SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V13I11P101

Volume 13 Issue 11, 1-15, November 2026
© 2026 Seventh Sense Research Group®

Original Article

Performance Evaluation of Self-Compacting Concrete with Varying Silt Percentages in Crushed Sand

Sarika P. Thombare[1], Arun Kumar Dwivedi[2], Ashwini Patil[3]

[1]*Department of Civil Engineering, Sandip University, Nashik, Ajeenkya DY Patil School of Engineering Lohegaon, Pune, Maharashtra, India.*
[2]*Department of Civil Engineering, Sandip University, Nashik, Maharashtra, India.*
[3]*Department of Civil Engineering, D.Y. Patil School of Engineering Akurdi, Pune, Maharashtra, India.*

[1]*Corresponding Author: sarika9922@gmail.com*

Received: 28 July 2026 Revised: 05 October 2026 Accepted: 20 October 2026 Published: 27 November 2026

Abstract *- Self Compacting Concrete (SCC) is an advanced concrete that can flow without external vibrating, fill congested reinforcement zones and provides complete compaction. The fineness of the fine aggregate used in SCC can have a significant effect on the fresh, mechanical and durability characteristics of SCC, especially if the fine aggregate comprises crushed sand that contains large amounts of silt. The aim of this study is to find out the influence of controlled silt content (3% to 15% crushed sand) on M30 grade SCC. Eight mixes were poured, one being the control mix (NSCC) and the other seven being of modified mixes with varying percentage of silt. Four fresh properties were tested using slump flow, T50 flow time, V-funnel and L-box tests. Mechanical properties were determined by compressive strength, flexural strength and split tensile strength tests, and durability properties were measured using water absorption, sorptivity and Rapid Chloride Penetration Test (RCPT). The fresh and hardened properties of SCCs were found to be negatively impacted with increase in silt content according to the results. The slump flow dropped from 690 mm to 550 mm, whereas the 28-day compressive, flexural and split tensile strengths were reduced from 39.2 MPa, 6.9 MPa and 4.2 MPa, respectively, to 30.5 MPa, 5.2 MPa and 3.2 MPa, respectively. Water absorption, sorptivity, and RCPT values increased with increasing silt content, indicating deterioration in durability performance and greater susceptibility to moisture and chloride ingress. The results show that the SCC up to 5% silt content was workable and met the strength and durability requirements, and that silt content over 7% led to some significant degradation in performance. The study defines a practically acceptable silt content limit for SCC with crushed sand that is produced using a structural grade.*

Keywords *- Self-Compacting Concrete, Silt content, Workability tests, Compressive strength, Flexural and tensile strength.*

1. Introduction

Self-Compacting Concrete (SCC) is the biggest contribution in the advancement of Concrete Technology in today's era. SCC can flow free of gravity, completely filling in formwork, pass through dense reinforcement and can be completely compacted without external vibration [1, 2]. These properties increase the productivity of the construction process, decrease manpower, minimize noise during placement and increase surface-finishing quality. Considering all these merits, it is gaining popularity in the manufacture of precast concrete, bridges, tunnels, high rise buildings and well-reinforced buildings. Optimization of the proportion of cementitious material and aggregate, the content of water and chemical admixture to ensure good passing ability, good filling ability and segregation resistance are essential to the success of SCC [3]. Fine aggregates are one of the constituents of SCC, which has a significant influence on the rheological behaviour and stability of SCC. The workability, viscosity and segregation resistance is highly affected by various parameters like particle-size distribution, grading, particle shape, surface texture and packing density. Optimization for packing can now lead to either an enhancement in flowability and decrease in the requirement for paste and segregation properties [4, 15].

The other previous studies also show that the properties of aggregates have significant effects on the permeability, mechanical strength and fracture of SCCs [5, 6]. In addition, the theoretical and experimental relationship between the fresh and hardened concrete properties and it's influenced due to particle packing and mixture proportions are mentioned [4, 7].

Apart from the unavailability of river sand resources, the increasing awareness about the pollution of natural river sand in environment has led to the use of Manufactured Sand (M-Sand) instead of the natural river sand [8]. Numerous studies have shown that M-sand can be successfully used as a natural sand in SCC without compromising the fresh, mechanical,

This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

rheological and durability properties [9, 10]. Moreover, there are some successful engineering projects that have been completed by using manufactured-sand SCC, for instance, a steel-tube molded concrete arch bridge with concrete-filled steel tubes [11].

But manufactured sand is much different from the natural river sand regarding of shape, angularity, surface texture, grading characteristics and fines content. Also, particle sizes, like microfines, stone dust and silt, which can be aroused in the crushing and screening process, can have a great influence in the behaviour of SCC. Zhu et al. [12] reported that manufactured sand has also microfines, which affect the yield stress and flowability of the cement paste. Similarly, Suriya et al. [13] pointed out the effects of manufactured-sand properties on the microstructural, mechanical and rheological properties of SCC. Li et al. [14] also performed experiments that investigated how the angularity of the aggregate affected the pumpability and fresh properties of manufactured-sand SCC and found that the amount of fine aggregate in the mixture also affected the results.

The packing of the particles can also be a very significant parameter influencing the SCC behavior. The study has shown that there are significant effects of the Fine Aggregate (FA) packing on the limits of paste rheological values and fresh state flow property [15]. It was also demonstrated recently that the manufactured sand may affect durability parameters, such as water absorption, sorptivity, chloride penetration resistance and pore structure property [16]. Furthermore, Jiang et al. [17] said that the addition of limestone filler with manufactured sand has a positive effect on the compressive strength and durability. Besides, the optimized property of aggregate and mixture proportioning have proven to increase the performance of high-strength SCC mixtures produced using manufactured sand [18].

The most important quality of Manufactured Sand is Silt/very fine particles. The effect of the effectiveness of a crushing process, the type of washing and the source of the parent rock (aggregate) can be significant with respect to the silt content. If the silt content is too high, the specific surface area of the aggregates should be high, water demand would be high, amount required of paste would be high, performance of water reducing/cementitious material would be impacted, packing performance would be affected, and viscosity and segregation resistance of the substance mix would be changed. Fresh and hardened properties of SCC can thus be affected.

A lot of researchers have talked about the prospects of improving the manufactured sand quality by grading modifications and classifications process. Anitha et al. [19] have stated that Manufactured Sand (MSCS), such as Air Classified Sand (ACS) and Wet Classified Sand (WCS) has proved to be quite significant in terms of durability of SCC in severe environments. In another study by Anitha and Ravi Kumar [20] similar result was obtained that the grade classified manufactured sand from both the methods has a significant effect on the durability of SCC. Other factors like the fineness content of sands, particle shape, type of sand crushers and grading are also available in the literature and have been mentioned in the recent studies that have an impact on the performance of manufactured-sand concrete [21, 22].

Studies on manufactured sand, aggregate grading, silt produced by microfines and techniques for microfines classification have been carried out, although the number of studies focusing on the permissible limits of silt in manufactured sand in SCC is relatively small [19, 20]. There is very little information available on the effects of controlled size specification of silt contaminants to the transport properties of cementitious materials: durability properties such as: water absorption, sorptivity and resistance to rapid chloride penetration.

To investigate the same, the present study focused on the effect of controlled silt addition of different crushed sand silt content percentage (3%, 7%, 15%) on the concrete performance of M30 grade was discussed here. Further testing was performed using a series of tests applied to the fresh concrete, slump-flow, T50 flow time, v-funnel, L-box tests, and a series of tests applied to the hardened concrete, compressive strength, split tensile strength, flexural strength, water absorption, sorptivity and rapid chloride penetration tests, as well as a series of hardness and durability tests. The aim of the study is: (I) to establish the relation between the silt content and the SCC performance on one hand, and (II) to determine the acceptable range of silt content for the crushed sand for use in SCC. The expected outcomes are to participate the sustainable use of manufactured sand in concrete construction, as well as participating in Quality Control at aggregate and SCC mix optimisation.

Although many studies have been conducted on manufactured sand, stone powder, microfines and aggregate grading in SCC, no study has been conducted to study the impact of controlled silt contamination in crushed sand on the performance of SCC. The authors did not study specifically on the percentage of M-sand replacement, while in the previous studies, it has concentrated on adding fillers to the concrete mix. There is a limited study which is focused on systematically adding silt into the concrete mix with a fixed concrete mix proportion. Besides, not much information is available on how silt affects the physical and durability properties associated with transportation, like water absorption, sorptivity and chloride permeability.

