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Effect of Size of Aggregate and Fines on Standard And High Strength Self Compacting Concrete

[1]S. Venkateswara Rao, [2]M.V. Seshagiri Rao, [3]P. Rathish Kumar

[1]Lecturer, Department of Civil Engineering, NIT Warangal, A.P, India
[2]Professor & Head, Dept. of Civil Engg, JNTU College of Engg., Hyderabad, A.P, India
[3]Asst. Professor, Department of Civil Engineering, NIT Warangal, A.P, India

Abstract: The present investigation aims at developing standard and high strength Self Compacting Concrete (SCC) with different sizes of aggregate based on Nansu's mix design procedure. The results indicated that Self Compacting Concrete can be developed with all sizes of graded aggregate satisfying the SCC characteristics. The mechanical properties viz., compressive strength, flexural strength and split tensile strengths were studied at the end of 3, 7 and 28 days for standard and high strength SCC with different sizes of aggregate. It was noted that with 10mm size aggregate and 52% flyash in total powder the mechanical properties were superior in standard SCC, while 16 mm size aggregate with a 31% flyash in total powder improved the properties of high strength SCC.

Key words:

INTRODUCTION

The guiding principle behind Self Compacting Concrete (SCC) is that the sedimentation velocity of a particle is inversely proportional to the viscosity of the floating medium in which the particle exists[1,2]. The 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[3,4]. One of the employed techniques to produce SCC is to use fine materials like flyash in the concrete besides cement[5,6]. Aggregates, typically occupy an important volume fraction in cement-based materials, and thus have important effects on different aspects of material properties[7]. In addition to their role as a economical filler, aggregates help control the dimensional stability of cement-based materials, which may be considered to consist of a framework of cement paste with relatively large shrinkage movements restrained by the aggregate particles[8,9]. Moreover, the presence of aggregates in a cement paste matrix tends to increase the tortuosity of the fracture path and therefore, the matrix fracture toughness. The increase in fracture toughness with increasing aggregate particles size is the result of the increased resistance to the propagating crack[10,11]. Therefore, the size of the aggregate particles is expected to have a significant influence on the fracture properties of the matrix. Because, the increase in aggregate size leads to an increase in the matrix toughness, commonly available normal sand with a higher maximum aggregate size could successfully be used in conjunction with high-volume FA in the production of standard and high strength SCC.

With regard to its composition, self-compacting concrete consists of the same components as conventionally vibrated normal concrete, which are cement, aggregates, water, additives and admixtures. However, the high amount of superplasticizer for better workability, the high powder content as lubricant for the coarse aggregates, as well as the use of viscosity agents to increase the viscosity of the concrete have to be taken into account.

Based on the review of recent studies[12,13], it was proved that self-compactability could be achieved when the coarse aggregate content was restricted to 46 percent instead of 50 percent tried by Okamura[14]. Nansu *et al*[15], conducted research on the simple mix design method for self compacting concrete. Compared to the method developed by the Japanese Ready-Mixed Concrete Association (JRMCA), Nansu method is simpler, easier for implementation and less time-consuming, requiring smaller amount of binders and cost. In this research[15], the amount of aggregates required is determined, and the paste of binders is then filled into the voids of aggregates to ensure that the concrete thus obtained has flowability, self-compacting ability and other desired SCC properties. The amount of aggregates, binders and mixing water, as well as type and dosage of superplasticizer (SP) are the major factors influencing the properties of SCC

Corresponding Author: S. Venkateswara Rao, Lecturer, Department of Civil Engineering, NIT Warangal, A.P, India

Research Significance: The volume content, type and maximum size of aggregate influence the properties of SCC such as workability and strength. It is felt that the flowability, filling ability and stability of SCC is greatly influenced by the ratio of volume between the coarse and fine aggregate and there exists an optimum ratio to achieve the best properties of SCC. With the need of high performance concrete, properties of aggregate gradually become an important factor during the concrete design. The maximum size of aggregate has a limitation in high strength concrete. SCC as a good performance concrete with a special requirement in workability has a specific demand for content of aggregate and other properties of aggregate. Hence, in the present work, the influence of aggregate on the properties of self consolidating concrete on fresh and hardened states were investigated through extensive experimentation aimed at obtaining a clear and over all knowledge related to the role of aggregates in standard and high strength SCC

Experimental Program: The experimental program was designed to study the role of different sizes of coarse aggregate on the standard and high strength concrete. Further, flyash optimization is done in the second stage of study with the graded coarse aggregate. To this effect a detailed experimental program was planned. The variables involved in the study are size of aggregate, dosage of flyash and grade of concrete.

