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ORIGINAL ARTICLE

Influence of Mineral Admixtures on the Properties of Self-Compacting Concrete: An Overview

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ABSTRACT – Mineral admixtures are often utilized in Self-Compacting Concrete (SCC) mixtures to provide stability and resistance to bleeding and segregation throughout transportation and placement. Additionally, these more refined materials help in lowering building costs and reducing the use of main resources. SCC is an innovative method of concrete, which is placed and compacted without the use of vibration. As a result, the concrete mixture has the ability to flow under its self-weight to fully fill formwork and achieve total compaction even when reinforced by crowded reinforcement. However, self-compacting concrete is not cost-effective, which results in the use of large amounts of ordinary cement and chemical admixtures. The utilization of mineral admixtures, including silica fume, ground granulated blast furnace slag, fly ash, and coal bottom ash, is an alternative method to decrease the high cost of self-compacting concrete - it is a term, which refers to the components that have been finely divided and added to concrete during the mixing process. Furthermore, the utilization of admixtures in the fabrication of self-compacting concrete has shown that it helps in lowering the heat of hydration. In addition, the inclusion of admixtures reduces the necessity for chemical admixtures that increase viscosity in concrete mixtures. This study aims to provide an overview of the previously conducted studies on mineral admixtures, which are utilized in SCC. Moreover, the study aims to discuss the durability and mechanical performance of SCC.

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INTRODUCTION

In the present era, the rate of technological demand for concrete has been increasing [1]. According to Mehta et al., concrete technology advancements are the outcome of an effort to overcome specific shortcomings of traditional concrete mixes of using main resources like cement and aggregate (fine and coarse) [2]. In the meantime, researchers have constantly strived to advance various types of concrete [3]. With the passing of time and the expansion of the construction industry, many kinds of concrete have been developed, comprising high-strength concrete, high-performance concrete, self-healing concrete, and self-compacting concrete [3]. In Tokyo, Japan, researchers from Japan University have developed SCC to create durable buildings, which has significantly transformed the construction sector [4] to address issues, such as concrete vibration in complicated buildings or the difficulty of filled formwork with a significant quantity of reinforcement, whereby the concrete must exhibit a strong passage ability characteristic to flow over [5]. SCC or Self-compacting concrete is described as concrete, which influxes under its self-weight and is capable of filling the workplace, especially when it is reinforced with a high density of reinforcing bars while retaining uniformity. SCC enjoys several benefits in the building process due to the concrete's increased efficiency, quality, and circumstances of the workplace [6]. However, as stated by Gupta et al. [7], SCC can provide a wide variety of possible mixture configurations. Thus, for all applications and needs, a significant gap exists to enhance the mix design for better efficiency and effectiveness. To increase the SCC utilization in the building sector, it is essential to reduce the cost of raw (pure) materials. Many studies in the literature have already supported this assertion [7].

It is worth mentioning that previous studies and international standard institutions have described SCC differently. The American Concrete Institute ACI -237 (2007) [8] defines SCC as one type of concrete, which does not necessitate compacting while placing it in a mold due to the SCC's spreadability and flowability, and because of its weight and capacity to fill the mold, even when reinforced with high-density steel, the resultant concrete is homogenous, very durable, and had engineering characteristics comparable to the conventional concrete [8]. According to the British Standard European Norm BS EN 206-9 [9], Self-Compacting Concrete is referred to as a type of concrete, which self-flows - it is compatible due to its weight and can fill the mold with reinforcement elements while maintaining homogeneity [9]. According to Siddique et al. [10], SCC is the concrete, which freely flows between the mold parts owing to its self-weight and significantly consolidates inside the mold's specified form. SCC does not need extrinsic vibration and produces defect-free components due to no bleeding or segregation. Also, based on previous [11]–[13] experimental studies, SCC has improved cohesion, strong flow, and passing capacity, and cohesiveness to accomplish complete compaction. Besides, the need for standards no longer prevents SCC from being widely used. At the moment, the British Standard European Norm EN 206-9 standard [9] and the American Concrete Institute ACI-237 guide are provided [8].

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An admixture can be referred to as a particular substance - it is not a fundamental raw material, which can be added to the concrete mixture just before or during mixing to enhance specific characteristics, as per ASTM C 125 [14]. Furthermore, incorporating mineral admixtures can eliminate the demand for chemical admixtures, which are viscosity-enhancing. By integrating admixtures, the cement or aggregate content is decreased, thereby minimizing environmental effects while improving the characteristics of SCC [10], which helps strengthen the SCC's durability. Additionally, disposal issues may be alleviated, since these admixtures are industrial waste materials [15], [16]. Previous researchers [17]–[19] pointed out that mineral admixtures like coal bottom ash, fly ash, ground granulated blast furnace slag, and silica fume are more pozzolanic materials [20], [21]. Numerous academic and technological advancements have been made as a result of the utilization of pozzolanic materials as raw materials for the SCC manufacture and as a partial replacement material [22].