2. Literature Review

2.1. Manufactured Sand and Self-Compacting Concrete

The composition of the mixture should be optimized to obtain the optimum balance between filling ability, passing ability, viscosity and resistance to segregation of SCC. Given

the significant volume of fine aggregate in SCC, its fresh properties and hardened properties are significantly influenced by the grading, particle shape and fines content of the fine aggregate. So, the application of microfine materials, crushed stone fines and synthetic sand to prepare SCC has received a lot of attention. Based on the research of Zhang et al. [9], stone powder content, particle shape and aggregate grading have significant impacts on the rheological properties and fresh concrete performance of using produced sand in SCC. The conclusion of this study that the use of synthetic sand might be a viable alternative to natural river sand depends critically on the optimum mix design. In the same manner, Mahalakshmi and Khed [10] compared the performance of SCC in presence or absence of silica fume with the use of 100% manufactured sand. They discovered that the manufactured sand-based SCC gave better sustainability and workability, together with good strength. Hou et al. [11] successfully demonstrated that manufacturedsand SCC has acceptable fresh and toughened property when the fines content is controlled properly. In practice, so far, various engineering works, including concrete-filled steel tube arch bridges, have proved its suitability. A progression of microfines produced by created sand will be observed to change the characteristics of the cement paste that consequently change the rheology of the SCC, according to Zhu et al. [12] for their study on the effects of created sand microfines on the properties of cement paste.

2.2. Influence of Aggregate Characteristics on SCC Performance

The properties of the fine and coarse aggregates are extremely important in determining the performance of SCC. In their study on manufactured-sand SCC, Suriya et al. [13] found that the flowability, mechanical strength, and microstructural development are all greatly affected by the aggregate characteristics. According to their research, the rheological performance of SCC is greatly influenced by the aggregates' quality and properties. Just like the high impacts of aggregate angularity and stone powder content on the rheological properties and pumping performance of concrete, Li et al. [14] studied the pumpability of the manufactured-sand SCC. Another important parameter that affects the efficiency of an SCC is particle packing. Research in the packing density of fine aggregate particles has shown that optimal particle distribution will help achieve a higher packing density, low void content, and good stability of the rheology of particles [15]. Moreover, the study has showed that different properties of the particles, such as grading and packing, have significant impacts on the fresh SCC behaviour and the consumption of paste.

2.3. Durability Performance of Manufactured-Sand SCC

One of the many challenges modern infrastructure projects demand from SCC is its durability. To investigate the durability aspects, water absorption test, sorptivity test and chloride penetration test were performed by Suriya et al. [16] in order to look into the microstructural characteristics of the SCC produced by the artificial sand. They found that the aggregate properties are significant factors affecting the SCC properties related with transport and durability properties over the long term. It has been observed by Jiang et al. [17] that improving the compressive strength, chloride resistance, carbonation resistance, and refining the pore structure has improved in SCC made using manufactured sand made of limestone and filler made of limestone. Optimization of properties of aggregates to achieve best fresh, mechanical and durability properties for gaining excellent SCC performance was established by Liu et al. [18], who developed a high strength SCC made from artificial sand. Early studies on the use of classification and grading approaches to improve the quality of produced sand have recently been undertaken. Based on Anitha et al. [19] it was observed that the durability performance of SCC in hostile environments was improved by incorporating manufactured sands, which were air-classified and wet-classified. Anitha and Ravi Kumar [20] also found that quality of manufactured-sand shape leads to lesser permeability and more dispersion of the particles, thus having a great impact on the durability performance of SCC.

2.4. Influence of Fines Content and Rheological Behavior

The workability and rheological properties of SCC highly depend on the grade and amount of fines content in the system of aggregates and sand quality produced in the system. Nuruddin et al. [21] have found that the properties of workability and strength of SCC are highly affected by the amount of fine materials in the combination. Therefore, in order to maintain the ideal self-compacting properties, it is essential to adequately regulate fines. Similarly, when analysing the impact of produced sand on concrete, the manufacturing process, shape of the sand and quantity of fines content in the sand are the most significant factors affecting the water requirement, rheological properties and properties of hardened concrete [22]. To guaranty constant concrete quality, the authors stressed the need of monitoring and regulating the creation of tiny particles during manufactured-sand manufacturing.

2.5. Research Gap

Many studies have been conducted on the properties and effects of various parameters of SCC, including aggregate grading, particle packing, durability improvement in the mix, the use of manufactured sand and the use of microfines, but very few studies have addressed how the presence of regulated silt content in crushed sand would affect the performance of SCC. Previous studies have typically focused on the amount of manufactured-sand replacement, inclusion of stone powder, fine-tuning of the grade proportions and classification techniques rather than the effect of silt contamination as a separate variable. Controlling fines in manufactured-sand SCC was found to be important, as reported by Hou et al. [11], and effect of aggregate property and durability behavior was highlighted by Suriya et al. [16]. Similarly, the beneficial

effect of limestone fines on the durability and strength of concrete was reported by Jiang et al. [17]. In none of these investigations the effects of the prescribed silt content on fresh and hardened properties of SCC have been fully studied. Some of the important SCC performance parameters that are not well studied yet in the context of Silt content are: Hence, there is a huge scarcity of studies to find out the appropriate amount of silt required for the structural-grade SCC with crushed sand.

2.6. Novelty and Contribution of the Present Study

The current work aims to bridge this research gap by experimentally evaluating SCC mixes produced with varying amounts of regulated silt (0–15%) while maintaining the same mix design. This study is intended to deeply investigate the effect of controlled silt contamination on fresh, mechanical and durability properties of SCC. Most of the previous studies have focused on using manufactured sand as the replacement material, adding some stone powder, or optimizing the grading of the aggregate. The novelty of this study lies in the realistic limit imposed on crushed sand, which can be used in structural SCC applications, for the presence of silt. The research details a slump flow, flow time (T50), flow time (V-funnel), ratio (L-box), compressive strength, flexural strength, split tensile strength, water absorption, sorptivity, and chloride penetration resistance.

The findings are expected to provide guidance to define an acceptable silt content for structural concrete applications and offer numerical guidelines for selecting suitable and controlling crushed sand to produce SCC.

Table 1. Research gap and novelty analysis

Author	Main Focus	Limitation	Present Study Contribution
Zhang et al.	Manufactured sand SCC review	No controlled silt evaluation	Controlled silt investigation
Hou et al.	Stone dust in SCC	No threshold identification	Threshold determination
Suriya et al.	M-sand SCC	No isolated silt study	Isolated silt effect
Jiang et al.	Limestone filler SCC	Filler addition only	Actual silt contamination
Present Study	0–15% silt variation	Fresh + Mechanical + Durability	Practical silt limit

2.7. Comparison with Existing Literature

The findings of the present study corroborate previous studies conducted on the use of manufactured sand and microfines in SCC. Zhu et al. [12] found that the amount of manufactured sand microfines positively affects the yield stress of the cement paste, while the fluidity of the cement paste gets lower with the increase of manufactured sand microfines. The same reduction in slump flow was observed in the present study from NSCC to MSCC-15 of 690 mm to 550 mm, respectively, and an increase in T50 and V-funnel with an increase in silt content was observed. Similarly, Hou et al. [11] showed that the amount of fine particles in the aggregate system has a significant effect on the performance of manufactured-sand SCC.

The present study shows the decrease in mechanical properties, which is in accordance with Suriya et al. [13, 16], that mechanical and rheological properties of SCC are impacted because of high amounts of fine particles. For the present study, the compressive strength of the specimens decreased from 39.2 MPa to 30.5 MPa with the inclusion of different percentage of silt (from 0% to 15%), which corresponds to a decrease of 22.19% only with the inclusion of silt material. In contrast with the previous studies, which mainly concentrated on replacement level of manufactured sand, content of stone powder or microfines, the present study systematically evaluated controlled silt content of 3% – 15% for all other parameters of a mix remained same. Based on the results, mixes with silt proportions of up to 5% fulfil the tests for workability, strength and durability, while silt proportions greater than 7% result in significant loss of performance of the SCC. For this reason, a realistic silt content limit for CRS was used for the structural grade application in SCC mixes, and useful guideline for controlling silt content in CRS and SCC mixes were provided in the study.

