A review: Mechanical Properties of Self-Compacting Concrete (SCC) and Influential Factors

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Abstract

Self-compacting concrete (SCC) has emerged as a promising construction material due to its unique characteristics of high flowability and self-leveling ability without needing external compaction. In this study, the mechanical properties and influential factors of SCC were analyzed to determine their impact on the overall performance of the material. The properties analyzed included compressive strength, flexural strength, split tensile strength, and modulus of elasticity. The influential factors included the water-to-binder ratio, type and dosage of superplasticizer, aggregate size and shape, and curing conditions.

The results of this study indicate that influential factors greatly influence the mechanical properties of SCC. A lower water-to-binder ratio leads to higher strength and lower permeability of the material. The use of a high-range water-reducing superplasticizer in the proper dosage can significantly enhance the workability and strength of SCC. The size and shape of aggregates can also affect the flowability and homogeneity of SCC, with smaller and more rounded aggregates yielding better results. Proper curing is critical to achieving the desired properties of SCC, with moist curing being the most effective.

Keywords: Self-Compacting Concrete; Mechanical Properties; Influential Factors of SSC; Mineral Admixtures; Chemical Admixtures

1 Introduction

Self-compacting concrete (SCC) is an innovative concrete that has great properties and does not require vibration for placement and compaction. Poor compaction or segregation may result in insufficient uniformity of the cast concrete, significantly reducing mature concrete's performance in situ. SCC was created to make sure that concrete was adequately compacted and to make it easier to pour concrete in buildings with crowded reinforcement and in confined spaces.

Concrete that compacts on its own is also known as quiet concrete and self-consolidated concrete. Limiting the water-cement ratio (w/c), adding a good plasticizer, increasing the sand aggregate ratio, and adding some material pozzolanic admixtures like fly ash, GGBFS, silica fume, stone powder, etc. are all ways to get SCC. SCC will enable the mass production of concrete structures and increase their quality, dependability, and durability while also removing human error. It can take the place of hand compacting of new concrete and enhance site security [1], [2].

To create long-lasting concrete structures, construction engineers have been particularly interested in the issue of the strength performance of structures for a number of years. SCC to attain durable concrete structures, Japanese professor Okamura (Kochi University) first introduced the concept in 1986. The first SCC mix, which utilized the same raw ingredients as normal vibrated concrete (NVC), was finished in 1988 at the University of Tokyo [2]–[6]. The primary goals of using SCC during construction were to reduce the amount of time required, prevent accessing difficult-to-reach vibrating confined zones, and reduce vibration-related noise [7]. Bridges and even precast portions have been built with self-compacting concrete. The Akashi-Kaikyo Suspension Bridge is one of the most amazing constructions made with self-compacting concrete [6], [8], [9].

In this review, we concentrated on SCC's mechanical characteristics and the key elements that affect its overall effectiveness. Compressive strength, flexural strength, split tensile strength, and modulus of elasticity are some of the mechanical properties that were examined in this study. The durability and structural integrity of concrete are highly dependent on these characteristics.

For SCC to perform optimally in various applications, it is crucial to comprehend the important factors that have an impact on these properties. The deciding elements were the ratio of water to binder, the type and dosage of superplasticizer, aggregate size and shape, and curing conditions. The water-to-binder ratio significantly influences SCC's strength and permeability, with lower ratios producing higher strengths and lower permeabilities. The kind and quantity of superplasticizer significantly influence SCC's workability and strength. Additionally, the flowability and homogeneity of SCC are influenced by the size and shape of the aggregates, with smaller and more rounded aggregates providing the best results. Furthermore, the desired properties of SCC must be obtained under ideal curing circumstances, particularly moist curing.

This study aims to offer valuable insights for engineers and researchers in optimizing the design and performance of self-compacting concrete by reviewing and analyzing the mechanical properties and significant factors of SCC. Acquiring a better understanding of these elements will help to create concrete structures that are more dependable and long-lasting while also enhancing safety on the job site.