According to previous researchers [23], [24], coal bottom ash is combined with cement additives like fly ash and metakaolin in producing SCC. However, fine aggregate has been substituted with 10%-30% coal bottom ash with the addition of water reducing agent. Likewise [25], [26] found that SCC, which contains coal bottom ash and fly ash, can be constructed to comply with the mandatory criteria for fresh SCC. The optimal amount of coal bottom ash for substituting fine aggregate in green concrete is established to be 10% [27]. Different ratios in SCC 0%, 5%, 10%, and 15% of GGBS or ground granulated blast furnace slag and silica fumes are cement substitutes. The cementitious materials' impact on improving the SCC durability and mechanical properties has been investigated in previous studies. After 28 curing days, silica fumes with 10 percent silica exhibited an improvement in mechanical properties [19], [28]. Incorporating GGBS into SCC has several benefits, such as improving its compatibility, as well as consistency, and maintaining it for a longer time while preserving cement against the attack of chloride and sulfate. GGBS has nearly 10% density, which is less than the cement density, and, therefore, by replacing GGBS for an equal mass of cement, this has resulted in a greater paste volume. This has increased the segregation resistance, as well as flowability significantly [29], [30]. Tangadagi et al. [31] examined different SCC mixes, including GGBS, and they reported that as the GGBS concentration rises, the water to binder ratio lowers for a similar consistency, which shows that GGBS exhibits a beneficial impact on the consistency and the compressive strength of concrete mixtures, which contains GGBS increases as the GGBS proportion increases [31]. For utilizing the mineral admixtures like fume, fly ash, coal bottom ash, and ground granulated blast furnace slag, the chemical and physical properties, in addition to fresh and mechanical characteristics in SCC must be studied. The purpose of this review paper is to summarize previous studies on using several mineral admixtures in SCC. This study mainly aims to review previous studies about using a mineral admixture as a substitute material in the SCC mixtures. Moreover, the study aims to identify the impact of the mineral admixture ashes on the concrete performance. Figure 1 provides a summary of previous studies in this review.

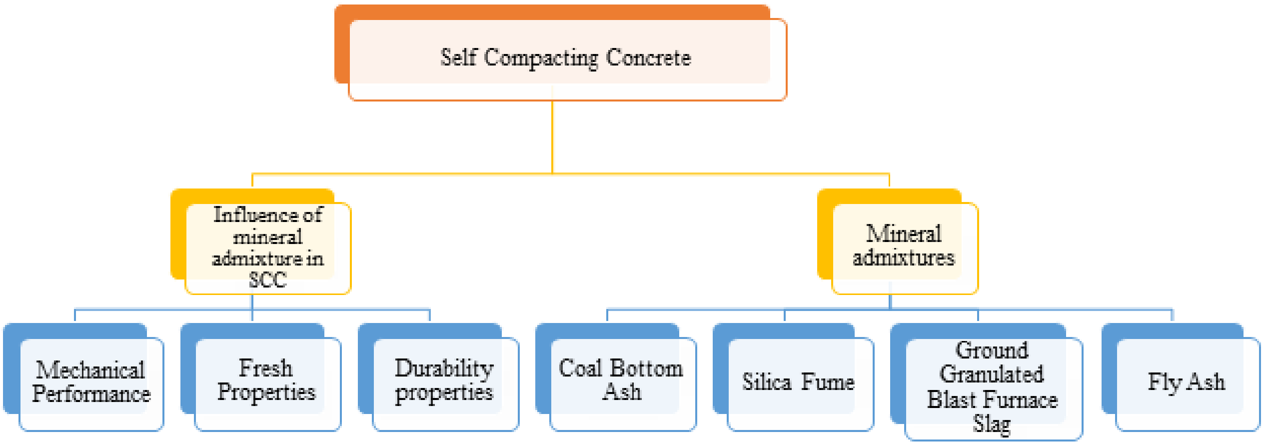

Figure 1. Overview outline for the review research

PHYSICAL PROPERTIES AND CHEMICAL COMPOSITION FOR DIFFERENT MINERAL ADMIXTURE

Physical Properties

The physical properties of mineral admixture, such as particle size, specific surface area, and specific gravity display a key role in the properties of the concrete mixture. Silica fume is a gray or white powder of high quality. The particles are very tiny, and they have a spherical form, whereby 95 percent of their particles are lower than 1μm in diameter [32]. The particles have a surface area, which ranges from 13000 to 30000 m^2/kg. The particles of silica fume are almost 100 times smaller in size compared with the particles of typical cement [33], [34]. Furthermore, fly ash has a soft gray color. The particle size ranges from 10μm to 100μm, with the majority of the FA particles being less than 35μm in overall size [35]. Generally, the FA particles' surface area ranges from 300 to 500 m^2/kg. However, the surface area's lowest and highest values are 170 and 1000 m^2/kg, correspondingly [36]. The FA-specific gravity ranges between 1.9-2.55 [37]. Moreover, coal bottom ash is dark grey in color and porous [38]. Nevertheless, after the grinding process, it darkens in color (as it becomes blackish) [38]. It is a porous irregular-shaped substance with a complex structure [39]. The coal bottom ash's specific gravity ranges from 1.39 to 2.47 [40], [41]. Such reduced values occur because of the voids' existence, depending on the coal combustion technique. The porous ash state can lead to increased water absorption of about 5.45-32.2 % [41]. The coal bottom ash's modulus of fineness varies from 1.37 to 3.44 [40], [41]. The physical properties of mineral mixtures, such as silica fume, fly ash, coal bottom ash, and GGBS are provided in Table 1 based on several researchers.

Table 1. Physical properties of mineral admixtures

Physical characteristics/ mineral admixture type	**Coal bottom ash (%)**	**Fly Ash (%)**	**Silica Fume (%)**	**GGBS (%)**
Shape	Irregular [42], [43]	Spherical [37]	Spherical [37]	Spherical [37], [44]
Specific gravity	1.39 -2.47 [40], [41], [45]–[47]	1.9–2.55 [37]	2.25 [37]	2.6 [37]
Average particle size	3.65-50.45µm [45]–[47]	0.5–300 µm [37]	0.1µ [37]	4.75 mm down [37], [44]
Bulk density (Kg/m^3)	2190 [41]	540–860 [37]	750–850 [37]	1000–1100 [37], [44]
Fineness modulus	1.37 – 3.44 [40], [41], [46], [47]	-	-	-
Water absorption (%)	5.45 32. 2[41], [45]–[47]	-	-	-

