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Effect of Gypsum Amount in Cement on Fresh and Hardened Properties of Self-Compacting Concrete

Chernet Getaneh Tebabal

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Self-compacting Concrete; Gypsum Powder; Partial Replacement; Cement; Compressive Strength

ABSTRACT

This study was conducted to assess the effect of gypsum amount in cement in the production of self-compacting concrete (SCC). It was found that, up to 15% replacement, the fresh properties of SCC are satisfied. The twenty-eighth-day compressive strength of SCC mixes with 5%, 10%, and 15% replacement showed a reduced strength having 72.18%, 58.12% and 60.56% of the control, 0% replacement, with a grade of 40MPa. Each replacement of gypsum showed an accelerating effect on the setting time of cement. Initial setting times of more than five hours are found due to the usage of superplasticizer in SCC.

1 INTRODUCTION

1.1. Background of the Study

Self-compacting concrete is a result of recent advancements in concrete technology. What makes this type of concrete special is its ability to be cast without any vibration to every corner of formwork. Its other advantage than the normal concrete is its ability to pass through highly congested reinforcement (Sathish Kumar & Dilli Babu, 2015). Compared to vibrated concrete, having the same water to cement ratio, self-compacting concrete exhibits relatively higher strength. The absence of vibration in SCC gives a better interface between the aggregate and concrete hardened paste (The European Project Group, 2005). Even though it is a short time since its development, self-compacting concrete has shown it has made a remarkable turning point in concrete technology (Paul & Bhattacharya, 2015).

The use of SCC gives ample benefits for the construction industry. Improved productivity, reduced cost of projects, and an overall improvement in the construction environment are among the benefits. Besides, it can be used when there is a shortage of labor, and also it helps in achieving a better surface finish. To entertain those benefits, concrete is required to have a high slump. This requirement can be achieved by the use of superplasticizers high range water reducers in the production of concrete. Increasing sand content is used as a measure to avoid segregation due to the addition of superplasticizers. A higher amount of coarse aggregate in concrete increases the chance of contact between aggregates. This contact between coarse aggregates causes interlocking which hinders the concrete to pass through reinforcement bars. To design a good SCC the first consideration to be taken is limiting the amount of coarse aggregate. SCC consumes a relatively higher amount of powder and a small amount of coarse aggregate as compared to traditional concrete(Okamura & Ouchi, 2003). Reduction in the amount of coarse aggregate for the sake of passability requires compensation with an increase in powder. If all the powder used is covered by cement, an increase in the amount of cement raises the cost of SCC in addition to its effect in increasing the concrete temperature. To overcome this problem (Pai, Nandy, Krishnamoorthy, Sarkar, & Ganapathy, 2014) advice to replace cement with mineral admixtures. Cement is playing a crucial role in world infrastructure development. In nineteen ninety-six, 1.3 billion tons of global cement production was estimated. Production of one ton of cement contributes 0.87tons of carbon dioxide to the environment. Generally, more than seven percent of the world's carbon dioxide emission originates from the cement trade.

Several studies have been done to replace cement partially with other materials. Gypsum, on the other hand, is used in the production of cement. Taking Sulfur trioxide content into consideration not more than three percent of gypsum is added to the final stage of clinker. The addition of gypsum to cement is to regulate the setting time of cement as a retarder. If gypsum is added more than this amount, it has an acceleration effect on the setting time (Bhanumathidas & Kalidas, 2004). Super-plasticizers play an important role in the production of self-compacting concrete. The acceleration due to the use of gypsum above the threshold level might be counterbalanced by the retardation effect of super-plasticizers which makes replacement of cement with gypsum possible. Even though gypsum is highly abundant naturally, use of it as a replacement of cement in SCC concrete as an optional material of replacement is not yet studied.

Gypsum is one of naturally abundant material in Ethiopia. Many reserves of gypsum for large scale mining are available in different parts of the country (Gseadmin, n.d.). Only in Muger and Jema Valleys, more than 57,000,000 tons reserve of gypsum is available (Sintayehu Z., 2009). Even though it is not quantified, comparable or more deposit is available in Abay gorge, Mekele outlier and other locations (Sintayehu Z., 2009).

This study was conducted to investigate the potential of factory grounded gypsum powder as a partial replacement of cement to increase its gypsum amount in self-compacting concrete. This study aimed to investigate the effects of using different replacement ratios of gypsum on fresh and hardened properties of SCC and to determine the optimum replacement percentage of gypsum for the desired property of SCC.