2 Definition of self-compacting high-performance concrete

There are various definitions of SCC in the literature. SCC can be defined, to a great extent, by its workability. Self-compacting high-performance concrete was defined in 1992 as follows at the three stages of concrete: [10]

Fresh: self-compactable

Early age: avoidance of initial defects

After hardening: protection against external factors

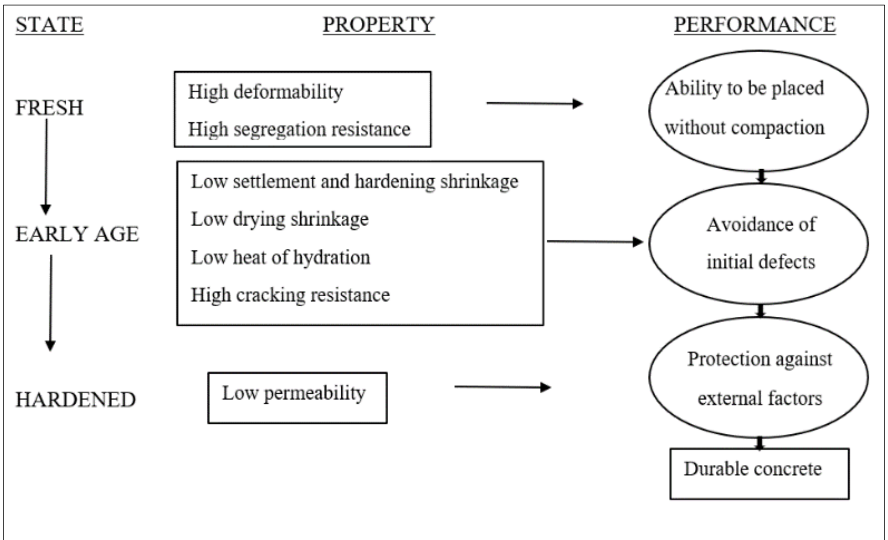

Figure 1: Definition of self-compacting high-performance concrete (After Okamura, 1992)

3 Application of SSC Briefly [11]–[15]

Self-Compacting Concrete Uses Self-compacting concrete has been used in bridges and even on precast sections. One of the most remarkable projects built using self-compacting concrete is the Akashi-Kaikyo Suspension Bridge. In this project, the SCC was mixed on-site and pumped through a piping system to the specified point, located 200 meters away. The construction time was reduced on this project from 2.5 years to 2 years. This type of concrete is ideal to be used in the following applications:

- Used for repair and rehabilitation of structures
- Used for retaining walls for highly durable and stable
- Used for construction pile foundations
- Used in the construction of raft foundation
- Used for complicated structures with steel
- Used in areas of pipes and conduits
- Columns
- Drilled shafts etc.

4 Mechanical Properties

This material is considered to have many advantages compared to conventional. In some cases, the cement content is replaced by other materials to improve durability, mechanical properties, reduce pollution and costs. [16] who has investigated the use of nanoproducts stating that it can improve the properties of concrete and increase its durability. According to the authors [17], these admixtures are classified into two main groups: mineral and chemical.