Chemical Composition

The chemical composition of several mineral mixtures, including silica fume, fly ash, coal bottom ash, and GGBS is illustrated in Table 2 based on previous researchers [37], [43]. The coal bottom ash's chemical composition differs depending upon the source and method of burning. Coal bottom ash has large amounts of alumina, silica, and iron, which are often found in pozzolanic materials. Together, these chemical components form up to 70 % of the overall chemical composition of CBA. The loss in CBA ignition ranges from 0.89 to 8.10 according to previous studies [43]. In line with ASTM C618 [48], CBA is categorized as a pozzolanic material (Class C or F) based on evidence collected from several studies [49]. Nevertheless, the coarse particle size of CBA results in reducing the pozzolanic reactivity [50]. Therefore, the finer CBA grinding increases the reactivity of silica and coal bottom ash [39]. The chemical composition of fly ash cannot be determined by the type of coal, which is utilized in the production only. It can also be determined by the combustion method used [51]. The characteristics of fly ash are determined using the boiler's design, its temperature, the burning condition, the gas cleaning equipment, and the particle size of coal [52]. Fly ash is mostly composed of alumino-silicate compounds, although it also includes metallic and calcium oxides. Enders et al. [53] found that the $A1_2O_3$+ SiO_2 proportion in fly ash spheres is consistent, suggesting that glassy spheres originate from coal's Kaolinite [53]. Also, fly ash contains numerous trace elements like Cr, Ba, Ni, Pb, Sr, V, and Zn, typically enriched in magnetospheres [54]. Since fly ash hydrates may promote heavy metal fixing, the concentration of leaching heavy metals decreases as fly ash hydration progresses [55]. Fly ash has two types of components: network formers, such as SiO_2, Al_2O_3, Fe_2O_3, TiO_2, and P_2O_5, and network modifications, such as CaO, MgO, Na_2O, and K_2O [51]. On the other hand, the silica fume's chemical composition possesses a large concentration of amorphous silicon dioxide, having very tiny spherical particles. Additionally, magnesium, iron, and alkali oxides were detected in trace quantities [56], [57]. The inclusion of silicon oxide enhances the pozzolanic reactivity and silica fume's cementitious properties, thereby making it ideal to be used in concrete mixtures [56], [57]. The chemical composition of mineral mixtures, including silica fume, fly ash, coal bottom ash, and GGBS is provided in Table 2 based on several previous studies.

Table 2. Chemical composition of mineral admixtures

Chemical elements/ References and type of admixture	**Coal bottom ash (%)** [43], [45]–[47]	**Fly Ash (%)** [37]	**Silica Fume (%)** [37]	**GGBS (%)** [37], [44]
SiO_2	59.82-48.0	25–60	95.75	27–38
Al_2O_3	18.1-27.76	10–30	0.35	13.24
Fe_2O_3	3.77-19.84	5–25	0.21	0.65
CaO	1.86-8.7	<10	0.17	34–43
MgO	0.4-3.3	<1	0.09	0.15–0.76
SO_3	0.24-1.39	<1	0.42	<1
K_2O	1.29-3.48	<1	<1	0.37
Na_2O	<1	<1	0.51	<1
TiO_2	1.11-3.36	<1	<1	<1
Loss on ignition	0.89-8.10	7–15	<1	<1

IMPACT OF MINERAL ADMIXTURE ON FRESH PROPERTIES

The properties of SCC in the fresh state are important due to their significant effect on the strength of mechanical properties. The SCC major properties in the fresh condition involve the complete filling of formwork, and the proper enclosing of the reinforcement (also in heavily reinforced places) without vibration, thereby producing no cracks or separation throughout cast [58,59]. Also, because of good fluidity, SCC demonstrates an outstanding ability to flow and passage through reinforcing bars, as well as an exceptional capability of flowing as a “viscous fluid” [58,59]. Nataraja et al. [60] devised a simple technique to produce SCC according to strength requirements via small changes to the IS 10262:2009, considering EFNARC [61] limitations (European Federation of National Associations Representing for Concrete). They established a connection using 25 mixture ratios between compressive strength, as well as the SCC water cementitious proportion [60].

Dar et al. [62] conducted an experimental study to verify the optimum cement replacement percentages incorporating fly ash in the SCC and using proper superplasticizers. They have also identified the effect on the SCC fresh properties. Several ratios of cement were replaced with fly ash ranging from 5% to 35% using EFNARC standards, and other tests such as the slump flow test. Other fresh properties were also examined to determine the most effective concrete mixes. The findings of the testing indicated that a 30% substitution ratio could be optimal for the production of SCC with elevated flowability [62]. Another research by Gesoğlu [63] investigated the characteristics of SCC with mineral additions in an experimental setting, whereby 22 concrete mixes were developed with a weight-to-volume ratio of 0.44. The primary mixture is composed entirely of cement paste, and the cement content utilized in all mixtures is between 180 and 450 kg/m^3, with SF providing for 5%, 10%, 15% of the weight of cement of 22.5, 45, 67.5 kg/m3, correspondingly. According to the results, slump flow time, and the slump flow radius, with the V-funnel flow time, in addition to the L-box height ratio were 5, 4, and 4 seconds, 67, 68, and 69.5 cm, 10, 10, and 10 S, and 0.73, 0.82, and 0.91 for mixes including by SF ratio 5%, 10%, and 15%, respectively. The inclusion of SF to all mixtures resulted in a viscous mixture, which was slightly more viscous than the normal mixture following the guidelines outlined by the standard EFNARC [61].