2. MATERIAL AND METHODS

2.1 Materials

Materials which are used in this research are:

a) Ordinary Portland Cement

Ordinary Portland cement of grade 42.5N manufactured by East cement manufacturer was used.

Property of cement	Property values
Fineness	98.1%
Normal consistency	31.5% water by weight of cement
Initial setting time at 19 ^{0}C atmospheric temperature	2 ½ hr
Final setting time at 19 ^{0}C atmospheric temperature	4 ½ hr

Table 2.1 Physical properties of cement

b) Gypsum

SEDE gypsum powder for plastering was used in this experimental study. Gypsum is chemically known as Calcium Sulphatedihydrate (CaSO4.2.H_2O). Gypsum is an abundant mineral in different parts of the world. It has several applications and uses for human and animal life. Its application in medication, soil improvement and construction is familiar. Sedimentary rocks are major sources of gypsum. Gypsum powder is used to be prepared by the process of crushing and grinding the quarried gypsum to the required size. Most of the time, the commercially available gypsum powder is available in the form of calcined gypsum. This form of gypsum powder is the end product of heating gypsum powder to nearly180 ^{0}C. This process is called calcining. It removes three-quarters of chemically bound water. This product is used in the production of gypsum board, gypsum plaster, and others. The fineness value of gypsum found was 98% sieved on No 100 (150μm) sieve.

Fig. 2.1 SEDE gypsum powder on a pan (left) and Determination of gypsum fineness (right)

c) Coarse aggregate

Crushed gravel or stones obtained by crushing of gravel or hard stone was used as coarse aggregate. The maximum size of aggregate was generally limited to 12.5mm. Aggregate was sieved by 12.5mm sieve and washed for any laitance.

d) Fine aggregate

The fine aggregate used was natural sand. The sand was sieved to remove all pebbles. The sieve size used was 4.75mm. The sand was sieved and washed for any laitance. The grading was uniform throughout the work. The moisture content or absorption characteristics were closely monitored as the quality of SCC will be sensitive to such changes.

Fig. 2.2 Washed coarse aggregate used for the study (left), washing aggregate (right)

Fig. 2.3 Fine aggregate (sand) (left) and sieving for fine aggregate (right)

Property	Fine aggregate	Coarse aggregate
Silt content	1%	-
Fineness modulus	2.96	2.3
SG (bulk)	1.72	2.64
SG (OD)	1.52	2.55
SG (SSD)	1.85	2.63
Moisture content	13.2%	3.4%
Absorption capacity	21.3%	2.9%
Powder(passing 150μm)	2.31%	-

Table 2.2 Properties of fine and coarse aggregate

e) Superplasticizer

Naphthalene formaldehyde sulphonate based superplasticizer called (Sikament® NN) which is a dark brown liquid produced by Sika Abyssinia Chemicals Manufacturing PLC was used as a super-plasticizer for the study. Sikament® NN is under type-F admixtures according to ASTM C 494 classification. As a high range water reducer, it reduces water up to 25%. Sikament® NN acting as superplasticizer or as high range water-reducer promotes very high plasticity and good slump keeping properties to concrete. According to manufacturer recommendation, it has a dosage range of 0.5 – 3.0% by weight of cement

Sikament® NN can be used when high fluidity and good quality concrete is required. It has benefits if it is used in the precast production and concrete to be transported for distance from the production point. If the situations in the placement site require delayed concrete placement, this admixture is ideal. Concrete production in areas with high temperature can be achieved by the use of Sikament® NN. As a high range water reducer, it can be used to produce concrete with high early strength.

Physical properties of Sikament® NN are shown in the following table:

Property type	Property value
Density	1.2 ± 0.02kg/l
PH (23 ± 2 ºC)	8 ± 1
Chloride content	< 0.1% (EN934-2)

Table 2.2 Property values of Sikament® NN

Fig. 2.4 Sikament® NN Jar (left) and Sikament® NN liquid in a plastic container (Right)

Apparatus which were used in the experiment are:

- ASTM Standard sieves
- Measuring balance
- Measuring tubes
- Abram's Slump cone
- V-funnel
- L-box
- Compressive test machine
- Concrete mixer machine
- Curing/ soaking tank
- Wheelbarrow
- Cube casting steel and timber forms
- Vicat apparatus
- Submerging tank

