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Experimental Study on Engineering Properties of Self-Compacting Concrete Using Fly Ash and Steel Fibres

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***Abstract**: Development of SCC has been considered as the turning point in the construction industry as it overcomes the inadequacies of normal concrete and also avoids the problem associated with it. SCC is emerging as a growing trend in the world construction scenario. Given its advantages and durability factors, SCC is particularly suitable for difficult working conditions such as structures with congested reinforcements and in places not accessible for normal concreting operations.*

Self-Compacting Concrete (SCC) has various advantages due to its field performance and ease of application. However, it is felt that more careful study is required at the stage of mix proportioning. In order to produce SCC, a more voluminous but also a more viscous matrix is needed compared to concrete of normal workability. The objective may be achieved by using different fillers with pozzolanic or inert in nature.

The main focus of the present work is to suggest the optimum mix proportion for utilizing the fly ash produced by the thermal power plants in India. It is also aimed to propose experimentally an optimum value of fibre content to be used in SCC. In the present work four mix of M30 grade SCC were prepared with variable percentages of fly ash (0, 10, 20, 30, 40 and 50%) and steel fibre (0, 0.5, 1.0 and 1.5%). It is observed that 20% fly ash in SCC mix gives maximum compressive and flexural strength. Addition of steel fibre results in increase of compressive and flexural strength for all the mixes. It has observed that mix with 1.5% of steel fibre shows significant increase in compressive and flexural strength for both 7 days and 28days.

Keywords: Self-Compacting Concrete (SCC), maximum compressive strength, flexural strength, steel fibre, concrete.

1. Introduction

General

Concrete is that the most generally used construction material today. It is all around us; from offices to schools, roads to railways and dams to homes. It is difficult to means another material of construction which is as versatile as concrete. It is the fabric of choice where strength, performance, durability, impermeability, fire resistance and abrasion resistance are required. The versatility and mould ability of this material, its high compressive strength, and discovery of the reinforcing and prestressing techniques which helped to make up for its low tensile strength have contributed largely to its widespread use. It is so closely associated now with every act that it touches every person in his day-to-day living. We can rightly say that we are in the age of concrete.

However, when it comes to considering its sustainable credentials, which will ensure that we balance our current rate of development with the resource requirements of future generations, it is important to look at special concretes like Self-Compacting Concrete(SCC), Fiber

Reinforced Self-Compacting Concrete (FR- SCC) and High Performance Concrete(HPC) from several angles: its environmental and lifecycle aspects, its economic impact, its strength and durability aspects and its contribution to our society in general. Taking the environmental aspect first, there is clear evidence that improvements in environmental performance are underway to minimize the impact of concrete production. These changes include actively reducing the emissions associated with the concrete manufacturing process, and lower the reliance on virgin raw materials by increasing the use of by products in concrete.

The greenhouse gas emissions can be significantly reduced by utilizing the fly ash which is a waste product from thermal plants. The use of fly ash will continue to make a significant contribution to reducing the environmental pollution.

Fiber Reinforced Concrete(FRC)

Concrete lends itself to a spread of innovative designs as a result of its many desirable properties. Not only can it's cast in diverse shapes, but it also possesse high compressive strength, stiffness, low thermal and electrical conductivity. Fiber reinforced concrete is the concrete in which fibers have been incorporated to strengthen a material that would otherwise be brittle. Fibers are added to a concrete mix, which normally contains cement, water and fine and coarse aggregate. Short discontinuous fibers have the advantage, however, of being uniformly mixed and dispersed throughout the concrete. The promise of thinner and stronger elements reduced weight and controlled cracking by simply adding a little number of fibers is a beautiful feature of fiber-reinforced concrete. Other properties of concrete, such as compressive strength and modulus of elasticity, are affected a much lesser degree by the presence of fibers. If the modulus of elasticity of the fiber is high with respect to the modulus of elasticity of the concrete, the fibers help carry the load, thereby increasing the tensile strength of the material. Fibers will improve the toughness, the flexural strength, or both, and are chosen on the basis of their availability, cost and fiber properties. Chemical admixtures are added to fiber- reinforced concrete mixes primarily to extend the workability of the combination. Innovations in engineering design, which frequently establish the necessity for brand spanking new building materials, have made fiber-reinforced cements very fashionable. The increased tensile strength and impact resistance offers potential reductions in the weight and thickness of building components and the fiber added will also reduce the damage resulting from shipping and handling.