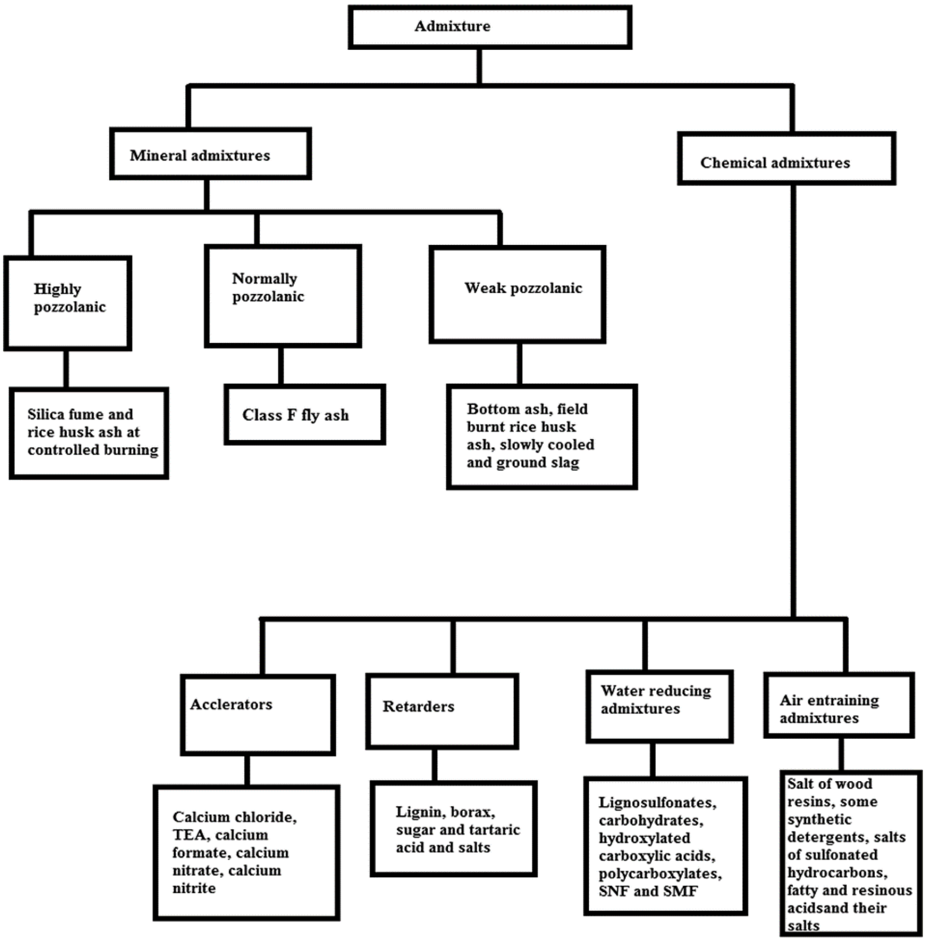

Figure – Classification of admixtures [17]

As mentioned before, there are other components involved in mixtures and therefore affect their mechanical properties: cement, water, and aggregates. Some examples of study mixes and variations are explained below regarding mineral admixtures.

4.1 Industrial byproducts admixtures

Industrial byproducts such as Ground Granulated Blast Furnace Slag (GGBFS), Silica Fume (SF), and Marble Dust (MP) in the preparation of HAC are being used as concrete mixes because, in addition to improving mechanical properties, have environmental advantages and are low cost. In 2018, [18] investigated it substituting ordinary cement for a SF content improved mechanical properties and durability. The authors [19] included other ideas, such as that the viscosity and yield strength decrease with increasing dose of GGBFS. Later, [20] also conducted experiments with three different fines. A novel conclusion was the improvement in durability against wear abrasion using both diabase and steel slag aggregate.

4.2 Rubber Aggregate (RA)

Regarding using ground elastic residues such as rubber in SCC, the authors' experiment[21] show that if the RA content is increased, the fresh properties improve. Instead, it decreases some of the properties like compressive strength and durability. Share these conclusions with the researchers [22] who studied mixes with granulated rubber (CR) generated from waste tires.

4.3 Other pozzolanic additives

[23] used metakaolin combined with limestone filler. It improves the mechanical properties and the durability of the HAC; also, it allows high workability and improves resistance at an early age. Years later, the study by [24], using metakaolin (MK) and recycled coarse aggregate (RCA), affirmed when the temperature increases, the residual resistance to compression, divided traction, and flexion decreases at all ages. Some chemical additives are used to improve the properties of this material, such as workability and curing time and temperature, curing time.

As explained in detail below, early age shrinkage in SCC has been a major setback in achieving the desired strength. SRAs used along with paraffin-based composites help to reduce cracking [25] these studies used Poly Carboxylate Ether (PCE) as SRA, showing that it has a similar effect in decreasing shrinkage as the use of SRAs. A specific example is the research of [26]which conducted a series of experiments with different concentrations of zinc oxide. Some conclusions are improving the pore structure had higher split tensile and flexural strengths.

There is a wide variety of waste materials that are used as a cement substitute in SCC [27] Such as nano-waste glass (NWG) and ceramics (NWC). Researchers [28] concluded that the flowability and viscosity of SCC decreased when these materials were increased. Both increased compressive strength (more NWG). Later, [29] included two further improvements found in microstructure and corrosion resistance by increasing these materials. Also, research by [30] concluded that mechanical properties were improved by using Glass Powder (GP) up to 20% cement substitution. Another option concerning the Nano-residues alternative proposed by [31] was medical radiology waste fibre (WMR), which reduces the fresh characteristics except for segregation resistance.

5 Influential Factors

5.1 Creep effect on self-compacting concrete

Creep affects the durability and safety of concrete structures, and in the case of prestressed concrete structures, it may result in prestress loss. The creep will cause the long-span beam's deflection to increase, which is detrimental to the structure. However, creep helps prevent concrete from cracking due to early shrinking. Early on, creep may reduce the tensile tension caused by shrinkage and temperature in the concrete, preventing the creation and progression of internal cracks. Therefore, it is crucial to rationally consider the expansion of concrete [32],[33]

5.2 Effect of shrinkage on the performance of SCC

The authors discussed that expansive cracking and capillary tension are considered as two main phenomena behind shrinkage in SCC. It is found that factors like a lower water/cement ratio or decreasing limestone filler/cement ratio lead to a reduction in autogenous shrinkage. Cracks cause specific problems like plastic shrinkage. The effect of shrinkage-reducing admixtures on SCC was observed to be positive. Shrinkage-reducing admixtures, along with paraffin-based curing compounds, helps in reducing cracks [34].