2.2 Methods

ASTM testing procedures were adopted in this study. The experimental procedure followed to conduct the research was:

I. Determination of properties of cement, gypsum, sand, and aggregate was done based on tests of the ASTM standard
II. Mix design of SCC of expected grade 40MPa was done according to the method recommended by ACI by using cement and superplasticizer (Sikament® NN) proportion of 0. 5% by weight of cement for the starting trial.
III. Fresh concrete properties of SCC were determined using the Slump flow test, L-box test, and V funnel test.
IV. Further trials by varying the amount of selected concrete ingredients until requirements of fresh properties of SCC were met.
V. SCC fresh properties were checked for 5%,10%,15% and 20% cement replacement by gypsum
VI. Initial and final setting time tests were done for each replacement according to the ASTM procedure.
VII. Nine concrete cubes of 150mm X 150mm X 150mm size were cast for each cement replacement satisfying fresh self-compacting concrete property requirements.
VIII. Casted samples were de-molded after 24 hours and soaked into a tanker.
IX. Three samples from each cement replacement proportions were crushed at 7, 14 and 28 days for compressive strength.

3. THEORY

3.1 Application of Gypsum in Concrete Production

Gypsum plays a very important role in cement. The percentage of gypsum in terms of SO_3 is 2.5-3.0, but its role in cement is significant. At the early age of hydration, gypsum keeps cement in a plastic state which fosters workability. Gypsum retards the hydration reaction of calcium aluminate by changing the course of the reaction. Due to this, it is labeled as a set regulator for cement. In addition to its retardation effect gypsum also contributes to the acceleration of strength gain in the early stages of hydration. If the cement has no gypsum, the flash setting will occur in a few minutes due to the rapid hydration of calcium aluminates (C_3A) to form calcium aluminate hydrate (CAH) which releases profuse exothermic heat with a drying effect to reduce the chances for remixing. The CAH which is formed through this process does not contribute to the strength of the matrix; instead, it hinders the hydration of calcium silicate. In the absence of gypsum commercial use of cement will be ruined. The following reaction shows the hydration of cement in the absence of gypsum.

$$3CaO.\ Al2O3 + n\ H2O \xrightarrow{\text{fast reactions}} CAH + \text{profuse exothermic heat}$$

Incorporating gypsum to the above reaction, aluminate tends to react with SO_3 due to its high affinity to the same. Thus, the reaction of aluminate with water is prevented which causes delayed hydration. The chemical reaction in the presence of gypsum which yields calcium tri-sulpho aluminate hydrate (ettringite) with moderate exothermic heat is given below.

$$3CaO.\ Al2O3 + 3CaSO4.\ 2H2O + nH2O \rightarrow 3CaO.\ Al2O3.\ 3CaSO4.\ 32H2O$$

When the percentage of gypsum in cement increases, ettringite accelerates the hardening process at an early age rather than retarding. Thus, increasing gypsum does not mean delaying the hydration more (Bhanumathidas & Kalidas, 2004).

3.2 Cement replacement for concrete production

Many studies have been done on replacing cement partially with gypsum related materials. Most of them have got improvement on properties of concrete.

Kamble, Pattekari, & Patil, (2018) have reviewed papers done on phospho-gypsum as a replacement of cement. It is an industrial by-product of the production of phosphoric acid which is mainly composed of gypsum but also contains high-level impurities such as phosphate, fluorides, heavy metals, and other trace elements. Chemical composition of phospho-gypsum are CaO 31.2%, SiO2 3.92%, SO3 42.3%, R2O3 3.6%, MgO 0.49% and phosphates 18.49%. It is found in the study that 10-15% replacement is optimum for the compressive strength of concrete. The setting time of cement is increased due to the use of phospho-gypsum. Split tensile strength has its maximum value at 10% replacement of cement with phospho-gypsum.

N. Vyshali & M.Jeganraj, (2019) reported cement replacement by combined gypsum and silica fume of 75% and 2% respectively gives satisfactory compressive and flexural strength for M25 grade concrete.

Bagade & Satone, (2012) in their study of normal concrete reported the compressive strength of phospho-gypsum cement concrete with five and ten percent is improved. It indicates that phospho-gypsum has immense potential to be utilized in concrete applications, especially mass concrete work.

