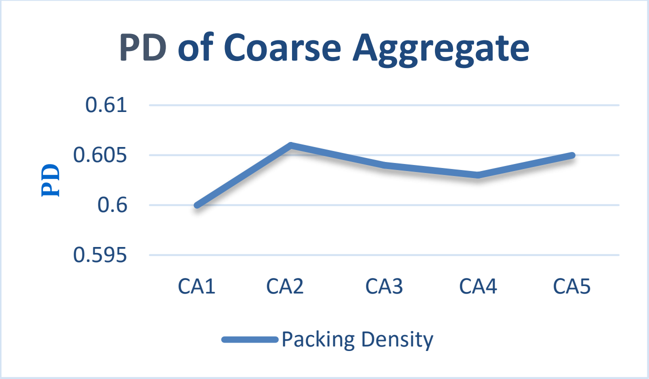

Fig -1. Relationships between Aggregate Proportion and PD of Coarse Aggregate.

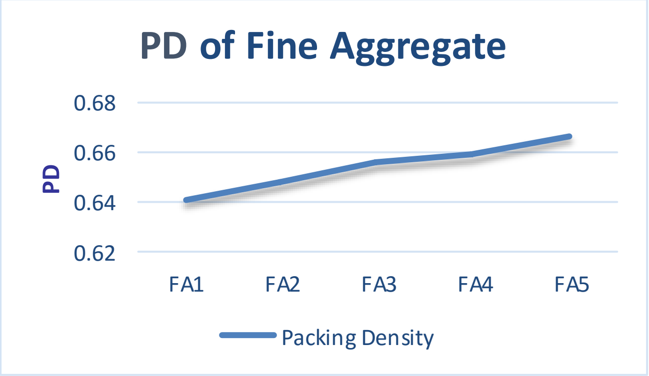

Fig-2. Relationships between Aggregate Proportion and PD of Fine Aggregate

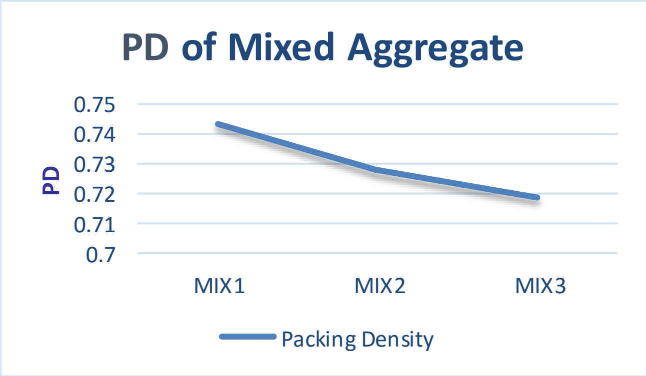

Fig -3. Relationships between Aggregate Proportion and PD of mixed Aggregate

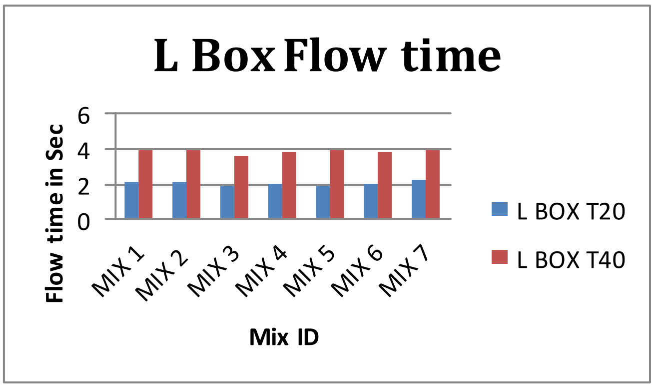

Fig -4 L-Box Flow Time.

