Experimental analysis of the compressive strength of concrete by replacing cement with microsilica

https://doi.org/10.56238/sevened2024.003-029

Luiza Ignez Mollica Marotta[1], Leonardo Donizete Bícego Geremias[2], Clayton Reis de Oliveira[3], Gustavo Soares Santos[4] and Fabiano Martins Cunha[5]

ABSTRACT

Currently, in Brazil, concrete is the most important element used as a structural material in every branch of civil construction, which has revolutionized the history of humanity in quality of life and development, with its most important physical index being compressive strength. Therefore, new techniques to improve this property have emerged, among them is microsilica, which can be used as an addition to concrete or as a substitute for cement in concrete. In this article, an analysis of the compressive strength of the replacement of microsilica in concrete was carried out, with the amounts of 0%, 5% and 10%, and consequently subtracted this same percentage of cement. With these materials, Slump Test tests were carried out, which showed a decrease in slump as the replacement of cement by microsilica was increased, and compressive strength tests, where an increase of about 13% of this strength was observed.

Keywords: Slump Test, Microsilica, Structures, Compression.

[1] Highest academic background: Master's Degree in Regional Development and Environment
Institution of operation: Libertas - Faculdades Integradas
E-mail: marotta.eng@gmail.com
ORCID: https://orcid.org/0000-0002-7504-3684
[2] Highest education: Undergraduate student in Civil Engineering
Institution of operation: Libertas - Faculdades Integradas
E-mail: leobgeremias@gmail.com
ORCID: https://orcid.org/0009-0005-1623-8886
[3] Highest education: PhD in Civil Engineering
Institution: Federal University of Alfenas - UNIFAL/MG
E-mail: clayton.oliveira@unifal-mg.edu.br
ORCID: https://orcid.org/0009-0000-8752-295X
[4] Highest education: PhD student in Biomaterials Engineering
Institution: Federal University of Lavras- UFLA
E-mail: gssengcivil@gmail.com
ORCID: https://orcid.org/0000-0003-3564-5426
[5] Highest academic background: Civil Engineer, Specialist in Transport and Highway Infrastructure.
Institution: CONSUL-PRIME-BRASIL Engenharia e Consultoria LTDA
E-mail: fabiano.cunha@consulprimebrasil.com
ORCID: https://orcid.org/0009-0000-9011-0841

INTRODUCTION

The development of Engineering and Engineering Education is directly related to advances in science and technology. As technology becomes more complex, in terms of the need for knowledge to solve problems, it becomes an object of study and application in Engineering. This knowledge is of the order of mathematics, physics, chemistry and graphic expression.

Concrete appeared in Rome, about 300 years B.C. and even today this material is used with recurrence in construction methods in the civil construction sector. Through it, he revolutionized the art of designing and building, enabling several designers and forms in the sector. This element is the most important structural material in the entire branch of civil construction, which has revolutionized the history of humanity in terms of quality of life and development (OLIVEIRA, 2016).

Concrete is constituted by mixing cement, sand, gravel and water, dosed with high criteria, with any additives that enhance its pre-defined characteristics, in addition to additions that aim to transform its original characteristics (OLIVEIRA, 2016).

Different chemical and mineral additions are used in the concrete mixture to improve its properties, which can reduce cement consumption, among which is microsilica, an industrial waste. Microsilica can cause influence of variable amounts on the additions of materials to the concrete mixture, such as partial replacement of cement on the mechanical strength to compression, workability and porosity. (BONFIM, 2021)

Silica is also part of the pozzolanic reaction, this reaction occurs when ca1cio hydroxide is consumed in the formation of hydrated calcium silicate, an effect that influences mechanical strength, resistance to penetration of aggressive agents and filling voids. These effects can lead to greater durability and better performance in different environments in concrete (DA SILVA; BONFIM, 2019).

In Brazil, the application of engineering practices to the construction of buildings began in the transition from the nineteenth to the twentieth century. The last 100 years have been one of transformations and innovations in construction methods. Thus, it can be said that it is a sector that acts as an advance in economic development, civil construction must pay attention to the quality aspects of the construction process and the durability of buildings

The Civil Engineer, or responsible for a work, must bear in mind that in addition to being a calculator, he must, whenever possible, carry out the technological control of the concrete used in his work, the appropriate trace of the concrete in such a way that it obtains the required resistance. This control should occur not only during the project period, but mainly during the course of the work (BAUER; FALCÃO, 2018).

