Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Incorporation of Silica Fume and Metakaolin on Self Compacting Concrete

To cite this article: O.M. Ofuyatan *et al* 2019 *J. Phys.: Conf. Ser.* **1378** 042089

Incorporation of Silica Fume and Metakaolin on Self Compacting Concrete

O.M. Ofuyatan[1,4*], A.M. Olowofoyeku[2], S.O Edeki[3]. J. Oluwafemi[1,4], A. Ajao[5] O. David[2]

[1 4]Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria
[2]Department of Civil Engineering, Yaba College of Technology, Lagos, Nigeria.
[3]Department of Mathematics, Covenant University, Ota, Ogun State, Nigeria
[5]Department of Building Technology, Covenant University, Ota, Ogun State, Nigeria
Corresponding author: *olatokunbo.ofuyatan@convenantuniversity.edu.ng
Corresponding Author: +234 8033308378

Abstract-
This study carried out an experimental design investigating the reaction of mineral admixtures on fresh and hardened properties of sustainable self compacting concrete (SCC). Silica fume (SF) and metakaolin (MK) were partially replaced by Portland cement at 5, 10, 15, 20 and 25% in varying proportions. The workability on the fresh concrete was examined and the strength performance. The water cement ratio of 0.38 was kept constant for all the samples tested. The compressive strength was measured at 7, 14, 21 and 28 curing days. The test results indicated that with the influence of 2% superplasticizer, the fresh concrete showed a satisfactory workability, decreased the segregation to resistance, ease of flowing ability with the addition of silica fume and metakaolin. It was concluded in this study that, the replacement with silica fume was found to have an early strength gain in the compressive strength of SCC samples and a decrease at varying dosages. However, 15% metakaolin was considered to be a suitable replacement with 49.08 MPa at 28days compared with the control mix..

Key words: Self-compacting concrete, metakaolin, silica fume, workability, compressive strength test.

1. Introduction

Self-compacting concrete (SCC) is a unique type of flowable, smooth-running concrete, which when placed in the formwork does not require vibration or compaction. From the early eighties the use of self-compacting concrete has been extended around the world due to it benefits of production. This concrete is a evolutional step in concrete technology, it is a sophisticated high-performance concrete due to its impact economically and environmental sustainability over the last two decades in the construction industry [1]. SCC being a fluid concrete offers divers' advantages which include manpower reduction, noise elimination, increase productivity rate, ability to flow and fill congested reinforcement effectively without voids and vibration, and when placed compact by itself in structures highly reinforced. Amongst its advantages is the disadvantage of the high volume of admixtures and Portland cement used in the process of mix. The way out of this high cost is the incorporation of pozzolanic materials and mineral admixtures like fly ash, metakaolin, silica fume, granulated blast slag, palm ash in partial replacement with Portland cement. [2] reported high compressive strength resistance, less permeability, high segregation resistance, reduce blocking of concrete by reinforcement in congested areas and high filling and flow ability of SCC when compared or plain concrete. In 1986 the concept of SCC was proposed by [3] while the prototype was discovered in 1988 by Professor Ozawa at Tokyo University in Japan. The recent trend and innovation for sustainability is to utilize the treated and untreated by-products and raw materials wastes in concrete, which provides an ecofriendly advantage in concrete preparation. Since then, various investigations have been carried out and SCC has been used in practical structures all over the world. Mineral admixtures are used as an extra fine material, besides cement, and in some cases, they partially replace cement and High-Range Water Reducers (superplasticizers) and Viscosity Modifying Agents are the chemical admixtures used which change the rheological properties of concrete. Silica fume particles has a smooth fine, non-crystalline silica also known as condensed silica fume or micro silica obtained from pure-chem. It is a byproduct of the production of elemental silicon or silica alloys. Metakaolin is produced mostly by calcination of kaolin clay at a temperature ranging from 700-850℃ without production of CO_2. Metakaolin can also be considered as addition in the production of self-compacting concrete. It has been available since the mid-1990s, metakaolin when used with cement lowers the temperature of Portland cement, yield lower cost in construction, environmental benefit and positive effect in both short- and long-term strength of concrete [15]. Flowing ability and segregation resistance of two mineral admixture (fly ash and blast furnace slag) where investigated by [6] to know the behavior and development in self-compacting concrete. Replacement with both mineral admixtures improved the flowing ability remarkably. 10-20% fly ash and 25-45% blast furnace slag gave the best strength and flowability. Various percentage of fly ash (10, 20 and 30%) by weight where replaced with cement by [11] investigate their properties. Based on the investigation they concluded, decrease of superplasticizer used was as a result of increase in fly ash content for better workability. They stated that additional use of fly ash resulted in decrease compressive strength of 7 and 28 days. As the fly ash increases to 30% the 28 days compressive strength decrease by 22-23%. [4] investigated the SCC with 5, 10, 15, 20 and 25% fly ash and 2.5, 7.5 and 12.5% silica fume as replacement of cement. The silica fume improved the fresh property and hardened properties while fly ash made it possible to reform the fresh property and decrease the hardened properties. [5] carried out the durability properties of palm oil fuel ash concrete. Dataset evaluate and understand the potential of waste material (POFA) which was tested in different exposure condition, hydrochloric acid solution, and sodium sulphate. It was observed that POFA can be use as replacement having durability properties at acceptable range. [9] performed the workability test to study the fresh property of SCC with rice husk ash as partial replacement of cement (0-20%). It was observed that the SCC mix decreased with rise in replacement with rice husk ash. [6] SCC with the partial replacement of Portland cement by the mineral admixture such as limestone powder, basalt powder and marble powder. Three types of mineral admixture gave positive effect on the workability of SCC at the fresh state, among which the marble powder was the best. Mineral admixtures have significant effects on the hardened property of SCC differently and the dosage of specific amounts of marble powder caused the maximum compressive strength. Finally, it has been drawn the conclusion that the usage of mineral admixtures may be one of good ways for reducing the cost per unit compressive strength. [5][7] suggested the use of statistical analysis to derive the compressive strength models of self-compacting concrete at 7, 28 and 90 days. Variable such as superplasticizer, aggregate combination, water cement ratio and binder combination affect the compressive strength of concrete. It was concluded that dataset can be use in prediction and modeling of concrete. Self-compacting mixture with low yield stress and moderate viscosity levels are obtained by minimizing the water content to enhance stability of the mix. To obtain the required deformability especially with lower binder content, high dosage of high range water reducer is used [12]. [14] attempt to characterize the properties of self-compacting concrete, different methods have been prepared. For universal approval no single method has been found each design should be tested by more than one test method to obtain workability parameters. The objective of this study was to know the influence of metakaolin and Silica fume of SCC.