Cement: Ordinary Portland Cement(OPC) conforming to IS: 12269[16] was used in the study. The specific gravity was 3.15 and the initial setting time was 40 minutes and final setting time was 450minutes.

Fine Aggregate: Locally available river sand was used as fine aggregate. The specific gravity of the sand is 2.63 and it is conforming to Zone-II of IS:383–1970[17]. The sand was dried before use to avoid the problem of bulking.

Coarse Aggregate: Locally available granite with a size 20 mm and down was used as coarse aggregate. The specific gravity of the coarse aggregate is 2.91.

Water: Potable water is used for mixing and curing

Mineral Admixtures: Mineral admixtures are used to improve the fresh and hardened properties of concrete and at the same time reduce the cost of concrete materials. In order to achieve the necessary viscosity to avoid segregation, additional fine materials are used. In this study flyash from a local thermal power station was used. The specific gravity was 2.1 and the reactive silica was 92%. Silica fume a by-product from the electric arc furnace from a ferro-silicon alloys industry is also used in the study. The silica fume is having a specific gravity was 2.0. The optimum dosage of silica fume in high strength self compacting concrete used was 5% by weight of cement.

Chemical Admixtures: Two types of chemical admixtures are used in the production of SCC viz.,superplasticizers and Viscosity Modifying Agents (VMA). Conplast SP 430 was used as a superplasticizer in this study. The specific gravity is 1.22 and is a product of FOSROC chemicals. The VMA used here is Glenium Stream-2. It is a product of Degussa construction chemicals. A dosage of 0.25% by weight of cement was adopted.

Mix Design: Designing an approximate mix proportion to suit the needs of standard and high strength SCC with different types of aggregates was developed. In the present experimental study Nansu's method of mix design was adopted using different sizes of graded aggregates making suitable adjustments. The principal consideration of the proposed method is to fill the paste of binders in the voids of the aggregate framework piled loosely. The volume ratio of aggregate is about 52% to 58%. The strength of SCC is provided by the aggregate binding the paste in the hardened state, while the workability of SCC is provided by the binding paste at fresh state. The mix proportions with different sizes of graded aggregate of standard self compacting concrete (M30) and high strength self compacting concrete (M70) based on Nansu's mix design methodology is as detailed in Tables 1 and 2.

Properties of Fresh SCC: Fresh SCC must possess the key properties including filling ability, passing ability and resistance to segregation at required levels. The filling ability is the ability of the SCC to flow into all spaces within the formwork under its own weight. Without vibrating the concrete, SCC has to fill any space within the formwork and it has to flow in horizontal and vertical directions without keeping air entrapped inside the concrete or at the surface. Passing ability is the ability of the SCC to flow through tight openings such as spaces between steel reinforcing bars, under its own weight. Passing ability is required to guarantee a homogenous distribution of the components of SCC in the vicinity of obstacles. The resistance to segregation is the resistance of the components of SCC to migration or separation and remains uniform throughout the process of transport and placing. To satisfy these conditions, EFNARC[18], has formulated certain test procedures. The slump flow equipment is currently widely used in concrete practice, and the method is very simple and straightforward.

