



Influence of Active Silica on the Mechanical Strength and Sustainability of Conventional Concrete

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Abstract: The construction industry is responsible for high levels of waste and pollutant generation, especially during the manufacturing of its materials. In this context, research has been developed with the aim of incorporating mineral additives that promote efficient performance of materials, aligning with environmental sustainability. Among these additives, Activate Silica (AS) stands out as a pozzolanic material that not only improves the mechanical properties of concrete but also allows for a partial reduction in the use of cement, contributing to a lower carbon footprint. This study aims to evaluate the performance of conventional concrete with additions of 0%, 10%, and 15% AS through compressive strength tests. The methodology included a literature review, using specific keywords and focusing on publications from 2020 to 2025. The results indicate that AS has high application potential due to significant improvements in concrete strength. However, parameters such as usage rates and other effects of its addition still require further investigation. Thus, this highlights the importance of studies capable of consolidating the efficient use of mineral additives for both environmental and scientific benefits.

Keywords: Concrete; Pozzolanic Materials; Active Silica; Environment; Compression.

1. Introduction

The construction industry plays a relevant role in the development of society. Although several materials have been used as building resources to meet human demands, concrete stands out as the main input on a global scale [1].

In 150 BC, the first records of the use of a type of rudimentary concrete appeared, serving as a material for load-bearing elements and local monuments. The rise of concrete occurred in 1824, with the creation of Portland Cement (PC) and the development of composites such as reinforced concrete [2,3].

Composed of cement, water, fine aggregate, and coarse aggregate, concrete stands out due to its physical-chemical characteristics and excellent compressive strength [4]. This performance is due to the compaction provided

by the aggregates and to its rigid matrix formed by the cement [1].

Concrete is widely studied in civil engineering due to the extraction and manufacturing of its raw materials, especially cement, whose production generates waste that causes environmental damage [5]. Considering its production impacts, the sector seeks to reduce its carbon footprint and partially replace the use of hydraulic binders [6].

Thus, in order to address environmental issues and improve the properties of concrete, additions of pozzolanic materials, such as active silica (SA), have been incorporated into concrete [7]. Also known as microsilica, AS is a byproduct of the ferrosilicon industry.

Composed of about 85% to 98% silicon dioxide (SiO₂) in amorphous form, it is an artificial pozzolanic material that contributes to



increased compressive mechanical performance and durability by forming a denser and more compact matrix in the concrete [8].

Representing technical and sustainable advantages, pozzolanic additives are siliceous products with little or no binding activity [9]. However, when they react with water and with calcium hydroxide ($\text{Ca}(\text{OH})_2$) present in the cement, they develop properties similar to those of a hydraulic binder [10].

As a result of these reactions, cementitious compounds are formed, giving the concrete high mechanical strength [11]. The extremely fine particle size of the mineral addition contributes to several benefits for concrete, such as improved mixing, minimization of bleeding and segregation risks, and reduced capillary porosity, which hinders the penetration of aggressive agents [12,13].

Considering the growing search for sustainable alternatives in the construction industry, the present study aims to evaluate the effects of active silica addition, in proportions of 0%, 10% e 15% as a cement replacement, on the mechanical strength of conventional concrete.

2. Methodology

This study was conducted through an experimental approach aimed at quantitatively assessing the effect of active silica addition on the mechanical properties of conventional concrete. The methodology was divided into four main stages: (i) characterization of the constituent materials; (ii) mix design and

production of the concretes; (iii) casting and curing of the specimens in accordance with Brazilian standards; and (iv) mechanical testing to evaluate compressive strength. The theoretical foundation supporting this research was built from a rigorous literature review, using the Bibliometrix tool to select and analyze articles from indexed journals, ensuring the relevance and up-to-dateness of the references.

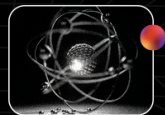
The databases Scopus, SciELO, and CAPES Journals—recognized for their credibility and comprehensive publication coverage—were used. The research scope was defined by the keywords: Portland cement, concrete, pozzolanic materials, mineral admixture, active silica, and microsilica, analyzing studies from 2020 to 2025 to ensure information consistent with scientific advancements.

With a quantitative approach, this research aims to analyze the effects of active silica addition on the compressive strength of concrete.

2.1. Materials

The concrete constituents were characterized in the laboratory in accordance with Brazilian technical standards to ensure the reproducibility of the tests.

