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Experimental Study on the Synergistic Effect of Expansive and Natural Fibres in Ternary Blended Self Compacting Concrete

Samuel Prabaharan J[1*], Sophia M[2], Ravikant Talluri[2] and Karthick A[3]

[1]Assistant Professor, Department of Civil Engineering, Francis Xavier Engineering College, Tirunelveli, Tamil Nadu 627003, India. E-mail: samuelfxec@gmail.com*

[2]Assistant Professor, Department of Civil Engineering, CMR Institute of Technology, Bengaluru, Karnataka 560037, India

[3]Assistant Professor, K.Ramakrishnan College of Technology, Trichy, Tamil Nadu 621112, India

Abstract

The present research works aims at the production of self compacting concretes with higher strength and durability by utilizing cement replacement and fibre reinforcement. Generally SCC has more powder content than the normal concrete to enhance their fluidity and hence to minimize the cement utilization, zeolite and silica fume has been used as cement replacement at 15% each by weight of cement. To provide flexibility, natural fibres (sisal and Prosopis juliflora) have been used at 1% by cement weight. Using expansive agents CaO and MgO with wide ranging proportions (0%, 2%, 4%, 6%), the fluidity is enhanced due to the dispersive effect produced by these agents. The utilization of super-plasticizers was also be reduced due to the expansive agents thereby the construction cost is reduced. The shrinkage resistance of the concrete was improved with high flexural strength with increasing expansive agent additions upto 1.5%. The developed self compacting concrete mixes containing expansive agents can also be commercialized for use in specific applications.

Keywords: *Self compacting concrete, sisal and Prosopis juliflora fibres, water demand, mechanical strength*

1.0 Introduction

Despite its multifaceted usage in today's world, its versatility state facing challenges and that probes the researches to find an alternate mixture of this concrete that has its own reformative properties. Those factors that are ignored during the process of producing an efficient concrete which is the next key problematic element and hence admixtures should be used to ensure the achievement of an indestructible concrete that meets a proper compaction and curing. Okamura et al (1995) suggested a proportion to mix the SCC. In this system, the self compatibility is to be attained by regulating the water or powder ratio with the dosage of the super plasticizer where the aggregates of coarse and fine contents are pre-determined. Regarding the composition of SCC, the elements may resemble the conventionally vibrated concrete which includes water, cement, supplements and other admixtures. SCM in various forms has provided an estimate generation of 100 million tonnes a year from various industrial processes, and its authentic pertinence in various framework of the project. Yield stress is reduced with the use of shrinkage reducing agents and the CaO with hydrophobic admixture causes increase even if limestone is replaced. Paste flow velocity is easily accessible at maintained shear stress and sufficient mobility in obtained without any internal or flow segregation in the self compaction concrete (Valeria Corinaldesi 2012). The expansive agents (EA) under water curing conditions are extremely effective in shrinkage control.

[*]Author for correspondence

The expanding feature of the expansive agent is ensured by the curing conditions, by the presence of ettringite and calcium hydroxide values (Dong Rong Zhen et al. 2014). Concrete expansion gets reduced with the higher content of calcium sulphoaluminate expansive agent. It also results in the reduction of the shrinkage with 8-10% of expansive agent and the crack removal proved to be excellent (Jia Li-Li et al. 2016). The field test results recorded by Fang liu et al. 2016, explained that the expansive strain of concrete can increased and the expansive agents have the ability to enhance the crack prevention. Autogenous shrinkage and that which is caused due to dryness was greatly reduced due to the magnesia expansive agents and the liquid expansive agents added (Kiazhi Liu et al. 2019). Prevented lime based expansive agent showed higher expansions than ettringite based expansive agent, whereas the lowered expansion falls to reduced levels in ordinary cement. Adding expansive agents for increasing the strength showed strength showed same results for both agents (Takayoshi Maruyamma et al, 2017). Porosity of the non-shrinking cement based elements has been greatly influenced by nano MgO and can also be used as a replacement for Mg with Ca and C-S-H cationic exchange (Reza Morapour et al. 2013). Adding of expansive agents reduces RH and increases dryness, causing shrinkage. Insufficient expansion may occur if EA is added at early stage to reduce shrinkage. High reactive CaO added at low water consumption forms an effective ultra high performance concrete with reduced shrinkage (Peiliang Shen et al 2020).

