Effect of Silica Fume and Super-Plasticizer on Mechanical Properties of Self-Compacting Concrete: A Review

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Abstract. Self-compacting concrete (SCC) is among the high-performance and modern concretes in the concrete industry. The inclusion of chemical and mineral admixtures and other aggregates causes better workability, flow ability, better compressive strength and high resistance to segregation. Silica fume (SF) is a mineral admixture which improves mechanical properties and reduced permeability. Secondly, the super-plasticizer (SP) is a chemical admixture and used for water-reducing, increase cohesiveness, improve passing and filling ability of SCC. However, SF affecting the physical properties of SCC if added in excess quantity in cement. Furthermore, the substitution of SP causes to deliver a negative surface charge on the concrete particles which in turns to result in electrostatic repulsion. Moreover, the higher quantity addition of both SF and SP will badly affect the fresh and hardened properties of SCC. Thus, an ample review was conducted to study the influence of SF and SP on the fresh and hardened properties of SCC. More than 50 previous research articles have been reviewed systematically to argue on the fresh ad hardened properties of SCC. Based on the reviewed literature, the conclusion has been drawn some future recommendations have been achieved related to the title of the research.

Keywords: Self-compacting concrete; Silica Fume; Super-plasticizer; Fresh properties; Hardened properties.

1. Introduction

SCC was firstly introduced in Japan in the 1980's decade as a means of producing a regular quality of concrete and to address any problem caused by poor labor. Moreover, the list of problems such as intricate designs, the density of reinforcing steel in the structural members, reducing the numbers of skilled labor, the rapid growth of construction industry and quality of construction necessitated introducing SCC to overcome these problems. Japanese researchers 1986 at the University of Tokyo firstly produced SCC and Ozawa et al., (1989) and his research team from the University of Tokyo presented the first model of SCC in 1989. During the 1990's decade and further than that, the
knowledge and application of SCC increased. The main advantage of the application of SCC is its capability of flowing to those portions of the mold where compaction cannot be applied, especially, congested reinforcement areas and this makes it more advantageous than traditional concrete (Aslani et al. 2018). Other lists of advantages include flow and compact under its own weight (Bogas et al. 2012), completely filling out mold by preserving homogeneity (Salman, 2018), the high degree of fluidity (Abdul and Khushpreet, 2018), highly cost-effective (Alvayacam et al. 2017) and productivity improvement will be offset by reduced labor and non-use of vibrators (Nehdi, M. and Rahman, 2004). Furthermore, due to no-use of vibrators; SCC is environmentally friendly as it eliminates the vibration noise. Also due to better passing and filling ability; SCC provides more design flexibility and increases productivity (Beigi et al. 2013).

Many authors and international standard organizations define SCC in their own way: according to American Concrete Institute (ACI) 237 (2007), it is a concrete type which does not need to be compacted when placed in the mold because of its flowability and spread due to its own weight and fill the mold completely even in the case of reinforcing high-density steel, the resulting concrete after hardening is homogenous, high durability, and possessed engineering properties similar to normal concrete. Whereas, the definition of SCC according to British Standard European Norm (BS EN) 206-9 (2010) is that the concrete which has self-flowability and compatibility because of its own weight, filling mold completely along with the reinforcements materials whilst preserving homogeneity. Rabar et al. (2020) define that SCC is a concrete which can flow easily in different sections of mold due to its own weight and created a significant consolidation within the directed shape of the mold, it does not require any external vibration and provides defect fewer parts due to no-bleeding or segregation (Abulkader et al. 2016; Al-Hadithia et al. 2019 and Mahmoud et al. 2019). And to achieve full compaction, SCC should have better cohesion and high flowing and passing ability and cohesive (Djelal, et al. 2004). However, the inclusion of viscosity modifying admixtures (VMA) provides resistance to segregation cohesiveness, while the addition of SP can increase the passing and flowing ability of SCC (Han and Yao, 2004).

Furthermore, the inclusion of SF, limestone (LS) and fly ash (FA) results improvement in stability and workability of SCC (Felekoglu et al. 2006 and Sahmaran et al. 2006). Though the addition of these materials in SCC will enhance durability and compressive strength, still SCC will fail in brittle mode (Deilami et al. 2019). Thus, the selection of these materials that mix and or reinforce with the design of SCC requires high accuracy because they are characterized by a high degree of fluidity and must reduce viscosity. And such can achieve by employing chemical (super-plasticizer SP) and mineral admixtures (silica fume SF) (Mahmoud, 2002). Most researchers have confirmed that the use of chemical and mineral admixtures gives better fresh and hardened of the concrete (Al-Hadithia and Hilal, 2016; Al-Hadithia et al. 2019; Mahmoud et al. 2019 and Rabar et al. 2020). SP inclusion reduced the use of water up to 30% without decreasing the workability of SCC which in turn increase productivity, flowing ability, self-leveling, self-compaction, higher performance and strength of the concrete. Furthermore, the addition of SP can improve the specific gravity, fresh and hardened properties of concrete when it added to concrete paste during mixing process. Generally, SP is classified as high-range water-reducing admixture (HRWRA) which produced self-compaction in concrete and produced high compressive strength up to 150 N/mm2 (ASTM C494/C494M, 2004), also affects the fresh concrete positively, such as increasing slump without adding a quantity of water, reducing the proportion of water to cement, improved workability and thus easy pumping for concrete (ACI–Committee 212, 2007). Whereas, SF can affect the different concrete properties of concrete like “setting time characteristics”, “water requirement for specified consistency”, “improve workability including cohesiveness and bleeding”, etc (Vivek and G. Dhinakaran, 2015). Additionally, the bleeding in fresh concrete can be stopped physically with the addition of SF, however, its appropriate addition may not change the unit weight of the concrete (Mohammadi et al. 2015). Nonetheless, the production of the SCC test depends on “trial and error” method, thus, finding optimal proportions of these components of the concrete mix, including mineral and chemical admixtures is important so as to reduce the experiments, cost, time and effort.

Therefore, in this research, the effort for an ample review has been made to emphasize the latest
research on the assessment of using SF and SP in the production of SCC. Furthermore, in this ample review work, the latest previous research until 2019 was reviewed on the use of SF and SP for SCC production. In contrast to argued different properties of concrete, this review work was focused on the influence of addition SF and SP on the fresh properties and compressive strength of SCC. At the end of this ample review work, future recommendations were also drawn related to the title of the research.