5.3 Factors influencing fire spalling of SSC

Several factors influence the risk and magnitude of fire spalling of concrete. The following ones have been identified as most important:

- Moisture content (higher content increases spalling)
- Permeability usually expressed as w/c or an equivalent w/c (lower w/c increases spalling)
- Powder content (powder: particles < 0.063 mm, higher content increases spalling)
- Compressive stresses (also small stresses increase spalling)

- Important findings are also that the addition of polypropylene fibers could expunge the spalling behavior [35], [36].

5.4 Influence of fly ash and steel fiber content on fresh and hardened properties of SSC

The mineral admixture of fly ash (FA) is important for preventing segregation and bleeding and increasing workability. Furthermore, adding steel fibers to SCC improves the properties of hardened concrete, but it also decreases the workability properties of fresh concrete. The authors investigated with adding fly ash (FA) as a partial replacement of cement (30% of cement mass) and hook-end steel fiber (HSF) to check the Influence of steel fiber and fly ash to the above statement. Their results showed that FA improved the workability of SCC. On the other hand, utilizing 60 mm, HSFs enhanced the properties of hardened concrete but reduced their workability [37].

5.5 Influence of cracks on the properties of SSC

The authors conducted research to check the Influence of cracks on SSC, and they proved in their paper the great Influence of the presence of cracks in the structure of the material on its mechanical and also water transport parameters. Values of compressive strength lowered significantly, and the resistance to the intersection and transport of water was also considerably worse for both used additions [38].

5.6 Effect of fire and high temperature on the properties of SSC

The authors showed the effect of high temperature on the properties of self-compacted concrete (SCC). Results from several tests show that the mechanical properties decreased with increasing temperatures. The mechanical properties of SCC cooled gradually are better than that cooled suddenly by water. For gradually cooling, the compressive strength at 200℃ was increased by (5.7%) of its reference compressive strength, and the reduction in splitting tensile strength was 26.67%, 44.17%, and 58.46% of its initial splitting tensile strength at 200℃, 400℃ and 600℃ respectively. The percentage of the reduction in flexural strength was (42.9%, 66.20%, and 88.87%) of its initial flexural strength at 200℃, 400℃, and 600℃. The bond strength decreases with increases in the temperature of the furnace using gradually cooling. The reduction in bond strength was 7.39%, 16.94%, and 29.74% of its initial bond strength at 200℃, 400℃ and 600℃ respectively [39]–[41].

5.7 The Influence of coarse aggregate size and Volume on the fracture behavior and Brittleness of SSC

The results of the authors' investigation into the brittleness and fracture characteristics of SCC revealed that as the size and content of coarse aggregate increases, (a) the fracture energy increases due to a change in fractal dimensions, (b) the behavior of SCC beams approaches the strength criterion, and (c) characteristic length, which is regarded as an index of brittleness, grows linearly. It was discovered that fracture energy rises as the w/c ratio decreases, which may be explained by an improvement in the structure of the transition zone between the aggregate and paste [42],[43]

5.8 Influence of mineral admixtures on SCC

The strength of mechanical properties is significantly influenced by the characteristics of SCC in the fresh condition, making them crucial. The full filling of the formwork and correct enclosing of the reinforcement (even in severely reinforced spots) without vibration are key components of the SCC's major features in the fresh condition. These properties prevent any cracks or separation from occurring in the cast as a whole. Additionally, because of its excellent fluidity, SCC has a remarkable capacity for flowing as a "viscous fluid" and for passing through reinforcing bars [44], [45]. Taking into account the constraints of EFNARC [46] (the European Federation of National Associations Representing for Concrete), Nataraja et al. [47] developed a straightforward method to construct SCC in accordance with strength criteria by making minor changes to the IS 10262:2009. The compressive strength and the SCC water cementitious proportion were connected using 25 mixture ratios [47].

