EXPERIMENTAL INVESTIGATION OF SELF COMPACTING CONCRETE WITH REPLACEMENT OF CEMENT BY SILICA FUME AND METAKAOLIN

S. GNANA VENKATESH[1], E.MALARVIZHI[2]

[1] Assistant Professor, Department of Civil Engineering, Nandha Engineering College, Tamilnadu, India

[2]PG student, Department of Civil Engineering, Nandha Engineering College, Tamilnadu, India

---

Abstract - *In this modern era, with the rise of material and labour costs and also with minimal availability of high skilled labours construction works are sometimes delayed or halted. To over come this, Self Compacting Concrete (**SCC**) can be used. In this study, Strength of Self Compacting Concrete (**SCC**) is determined by replacement of cement by Silica Fume and Metakaolin. Silica Fume mix and Metakaolin mix is tested and the results are compared. Cement of M40 grade is to be used. Super plasticizer Conplast SP430 is used for the reduction in water content. Viscosity Modifying Agent is used to lower the slump of concrete. Replacement of cement starting from 2.5% to 10% is done and the optimised percentage of replacement is calculated. Mix design is arrived by IS-10262-2019. Fresh concrete tests such as slump test, J ring test, L box tests and V funnel test are done to determine the workability of the concrete. Compressive strength tests, Split tensile strength test and deflection test are done to determine the strength of the hardened concrete. The maximum compressive strength is achieved for 7.5% replacement of Silica fume. The maximum split tensile strength is obtained for 7.5% replacement of Silica fume. When strength obtained by Silica fume and Metakaolin replacement is compared maximum strength is achieved by Silica fume replacement.*

Key Words: **SCC, Fly ash, Silica Fume, Superplasticizer, Metakaolin, Viscosity Modifying Agent**

1. INTRODUCTION

1.1 General

Normally, when concrete is mixed and used in construction it requires use of vibrators or other techniques to remove air bubbles , honey comb like holes which are present at the surface because of air trapping caused during concrete pouring. This air content weakens the concrete structures. Self compacting concrete is administrated to avoid this problem. Self Compacting Concrete (SCC) also known as Self Consolidating Concrete is a special type of concrete mix. It does not requires vibration for placing and compaction and it has higher fluidity. SCC was first introduced in Japan in 1986 to counter the shortage of skilled labours. It was first developed by Prof. Okamura, Japan who is known as the "Father of SCC Technology". SCC is mainly used for casting heavily reinforced sections, under water concreting, Cast in-situ pile foundations and also in columns with congested reinforcement. While using these types of concrete, several special conditions are to be followed to achieve the best outcome. Production of SCC requires more experience and care. The formwork used must be designed to withstand high pressure than regular concrete. Mineral admixtures (Fly ash, GGBS, Marble powder , Silica fume .....) and chemical admixtures (Super Plasticisers) can be added to achieve SCC. Poly Carbolic admixture along with viscosity modifying agents can be used which provides Segregation resistance.

1.2 OBJECTIVES

The main objective of this study is to determine the suitable percentage of Silica fume and Metakaolin replacement mixes and also to compare the results of two mixes.

1.3 SCOPE

The scope of this project is to make use of Silica fume and Metakaolin as a cement replacement materials as both element has cementitious properties and it can be a better replacement for cement.

2 LITERATURE REVIEW

2.1 SCC WITH VMA:

In SCC the main problem is to maintain the flowability and stability. This can be achieved by using High Range Water Reducing Admixtures (HRWRA) for maintaining flowability and adding VMA for stability. Cellulose Filament (CF), a new type of nano cellulose material is used for rheology modification and strength enhancement in SCC. CF can be used in range from 0.05% to 0.30%. The Results of using CF as VMA is compared with commonly available VMA Welan gum. The results showed that the CF can be used as a VMA and has positive effects on SCC when compared with Welan gum [17]. Polysaccharides can be used as a (VMA) along with a fine material to improve the viscosity and hence achieve stability in concrete. Three types of polysacchrides welan gum, Xanthan gum and starch ether are used as VMA. Xanthan gum and starch ether reduced the bleeding to zero while welan gum did not reduce the bleeding to zero.The test also showed that the addition of VMA's did not have any beneficial effects on strength of concrete but it increased the stability of SCC.