On the other hand, previous studies [64–66] have experimentally examined the SCC mixtures containing mineral admixtures like CBA as sand aggregates. Also, Keerio et al. [67] showed that increasing coal content has led to reducing slump flow. However, it was within the normal value range (650- 850mm). Additionally, slump flow was reduced as the CBA replacement ratios increased due to the CBA’s increased surface area, which led to increasing the viscosity and porosity of CBA, thereby absorbing additional water despite having a high coal bottom ash ratio in SCC. The conducted V-funnel test showed the ratio, which ranged between 11.4 and 12 [67]. Similarly, another study by Siddique [64] investigated the fresh characteristics of SCC, which includes 10%, 20%, 30% CBA with the superplasticizer’s content of 1.88-2.0%. The findings indicated that slump flow was within the range of (650-800 mm) as mentioned in the guidance of EFNARC standard [61] of SCC for all substitution ratios, except for the one having 20% CBA and 1.90% superplasticizer (591mm). The increase in the proportion of superplasticizers has led to an increased flow, whilst augmentations in the quantities of CBA led to a decreased slump flow [64]. Besides, Ibrahim et al. [27] examined the self-compacting concrete mixtures containing CBA with a replacement ratio from 0 to 30% with a 10% increase as sand aggregate at a water-to-cement ratio of 0.35, 0.4, and 0.45. The SCC mixture’s slump flow, which did not contain CBA, was greater than the slump flow of SCC mixtures containing CBA as shown in Figure 2. In proportion of CBA rises in the SCC mixtures, the L-box proportion, the segregation resistance, and slump flow of all mixtures were declined [27].

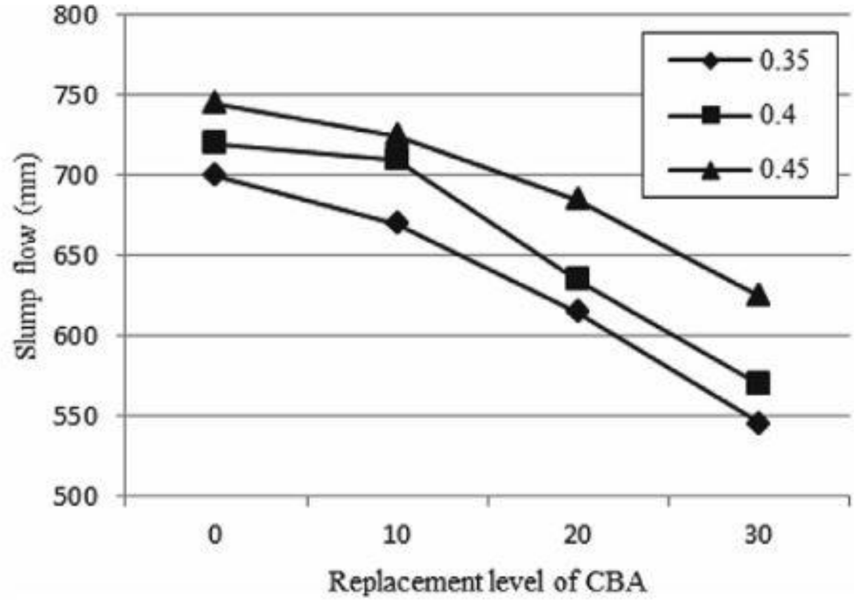

Figure 2. The CBA Slump flow Test in SCC as reported by [27]

Furthermore, previous studies [68–70] have experimentally examined the replacement material of GGBFS in SCC. Al-Oran et al. [71] reported that the fresh characteristics of SCC containing GBBFS as a cement substitute at the replacement levels of 15%, 20%, 25%, and 30% while maintaining a consistent 10% replacement rate for cement with metakaolin. Based on the results, the GGBS incorporation into the SCC mixes with a substitution level of up to 25% has led to enhancing fresh properties, as well as flowability. Also, when GGBS was combined with Mk, it was shown that all fresh properties have declined. The slump test, the slump flow T50 cm, the L-box height ratio, together with the V-funnel flow time of the entire mixes ranged between (690 and 720 mm, 2.7 and 3.2 seconds, 0.85 and 0.92 seconds, and 7.5 to 11 seconds), respectively, and was set at 0.38 for the water-to-cement ratio [71] in the range as prescribed by the EFNARC standard [61]. Furthermore, another study by Zhao et al. [72] examined the SCC slump flow and the results revealed that the GGBS blended mixtures with a GGBS content of 0 to 70% in SCC partial cement substitution performed better between 620 and 680 mm, and the L-box high ratio test recorded a value between 0.9 and 0.9. Figure 3 illustrates the fresh characteristics of SCC incorporating GGBS [72]. Tavasoli et al. [73] investigated the fresh properties of SCC incorporating GGBS at varying ratios as a cementing material. The study found that GGBS increased the (filling, and passing) ability, as well as the resistance to segregation. Based on the results, the slump flow diameter was 680 to 760 mm and the J-ring value was 9-14 mm. The justification for the increased flowability is that GGBS requires less water in the mixture, and the free water is absorbed by the particles of GGBS, which are glassier and smoother than the cement particles [73]. Since GGBS has a lower density than cement particles, when it is replaced with an equivalent quantity of cement, the mixture generates a high volume of paste, which has positively impacted the fresh characteristics [74]. Table 3 summarizes previous studies on the impact of mineral admixtures on the fresh properties of SCC.