The study by Selvamony et al. 2009 recorded that silica fume had positive effects towards the mechanical specifications of SCC whereas limestone with quarry dust had adverse effects. Incorporating SF up to 10% in silica fume binary mixtures increased the compressive strengths at all ages as compared to OPC, despite the fact that the rate strength development of silica fume binary mixes is higher at early ages than that of later ages (Tahir Kemal Erdem et al. 2008). The early strength development of silica fume mortar mixes is significantly influenced by the inclusion of silica fume, especially in the early days of curing (Appa Rao 2003). The best compressive strength values are from specimens that have been water cured for 28 days and have an SCC with 15 per cent SF as opposed to 30 per cent FA (Heba A.Mohamed 2011). The total charge transmitted was significantly decreased and chloride ion penetration was effectively controlled by silica fume. The temperature of the solutions used during the test was likewise under the control of silica fume, indicating that the movement of ions in the penetration into concrete was also under control (Sasanipour et al. 2019). Silica fume can considerably enhance the mechanical and durability aspects of SCC and offset the negative effects of recycled coarse aggregate (Guo et al. 2021).

Due to their highly reactive silica and alumina content, zeolites are among the most commonly utilised mineral admixtures (Cenk et al. 2010). Zeolites operate as water reservoirs, may absorb and release more than 30% of their own weight in water, and are effective internal cures (Sadegh et al. 2013). The work by Samimi et al. (2018) illustrates and quantifies the beneficial impact of partial Portland cement substitution with 10% and 15% of pumice and 15% of zeolite on enhancing chemical resistance to acid attack. It will undoubtedly be able to get greater performance and, consequently, better profits from this natural pozzolan thanks to the characteristics of concrete including zeolite in order to boost the mechanical strength. Zeolite pozzolan has been found to significantly boost resistance to chloride penetration in both immersion and tidal settings and 10% of zeolite in high strength has also been proven to have this effect (Samimi et al. 2017). The use of zeolites boosted compressive strength, with the best results being obtained when less than 20% of cement was substituted (Perraki et al. 2003). Due to their enormous surface area and very porous structure, zeolites also function as internal curing agents to lessen autogenous shrinkage. They can therefore absorb and desorb pore solution (Zhang et al. 2018). The advantages are often brought about by natural zeolites' distinctive internal structure and significant pozzolanic reactivity (Poon et al. 1999). The characteristics of concrete have been improved by the inclusion of zeolite in binary and ternary blends of SCMs, particularly in terms of providing resistance against damage during reloading (Sophia et al. 2019).

Over the past ten years, scientists have investigated various plant-based fibres for use as reinforcement in polymer matrixes to create composites. According to a recent study, sisal fibre that has been alkali-treated appears to be a suitable and long-lasting replacement for cement-based matrices (Castoldi et al. 2022). It has been discovered that sisal fibres combined with glass fibre improve the properties of energy absorption (Padanattil et al. 2017). Sisal fibres slow the spread of cracks by regulating their opening and may prevent concrete elements from rupturing prematurely when compared to specimens of plain concrete (Silva et al. 2010). As sisal fibre length and volume percentage increased, the flowability of the freshly mixed ultra-high performance concrete mixture declined (Ren et al. 2021). Sisal fibres can be added to cement to slow down the cement's hydration process and extend setting durations. The cost of manufacturing and the carbon footprint of UHPC can be decreased by using renewable sisal fibre as a shrinkage-reducing ingredient (Ren et al. 2022). One of the biological foreign species that disturbs the environment and the economy the most is the Prosopis juliflora (Gopinath et al., 2015) With the inclusion of the prosopis juliflora fibres, the composite hardness was also significantly improved (Sakthieswaran and Sophia 2020). The present research deals with the possibility of utilizing CaO and MgO based expansive agents in enhancing the performance of ternary blended SCC containing natural fibres additive.