VMA added SCC concretes had sorptivities less than SCC's with out VMA [18]. Rice Husk Ash (RHA) can be used as a VMA to maintain stability of the SCC concrete. The test results showed that the density increased with the amount of RHA. This mainly due to the micro filler effect and products filling the pores and hence densifying the concrete. Water absorption decreased with the increase in RHA content [19]. Silicon Carbide Waste (SCW) can be used as a VMA. With the usage of SCW there is a improvement in viscosity, filling and passing ability, segregation resistance and flowability retention for proper percentage of SCW even though it increases the amount of Superplasticizers used [20].

2.2 SCC WITH VARIOUS REPLACING MATERIALS

Usage of Fly ash and Silica Fume as a cement replacement materials has a beneficial effect on SCC. Both Fly ash and Silica Fume has cementitious properties and thus it can be used as a replacement materials. Maximum Compressive strength is achieved with 30% replacement by Fly ash and 15% replacement by Silica Fume. When both Fly ash And Silica fume are replaced in combination the strength achieved is more when compared with both former replacements with minimum replacement of 10% [1,10]. Using Calcareous High volume of fly ash has more economical and enviromental advantages. It improves the consistency of concrete mixes. With more Fly ash content as a replacement the compressive strength decreases. But the 52.5% replacement of fly ash gives great strength [2,7]. High range water reducing plasticizer Varaplast SP123 can be used to increase the workability and can be used along with VMA in SCC with replacement of cement by Type C Fly ash [9]. Metakaolin is a cementitious material which can also be used as a cement replacement material as it has properties similar to cement. Silica Fume and Metakaolin can be replaced in which Silica Fume has maximum strength in early minimal replacement while Metakaolin gives maximum strength at 15% replacement [3]. Silica Fume along with recycled aggregates can be used in SCC to increase the workability and strength. SCC with recycled aggregates and Silica fume showed better results when compared with SCC with recycled aggregates and without Silica Fume [4]. SCC produced with high volume of Fly ash and Metakaolin with the addition of 5% of hydrated lime gives maximum strength when compared with fly ash replacement only. Formation of gismondine and C-S-H in SCC can are shown by the XRD and SEM analysis [5]. SCC can be produced with replacement of Fly ash and Dolomite powder. Mix with 3: 1 ratio of Fly ash and Dolomite powder seem to satisfy EFNARC standards [6]. Granite waste and Fly ash which has lower carbon footprints can be used in the production of SCC. Granite waste can be used as a replacement for fine aggregates. When the mix with replacement of granite waste alone has adverse effect on the fresh properties of the concrete. But when it is used alongside Fly ash the adverse effect can be reduced due to the presence of Fly ash [8]. When Silica Fume is used in Fly ash based Self Compacting Concrete it increased the hardened properties of the concrete. Here Silica Fume is used as a partial replacement for Fly ash [11]. Fly ash has lower early strength due to slower pozzolanic reaction rate. Nano Silica which is among one of the available Nano materials can be used along with Fly ash. The presence of Nano Silica can accelerate the reaction rate and fill the voids of Calcium-Silicate-Hydrates [12]. Fly ash along with Wood ash and Superplasticizer Master Glenium SKY B233 an admixture can be used as replacing materials. Wood ash replacement alone adversely affects the strength of the concrete. But when used along with Fly ash it can be beneficial [13]. Alcoffine is a new generation ultra-fine supplementary cementitious material which can used as a cement replacement in SCC. The replacement of Alcoffine when compared with fly ash replacement gives more strength. Because of the high pozzolanic nature of Alcoffine it resulted in production of C-S-H gel helps in formation of compact strutcure in concrete [14].Calcium Carbonate does not have pozzolonic property but it has filler effects and Fly ash has pozzolonic property. SCC containing Fly ash and Calcium Carbonate blends satisfy EFNARC standards requirements of Filling ability, Passing ability and resistance to segregation [15]. Oil palm shell along with fly ash can be used as a replacement material in SCC [16].