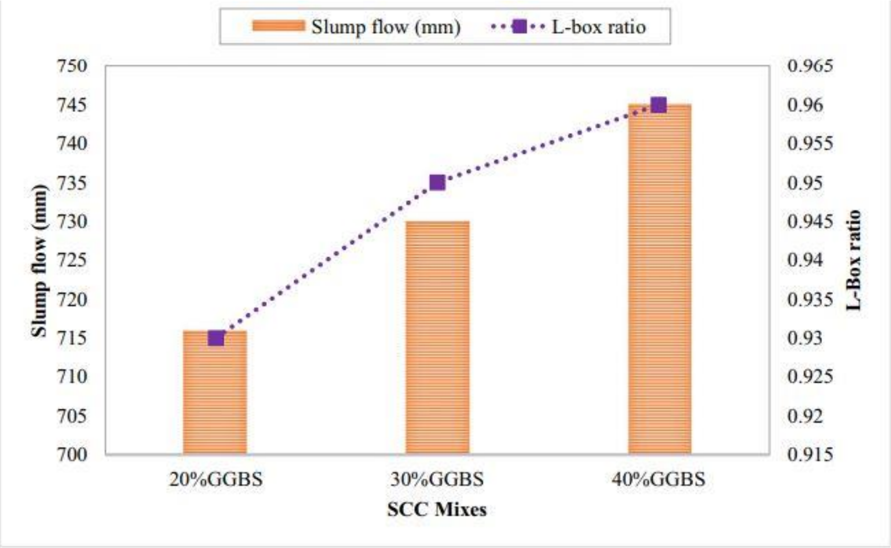

Figure 3. Fresh properties of GGBS in SCC as reported by [72]

Table 3. Fresh properties of mineral admixtures in SCC mixtures as reported by several researchers

				Fresh concrete properties			
Ref	**Type of admixture**	**w/r or w/b**	**Replacement (%)**	**Slump flow (mm)**	**L-box (H2/H1)**	**V-funnel (s)**	**J-ring h2-h1 mm**
[62]	Fly ash	0.43	0, 5%, 10%, 15%, 20%, and 25%	653-710	0.85-0.98	9.0-11	-
[75]		0.28	0, 30%, 40%, 50%, and 60%	710-800	-	12-42	-
[76]		0.38	0, 40%, 50% and 60%	680-710	0.87-0.99	8-19	-
[77]	Silica Fume	0.33	0, 5%, 25%, and 35%	705-745	0.85-0.95	7-12	0.8-0.9
[78]		0.31	0%, 25%, 35%, 50%, 60%, and 75%	550-650	0.80-0.88	10.2-12	-
[79]		0.39	0, 5%, 10%, and15%	680-708	0.69-0.86	8.0-12	-
[67]	Coal Bottom Ash	0.38	0, 10%, 20%, 30%, 40%	735-750	-	10.22-11.4	2.5-8.7
[80]		0.4	0, 10%, 15%, 20%, 25%, 30%,	550-715	0.65-0.92	-	-
[64]		0.52	0, 10%, 20%, and 30%	627-591	0.80-0.89	4- 7.5	2.3-11.6
[71]	GGBS	0.38	0, 15%, 20%, 25%, and 30%	680-720	0.84-0.94	7.5- 11	-
[72]		0.35	0, 20%, 30%, and 40%	600-750	0.92-0.96	-	-
[73]		0.44	0%, 30%, 50%, 65% and 80%	680-720	-	-	8-14

INFLUENCE OF MINERAL ADMIXTURE ON THE MECHANICAL PROPERTIES IN SCC

This study reviews the findings of previously conducted studies, which examined flexural strength, compressive strength, modulus of elasticity, and splitting tensile strength by incorporating mineral admixtures like fine or coarse aggregate and cement in SCC [22], [81]. In a study by Keerio et al. [67], comprehensive laboratory research has been conducted on the SCC mixtures containing CBA as a fine aggregate replacement within the range of 0 to 40% at a water-to-binder ratio of 0.38 and a 5-17% superplasticizer concentration in the mixture. The findings demonstrated strength properties with replacement levels range between 10% and 30%. It is self-evident that the optimal compressive strength, 41.5 MPa (14.5 %), increased versus the control mixture's samples at 28 curing days. This occurred as a result of the concrete matrix's porous refining and pozzolanic reaction to coal bottom ash [18]. At a high percentage, 40% of CBA was replaced, and at 180 days of curing, the strength characteristics were enhanced versus the normal control mixture's samples. Figure 4 demonstrates the results of the strength of coal ash at the following 3, 28, 180 curing days [67]. Another observation has been made by Siddique et al. [25], [26], who found that when fine aggregates were substituted for CBA at 0%, 10%, 20%, 30%, compressive strength, and flexural strength, as well as splitting tensile strength, together with the modulus of elasticity (MOE) were decreased at the 28 days of curing. Based on the CBA comparable results in SCC, the reduced strength occurred due to the delayed pozzolanic reaction that occurred over the increased porosity in CBA aggregate replacement [24]. Previous researchers confirmed that the CBA suitable percentages of use are 10%-20% in the SCC mixture, which contributed to enhancing the properties of compressive strength [82], [83].

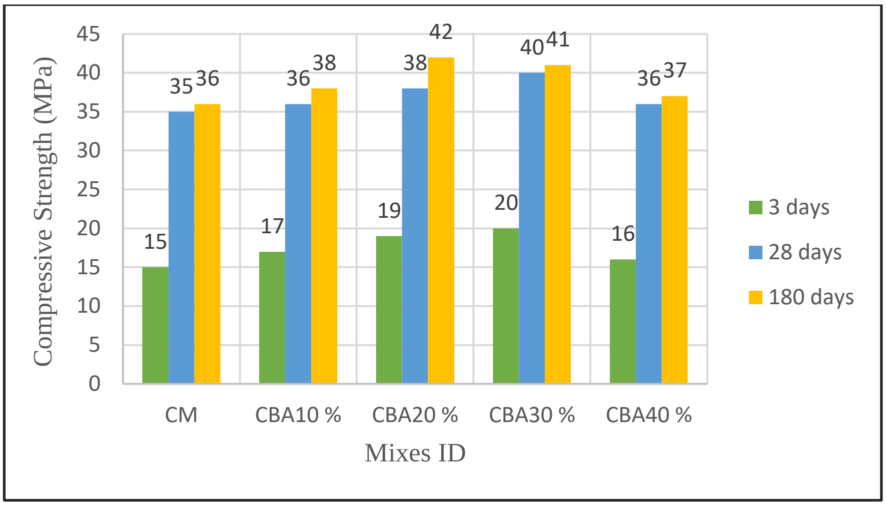

Figure 4. Compressive Strength of CBA with various replacement ratios in SCC [67]