2.0 Materials

Ordinary Portland cement of 53 grade conforming IS 12269-1987 is used. Clinoptilolite, also referred to as Clinozeolite, is the kind of natural zeolite that was used for this investigation. It was bought from India's commercial mineral sector. The natural zeolites have a crystal structure resembling a honeycomb with tiny pores or apertures that are easily filled with water (Ikotun & Ekolu 2010). The main ingredient in the fine aggregate used for this investigation is actual river sand. Locally available gravel with a 10 mm size is used as coarse aggregate and meets the requirements of IS 383-1989. It is advised to replace the binder due to the fineness of the silica fume because doing so would result in excellent waste management. A benefit of utilizing silica fume is that it lowers calcium hydroxides and improves the bonding phase between paste-metal matrixes. Table 1 presents the oxide composition of raw materials employed in the current study. The biodegradable sisal fibre is a highly renewable energy source that is specified using its thermal and mechanical specifications. The sisal plant, which matures at eight to twelve years in hot, dry regions of Tamilna Nadu with a roughly 6m tall stalk, was used in this study as a natural raw cellulose type fibre. The prosopis juliflora (PJ) fibres size was set in accordance with the information acquired from earlier research projects (Fabio et al., 2015). The length of the PJ fibres, which was fixed at roughly 10 mm, was obtained using conventional cutting techniques. By visual inspections, the diameters of the PJ fibres were fixed to roughly 10.25±2 μm. Volumetric expansion caused by the expanding agent during the early phases of hardening reduces shrinkage's contraction. In the current work, two expanding agents were used: analytical grade CaO and MgO. Conplast 430 is used as a superplasticizer to minimize water content since SCC necessitates large quantities of the substance for fluidity and water reduction.

Table 1: Chemical oxide composition of raw materials

Component (%)	OPC53	Zeolite	Silica fume
SiO_2	22.6	63.87	93.45
CaO	62.5	2.37	0.69
Al_2O_3	5.8	11.47	0.17
MgO	0.8	1	0.03
SO_3	3.2	-	0.39
Fe_2O_3	4.2	0.215	0.04
Cl	0.04	-	-
K_2O	0.36	0.94	0.08
Na_2O	0.41	6.81	-
P_2O_5	<0.04	-	-
LOI	2.1	11.97	3.2

3.0 Mix Details

The production of SCC was done as per the procedure stated in BIS methodology and M30 grade self compacting concretes are produced. The mix design for the production self compacting concrete was done as per the EFNARC specifications. The main variables used on the study are expansive agents of two different types namely CaO and MgO based. The expansive mixtures SCa1, SCa2 and SCa3 are formed with 15% constant replacement of zeolite and silica fume and CaO based expansive agent added as 2%, 4%, 6% respectively. SMg1, SMg2 and SMg3 had the same values except the MgO based expansive agent added in 2-6% with increment of 2%. All the SCC mixtures except the control mix (CTRL) has the natural fibres content of 1% each for sisal and prosopis juliflora. Table 2 depicts the developed mix proportioning details of SCC. The water cement ratio was constantly maintained at 0.8 throughout the concrete mixes. The superplasticizer dosage was maintained at 2.5% of the binder content.

Table 2: Mix proportion of SCC mixes

Mix Id	Cement	Z	SF	EA		Sis	Pj
				CaO	MgO		
CTRL	100	-	-	-	-	-	-
SCa1	70			2	-	1	1
SCa2	70			4	-	1	1
SCa3	70	15	15	6	-	1	1
SMg1	70			-	2	1	1
SMg2	70			-	4	1	1
SMg3	70			-	6	1	1

where, Z- zeolite, SF- silica fume, EA- expansive agent, Sis- sisal fibre, Pj- Prosopis juliflora fibre, CaO- calcium oxide, MgO- magnesium oxide

Note: Sand and Coarse aggregate content is considered as 100%

4.0 Experimental Techniques

The first stage of investigation included the experimental methods to determine its fluidity and viscosity when silica fume and zeolite was used to constant replacement of cement with varied proportions of expansive agents were analyzed and slump flow (J Ring, T 50, V Funnel, L Box), was carried out to determine its fresh properties. In this study, compressive and tensile tests are carried out using 150 mm cubical and 150x300 mm cylindrical specimens as per 1S: 516 (1959) and IS: 58816- (1999) respectively. Flexural strength testing was done using 150mm cubes in accordance with IS:

Figure 1: Workability tests

Figure 2: Mechanical and durability tests

9399-1979 specifications. The self compacting concrete mixes are subjected to the attack of acids, chlorides and sulphate by immersing the concretes in various chemicals. To assess the acid resistance potential the concretes are immersed in 1% HCl solution for period of 4 and 8 weeks. The chloride resistance of the concretes were obtained by immersing the concrete specimens in 5% sodium chloride solution for 4 and 8 weeks. Figure 1 and 2 displays the experimental images of the tests carried out in the present research.