2. Methodology

2.1 Material Processing

Ordinary Portland Cement (OPC) with grade 53 in accordance to ASTM in Nigeria was used. It was purchased in sealed 50Kg bags from local dealers at Sabo, Yaba. The river sand used was screened and washed to remove all the organic and inorganic components that are likely to be present in it. Coarse aggregate of 12mm was used. Furthermore, the supplementary cementitious materials (Metakaolin) were sourced from deposits along Abeokuta-Ajebo Road, Ogun state. The deposit was located at a depth ranging from about 10 meters from the ground level; the bulk density and specific gravity carried out are shown in table 1. The collected clay was later processed to produce metakaolin. Its physical and chemical properties conform to standards as stipulated in ASTM C618-12 requirement for pozzolans. And the brand of silica fume used was silica fume (grade MS940U) supplied by Pure-chem manufacturing industries limited located at Sango-Ota, Ogun state. Superplasticizer (Conplast SP 430) which helps in reducing water content up to 25% was used as the chemical admixture to increase the paste flow and to prevent segregation. The super plasticizer has a P_H percentage greater than 6. Portable water was used for mixing and curing. Shown in table 2 is the characteristic properties and mineralogical composition of the mineral admixtures are given.

Table 1: showing the bulk density and specific gravity of material used

Material	Bulk density(kg/m^3)	Specific gravity
Cement	1470	3.15
Silica Fume	585	2.3
Metakaolin	1100	2.54
Coarse aggregate(20mm)	1662.50	2.77
Fine Aggregate	1580	2.65

Table 2: Chemical composition of Portland cement, silica fume and metakaolin

Property	Cement (%)	Silica Fume (%)	Metakaolin (%)
Loss on Ignition	2.0	1.7	0.70
SiO_2	20	97.1	52.24
Fe_2O_3	0.6	0.3	0.60
Al_2O_3	4.85	0.4	43.18
CaO	62.56	0.3	1.03

MgO	2.5	0.0	0.61

The European Federation of Specialist Construction Chemicals and Concrete Systems [17] provide the guidelines for development of SCC. This experimental study adopted a trial and error approach of sample proportioning and mixing in order to know the appropriate mix ratio which is listed in Table 4.

Table 3: Limitations specified by European standard

Test methods	Units	Minimum	Maximum
Slump flow	Mm	650	800
T50	Sec	0	7
L box	H2/H1	0.8	1
V funnel	Sec	0	10

2.2 Mix Proportion

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 mix and cast to examine and quantify the properties of self-compacting concrete mixtures. The replacements were done at levels of 5%, 10%, 15%, 20% and 25% by mass. The water/powder mass ratio (w/p) was selected as 0.38 after different trial mixes. The total powder content was varied at different value and was finally is fixed as 600 kg/m3.