5.8.1 Influence of mineral admixture on the mechanical properties in SSC

This study summarizes the results of earlier studies that investigated the effects of adding mineral admixtures like fine or coarse aggregate and cement to SCC on flexural strength, compressive strength, elastic modulus, and splitting tensile strength [48], [49]. In a study by Keerio et al. [50], in-depth laboratory research was done on 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 results showed strength characteristics, with replacement levels ranging from 10% to 30%. At 28 curing days, it is obvious that the ideal compressive strength, 41.5 MPa (14.5%), increased compared to the samples from the control mixture. This happened as a result of the concrete matrix's pozzolanic reaction to the coal bottom ash and its porous refinement. 40% of the CBA was replaced at a high percentage, and after 180 days of curing, the samples, compared to the typical control mixture, had stronger strength characteristics. The strength of coal ash is shown in Figure 4 at the following 3, 28, and 180 curing days [50]. Another finding was made by Siddique et al. [51] who discovered that when fine aggregates were used in place of CBA at 0%, 10%, 20%, and 30%, the compressive, flexural, and splitting tensile strengths, as well as the modulus of elasticity (MOE), were all reduced at the end of the 28-day curing period. According to the results of the CBA comparison tests in SCC, the CBA aggregate replacement's increased porosity caused a delayed pozzolanic reaction, which resulted in reduced strength [52]. Previous studies supported the use of CBA in the SCC mixture at appropriate percentages of 10% to 20%, which improved compressive strength properties[53], [54].

5.8.2 Influence of mineral admixture on the durability properties in SSC

The capacity of a structure to sustain the desired behavior while being subjected to degradation factors over the duration of the defined service time is known as durability. Concrete often has a long lifespan and requires little to no preservation during construction [55]. The mixture's design ratios, the work's quality, the concrete's placing and compaction, and the concrete's mechanical properties all affect how long the SCC will last. The ingredients used can be used to determine the concrete's chemical resistance, and adding air bubbles to the concrete mix can further improve weather action. The SCC durability characteristics were investigated by Siddique et al. [56] using CBA at various replacement percentages up to 30%. According to the results, increasing the replacement percentages causes the SCC mixture's sorptivity and water absorption to increase. The water absorption values varied from 5.8 to 7.1 percent for all SCC mixes, CBA or not. All SCC combinations, whether they contained CBA or not, had sorptivity values that ranged from 0.055 to 0.0145 [56]. Wan Ibrahim et al. [53] reported the characteristics of SCC with CBA as fine aggregate substitution from 10% to 30% with a fixed water/binder ratio of 0.40 and made similar observations. The fast migration experiments revealed that SCC with 10% BA exhibited outstanding resistance to chloride ion migration when exposed to seawater in wetting-drying cycles. When CBA at 10% was added to SCC instead of the original combination sample after 180 days of curing, the depth of carbonation was reduced by 4.5%. However, the carbonation depth was larger for the substitution ratios of 15%, 20%, 25%, and 30%[53]. Due to the presence of CBA in the concrete mix, the delayed pozzolanic reaction has densified the pore structure and outweighed the increase in porosity [57]–[60].

5.9 Influence of M-Sand in SSC with the addition of Steel fiber in M30 grade

The effect of using manufactured sand (M-Sand) in self-compacting concrete (SCC) with steel fibers is examined by the authors [61]. The experiment was carried out by creating SCC mixes with varying amounts of steel fiber and M-Sand replacement. The SCC mixes' workability, compressive strength, split tensile strength, flexural strength, and durability were all assessed for both their fresh and hardened properties.

The study's findings show that using M-Sand in SCC along with steel fibers improves the material's mechanical characteristics. The study discovered that adding steel fibers can improve the compressive, split tensile, and flexural strengths of the SCC mix and that using M-Sand can significantly improve the workability of the SCC mix. The study also discovered that the addition of M-Sand and steel fibers had no appreciable impact on the SCC mix's durability. The study's findings suggest that using M-Sand in SCC along with steel fibers can produce an SCC mix with improved mechanical properties. The results of this study can be used to design SCC mixes with steel fibers and M-sand for a variety of construction applications, particularly for the building of high-rise structures, bridges, and other infrastructure projects.

5.10 Influence of the properties of SSC on the effect of air entrainment

The authors examine the effect of self-compacting concrete's (SCC) slump flow, viscosity, and yield stress on the efficiency of air entrainment in SCC[62]. The study discovered that the rheological characteristics of the concrete, particularly its yield stress, had an impact on the efficiency of air entrainment in SCC. The air content decreases with increasing SCC yield stress, which reduces air entrainment efficiency. In order to attain the appropriate air content and increase the durability of concrete buildings, the study emphasizes the significance of considering the rheological features of SCC when constructing air-entrained SCC mixtures.