Self-Compacting Concrete(SCC)

Development of SCC has been considered as the turning point in the construction industry as it overcomes the inadequacies of normal concrete and also avoids the problem associated with it. SCC is emerging as a growing trend in the world construction scenario. Given its advantages and durability factors, SCC is particularly suitable for difficult working conditions such as structures with congested reinforcements and in places not accessible for normal concreting operations.

Self-Compacting Concrete (SCC) as a special concrete, has practical advantages thanks to its mechanical performance and application easiness. However, a more careful study is needed at the stage of mix proportioning. In order to supply SCC, a more voluminous but also a more viscous matrix is required compared to concrete of normal workability.

This may be achieved by using additional fillers with pozzolanic or inert nature. The employment of sands rich in fines could also be a second alternative source of filler. Despite the obstacles, the past decades have seen significant innovation in cementitious materials. The most significant of these are the high performance (strength) and self-compacting concrete have been achieved by the optimized packing of particles of different sizes, which is facilitated by the use of organic admixtures. Sustainability will be the main driver for innovation in the near future and therefore we are likely to see an increasing range of supplementary cementitious materials and even new clinker types emerging over the coming years. The building industry is progressively trying to use self-compacting concrete (SCC) so as to enhance many aspects of construction, principally ferroconcrete. The use of self- compacting concrete (SCC) with its improving production techniques is increasing a day in concrete production. The Self Compacting Concrete (SCC) has a high flow-ability and can be placed without vibration. It is defined as a concrete that exhibits a high deformability and a good resistance to segregation. This kind of concrete is of great interest and has gained wide use especially in the case of difficult casting conditions such as heavily reinforced sections. From a rheological point of view, the utilization of a Viscosity Enhancing Admixture (VEA) alongside adequate Super-Plasticizer (SP) content enables to make sure high deformability and stability. Compared to Fiber Reinforced Concrete (FRC), Self-Compacting Concrete (SCC) is a relatively new type of concrete with high flow-ability and good cohesiveness. It offers very attractive economical and technical benefits, which may be further extended when combined with FRC.

Self-compacting concrete reduces the preparation time, manpower and equipment on construction sites, makes the development of heavily congested structural elements and hard to succeed in areas easier, reduces noise and vibration related injuries and helps in achieving higher quality finish surfaces. However, because it always requires a bigger content of binder and chemical admixtures compared to ordinary concrete, its material cost is usually higher, which has been a serious hindrance to a wider implementation of its use. There is growing evidence that incorporating high volumes of mineral admixtures and micro-fillers as partial replacement for hydraulic cement in SCC can make it cost effective.

2. Literature Review

Many studies have been reported on SCC and FRC separately in general. However, studies on FR-SCC are very limited. Further, SFR-SCC due to its special characteristics like ductility and split tension components added to it is gaining importance in recent days. Research and developments on FRC composites started in India only during early 1970_s and that on SCC during 1980_s. The analytical and experimental investigations carried out by various investigators were confined either to FRC or to SCC. Contribution of different researchers is presented briefly in the following paragraphs.

Vengala et al (2003) developed a sequential procedure for achieving SCC. Fifteen mixes were investigated, maintaining w/c ratio and super-plasticizer dosage constant for all excepting for the initial mixes. To obtain the required flow in SCC fly ash replacement of 5, 10, 15, 20 and 25 percent respectively of coarse aggregate was adopted. A VMA was also tried in different dosages to stabilize the mix. Slump flow test and L-box tests as recommended in literature were carried out to obtain the properties of flow ability and workability of fresh concrete. The mechanical properties of hardened concrete were also investigated in terms of compressive strength. The results indicated that using the sequential procedure developed, SCC could be achieved successfully. It was reported that VMA may not be strictly necessary for making SCC.

