Effects of Admixtures on the Self Compacting Concrete- State of the Art Report

S Christopher Gnanaraj¹, Ramesh Babu Chokkalingam², G Lizia Thankam³

¹Assistant Professor, Civil Engineering, KARE, virudhunagar, India
²Associate Professor and Head, KARE, virudhunagar, India
³Research Scholar, KARE, virudhunagar, India

E-mail: s.christophergnanaraj@klu.ac.in

Abstract. In concrete, many properties influence the strength parameters, among that most important parameter is proper compaction. Complete compaction is not possible using conventional concrete with hand compaction or machine vibration in structural element like long column and beam column joints. In these cases, self-compacting concrete (SCC) plays a vital role. It gives full compaction without any external effort. This type of concrete compacts by its own weight, another important advantage with SCC is the absence of segregation. Hence SCC usage has increased enormously in the last few decades. Having lot of merits SCC also has few demerits. One important demerit is that, to prepare SCC lot of cement content is needed compare to conventional concrete; this may increase the CO₂ emission also it leads to higher heat of hydration this may cause shrinkage cracks if adequate curing is not provided. This study is an attempt to review the influence of different types of mineral admixtures and chemical admixtures used in self compacting concrete along with a brief knowledge about the change in mechanical behaviour with respect to the influence of these admixtures.

1. Introduction

Concrete, being one of most extensively used construction material because of its durability and cost effectiveness, however, concrete structure has some demerits also like weak tensile force, emitting more amount of CO₂, optimum strength will not obtain if it is not fully compacted and properly cured. To overcome this issues lot of research taking place to enhance the specialty of concrete. One of such research ended up with a new innovation called SCC in which full compaction will be achieved without any external effect. SCC has high workability which makes it pump able and SCC have high resistance against segregation. Chemical admixtures such as super plasticizer and viscosity modifying agent enhances the workability of concrete by minimizing the segregation and bleeding in fresh concrete. The chemical admixtures also improves the pumpability of the freshly prepared concrete and thereby mitigating the water to cement ratio, which results in highly impermeable concrete paving way for the overall resistance[1]. Mineral admixtures like fly ash and silica fume improves the compressive strength and flexural strength [2]. The yielding stress of a concrete is elevated with silica fume up to 16%, where as the plastic viscosity decreases at the start (0% - 4%) and then increases with respect to increase in silica fume content up to 16%[3]. Mechanical properties of a concrete can also be increased with the series effects of silica fume and recycled steel fiber [4]. Addition of silica fume develops the strength, porosity, bound water of the
concrete specimen [5]. In SCC combined effect of fly ash and silica fume has high reduction in water absorption comparatively to that of SCC prepared with fly ash alone [6]. Rice husk ash as an alternative to cement also increase the mechanical behaviour of hardened concrete up to 15% replacement [7]. High degree of fine marble powder produces very good cohesiveness of concrete and Limestone powder enriches the mechanical as well as the durability parameters of concrete by exhibiting a good compact network [8]. Concrete mixture with more silica fume has smaller diameter of slump flow [9]. SCC mixes developed with bottom ash exhibits a minimal resistance to chloride permeability, abrasion resistance, water absorption and sorptivity at earlier age of concrete, however these properties decreases with increase in age and 30% rise in fly ash improved its flow properties [10]. The objective of this paper is to revels the effect of various chemical and mineral admixtures in the performance of the fresh and hardens concrete. In the production process of SCC Chemical admixtures has a vital role. The commonly used chemical admixtures are Polycarboxyle ether, synthetic copolymer, poly alcohol which technically know as super plasticizer, viscosity modifying agent, and anti-forming admixture respectively. These Chemical admixtures increase the workability of concrete and it also affect the strength parameter significantly. Classification of these admixtures, their physical and chemical parameters and the major effects with cement paste were been analysed in several studies [11,12]. Influence of these chemical admixtures increases the pump-ability, workability and resistance against segregation and bleeding and optimum compaction level. It also reduces the required water content, and air voids. This makes the concrete more impermeable, denser and durable [11].In the process of preparation of SCC we need to use more cement content which may cause high heat of hydration this may result in shrinkage cracks and high CO₂ emission. But by means of using mineral admixtures such as fly ash, GGBS, silica fume, Metakaolin may reduce these effects and also achieves more durable and denser concrete. Supposedly, the incorporation of metakaolin improves the penetration of chloride ions in the SCC specimens. When metakaolin is included as an alternative to cement content in different percentages, the mechanical properties such as the compressive strength and the tensile strength of the concrete specimens were noted to improve well at lower W/B ratio. Metakaolin tends to have better performance by means of splitting tensile strength. The absorption capacity of the control specimens were visualized to decrease with the addition of metakaolin. SCC is also developed with metakaolin by not including any viscosity modifying agent also [12,13]