Table 1: Mix Proportions and Quantities of M30 grade of SCC

Size of Graded Aggregate (mm)	Mix Proportion	Water binder w/b	Quantities (kg/m^3)				
			Cement	Fly Ash	Fine aggregate	Coarse Aggregate	S.P
20.0	1:1.083:4.884:3.254: 0.021	0.435	214	231.76	1045.20	696.48	4.494
16.0	1:1.083:4.715:3.457: 0.021	0.435	214	231.76	1009.20	739.77	4.494
12.5	1: 1: 4.63: 3.77: 0.022	0.435	214	214.00	991.13	867.3	4.708
10.0	1: 1: 4.63: 3.77: 0.021	0.435	214	214.00	991.13	867.3	4.494

Table 2: Mix Proportions and Quantities of M70 grade of SCC

Size of Graded Aggregate (mm)	Mix Proportion	Water binder w/b	Quantities (kg/m^3)					
			Cement	Fly Ash	Fine aggregate	Coarse Aggregate	S.P	VMA
20.0	1:0.507:1.346:1.103: 0.028	0.236	680	344.77	915.71	750.04	19.34	1.75
16.0	1: 0.459:1.346: 1.082:0.025	0.250	680	312.43	915.71	736.24	17.36	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
10.0	1: 0.425: 1.214:1.170: 0.023	0.269	680	289.28	850.30	795.65	15.85	1.75

The time taken for the concrete to reach the 500mm spread circle is defined as the T50 time as per EFNARC specifications. Thus, the slump flow combined with T50 was selected as the first priority test method for the filling ability of SCC. The V-funnel or Orimet tests are recommended as second priority alternatives to the T50 measurement. The passing ability of fresh SCC can be tested by U-box or J-ring. The results of the tests of the fresh properties of SCC with different sizes of aggregate for M30 and M70 grade concretes is given in the Tables 3 and 4. It can noted that SCC satisfying the EFNARC specifications could be developed with M30 and M70 grades ie: standard and high strength concretes with all the sizes of graded coarse aggregate.

Mechanical Properties of SCC: The influence of size of coarse aggregate on the behavior of compressive strength, split tensile strength and flexural strength is being investigated. 150x150mm cubes for compressive strength, 150mm diameter and 300mm height cylinders for split tensile strength and 100x100x400mm prism specimens were adopted for studying the modulus of rupture. The program consisted of casting and testing a total number of 72 cubes, 72 cylinders and 72 prisms cast in 8 batches for M30 & M70 grades of concrete. Of these 36 cubes, 36 cubes and 36 prisms correspond to each of M30 and M70 grades of concrete. Of these 36 cubes, 9 cubes each correspond to 20, 16, 12.5 and 10mm maximum size of aggregate tested at the end of 3,7 and 28 days. 1000 KN Servo controlled dynamic testing machine was used for testing the specimens under displacement control. While testing, precautions were taken to ensure axial loading. For flexural strength, standard three point loading was adopted. The results of the compressive strength, split tensile strength and flexural strength are plotted for different sizes of aggregate at the end of 3,7 and 28 days in Figs 1-6 for M30 grade and M70 grade concretes

It can be noted from Figures 1 and 2, that for standard grade concrete ie: M30 grade 10mm size aggregate gave the higher compressive strength and similarly, for higher grade concrete ie: M70 grade, the optimum size of aggregate was 16mm. Similar results were noted in case of split tensile strength and flexural strength studies on standard and high strength concrete. Hence, in the further investigation of optimizing the flyash content 10mm size aggregate for M30 grade and 16mm size for M70 grade was adopted.

Optimization of Fly Ash: Out of 4 mixes with graded aggregate of size 20mm, 16mm, 12.5mm and 10mm, for M30 grade, as explained earlier, the mix with 10 mm size aggregate have the higher strengths compared to the other mixes and for M70 grade, the mix with 16 mm size aggregate have the higher strengths compared to other mixes. Flyash dosages as high as 50% was used as powder in standard scc while higher than 20% is used in high strength self compacting concretes. Using Nansu's method[15], again the mix design proportioning was done and the details are shown in Tables 5 and 6. Also the details of the fresh properties of flyash based mixes are shown in Tables 7 and 8. It can be noted that all the fresh properties were satisfying the EFNARC specifications.