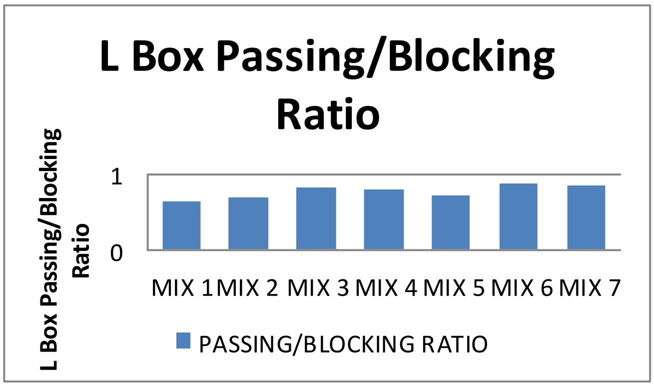

Fig -5 L-Box Passing/Blocking ratios for Different Mixes.

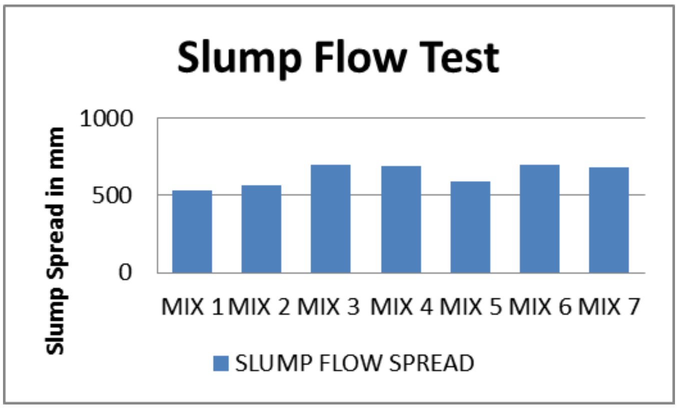

Fig -6. Slump flow spread for different mixes.

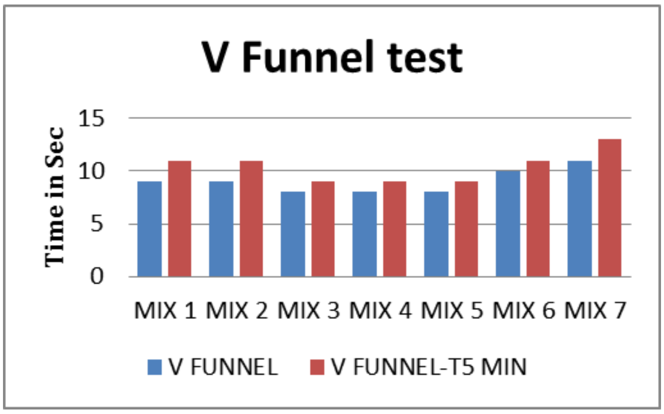

Fig -7. V Funnel and V Funnel T-5 Min Flow Time for Different Mixes.

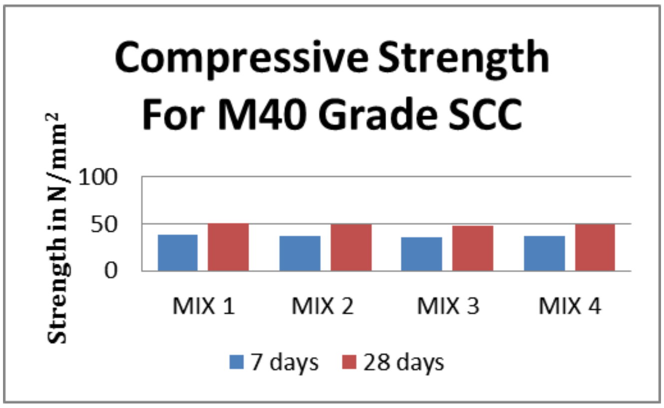

Fig -8. Compressive Strength at Different Age of M40 Grade of SCC Concrete.