The objective of this article was to present the study of concrete using microsilica in its structure. For this purpose, several specimens were made with and without the addition of microsilica, which were studied in the laboratory for analysis of workability and compressive strength.

CONCRETE

In this chapter, the main factors that directly influence the manufacture of traditional concrete and with the addition of microsilica aggregates will be presented.

CONCRETE COMPOSITION

According to NBR 6118 (ABNT, 2014):

> Concrete structures must be designed and constructed in such a way that, under the environmental conditions foreseen at the time of design, and used as recommended in the project, they maintain their safety, stability and suitability for service during the period corresponding to their useful life.

According to NBR 12655 (ABNT, 2006), Portland cement concrete is a material formed by the homogeneous mixture of cement, fine and coarse aggregates and water, with the incorporation of minority components (chemical additives, metakaolin or microsilica activation), which develops its properties by hardening the cement paste (cement and water).

Concrete is made up of cement, fine aggregates, coarse aggregates and water. Cement is a hydraulic binder, i.e., it requires the addition of water for its hardening and, consequently, mechanical resistance to compression (BRAGA; RAMOS, 2019).

According to Bauer and Falcão (2018), fresh concrete works simultaneously with its aggregates surrounded by cement paste (water and cement), it has air-filled spaces called matrix, air is found through bubbles through the paste, in interconnected spaces, determining the predominance of these forms of presentation.

For the elaboration of an impermeable concrete, it is necessary to incorporate additives or additions. In addition, it is essential to study its best trait, that is, the proportion of aggregates, cement and water, which can eliminate the voids without losing resistance.

Cimento Portland

It is an artificial hydraulic binder obtained by grinding Portland clinker the manufacture, the necessary amount of one or more forms of calcium sulfate and mineral additions at the levels established in this Standard (ABNT NBR 16697:2018).

Table 1: Standard designation, abbreviation and grade of Portland cement

Designação normalizada (tipo)	Subtipo	Sigla	Classe de resistência	Sufixo
Cimento Portland comum	Sem adição	CP I	25, 32 ou 40 [c]	RS [a] ou BC [b] –
	Com adição	CP I-S		
Cimento Portland composto	Com escória granulada de alto forno	CP II-E		
	Com material carbonático	CP II-F		
	Com material pozolânico	CP II-Z		
Cimento Portland de alto-forno		CP III		
Cimento Portland pozolânico		CP IV		
Cimento Portland de alta resistência inicial		CP V	ARI [d]	
Cimento Portland branco	Estrutural	CPB	25 , 32 ou 40 [c]	
	Não estrutural	CPB	–	–

[a] O sufixo RS significa resistente a sulfatos e se aplica a qualquer tipo de cimento Portland que atenda aos requisitos estabelecidos em 5.3, além dos requisitos para seu tipo e classe originais.

[b] O sufixo BC significa baixo calor de hidratação e se aplica a qualquer tipo de cimento Portland que atenda aos requisitos estabelecidos em 5.4, além dos requisitos para seu tipo e classe originais.

[c] As classes 25, 32 e 40 representam os valores mínimos de resistência à compressão aos 28 dias de idade, em megapascals (MPa), conforme método de ensaio estabelecido pela ABNT NBR 7215.

[d] Cimento Portland de alta resistência inicial, CP V, que apresenta a 1 dia de idade resistência igual ou maior que 14 MPa, quando ensaiado de acordo com a ABNT NBR 7215 e atende aos demais requisitos estabelecidos nesta Norma para esse tipo de cimento.

Font: NBR 16697 (ABNT, 2018).

Added

For this study, aggregate is defined as gravel 0 and gravel 1, and washed sand, which are classified by their granulometry.

> Aggregates shall be composed of hard, compact, stable, durable and clean mineral grains, and shall not contain substances of a nature and quantity which may affect the hydration and hardening of the cement, the protection of the reinforcement against corrosion, the durability or, where required, the external visual appearance of the concrete. (ABNT NBR 7211, 2005).