Table 3: Properties of Fresh Concrete of M30

S.N0	Aggregate Size (mm)	Slump (mm)	T50 (Sec)	V-Funnel (Sec)	V-Funnel($T_{5\ Minutes}$) (Sec)	L-Box H_2/H_1
1	20.0	650	3	4	5	0.790
2	16.0	640	4	4	5	0.805
3	12.5	660	3	4	4	0.820
4	10.0	660	4	3	4	0.810

Table 4: Properties of Fresh Concrete of M70

S.N0	Aggregate Size (mm)	Slump (mm)	T50 (Sec)	V-Funnel (Sec)	V-Funnel($T_{5\ Minutes}$) (Sec)	L-Box H_2/H_1
1	20.0	720	5	9	12	1.00
2	16.0	725	5	7	9	1.00
3	12.5	715	5	6	8	1.00
4	10.0	735	5	7	9	1.00

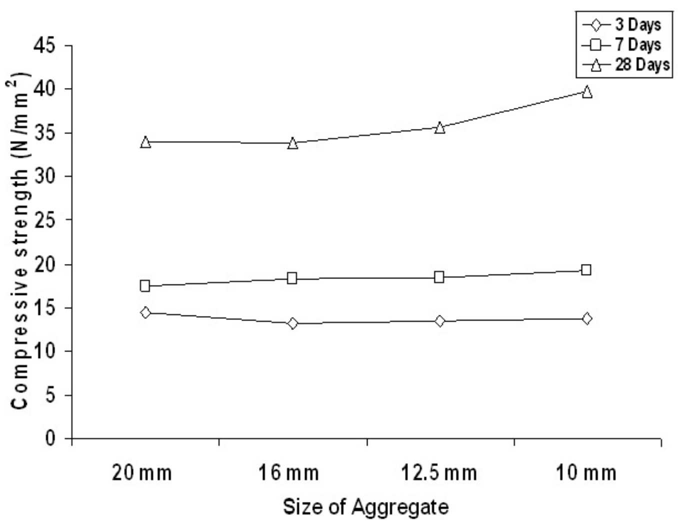

Fig. 1: Compressive Strength of M30 grade concrete

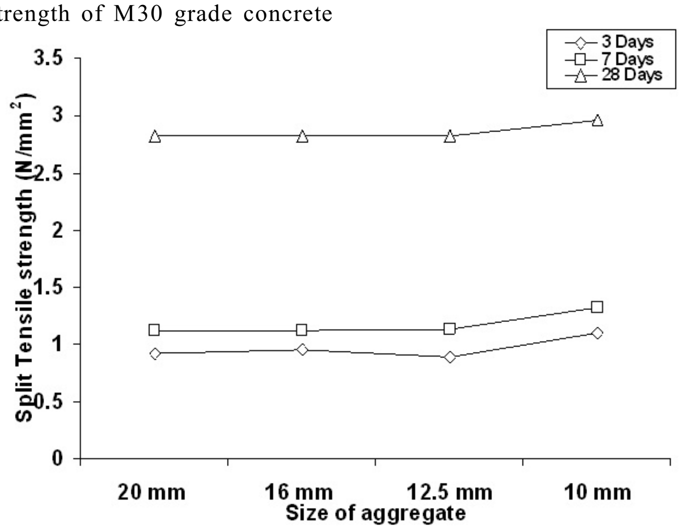

Fig. 2: Compressive strengths of M70 grade concrete

Table 5: Mix proportions and quantities of M30 grade SCC

% Fly Ash in total powder	Mix Proportion	Water binder w/b	Quantities (kg/m^3)				
			Cement	Fly Ash	Fine aggregate	Coarse Aggregate	S.P
50%	1: 1.00: 4.63: 3.77: 0.021	0.435	214	214.00	991.13	807.3	4.494
52%	1: 1.08: 4.63: 3.77: 0.021	0.435	214	231.80	991.13	807.3	4.494
55%	1: 1.22: 4.63: 3.77: 0.021	0.435	214	261.55	991.13	807.3	4.494
60%	1: 1.50: 4.63: 3.77: 0.021	0.435	214	321.00	991.13	807.3	4.494
65%	1: 1.86: 4.63: 3.77: 0.021	0.435	214	397.43	991.13	807.3	4.494
70%	1: 2.33: 4.63: 3.77: 0.021	0.435	214	499.33	991.13	807.3	4.494