2. Literature analysis

Erhan et al, 2015[14] in their experimental study detailed the fresh as well as the rheological behavior of the SCC when it is merged with nano silica and fly ash. Four different mixes with a w/c ratio of 0.3 and nano silica replaced with Portland cement at 0%, 2%, 4% and 6% to the weight of binder were formulated. Fly ash is incorporated for the 2%, 4% and 6% of nano silica containing self compacting concrete at 25%, 50% and 75% respectively to the weight of the total binder ratio. The incorporation of the nano silica in SCC is noted to enhance the slump flow and the V funnel flow at 25%, 50% and 75% also. Whereas for the L-Box test, the L-Box height ratio tend to increase with the fly ash content. The rheological tests for the same exposed the shear thickening of the self-compacting concrete by theaddition of the nano silica whereas the addition of the fly ash decreased the same. The fly ash content in SCC is also noted to decrease the mechanical properties of the SCC developed in this investigation

Benaicha et al,2015[15] experimentally studied the effects of silica fume and viscous modifying agents on the rheological and the mechanical behaviour of the SCC. In order to ascertain the rheological parameters slump test, L-box test, segregation test, V-Funnel test were conducted. In case of the mechanical properties, the compressive strength, tensile strength and modulus of elasticity were analysed. This study revealed the improvement in the plastic viscosity and the yield stress under a regulated condition of constant water/cement ratio along with the super plasticizer. In case of the mechanical properties, the SCC obtained with silica fume is noted to show better results than the SCC with VMA. Henceforth the paper concludes that based on the easy availability of a
material, the VMA or the silica fume can be chosen accordingly.

Divya et al, 2015[7] experimentally investigated the fresh concrete studies, mechanical properties and durability properties of SCC developed with replacement of the binder with 0%, 5%,10%,15% and 20 % of rice husk ash (RHA). A rise of 33% is noted in the compressive strength whereas the split tensile strength is noted to elevate up to 15% of replacement with RHA. Notable reduction is spotted in chloride ion permeability. Adequate non permeability is visualized for the SCC developed with 15% of RHA replacement. Porosity of the specimens considerably reduced with longer curing time owing to the higher percentage of rate of hydration with the longer concrete age. Henceforth a much denser concrete is obtained by 15% replacement of RHA which in turn developed the maximum compressive strength than all the other specimens casted.

Rahmat et al,2015[16] detailed the influence of nano silica and carbon nano fibers in the self compacting concrete. A combined study with fresh and hardened characterization along with the hardened concrete study is conducted in this study. The SCC thus developed in this study is continuously monitored for the first 24 hours to clearly observe the accurate characterization of the SCC. The carbon nano fiber in the cement paste elevated the flexural strength by 30% which also caused surface cracking. However maximum shrinkage is observed for an ultrasonic pulse velocity value between 1500-2000m/s. The nano silica in SCC notably improved the compressive strength also improved the early age cracking and thereby affecting the durability of the SCC developed too.

Mehmet et al, 2012[8] included the industrial waste materials such as marble powder, limestone powder and fly ash. In this experimental analysis, industrial waste materials were included in SCC replacing the total binding material at 5%, i10% and 20% by weight. Though the use of marble powder and lime stone powder tend to increase the water content, the addition of fly ash neutralized the same in turn achieving a target slump flow. Thus, the fillers elevated the percentage of super plasticizer in concrete and also increased the initial and final setting time of SCC. The 28 days compressive strength of the ternary mixes were comparatively lower than that of the binary mixes. And a much similar pattern is noted for the spit tensile strength of SCC also. Both binary and ternary mixtures developed lower chloride ion penetration properties.

Mostafa et al,2015[17] studied the influence of class F fly ash, nano silica and silica fume on the SCC with high performance. In this analysis, adequate fraction of these admixtures was replaced with the total cement content in SCC. The rheological properties, thermal properties, transport properties and the mechanical properties were detailed in this study. The fly ash content is noted to improve the rheological parameters whereas the silica nano particles and silica fume improved the transport as well as the mechanical properties. The larger portion of mineral admixtures blended with minimum fraction of the nano powders is a promising combination for a high performance self-compacting concrete.