Within the aggregates, there are two groups used, being the fine aggregates and the coarse aggregates, these aggregates are defined by their granulometry, that is, by the size of their grains. According to NBR 7211 (ABNT, 2005):

> ✓ Fine aggregate is defined as the one whose grains pass through the sieve with a mesh opening of 4.75 mm and are retained only in the sieve with a mesh opening of 150 mm, in a test carried out in accordance with ABNT NBR NM 248, with sieves defined by ABNT NBR NM ISO 3310-1.
>
> ✓ Coarse aggregate, on the other hand, is defined as the one whose grains pass through the sieve with a mesh opening of 75 mm and are retained in the sieve with a mesh opening of 4.75 mm, in a test carried out in accordance with ABNT NBR NM 248, with sieves defined by ABNT NBR NM ISO 3310-1.

Water

The hydration process of Portland cement comprises the stabilization of clinker minerals by water, generating compounds such as C-S-H, ethringite and portlandite. This hydration of Portland cement does not depend exclusively on the mineralogical components of clinker and the active cement additions, but also on the water-cement ratio, fineness, temperature, curing procedures and other physical factors (FONSECA, 2010, p. 20).

The amount of water required for the hydration of this material is defined through calculations, where the strength of the concrete to be used must first be defined and then the trace. This relationship depends on where this material will be used and has maximum quantities defined in table 7.1 of NBR 6118 (ABNT, 2023), as shown in Table 2.

Table 2: Correlation table of aggressiveness class and concrete quality

Concreto [a]	Tipo [b, c]	Classe de agressividade (Tabela 6.1)			
		I	II	III	IV
Relação água/cimento em massa	CA	≤ 0,65	≤ 0,60	≤ 0,55	≤ 0,45
	CP	≤ 0,60	≤ 0,55	≤ 0,50	≤ 0,45
Classe de concreto (ABNT NBR 8953)	CA	≥ C20	≥ C25	≥ C30	≥ C40
	CP	≥ C25	≥ C30	≥ C35	≥ C40

[a] O concreto empregado na execução das estruturas deve cumprir com os requisitos estabelecidos na ABNT NBR 12655.
[b] CA corresponde a componentes e elementos estruturais de concreto armado.
[c] CP corresponde a componentes e elementos estruturais de concreto protendido.

Fonte: NBR 6118 (ABNT, 2023).

Additives and Additions

According to NBR 11768 (ABNT, 1992), additives can be defined as products that, added in small quantities to Portland cement concrete, modify some of its properties, in order to better adapt them to certain conditions. Among the additives described in this standard, whose equivalent characteristics must be guaranteed by the manufacturer, are:

- ✓ Plasticizer additive (type P): increases the consistency index of the concrete while maintaining the amount of kneading water, or that allows the reduction of at least 6% of the amount of mixing water, to produce a concrete with a certain consistency;
- ✓ Retardant additive (type R): increases the start and end times of concrete setting.
- ✓ Accelerator additive (type A): decreases the start and end times of concrete set-up, as well as accelerates the development of its initial strengths.
- ✓ Retardant plasticizer additive (PR type): combines plasticizer and retardant additives.
- ✓ Accelerator plasticizer additive (PA type): combines the effects of plasticizer and accelerator additives.
- ✓ Air Incorporating Additive (IAR type): incorporates small air bubbles into the concrete.
- ✓ Super-plasticizer additive (SP type): increases the consistency index of the concrete while maintaining the amount of water in the kneading, or that allows the reduction of at least 12% of the amount of kneading water, to produce a concrete with a certain consistency.
- ✓ Retardant super-plasticizer additive (SPR type): combines the effects of super-plasticizer

and retardant additives, and accelerator super-plasticizer additive (SPA type): combines the effects of super-plasticizer and accelerator additives
(ABNT NBR 11768, 1992).

Mineral additions

Additives are finely ground mineral materials mixed into concrete to obtain specific characteristics. When added to concrete in an adequate amount, it obtains an improvement in the fresh state, causing greater cohesion, mechanical, chemical and mineral resistance.