3. Materials and Methodology

The properties of materials used in SCC are crucial for both the fresh and hardened properties. Ordinary Portland Cement (OPC 53 grade) was used as the cement as it has good early strength and hydration properties. The choice of fine aggregate was based on criteria of river sand (NSCC) and crushed sand having controlled silt content (3–15%) for MSCC mixes. However, the workability of the river sand as compared to the crushed sand with silt was seen to be better, and there was observed variation in workability and strength for this crushed sand with silt. Coarse aggregate was used was angular with 20 mm maximum size to ensure good interlock and strength.

The fly ash and GGBS were used as supplementary cementitious material to enhance the durability and reduce the heat of hydration, and increase the workability. The admixtures played an important role in achieving the desired properties of SCC. The high flowability was achieved by the addition of a superplasticizer (polycarboxylate ether-based), and the Viscosity Modifying Agent (VMA) helped to prevent segregation and bleeding to ensure stability without increasing the amount of water used. The water employed was potable and free from impurities, and the water binder ratio was kept constant (0.40). These materials offered the required workability, strength and durability and it was found that the key parameter that affected the performance of SCC was the silt content in the fine aggregate.

The main binding material was Ordinary Portland Cement (OPC 53 grade) with a specific gravity of 3.15, which conformed to IS 12269. For supplementary cementitious material, fly ash of Class F type (specific gravity of 2.20) & Ground Granulated Blast Furnace Slag (GGBS) (specific gravity of 2.90) were used. The primary chemical components of these cementitious applications were Silica (SiO_2), Calcium Oxide (CaO), Alumina (Al_2O_3), and Iron Oxide (Fe_2O_3), all of which play a role in the hydration and pozzolanic reactions as well as on long-term strength. By improving SCC particle packing density and durability properties, the use of fly ash and GGBS enhanced the qualities of SCC.

3.1. Mix Proportions

The mix proportions designed for the experimental programme were maintained in the binder content, coarse aggregate content and fine aggregate content and only the percentage of silt content of fine aggregate was altered to investigate its impact on the performance of the Self-Compacting Concrete (SCC). A quantity of 400 kg/m³ of cement, 800 kg/m³ of coarse aggregate and 1350 kg/m³ of fine aggregate were kept constant for all the mixes. The amount of total binder used (400 kg/m³) consisted of 280 kg/m³ OPC, 60 kg/m³ fly ash and 60 kg/m³ GGBS. The ratio of water-to-binder was fixed at 0.40 while the percentage of superplasticizer added was fixed at 1.0% of binder, and percentage of Viscosity-Modifying Agent (VMA) added was kept at 0.10% of binder for getting the required workability and flowability. The natural river sand was used as control mix (NSCC), and crushed sand adjusted with different volume percentage of silt (MSCC-3 to 15, at 2% increments) was used for the modified SCC mixes (MSCC-3 to MSCC-15). A systematic variation was made possible, which allowed for a direct comparison of the mechanical properties and workability of normal SCC and silt-modified SCC, assisting the search for an optimum mix design for use. Mix Proportions of SCC with Silt Variations shown in Table 2.

3.2. Characterization of Silt

The silt material in this study was collected as crushed sand from a nearby quarry. According to IS 383:2016, the fine material passing through the 75 μm sieve is considered as silt or deleterious fines in fine aggregate. In the present study, the silt fraction was separated and incorporated into crushed sand at controlled percentages ranging from 3% to 15%. The silt content was calculated as a percentage of the fine aggregate using dry mass, and it was added by substitution of the same amount from crushed sand in the fine aggregate content of all mixtures, which is kept constant at 1350 kg/m³. The controlled silt contents investigated were 3%, 5%, 7%, 9%, 11%, 13%, and 15%. The aim was to investigate the individual effect of varying the content of silty material on the fresh, mechanical and durability characteristics of Self-Compacting Concrete (SCC). The higher content of silt (SSA) will increase the SSA of fine aggregates, which potentially affects water demand, flowability, packing density and permeability properties of SCCs. It was possible, therefore, to verify the effect of varying the silt content on concrete performance at constant mix composition.

The fine aggregate and coarse aggregate used in this research were crushed sand with a specific gravity of around 2.65 and crushed stone with a maximum size of 20 mm and specific gravity of around 2.70, respectively. The sand used for controlled addition was made from crushed rocks and was sieved and procured for this purpose. The silt was non-plastic silt with high surface area, that affected the water requirement, packing conditions and permeability properties of SCC mixtures. Crushed sand has been withdrawn from the fine aggregate mix for the same amount of silt added in those fine aggregates that produced the controlled silt contents, keeping the total amount of fine aggregate constant during the experimental programme. The silt content reported in this study represents the percentage by mass of particles passing the 75 μm sieve relative to the total fine aggregate content.

Table 2. Mix proportions of SCC with silt variations

Mix ID	Cement (kg/m³)	FA (kg/m³)	GGBS (kg/m³)	Total Binder (kg/m³)	Coarse Aggregate (kg/m³)	Fine Aggregate (kg/m³)	Silt Content (% by sand)	W/B Ratio	Superplasticizer (% binder)	VMA (% binder)
NSCC	280	60	60	400	800	1350	0	0.40	1.0	0.10
MSCC-3	280	60	60	400	800	1350	3	0.40	1.0	0.10
MSCC-5	280	60	60	400	800	1350	5	0.40	1.0	0.10
MSCC-7	280	60	60	400	800	1350	7	0.40	1.0	0.10
MSCC-9	280	60	60	400	800	1350	9	0.40	1.0	0.10
MSCC-11	280	60	60	400	800	1350	11	0.40	1.0	0.10
MSCC-13	280	60	60	400	800	1350	13	0.40	1.0	0.10
MSCC-15	280	60	60	400	800	1350	15	0.40	1.0	0.10

3.3. Mix Procedure

All SCC batches were mixed in a systematic way to assure uniformity and repeatability for various silt content. Preparation of Coarse Aggregate and Fine Aggregate was done in above order, coarse aggregate and fine aggregate was first added to the pan mixer, then dry mixing was done for 1 minute to obtain homogeneity. This was followed by adding the cement and mixing with the aggregates, and water was dripped in, together with the superplasticiser and Viscosity Modifying Agent (VMA) to bring it to the desired workability. A uniform, cohesive, flowable mix was obtained by continuing the mixing for three to five minutes. The special attention was taken during segregation and bleeding to try to prevent this, and a new SCC, with good self-compacting properties, was used without any external vibration. The same approach was used throughout for the control mix (NSCC) and all the Modified SCC mixes (MSCC-3, MSCC-5, MSCC-7, MSCC-9, MSCC-11, MSCC-13 and MSCC-15), where the only difference between the mixes was the amount of silt content in the fine aggregate, allowing the performance of the various mixes to be compared directly.

3.4. Specimen Casting and Curing Process

The fresh SCCs were cast in standard moulds without vibration for each mix, and its performance was studied for the self-compacting and structural performance. Cube, cylindrical and prism samples of 150 mm, 150 mm × 300 mm and 100 mm × 100 mm × 500 mm were used for the tests of compressive, splitting tensile and flexural strength, respectively. The flowability of the SCC also allowed for a single pour of the mix, without any cold joints or inconsistent compaction. The casting and then positioning on plastic sheets to stop the loss of moisture from the specimen was done, and casting was demolded after 24 hours. Afterward, all were cured in the same manner, under controlled laboratory conditions (27 ± 2 °C; 95% RH) to maintain the same degree of moisture. In order to make a reliable comparison of the mechanical properties of the control mix (NSCC) and the Modified SCC (MSCC-3 to MSCC-15), the same curing regime was used in both.

3.5. Testing Procedure for Mechanical Properties

The mechanical properties of the SCC mixes were evaluated by conducting conventional testing of the mixes prepared from each mix proportion. C cube samples (of 150 mm) were tested at 7 and 28 days for their compressive strength in a calibrated compression testing machine. Splitting tensile strength of cylindrical specimens of size 150 mm × 300 mm were determined when tensile stresses were imposed on the specimen in the vertical plane. The two-point loading of prism specimens (100 mm × 100 mm × 500 mm) was employed to evaluate the flexural strength (modulus of rupture). Appropriate IS codes were followed for accuracy and repeatability of all tests performed. This systematic test procedure facilitated a detailed comparison of mechanical performance among Normal SCC (NSCC) and Modified SCC mixes (MSCC-3 to MSCC-15), and enable the influences of silt content on the development of strength and structural performance to be revealed.