On the other hand, another study work by Kavitha [84] demonstrated unequivocally that adding GGBS as a partial substitution for cement at 30% in SCC resulted in a substantial boost in the strength properties versus the control concrete. They were improved, along with an increased compressive strength 36.6 N/mm2 - 42.9 N/mm^2, increased tensile strength 3.8 N/mm^2 -7.9 N/mm^2, and an increased flexural strength increasing 4.9 N/mm2 - 8.3 N/mm^2 [84]. This performance has been explained by the agglomeration of the concrete microstructure caused by the addition of mineral admixture, as shown in Figure 5. It was also found that in the concrete mixture containing mineral admixture is significantly less resistant due to the higher hydration rate in the samples [21]. Similarly, another study by [71] reported a compressive strength, ranging between 52.5 and 60.3 MPa at 28 days and the mixture of 30% GGBS replacement has a maximum Splitting tensile strength of approximately 4.38 MPa at 20 % of GGBS mixed with Metakaolin in self-compacting concrete [71]. Dinakar et al. [85] recommended a new approach for designing an SCC mixture with GGBS concentrations ranging from 20% to 80%, with strength values ranging from 30 to 100 MPa. Also, according to Djelloul [86], 15% of GGBS powder is the optimal utilization ratio as a partial cement substitute for introducing self-compacting concrete. This has occurred due to the pozzolanic interaction, involving calcium hydroxide produced during the hydration reaction and silica from GGBS powder in the presence of moisture. The strength values ranged between 30.2 MPa and 53.5 MPa. The use of GGBS as a cement replacement resulted in a reduction in strength at an early age of curing, but strength is equivalent to or higher than that of normal concrete at the long term of curing (56 and 90 days). Mixing SCC with 15% GGBS achieved the highest compressive strength result [86].

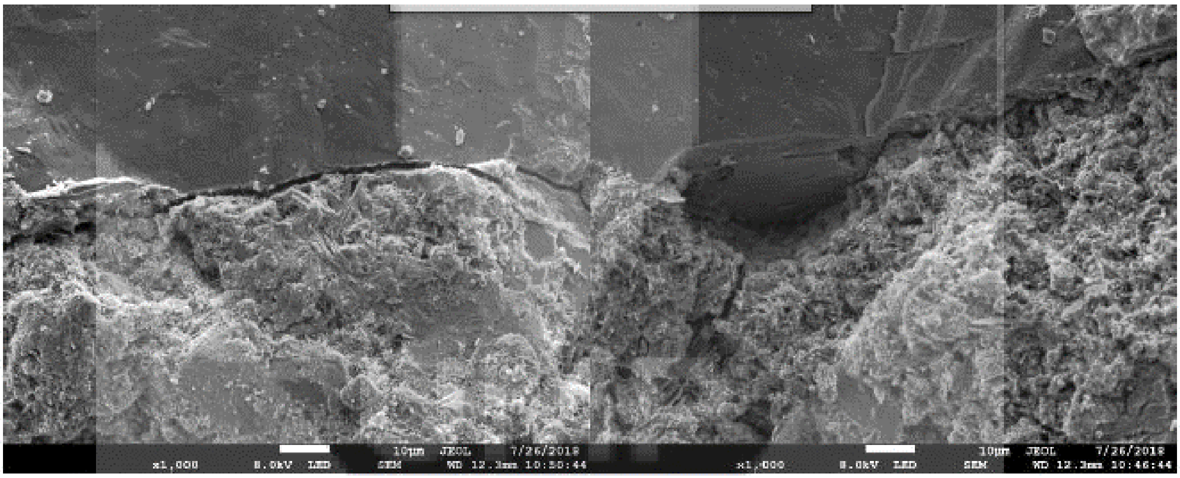

Figure 5. Microstructure of mortar mixture containing mineral admixture as reported by [21]

Furthermore, Choudhary et al. [77] investigated the mechanical characteristics of SCC, which incorporates silica fume and fly ash with relevance to compressive strength, splitting tensile strength, and flexural tensile strength. Based on the results, the highest volume fly ash content results in an increased compressive strength at 28 to180 curing days. This result confirmed the persistence of fly ash pozzolanic action throughout time, although tensile strength diminished as the fly ash concentration increased. Meanwhile, replacing cement with the constant percentage of silica fume has enhanced and maintained the SCC tensile strength, having a large volume of fly ash. Additionally, the unit weight of SCC mixes dropped because fly ash and SF have lower specific gravity than cement [77].

In the same vein, Wongkeo et al. [87] examined the SCC compressive strength and chloride resistance when 50, 60, and 70% height calcium fly ash and SF were used in replacement of Portland cement. The results revealed that FA and SF improved the SCC chloride resistance if used in large quantities to replace cement. Likewise, Yazici et al. [75] examined the impact of replacing cement with FA at values ranging from 30% to 60% on the compressive strength, splitting tensile strength, modulus of elasticity of the SCC, utilizing 10% silica fume as a filler, and a fixed W/b ratio of 0.28. The findings show that adding SF increases the tensile strength of SCC at all ratios of FA substitution. Additionally, increasing FA to 50% substitution ratios has slightly influenced the SCC modulus of elasticity. De Matos et al. [76], on the other hand, reported the development of high strength with a high volume FA in SCC of a grade more than M 60 with a cement replacement of 40%-60% was investigated, as well as the durability characteristics. The results showed that MOE declined with increasing cement replacement levels, with MOE values of 37, 35, and 33 GPa for 40, 50, and 60% FA, respectively [76]. Table 4 summarizes previous researches on the impact of mineral admixture on the mechanical properties of SCC.