For this to occur, it depends on the situation of the process of obtaining the material, chemical composition, mineralogy, the degree of amortification, granulometry, and the amount used in the curing conditions (BAUER; FALCÃO, 2018).

According to NBR 11172 (ABNT, 1990), binders of mineral origin, such as any material other than water, aggregates, hydraulic cements or fibers, used as an ingredient of concrete or mortar added to the mass before or during mixing.

According to NBR 12.653 (ABNT, 2014), it deals with requirements for Pozzolanic Materials, which are defined as siliceous or silicoaluminous materials that, alone, have little or no binding properties but that, when finely divided and in the presence of water, react with calcium hydroxide at room temperature, forming compounds with binding properties.

Figure 1: : microxylic

Cast Iron: https://www.tecnosilbr.com.br

Figure 2: microsylic

Fonte: https://www.ecopore.com.br/

Microsilica

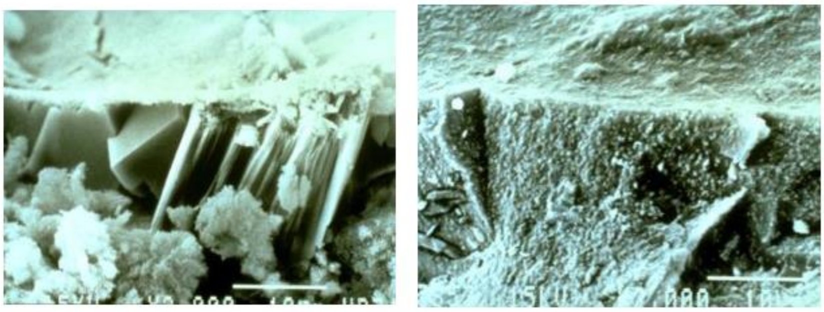
As explained in Vaske's (2005) dissertation, microsilica is a by-product from the production of metallic silicon or ferro-silicon alloys from high purity quartz and coal in electric furnaces. Through the heating of the raw materials used, chemical reactions occur, which generate SiO2 (Silicon Oxide) vapor, this vapor generates, at low temperatures, extremely small spherical particles, in the order of 0.1 μm and specific surface in the order of 20,000 to 25,000 m²/Kg.

According to Coelho (2016), when used from 3% to 10% in concrete mixtures, Silica Fume improves the concrete, offering a series of benefits, such as:

- ✓ Increased wear or abrasion resistance of concrete surfaces under these loads;
- ✓ Increased mechanical strength, compressive strength;
- ✓ Increased modulus of elasticity.
- ✓ Reduced permeability due to reduced porosity.

In Figure 3, it is possible to observe the microstructure of the concrete: without the insertion of active microsilica there is a greater segregation of the materials, and consequently greater porosity. On the other hand, with the addition or substitution of cement by microsilica, it can be observed that the concrete presents a more homogeneous material, since the microsilica enters the pores existing in the concrete, creating a greater interaction between its components.

Figure 3A: Concrete microstructure.



Sem sílica ativa. *Com sílica ativa.*

Source: Bonfim (2021)

TESTS

Slump Test

The Slump Test evaluates the consistency of fresh concrete, ensures workability during concreting and pumping, and has the function of avoiding serious problems such as concreting failures and pipe clogging. In addition, the lack of consistency control can result in deterioration of the cured performance of the product as well as decreased durability (ENGMIX, 2022).

Each work or construction phase can have variations in workability or abatement, according to the customer's needs, because as the building grows to greater heights, pumping concrete becomes difficult. The problem can be solved by providing a more fluid product, which in addition to the design guidelines aims to help the concrete penetrate deeper into the reinforcement, thus facilitating compaction (ENGMIX, 2022).