Table 6: Mix proportions and quantities of M70 grade SCC

% Fly Ash in total powder	Mix Proportion	Water binder w/b	Quantities (kg/m^3)					
			Cement	Fly Ash	Fine aggregate	Coarse Aggregate	S.P	VMA
20%	1: 0.250: 1.346: 1.082: 0.025	0.250	680	170.00	915.71	736.24	17.36	1.75
31%	1: 0.459: 1.346: 1.082: 0.025	0.250	680	312.43	915.71	736.24	17.36	1.75
40%	1: 0.670: 1.346: 1.082: 0.025	0.250	680	453.33	915.71	736.24	17.36	1.75
50%	1: 1.000: 1.346: 1.082: 0.025	0.250	680	680.00	915.71	736.24	17.36	1.75
60%	1: 1.500: 1.346: 1.082: 0.025	0.250	680	1020	915.71	736.24	17.36	1.75

Table 7: Properties of Fresh Concrete of M30

S. No	% Fly Ash in total powder	Slump Flow Value(mm)	T_{50} (Sec)	V-Funnel (Sec)	V-Funnel at $T_{5\ Minutes}$(Sec)	L-Box H_2/H_1
1.	50	690	4.20	4	7	0.94
2.	52	695	4.17	4	7	0.98
3.	55	720	4.0	4	6	1.00
4.	60	745	3.0	4	6	1.00
5.	65	700	3.0	4	6	1.00
6.	70	720	3.0	3	5	1.00

Table 8: Properties of Fresh Concrete of M70

S. No	% Fly Ash in total powder	Slump Flow Value(mm)	T_{50} (Sec)	V-Funnel (Sec)	V-Funnel at $T_{5\ Minutes}$(Sec)	L-Box H_2/H_1
1.	20	690	4.17	4.5	5.0	0.94
2.	31	720	4.00	6.0	6.0	1.00
3.	40	720	5.15	5.0	5.0	1.00
4.	50	720	5.62	6.5	7.0	1.00
5.	60	730	4.06	4.5	6.7	1.00

Mechanical Properties of Flyash Based SCC: In the previous article the method of developing a mix design methodology and the fresh properties of standard and high strength SCC has been examined. All the specimens were made with either 10mm maximum size aggregate or 16mm maximum size aggregate as per the grade of concrete discussed earlier. The mechanical properties are also investigated to confirm the utility of flyash in standard and high strength concretes. Figs. 7 and 8 show the details of compressive strength of M30