Saak et al. (2004) proposed a three-dimensional model relating slump to yield stress is further developed and generalized as a function of cone geometry. It was observed that the model fits the experimental data for cylindrical slump over a wide range of yield stress values for a variety of materials including cement paste, clays, and ceramic suspensions. It was noted further that the cone tests do not fit the derived model but instead follow the cylindrical slump model at low yield stress values. This is consistent with the final shape of the slumped material. At high yield stress, the data deviate from the conical model as filling the slump cone becomes difficult and large air voids are present. The data also showed a simple relationship between slump and the area of the final spread (slump flow). Multiple models derived predicted identical yield stress for a given slump when converted to dimensionless form. These results suggest a fundamental relationship between yield stress and slump that is material independent and largely independent of cone geometry.

Djelal C. et al (2004) have observed and reported that the placing process for fresh, so-called self-compacting concrete (SCC) depends on the friction that occurs at the concrete/wall interface. A device called a rectilinear movement tribo-meter was developed to characterize SCC. The effect of several parameters affecting the concrete/metal plate friction coefficient was examined and reported. These parameters include the roughness of the plate, the sliding velocity against the plate, the pressure or normal stress and the nature of the demoulding agent at the concrete/wall interface. Few physical mechanisms are proposed.

Brouwers H. J. H. and Radix H. J. (2005) addresses the experiments and theories on Self- Compacting Concrete. The features of __Japanese and Chinese Methods__were discussed, in which the packing of sand and gravel plays a major role. The grading and packing of all solids in the concrete mix serves as a basis for the development of new concrete mixes.

Authors in their investigation developed mixes consisting of slag blended cement, gravel (4- 16 mm), three types of sand (0-1, 0-2 and 0-4 mm) and a poly carboxylic ether type super- plasticizer. These mixes were extensively tested, both in fresh and hardened states, and found to meet all practical and technical requirements such as medium strength and low cost. Furthermore, the packing behavior of the powders (cement, fly ash, stone powder) and aggregates (three sands and gravel) used are analyzed in detail. It was observed and reported that their loosely piled void fraction are reduced to the same extent (23%) upon vibration (aggregates) or mixing with water (powders). Finally, the paste lines of the powders were used to derive a linear relation between the deformation coefficient and the particle density.

Ganesh Babu K. and Dinakar P. (2005) have attempted to review the basic requirements of SCC, having recognized the fact that all the proportioning methodologies attempting to have high paste volumes but follow different approaches. The experimental investigation was carried out on concretes containing 30-40% fly ash with cement contents ranging from 360- 460 Kg/m3, at water to powder ratios varying from 0.33 to 0.40. It was noted that with the proper modification of the mix proportions a wide range of SCCs confirming to the extremely high fluidity requirements can be produced with ease through the utilization of high-volume fly ash incorporated through the efficiency concept. It was further noted that the use of fly ash enhances the paste content and improves the flow-ability of the mix. The efficiency concept methodology proposed by the authors earlier was successfully implemented for the design of self-compacting concretes. It was reported that the mixes with strengths from 60-90 Mpa can be achieved.

Domone P. L. (2006) has reported sufficient number of case studies of SCC applications with details of fresh properties, compressive strength, constituents and mix proportions to enable some useful conclusions for practitioners and researchers to be drawn. Author has analyzed sixty-eight case studies of applications of self-compacting concrete (SCC). These were published from 1993 to 2003, the period of increasingly widespread use of SCC in many countries. They were selected for analysisonthebasisofincludingdetailsofconcreteformulation sandproperties. The ranges of properties, component materials and mix proportions show the diverse nature of SCC, and confirm that it should be considered as a family of mixes suitable for a wide range of applications with widely varying requirements. The outcome of the analysis of the above factors is given in statistical terms like: ranges, frequencies, cumulative distributions, medians and deciles. This will be of value to those new to SCC, current users and researchers.