2. Mineral Admixtures

The addition of mineral admixtures in SCC production decreases the proportion of use of cement in the concrete mix and can save the cost of cement. And their inclusion also decreases the heat resulting from the chemical reactions during the mixing process. The mineral admixtures like “SF”, “FA”, “blast furnace slag (BS)” and “metakaolin (MT)” improve the concrete porous structure and by that can thus increase durability. Most of the materials used are in a powder form that exceeds the thickness of the pozzolan cement, thus affecting the physical properties of the soft cement paste in a similar cement style. These admixtures are used in any type of concrete. Keeping such facts, in this research, the mineral admixture: SF was considered for arguing its impact on fresh and hardened properties of SCC.

2.1 Silica Fume (SF)

The first practice of using silica fume in Portland cement was in 1952. Afterward, SF was used in concrete in 1971 at Fisko metallurgical plant in Norway and in 1978, the standard of using SF in concrete was adopted by Norway’s government. Later, in 1981, the use of SF in concrete was approved by the Canada government also and then the practice was continued in other countries (Stanislav et al. 2017). SF is usually characterized as supplementary cementitious material and exhibited pozzolanic and cementitious properties. The other common names such as condensed SF, micro SF ad volatilized SF are frequently referred for SF. SF is a by-product of “ferro-silicon alloys” or only “silicon metal” produced through the smelting method by electric arc furnaces as shown in Figure 1 (Terence, 2005).

![Figure 1. Silica fume production (Terence, 2005)](image)

Among other applications of SF, it has a more prominent application in the construction industry for manufacturing better quality concrete. The primary chemical and physical properties of SF are show in Tables 1. It is commonly available in gray colored powder and somehow resembles Portland cement as shown in Figure 2 (Terence, 2005).
Table 1. chemical and physical properties of SF (Terence, 2005)

| Chemical Properties of SF | Physical Properties of SF | Value                          |
|---------------------------|---------------------------|-------------------------------|
| Silicon dioxide > 85%    | Particle size (typical)   | < 1μm                         |
| Amorphous                 | Specific gravity          | 2.2                           |
| Trace elements depending upon type of fume | Bulk density (As-produced) | 130 to 430 kg/m³              |
|                           | Bulk density (Densified)  | 480 to 720 kg/m³              |
|                           | Specific surface          | 15000 to 30000 kg/m²          |

There is a list of important characteristics of SF which make it right choice to use and mix in concrete mixes such as the fine spherical granules of (0.1-0.2microns) which are 100 times smaller than the granules of normal Portland cement (ACI 116R-8, 1985). The fine spherical granules of SF have an average diameter of 0.1 μm as shown in Figure 3.

Therefore, they fill the gaps between the cement blocks of Portland cement, filling the sand spaces between the granules of coarse aggregate and SF granules, the spherical shape of SF particles increases the impact of slipping in cement, increasing the physical effect of SF on concrete to produce dense and cohesive concrete. SF is non-crystallized and due to that, they increase the reactivity with normal Portland cement. However, such effects are compounded because of the low specific gravity of SF which increases the size of the cement sample to reduce voids and areas of weakness, such as drainage channels and inter-transition zone (ITZ). Because of these distinct characteristics of SF, the pozzolanic reaction often begins within 24 hours, producing large amounts of secondary water calcium silicate and significantly improving the concrete microscopic structure at weak vicinity (ITZ) area. The use of SF in concrete decreases the pool of bleeding water under aggregates of iron bars, which reduces the porosity of the transition area and consequently increases the compressive and bond strengths, and corrosion resistance in reinforcing steel.
SF significantly affect the fresh properties of concrete and can resulted more cohesive and less or no bleeding (segregation) on the fresh concrete as shown in Figure 4 (Terence, 2005). The concrete with SF is less prone to segregation than concrete without SF. And such higher cohesion of SF in fresh concrete has typically resulted to increase 40-50 mm more slump than the concrete without SF in the same placement (Terence, 2005).

Figure 4. Effects of silica fume on fresh concrete (Terence, 2005)

While the effect of SF on hardened concrete, there are also two main positive impacts such as better mechanical properties and reduce permeability (enhance durability) as shown in Figure 5 (Terence, 2005). The enhancement in mechanical properties such as compressive and flexural strengths, and modulus of elasticity. Though the concrete with SF could improve other mechanical properties, the most important focus is of concrete compressive strength in the construction industry. Furthermore, the durability is directly corresponded with the concrete permeability. The reduction in permeability resulted to extend the time for any chemical (aggressive chemical) to proper mix to the concrete and can damaged permeability as shown in Figure 6 (Terence, 2005).

Figure 5. Effects of silica fume on hardened concrete (Terence, 2005)
The influence of adding SF on fresh and hardened properties of concrete is explained in detail following previously published research work. However, all the previous research work was reviewed systematically.

2.2 Influence of Silica Fume on Fresh and Hardened Properties.

Mehmet Gesoglu et al. (2009) conducted experimental investigation of SCC properties with mineral additives. Twenty-two concrete mixes were designed, the ratio of water to powders was fixed at 0.44 and the percentage of powders in the main mix was fixed at 450 kg / m³. The main mix contains Portland cement only and the cement ratio used for all mixes was ranged from 180 to 450 kg /m³, and SF was used by 5%, 10% and 15% of cement weight of 22.5, 45 and 67.5 kg / m³ respectively with SP 4.9, 5.2 and 7.8 kg / m³ respectively. The results showed the tests slump flow time, slump flow diameter, V-funnel flow time, and L-box height ratio for mixes containing SF by 5%, 10%, and 15% were 5, 4 and 4 seconds, 67, 68 and 69.5 cm, 10, 10 and 10 seconds, and 0.732, 0.824, 0.918 respectively. Whereas for the control mix; slump flow time, slump flow diameter, V-funnel flow time, and L-box height ratio were 1 second, 67 cm, 3.2 second, and 0.706 respectively. The replacement of SF in all mixes resulted more viscous than the control mix but within the EFNARC specifications [18]. The mechanical test results for the control mix and 5%, 10% and 15% of SF mixes were 73.6 MPa and 71.2, 76.1 and 74.8 MPa respectively.