5.0 Discussion on Results

5.1 Workability measurements

Satisfactory results were obtained in the increase of diameter using the expansive agents when compared to the reference mix. SCa3 mix with 6% CaO showed increased flow value of about 734 mm whereas SMg3 showed 736 mm in case of MgO based mixes. The CaO and MgO based expansive agents showed a T50 slump flow value ranging between 2.25 to 2.55 seconds respectively. The values obtained in T50 Slump flow was reduced in all the mixes that contained expansive agents when compared to the reference mixture. All of which revealed decrease in the percentage of flow time but falls under the EFNARC guidelines the filling ability of all the mixtures with silica fume, zeolite, natural fibres and expansive agents showed satisfactory results in its filling ability. The developed SCC mixes showed the height ratio values between 0.88 to 0.97 when measured using L box test which falls between safe limits. The results obtained from Table 3 are satisfactory where the guidelines for J Ring mention the values exceeding 2 inches shows poor passing ability of the mixture and it is observed that all the mixtures fall into these limitations. The usage of both the expansive agents has helped in the increase of the passing ability of the mixture. The inclusion of CaO and MgO based expansive agents resulted in optimum V-funnel values from 7 to 10 seconds which shows the efficiency in filling ability of the SCC mixtures. The obtained results are found to be within the limit of 6 to 12 seconds as suggested by the EFNARC.

Table 3: Workability results of SCC mixes

Mix/Unit	Slump	T50 slump	L-Box Height ratio	J-Ring Height	V-funnel
	mm	sec	mm	mm	sec
CTRL	720	2.53	0.88	8.82	9.5
SCa1	724	2.42	0.91	9.22	8.6
SCa2	729	2.35	0.9	9.52	7.9
SCa3	734	2.32	0.94	9.76	7.6
SMg1	726	2.41	0.93	9.36	8.4
SMg2	728	2.3	0.94	9.65	7.6
SMg3	736	2.28	0.97	9.92	7.2

5.2 Mechanical characterization

5.2.1 Compressive strength

Addition of CaO and MgO based expansive agent has resulted in the improved compressive strength which is clearly evident from Figure 3. The maximum strength attained was for SCa2 which has 4% of CaO expansive agent and the value was measured to be 34.81 MPa at 28 days. It can be said that the compressive strength has shown increase with the inclusion of silica and the concrete specimens show increase with the influence of expansive agents with zeolite and silica fume that has contributed to the strength by densifying the paste in the mixture, thus reducing the pores in the concrete. This helped the concrete mixture to attain the expected compressive strength. This property along with the CaO expansive agent has shown increase till SCa2 whereas MgO expansive agent increased till SMg2 and reduced compressive strength when excess expansive agent is added. On comparing the effects of CaO and MgO, the CaO usage proves to be more beneficial than MgO usage. Thus the use of expansive agents in the self compacting concrete improved the strength of concrete at early and later ages which shows that expansive agents reduce the shrinkage properties of concrete especially when zeolite is used as an admixture.