Table 4. A Summary of Mechanical properties of mineral admixture in SCC

References	Type of mineral admixture	Replacement %	Compressive strength	Flexural Strength	Splitting Tensile Strength	Modulus of Elasticity
[63]	Fly Ash	0, 20%, 40%, and 60%	Decreased all substitution level	-	-	-
[87]		50%, 60%, and 70%	Decreased all substitution level	-	-	-
[75]		0, 30 %, 40% 50%, and 60%	Decreased all substitution level	Decreased all substitution level	Increased at 30%, substitution level	Increased at 30% substitution level
[76]		0, 40%, 50%, and 60%	Increased at 40% substitution level	-	-	Increased at 40% substitution level
[77]	Silica Fume	0, 5%	Increased all substitution level	Increased all substitution level	Increased all substitution level	-
[78]		0%, 10%	Increased at 10% SF mixed with 65% FA substitution level	-	Increased at 10% SF mixed with 50% FA substitution level	Decreased all substitution level
[79]		0,5%,10%, 15%	Increased at 5% SF substitution level	-	Increased at 5% SF substitution level	Increased at 5% SF substitution level
[88]		50%, 75%, and 100%	Decreased all substitution level	-	Decreased all substitution level	-

Table 4. A Summary of Mechanical properties of mineral admixture in SCC (cont.)

References	Type of mineral admixture	Replacement %	Compressive strength	Flexural Strength	Splitting Tensile Strength	Modulus of Elasticity
[67]	Coal Bottom Ash	0,10%, 20%, 30%, 40%	Increased all substitution level	Increased all substitution level	Increased all substitution level	-
[80]		0, 10%, 15%, 20%, 25%, and 30%	Increased at 15% CBA substitution level	Increased at 15% CBA substitution level	Increased at 15% CBA substitution level	-
[64]		0, 10%, 20%, and 30%	Decreased all substitution level	-	Decreased all substitution level	-
[24]		5%, 10%, 15%, 20%, 25% and 30%	Increased at 5% and 10 % CBA substitution level	Increased at 5%, and 10% CBA substitution level	Increased at 5% and 10 % CBA substitution level	
[84]	GGBS	0, 5%, 10%, 15%, and 20%	Increased all substitution level	Increased all substitution level	Increased all substitution level	-
[28]		0,10%, 20%, and 30%	Increased all substitution level	-	-	Increased all substitution level
[71]		0,15%,20%, 25%, and 30%.	Increased all substitution level	Increased all substitution level	Increased all substitution level	-

INFLUENCE OF MINERAL ADMIXTURE ON THE DURABILITY PROPERTIES IN SCC

Durability can be described as the structure's ability to maintain the required behavior under the impact of degradation elements throughout the specified service time. Typically, concrete is a long-lasting material that needs little or no conservation of the building period [6]. The SCC durability depends upon the mixture's design ratios, the craftsmanship of the job, the placement and compaction of the concrete, and the mechanical characteristics of the concrete. The concrete's chemical resistance can be identified by the utilized materials, weather action can be enhanced further via adding air bubbles to the concrete mix [6]. Siddique et al. [89] studied the SCC durability properties, with CBA at various replacement percentages up to 30%. The findings showed an increased water absorption, as well as sorptivity of the SCC mixture when the percentages of substitution are increased. Water absorption values ranged between 5.8 and 7.1 percent for all SCC mixtures either with or without CBA. The sorptivity values for all SCC mixtures either with or without CBA ranged from 0.055 to 0.0145 [89]. Similar observations were made by Wan Ibrahim et al. [82] as they reported the properties of SCC with CBA as fine aggregate substitution from 10% to 30% with a fixed water/binder ratio of 0.40. The rapid migration tests showed that when displayed to saltwater in wetting-drying cycles, SCC with 10% BA exhibited excellent resistance to the chloride ion migration. The carbonation's depth has been decreased by 4.5% when CBA at 10% has been incorporated into SCC versus the original mixture sample at 180 curing days. However, the carbonation depth was greater at the substitution ratios of 15%, 20%, 25%, 30%. [82]. The delayed pozzolanic reaction has outweighed the increased porosity, and the pozzolanic reaction has densified the pore structure because of CBA presence in the concrete mix [90].

On the other hand, an experimental study by Benli et al. [91] examined silica fume and fly ash impact on the SCC durability characteristics mixes at 7, 28, 180 days. The findings showed that although the sorptivity coefficients of binary FA mixtures increased as the substitution level increases, a small reduction in FA 25% after 28 days of curing could be seen due to the addition of FA increasing the large pore content. The SF substitution ratio in binary supplementary cementitious materials mixtures, the sorptivity coefficient reaches a maximum of 3.41*103 $cm/s^{0.5}$ at SF 5% doses and a minimum of 2.96*103 $cm/s^{0.5}$ at SF15%. Additionally, as the proportion of FA added increased, porosity and water absorption increased as well [91]. Çelik et al. [92] reported a high electrical resistance of SCC with silica fume and fly ash [92]. This is because the pozzolanic reaction happened at lower rates, but this has led to a lower ultimate absorption capacity due to decreased pore connectivity and porosity [93]. In [75], the researchers have synthesized a high-strength SCC using a high-volume FA with 10% SF, and when compared with the conventional concrete, their SCC demonstrated superior durability regarding the chloride permeability and the freeze-thaw resistance. It has been found that when SF is used to substitute 10% of OPC, SF substantially improved the carbonation resistance of SCC integrating various amounts of recycled concrete aggregate as a substitute for natural aggregates [75]. This increased durability could be attributed to the superior quality of SCC compared with the conventional concrete and the pore refining capabilities of SF. As a result, a concentration of SF of 10% may be considered optimal to be used in SCC. Also, the OPC substitution amount with SF is consistent with many guidelines as mentioned by [94].