Heba, (2011) used three kinds of mixes to experimentally investigate the properties of SCC. The first mix have different FA ratios, second have different percentages of SF and third mix was combined of FA and SF. Total 9 specimens (cylinder) were created for each kind mix, three of them were cured for 28 days in water, another three were cured for 7 days in water, while the remaining three were left in air for 28 days. The mixture proportions for cement used in their research are shown in Table 2. The results of SCC fresh properties revealed that increasing the ratio of “SF” and “FA” resulted in improvement in passing and filling ability together with segregation resistance. The replacement of cement with 15% of SF results higher compressive strength than replacing cement by 30% of FA for 550 kg/m³ and 450 kg/m³ cement content as 12% and 10% respectively.

| Table 2. Mix proportions (Heba, 2011) |
|--------------------------------------|
| Cement (Kg/m³) | 450 |
| F-agg (Kg/m³) | 1109 |
| C-agg (Kg/m³) | 612 |
| Water (Kg/m³) | 189 |
| Water-to-cement ratio | 0.42 |
Dehwah, (2012) conducted experimental investigation on SCC and produced 15 SCC specimens. All the 15 SCC specimen were trial tested for V-flow, slump flow, L-box flow, and U-box flow and tests. Only five mixes out of these 15 mixes meet the general requirement flow criteria and accepted for further evaluation. All these five mixes have water to cement and powder ratio as: (M1): “w/cm ratio of 0.40” and “8% QDP (quarry dust powder)”, (M2): “w/cm ratio of 0.38 and 8% QDP”, (M3): “w/cm ratio of 0.4 and 10% QDP”, (M4): “w/cm ratio of 0.40 and 8% QDP” plus “5% of SF” and (M5): “w/cm ratio of 0.40” and “30% FA”. Moreover, all these five mixes have cement quantity of 400 kg/m³. Results revealed that M2 and M3 have the maximum compressive strength and was more than that of M1, M4, and M5. However, M5 had the lowest compressive strength. The compressive strength of “62.7”, “70.1”, “65”, “64.4”, and “52.1” MPa were obtained for M1, M2, M3, M4, and M5 specimens respectively for curing at 28-days and were “64.8”, “79.0”, “70.7”, “68.5”, and “56.1” MPa respectively for curing at 90-days curing. The flexural strength results for “M1”, “M2”, “M3”, “M4”, and “M5” were 6.6, 6.9, 6.7, 6.6, and 5.2 MPa respectively for curing at 28-days age. And split tensile strength was 5.5, 6.5, 6.4, 5.8, and 4.9 MPa for M1, M2, M3, M4, and M5 respectively for curing at 28-days age.

Ali (2012) conducted experimental research on polymer-modified SCC (PMSCC). A total of 12 concrete mixes were used and cured for 90 days for evaluation and compared with traditional concrete and SCC. The SF and limestone (LS) were used as fillers and SP such as naphthalene and modified polycarboxylic were used to increase the flow properties. Polynvinyl acetate (PVA) and styrene-butadiene rubber (SBR) were used in different dosage from 0%, 5%, 10%, and 15%. The mixture design used in this research is shown in Table 3. The results revealed that PVC has a significant effect on compressive strength when curing at an early age and later increase as 27.3% and 23.3% when curing at 90-days for PMSCC with 5.0% and 10.0% of PVC respectively as compared with traditional SCC. And the effect of mineral additives on all concrete mixes showed that the LS gave a higher compressive strength with concrete than SF at the same age. Furthermore, higher compressive strength for modified polycarboxylic for both traditional SCC and concrete was obtained when used naphthalene. The use of 10% of SBR with SP has little effect at different referred ages. The tensile strength and modulus of elasticity for PMSCC were higher than the traditional SCC at different ages. LS powder and chemical admixture based on naphthalene usually have a progressive effect on tensile strength and the use of naphthalene caused higher tensile strength than with modified polycarboxylic. While the use of LS powder (as a filler) provides a higher dynamic modulus of elasticity compared for concrete mixes with SF. Thus, it can be determined that the partial replacement of cement with fine materials reduces the segregation process in SCC and the use of mineral additives with SCC gives satisfactory results.

Table 3. Description of concrete mixes Ali (2012)

| Cement | Water | C/F- agg | Filler | Polymer | Plasticizer | Characterize | Filler Type | Polymer Type | Plasticizer /C% | Polymer /C% |
|--------|-------|----------|--------|---------|-------------|--------------|-------------|--------------|----------------|-------------|
| 400    | 180   | 875      | -      | -       | 2           | TC           | -           | -            | MPCE          | 0.45        |
| 400    | 180   | 855      | 40     | -       | 13.6        | TSCC         | SF          | -            | MPCE          | 0.41        |
| 400    | 180   | 845      | 40     | 20      | 9.1         | PSCC         | SF          | SBR          | MPCE          | 0.43        |
| 400    | 180   | 825      | 40     | 40      | 5.8         | PSCC         | SF          | SBR          | MPCE          | 0.45        |
| 400    | 180   | 820      | 40     | 60      | 5.5         | PSCC         | SF          | SBR          | MPCE          | 0.48        |
| 400    | 180   | 840      | 40     | 20      | 10.6        | PSCC         | SF          | PVA          | MPCE          | 0.43        |
| 400    | 180   | 825      | 40     | 40      | 8           | PSCC         | SF          | PVA          | MPCE          | 0.45        |
| 400    | 180   | 855      | 40     | -       | 13          | TSCC         | LP          | -            | MPCE          | 0.41        |
| 400    | 180   | 825      | 40     | 40      | 10          | PSCC         | LP          | SBR          | MPCE          | 0.45        |
| 400    | 180   | 875      | -      | -       | 2           | TC           | SF          | -            | NAPH          | 0.45        |
| 400    | 180   | 855      | 40     | -       | 15          | TSCC         | SF          | -            | NAPH          | 0.41        |
| 400    | 180   | 820      | 40     | 40      | 12          | PSCC         | SF          | SBR          | NAPH          | 0.45        |
Anhad, (2012) carried out an experimental study to SCC, 7 concrete mixing mixes were designed, the control mix contains only the concrete cement without the powders. The remaining mixes contain different proportions of powders. The cement ratio used for all mixes ranges from 467 to 550 kg / m³. SF was used by 5%, 10% and 15% of the weight of cement 28, 55 and 83 respectively and 1.8% of SP was used for manufacturing SCC. The mixture design is shown in Table 4. Fresh tests showed that slump flow, V-funnel flow time, and L-box height ratio for mixes containing 5%, 10% and 15% of SF were 610, 660, 685 mm, 0.9, 0.9 and 0.9 and 11, 10 and 8 seconds respectively. The control mix slump flow, V-funnel flow time, and L-box height ratio were 585 mm, 0.9 and 11 seconds respectively. This means that the control mix and mix containing 5% of SF is not within the required limits for slump flow only, while the remaining mixes are within the required limits and for all tests. The compressive strength results with the water-to-powder ratio of 0.48 were 38.7, 43.5 and 39.3 MPa for 5%, 10%, and 15% respectively for 28 days curing age and were higher than the control mix (31.7 MPa). These results indicated that 15% of SF can be used for possible design SCC mixes.