According to NBR 16889 (ABNT, 2020) the slump test must be done when "*the maximum nominal dimension of the aggregate is greater than 37.5 mm, the test must be carried out on the fraction of the concrete that passes through the sieve with a mesh opening of 37.5 mm*", for this, the standard establishes that it must:

> ✓ Place the base plate on a rigid, flat, horizontal and vibration-free surface. Dampen the mold and base plate and place the mold on the base plate. During the filling of the mold with the test concrete, using the U-section shell, the operator must position himself with his feet on the fins, in order to keep it stable. Quickly fill the mold with the collected concrete as the standard establishes, in three layers, each approximately one-third of the height of the mold.
> ✓ Thicken each layer with 25 strokes of the thickening rod. Evenly distribute the strokes over the section of each layer. To thicken the lower layer, it is necessary to tilt the rod slightly and make about half of the strokes in a spiral shape to the center. Thicken the bottom layer to its full thickness. Thicken the second and third layers, each for its full thickness and so that the blows only penetrate the previous layer. In the filling and compaction of the top layer, accumulate the concrete on the mold before starting the thickening. If, during the compaction operation, the concrete surface falls below the edge of the mold, add more concrete to maintain an excess over the mold surface throughout the upper layer operation and scrape the concrete surface with a planer, or with a trowel, or with rolling movements of the compaction rod.
> ✓ Clean the base plate and remove the mold from the concrete, carefully lifting it in a vertical direction. The operation of removing the mold should be carried out in 4 to 6 s. com a constant upward movement, without subjecting the concrete to lateral torsional movements.
> ✓ Immediately after removing the mold, measure the slump of the concrete, determining the difference between the height of the mold and the height of the specimen axis, which corresponds to the average height of the demolded specimen, approximating the nearest 5 mm.
> (ABNT NBR 16889:2020).

Compressive Strength

To perform the compressive strength tests, NBR 5739 (ABNT, 2018) must be followed, where after the specimens are executed, they must be carefully centered on the lower plate of the press, with the help of concentric reference circles, making the loads evenly distributed along the specimen axis.

MATERIALS AND METHODS

In this article, a comparison was made between conventional concrete and concrete with the addition of microsilica, where the properties for the fresh state regarding their workability were analyzed through the Slump Test and in the hardened state, where the compressive strength was verified, according to the parameters established by NBR 5739 (ABNT, 2018) at 28 days.

As a reference parameter, a conventional concrete with a 1:2:2.5:0.55 trace was used, where it is interpreted as 1 unit of cement for 2 units of sand, 2.5 units of gravel and, finally, 0.5 units of water. The cement of this concrete was replaced by 5% and 10% by microsilica, defining the trace for the Fck of 25 MPa. This trait was taken from Souza's (2022) monograph, as described in Table 1.

Table 1: Concrete Trace with Active Microsilica

Type of Concrete	Cement (kg)	Sand (kg)	Gravel (kg)	Water (kg)	Active Microsilica (kg)
Conventional	6,915	13,835	17,295	3,800	-
Substitution 5%	6,569	13,835	17,295	3,800	0,346
Replacement 10%	6,223	13,835	17,295	3,800	0,692

Source: Adapted from SOUZA (2022)

MOLDING OF THE SPECIMENS

NBR 5738 (ABNT, 2015) was used as a basis for the execution of the specimens, where samples of the 10x20 cm specimens were made (Figure 4). The molds were greased with a thin layer of release agent to reduce friction and facilitate the demolding of the specimens.

For sampling purposes, 4 conventional specimens and 8 specimens with microsilica replacement were molded, with the percentages indicated in Table 1.

Figure 4– specimen shapes

Source: Authors (2023)

The following materials and equipment were used to make the concrete, described below, with their respective images.

- **Concrete mixer:** this equipment was used to mix the material, thus creating a concrete with greater integration between its components. (Figure 5).

Figure 5–Cement mixer

Source: Authors (2023)

- **Cement:** Binding material, essential for the execution of CP II F 32 concrete - Votorantim (Figure 6).

Figure 6–Cement

Source: Authors (2023)

- **Fine Aggregate:** medium sand, this material was previously screened to obtain a material free of impurities and with adequate dimensions (Figure 7).

Figure 7– Medium Sand

Source: Authors (2023)

➢ **Coarse aggregate:** gravel 1 with a diameter of 19 mm This material was previously screened to obtain a material free of impurities and with adequate dimensions (Figure 8).

Figure 8– Gravel 1

Source: Authors (2023)

➢ **Active Microsilica: Also** known as microsilica, it was tested in the laboratory to obtain its chemical components (Figure 9).