3.6. Testing Standards

Experimental studies were undertaken in compliance with the standards set nationally and internationally, to ensure the reliability, consistency and ability of comparisons. EFNARC (2005) guidelines for SCC were followed to determine the fresh properties - slump flow of SCC, flow time (T50), v-funnel flow time (Vf) & L-box passing ability. The mechanical properties were studied in the standard test methods, and compressive strength, flexural strength, and split tensile strength were tested as per IS 516:2018, IS 5816:1999 and IS 517:2006, respectively. Internationally accepted ASTM standards were used to evaluate the parameters related to the durability aspects. The water absorption was measured pursuant to the ASTM C642, the sorptivity was determined in accordance with ASTM C1585, and chloride ion penetration resistance was performed in accordance to ASTM C1202 (Rapid Chloride Penetration Test). The application of these standardized testing systems gave the possibility to evaluate SCC mixtures with different percentages of silt with a reliable method of assessing both the fresh and mechanical performance and the durability of the fresh mixtures.

4. Results and Discussion

4.1. Workability

The slump flow, T50 flow time, V-funnel flow time and L-box ratio tests were applied to evaluate the workability of SCC mixtures based on the EFNARC (2005) guidelines. Evaluation of SCC with various silt contents has been carried out by these tests to determine the filling ability, passing ability and flow properties of SCC. The results give an understanding about the effect of silt on the fresh properties and self-compacting of concrete mixtures. Test Results for Workability of SCC Mixes with Silt are shown in Table 3.

Table 3. Test results for workability of SCC mixes with silt variations

Mix ID	Slump Flow (mm)	T50 Time (sec)	V-Funnel (sec)	L-Box Ratio
NSCC (0% Silt)	690	2.8	8.5	0.92
MSCC-3	670	3.0	9.0	0.91
MSCC-5	650	3.3	9.8	0.90
MSCC-7	630	3.6	10.5	0.88
MSCC-9	610	3.9	11.2	0.86
MSCC-11	590	4.2	12.0	0.84
MSCC-13	570	4.5	12.8	0.82
MSCC-15	550	4.8	13.5	0.80

4.1.1. Slump Flow

Slump flow test is an immediate measurement of the filling ability of SCC and the overall flowability of SCC. The self-compacting properties were very good, the mixture with the control (NSCC) has a slump of 690 mm, which is satisfactory for compliance with EFNARC requirements for SCC. The slump flow value was decreasing gradually with the increasing of silt content up to MSCC-15 (550 mm). This reduction is a result of the small sizes of the silt particles that will need more water for the mix and will flow less well as a paste. Water content, or internal friction, increases with an increase in silt content, which, in turn, decreases the self-compacting properties of the mixture. The self-compacting property worsens with an increase of silt content, as this causes an increase in water content and internal friction.

The mixes containing 3–5% silt (650–670 mm) were still within the acceptable range, which suggested that some degree of acceptable silt contamination has not affected the filling ability, but care must be taken in ensuring no segregation or lack of compaction. The results of slump flow are given in Figure 1.

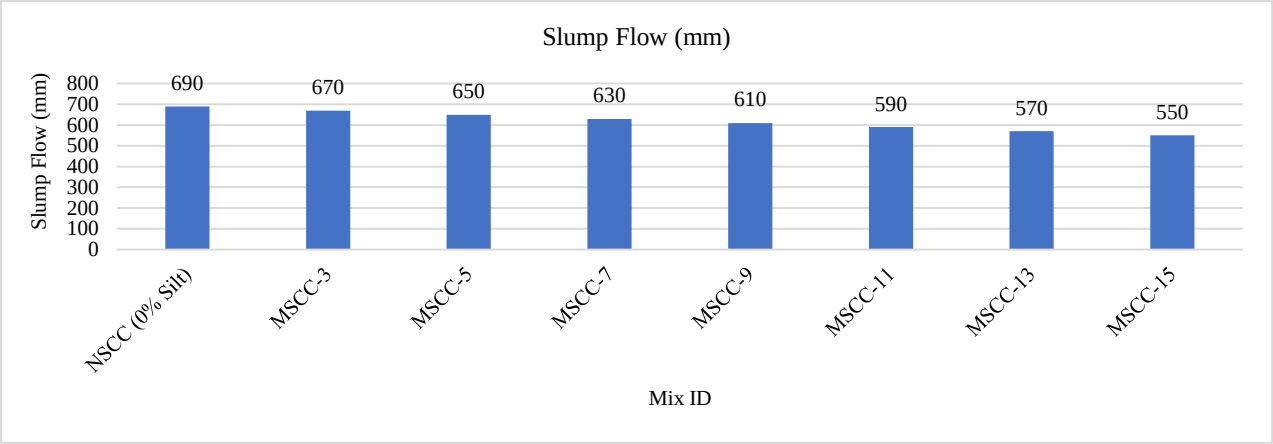

Fig. 1 Slump flow results

4.1.2. T50 Time (sec)

The viscosity and flow rate of SCC is measured against the T50 time. The time for the control mix of 2.8 s had a low viscosity, which indicates the spreading was rapid. As the silt content increased, the T50 time was also gradually increased, from 2.8 s to 4.8 s when the silt content in the sample was MSCC-15. The tendency points to the fact that the silt particles generate internal friction and decrease the mobility of the paste, which drives down the flow rate. The greater the T50 time, the less prone to deformation the mortar is, which is not desirable for SCC to cover reinforcement.

This suggests that SCC values are workable in the range between 30 to 35, with the mixes containing more than 35 exhibiting lower values and those containing less than 30 exhibiting higher values. Mixes with silt contents (3–5%) close to the control range (3.0–3.3%); the SCC values seem to be workable in this range. However, at silt content above 7%, the viscosity increases significantly causing to the loss of efficiency in placing and concerns regarding possible honeycombing in structural applications. The results T50_TIME (sec) are displayed in Figure 2.

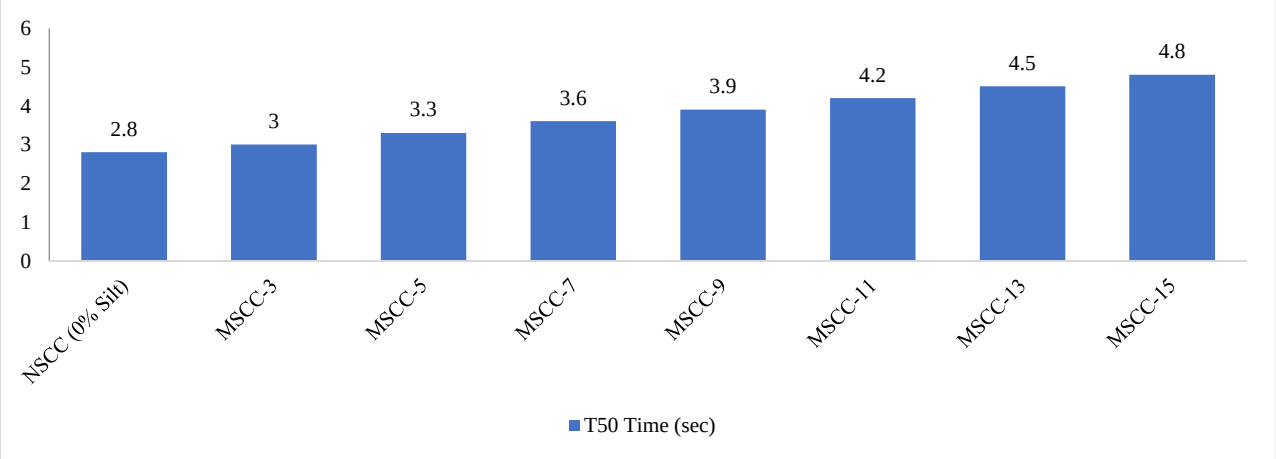

Fig. 2 T50 time (sec) results

4.1.3. V-Funnel (sec)

The V-funnel test is used for the assessment of flow speed and segregation resistance. The discharge time that NSCC achieved was 8.5 s, which is excellent for SCC. The discharge times also rose quite dramatically with increase in silt content — 13.5 s for MSCC-15. These have longer discharge times, which results in a more viscous discharge with less ability to flow through small reinforcement gaps. Silt also makes the paste more cohesive, which decreases its flowability, at the same time increasing it. The marginal increases were between 9.0 and 9.8 s for mixes containing 3–5% silt and was within acceptable limits.