Rahmat et al, 2012[11] predicted the fresh and hardened properties of SCC incorporated with metakaolin. A total of 15 mixes with MK content of 0%, 5%, 10%, 15% and 20% were developed by varying the w/c ratio as 0.32, 0.38 and 0.45. With no VMA, the various mixes showed up good workability and rheological properties. The compressive strength of the concrete specimens were noted to increase up to 27% upon the 14 days of curing. The compressive strength of the same were also predicted by multiple regression analysis in terms of ultrasonic pulse velocity. The tensile strength gained up to 11 % than the control specimen. Lower absorption is recorded in the SCC specimens with good electrical resistivity also. Altogether a SCC mix with 10% of metakaolin replacement is an ideal proportion for developing economically efficient concrete with better fresh and hardened concrete properties.

Beata et al, 2013[12] experimentally investigated the effects of chemical admixtures on the hydration of cement and mixture properties in SCC with very high performance. With few admixtures, micro cracking is developed whereas with the analyzed mixtures, the C-S-H gel showed improvement. The workability loss is visible according to the type of admixture that is chosen, but it does not affect the air content of very high-performance self -compacting concrete. The HRWR admixtures based cement pastes also developed bubble bridges that overtook any other
Rafat et al., 2013 [18] investigated the properties of SCC developed with coal bottom ash. Fine aggregate is replaced with 10%, 20% and 30% of coal bottom ash to investigate the fresh concrete properties such as slump flow, U-funnel test, L-box test, and J-ring test, along with the hardened concrete parameters such as abrasion resistance, compressive strength, chloride permeability and sorptivity. Betterment in compressive strength is observed at 28 days whereas the chloride permeability resistance decreases for 90 days and 365 days. A correlation between the abrasion resistance and the compressive strength is developed such that both are directly proportional, since the abrasion resistance highly influenced the compressive strength of the concrete.

Ha Thanh et al., 2016 [19] presented the influence of the super plasticizer and mineral admixtures (rice husk ash, silica fume and fly ash) on the self-compacting high-performance concrete in terms of the compressive strength of the mortar specimens. Expect the rice husk ash (RHA), both the fly ash and silica fume notably decreased the filling and passing ability along with a hike in resistance to segregation and plastic viscosity. The bleeding in concrete is observed to mitigate with the addition of the rice husk ash. Thus, the macro-mesoporous nature of the rice husk ash can also be used as viscous modifying agent to improve the robustness of high-performance self-compacting concrete (HPSCC) at higher super plasticizer dosages. The coarser particles in RHA with large specific surface area which thereby stipulated the attraction of the inter molecular forces and improved the compressive strength of the HPSCC. Therefore, a maximum compressive strength is visualized for SCC with 20% of fly ash and 20% of RHA.

Ali sadramontazi et al., 2016 [20] investigated the rheological, mechanical and durability characteristics of SCC developed with polyethylene terephthalate (iPET) particles combined with the pozzolanic materials (fly ash and silica fume). These PET particles in SCC minimized the mechanical properties such as compressive strength, tensile strength and flexural strength. To counterbalance the same, fly ash and silica fume were introduced into the mix. The lower specific gravity of these PET aggregates in concrete also reduced the density of concrete owing to the weak bonding between the PET aggregates and the cement paste. These parameters also reduced the ultra-sonic pulse velocity values due to the larger number of pores in the mix.

Wongkro et al., 2014 [21] studied the effects on the compressive strength and chloride resistance of the SCC developed with high volume fly ash (HVFA) and silica fume in binary blended cement and ternary blended cement. Both HVFA and silica fume were replaced with cement at various proportions each and the tests were conducted. The binary blended cement with HVFA is noted to reduce the mechanical property (compressive strength). In contrary to the binary blended cement, the ternary blended cement improved the compressive strength. Nevertheless, both fly ash and silica fume were noted to increase the chloride resistivity at higher levels.

Navid et al., 2016 [22] analysed the influence of industrial waste (palm oil fuel ash) from power plant of palm oil industry in the SCC due to its high pozzolanic characteristics and abundance as an industrial waste. This industrial waste is replaced with OPC at 10%, 15% and 20% to investigate the mechanical and durability properties of the SCC thus developed. Both the mechanical and durability properties were noted to improve due to the reduced amount of portlandite in the system leading to the production of the C-S-H gel thereby densification of the matrix. This phenomenon also mitigated the open pores by blocking the networks.