Table 4: Mix Proportions for Silica Fume self-compacting concrete (kg/m^3)

Materials	Control	SF 5%	SF 10%	SF15%	SF20%	SF25%
Cement	600	570	540	510	480	450
Silica Fume	-	30	60	90	120	150
Water/Powder	0.38	0.38	0.38	0.38	0.38	0.38
Sand	800	800	800	800	800	800
Coarse Agg.	650	650	650	650	650	650
Super plasticizer	2%	2%	2%	2%	2%	2%

Table 5: Mixture Proportions for Metakaolin Self-Compacting Concrete (kg/m^3)

Materials	Control	SF 5%	SF 10%	SF15%	SF20%	SF25%
Cement	600	570	540	510	480	450
Metakaolin	-	30	60	90	120	150
Water/Powder	0.38	0.38	0.38	0.38	0.38	0.38
Sand	750	750	750	750	750	750
Coarse Agg.	600	600	600	600	600	600
Super plasticizer	2%	2%	2%	2%	2%	2%

2.3 Casting, Curing and Testing

The concrete cubes of 150mm size, are cast per mix constituent indicated in table 4 and 5. Compressive strength test was carried out on the hardened concrete for each mixture of metakaolin and silica fume mixes. Prior to these strengths' study, the slump flow, L-box, T50 and V-funnel tests were done to study the workability properties of self-compacting concrete. These specimens are removed from the moulds after 24 hours and submerge completely in the curing tank for 7, 14, 21 and 28 days.

3. Result and discussions

3.1 Fresh Properties

The slump flow of the mixes with metakaolin and silica fume were reported in table 6. From the report it was observed that the slump flow range between 675-731mm as per EFNARC exhibit satisfactory slump flow. It is observed that high replacement of mineral admixtures has shown better slump. All the mixtures had constant water/cement ratio and superplasticizer content. Increase slump flow was observed up to 25% of metakaolin content. Dosage of water superplasticizer and volume of coarse aggregate influence the T50cm slump which serves as indicator for the viscosity of the mix. The v-funnel assessed the filling ability and stability of the various mix and the values obtained from the experiment is within the limit of EFNARC. Prolonged flow time may give indication of the mix susceptible to blocking and not fluid enough. L-box is sensitive to blocking of the mixes. The obtained l-box values are reported in the table 6 which indicate the filling and passing ability of each mix.

Table 6: Fresh properties of self-compacting mixes

Mix No.	Slump(mm)	V-funnel (sec)	L-Box (h2/h1)	T50 (sec)
Control	660	6.0	0.99	7.0
SA 5%	695	8.0	0.92	6.1
SA10%	709	7.8	0.90	6.0
SA15%	711	7.5	0.87	6.6
SA20%	715	7.2	0.85	6.0
SA25%	722	6.9	0.70	5.5
MK5%	704	9.2	0.95	7.1
MK10%	709	8.5	0.90	6.9
MK15%	722	8.1	0.89	6.5
MK20%	728	7.9	0.85	6.2
MK25%	731	7.2	0.82	6.0