Nigade & Bagade, (2015) observed that even for five percent replacement of cement with impure phospho-gypsum the initial and final time was increased beyond standard value for Ordinary Portland Cement as specified in IS: 12269-1987.

(S. Deepak, C.Ramesh, & R.Sethuraman, 2016) reported that compressive strength and splitting tensile strength has its maximum value at 10% replacement of cement with phospho-gypsum. They are reduced if the percentage replacement is more than 10%. Thus the optimum amount of phospho-gypsum to be added to concrete is 10%.

Saikhede & Satone, (2014) have shown that a part of ordinary Portland cement can be replaced with combined phospho-gypsum and fly ash to develop a good and hardened concrete to achieve the economy. Above 10% replacement of phospho-gypsum and 20% replacement of fly ash in the concrete lead to a drastic reduction not only in the compressive strength but also in the Flexural and split tensile strength of concrete.

K. Madhuralalasa & Dr.K.Rajasekhar,(2016) researched SCC with partial replacement of cement by Phosphogypsum and applying both super-plasticizer and viscosity modifying agent. They have reported that replacement of phospho-gypsum up to 10% improve compressive, split, tensile and flexural strength while more than 10% increases crack width and create a drastic decrease in compressive and split tensile strength.

3.3 Acceptability criteria for fresh properties of SCC

Acceptance criteria for SCC characteristics by ACI and the European methods are shown in the table below:

Characteristic to be measured	Preferred test method(s)	ACI acceptability criteria	European Acceptability criteria
Flowability	Slump-flow test	450 to 760 mm	550 to 850mm
Viscosity (assessed by rate of flow)	T_{500} Slump-flow test or	<=2s low viscosity >=5s high viscosity	<=2s low viscosity >2s high viscosity
	V-funnel test	- -	<=8s low viscosity >9s high viscosity
Passing ability	L-box test	ΔH >=0.8	ΔH >=0.8
Segregation resistance	Visual stability index	0 or 1	-
	Column segregation	<10%	-
	Sieve segregation resistance test	-	<20%

Table 3.1 Comparison of acceptability criteria of different methods for characteristics of SCC

4. RESULTS AND DISCUSSION

4.1 Mix design of SCC without cement replacement

Mix design after five trials with satisfactory results of fresh self –compacting concrete properties is found to have water to cement ratio of 0.32 and admixture amount of 2.1% by weight of cement and other amount of ingredients as listed in the table below.

Ingredient	For one cubic meter (kg)	For trial batch (kg)
Cement	546.88	15.00
Sand	1019.40	30.58
Coarse aggregate	557.24	18.02
Water	245.25	7.35
Sikament® NN	11.48	0.45

Table 4.1 Summary of mix proportion of ingredients for SCC

From the above result, it is noticed that the composition of SCC comprises fine aggregate (44.13%), coarse aggregate (24.12%), cement (23.67%), water (7.58%) and superplasticizer (0.5%) of the total mass of concrete. The powder (cement and fine materials in fine aggregate) is found to be 570.43kg/m^3 which is 24.7% of the mass of fresh concrete.

The fresh self-compacting concrete property test for the mix showed the following results as shown in table 4.2.

Test method	Observation	Requirement
Slump-flow test	735mm	450 to 760 mm
T_{500} Slump-flow test	<1.6s	<=2s low viscosity >=5s high viscosity
V-funnel test	4s	<=8s low viscosity >9s high viscosity
L-box test	0.8	ΔH >=0.8
Visual stability index	1	0 or 1

Table 4.2 SCC fresh property test results

The mix above satisfied all fresh self-compacting property requirements and the proportions taken for self-compacting concrete cube production without cement replacement. Due to enough amount of powder materials and superplasticizer, the mix tends to have low viscosity. The concrete flows without blocking at the reinforcement barriers in the L-Box. For this mix, segregation and aggregate hallo is not observed.

Fig. 4.1 Slump flow spread of SCC without cement replacement

Fig. 4.2 L- Box flow of SCC without cement replacement

4.2 Fresh properties of SCC with cement replacement

The effect of cement replacement with different percentages of gypsum keeping the other amounts of ingredients mentioned in table 4.1 is summarized in table 4.3. 5, 10 and 15% replacements satisfy the fresh SCC property requirements while 20% replacement does not satisfy.