Badogiannis et al., 2015 [23] studied the effects of metakaolin on the durability properties of self-compacting concrete. The Portland composite cement and limestone powder of high fineness were replaced with high purity metakaolin. Four mixtures were developed to find the blending nature of metakaolin with cement thereby to study the enhancement of the packing density. And another four mixes replacing metakaolin with lime-stone powder at different percentages were obtained to procure the same results. These two categories were compared with another one control mix, thus developing a total of nine mixes in this study. Crushed calcareous lime-stone aggregate and polycarboxylic based super plasticizer is involved to develop SCC at a w/c ratio of 0.6. to produce SCC. Various durability study such as open porosity, sorptivity, near surface water
penetrability, Gas permeability and chloride penetrability were studied. Bases on the study the following conclusions were made. Slight improvement is found in open porosity percentage for both the replacement of cement with metakaolin and limestone powder with metakaolin. And the highest improvement is found at 14% replacement of cement with metakaolin and in limestone powder replacement as the metakaolin increases the results were getting reduced. In Sorptivity when higher order replacement metakaolin to cement and limestone powder the sorptivity value getting reduced. And the improvement in results were in between 6% to 41% for cement replaced by metakaolin and for limestone powder replaced by metakaolin the improvement was found to be in between 22% to 53%. In water permeability test as the metakaolin replacement level increase instead of cement the water permeability decreases. And for limestone powder replacement with metakaolin as the metakaolin percentage increases water permeability got reduced to some extent further increase it starts increasing the permeability value. Regarding Gas permeability slight improvement is found in both the replacement of cement with metakaolin and limestone powder with metakaolin. And the maximum reduction of 34% is obtained in higher order replacement level of cement with metakaolin. Whereas for chloride penetrability test it is found that in higher order replacement of metakaolin with cement and limestone powder resistance to chloride penetrability increases and the best results as obtained for higher order replacement of limestone powder with metakaolin.

3. Conclusions
Based on the analysis of the literatures, it is clearly evident that both chemical and mineral admixtures play a key role in the betterment of the self-compacting concrete in the following parameters.

- When silica fume is included in SCC it improved the compressive strength of the concrete whereas the workability is also noted to improve when silica fume is included in SCC along with fly ash.
- Fly ash in SCC decreased the compressive strength of the concrete, whereas fly ash along with silica fume and PET particles improved the compressive strength to a greater extend.
- The nano silica and nano fly ash in contrary to the fly ash and silica fume highly improved the compressive strength of SCC by densifying the pore structure. But the nano silica and nano fly ash reduced the workability owing to the finer nature of these mineral admixtures.
- The incorporation of admixtures such as marble powder and lime stone powder increased the water content in the concrete mix thus affecting the rheological properties of the SCC.
- The addition of mineral admixture like rice husk ash improved the mechanical properties of the SCC up to 15% of replacement with ordinary Portland cement. However the same exhibited low chloride ion resistance and developed to be a highly flowable matrix.
- The carbon nano fibers in SCC developed surface cracks along with improved mechanical properties in concrete.
- Metakaolin with SCC considerably improved the mechanical properties up to a certain percentage of replacement and also decreased the absorption of the concrete specimens. It also highly improved the durability of SCC when it is included along with lime stone powder.
- The palm oil fuel ash, a natural mineral admixture highly improved the mechanical properties as well as the durability properties of the SCC when included at adequate level.
- Coal bottom ash, an industrial by-product elevated the compressive strength of the SCC specimens. But it tends to decrease the chloride ion resistance in the SCC.
- Chemical admixtures like HRWR admixtures behaved better with the SCC by improving the C-S-H gel comparatively than the mineral admixtures in SCC.
References

[1] H A F Dehwah 2012 Corrosion resistance of self compacting concrete incorporating quarry dust powder, silica fume and fly ash Construction and building materials 37 227-282.

[2] Ahmet Benli, Mehmet Karatas, Yakup Bakir 2017 An experimental study of different curing regimes on the mechanical properties and sorptivity of self-compacting mortars with fly ash and silica fume Construction and Building Materials 144 552–562.

[3] Cai Tuo Lu, Hu Yang, Guoxing Mei 2015 Relationship between slump flow and rheological properties of self compacting concrete with silica fume and its permeability Construction and Building Materials 75 157–162.

[4] M Mastali, A Dalvand 2016 Use of silica fume and recycled steel fibers in self-compacting concrete(SCC) Construcion and Building Materials 125 196–209.