5.11 Influence of silica fume on the properties of SSC

According to the study [63], adding silica fume to SCC increased its compressive strength, flexural strength, and splitting tensile strength. The filler effect of silica fume, which fills the holes in the concrete matrix and improves its densification, is responsible for the increase in strength. Additionally, silica fume usage decreases the porosity and permeability of SCC, improving durability and resistance to chloride ion penetration. The study also demonstrates how several elements, including cement type, water-to-cement ratio, and superplasticizer concentration, affect the ideal dosage of silica fume in SCC mixtures. Overall, the article emphasizes the major impact silica fume has on the characteristics of SCC and demonstrates its potential as a successful mineral additive to improve SCC performance.

5.12 Influence of waste copper slag on flexural strength properties of SSC

The effect of using waste copper slag as a partial replacement for fine aggregate on the flexural strength of self-compacting concrete (SCC) is the main Influence of the study [64] of waste copper slag on flexural strength attributes of self-compacting concrete. The findings demonstrated that the flexural strength of SCC reduced as the amount of copper slag in the mixture increased. However, the workability of SCC was not considerably impacted by the addition of up to 40% copper slag as a partial replacement of fine aggregate. The study found that using waste copper slag as a partial replacement for fine aggregate in SCC without sacrificing its workability and strength attributes can be a viable solution for sustainable development.

5.13 Influence of carbon fibers on strain and damage sensing of SSC under external applied forces

The analysis of carbon fibres' effects on the strain and damage sensing of self-compacting concrete (SCC) under externally applied forces is the primary contribution of this research [65]. According to the study, adding carbon fibres to SCC increases the concrete's electrical conductivity while lowering its resistance. By measuring changes in electrical characteristics enables the detection and monitoring of the occurrence and spread of cracks and damage in the concrete. The study also demonstrates that the addition of carbon fibres significantly impacts the mechanical characteristics of SCC. The inclusion of carbon fibres improves the SCC's overall performance under external loads by increasing its tensile strength and elastic modulus. The study also emphasizes the potential of employing SCC reinforced with carbon fibre as a structural material with built-in damage-detecting capabilities.

5.14 Effect of glass fibers on self-compacting concrete

The article [66] examines the effects of introducing glass fibres on the properties of self-compacting concrete (SCC) when it is fresh and hardened. By lowering the yield stress and plastic viscosity of the mixture, the study shows that the addition of glass fibres improves the workability of SCC. The fresh qualities were shown to be significantly influenced by the fibre content, with larger fibre contents resulting in greater workability. The SCC's compressive strength and flexural strength were increased as a result of the addition of glass fibres in terms of their toughened qualities. Another finding of the study was that the addition of glass fibres reduced the drying shrinkage and water absorption of SCC. The majority of the research points to the possibility that adding glass fibres to self-compacting concrete is a practical technique to increase its mechanical strength and durability.

5.15 Effect of internal curing on the performance of SSC by using sustainable materials

The impact of internal curing on the functionality of self-compacting concrete made using sustainable resources is covered in the article [67]. The study discovered that the inclusion of internal curing agents, such as lightweight particles and superabsorbent polymers enhanced the mechanical qualities of self-compacting concrete. The concrete's shrinkage and cracking were also lessened as a result of internal curing, which may have increased longevity. The environmental performance of self-compacting concrete was enhanced by using sustainable ingredients like fly ash and recycled aggregates. According to the study's findings, self-compacting concrete's performance and sustainability can be enhanced through internal curing utilizing sustainable ingredients.

5.16 Other factors affecting self-compacting concrete [68]

These factors can affect the behavior and performance of self-compacting concrete:

- Hot weather.
- Long-haul distances can reduce the flowability of self-compacting concrete.
- Delays on the job site could affect the concrete mix design performance.
- Job site water addition to Self-Compacting Concrete may not always yield the expected increase in flowability and could cause stability problems.

6 Conclusion

Self-compacting concrete has many advantages over conventional concrete and is a relatively new and promising material. SCC is the best material for intricate and crowded reinforcement structures because of its special flow and self-leveling characteristics. However, the water-to-binder ratio, superplasticizer dosage, aggregate size and shape, and curing conditions significantly impact the mechanical properties of SCC. These factors must be carefully controlled for SCC to have the desired strength, durability, and workability. In order to maximize the mechanical properties of SCC, future research can concentrate on creating new and more effective superplasticizers and perfecting the mix design.

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