Replacement percentage	Test method	Observation	Requirement
5%	Slump-flow test	725mm	450 to 760 mm
	T_{500} Slump-flow test	<1.5s	<=2s low viscosity >=5s high viscosity
	V-funnel test	4.78s	<=8s low viscosity >9s high viscosity
	L-box test	0.89	ΔH >=0.8
	Visual stability index	1	0 or 1
10%	Slump-flow test	720mm	450 to 760 mm
	T_{500} Slump-flow test	<1.62s	<=2s low viscosity >=5s high viscosity
	V-funnel test	5.37s	<=8s low viscosity >9s high viscosity

	L-box test	1	ΔH >=0.8
	Visual stability index	1	0 or 1
15%	Slump-flow test	700mm	450 to 760 mm
	T_{500} Slump-flow test	<1.8s	<=2s low viscosity >=5s high viscosity
	V-funnel test	6.26s	<=8s low viscosity >9s high viscosity
	L-box test	1	ΔH >=0.8
	Visual stability index	1	0 or 1
20%	Slump-flow test	645mm	450 to 760 mm
	T_{500} Slump-flow test	<4s	<=2s low viscosity >=5s high viscosity
	V-funnel test	7s	<=8s low viscosity >9s high viscosity
	L-box test	0.47	ΔH >=0.8
	Visual stability index	1	0 or 1

Table 4.3 Fresh SCC property test results of different percentage of replacements

Increasing the amount of gypsum replacement, viscosity tends to increase together. At 20% replacement, due to high viscosity, the SCC could not pass the L-Box reinforcement easily without blocking.

4.3 Setting time of different cement replacements

Setting time for different cement replacement percentages with gypsum powder has been done according to the test procedures ASTM C 191-08 standard test methods for a time of setting of hydraulic cement by Vicat needle. The summarized setting times of different percentages of replacements are given in table 4.4 below.

Cement replacement	Normal consistency of replaced cement	Initial setting time	Final setting time	Initial setting time with normal consistency of cement	Final setting time with normal consistency of cement	Initial setting time with normal consistency of cement and 2.1% admixture
0%	31.5%	-	-	2 ½ hr	4 ½ hr	More than 5 hrs
5%	38%	2hrs	6hrs	1hr 50min	4 ½ hr	
10%	50%	30min	5 ½ hr	10min	1hr 45min	
15%	63%	10min	5 ½ hr	5min	50min	

Table 4.4 Initial and final setting times of different replacements

According to ASTM C 150-12 standard specification for Portland cement, the setting time minimum and maximum limits are set to be 45min and 375min (6 hrs and 15min). Based on ASTM limits only 5% cement replacement with gypsum powder satisfies the requirement. As the replacement of cement with gypsum powder increases both initial and final setting time reaches quickly in the case of using normal consistency of unreplaced cement and only the initial setting time drops faster when normal consistency of replaced cement is considered. Test for setting time of replaced and un-replaced cement with normal consistency of un-replaced cement and addition of 2.1% Sikament®NN admixture by weight of cement was conducted and initial setting time of un-replaced and all five to fifteen percent replaced cement was found to be more than 5 hrs which is far more extended from cement without admixture. The normal consistency of cement increases with an increased percentage of replacement. The reduction in setting time and the requirement for higher normal consistency of replaced cement is due to the use of calcined ($CaSO_4.0.5H_2O$) gypsum powder instead of gypsum ($CaSO_4.2H_2O$). Onat, Valiyev, Agapov, & Kangarli, (2016) have found similar effects on their work to analyze the effect of anhydrite gypsum ($CaSO_4$) on the quality of cement. Theoretically, when cement is mixed with water, CaSO4 particles in gypsum react with water to produce sulfate ions which are responsible for the formation of ettringite from reaction with C_3A particles. The thin coating of ettringite crystals prevents the reaction of C_3A with water. Due to this prevention, delay in setting time occurs. The following chemical reaction equation summarizes what has been discussed so far.

$$3CaO.Al_2O_3 + 3CaSO_4.2H_2O + nH_2O \longrightarrow 3CaO.Al_2O_3.3CaSO_4.32H_2O$$