3 MATERIAL PROPERTIES

- Cement
- M-Sand
- Coarse Aggregate
- Fly Ash
- Silica Fume
- Metakaolin
- Superplasticizer (Conplast 430)
- Viscosity Modifying Agent (Glenium stream 450)

Table 3.1 Physical properties of Fine Aggregate and Coarse Aggregate

Physical properties	Fine Aggregate	Coarse Aggregate
Bulk Density (kg/m^3)	1860	1300
Fineness modulus	5.24	7.53
Specific gravity	2.65	2.78

Table 3.2 Physical properties of powder content

Properties	OPC	Fly ash	Silica Fume	Metakaolin
Specific gravity	3.15	2.12	2.25	2.6
Specific Surface Area (m^2/kg)	3200	7197	17000	8560

4 CONCRETE MIX DESIGN

The mix proportion is an important factor to be considered to achieve SCC. The control (which had no admixture), and the various admixture (metakaolin and silica fumes) with cement were mixed and casted to examine and quantify the properties of self-compacting concrete mixtures. The replacements were done at levels of 2.5%, 5%, 7.5% and 10% by mass. The water/powder mass ratio (w/p) was selected as 0.40 after different trial mixes. The total powder content was varied at different value and was finally is fixed as 550 kg/m3.

Table 4.1 Designation of Specimens

MIX DESIGNATIONS	PROPORTION OF CEMENT AND SILICA FUME
SF 0%	100% Cement
SF 2.5%	97.5% Cement + 2.5% Silica Fume
SF 5%	95% Cement + 5% Silica Fume
SF 7.5%	92.5% Cement + 7.5% Silica Fume
SF 10%	90% Cement + 10% Silica Fume

Table 4.2 Designation of Specimens

MIX DESIGNATIONS	PROPORTION OF CEMENT AND METAKAOLIN
MK 2.5%	97.5% Cement + 2.5% Metakaolin
MK 5%	95% Cement + 5% Metakaolin
MK 7.5%	92.5% Cement + 7.5% Metakaolin
MK 10%	90% Cement + 10% Metakaolin

Table 4.3 Mix Proportion

DESIGNATION	CEMENT	SILICA FUME	MIX FLY ASH	FINE AGGREGATE	COARSE AGGREGATE	W/C RATIO
SF 0%	332	0	143	938	748	0.40
SF 2.5%	323.7	8.3	143	938	748	0.40
SF 5%	315.4	16.6	143	938	748	0.40
SF 7.5%	307.1	24.9	143	938	748	0.40
SF 10%	298.8	33.2	143	938	748	0.40

Table 4.4 Mix Proportion forMetakaolin

MIX DESIGNATION	CEMENT	METAKAOLIN	FLY ASH	FINE AGGREGATE	COARSE AGGREGATE	W/C RATIO
MK 2.5%	323.7	8.3	143	938	748	0.40
MK 5%	315.4	16.6	143	938	748	0.40
MK 7.5%	307.1	24.9	143	938	748	0.40
MK 10%	298.8	33.2	143	938	748	0.40

5 TESTS ON CONCRETE

5.1 COMPRESSIVE STRENGTH TEST

Compressive strength test is a mechanical test measuring the maximum amount of compressive load a material can bear before fracturing. The strength of concrete is found and determined by the crushing strength of 150mm x 150mm x 150mm, at an age of 7 and 28 days. The moulds and its base rigidly clamped together so as to reduce leakages during casting. The sides of the moulds and base plates were oiled before casting to prevent bonding between the moulds and concrete. The cube was then stored for 24 hours undisturbed.

$$f_c = (P/A)\ N/mm^2$$

where,

P = Load at which the specimen fails in Newton (N)

A = Area over which the load is applied in mm

F_c = Compressive stress in N/mm^2

5.2 SPLIT TENSILE STRENGTH TEST

The determination of tensile strength of concrete is necessary to determine the load at which the concrete member cracks. In this test, cylindrical specimens of dimension 150 mm diameter and 300 mm length were cast. The specimens are tested after 7 days and 28 days. The split tension test was conducted by using digital compression machine having 2000 kN capacity.

$$f_t = 2P / \pi DL\ (N/mm^2)$$

where, P = Maximum Load (kN)

D = Diameter of Specimen (150 mm)