The discharge times, however, were found to be outside the recommended ranges beyond 7% silt, indicating that the self-compacting nature of SCC is lost at high silt content and it becomes prone to segregation and poor consolidation. For V-Funnel (sec): Results display in Figure 3.

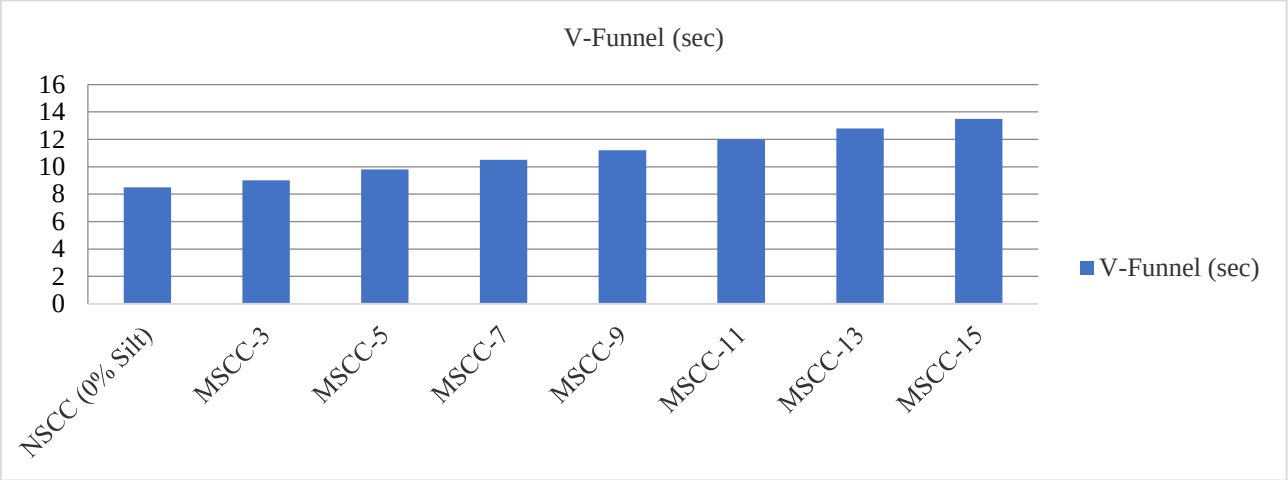

Fig. 3 V-Funnel (sec) results

4.1.4. L-Box Ratio

Very important property of SCC in structural work is the L box ratio, which is a measure of its passing ability through the reinforcement. The results of this control mix were found at a level of 0.92, where an extremely high level of passing ability was recorded. The lowest value was found in MSCC-15, and they were decreasing with the increase in silt content. This refers to a loss of ability of SCC to flow through the clogged rein without blockage or segregation. Excessive silt increases the viscosity and workability of the concrete, reduces its ability to achieve compaction and results in reduced strength in heavily reinforced sections. For the mixes containing between 3% and 5% silt, the ratios remained fairly similar (0.90–0.91) and would still be considered acceptable for SCC produced for structures. When the silt content exceeds 7%, however, the loss is substantial, and for practical applications where there is a great demand for reinforcement congestions, it is not recommended to be used. The results of L-Box ratio are presented in the above Figure 4. The standard cement tests carried out with the Self Compacting Concrete are shown in Figure 5, they are: a) the slump-flow test, b) T50 test, c) V-funnel test, d) L-box test, which are used to check its filling ability, passing ability, and resistance to segregation.

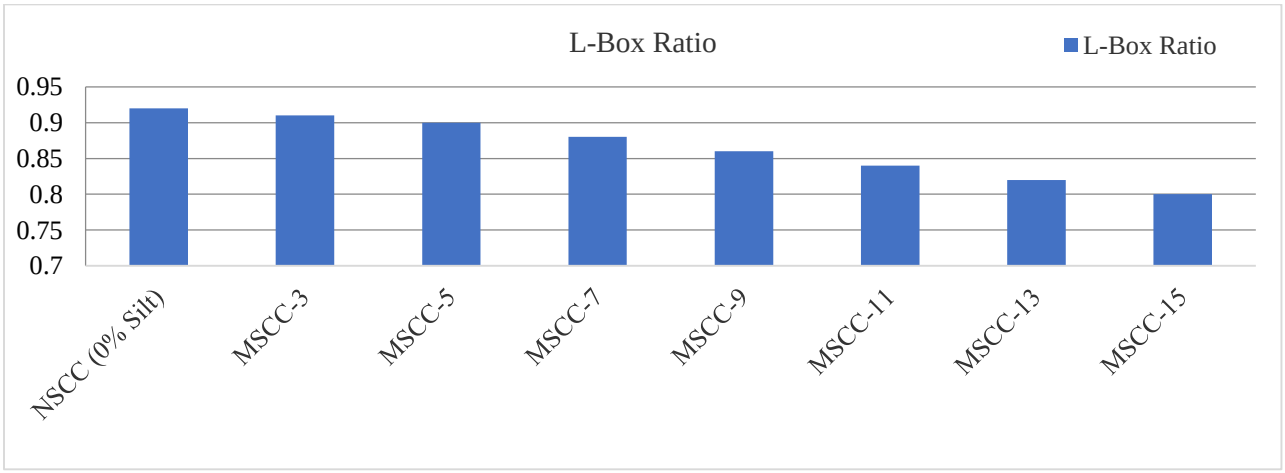

Fig. 4 L-Box ratio results



Slump Flow



L-Box Test



V-Funnel Test

Fig. 5 Self-Compacting Concrete tests

4.2. Compressive Strength

All 7 and 28-day compressive strength results are shown in Table 4, and the compression testing set-up and compressive strength of the different ages of curing are given in Figures 6 and 7, respectively. The result shows that there is a gradual decrease in Compressive strength as the amount of silt in the crushed sand increases. The compressive strength of the control mix (NSCC) was 28.5MPa at 7 days and 39.2MPa at 28 days. With low amounts of silt contamination, 3% and 5%, the strength reduction was only marginal, suggesting that this amount has only a moderate effect on strength development.

But when the amount of silt more than 7%, it was noticed that there was a considerable loss in compressive strength. The compressive strength loss value was observed as 22.19%, which was reduced from NSCC 39.2 MPa to MSCC-15 30.5 MPa at 28 days. In correspondence, 7-day compressive obtained a reduction from 28.5 to 19.5 MPa, indicating a decrease in silt content from 0 to 15%. From the results of Table 4, it has been seen that the strength loss increased gradually after exceeding 5% silt content, while it did not exceed a definite value untill 5% silt content of the aggregate.

The increase in water required was due to the excessive amount of silt particles, which increased the specific surface area of the aggregate system and caused a weak bond among the cement paste and silt particles. In addition, too much silt can cause the hardened concrete matrix to be too porous, and as a result, the strength development is reduced. According to the test results, the mixes with no more than 5% of Silt had satisfactory compressive strength for building use, and those with more than 7% Silt had a significant decline in mechanical properties.