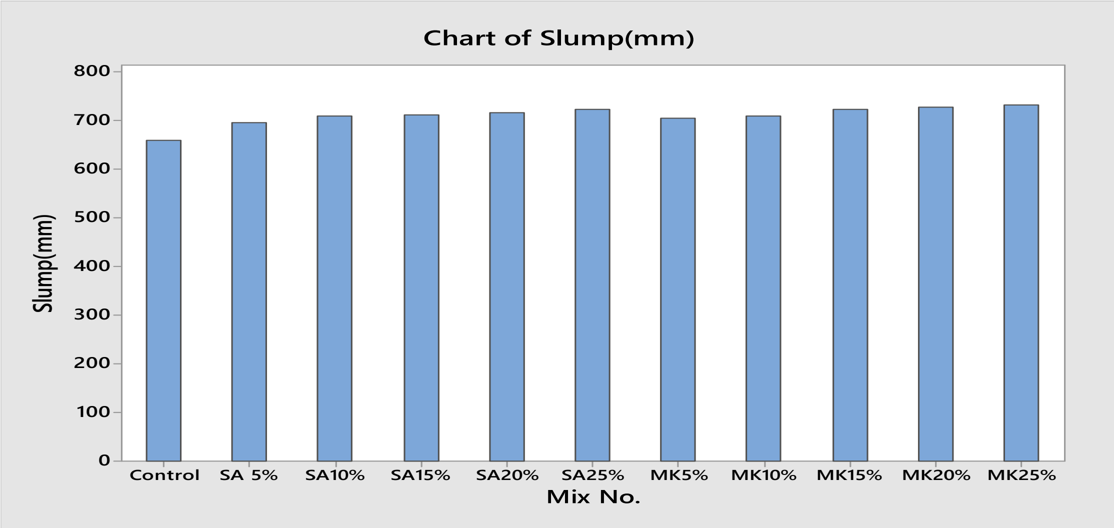

Fig 1. Slump flow of self-compacting concrete with Silica Fume and metakaolin

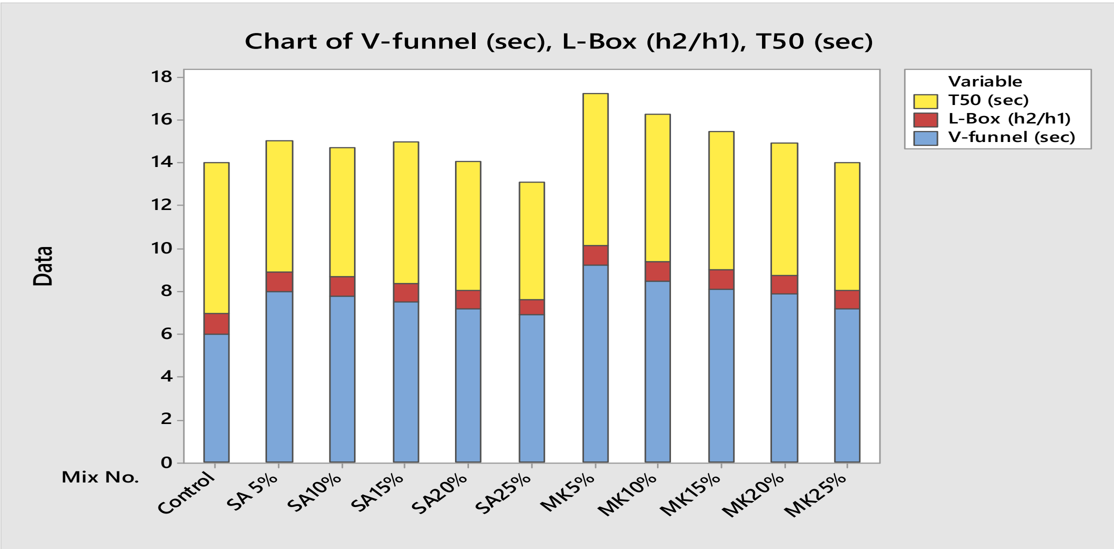

Fig 2. Graph of T50cm, L-box and V-funnel of self-compacting concrete with Silica Fume and metakaolin

3.2: Hardened Properties

The compressive strength at 7, 14, 21 and 28days of curing. This was conducted for all the mixes. Strength at the respective curing days are listed on the table 7. The average value of compressive strength at 7 and 28 days of both metakaolin and silica fumes of all the mixes increased respectively.

Table 7: Compressive strength test results for Self-Compacting Concrete cubes on metakaolin and Silica Fume

Compressive Strength

Metakaolin					Silica fume				
Mix (MK)	7 days	14 days	21 days	28 days	Mix (SF)	7 days	14 days	21 days	28 days
0%	21.22	25.60	32.81	39.15	0%	41.22	43.60	44.81	46.15
5%	25.32	29.11	35.06	40.55	5%	60.85	63.19	66.36	68.38
10%	27.56	36.81	42.09	46.79	10%	52.19	54.54	55.58	56.01
15%	32.77	39.16	45.87	49.08	15%	46.15	47.44	48.85	50.78
20%	30.45	37.30	44.60	47.90	20%	39.79	42.28	43.11	43.88
25%	29.76	32.33	41.11	45.75	25%	30.15	32.11	34.63	35.71

As seen in figure 3 and 4 silica fume inclusion increase early age strength. However, the rate of strength development was significant all through. The most remarkable strength development was found to attain for metakaolin replacement at 15% SF. While for silica fume it showed that the use of silica fume admixture in self-compacting concrete mostly resulted in decrease in strength of concrete.