An experimental study by Dadsetan et al. [28] reported that shrinkage has been enhanced when GGBS and FA were increased as replacement materials in SCC but kept rising once SF was added. The SF ternary and quaternary systems resulted in a reduction in drying shrinkage [28]. Another study by Druta et al. [95] showed that SCC exhibited a reduced micro-crack at the aggregate–mixture friction compared to the standard concrete. Also, SCC featured fewer and more circular air gaps than conventional vibrated concrete [95]. Altoubat et al. [96], for example, showed that the GGBS concentration and curing regime had a substantial effect on the SCC's cracking potential regardless of the restriction degree. GGBS at 50% - 70% may be utilized in structural elements with a high or low degree of constraints, respectively, after a seven-day wet curing period. With three days of wet curing at a higher degree of constraint, the combined FA with GGBS improved the SCC's cracking resistance [96]. MK has a high C–S–H gel concentration with a greater water-cement ratio. Based on the EDS analysis in Figure 6, it can be observed that MK had a greater influence on the transitional zone's micro-structural strength than GGBS and the reduced Ca/Si ratio indicated an increase in compressive strength [28].

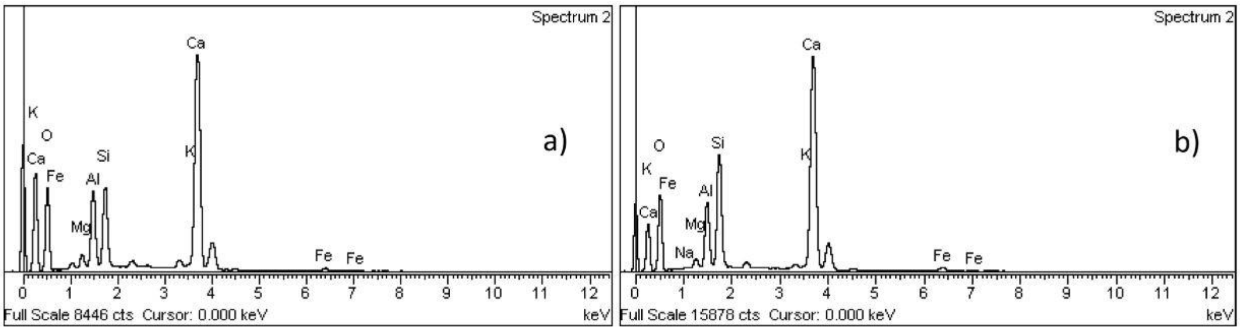

Figure 6. EDx analysis for GGBS in SCC as reported by [28]

CONCLUSION

Based on the conducted review in this study, the development of SCC can be investigated by utilizing various kinds of mineral admixtures, particularly by utilizing industrial by-products from industry to mitigate environmental impacts. The current findings focused on the influence of admixtures like silica fume, fly ash, GGBS, and CBA on fresh mechanical, as well as durability characteristics of SCC. This review study presented the results of previous studies. The following conclusions are drawn based on reviewing previously published studies:

1. Self-compacting concrete improves concrete quality and eliminates the need for on-site maintenance. It reduces construction time, decreases overall costs, and improves health. Avoiding handling vibration ensures safety.
2. Self-compacting concrete can be regarded as an ecologically friendly concrete in comparison with other technologies of concrete because it has the capability of reducing energy consumption, as well as environmental pollution.
3. Silica fume increased the demand for superplasticizers to enhance their strength characteristics, while also enhancing their fresh properties. Also, the ultimate absorption has been reduced by using silica fume. Together with other admixtures, silica fume enhanced the pore structure.
4. Previous studies have shown each admixture is partly replaced with cement or aggregate in varying amounts. If the limit is set too high, it influences compressive strength, splitting tensile, as well as the flexural strength of concrete, in addition to the concrete's durability.
5. The incorporation of these mineral admixtures into SCC has resulted in a reduction in cement use, thus indirectly reducing CO_2 emissions and the greenhouse impact. By using industrial waste as a partial cement or aggregate replacement material, we may also help preserve the soil from contamination and deterioration.

RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the findings of this research, literature gaps have been identified. Therefore, it is recommended that further studies concentrate on the following areas:

1. The previous review studies showed that the advancement of SCC can still be explored via using mineral admixtures to create environmentally friendly solutions in the SCC application
2. The utilization of recycled products and materials can come into existence in SCC, which can be part of the investigated design efficiency, practicability, and economic value.

3. This endeavor aims to provide efficient solutions in the concrete's technology, thereby providing greater advantages with relevance to the potential economic value in the industry and the whole local community due to significant indirect effects and due to the mechanical and physical characteristics.
4. Further review studies are required to identify the optimum mix of materials to obtain the maximum strength possible from this material when used in construction.
5. The utilization of mineral admixtures in the production of various types of SCC contributes to reducing the exploitation of natural resources required for SCC manufacturing, while also limiting the number of mineral admixtures (by-product waste from the industry), which would otherwise be disposed of as an environmentally polluting waste.
6. Significant improvements can be achieved to facilitate future concrete technology developments. Further studies should, therefore, be conducted to identify the optimum mix of materials so that the maximum strength can be obtained from the utilized materials in concrete applications.

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