Figure 9 – Active Microsilica

Source: Authors (2023)

➢ **Cone Trunk:** Cone for Slump Test, used to obtain the consistency of concrete in the face of its slump, this test is standardized by NBR 16889 (ABNT, 2020). (Figure 10).

Figure 10– Cone para Slump Test.

Source: Authors (2023)

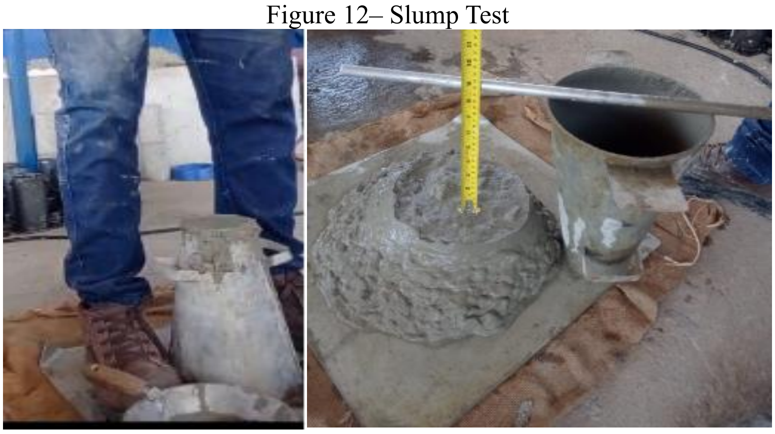
When turning on the concrete mixer, an impression was made, where gravel and water are used, which remain for about 2 minutes inside the connected concrete mixer, hitting the walls of the equipment so that the materials that are later added do not stick to the machinery.

With the use of the conventional trace, half of the water and gravel were added and mixed for about a minute. Then, the remaining materials of gravel and water were added, sand and cement were added and mixed for another 5 minutes (Figure 11). Finally, the concrete was removed to perform the slump test to verify the workability of the material and its slump (Figure 12).

Figure 11 – Concrete inside the concrete mixer.

Source: Authors (2023)

Figure 12– Slump Test

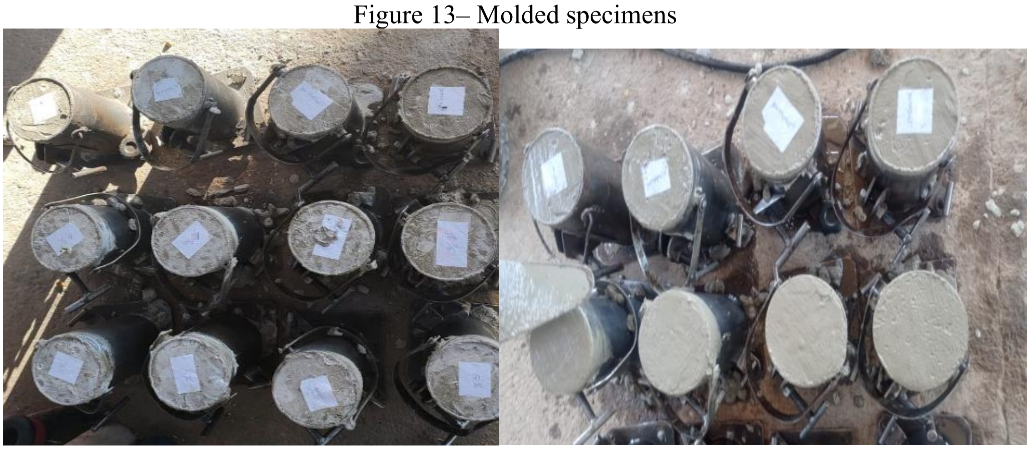


Source: Authors (2023)

To perform the Slump Test, the thickening was performed manually by a rod, the specimen was filled in two layers, in each layer 25 strokes were given, according to NBR 5739 (ABNT, 2018). In the end, after the last layer was filled, the molds were left with excess concrete, so the finishing was done using a trowel. The same process was done for the concretes with replacement of cement by activated microsilica, but in this case the microsilica is added to the cement, avoiding loss of the material in the walls of the concrete mixer.