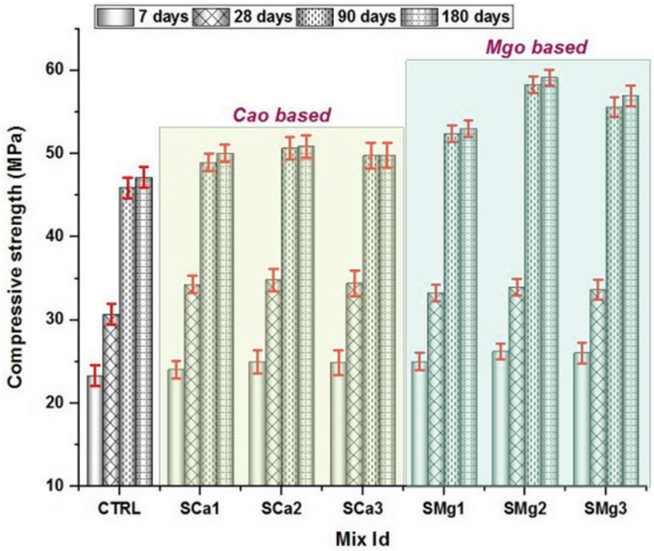

Figure 3: Compressive strength of developed SCC mixes

5.2.2 Split tensile strength

Crack formation is reduced with the addition of all these admixtures in a brittle cement matrix. The concrete mix is enhanced in its tensile properties by using various mixtures like CaO based and MgO based expansive agents as evident from Figure 4. The 28 days strength of the SCC mixes was recorded to be 3.27 MPa for SMg1 mix, 3.38 MPa for SMg2 mix and 3.17 MPa for SMg3 mix. The CaO percentage more than 4% showed declining trends of increase in flexural strength but the values were higher than the reference mix. Thus it can be inferred that the addition of MgO based expansive agent increases the flexural strength of concrete and the mix SMg2 expressed the maximum tensile strength with 15% of silica fume and zeolite, 1% natural fibres and 4% of MgO based expansive agent. The increased split tensile strength was seen in adding CaO expansive agent in SCa2 mixes showed a value of 3.12 MPa, 3.38 MPa, 3.53 MPa and 3.61 MPa at 7, 28, 90, 180 days and these values are measured to be higher than the reference mix value.

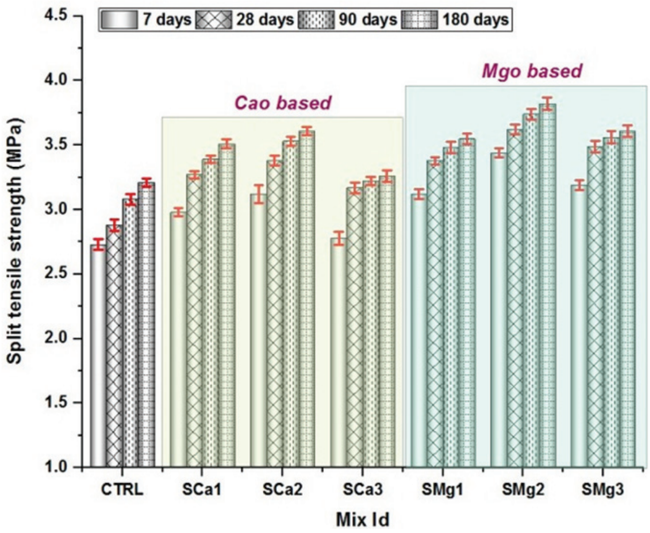

Figure 4: Split tensile strength of developed SCC mixes

5.2.3 Flexural strength

The highest flexural strength of 3.92 MPa was seen in SCa2 mix having 4% of CaO expansive agent, 15% silica fume and zeolite. All the mixture with the addition of the expansive agents resulted in increased flexural strength and the rate of attainment of flexural strength on 28, 90 and 180 days was also much higher that indicates improved ductility of the concrete which can be evident from Figure 5. The

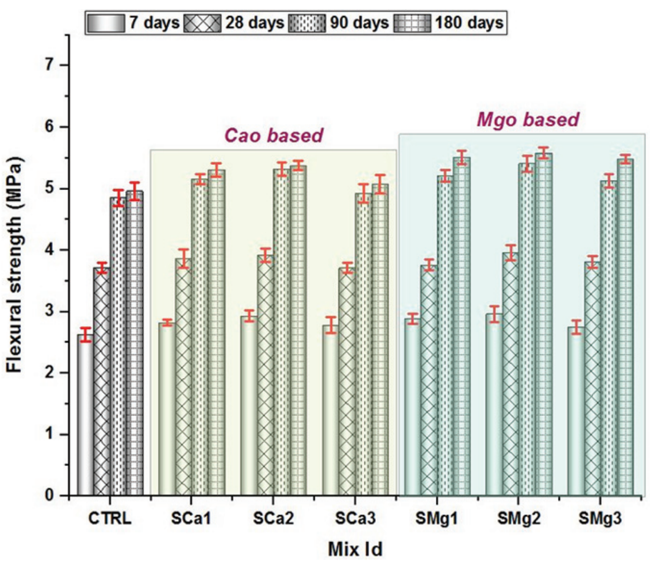

Figure 5: Flexural strength of developed SCC mixes

agglomeration property of the concrete ingredients was reduced due to the use of expansive agents that shows increased flexural strength. The improved flexural strength may be because of the combined usage of zeolite, natural fibres that blended with the expansive agents in the concrete and silica fume leads to the formation of CSH at the later ages for increased flexural strength. On comparing the CaO and MgO effects, the MgO expansive agent showed better flexural strength than the CaO implemented mixes at all ages.