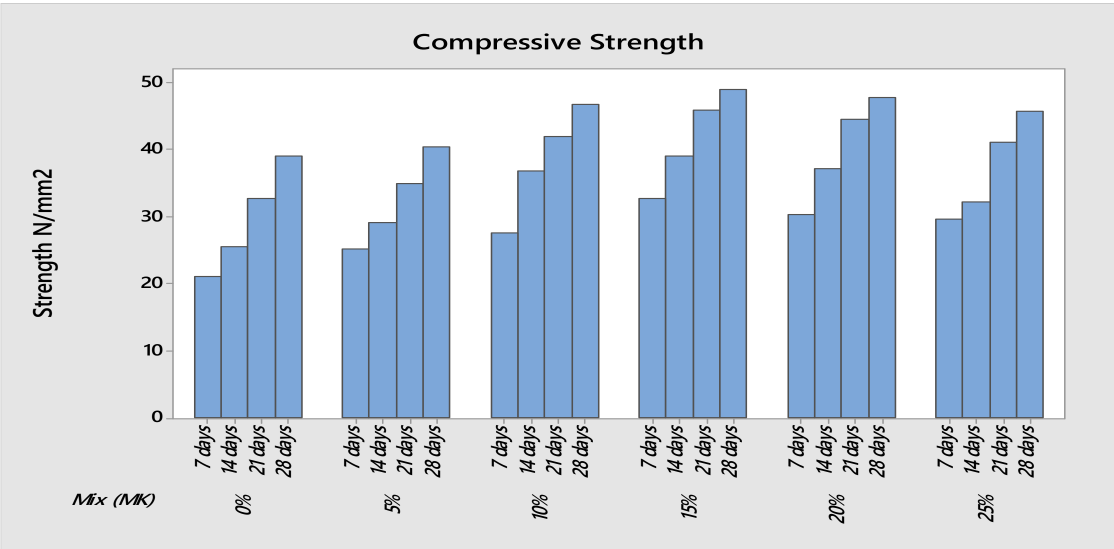

Fig 3. The Compressive strength of Metakaolin at Various curing day

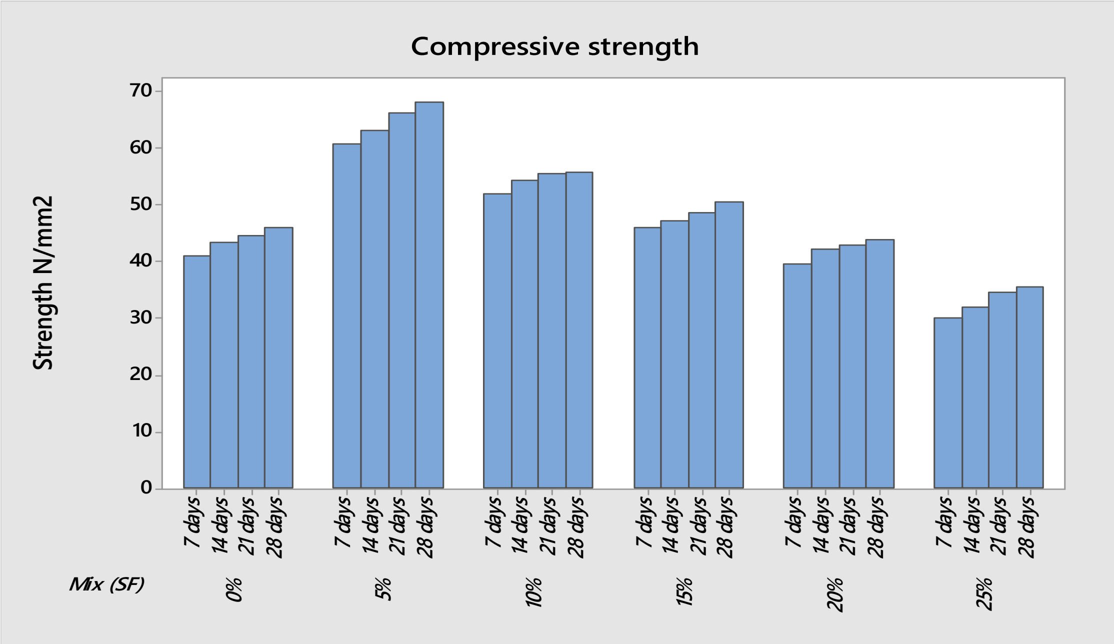

Fig 4. The Compressive strength of Silica Fume at Various curing day

Table 8: Split tensile strength test results for Self-Compacting Concrete cubes on metakaolin and Silica Fume

Split Tensile Strength									
Metakaolin					Silica fume				
Mix (MK)	7 days	14 days	21 days	28 days	Mix (SF)	7 days	14 days	21 days	28 days
0%	2.46	3.03	3.90	4.15	0%	2.46	3.03	3.90	4.15
5%	2.5	3.19	4.02	4.55	5%	3.82	4.6	5.74	6.91
10%	2.68	3.42	4.3	4.79	10%	3.75	4.4	5.6	6.8
15%	2.82	3.7	4.18	5.08	15%	3.68	4.26	5.38	6.5
20%	2.76	3.5	4.11	4.90	20%	3.46	4.05	5.29	6.2
25%	2.45	3.26	4.06	4.57	25%	3.2	3.8	4.74	5.81

It was observed that very high percentage of silica fume did not significantly increase the splitting tensile strength and increase was insignificant beyond 15%SF as seen in table 8 compared to the normal concrete. The split tensile strength increased with age, highest split tensile was observed in 5% of silica fume cement concrete. For metakaolin in a similar trend to that observed in compressive strength, self-compacting mix containing 10-20% metakaolin provided better performance in terms of splitting tensile strength as seen in table 8.