Salih Yazicioglu et al (2006) reported an experimental study investigating the effect of curing conditions on the engineering properties of SCCs. Portland cement concrete (PCC) and two types of SCC i.e., SCC1 with fly ash and SCC_2 with silica- fume specimens were prepared and cured in three different curing conditions, namely standard 200 C water, sealed and air cured for the periods of 3, 7, 14 and 28 days. At the end of each curing period compressive and tensile strengths and ultrasonic pulse velocity(UPV)values were determined. The authors have reported that the water cured specimens always give the highest values followed by those cured as sealed and in air irrespective of type and age of concrete and test methods for both compressive and tensile tests, the SCC_2 gives the highest values followed by SCC1 and then PCC for all curing periods and conditions. Whilst, the UPV (ultrasonic pulse velocity) results showed that the highest values are obtained from the SCC1 and then from the PCC and SCC_2 for all curing conditions.

BurakFelekoglu et al (2007) have conducted an experimental investigation on five mixtures with different combinations of water/cement ratio and super-plasticizer dosage levels. Several tests such as slump flow, V-funnel, L-box were carried out to determine optimum parameters for the self-compactibility of mixtures. Compressive strength development, modulus of elasticity and splitting tensile strength of mixes were also studied. Based on the experimental investigation, they arrived at the following conclusions.

- Optimum water/cement ratio for producing SCC is in the range of 0.84-1.07by volume. The ratios above and below this range may cause blocking or segregation of the mix, respectively. Self-compactibility test method stipulations are not universally accepted rules. Degree of toleration depends on the engineering judgment, material type and variety. Proper concrete mixes can be produced by trial-and-error method.
- Highersplittingtensilestrengthandlowermodulusofelasticiti esareobtained from SCC mixtures when compared with normal vibrated concrete. Further research is necessary to establish proper relationships between mechanical properties of SCCs at different strength grades and including different constituent materials.

Dinakar P. et al (2008) presents an experimental study on the durability properties of self- compacting concretes (SCCs) with high volume replacements of fly ash. Eight fly ash self-compacting concretes of various strength grades were designed at desired fly ash percentages of 0, 10, 30, 50, 70 and 85, in comparison with five different mixtures of normal vibrated concretes (NVCs) at equivalent strength grades. The investigation on durability properties such as permeability, water absorption, acid attack and chloride permeation were carried out. There sults indicated that the permeability decreased with an increase in strength and increased with increase in fly ash dosage. It was noted that the water absorption was less with a decrease in permeability. However, in acid attack and chloride diffusion studies the high-volume fly ash SCCs exhibited significantly lower weight losses and chloride ion diffusion. It was reported that all high-volume fly ash concretes satisfy the norms that were set to qualify them as self-compacting concretes.

HalitYazici (2008) conducted experimental investigation in which cement was replaced with a fly ash (FA) in various proportions from 30% to 60%. Durability properties of various self- compacting concrete (SCC) mixes such as, freezing Similar tests were carried out with the incorporation of 10% silica-fume (SF) to the same mixes. Test results indicated that SCC could be obtained with a high- volume FA. Ten percent SF additions to the system positively affected both the fresh and hardened properties of high-performance high-volume FA SCC. Although there is a little cement content, these mixes exhibited good mechanical properties, freeze–thaw and chloride penetration resistance.

Karen L. Scrivener and R. James Kirkpatrick (2008) have discussed in detail the past and present scenario in the field of concrete technology giving an emphasis to the special concretes such as high-performance concrete and self-compacting concrete. The need for sustainability with lower environmental impact was discussed. Recent advances in materials characterization techniques facilitated by advanced computational approaches were discussed at length.

Raghu Prasad B.K. et al (2009) presented an artificial neural network (ANN) to predict a 28- day compressive strength of a normal and high strength self- compacting concrete (SCC) and with high volume fly ash. The compressive strengths of SCC and HPC as well as slump flow of SCC estimated by the proposed neural network were validated by experimental results. It was observed that the high-volume fly ash in SCC and HPC cause good increase in compressive strength at 56 days and 90 days and not so much at 28 days. It was advised to depend on the 90-day compressive strength instead of 28-day strength if the volume of fly ash.

Conclusion of Literature

Detailed study of the literature involving SCC reveals that sufficient work has been carried out incorporating a wide range of materials in various proportions with a focus on arriving at an ideal mixture proportion which yields required fresh and hardened properties of SCC. In most of the work, cement has been replaced with industrial byproducts like fly ash, Ground granulated blast furnace slag, silica fume, lime powder, etc. It is also observed that a very little work is done on the use of steel fibre or any other fibre in self-compacting concrete.