Table 4. Mix proportions Anhad, (2012)

| Mix   | Cement (Kg/m³) | MK (Kg/m³) | SF (Kg/m³) | C-agg (Kg/m³) | F-agg (Kg/m³) | Water (Kg/m³) | W/P | SP (Kg/m³) |
|-------|----------------|------------|------------|---------------|---------------|---------------|-----|------------|
| Control | 550         | 0          | 0          | 590           | 910           | 265           | 0.48| 9.91       |
| 5% SF  | 522         | 28         | 0          | 590           | 910           | 265           | 0.48| 9.91       |
| 10% SF | 495         | 55         | 0          | 590           | 910           | 265           | 0.48| 9.91       |
| 15% SF | 467         | 83         | 0          | 590           | 910           | 265           | 0.48| 9.91       |
| 5% MK  | 522         | 28         | 0          | 590           | 910           | 265           | 0.48| 9.91       |
| 10% MK | 495         | 55         | 0          | 590           | 910           | 265           | 0.48| 9.91       |
| 15% MK | 467         | 83         | 0          | 590           | 910           | 265           | 0.48| 9.91       |

E. Güneyisi et al. (2012) conducted an experimental investigation of fresh properties of SCC mixed with SF and FA. Total nine mixtures were designed having “water to binder ratio” of “0.35” and total binder of 550 kg/m³ was used. The results revealed that V-funnel time and slump flow time decreased, and L-Box ratio was improved significantly with the addition of SF and FA together.

Kennouche et al. (2013) produced SCC by using locally available materials to demonstrate the influence of SF on the concrete rheological behavior. The SF was replaced with 15% of cement. Two types of Portland cement and SP were used. Table 5 shows the mixture design. The results showed that the diameter of the spread obtained from 650-750mm, L-box test was easy traffic and flow without obstruction and isolation due to high liquidity o account of using SP. The minimum compressive strength was 20 MPa when curing at an age of 7-days and the highest is 40.93 MPa when curing at an age of 28-days.

Table 5. Quantity (kg) of the components in each formulation (Kennouche et al. (2013))

| Mode Code | Cement (Kg/m³) | SF (Kg/m³) | Aggregate 3/8mm | Aggregate 8/15mm | C-Sand (Kg/m³) | F-Sand (Kg/m³) | Water (Kg/m³) | Super-plastizer (Kg/m³) |
|-----------|----------------|------------|----------------|-----------------|----------------|----------------|---------------|------------------------|
| F1        | 400            | 60         | 533.14         | 265.04          | 582.92         | 243.78         | 193.2         | 7.2                    |
| F2        | 400            | 60         | 534.27         | 264             | 582.41         | 241.66         | 193.2         | 8                     |
| F3        | 400            | 60         | 534.08         | 264.99          | 584.64         | 242.55         | 193           | 6                     |
| F4        | 400            | 60         | 534.27         | 264             | 243.69         | 241.46         | 193.1         | 8                     |

Fareed, et al. (2013) conducted experimental investigation on SCGC and produced a total 4-mixture specimen with a geopolymer and SF addition. 3-mixes were prepared with different percentages of SF (5, 10 and 15%) and 1-without SF (control mix). FA was replaced with SF, the total powder content was fixed at 400 kg/m3 and the “water to geo-polymer solids (W/Gs) ratio” was maintained at “0.33” for all the mixes. 12% of water and 6% of SP by mass for binders were used to attain the desired workability characteristics of SCC. Table 6 shows the mixture design. The workability-related fresh and hardened properties of SCGC were assessed at age of “1”, “7”, and “28” days after curing 48-h in oven. The results of fresh properties indicated that the partial replacement of FA with SF in SCGC provides loss of workability and revealed poor results than the control mix. However, the values of fresh properties of all mixes were within EFNARC specifications (2002) except for the mix contain
15% of SF. The compressive strength values for SCGC were 53.38, 55.02, and 53.96 MPa for 5, 10 and 15% of SF respectively, all these values were higher than the compressive strength (51.43 MPa) for mix without SF (control mix) at all curing age. The compressive strength values indicated that 10% of SF in SCGC is the optimum percentage. The same trend was also observed for flexural strength; the maximum value achieved at 10% of SF. Thus the overall conclusion from their research is to replace SF with FA should be maximum up to 10% for producing better SCGC.

Karthikeyan et al. (2013) carried out and an experimental study on SCC with the inclusion of two mineral admixtures such as SF (2.5, 5, 7.5 and 10%) and FA (5, 10 and 15%) by weight of cementitious material with a reference mix design (without mineral additives). While reducing the “water to powder ratio” as 0.36 l/m3 and with SP at 0.013 l/m3. Total 8-SCC mixes were designed according to the required requirements (EFNARC, 2002) as shown in Table 7. The results of fresh properties indicated that all the mixes were within the specified specifications, except the slump flow for the mix containing the 10% SF. The compressive strengths were 62.48, 64.85, 64.95 and 65.60 MPa for 2.5, 5, 7.5 and 10% of SF respectively and 62.20, 63.40 and 63.90 MPa for 5, 10 and 15% of FA respectively, while the reference mix has 61.79 MPa. As based on these compressive strength values, 10% of SF mixture provides the highest values and concluded for the optimum percentage of SF in their research. However, at 10% of SF mixture, flowing, filling and passing ability decreased.