Considering anhydrite ($CaSO_4$) in place of gypsum, the solubility of anhydrite is relatively small and its water requirement for solubility is more. Due to the low degree of solubility of anhydrite, ettringite formation is not as fast as gypsum. The delayed formation of ettringite reduces the ability to prevent the reaction of C_3A with water which is responsible for shorter setting time. The formation of ettringite can be speeded up by the addition of more water. This requirement for more water is the reason for the increase in normal consistency of gypsum powder replaced cement. The same principles apply for use of calcined gypsum powder instead of raw gypsum. On the other hand, the use of superplasticizer on replaced cement showed increases in the initial setting time. This improvement in setting time is due to the usage of high concentration high range water reducer. Mainly superplasticizers work on the rule of dispersion. Molecules of superplasticizers form a film around positively charged cement particles on the inner side and positively charged water molecules on the outer shell. This separation of cement and water molecules will form a lubricated flow of cement particles against water molecules without mixing each other. Adsorption of superplasticizer molecules will be done primarily by C_3A and gypsum molecules. If the concentration of superplasticizer is more adsorption of superplasticizer by C_3S will be done to some extent. Once the adsorption of superplasticizer is complete, the hydration process will start and agglomeration of cement particles will continue for hardening. The extra amount of superplasticizer adsorbed by C_3S contributes to prolonged workability retention and longer setting time in addition to the delay caused by the prevention of hydration reaction of C_3A particles (Ziad & Ramon, 1989).

4.4 Hardened properties of SCC with different replacements

Figure 4.3 and Table 4.4 summarize 7, 14 and 28-day compressive strength test results of different replacement percentages. All replacement percentages show an increase in strength from 0 days to 28 days. 15% replacement shows little increase in compressive strength than 10%replacement at 7 and 28 days. The difference in strength between each consecutive percentage replacements decreases as replacement increases. With 5% replacement strength at 28 days highly dropped with 10.82MPa from 0% replacement. Strength drop from 5% to 10% replacement at 28days reduces to 5.47MPa. From 10% to 15% replacements, 0.95MPa increase in strength is observed. The reduction in compressive strength for increased replacement of gypsum powder is because gypsum has no strength contribution and the increased replacement of gypsum powder will decrease the amount of calcium silicates C_3S and C_2S which are responsible for early and long term concrete strength. Amin & Mohamad, (n.d) on their report for the determination of the optimum quantity of raw gypsum addition for cement clinker, showed that an increase of raw gypsum in cement above 5% severely reduced the compressive strength of concrete.

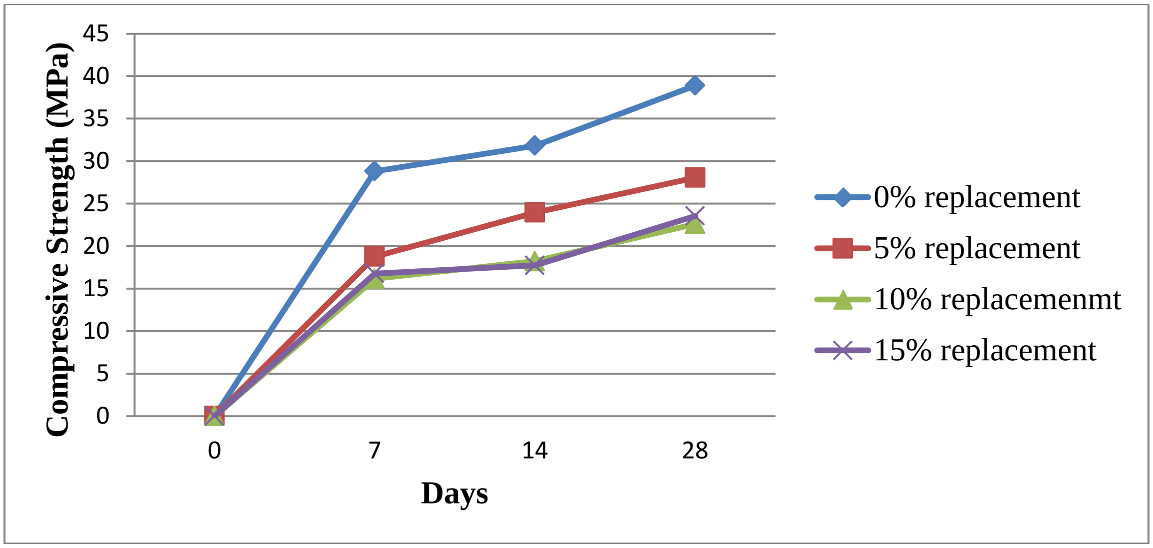

Fig. 4.3 Compressive strength of SCC with different percentage of cement replacement