Fig. 6 Compression test

Table 4. Compressive strength results of SCC mixes

Mix ID	7 Days (MPa)	28 Days (MPa)	Reduction (%)
NSCC	28.5	39.2	0.00
MSCC-3	27.8	38.5	1.79
MSCC-5	27.0	37.8	3.57
MSCC-7	25.5	36.2	7.65
MSCC-9	24.0	34.8	11.22
MSCC-11	22.5	33.5	14.54
MSCC-13	21.0	32.0	18.37
MSCC-15	19.5	30.5	22.19

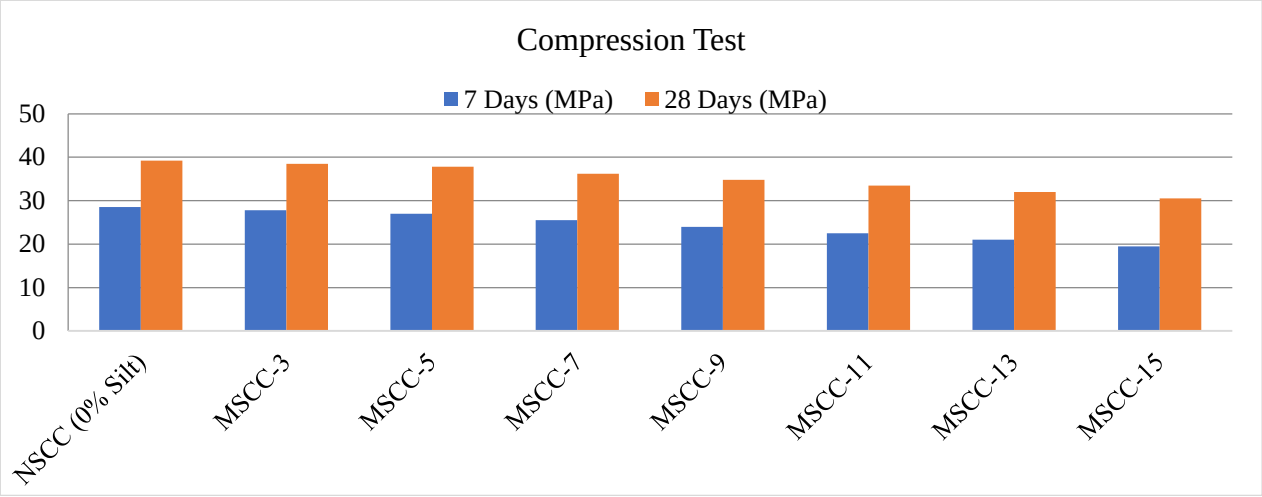

Fig. 7 Variation of compression test of mixes at 7 and 28 days

4.3. Flexural Strength Results

The flexural strengths of all the SCC mixes at 7 days and 28 days of ageing are summarized in Table 5, and the setup used for flexural strength testing and the variation with curing age is shown in Figures 8 and 9, respectively. Results show that flexural strength decreased with increasing silt content of crushed sand. The flexural strengths of control mix (NSCC) at 7 and 28 days were 4.8MPa and 6.9MPa, respectively. The flexural strength of SCCs was found to be slightly decreased at 3% and 5% silt contents, indicating a relatively small influence from a limited amount of silt contamination on the flexural properties of concrete.

The flexural strength loss was more substantial than in the other tests when the silt value was more than 7%. The flexural strength was observed when compared to the control mix of 6.9MPa and reduced to 5.2MPa on MSCC-15, a 24.64% decrease. Similarly, the 7-day flexural strength was reduced from 4.8MPa to 3.5MPa with the increased of silt content from 0% to 15%. It can be seen from Table 5 that flexural strength is decreased with a relatively low percentage up to 5% silt content, and then considerable reduction starts when beyond 5%.

This decrease in flexural strength is believed to be due to the addition of fines, which disrupt bond between the aggregates and the cement paste and will create a weaker interfacial transition zone. The presence of too much silt may also lead to the concentration of pores inside the hardened concrete matrix, decreasing its bending strength. Based on the experimental results, it can be concluded that SCC mixtures with a maximum silt content of 5 % can achieve satisfactory flexural properties, while mixes with a silt content exceeding 7 % exhibit significant negative properties. It is therefore crucial to control the silt content so as to guarantee the long-term structural and serviceability performance of the SCC involving in practical construction application.



Fig. 8 Flexural strength test

Table 5. Flexural strength results of SCC mixes

Mix ID	7 Days (MPa)	28 Days (MPa)	Reduction at 28 Days (%)
NSCC (0% Silt)	4.8	6.9	0.00
MSCC-3	4.6	6.7	2.90
MSCC-5	4.4	6.5	5.80
MSCC-7	4.2	6.2	10.14
MSCC-9	4.0	5.9	14.49
MSCC-11	3.8	5.6	18.84
MSCC-13	3.6	5.4	21.74
MSCC-15	3.5	5.2	24.64

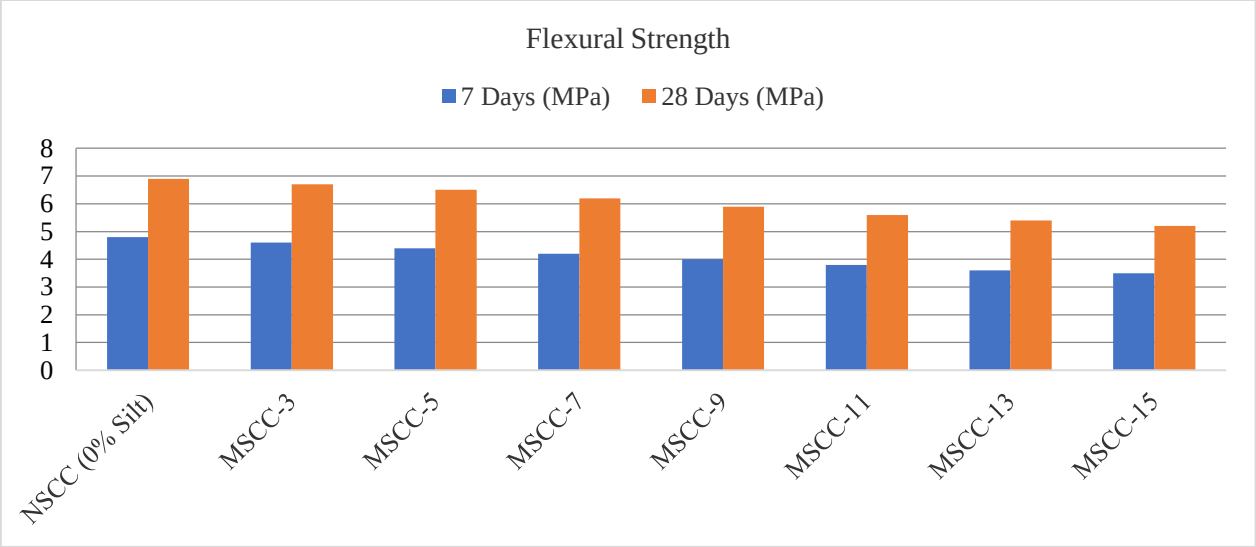

Fig. 9 Variation of flexural strength of mixes at 7 and 28 days

4.4. Split Tensile Strength Results

The split tensile strength for all the SCC mixtures at 7 and 28 days are shown in Table 6, and the split tensile test setup and the variation in tensile strength with age of curing is shown in Figures 10 and 11, respectively. The results show that both of the split tensile strength decreased gradually as silt content of crushed sand increased. The control mix (NSCC): 7 days and 28 days split tensile strength were 2.9 MPa and 4.2 MPa, respectively. However, the SCC mixes with low contents of silt, 3% and 5% silt, had only small decreases in tensile strength, showing the low amounts of silt contamination have a very restricted influence on bond development and tensile performance.

When the percentage of silt content was more than 7%, it was noted that there was a significant drop in the split tensile strength. The 28th day tensile strength for MSCC-15 was 3.2 MPa, which is a decrease of 23.81% from the control mix of 4.2 MPa. Likewise, with the increase in silt content from 0% to 15%, the 7 day split tensile strength dropped from 2.9MPa to 2.1MPa. It is found that reduction in tensile strength was relatively small, even up to 5% silt content, and a significant loss occurred above that.

This effect of diminishing ST can be attributed to excess silt content, due to which water requirement increases and bond between the cement paste and the aggregate particles weakens. Excessive silt may also contribute to hardening of the concrete matrix with a high level of porosity and contribute to the formation of microvoids, thereby affecting the resistance to tensile stresses. The result is that SCC mixes with a high silt content had lower tensile capacity and lower structural reliability. From the experimental results, SCC mixtures with the proportions of up to 5% silt showed a good performance in its split tensile strength and might be used in structural works. High silt percentage of more that 7% causes a significant reduction in tensile performance, however, and this may impact the long-term serviceability and durability of SCC structures in the future.