Table 6. Mix proportions Fareed, et al. (2013)

| Mix | FA (Kg/m³) | SF (Kg/m³) | C-agg (Kg/m³) | F-agg (Kg/m³) | Sodium hydroxide (Kg/m³) | Sodium silicate (Kg/m³) | Water to geo-polymer solids (W/Gs) ratio | SP/ wt % | Extra water/ wt % | Oven treatment Time/h | Temperatur e/°C |
|-----|------------|------------|---------------|---------------|--------------------------|------------------------|---------------------------------------|--------|-----------------|-------------------|-----------------|
| M1  | 400        | 0          | 950           | 850           | 57                       | 10                     | 143                                   | 0.33   | 6               | 12                | 48              | 70               |
| M2  | 380        | 20         | 950           | 850           | 57                       | 10                     | 143                                   | 0.33   | 6               | 12                | 48              | 70               |
| M3  | 360        | 40         | 950           | 850           | 57                       | 10                     | 143                                   | 0.33   | 6               | 12                | 48              | 70               |
| M4  | 340        | 60         | 950           | 850           | 57                       | 10                     | 143                                   | 0.33   | 6               | 12                | 48              | 70               |

Salem Alsanusi, (2013) conducted experimental investigation on SCC and nine concrete mixes were produced with different percentages of SF as 3, 6, 9% and “water to powder ratio” were 0.3, 0.34 and 0.37 for each percentage of SF. The results indicated that the “slump flow”, “slump flow T50 cm”, “U-Box”, “L-box height ratio”, “V-funnel flow time” and “slump flow with J-Ring” for all mixes with water to powders 0.34 were “530, 660 and 550 mm”, “2, 3 and 3 seconds”, “0.76, 0.9, 0.95”, “0.78, 0.87, 0.87”, “11, 5 and 8 seconds” and “510, 510 and 520 mm” respectively and were optimum for the “water-to-powder ratio” of “0.34”. Also, the compressive strength for mixes with the “water-to-powder ratio” of “0.34” was 36.84, 47.63 and 46.18 MPa for each percentage of SF respectively and these values of compressive strength were optimum as compared to other water to powder ratio. Moreover, on these results basis, 6% of SF was concluded as the optimum percentage.
Ramanathan et al. (2013) conducted experimental investigation on SCC and produced 9-specimen and 1-control mix. Portland cement was replaced with 30%, 40% and 50% of mineral admixture (SF), the “water/powder mass ratio” was considered as 0.35. The total powder content was added with different quantity as “400 kg/m3”, “450 kg/m3”, “500 kg/m3” for iteration trials and finally, 500 kg/m3 was fixed. All concrete mixes showed slump flows and V funnel tests value obtained through experimental investigation were within European standards (2005). Concerning mechanical results; 30% of SF showed the best performance when curing at 7 and 28-days age.

Vivek et al. (2015) produced 4-SCC mixes by replacing cement with various percentages of SF from “5% to 20%”. The SP (Conplast SP430) at the optimal dose equal to (1%) and the “water-to-binder ratio (w/b) ratio” of “0.8” was used for producing SCC mixes. The design mixture used in their research is shown in Table 8. The better fresh properties were achieved at replacing the cement with 15% of the SF, while the highest compressive strength was achieved at the replacement of cement by 5% of SF at 7 and 14 days curing age.

Table 8. Materials required of SCC (Vivek et al. 2015).

| Materials  | SF5 | SF10 | SF15 | SF20 |
|------------|-----|------|------|------|
| Cement (Kg/m³) | 4.75 | 4.5  | 4.25 | 4    |
| Water (Litrs)     | 4   | 4    | 4    | 4    |
| W/P              | 0.8 | 0.8  | 0.8  | 0.8  |
| SF (Kg/m³)       | 0.25 | 0.5  | 0.75 | 1    |
| C-agg (Kg/m³)    | 8.2 | 8.2  | 8.2  | 8.2  |
| F-agg (Kg/m³)    | 10  | 10   | 10   | 10   |
| HRWR (%Kg/m³)    | 1   | 1    | 1    | 1    |

Mehrdad, et al. (2015) conducted experimental investigation on SCC and produced a total of 14-SCC mixes containing a high volume of LS, SF, zeolite (ZL), metakaolin (MT), and VMA. The results showed that the mixes containing MT, SF, and ZL did not show segregation of these mixes, the results L-box height ratio results were unsatisfying for mixes containing SF and ZL. The lower compressive strength of the mix containing ZL was achieved as compared to other mixes. They concluded that SF compensates for poor sand quality and the SCC made of SF can pass the tests successfully. The mixes contain SF and ZL deteriorated the mechanical properties because of the high absorption of water as compared to reference mix.

Jhansirani et al. (2015) conducted experimental investigation on SCC and produced total 11-SCC mixes with various partial replacements of FA (10, 20 and 30%), SF (5, 10 and 15%) and combination of both FA and SF (SF5+FA30, SF10+FA20, SF15+FA10%). From the results, it was identified that SF shows more resistance against the acid, alkaline, chloride penetration. It was also observed that by increasing mineral admixes in SCC both fresh and durability properties were increased. Results revealed that the “slump flow”, “T50 (sec)”, “V – Funnel T50 min (sec)”, “L - Box (H2/H1)” were within the limits of the EFNARC specifications (2002). Moreover, the replacement of cement by 20% of FA and 15% SF and the combination of both SF15 + FA10% shows that the maximum durability factor. And replacement of cement by 15% of SF and 20% of FA and a combination of SF15% and FA10% shows that lower absorption.