After the Slump Test, all samples were molded (Figure 13), which were stored in one place for 48 hours in the curing process and then added to a tank with water for 28 days.

Figure 13– Molded specimens



Source: Authors (2023)

Compressive Strength Test

The specimens were submitted to compression tests at 7 days, obtaining their initial strengths and at 28 days. According to NBR 6118 (ABNT, 2023), the rupture to verify the strength must be done in the adult age of the concrete, that is, at 28 days.

The tests to verify compressive strength were carried out in the laboratory of the company Cantieri, located in the city of São Sebastião do Paraiso, using a hydraulic press, properly calibrated, as shown in Figure 14.

Figure 14 – Samples in the Hydraulic Press.

Source: Authors (2023)

RESULTS AND DISCUSSIONS

IN THIS CHAPTER, THE RESULTS OBTAINED FROM THE TESTS CARRIED OUT AND THEIR RESPECTIVE DISCUSSIONS WILL BE DISCUSSED.

Slump Test

In the Slump Test, the following results were obtained, as shown in Table 2:

Table 2: Slump Test Result

CONCRETE TYPE	ABATEMENT	A/C FACTOR:
CONVENTIONAL	22 CM	0,55
5% SUBSTITUTION	20 CM	0,55
10 % SUBSTITUTION	12 CM	0,55

Source: Authors (2023)

In view of the result obtained, it can be observed that as the cement was replaced by microsilica, the slump decreased, about 22.72% with microsilica at 5% and about 54.54%, with substitution at 10%, thus occurring a hardening of the material, and reducing, even if in small dimensions, its workability.

Compressive Strength Test

After performing all the compressive strength tests, respecting all the current standards, the following results were obtained, as shown in Table 3, below:

Table 3: Compressive Strength Test Results

CONCRETE TYPE	Fck (MPa) 7 DAYS	Fck (MPa) 28 DAYS	Fck (MPa) adopted
CONVENTIONAL	19	23	**22**
		21	
		22	
MICROSILICA 5%	15	23	**23**
		23	
		23	
MICROSILICA 10%	16	24	**25**
		27	
		24	

Source: Authors (2023)

It can be observed that the replacement of cement by active microsilica presented an improvement in its compressive strength, which makes its use viable, where by replacing cement by microsilica in concrete, compared to conventional concrete, concrete with 10% substitution, generated a performance improvement of 13.63% in relation to mechanical strength and, with the replacement of 5% of microsilica in concrete, obtained a performance improvement of 4.54%.

It was also observed that at 7 days of age it was found that the conventional concrete obtained higher strength, but during the curing process it was overcome by the use of microsilica in the other traces. This fact may have occurred due to the pores present in the concrete, where during the maturation of the material, the microsilica may have decreased the porosity of the concrete with the use of substitution.

FINAL THOUGHTS

The objective of this article was to compare the mechanical and physical properties of concrete and conventional concrete and concrete with substitution of cement by microsilica.

However, it was possible to observe that the concrete with cement substitution for the cement obtained lower workability, about 54.54%, this fact occurs due to the need for greater hydration of the material.

In view of the results obtained, it can be concluded that the replacement of cement by active microsilica affects and increases the performance of the concrete in adulthood, where the compressive strength was increased by up to 13.63% with the replacement of 10% of the material.

Thus, it can be said that the positive effects of microsilica have been confirmed, reinforcing existing studies, where a more resistant concrete was produced. Thus, it can be said that microsilica is a viable material and also contributes in a beneficial way to sustainability, as it takes advantage of an industrial by-product that is discarded.

REFERENCES

1. Associação Brasileira de Normas Técnicas. (2014). NBR 6118: Projetos de Estruturas de Concreto – Procedimentos. Rio de Janeiro.

2. Associação Brasileira de Normas Técnicas. (2015). NBR 16889: Concreto — Determinação da consistência pelo abatimento do tronco de cone. Rio de Janeiro.