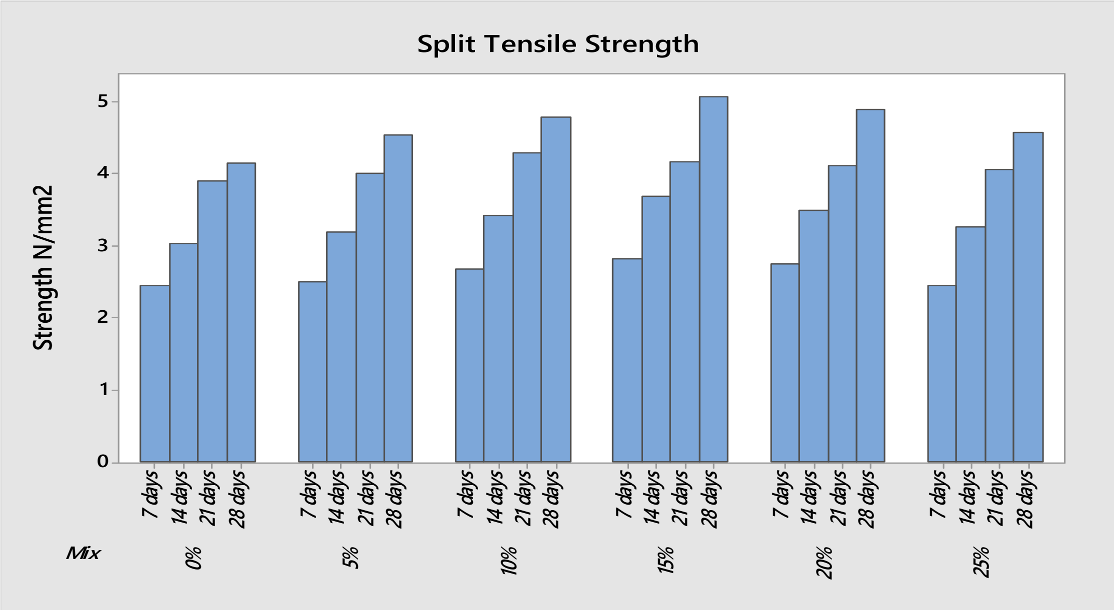

Fig 5. Showing the Split tensile strength of Metakaolin at Various curing days.

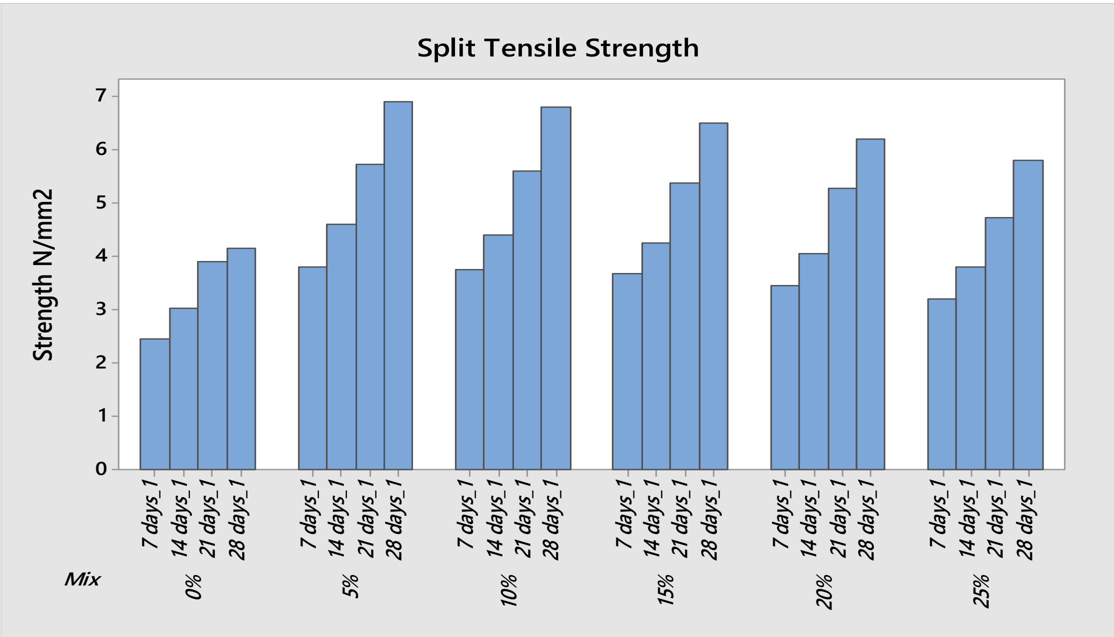

Fig 6. Showing the Split tensile strength of Silica Fume at Various curing days.