5.3 Chemical Attack measurements

5.3.1 Acid Attack

Figure 6 presents the results of SCC mixes after acid exposure. CaO and MgO based expansive agent added to 15% silica fume and zeolite, showed pronounced weight loss and the weight loss was measured to be 5.58%, 5.72%, 5.94%, 13.15%, 13.48% and 13.74% for the SCC mixes SCa1, SCa2, SCa3, SMg1, SMg2 and SMg3 respectively after 4 weeks exposure. The corresponding loss in the strength of those concrete mixes were measured to be 8.65%, 9.10%, 11.20%, 19.99%, 20.90% and 21.90% after 4 weeks exposure. The progress of strength loss and weight loss increased marginally at 8 weeks exposure and followed the similar trends of 4 weeks exposure. The MgO based SCC mixes exhibited greater loss than the CaO based mixes in both aspects of strength and weight.

5.3.2 Chloride Attack

Addition of CaO based expansive agent and MgO based expansive agent are checked for the chloride attack and the results obtained in 4 and 8 weeks are shown in Figure 7. The

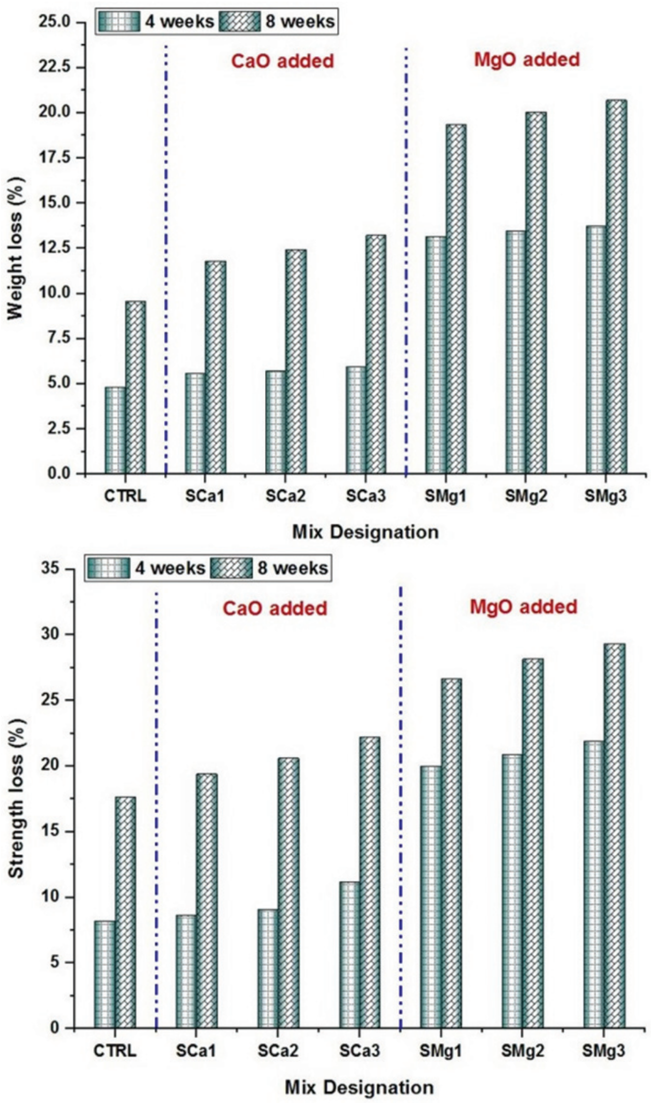

Figure 6: Strength and weight loss of SCC mixes under acid exposure

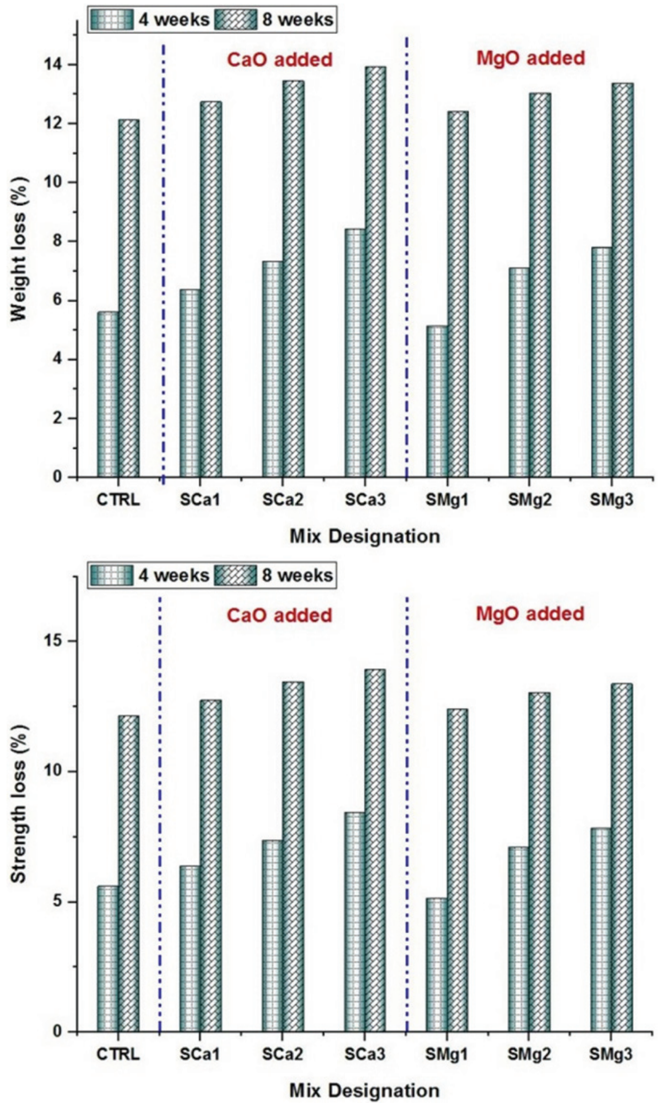

Figure 7: Strength and weight loss of SCC mixes under chloride attack

loss in weight for the mixtures SCa1, SCa2 and SCa3 was observed to be 3.78%, 3.92% and 4.14% respectively and the loss in strength was 6.39%, 7.35%, 8.44% after 4 weeks exposure. Increase in the values of chloride attack has been observed with reference to the reference mixture. MgO based expansive agent also showed increase in percentage loss of the concrete mixes after 4 weeks and 8 weeks exposure. Their 4 weeks and 8 weeks exposure values observed are 3.57%, 3.71%, 3.93% and 6.15%, 6.48%, 6.96% of loss in weight respectively for SMg1, SMg2, SMg3 mixes. The loss in strength of the concrete mixes after 4 weeks exposure was measured to be 6.39%, 7.35%, 8.44%, 5.15%, 7.12% and 7.83% for the mixtures SCa1, SCa2, SCa3, SMg1, SMg2 and SMg3 mixes respectively. The increment in the loss in strength and weight of the concrete mixes containing expansive agents may be attributed to the readiness of the expansive agents to react readily with the chloride ions. However these increments in the values were only marginal and hence acceptable.

6.0 Conclusions

Based on the findings from the presented study, the following conclusions may be drawn:

1. The use of expansive agents in concrete improved the workability of concrete by providing air entraining effect on concrete. The fresh state results showed that all the SCC concrete mixes yielded good workability and thus fulfilled the compacting requirements. The improvements in the workability were due to the use of expansive agents that induced mixture air bubbles thereby increasing the workability.
2. The growth rates of the use of expansive agents on the strength were inclined in the positive direction which may be due to their ability to promote pozzolanic reactivity that can react certain with CH present in the concrete. The use of expansive agents beyond certain limit may reduce the strength of concrete. The dimensional stability maintenance due to the loss of moisture was done by expansive agents has caused a significant improvement in the strength values of the concrete. The expansive agents along with the natural fibres can also optimizing the microstructure of concrete by reducing their pores thus increasing the strength values.
3. The flexural strength of the SCCs is also improved due to the use of expansive agents which indicated their self distributing property that gets uniformly distributed throughout the cement matrix and improved their compactness and denseness with increase in time. Thus it can be ascertained that the use of expansive agents of appropriate amounts can produce expansive properties in concrete hereby imparting strength gain.
4. The split tensile strength values also showed improved values at all ages due to the influence of expansive agents. The drying of concrete and evaporations water can create internal shrinkage of the SC concrete thereby causing micro cracks. This is avoided due to expansive effect of the CaO and MgO based agent that provided space for formation of hydration products without leading to self desiccation.
5. The behaviour of the SCC mixes when subjected to the attack of chemical is significant and clearly shows the synergistic effect of expansive agents in improving the durability of the concrete though expansive agents are not that resistant to the attack of chemicals. This is due to their inherent chemical structure that easily susceptible to the reactions of acids and chlorides forms another compared.

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