Fig. 10. Splitting tensile test

Table 6. Split tensile strength results of SCC mixes

Mix ID	7 Days (MPa)	28 Days (MPa)
NSCC (0% Silt)	2.9	4.2
MSCC-3	2.8	4.1
MSCC-5	2.7	4.0
MSCC-7	2.5	3.8
MSCC-9	2.4	3.6
MSCC-11	2.3	3.5
MSCC-13	2.2	3.3
MSCC-15	2.1	3.2

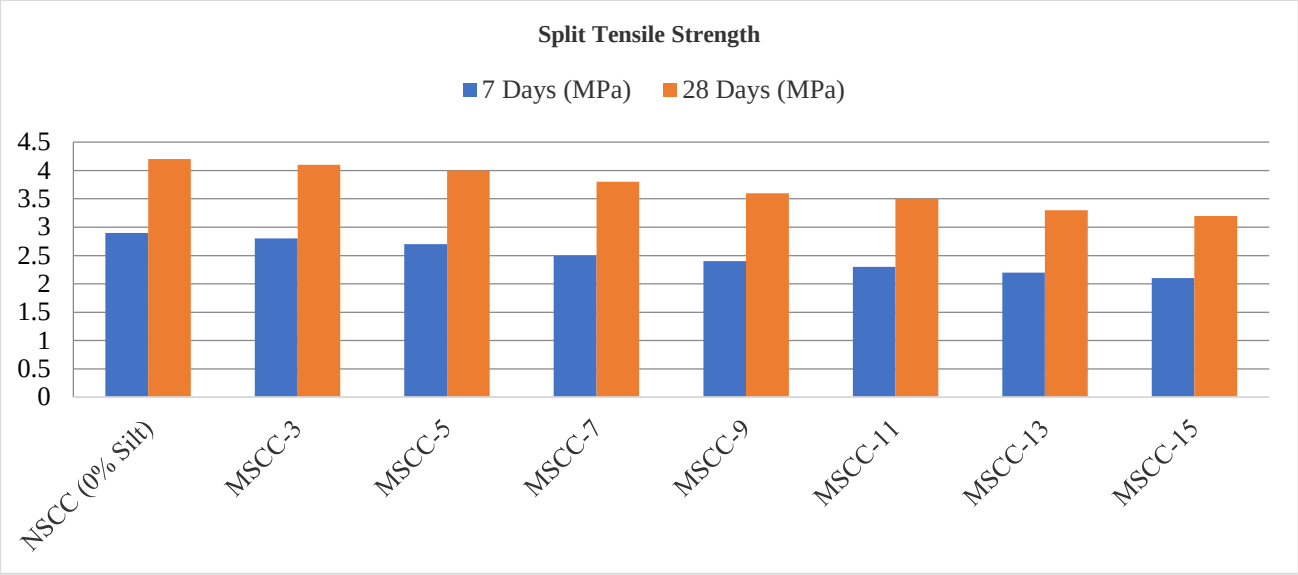

Fig. 11 Variation of split tensile strength of mixes at 7 and 28 days

4.5. Durability

Water absorption, water sorptivity and Rapid Chloride Penetration Test (RCPT) were used to evaluate the durability of the SCC mixtures. The parameters were chosen to assess the resistance of concrete to penetration of moisture and chlorides. The achieved results can improve one's understanding about how the performance of SCC permeability changes with varying amount of silt content and how the long-term durability performance is affected by the increased silt content.

4.5.1. Water Absorption & Sorptivity

The water absorption and sorptivity tests showed the effect of the silt content on the pore structure and permeability of SCC mixes. The control mix (NSCC) showed the least sorptivity (0.09 mm/√min) and the least absorption (0.62%). This means that the matrix for this occurs in dense and impermeable condition.

4.5.2. Rapid Chloride Penetration Test (RCPT)

The results presented in Table 7 indicate that, as the silt content increased, the SCC performance was increasingly decreasing. The control mix (NSCC) also had the least water absorption (0.62%), sorptivity (0.09 mm/√min) and RCPT value (1450 coulombs), which shows its resistance to moisture uptake and chloride penetration is better. The durability parameters were just lower in the SCC mixes containing 3% and 5% silt, and remained low in permeability class. Water absorption and sorptivity values, however, increased at a much higher rate with increasing silt content, which also increased the RCPT values. The results show that a high silt content is undesirable as it adversely affects pore structure of SCC, ultimately resulting in degradation under an aggressive environment over time. The workability characteristics of the SCC mixtures produced with different percentages of silt in crushed sand are shown in Table 7. The control mix (NSCC) performed well in slump flow with 690 mm, the lowest T50 time of 2.8 s, the shortest V-funnel time of 8.5 s and the highest L-box ratio of 0.92. This was good in terms of filling and passing ability. Slump flow reduced with an increasing proportion of silt from 3% to 15%, and T50 time and V-funnel time increased from 3.0 s to 4.8 s and 9.0 s to 13.5 s, respectively, with an increase in the silt content of the sample. L-box ratio also fell from 0.91 to 0.80, which suggests that there was less passing through reinforcement. The loss of workability can be attributed to the increase in spec. surface area of the silt particles, which adds more water needed and internal friction to the mix.

Table 7. Durability results of SCC mixes

Mix ID	Water Absorption (%)	Sorptivity (mm/√min)	RCPT (Coulombs)
NSCC (0% Silt)	0.62	0.09	1450
MSCC-3	0.70	0.11	1600
MSCC-5	0.78	0.12	1750
MSCC-7	0.95	0.15	2100
MSCC-9	1.05	0.16	2300
MSCC-11	1.12	0.17	2500
MSCC-13	1.19	0.18	2650
MSCC-15	1.25	0.19	2800

Both 3% Silt and 5% Silt SCC mixtures were imaginable to be kept within the requirements of workability property, and the performance of both SCCs was found to be similar with the performance of control SCC mixture. However, mixes containing >7% silt experienced a large decrease in flowability and passing ability. The workability properties of these mixes were more similar to the lowest end of the SCC properties range proposed, with the mix having a higher silt content (11-15%), indicating lower flow and effectiveness of the self-consolidating properties when heavily reinforced structural elements are used.

The relationship between water absorbing capacity, sorptivity, and RCPT values being increased in the order of the increasing silt content have made it clear that the silt content decreases the durability characteristics of the mixtures. Concretes with higher silt contents have more fine particles, and could provide an even less dense concrete matrix, which allows more pore space and increased water and chloride ion permeability into the concrete. The mixtures with percentages of silt greater than 5% showed poor resistance to the mechanisms of deterioration of permeability, compared to the control mix.

The durability evaluation was carried out to be able to understand the durability of the SCC mixes with different silt content in the long term. The results of Rapid Chloride Penetration Test (RCPT) were also comparable with deterioration from NSCC (low permeability) to MSCC 15 (high permeability), passing at increased charges of 1450 and 2800 coulombs, respectively. The results show that the silt content more than 5% decreases the durability, but also the silt content increase causes decrease in reinforcement protection and service life. The comprehensive evaluation of both fresh and hardened parameters also showed the gradual effect of the silt content on the performance of SCC. With increasing levels of silt, the slump flow, T50 time and V funnel discharge and L box ratio all decreased regularly, and the acceptable range of these parameters could be maintained up to 3-5% silt. Mixes with more than 7% lost some flowability and passing ability; did not work well with a congested reinforcement zone. The mechanical properties were similar with a 28-day compressive strength of 39.2 MPa (NSCC) and 30.5 MPa (MSCC 15); a flexural strength of 6.9 MPa (NSCC) and 5.2 MPa (MSCC 15); and a split tensile strength of 4.2 MPa (NSCC) and 3.2 MPa (MSCC 15). The results indicate that generally SCC mixes up to 5% silt can be used for structures of acceptable long-term and short-term performance (durability, workability and strength). And, as the silt content increased, long and short-term performance decreased.

Using the experimental results and comparing with the performance criteria recommended by EFNARC (2005) for SCC, the mixes with up to 5% silt were found to meet the limits for the slump flow, T50 time, V-funnel flow time and L-box ratio, and still provide acceptable strength and durability. However, mixes containing more than 7% silt were still within some acceptable workability limits, but had significant decreases in compressive strength, flexural strength, split tensile strength, water absorption, sorptivity and chloride permeability. Further, IS 383:2016 specifically emphasises the need for avoiding excessive production of fine material in aggregates, to ensure that the resulting concrete will be of satisfactory quality and durability. With the code-based requirement plus experimental observations, a practical limit of 5% for silt content was considered for SCC produced with crushed sand for structural grade SCC, a higher content of silt may result in poor performance and durability over time.