3. Associação Brasileira de Normas Técnicas. (2005). NBR 7211: Agregados para concreto – Especificação. Rio de Janeiro.

4. Associação Brasileira de Normas Técnicas. (2003). NBR 9575: Impermeabilização – Seleção e Projeto. Rio de Janeiro.

5. Associação Brasileira de Normas Técnicas. (2012). NBR 9779: Argamassa e concreto endurecidos — Determinação da absorção de água por capilaridade. Rio de Janeiro.

6. Associação Brasileira de Normas Técnicas. (2006). NBR 12655: Concreto – Preparo, controle e recebimento. Rio de Janeiro.

7. Associação Brasileira de Normas Técnicas. (1996). NBR 12655: Concreto - Preparo, controle e recebimento. Rio de Janeiro.

8. Associação Brasileira de Normas Técnicas. (2015). NBR 5738: Concreto – Procedimentos para moldagem e cura de corpos de prova. Rio de Janeiro.

9. ABNT. (2018). NBR 5739: Concreto -Ensaio de compressão de corpos de prova cilíndricos. Rio de Janeiro.

10. Associação Brasileira de Normas Técnicas. (2005). NBR 9778: Argamassa e concreto endurecidos – Determinação da absorção de água, índice de vazios e massa específica. Rio de Janeiro.

11. Associação Brasileira de Normas Técnicas. (2015). NBR 8953: Concreto para fins estruturais - Classificação pela massa específica, por grupos de resistência e consistência. Rio de Janeiro.

12. Associação Brasileira de Normas Técnicas. (2018). NBR 16697: Cimento Portland – Requisitos.

13. Bauer, R. J. F. (2018). Estruturas Pré-fabricadas de Concreto: Desempenho e Sustentabilidade.

14. Bomfim, D. S., et al. (2021). Análise da microssílica como suplemento cimentício. *Brazilian Journal of Development, 7*(4), 43511-43522.

15. Braga, F. M., & Ramos, I. M. (2019). Análise da resistência do concreto com adição de vidro moído após exposição a elevadas temperaturas. Trabalho de conclusão de curso (Graduação em Engenharia Civil). Faculdade Evangélica de Jaraguá.

16. Coelho, G. M. (2016). Estudo do efeito de adições minerais em concreto. Trabalho de conclusão de curso. Joinville.

17. Oliveira, F. (2016). O Concreto: sua origem, sua história. Tese de Doutorado.

18. Souza, S. M. (2022). Estudo comparativo das propriedades do concreto convencional e concreto com contribuição de sílica ativa.

19. Santiago, W. C., & Beck, A. T. (2017). Um estudo da conformidade da resistência do concreto convencional produzido no Brasil. Congresso Brasileiro do Concreto.

20. Vaske, N. R. (2005). Contribuição ao estudo de argamassa com adição de sílica ativa em reforços de elementos comprimidos de concreto. Dissertação de Mestrado, Universidade Federal de Rio Grande do Sul.

21. Associação Brasileira de Normas Técnicas. (2015). NBR 8953: Concreto para fins estruturais- classificação pela massa específica, por grupos de resistência e consistência. Rio de Janeiro.

22. Votorantim Engmix. (2022). Slump Test: Abatimento de tronco de cone.

.

ATTACHMENT

MICROSILICA USED DATA SHEET

Metha

Metha Tecnologia em Sustentabilidade de Materiais Ltda
CNPJ: 02.826.480/0001-70

ANÁLISE QUÍMICA	
Microssilica Ativa	
Ensaios	**Resultados (%)**
SiO2	95,60%
Al2O3	0,610%
MgO	0,794%
CaO	1,300%
Fe2O3	0,256%
Equivalente alcalino Na2O	1,498%
Umidade	0,40%
Densidade	0,54%
Perda ao fogo	2,21%
Índice desempenho c/ cimento Portland aos 7 dias	119,10%
Finura por meio da peneira 45 retido	2,30%

ANÁLISE GRANULOMÉTRICA

Umidade: 3% máximo

Granulometria: 5% máximo

Retido: na # 325 mesh

Data: 11/01/22

Químico: Sérgio Monteiro

Fábrica:
Av. Tiradentes, 38, Centro
Bom Jesus dos Perdões – São Paulo
CEP 12955-000 – TEL.: (11) 4891-3006
adm@methatec.com.br
comercial@methatec.com.br