Replacement percentage	Test day	Sample Cubes	Compressive Strength (MPa)	Average Compressive Strength (MPa)
0%	7	1	30.45	28.81
		2	30.06	
		3	25.91	
	14	1	30.45	31.83
		2	31.2	
		3	33.85	
	28	1	38.69	38.89
		2	41.24	
		3	36.75	
5%	7	1	17.83	18.77
		2	19.37	
		3	19.12	
	14	1	23.68	23.97
		2	25.17	
		3	23.05	

	28	1	28.86	28.07
		2	29.41	
		3	25.93	
10%	7	1	16.01	16.15
		2	15.41	
		3	17.02	
	14	1	19.06	18.23
		2	17.31	
		3	18.31	
	28	1	23.43	22.6
		2	21.71	
		3	22.68	
15%	7	1	17.14	16.78
		2	16.58	
		3	16.63	
	14	1	17.25	17.73
		2	19.41	
		3	16.52	
	28	1	23.4	23.55
		2	23.38	
		3	23.87	

Table 4.4 Summary of compressive strength test results

5. CONCLUSIONS

From the research the following points can be concluded:

I. Replacing cement in 40Mpa SCC mix with gypsum powder can be done up to 15% with the expense of strength for each percentage increase.
II. Replacing cement by more than 15% gypsum powder does not satisfy the fresh concrete property requirements of SCC.
III. 28 days compressive strength of SCC decreases continuously from 0% to 10% and little increases from 10% to 15% gypsum powder replacement. 72.18%, 58.12% and 60.56% from the control un-replaced SCC 28 days compressive strength is observed for 5%,10% and 15% replacements respectively.
IV. 0, 5, 10 and 15% cement replacement by gypsum has little effect on deformability, flowability/ fill ability, passability, and stability of SCC. With an increasing percentage of replacement by gypsum viscosity and passability increases while deformability/fill ability decreases within the acceptable range.
V. 20% cement replacement by gypsum powder does not satisfy the fresh concrete properties of SCC.
VI. Replacement of gypsum powder has little effect on the density of SCC. Increase in 2.45kg/m^3 observed from 0 to 5% while decrease by 16.8 and 19.88 kg/m^3 is observed from 5 to 10% and 10 to 15% increase respectively.
VII. Replacement of cement with gypsum powder has a significant effect on setting time. It has an accelerating effect. When replacement increases, both initial and final setting times decrease. With normal consistency of un-replaced cement, only 5% replacement satisfies the requirement of ordinary Portland cement setting time with 1hr and 50 min and 4½hr initial and final setting time respectively. While others initially set within 10 minutes.
VIII. The normal consistency of replaced cement is higher than the normal consistency of un-replaced cement. It increases from 31.5% of normal cement to 38,50 and 63% of 5,10 and 15 % replacement respectively. Setting time of 5% gypsum replacement is improved to 2hrs and 6hrs of initial and final setting time respectively using normal consistency of replaced cement. 10% and 15% replacements show improvement both in initial and final setting time but initial setting times are below 45 minutes.
IX. The initial setting time of all replacement percentages of cement is improved by using the Sikament® NN superplasticizer. It is extended to more than 5hrs by adding 2.1% superplasticizer by weight of cement in addition to the normal consistency of un-replaced cement.

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ACI and ASTM Standards:

ACI 237R-07 Self Consolidating Concrete
ACI 211.1-91 Standard practice for selecting proportions for normal, heavyweight, and mass concrete
ASTM C 187-04 Standard test methods for normal consistency of hydraulic cement
ASTM C 191-08 Standard test methods for a time of setting of hydraulic cement by Vicat needle
ASTM C 184-94 Standard test method for the fineness of hydraulic cement by the 150-µm (No. 100) and75-µm (No. 200) Sieves
ASTM C 472-99 Standard test methods for physical testing of gypsum, gypsum plasters and gypsum concrete
ASTM C 136/136M-14 Standard test methods for sieve analysis of fine and coarse aggregates
ASTM C 128-04a Standard test method for density, relative density (specific gravity), and absorption of fine aggregate
ASTM C 127-07 Standard test method for density, relative density (specific gravity), and absorption of coarse aggregate
ASTM C 33/C 33M Standard test method for sieve analysis of fine and coarse aggregates
ASTM C 150-12 standard specification for Portland cement