3. Experimental Programme

Fresh Concrete Properties of SCC

SCC is unique among major construction materials because it offers social, environmental and economic advantages. It enables faster construction due to increased Cementous material, noise elimination and placement of concrete without skilled labour. Three basic criteria required to achieve SCC are high deformability, high passing ability and high resistance to segregation. SCC with fluidity and resistance to segregation ensures a better homogeneity, reduces void in concrete and gives uniform concrete strength and superior level of finish with high durability.

To prepare the concrete mix, coarse aggregate was placed inside the cement mixer followed by fine aggregate. Then 20% of the total quantity of water was added. The cement mixer was allowed to rotate a couple of times after which ash and cement were added. Approximately 40% of the entire quantity of water was poured into the cement mixer and therefore the materials were mixed for 1 minute. Super plasticizer and VMA were added to the remaining quantity of water and added to the mixer. Mixing was continued for another 2 minutes. After mixing, tests were conducted to determine the properties of fresh concrete as per EFNARC Guidelines. Following test were performed to evaluate the fresh concrete properties of SSC.

1. Slump flow Test
2. U-Box Test
3. L-Box Test
4. V-Funnel Flow time

Slump Flow Test

Deformability, horizontal free flow and viscosity of fresh SCC is ascertained by slump flow time and diameter using Abrams cone. The Abrams cone is size of top diameter 100 mm, bottom diameter 200 mm and a height of 300 mm. This testing involves filling the cone gently and lifting it and reading are recorded for spread touches 500Ø and the total spread when the flow stops. The higher the slump flow value,the greater is its ability to fill form work under its own weight. The total spread of the concrete, after the slump cone is lifted, shown in Figure 1.

Figure 1 Slump flow test

U-Box Test

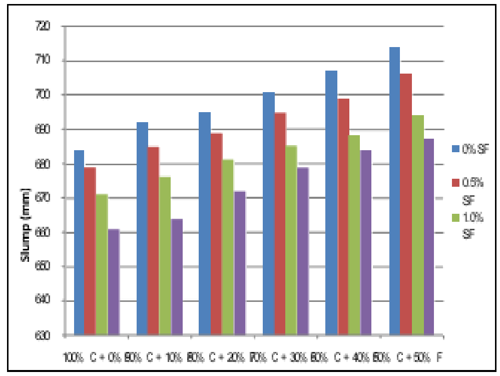
The test is used to measure the filling ability of self-compacting concrete. The U-flow test examines the behavior of the concrete in a simulated field condition. It is one of the most widely adopted test method for characterization of SCC. This test simulates the flow of concrete through a volume containing reinforcing steel. This test is considered more appropriate for characterizing self-compatibility of concrete.

Fresh Concrete

Test methods used to study the characteristics of fresh concrete include slump flow test, U – box, V – funnel and L – box test. These tests had been conducted to determine the filling ability and passing ability of the various SCC mix prepared using variable percentages of fly ash and steel fibres. Table 5.1 provides the fresh concrete properties of the SCC mix for M30 grade of concrete. From the results, it is evident that the basic requirements for high flow ability and segregation resistance as specified by guidelines on SCC, namely European Guidelines for SCC, are satisfied. For all tests, up to 50% replacement of cement is considered since after 50% the flow properties are not satisfied.

Without steel fibres, for mix M11 with 100 % cement + 0 % fly ash, the slump flow was 679 mm and for mix M16 with 50 % cement + 50 % fly ash, the slump flow was 706 mm. With the addition of steel fibres, for mix M41 with 100 % cement + 0 % fly ash, the slump flow was 661 mm and for mix M46 with 50 % cement + 50 % fly ash, the slump flow reduced to 687 mm. The workability of SCC increases with the increase in steel fibre percentage. Addition of steel fibres, reduced the flow ability and passing ability but satisfying the suggested limits for SCC.