Faseyemi, (2015) conducted experimental investigation on SCC and produced a total 6-SCC specimen. 5-SCC specimen were containing micro SF (10, 8, 6, 4 and 2%) together with FA (35, 30, 25, 15 and 10%) by weight of cement and 1-SCC mix without mineral additive (control mix). The “w/c ratio” ranged from 0.35-0.30 for SCC contain mineral additives and 0.40 for the control. The total binder ratio was 450kg/m3 and SP and rheomatix (III) were used as a viscous modifier. Table 9 shows he mixture design used in this research. Based on hardened properties in their research, they conclude that the highest compressive strength was obtained at 2% of micro SF and 10% of FA, while all other values were above the design strength expected for SCC at all curing ages.
Table 9. Mix Proportion for 50Npa SCC (Faseyemi, 2015).

| Materials       | Mix Proportion          |
|-----------------|-------------------------|
|                 | Reference | 10%M/S +30%FA | 8%M/S +25%FA | 6%M/S +20%FA | 4%M/S +15%FA | 2%M/S +10%FA |
| Cement (Kg/m³)  | 450       | 324            | 384          | 400          | 437          | 475          |
| Fly Ash (Kg/m³) | -         | 162            | 113          | 108          | 81           | 54           |
| MSF (Kg/m³)     | -         | 54             | 43.2         | 32.4         | 22           | 11           |
| C-agg (Kg/m³)   | 1037      | 1037           | 1037         | 1037         | 1037         | 1037         |
| WSand (Kg/m³)   | 880       | 880            | 880          | 880          | 880          | 880          |
| W/C             | 0.37      | 0.4            | 0.4          | 0.4          | 0.4          | 0.4          |
| Water %         | 200       | 218            | 218          | 218          | 218          | 218          |
| SP %            | 5         | 3.5            | 3.5          | 3.5          | 3.5          | 3.5          |
| Rheomatrix %    | -         | 0.5            | 0.5          | 0.5          | 0.5          | 0.5          |

E. Güneyisi et al. (2015) conducted experimental investigation on hardened properties of SCC produced cold bond FA lightweight aggregates. Total nine specimen of SCC mixed with SF and FA were produced having constant “water to binder ratio” of “0.35” and total quantity of binder quantity of 550 kg/m³ was used. The hardened properties of SCC specimens were determined for 28 and 56-days curing age. The results revealed that the addition of mineral admixture significantly improved permeability of the SCC. Moreover, compressive strength of SCC specimens mixed with lightweight aggregates was much higher as compared to control concrete (without mineral admixture).

3. Chemical Admixtures

In order to improve the fresh and hardened properties of concrete, chemical admixtures are usually added in small quantities. However, the addition of chemical admixtures is proportional to the increase in cost and the addition must not adversely affect the concrete. The most important types of chemical admixtures used with concrete are water-reducing admixtures, water-preventing admixtures for concrete, and air agent entraining additives. In general, the main function of adding chemical admixtures in the concrete is to adjust fresh properties of concrete and improve workability without increasing water content. Superplasticizers are chemical admixtures which are used for improving workability of concrete. In other sense, they can also help to decrease the water quantity in the concrete (for the same slump and workability) and thus advantage to increase the concrete strength and durability. Keeping such facts, in this research, the chemical admixture: superplasticizers was considered for arguing its impact on fresh and hardened properties of SCC.

3.1 Super-plasticizer (SP)

SP is added to the cement mix by 1% - 3% of the weight of the cement in the liquid form (Mahmoud, 2002). SP is used to increase compressive strength in the early and late ages, increase flexure strength, increase adhesion strength, reduce permeability, increase the modulus of elasticity (Mahmoud, 2002). Mainly; SP is used in different applications of concrete like high-performance-concrete, the hot-air-concrete that requires to maintain the workability for a longer period, concrete pumping, and pre-cast concrete especially in narrow sections where the amount of armament is dense as it increases the susceptibility to spreading in all parts of the mold. SP can surround the grains of cement and aggregates and works on the lubrication of the region so that the grains slide on each other and distributed in the size of the total concrete and more than all of that is to make the concrete more homogeneous as shown in Figure 7 (Koehler, E. P. and Fowler, 2007).
Figure 7. Embracing of SP for grains cement and aggregates (Koehler, E. P. and Fowler, 2007)

However, the application of SP gives negative surface charge on the cement particles and result in electrostatic repulsion, liberates the trapped free water and prevents flocculation and agglomeration, and as shown in Figure 8. (Wajde, 2016). For more detail knowledge, the influence of adding SP on fresh and hardened properties of concrete is explained below by considering previously published research work. However, all the previous research work was reviewed systematically.

Figure 8. Flocculation of cement particles deceiving water and the dispersion effect by SP (Wajde, 2016)

3.2 Effect Superplasticizer (SP) on Fresh and Hardened Properties.

Nuruddin et al. (2011) conducted experimental research on geopolymer SCC (SCGC) and produced 8-SCGC mixtures to examine the influence of various percentages of SP on fresh and hardened properties. FA and molarity of sodium hydroxide alkaline solution were also in SCGC mixtures. Table 10 shows the mixture design used in their research. The workability and compressive strength increased with the increasing percentage of SP. All SCGC mixtures meet EFNARC specifications (2002) except SCGC mixture 1, 2 and 3. The maximum compressive strength (53.8 MPa) was obtained for SCGC mixture 5 containing 7% of SP at 28-days curing age. They concluded that a lower percentage (3, 4 and 5%) of SP had poor passing and filling ability and workability. Moreover, the mixture of 6% of SP and 12% of alkaline sodium hydroxide results in satisfactory fresh properties as per EFNARC specification (2002) and also results in the higher value of compressive strength (51.52 MPa) at 28-days curing age.
Dumne, (2014) carried out experimental research on SCC and produced 6-SCC mixes with M20 mixes grade. The w/c ratio was 0.55, 10% replacement of cement with FA and different percentage of SP (0.25, 0.30%) of cement content were used for producing SCC. One normal concrete (without SP) was also produced to compare the SCC fresh and hardened properties. Table 13 shows the mixture design used in their research. Fresh properties results showed that normal concrete mix has a slump value of 120 mm, whereas for a mix containing 10% FA and 0.35% SP; the slump value achieved as 285 mm which is very high. Moreover, at 10% of FA and addition of SP; the compressive strength also accelerates and achieved very high.