[5] G Vagelis, Papadikisa 1999 Experimental investigation and theoretical modeling of silica fume activity in concrete Construction and building materials 29 79-86.

[6] H Y leung, J Kim, A Nadeem, Jaya prakashgananthan, M P Anwar Sorptivity of self compacting concrete containing flyash and silica fume Construction and building materials 113 369-375

[7] Divya Chopra, Rafat Siddique and Kunal 2015 Strength, permeability and microstructure of self-compacting concrete containing rice husk ash Bio systems Engineering Volume 130 Pages 72-80.

[8] Mehmet Gesoglu, Erhan Guneyisi, Mustafa E Kocabag, Veyesel Bayram and Kasim Mermerdas 2012 Fresh and hardened characteristics of self compacting concretes made with combined use of marble powder, limestone filler, and fly ash Construction and Building Materials 37 Pages 160-170.

[9] Aleksandra Kostzanowska-Siedlarz, Jacek Golaszewski 2015 Rheological properties and the air content in fresh concrete for self compacting high performance concrete Construction and Building Materials Volume 94 30 Pages 555-564.

[10] Rafat Siddique 2013 Compressive strength, water absorption, sorptivity, abrasion resistance and permeability of self compacting concrete containing coal bottom ash Construction and Building Materials, Volume 47 Pages 1444-1450.

[11] Rahmat Madanous, S Yasimrousavi 2012 Fresh and hardened properties of self compacting concrete containing Metakolin Construction and Building Materials Volume 35 Pages 752-760

[12] Beata lazniwska Piekarczy 2013 The influence of chemical admixtures on cement hydration and mixture properties of very high performance self compacting concrete Construction and Building Materials Volume 49 Pages 643–662.

[13] Nocun, Waszelik W, Trybalska B 2007 Effect of admixtures on the rate of hydration and microstructure of cement paste Cement WapnoBeton p. 284–9.

[14] Guneyisi, Erhan, Mehmet Gesoglu, Asraa Al-Goody and Suleymanpek 2015 Fresh and rheological behavior of nano-silica and fly ash blended self-compacting concrete Construction and Building Materials 95 29-44.

[15] Benacha, Mouhine, Xavier Roguez, Olivier Jalbaut, Yves Burtsschell and Adil Hafidi Alaoui 2015 Influence of silica fume and viscosity modifying agent on the mechanical and rheological behavior of self compacting concrete Construction and Building Materials 84 103-110.

[16] Rahmat Madandoust, Malek Mohammad Ranbar, Reza Ghavidel and S Fatemeh Shahabi 2015 Assessment of factors influencing mechanical properties of steel fiber reinforced self-compacting concrete Materials & Design Volume 83 Pages 284-294.

[17] Mostafa Jalal, Ali Reza Fouladkhah, Omid Fasahi Harandi and Davoud Jafari 2015 Comparative study on effects of class F fly ash, nano silica and silica fume on properties of high performance self compacting concrete Volume 94 Pages 90-104.

[18] Siddique, Rafat 2013 Compressive strength, water absorption, sorptivity, abrasion resistance and permeability of self-compacting concrete containing coal bottom ash Construction and Building Materials 47 1444-1450.

[19] Le, Ha Thanh and Horst-Michael Ludwig 2016 Effect of rice husk ash and other mineral admixtures on properties of self-compacting high performance concrete Materials & Design 89 156–166.

[20] Sadrmontazi, Ali, Sahel Dolati-Milehsara, Omid Lotfi-Orman and Aref Sadeghi-Nik 2016 The combined effects of waste Polyethylene Terephthalate (PET) particles and pozzolanic materials on the properties of self-compacting concrete Journal of Cleaner Production 112 2363-2373.

[21] Wongkeo, Watcharapong, Pailyn Thongsamitgorn, Athipong Ngamjarurojana and Arnon Chaipanich 2014 Compressive strength and chloride resistance of self-compacting concrete containing high level fly ash and silica fume Materials & Design 64 261-269.

[22] Ranjar, Navid, Arash Behnia, Belal Alsabari, Payam Moradi Birgani and Mohd Zamin Jumaa 2016 Durability and mechanical properties of self-compacting concrete incorporating palm oil fuel ash Journal of Cleaner Production 112 723-730.

[23] Badogiannis, Efstratios G, Ioannis P Sfikas, Dimitra V Voukia, Konstantinos G Trezos and Sotirios G Tsivilis 2015 Durability of metakaolin self-compacting concrete Construction and Building Materials 82 133-141.