- **Cement:** Portland composite cement with the addition of limestone filler (CP II-F 32) was used, in accordance with NBR 16697:2018.



- **Fine Aggregate:** Fine sand was used with particle size distribution and the fineness module determined according to the standards ABNT NBR 7211:2022 and ABNT NBR 17054:2022.
- **Coarse Aggregate:** Crushed basalt rock was employed as coarse aggregate, with grain size distribution and fineness modulus determined according to the ABNT NBR 7211:2022 and ABNT NBR 17054:2022 standards.
- **Mineral Addition:** The active silica used is a by-product of the production process of metallic silicon and ferrosilicon alloys.
- **Water:** The mixing water came from the local supply network, meeting the drinking water requirements.

2.2. Experimental Procedures

The ABCP/ACI method was used, an empirical technique for concrete dosage, adapted to the characteristics of the materials used. The following unit mix was obtained, presented in Table 3, where REF is the concrete without active silica, C10 and C15 are the concrete with 10% and 15% of cement replacement with active silica, respectively.

The water/cement ratio used was equal to 0.6, meeting the requirements for concrete of aggressive class II, according to ABNT NBR 6118: 2023, which must present a w/c ratio less than or equal to 0.60 and a strength greater than or equal to 25 MPa at 28 days.

For each mix/day, three cylindrical specimens with dimensions of 100 × 200 mm were molded, following the procedures of NBR 5738/2015. Concrete compaction in the molds was performed mechanically using a vibrating table.

Table 1. Unit trace used in the experiment.

MIX (% silica)	CIM	SÍLICA	SAND	COARSE AG.	WATER
0	1,00	0,00	1,83	2,37	0,60
10	0,90	0,10	1,83	2,37	0,60
15	0,85	0,15	1,83	2,37	0,60

After molding, the specimens remained in their molds for 24 hours. Subsequently, they were demolded and subjected to water curing in a tank with lime-saturated water, maintained at a temperature of $(23 \pm 2) ^\circ\text{C}$, until the testing ages, as prescribed by NBR 5738.

2.3. Mechanical Tests

At the age of 28 days, the specimens were removed from curing, and their top surfaces were prepared by mechanical grinding to ensure the flatness and parallelism required by the standard. The compressive strength test was carried out in accordance with NBR 5739, using a hydraulic press with a constant loading rate. For each age, the final result was the arithmetic mean of the obtained values.

2.4. Results Analysis

The characterization of the concrete constituents and the 28-day compressive



strength values for concrete without silica and with silica are presented. A comparative analysis of the mechanical performance between the reference mix (without silica) and the mixes with active silica (10% and 15%) was performed through graphs produced using scripts developed in the Python programming language, allowing for a clear and accurate visualization of the results.

4. Results and Discussion

4.1 Characterization of Materials

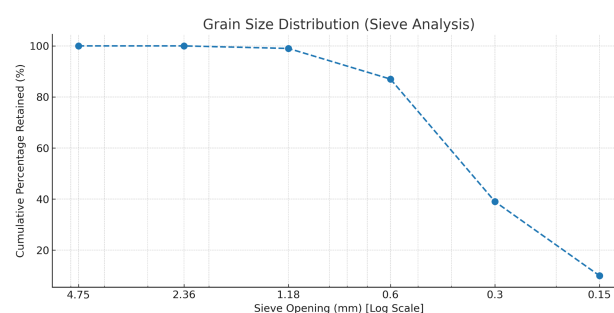
4.1.1 Fine Aggregate

This test, conducted in accordance with ABNT NBR 7211, allows determining the particle size distribution and the fineness modulus (FM), crucial parameters that influence the properties of concrete both in the fresh and hardened states. The fineness modulus, in particular, is an indicator of the average coarseness or fineness of the aggregate particles and is used to assist in mix proportioning and in estimating the cement consumption of the mixture [14]. The detailed results of the fine aggregate sieve analysis are presented in Table 2, while the corresponding particle size distribution curve is shown in Figure 1.

Table 2. Particle Size Composition of Fine Aggregate.

Sieve (mm)	Retained Mass (g)	Individual % Retained	Cumulative % Retained
4,75	0,00	0,00	0,00
2,36	0,31	0,08	0,08
1,18	3,03	0,79	0,87
0,60	49,41	12,93	13,81
0,3	181,74	47,56	61,37
0,15	107,09	28,03	89,40
Pan	40,48	10,60	100,00
Fineness Modulus:			1,65

Figure 1. Particle Size Distribution of Fine Aggregate.