Table 9: The Flexural strength test results for Self-Compacting Concrete cubes on metakaolin and Silica Fume

Flexural Strength	
Metakaolin	Silica fume

Mix (MK)	7 days	14 days	21 days	28 days	Mix (SF)	7 days	14 days	21 days	28 days
0%	3.2	4.41	5.2	6.10	0%	3.2	4.41	5.2	6.10
5%	3.34	4.45	5.41	6.23	5%	3.34	4.65	5.6	6.69
10%	3.41	4.59	5.72	6.34	10%	3.48	4.78	5.9	7.2
15%	3.62	4.88	5.91	6.44	15%	3.55	4.9	6.04	7.6
20%	3.55	4.74	5.32	6.2	20%	3.69	5.06	6.11	7.74
25%	3.48	4.6	5.11	6.13	25%	3.7	5.13	6.25	7.9

It was observed that silica fume seemed to have a pronounce effect on flexural strength in comparison with split tensile strength. The flexural strength of even the high percentage of silica fume significantly improved the strength. There was steady increase in the flexural strength with increase in the silica fume replacement

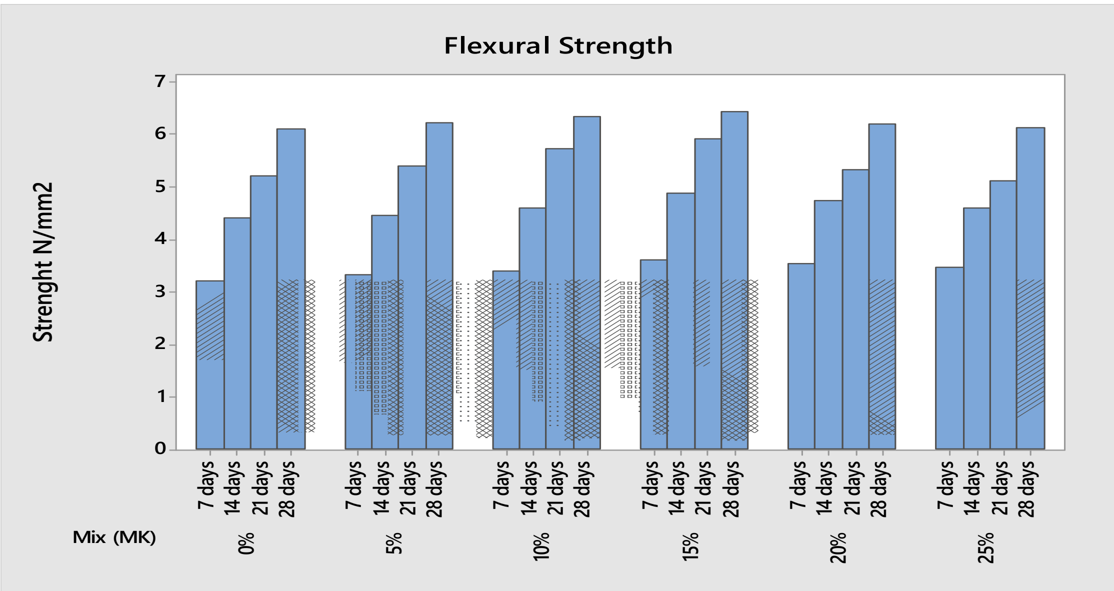

Fig 7. Showing the Flexural Strength of Silica Fume at Various curing days.

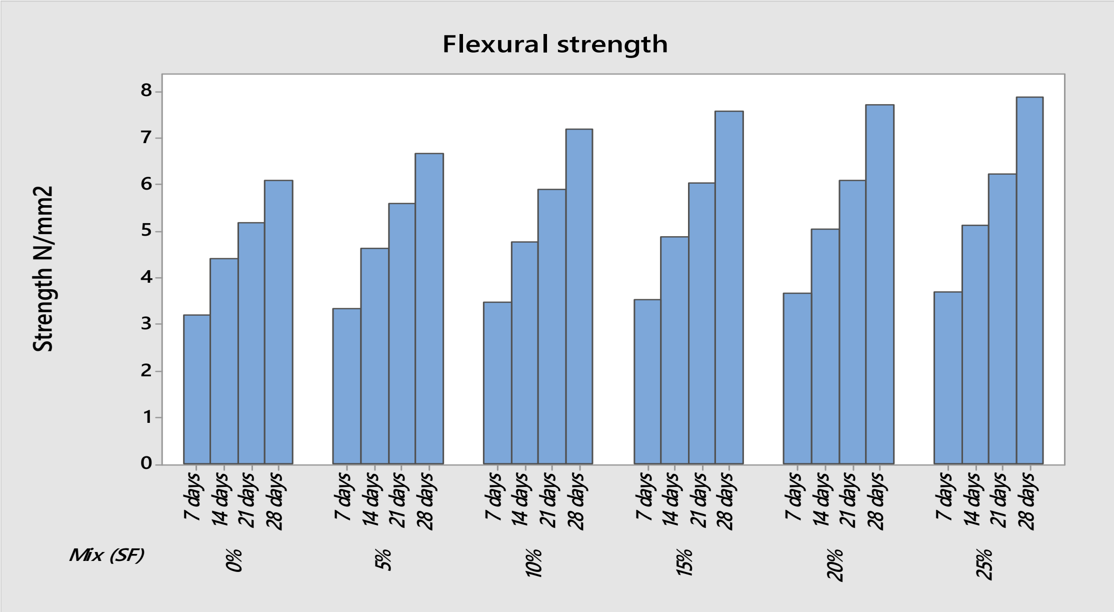

Fig 8. Showing the Flexural Strength of Silica Fume at Various curing days.