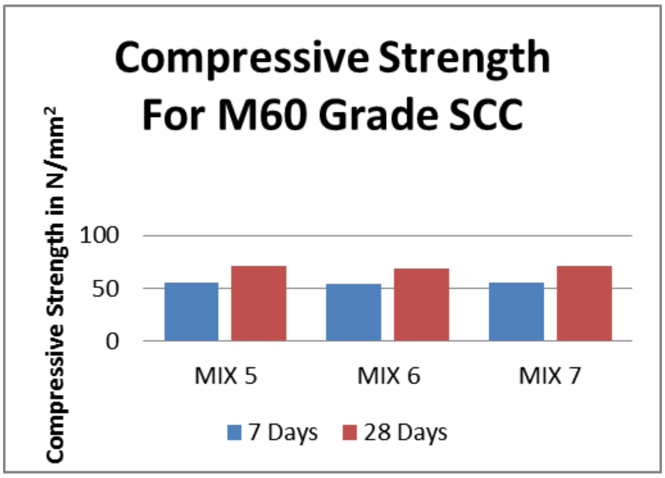

Fig -9. Compressive Strength at Different Age of M60 Grade of SCC Concrete.

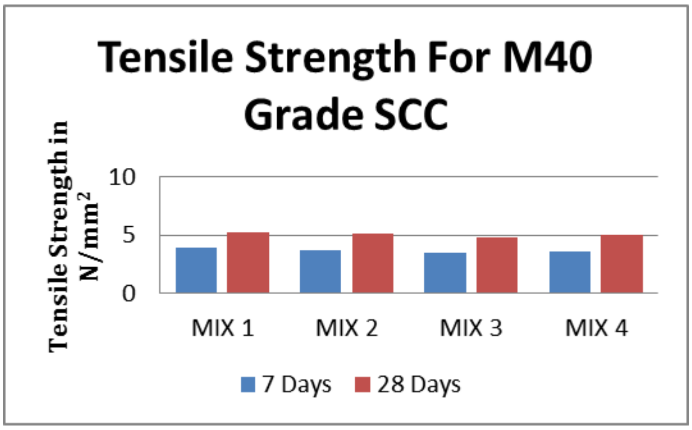

Fig -10. Tensile Strength at different Age of M40 Grade of SCC Concrete.

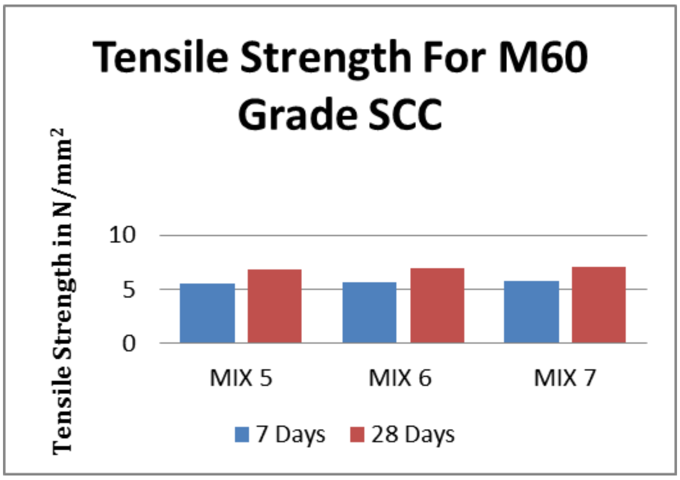

Fig -11. Tensile Strength at different Age of M60 Grade of SCC Concrete.

6. CONCLUSIONS

1. Multi sized mixtures having higher PD. Thus to have higher PD aggregates of different sizes are used.

2. Proportion of different size fractions shall be appropriate for maximization of PD.

3. Higher packing densities leave less space for voids to be filled with water, which reduces the water demand and increases the strength of concrete mixtures.

4. As the (SCC) possess special characteristics like flowing ability, passing ability, segregation resistance etc. This is not considered or given much importance in case of normal concrete. Thus when SCC was manufactured by considering the mix proportion prepared by taking in consideration maximum PD. it was observed that the concrete does not satisfies or meet the standards of SCC in fresh state as per EFNARC specification. Whereas the minimum proportion designed by considering PD. gives less powder content and more aggregate content. From first trials the SCC manufactured by considering PD. does not satisfies the minimum values for L-Box, J-Ring and Slump Cone test in fresh state, but in case of hardened properties i.e. compression and tensile tests the result shows 2-6% increase in strength then the other trails which satisfies EFNARC guidelines for comparatively less aggregates.

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