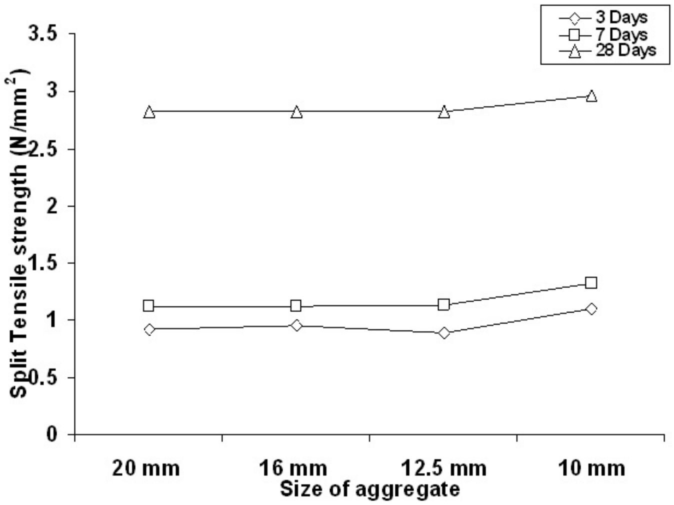

Fig. 3: Split Tensile strength of M30 grade concrete

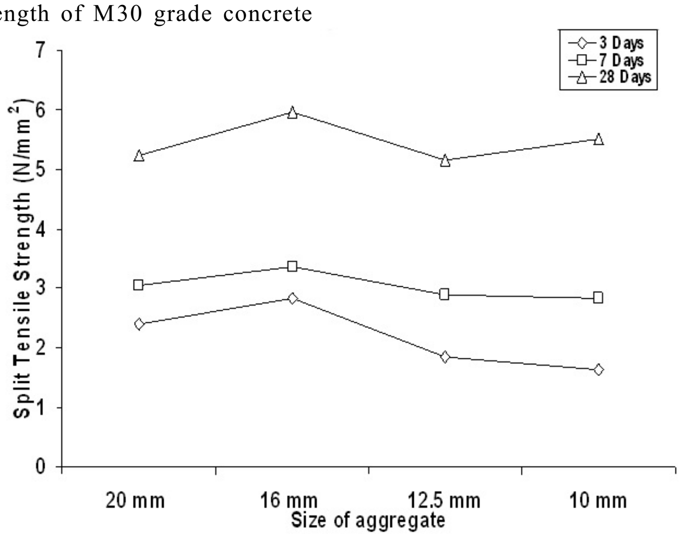

Fig. 4: Split Tensile strength of M70 grade concrete

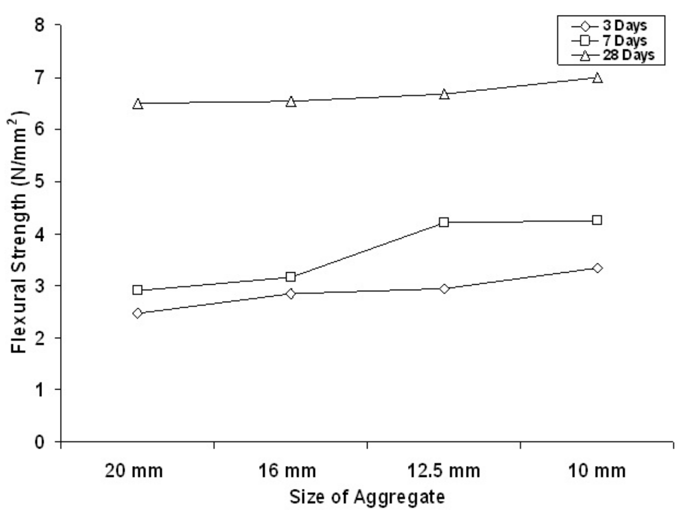

Fig. 5: Flexural strength of M30 grade concrete

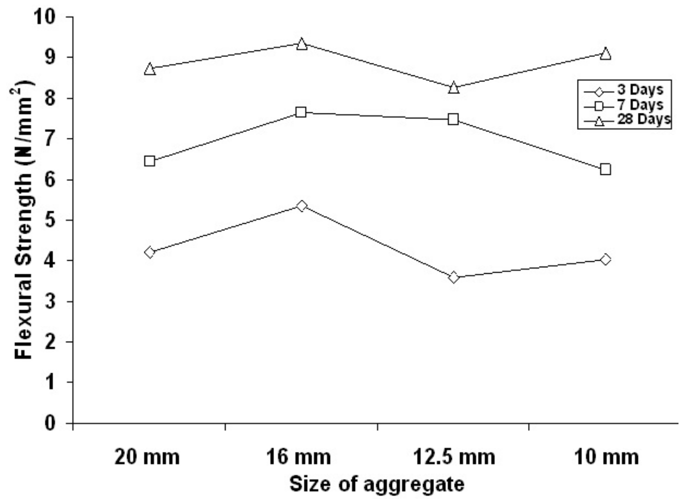

Fig. 6: Flexural strength of M70 grade concrete

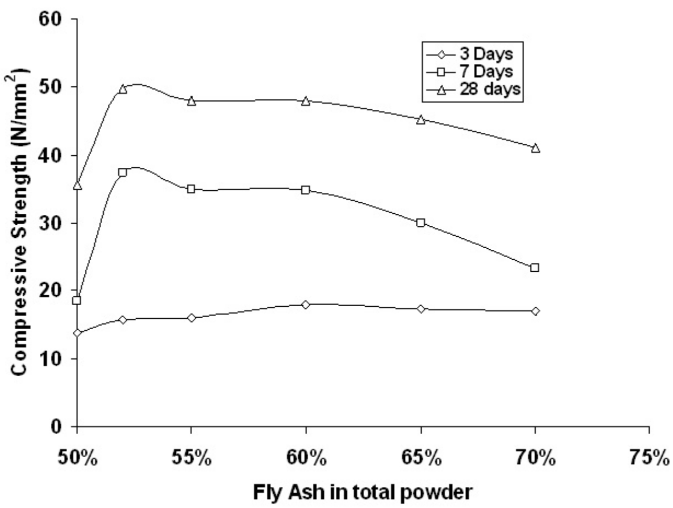

Fig. 7: Comp. strength of M30 flyash SCC

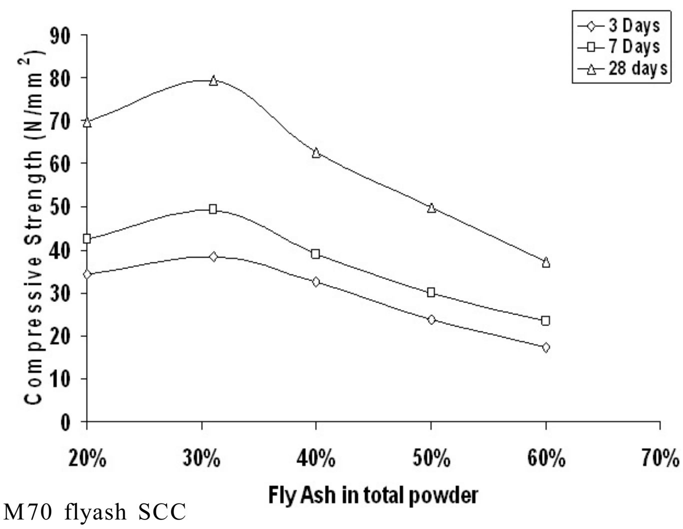

Fig. 8: Comp. strength of M70 flyash SCC

and M70 grade concretes. It can be noted that the optimum dosage was 52% for standard concrete and 31% addition for high strength concrete. A similar dosage was also true for split tensile strength and flexural strength for standard concrete and high strength concrete as shown in Figs 9-12.

Conclusions: The optimum size of aggregate was 10mm for standard self compacting concrete(M30), while it is 16mm for high strength self compacting concrete(M70) though all other sizes also could develop properties satisfying that of SCC.