Based on the sand data, a fineness modulus (FM) of 1.65 was observed. This value is considerably below the commonly accepted range of 2.3 to 3.7 for sands used in concrete. This classifies the aggregate as a very fine material, which has important implications [14].

The finer particle size distribution of the sand can negatively affect the workability and



handling of fresh concrete. The study by Zhao et al. (2025) indicates that using sands with finer grains results in lower initial flowability and reduced flow retention over time. This occurs due to the increased specific surface area of fine particles, which raises internal friction and the demand for water or superplasticizer admixtures to maintain the desired workability. In a self-compacting concrete (SCC) mix, for example, fine sand can hinder the passing ability of the mixture and increase its plastic viscosity [15].

Despite the workability challenges, fine sand gradation can offer significant benefits for the properties of hardened concrete. The presence of fine particles in adequate quantities allows for better filling of voids between larger aggregates, resulting in a denser structure with lower porosity. This more compact microstructure is directly linked to improved mechanical performance and increased durability [15].

The study by Zhao et al. (2025) showed that finer sands contribute to higher compressive strength, bulk density, and lower volume of permeable voids in hardened concrete. Furthermore, improved compaction enhances resistance against the penetration of aggressive agents such as carbon dioxide (CO₂) and chloride ions. The study demonstrated that mixtures with sand of lower FM (1.94) presented lower carbonation depth and lower chloride migration coefficient when compared to mixtures with sand of higher FM. [15].

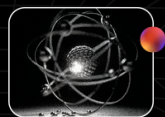
4.1.2 Coarse Aggregate

The particle size characterization of the coarse aggregate is a critical step to understanding its behavior in concrete mixes. The crushed stone test results show a particle size distribution concentrated in the 19 mm to 9.5 mm range, as shown in Table 3 and Figure 2, with a fineness modulus (FM) consistently high, ranging from 6.73 to 6.84.

This FM value is typical for coarse aggregates and aligns with existing literature. For example, a study on the influence of basalt and granite aggregates in high-strength concrete also found fineness modulus values for coarse aggregates around 6.7.

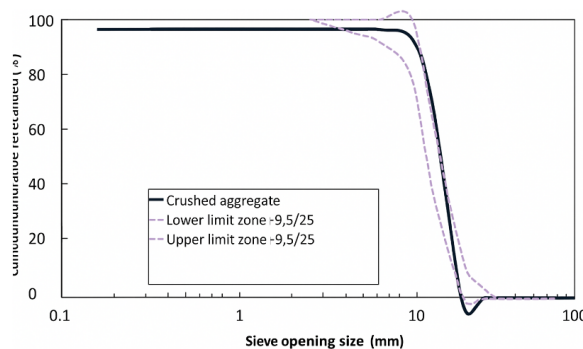
Table 3. Particle Size Distribution of Coarse Aggregate.

Sieve (mm)	Retained Mass (g)	Individual % Retained	Cumulative % Retained
19,00	30,80	0,61	0,61
12,50	3.497,25	69,57	70,18
9,50	1.240,30	24,67	94,86
6,30	125,78	2,50	97,36
4,75	13,25	0,26	97,62
Pan	119,45	2,38	100,00



Fineness Modulus:	6,79
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Figure 2. Particle Size Distribution of Coarse Aggregate.

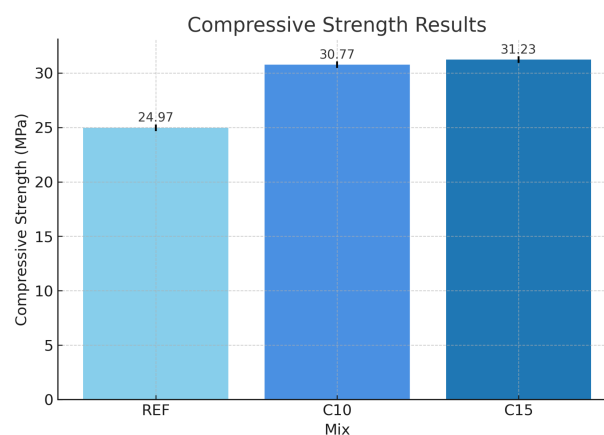


The size of the coarse aggregate is a factor that significantly influences the mechanical properties of concrete. According to the study by Pompeo Neto et al. (2011), aggregate size effects are more pronounced when the dimension exceeds 5 mm, with the potential to create stress concentrations in the transition zone between the aggregate and the cement paste, which may lead to the formation of microcracks. The particle size distribution of the crushed stone, concentrated in the 19/31.5 mm range, fits directly into this scenario [16].