L = Length of Specimen (300 mm)

f_t = Tensile strength N/mm^2

6 RESULT AND DISCUSSIONS

6.1 COMPRESSIVE STRENGTH OF SCC

The Compressive Strength of SCC is represented in the Fig 6.1 and Fig 6.2. The Compressive Strength attained after 28 days curing ranges between 42 N/mm^2 and 45.52 N/mm^2 for Silica fume replacement. The maximum strength for Silica fume replacement is achieved at 7.5% replacement (45.52 N/mm^2). Silica fume replacement strength reduces after 7.5% replacement. The Compressive Strength attained after 28 days curing ranges between 40 N/mm^2 and 45 N/mm^2 for Metakaolin replacement. The maximum strength for Metakaolin replacement is achieved at 7.5% replacement (44.29 N/mm^2). Metakaolin replacement strength reduces after 7.5% replacement. When compared, Silica fume replacement gives maximum strength.

Table 6.1 Compressive Strength Obtained By Silica Fume Replacement

SILICA FUME	7 DAYS (N/mm^2)	28 DAYS (N/mm^2)
SF 0%	28.56	40.11
SF 2.5%	29.75	43.13
SF 5%	32.60	44.55
SF 7.5%	35.23	45.52
SF 10%	60.15	43.05

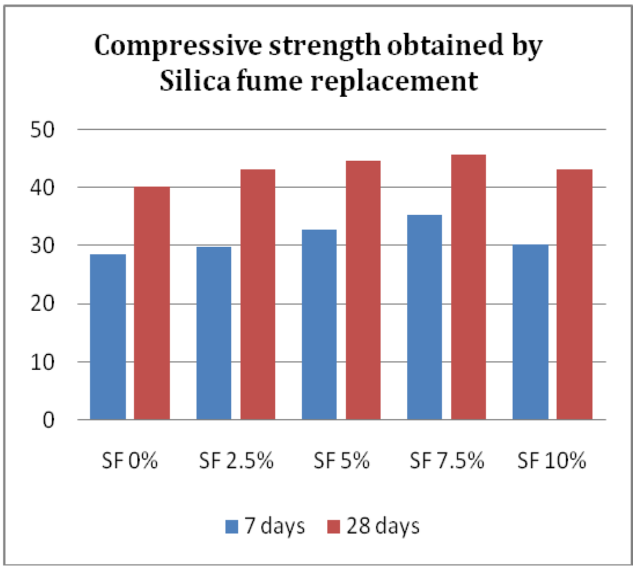

Fig 6.1 Compressive strength obtained by replacement by Silica Fume

Table 6.2 Compressive Strength Obtained By Metakaolin Replacement

METAKAOLIN	7 DAYS (N/mm^2)	28 DAYS (N/mm^2)
MK 2.5%	28.45	42.18
MK 5%	31.24	43.23
MK 7.5%	34.6	44.29
MK 10%	31.41	41.88

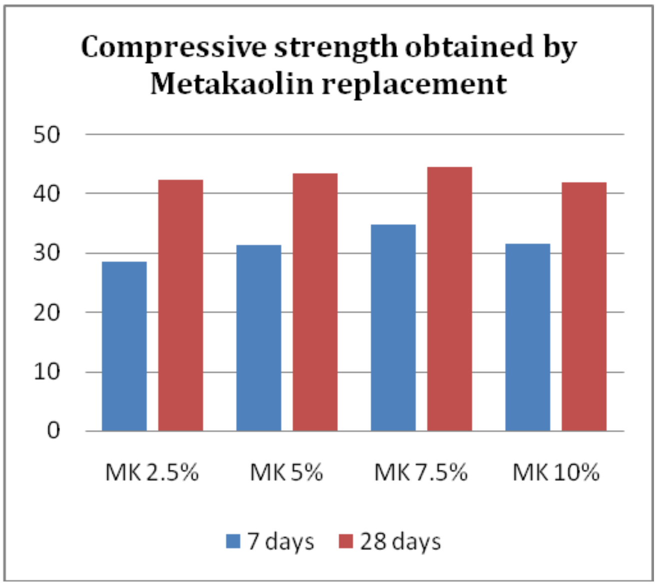

Fig 6.2 Compressive strength obtained by replacement by Metakaolin

6.2 SPLIT TENSILE STRENGTH OF SCC

The Split tensile Strength of SCC is represented in the Fig 6.1 and Fig 6.2. When the strength of Silica fume and Metakaolin replacement is compared Silica fume replacement of 7.5% gives the maximum strength.