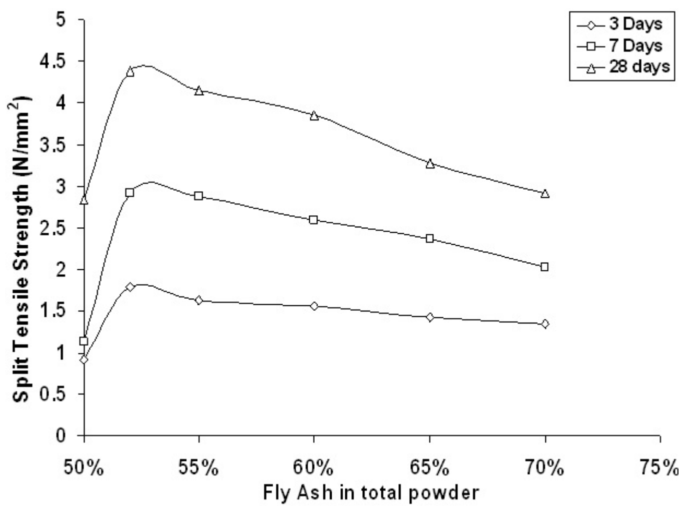

Fig. 9: Split Tensile strength of M30 flyash SCC

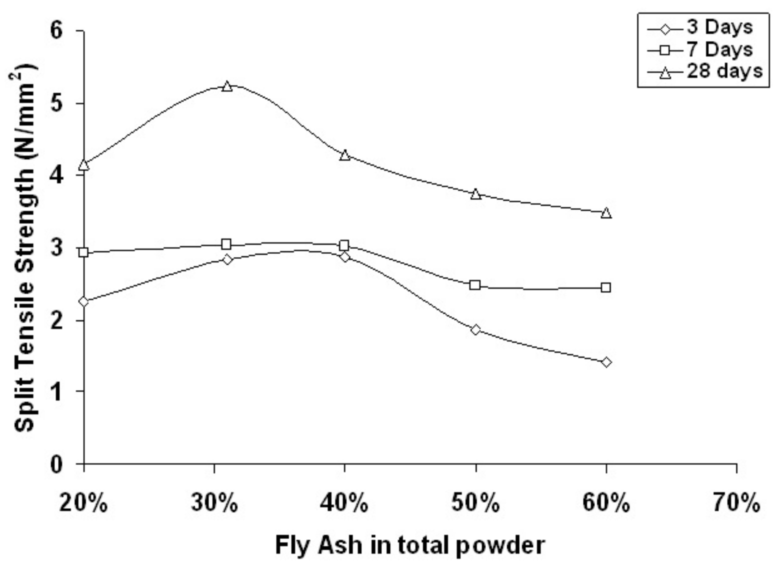

Fig. 10: Split Tensile strength of M70 flyash SCC

A comparison of M30 and M70 grade concretes confirmed that the filling ability, passing ability and segregation resistance was better for higher grade concretes for the same size of aggregate. This is due to the higher fines content in M70 concrete.

Higher volumes of flyash as high as 50-70% was added in total powder to generate SCC. It was noted that the fresh properties improved with increase in flyash percentages.

It was noted that the optimum dosages of flyash were 52% addition in case of standard grade SCC and it is 31% addition in case of high strength Self Compacting Concrete.

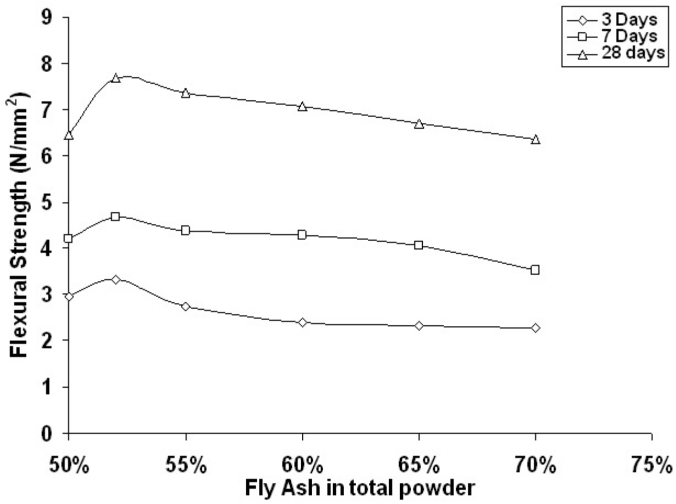

Fig. 11: Flexural strength of M30 flyash SCC

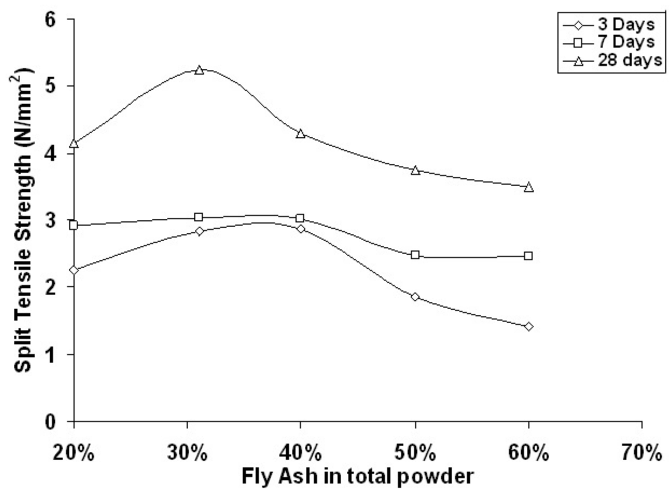

Fig. 12: Flexural strength of M70 flyash SCC

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