4. Conclusion

The fresh and mechanical test properties where performed on the self-compacting concrete mixture and was observed that:

The fresh state of all self-compacting concrete mixes with both mineral admixture had satisfactory performance which as seen in figure 1. Mix with metakaolin had good workability properties than the other mineral admixture used. The use of metakaolin and silica fume as replacement add to the cohesiveness of the mixes, workability and durability. It is evident from the experiment that the compressive strength increase with age of curing days and the strength increase in percentage of metakaolin up to 15% which had the highest strength and further replacement led to decrease in strength while mineral admixture with silica fume had it highest compressive strength at 5% and further increase in percentage replacement led to decrease in the concrete strength all throughout the curing days. It was also observed from the result gotten that silica fume had higher compressive strength compared to metakaolin. The flexural strength result at 15% metakaolin had an increase in resistance of 14.6% to split tensile and at 28 days had 22.4% increase in resistance compared to reference mix. Silica fume

Acknowledgement

The authors wish to acknowledge the financial support offered by Covenant University in actualization of this research work for publication

Reference

[1] Hossain KMA and Lachemi M, "Fresh, Mechanical and Durability of the Characteristic of Self-compacting concrete incorporating Volcanic ash" Material of Civil Engineering 2010; vol 22 (7):651-7

[2] Liu M. "self-compacting concrete with different levels of pulverizes fuel ash", Constr. Build. Mater. 24 (2010) 1245-1252

[3] Okamura Hajime and Ouchi Masahiro."Self – Compacting Concrete".Journal of advanced concrete technology, 2003, Vol.1, No.1, pp 5 – 15.

[4] Dinesh, S. Harini, J. P. Jasmine, J. Shagufta, "Experimental study on self-compacting concrete", International Journal of Engineering Sciences & Research Technology, vol. 6, 2017, pp. 42-50, doi: 10.5281/zenodo.345692.

[5] Ofuyatan O.M, Edeki S.O (2018) Dataset on predictive compressive strength model for self-compacting concrete, Data in Brief journal. February, 17(2018)801–806

[6] M. Uysal, K. Yilmaz, "Effect of mineral admixtures on properties of self-compacting concrete", Cement and Concrete Composites, vol. 33, 2011, pp. 771–776, doi: 10.1016/j.cemconcomp.2011.04.005.

[7] Ofuyatan, S.O., Edeki Dataset on the durability behavior of palm oil fuel ash self-compacting concrete. Data in Brief journal May, 19(2018)853–85

[8] M. Mazloom, A. Ranjbar, "Relation between the workability and strength of self-compacting concrete", 35th Our World in Concrete and Structures (OWICs) – 2010, http://www.cipremier.com/page.php?162.

[9] Singh, S.P. Singh, R. Khan, S. Kumar, "Workability of Self Compacting Concrete Containing Rice Husk Ash", UKIERI Concrete Congress - Innovations in Concrete Construction, Mar. 2013, https://www.scribd.com/document/162458543/Workability-Of-Self-Compacting-Concretecontaining-Rice-Husk-Ash.

[10] EFNARC (The European Federation of Specialist Construction Chemicals and Concrete Systems), the European Guidelines for Self-Compacting Concrete, May 2005.

[11] Khatib JM, Hibbert JJ. Selected engineering properties of concrete incorporating slag and metakaolin. Construction Building Materials 2005; 19:460–72.

[12] Sahmaran M, Christianto H.A, Yaman I.O. The effect of chemical admixtures and mineral additives on the properties of self-compacting mortars. Cement Concrete Composite 2006; 28:432–40.

[13] Al-Akhras NM. Durability of metakaolin concrete to sulfate attack. Cement Concrete Res 2006; 36:1727–34.

[14] Sabir B.B, Wild S, Khatib J.M. On the workability and strength development of metakaolin concrete. In: Dhir RK, Dyer TD, editors. Concrete for environmental enhancement and protection. London (UK): E&FN Spon; 1996. p. 651–6.

[15] Vejmelkova E, Keppert M, Grzeszczyk S, Skalin ski B, Cerny R. Properties of selfcompacting concrete mixtures containing metakaolin and blast furnace slag. Constr Build Mater 2011; 25:1325–31

[16] Vejmelkova E, Pavlikova M, Keppert M, Kersner Z, Rovnanikova P, Ondracek M, et al. High-Performance Concrete with Czech Metakaolin: Experimental analysis of strength, toughness and durability characteristic. Constr Build Mater 2010; 24:1404-11

[17] The Europeans Guidelines for Self-Compacting Concrete, Specification, Production &use. 2) Specification and guidelines for Self-Compacting Concrete, EFNARC, Feb.2002.