Table 6.3 Split Tensile Strength Obtained By Silica Fume Replacement

SILICA FUME	7 DAYS (N/mm²)	28 DAYS (N/mm²)
SF 0%	2.75	4.32
SF 2.5%	2.89	4.41
SF 5%	2.93	4.83
SF 7.5%	3.83	5.34
SF 10%	2.85	3.89

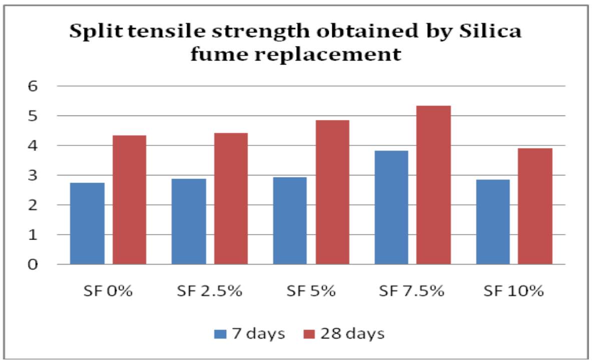

Fig 6.3 Split tensile strength obtained by replacement by Silica Fume

Table 6.4 Split Tensile Strength Obtained By Metakaolin Replacement

METAKAOLIN	7 DAYS (N/mm²)	28 DAYS (N/mm²)
MK 2.5%	2.86	4.3
MK 5%	2.9	4.74
MK 7.5%	3.76	5.18
MK 10%	2.81	3.65

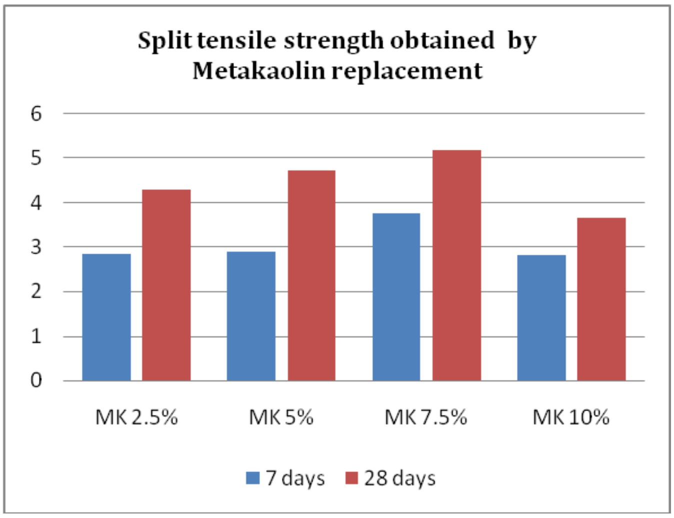

Fig 6.4 Split tensile strength obtained by replacement by Metakaolin

7. CONCLUSIONS

On the basis of the results obtained in this study, the following conclusions have been drawn:

(i) It is possible to manufacture self-compacting concrete using Silica fume and Metakaolin with acceptable fresh and hardened properties.

(ii) Mix with Silica fume gives best result when compared with Metakaolin mix.

(iii) The mix with 7.5% Silica fume gives the maximum strength.

REFERENCES:

1. Heba A. Mohamed Effect of fly ash and silica fume on compressive strength of Self Compacting Concrete under different curing conditions. Ain Shams Engineering Journal (2011) 2, 79–86

2. Adnan Mujkanović, Ilhan Bušatlić, Marina Jovanović, Dženana Bečirhodžić, Nevzet Merdić Environmental-friendly Self Compacting Concrete containing Calcareous Fly ash. The 5th International Conference on Environmental and Material Flow Management (2015)

3. O. M. Ofuyatan, A. M. Olowofoyeku, S. O. Edeki, J. Oluwafemi, A. Ajao O. David Incorporation of Silica fume and Metakaolin in Self Compacting Concrete. Journal of Physics: Conference series 1378 (2019) 042089 doi:10.1088/1742-6596/1378/4/042089