Table 10. Mix design proportion Nuruddin et al. (2011)

| Mix | FA (Kg/m³) | G-ag (Kg/m³) | F-ag (Kg/m³) | NaOH (Kg/m³) | Na-Silicate (Kg/m³) | Extra Water (Kg/m³) | SP (Kg/m³) | Curing |
|-----|------------|--------------|--------------|--------------|-------------------|-------------------|------------|--------|
|     |            |              |              |              |                   |                   |            | Time hr | Temp °C |
| S1  | 400        | 950          | 850          | 57           | 143               | 48                | 12         | 48     | 70     |
| S2  | 400        | 950          | 850          | 57           | 143               | 48                | 16         | 48     | 70     |
| S3  | 400        | 950          | 850          | 57           | 143               | 48                | 20         | 48     | 70     |
| S4  | 400        | 950          | 850          | 57           | 143               | 48                | 24         | 48     | 70     |
| S5  | 400        | 950          | 850          | 57           | 143               | 48                | 28         | 48     | 70     |
| S6  | 400        | 950          | 850          | 57           | 143               | 48                | 24         | 48     | 70     |
| S7  | 400        | 950          | 850          | 57           | 143               | 48                | 24         | 48     | 70     |
| S8  | 400        | 950          | 850          | 57           | 143               | 48                | 24         | 48     | 70     |

Dubey et al. (2012) conducted experimental research on SCC and produced 6-SCC mixes with different percentages of SP (2% to 10%) of cementitious material. Table 11 shows the mixture design used in their research. Concrete setting time was achieved as 1, 3, 7 and 11 for 2, 4, 6, 8 and 10% of SP respectively. The compressive strength of the SCC was reduced for 2% of SP, on the other hand significant increment was observed at 4% of SP for higher curing age. Furthermore, a minimal increase in compressive strength was observed until 8% of SP addition at any curing age and 10% of SP; another significant increment in compressive strength was obtained at higher curing age. Thus, they concluded that increasing the curing age period causes an increment in compressive strength and 4% and 10% of SP provide higher values of compressive strength in their research.

Table 11. Mix proportions used in the trials Dubey et al. (2012)

| Mix | Cement (Kg/m³) | SF (Kg/m³) | FA (Kg/m³) | C-ag (Kg/m³) | F-ag (Kg/m³) | W/Powder |
|-----|---------------|------------|------------|--------------|--------------|----------|
|     |               |            |            |              |              | 0.38     |
| 1   | 400           | 30         | 170        | 700          | 790          |          |

Table 12. Mix proportions of the SCC mixes (kg/m3) Ali Mardani et al. (2013).

| Mix | Cement (Kg/m³) | L.P Aggregate | Water (Kg/m³) | SP (Kg/m³) |
|-----|---------------|--------------|--------------|------------|
|     |               | 0-0.125 mm 6-15 mm | 6-15 mm |          |
| A   | 465           | 173          | 793         | 186        | 6.6       |
| B   | 459           | 171          | 763         | 183        | 6.1       |
| C   | 461           | 172          | 766         | 184        | 5.7       |
| D   | 442           | 165          | 754         | 177        | 7.4       |
Salahaldein Alsadey, (2015) carried out experimental research on SCC and produced 6-SCC mixtures with M35 mixes grade. The “w/c ratio” was “0.475” and different percentage of the SP (0.6, 0.8, 1.2, 1.8 and 2.5%) was used to study the influence on fresh properties and compressive strength of SCC. However, a control mix (without SP) was produced to compare the above-said properties. Table 15 shows the mixture design used in their research. The results indicated that increasing the amount of SP leads to improve workability. However, the highest value of compressive strength (40.24 MPa) was achieved for the control mix (without SP) as compared to other SCC mixtures except for the SCC mixture having 0.8% SP. Moreover, the SCC mixture containing 0.8% of SP provides higher than the desired characteristics strength for SCC as per EFNARC specifications (2002).

Nagaraju et al. (2018) conducted experimental investigation on SCC and produced 25-SCC mixtures with M40 mix grade to obtain the required admixture dosage of ADVA960 (Poly-carboxylate-based) admixture and its effect on fresh properties and compressive strength of SCC at 7 and 28-days curing age. Table 14 shows the mixture design used in their research. Results obtained in their research showed that only SCC-mix-7 having water to cement ratio of 0.5 and the 0.5% dose of SP achieved all the requirements of the SCC as per EFNARC specifications (2002) as compared to other SCC mix. SCC-mix-1 (500Kg/m3 of powder, 0.8 of w/c and 0.35% of SP) and SCC-mix-2 (500Kg/m3 of powder, 0.8 of w/c and 0.4% of SP) had unsatisfactory fresh properties results and bleeding and segregation phenomenon was observed due to high dose of SP especially in SCC-mix-2 with lower w/c ratio (0.8). SCC-mix-4 to 6 contain 0.4%, 0.45% and 0.5% of SP respectively also failed and did not meet EFNARC specifications for SCC, it was mainly because of the high dose of SP and lower w/c ratio (0.8). Thus, they concluded that the combination of the higher dose of SP (0.5%) with a higher w/c ratio (1.1) can be used to produce SCC as per EFNARC specifications (2002). Moreover, such a combination of SP (0.5%) and w/c ratio (1.1) targeted compressive strength values (at 7 and 28 days curing age) very near to EFNARC specification [35] for compressive strength for SCC.

### Table 13. Mix proportion for various trials mixes of M20 concrete grade Dumne, (2014).

| Mix | Cement (Kg/m³) | FA (Kg/m³) | C-agg (Kg/m³) | F-agg (Kg/m³) | Water (Liters) | SP (Liters) |
|-----|----------------|-----------|---------------|---------------|----------------|-------------|
| A   | 348            | 0.11      | 1207          | 558           | 191.4          | 1.12        |
| A1  | 313.2          | 0.11      | 1207          | 558           | 191.4          | 1.04        |
| A2  | 313.2          | 0.11      | 1207          | 558           | 191.4          | 0.87        |
| A3  | 313.2          | 0.11      | 1207          | 558           | 191.4          | 1.12        |