4.6. Determination of Acceptable Silt Threshold

According to EFNARC limits, durability test results and the fact that strength retention was above 95%, of the control mix, SCC mixtures containing as much as 5% silt were considered acceptable. When the reduction went beyond 5% there was a more salient decrease in workability and durability. Five per cent was therefore arbitrarily chosen as a practical limit to consider as quality control instead of an abrupt failure limit. The natural river sand was used in the control mixture, and the various mixtures used crushed sand with different silt contents. So, both the aggregate type and silt content were changed. A limitation of the present investigation is that the control mixture used natural river sand, whereas the modified mixtures contained crushed sand with varying silt contents. Therefore, aggregate type and silt content were varied simultaneously. Future research should include a crushed-sand SCC mixture with 0% silt content to isolate the independent influence of silt on SCC performance. In addition, it would be desirable to carry out SEM, XRD and mercury intrusion porosimetry analyses, which were not performed in this work. It is important to note that all of the control mix (NSCC) was made using natural river sand, while all of the Modified SCC mixes (MSCC-3 to MSCC-15) were made using crushed sand of various silt content percentages. The silt content, therefore, may not be the only factor affecting the observed differences in fresh, mechanical and durability properties, as differences in the characteristics of the aggregates (particle shape, surface texture and grading) may also influence the properties. Note that all crushed sand mixes were made from the same source of sand and the same mix proportion differing only in the variation of silt content therefore, these trends observed can reasonably be interpreted to be due to the increasing silt content. Future studies should incorporate a crushed sand control sample with 0% silt content that will provide better separation of the silt content effect and remove the type of aggregate effect.

5. Conclusion

In the present study, the effects of varying silt content (0% to 15%) of crushed sand on the fresh, mechanical and durability properties of Self Compacting Concrete (SCC) were evaluated. The experimental results indicated that an increase

of silt content was detrimental on the performance of SCC. With the addition of silt into the mixture, slump flow, T50 flow time, V-funnel flow time and L-box ratio all showed a gradual decrease with respect to workability. Likewise, the percentage of silt was seen to decrease the compressive, flexural and split tensile strength values. The tests for SCC containing up to 5% silt resulted in mixtures that met the fresh, mechanical and durability requirements, as well as the respective acceptance criteria. From this point onwards, decreases in workability and strength were noticed, and sample of considerable strength was achieved at 15 silts, i.e. loss in compressive strength is about 22.2%, flexural strength loss of 24.6 % and split tensile strength loss of 23.8 % as compared to the control mix. The same trend was observed for durability indicators, where water absorption, sorptivity and RCPT values increased with increasing silt content, indicating reduced resistance to moisture penetration and chloride ingress. From the experimental results, a silt content up to 5% is a realistic limit for quality-control purposes for structure-grade SCC produced with crushed sand. However, further investigation using crushed sand with 0% silt as a reference mix is recommended to fully isolate the effect of silt content from aggregate type variations. It is believed that more of these changes may relate to packing density and pore structure changes, which could be observed in composites with higher silt content, but which are not confirmed by the microstructural investigations and therefore require further research. Future studies could allow for a separation and better understanding of the contribution silt gives to the SCC performance when tested with an increase in the crushed sand content, and when testing a crushed sand mix of 0% silt content.

References

[1] H. Okamura, M. Ouchi, *Self-Compacting Concrete: Development, Present and Future*, First International RILEM Symposium on Self-Compacting Concrete, pp. 3-14, 1999. [Google Scholar] [Publisher Link]

[2] Hajime Okamura, "Self-Compacting High-Performance Concrete," *Concrete International*, vol. 19, no. 7, pp. 50-54, 1997. [Google Scholar] [Publisher Link]

[3] Ravichandran Subbarayalu, A.M. Vasumathi, and P. Kalai Selvi, "Performance Analysis of Self Compacting Concrete without Super Plasticizer," *Journal of Building Pathology and Rehabilitation*, vol. 2, pp. 1-10, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[4] H.J.H. Brouwers, and H.J. Radix, "Self-Compacting Concrete: Theoretical and Experimental Study," *Cement and Concrete Research*, vol. 35, no. 11, pp. 2116-2136, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[5] L.A. Pereira-de-Oliveira et al., "Permeability Properties of Self-Compacting Concrete with Coarse Recycled Aggregates," *Construction and Building Materials*, vol. 51, pp. 113-120, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[6] I.M. Nikbin et al., "Effect of Coarse Aggregate Volume on Fracture behavior of Self-Compacting Concrete," *Construction and Building Materials*, vol. 52, pp. 137-145, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[7] F. Ernst et al., "*Research on Self-Compacting Concrete*," Thesis, Eindhoven University of Technology, 2000. [Google Scholar] [Publisher Link]

[8] Aleksandra Kostrzanowska-Siedlarz, and Jacek Gołaszewski, "Rheological Properties and Air Content in Fresh Self-Compacting High-Performance Concrete," *Construction and Building Materials*, vol. 94, pp. 555-564, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[9] Zhang Yankun, Cai Guangzhi, and Qian Dongya, "Review on Self-Compacting Concrete with Manufactured Sand," *IOP Conference Series: Earth and Environmental Science: 2nd International Conference on Civil Engineering, Environment Resources and Energy Materials*, Changsha, China, vol. 634, pp. 1-5, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[10] S. Hima Venkata Mahalakshmi, and Veerendrakumar C. Khed, "Experimental Study on M-Sand in Self-Compacting Concrete with and without Silica Fume," *Materials Today: Proceedings*, vol. 27, pp. 1061-1065, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[11] Wen-Qi Hou et al., "Experimental Study and Application of Manufactured Sand Self-Compacting Concrete in Concrete-Filled-Steel-Tube Arch Bridge: A Case Study," *Case Studies in Construction Materials*, vol. 15, pp. 1-15, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[12] Jiang Zhu et al., "Effect of Microfines from Manufactured Sand on Yield Stress of Cement Paste," *Construction and Building Materials*, vol. 267, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[13] D. Suriya, S. Prakash Chandar, and P.T. Ravichandran, "Impact of M-Sand on Rheological, Mechanical, and Microstructural Properties of Self-Compacting Concrete," *Buildings*, vol. 13, no. 5, pp. 1-25, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[14] Huajian Li et al., "Pumpability of Manufactured Sand Self-Compacting Concrete," *Journal of Wuhan University of Technology-Materials Science Edition*, vol. 38, no. 6, pp. 1382-1390, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[15] Miao Lv et al., "Influence of the Fine Aggregate Particle Packing Effects on the Paste Rheological Thresholds of Self-Compacting Concrete," *Construction and Building Materials*, vol. 397, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[16] D. Suriya et al., "Durability and Microstructural Characteristics of Self-Compacting Concrete Incorporating M-Sand," *Journal of the Chinese Institute of Engineers*, vol. 47, no. 6, pp. 643-654, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[17] Zhengwu Jiang et al., "Limestone Filler as a Mineral Additive on the Compressive Strength and Durability of Self-Compacting Concrete with Limestone Manufactured Sand," *Journal of Building Engineering*, vol. 94, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[18] Xuan Liu et al., "Mix Design and Performance Study of High-Strength Self-Compacting Concrete with Manufactured Sand," *Materials*, vol. 18, no. 1, pp. 1-21, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[19] J. Anitha, H. Ravi Kumar, and K.G. Subramanya, "Influence of Air-Classified and Wet-Classified Manufactured Sand on Self-Compacting Concrete Exposed to Severe Environmental Conditions," *Civil Engineering and Architecture*, vol. 13, no. 4, pp. 3207-3219, 2025. [CrossRef] [Publisher Link]

[20] J. Anitha, and H. Ravi Kumar, "Impact of Manufactured Sand Grading Method on Durability of Self-Compacting Concrete," *Research on Engineering Structures and Materials*, vol. 11, no. 3, pp. 1305-1330, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[21] Muhd Fadhil Nuruddin, Kok Yung Chang, and Norzaireen Mohd Azmee, "Workability and Compressive Strength of Ductile Self Compacting Concrete (DSCC) with Various Cement Replacement Materials," *Construction and Building Materials*, vol. 55, pp. 153-157, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[22] Barbara Aboagye, Ryan Gosselin, and William Wilson, "Influence of Manufactured Sand on Concrete Properties: A Review," *Canadian Journal of Civil Engineering*, vol. 53, 2026. [CrossRef] [Google Scholar] [Publisher Link]