4. Hossein Sasanipour , Farhad Aslani , Javad Taherinezhad (2019) Effect of Silica fume on durability of self compacting concrete made with waste recycled concrete aggregates. Construction and building materials 227 (2019) 116598

5. Macros. A. S. Anjos, Aires Camoes, Pedro Campos, Givanildo A. Azeredo, Ruan S. L. Ferreira (2020) Effect of high volume fly ash and metakaolin with and without hydrated lime on the properties of SCC. Journal of Building Engineering 27 (2020) 100985

6. Salim Barubhiya Effects of fly ash and dolomite powder on the properties of self compacting concrete. Construction and Building Materials 25 (2011) 3301–3305

7. Marina Jovanović, Adnan Mujkanović, Asim Čamdžić, Denis Vejzović Properties of Self Compacting Concrete with Type C fly ash (2014)

8. Abishek jain, Rajesh gupta, Sandeep jain (2020) Sustainable development of self compacting concrete by using granite waste and fly ash. Construction and Building Materials 262 (2020) 120516

9. Manikandan. S and Prof. A. Safi Experimental investigation on flyash based self compacting concrete. International Journal of Engineering (IJE) Singaporean Journal of Scientific Research(SJSR) Vol 6.No.2 2014 Pp. 76-79

10. Kumar Sathish, Sanjay kumar, Baboo Rai Self Compacting Concrete Using Fly Ash and Silica Fumes as Pozzolanic Material. Journal of Engineering Technology (ISSN: 0747-9964) Volume 6, Issue 2, July, 2017, PP.394-407

11. Fareed Ahmed Memon, Muhd Fadil Nuruddin, Nasir Shafiq (2013) Effect of Silica fume on the fresh and hardened properties of Fly ash based Self Compacting Geo Polymer Concrete. International Journal of Minerals, Metallurgy and Materials Volume 20, Number 2, February 2013, Page 1 DOI: 10.1007/s12613-013-0000-0

12. Chinamaya Kumar Mohapatra, SudhirKumar v. Parai Hybrid fiber reinforced self compacting concrete with fly ash andcolloidal nano silica: A systematic study. Construction and Building Materials (2017)

13. P. SachinPrabhu, Ha. Nishaant, T. Anand Behaviour of Self-Compacting Concrete with Cement Replacement Materials. International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-8 Issue-2S December, 2018

14. Bode Venkata Kavyateja , J. Guru Jawahar, C. Sashidhar Effectiveness of alccofine and fly ash on mechanical properties of ternary blended self compacting concrete. Materials Today: Proceedings (2020)

15. Pongaskon Promsawa, Burachat Chatveera, Gritsada Sua-iam, Natt Makul Properties of self-compacting concrete prepared with ternary Portland cement-high volume fly ash-calcium carbonate blends. Case Studies in Construction Materials 13 (2020) e00426

16. Timothy Zhi Hong Ting, Muhamed Ekhlasur Rahman, Hieng Ho Lau Sustainable lightweight self-compacting concrete using oil palm shell and fly ash. Construction and Building Materials 264 (2020) 120590

17. Ousmane A. Hisseine, N. Basic, Ahmed. F. Omran, Arezki Tagnit- Hamou Feasability of using Cellulose filaments as a viscosity modifying agent in self consolidating concrete. Cement and Concrete Composites (2018)

18. Ibrahim E. Isik, M. Hulusi Ozkul Utilization of polysaccharides as viscosity modifying agent in self-compacting concrete. Construction and Building Materials 72 (2014) 239–247

19. Shazim Ali Memon, Muhammed Ali Shaik, Hassan Akbar Utilization of Rice Husk Ash as viscosity modifying agent in Self Compacting Concrete. Construction and Building Materials 25 (2011) 1044–1048

20. Qiang Ren, Zhengwu Jiang, Haoxin Li, Xinping Zhu, Qing Chen Fresh and hardened properties of self-compacting concrete using silicon carbide waste as a viscosity-modifying agent. Construction and Building Materials 200 (2019) 324–332