Details	Fly Ash Proportion						Acceptable range
Mix proportion (C=Cement, F=Fly Ash)	100% C + 0% F	90% C + 10% F	80% C + 20% F	70% C + 30% F	60% C + 40% F	50% C + 50% F	
	M11	M12	M13	M14	M15	M16	
Concrete Mix M1 : Without Steel Fibre							
Slump flow by Abrams cone (mm)	684	692	695	701	707	714	650 to 800 mm
T50cm slump flow (Sec)	6	5	5	4	3	2	2 to 5 Sec
U Box test (mm)	24	22	22	20	18	17	h2-h1 = 0 to 30 mm
L Box test	0.76	0.82	0.83	0.85	0.89	0.91	h2/h1 = 0.8 to 1.0
V funnel test (Sec)	13	11	10	9	8	6	8 to 12 Sec
V funnel at T5 min (Sec)	15	13	13	12	10	8	Up to +3 Sec
Concrete Mix M2 : With Steel Fibre (0.5%)							
	M21	M22	M23	M24	M25	M26	
Slump flow by Abrams cone (mm)	679	685	689	695	699	706	650 to 800 mm
T50cm slump flow (Sec)	6	6	5	4	4	3	2 to 5 Sec
U Box test (mm)	25	24	24	22	21	19	h2-h1 = 0 to 30 mm
L Box test	0.75	0.78	0.79	0.82	0.84	0.86	h2/h1 = 0.8 to 1.0
V funnel test (Sec)	13	12	12	10	9	9	8 to 12 Sec
V funnel at T5 min (Sec)	16	14	14	13	13	12	Up to +3 Sec
Concrete Mix M3 : With Steel Fibre (1.0%)							
	M31	M32	M33	M34	M35	M36	
Slump flow by Abrams cone (mm)	671	676	681	685	688	694	650 to 800 mm
T50cm slump flow (Sec)	7	6	6	5	4	4	2 to 5 Sec
U Box test (mm)	27	25	24	24	22	21	h2-h1 = 0 to 30 mm
L Box test	0.73	0.78	0.80	0.82	0.85	0.86	h2/h1 = 0.8 to 1.0
V funnel test (Sec)	14	13	12	12	10	10	8 to 12 Sec
V funnel at T5 min (Sec)	18	16	15	16	14	13	Up to +3 Sec
Concrete Mix M4 : With Steel Fibre (1.5%)							
	M41	M42	M43	M44	M45	M46	
Slump flow by Abrams cone (mm)	661	664	672	679	684	687	650 to 800 mm
T50cm slump flow (Sec)	7	7	6	5	5	5	2 to 5 Sec
U Box test (mm)	30	28	27	25	24	23	h2-h1 = 0 to 30 mm
L Box test	0.69	0.72	0.74	0.78	0.81	0.83	h2/h1 = 0.8 to 1.0
V funnel test (Sec)	16	15	15	14	13	13	8 to 12 Sec
V funnel at T5 min (Sec)	19	18	17	17	16	15	Up to +3 Sec



4. Conclusion and Future Work

1. The main focus of the present work is to suggest the optimum mix proportion for utilizing the fly ash produced by the thermal power plants in India.
2. It is also aimed to propose experimentally an optimum value of fibre content to be used in SCC.
3. Addition of steel fibre results in increase of compressive strength for all the mixes.
4. It has observed that mix with 1.5%SF shows significant increase in compressive strength for both 7 days and 28days.
5. Mix M2 with 0.5%SF and M3 with1.0%SF shows a little variation in compressive strength.
6. Addition of steel fibre results in increase of flexure strength for all the mixes. It has observed that mix M4 (with 1.5%SF) shows significant increase in flexure strength for both 7 days and 28days.
7. Mix M2 (0.5%SF) and M3 (1.0%SF) shows a little variation in flexure strength.

Future Scope

1. Detailed study of the thesis involving SCC reveals that sufficient work has been carried out incorporating a wide range of materials in various proportions with a focus on arriving at an ideal mixture proportion, which yields required fresh and hardened properties of SCC. In most of the work, cement has been replaced with industrial byproducts like fly ash, Ground granulated blast furnace slag, silica fume, lime powder, etc. It is also observed that a very little work is done on the use of steel fibre or any other fibre in self-compacting concrete.
2. Hence, it is necessary to work on the use of waste material like fly ash and steel fibres in self-

compacting concrete to enhance its properties. In the proposed work, an attempt is made for the same.

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