4.2 Mechanical Property

Figure 2 presents the compressive strength results of the mixtures containing silica fume after 28 days. It can be observed that the use of silica resulted in an increase in the strength of the concrete.

Figure 2. Presentation of the results at 28 days

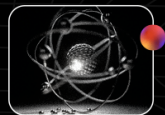


The reference mix (REF) established the baseline with an average strength of 24.97 MPa, the substitution of 10% (C10) of cement with silica fume resulted in an increase in strength, with an average of 30.77 MPa, representing a substantial increase of 24%. This significant gain is attributed to the well-known mechanisms of active silica, which promote intense refinement of the concrete microstructure [4].

The high fineness and pozzolanic nature of active silica contribute to reducing porosity and permeability of the cementitious matrix [1], leading to significant improvements in both mechanical strength and durability [2,3].

This structural optimization occurs mainly through the consumption of calcium hydroxide ($\text{Ca}(\text{OH})_2$) to form additional C-S-H and by physically filling voids between cement particles, thereby strengthening the Interfacial Transition Zone (ITZ) [1,2].

An interesting point emerges when analyzing the mix with 15% active silica. Figure 1 shows a slight decrease in average strength to 30.4 MPa, a value slightly lower than that obtained with the 10% addition. Although some



studies, such as Silva (2024), have reported a continuous strength gain with additions up to 14% silica in high-performance concretes [3], the results obtained here are more aligned with the concept of an “optimal content” of addition.

The literature indicates that this optimum often falls in the range of 7% to 10% [5]. The drop in performance at higher contents can be attributed to the difficulty in homogeneously dispersing such a large quantity of ultrafine material. Silica particle agglomeration may occur, creating weak points in the cement matrix instead of contributing to its densification [3].

Another relevant hypothesis, raised by Silva (2024), is that in higher-performance concretes, the cement paste and transition zone become so strong that the coarse aggregate becomes the “weak link,” limiting the final strength of the composite [3]. It is plausible that, in the present study, the 10% active silica content was already sufficient to optimize the matrix to a level close to the aggregate’s strength capacity, so that a higher addition (15%) did not result in an additional strength gain, as the failure mode became conditioned by the aggregate.

5. Conclusion

Considering that the reference mix (without addition) showed a compressive strength of 24.9 MPa, it is concluded that the 10% and 15% additions of active silica provided significant improvements in the mechanical performance of the concrete. Compared to the

reference mix, the 10% and 15% additions resulted in strength increases of 23.7% and 22.1%, respectively.

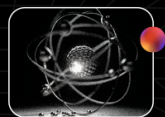
The 10% addition showed the highest strength gain, reaching approximately 30.8 MPa. This increase is attributed to the presence of the pozzolanic material, which reacts with calcium hydroxide (Ca(OH)_2) to form additional calcium silicate hydrate (C-S-H) gel — the main compound responsible for the strength of concrete.

Moreover, the ultrafine particles of active silica contribute to a more effective filler effect, occupying voids in the cementitious matrix, which results in a denser and less porous structure.

However, although both addition levels led to higher strength values compared to the mix without silica, it is observed that increasing the silica content from 10% to 15% led to a slight decrease in performance. With 15% addition, the average strength was 30.4 MPa, suggesting that the excess silica may cause agglomeration of ultrafine particles, which compromises the homogeneity of the matrix and creates weak zones in the cementitious material.

From another perspective, it can be stated that active silica has high potential for application in the construction industry. As a reused industrial by-product, it contributes to the circular economy, bringing both environmental and technical value.

Its rational use also represents an environmentally efficient solution, as it allows



for the partial replacement of cement, helping to reduce greenhouse gas emissions into the atmosphere.

In addition to strength improvement, the microstructure of the concrete becomes more refined, with reduced porosity and permeability, increasing the durability of the material. As a result, the concrete requires less maintenance and presents greater service life, reducing long-term costs.

Therefore, the results of this study reinforce the potential of pozzolanic materials, particularly active silica, for optimizing the mechanical performance of concrete and as a strategic tool for sustainable development in civil construction, highlighting the importance of studying optimal addition levels to ensure both technical performance and environmental benefits.

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