### Table 14. Mix Quantities Nagaraju et al. (2018)

| Mix | Cement (Kg/m³) | FA (Kg/m³) | C-agg (Kg/m³) | F-agg (Kg/m³) | Water (Kg/m³) | W/C (based on vol.) | Admixture |
|-----|----------------|-----------|---------------|---------------|---------------|---------------------|-----------|
| Mix1 | 350            | 150       | 902.066       | 788.76        | 177           | 1                   | 1.75      |
| Mix2 | 350            | 150       | 902.066       | 788.76        | 177           | 1                   | 2.5       |
| Mix3 | 350            | 150       | 950.85        | 823.85        | 163.4         | 0.92                | 2         |
| Mix4 | 400            | 150       | 840.85        | 871.85        | 188.18        | 1                   | 2.2       |
| Mix5 | 400            | 150       | 855.71        | 748.57        | 207.14        | 1                   | 2.47      |
| Mix6 | 400            | 150       | 856.71        | 671.42        | 207.14        | 1                   | 2.75      |
| Mix7 | 400            | 150       | 933.571       | 664.28        | 215           | 1.1                 | 2.75      |
Mehena, et al. (2018) conducted experimental research to examine the rheological and hardened properties of SCC. The mixture paste was designed as “70% of cement”, “w/c ratio (w/c + f) of 0.35”, “30% of pozzolana” and “three types of SP (poly naphthalene sulfonate (PNS), poly melamine sulfonate (PMS) and polycarboxylate (Poly)” with different percentages were used for producing SCC. The rheological results were achieved as slump flow cone was 72, 72 and 73 cm and L-box (H1/H2) was higher than 90% for the SP dose: PNS= 1.75, PMS= 2.5 and Poly=1% respectively. The compressive strength was 39, 47 and 41 MPa for the SP dose: PNS= 1.75, PMS= 2.5 and Poly=1% respectively. They concluded that for rheological properties; Polytype of SP is best and for hardened properties; PMS type of SP is best.

Benaichaa et al. (2019) produced total 9-concrete including 1-normally-vibrated carried (N) concrete and 8-SCC with different percentage of SP (0, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1). The design mixture used in their research is shown in Table 15. They found in their results that all SCC mixes containing SP were within the EFNARC specification (2002) limits except the N concrete. Moreover, the inclusion of SP causes to decrease the time taken by the mixes to empty the funnel and yield stress and plastic viscosity decreases. The best mechanical properties (74.4 MPa) were achieved for the mix SCC-SP1 (0.3 SP in SCC) at an age of 28-days as compared to other SCC mixtures and N concrete.

| Mix  | W/P | Cement (Kg/m³) | Limestone filler (Kg/m³) | C-agg (Kg/m³) | F-agg (Kg/m³) | (SP)% |
|------|-----|----------------|--------------------------|---------------|---------------|-------|
| N    | 0.37| 350            | 170                      | 900           | 890           | -     |
| SCC-SP1 | 0.37| 350            | 170                      | 900           | 890           | 0.3   |
| SCC-SP2 | 0.37| 350            | 170                      | 900           | 890           | 0.4   |
| SCC-SP3 | 0.37| 350            | 170                      | 900           | 890           | 0.5   |
| SCC-SP4 | 0.37| 350            | 170                      | 900           | 890           | 0.6   |
| SCC-SP5 | 0.37| 350            | 170                      | 900           | 890           | 0.7   |
| SCC-SP6 | 0.37| 350            | 170                      | 900           | 890           | 0.8   |
| SCC-SP7 | 0.37| 350            | 170                      | 900           | 890           | 0.9   |
| SCC-SP8 | 0.37| 350            | 170                      | 900           | 890           | 1     |

4. Conclusion
Recently, extensive research works have been conducted to comprehend the influence of the inclusion of SF and SP on the SCC fresh and hardened properties. In this review work, the previous research works has been reviewed and presented. On the basis of the previous research revision which was argued and reported in this research work, the notable conclusions were drawn and presented as follows:

- The production of the SCC test depends on the trial and error based methods, thus, it is utmost necessary to determine the optimal proportions of the components of the concrete mix including mineral and chemical admixtures.
- Such optimal proportions of concrete admixtures reduce the experiments, cost and time for producing SCC.
- The use of SF as an alternative to cement improves the ITZ as it is considered a filler material. Because of the smaller surface area SF particles; the porosity decreases, increases density and provides more cohesion than non-SF mixes. SF imparts to increase the cement content, thus reducing the percentage of water to the cement which in turn reduced bleeding and segregation of the SCC.
- The use of SF as an alternative to cement decreases the workability and therefore increases the need to increase the amount of water.
- The use of SP with SF improves the workability of the SCC which in turn decreases in the amount of cement required for producing SCC. Such a reduction in cement quantity reduces the cost of producing SCC and hence enhance sustainability in the construction.
• Previous studies have shown the compressive strength decreases with the increase in the percentage of SP. Although the inclusion of SP has slightly influenced on the compressive strength, but early curing ages; it pronounced a better effect on the compressive strength of SCC.
• The increased percentage of SP indications to an improvement in workability, but higher percentage of SP leads to damage the concrete cohesiveness.
• The increased percentage of SP will produce the phenomenon of bleeding and Segregation.
• In general, it was confirmed by researchers that the use of SF and SP increases the hardened and fresh properties of concrete, but it should be within optimal quantities and doses.

5. Future Recommendations

The application of SCC in increasing day by day in the construction industry due to many attractive characteristics. Better fresh and improved hardened properties make SCC for use in the construction industry. Better fresh and hardened properties were achieved by incorporating mineral and chemical admixtures and different aggregates. Though the review has been taken as per the title of the research and ample information was presented in this review work, but still, there are a lot of research gaps that could be investigated further in this research area.

To focus the application of SCC in the construction industry, it is recommended to investigate the effect of the addition of SF and SP on other mechanical properties such as bond strength, impact resistance, and abrasion resistance. Besides these mechanical properties; the time-dependent mechanical properties such as creep and shrinkage of SCC are also recommended for further investigation in focusing the title of the research. Though the addition of SF and SP are mineral and chemical admixtures and increase passing and flowing ability of SCC, the other types of mineral and chemical admixtures are also encouraged to investigate their effect on fresh and hardened properties of SCC. Moreover, very few research work was observed on rheological and thixotropic behavior of SCC, thus for better understanding workability, such behaviors are recommended for investigation by adding SF and SP in SCC. The major contribution and output of conducting this review work are demonstrating that the use of SF and SP in SCC beneficial and recommending their use in SCC.

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